GEOLOGICAL SURVEY OF CANADA

OPEN FILE 3742

Lake Ainslie Barite-Fluorite Veins, Cape Breton Island, Nova Scotia

A.S. Macdonald

1999

Natural Resources Canada | Ressources naturelles Canada

Canada

COOPERATION

COOPERATION AGREEMENT ON MINERAL DEVELOPMENT

ENTENTE DE COOPÉRATION SUR L'EXPLOITATION MINÉRALE

Contribution to Canada-Nova Scotia Cooperation Agreement on Mineral Development (1992-1995), a subsidiary agreement under the Economic and Regional Development Agreement.

Contribution à l'Entente de coopération Canada-Nouvelle-Écosse sur l'exploitation minérale (1992-1995), entente auxiliaire négociée en vertu de l'Entente Canada-Nouveau-Brunswick de développement économique et régional.

Canada

Nova Scotia

Province of Nova Scotia

GEOLOGICAL SURVEY OF CANADA

OPEN FILE 3742

Lake Ainslie Barite-Fluorite Veins, Cape Breton Island, Nova Scotia[1]

A.S. Macdonald
Department of Geology, Acadia University
Wolfville, Nova Scotia, B0P 1X0

1999

1 Contribution to the Canada-Nova Scotia Cooperation Agreement on Mineral Development (1992-1995), a subsidiary agreement under the Canada-Nova Scotia Economic and Regional Development Agreement

CONTENTS

LIST OF ILLUSTRATIONS

Figure 10. Details of typical mineral textures within the veins:
(a) coarse tabular and fine granular barite, with minor calcite (cc) and fluorite (black);
(b) deformed barite showing strain extinction and mortar texture;
(c) "early stage" turbid, colloform fluorite;
(d) "late stage" clear, growth-zoned crystalline fluorite. (Traced from photomicrographs).

11. General geology of Lake Ainslie - Gillanders Mountain areas (Barr et al., 1995) with inferred structural relations illustrated in vertical cross-section.

12. Structural orientations of layered rocks in Lake Ainslie: equal-area stereoplots of poles to:
(a) gneissic and mylonitic foliations in basement rocks,
(b) bedding and flow-banding in the Fisset Brook Formation, and
(c) bedding in the Horton and Windsor groups. (Great circles represent best-fit pole girdles and FA's represent modal fold axes)

13. Minor fault patterns developed in Lake Ainslie area:
(a) stereoplot of poles (with slip linears) to minor fault planes,
(b) rose diagram of minor fault directions,
(c) Kamb contoured stereoplot of poles to minor faults, and
(d) stereoplot of modal fault planes and slip directions.

14. Joint patterns developed in Lake Ainslie area:
(a) stereoplot of poles to joints,
(b) rose diagram of joint directions,
(c) Kamb contoured stereoplot of poles to joints, and
(d) stereoplot of modal joint orientations.

15. Inferred NE dextral strike-slip regime in the Mabou-Lake Ainslie area, with related interference folds and push-up fault blocks (mainly after Giles et al. (1995), with modifications in the area of the Mabou highlands from Barr and Macdonald (1989)).

16. Orientations and movement directions of barite-fluorite veins:
(a) stereoplot of poles to all veins,
(b) rose diagram of all vein directions,
(c) Kamb contoured stereoplot of poles to all veins,
(d) & (e) stereoplots of slip linears associated with the MacInnis and Campbell-MacMillan veins showing modal movement planes and slip directions.

17. Orientations of stress and strain axes determined for the barite-fluorite veins: lower hemisphere projections of (a) and (b) compressional and extensional strain axes derived using the method of Marrett and Aldeminger (1990), and (c) stress axes derived using the graphic method of Aleksandrowski (1985).

18. Structural model for the development of fracture and vein patterns in Lake Ainslie area within a transpressive regime.

Lake Ainslie Barite-Fluorite Veins, Cape Breton Island, Nova Scotia

A.S. Macdonald

Abstract

Fault block inliers, on the east side of Lake Ainslie, Cape Breton Island, are hosts to a series of barite-fluorite vein occurrences. The blocks are comprised of an Ordovician-Silurian(?) basement of psammitic gneisses, diorite and granite, together with nonconformable conglomerate, sandstone, basalt, and rhyolite assigned to the Fisset Brook Formation of Middle to Late Devonian age. Clastic and carbonate rocks, of the Mississippian Horton Group and Windsor Group respectively, surround and locally cap the fault blocks.

Evidence of brittle faulting is pervasive throughout the area and many fracture surfaces are slickensided and slip-lineated. The pattern and sense of movement of minor faulting deduced from slip linear plots of these surfaces suggests that similarly oriented map-scale faults, forming the N-S array of rhombic fault blocks, were formed within a dextral transpressive regime of post-Visean to Westphalian age.

The barite-fluorite veins occupy zones with similar orientations as the faults and are characterized by a wide variety of essentially brittle deformation structures and textures that indicate that mineralization was essentially syn-deformational.

Fluid inclusion and stable isotope data from the veins show that they were formed from saline, relatively low temperature fluids typical of formation waters derived from sedimentary basins, and the data are similar to those from other Ba and related Zn-Pb occurrences hosted by Mississippian rocks in Nova Scotia.

Acknowledgments

The author is indebted to D.J. Kontak of the Mines and Energy Division of the Nova Scotia Department of Natural Resources for undertaking the fluid inclusion study. P.S. Giles of the Geological Survey of Canada's Atlantic Division kindly made available provisional copies of his Port Hood - Lake Ainslie 1:50 000-scale map sheet, and was supportive of the project as a contribution to the Magdalen Basin NATMAP Project. R. Moore of Wolfville examined thin-sections of the carbonate rocks for comparison with Windsor Group rocks. A.L. Sangster of the Geological Survey of Canada, Ottawa supervised the project, and is thanked for his support and encouragement. The project was funded by a contract from the Geological Survey of Canada under the 1992-1995 Canada-Nova Scotia Cooperation Agreement on Mineral Development.

INTRODUCTION

The barite-fluorite vein deposits on the east side of Lake Ainslie (Figs. 1 & 2) have been explored and partially mined intermittently over the last 100 years, ever since their initial discovery in 1895. The first phase of development and production lasted from 1896 until 1920, during which all the main veins were found and most of them worked on a small scale, via pits and shallow underground workings (Douglas, 1944). Apart from limited drilling of the Evans vein in the early 1940's, there was no more systematic exploration until 1965-72, when there was extensive drilling of the Johnson-MacDougall and Campbell-MacMillan vein systems, near East Lake Ainslie (Zurowski, 1968, 1972). From 1982 until 1986, activity was focussed on the Peter Campbell and MacInnis veins in the Scotsville area, culminating in limited open-pit production from the MacInnis vein (Felderhof and MacDonald, 1984). Reserves have been estimated at 1 Mt (50% barite, 17% fluorite) for the Upper Johnson vein, 3 Mt (28% barite, 19% fluorite) for the Campbell-MacMillan vein (Zurowski, 1971, 1972a,b), and 0.1 Mt (61% barite, fluorite unspecified) for the MacInnis vein (Felderhof and MacDonald, 1984).

Much effort has also gone into testing beneficiation processes for the barite-fluorite ores in order to produce chemical grade materials (e.g. Zurowski, 1972b; Lutwick, 1990).

Overview descriptions of the occurrences have been given by Douglas (1944) and Felderhof (1978). Previous academic research on the veins has been in the form of (i) a textural and mineralogical study of the veins and their rhyolitic wall rocks, together with a discussion of a genetic model for their formation from compaction-driven formational fluids (Creed, 1968), and (ii) a geochemical study of the volcanic rocks of the Fisset Brook Formation which generally host the veins, including a volcanogenic model for vein formation (Huard, 1984). Summarizing previous work on the veins, Dawson (1985) classified them as dilatant fissure-fillings deposited either from brines associated with the Horton and Windsor groups, or from volcanogenic exhalations associated with the Fisset Brook Formation.

The primary purposes of this study were (i) to document the structural features of the veins in order to understand how and when the veins were emplaced during the structural evolution of the area, and (ii) to estimate the P-T conditions of ore mineral deposition using fluid inclusion and stable isotope data.

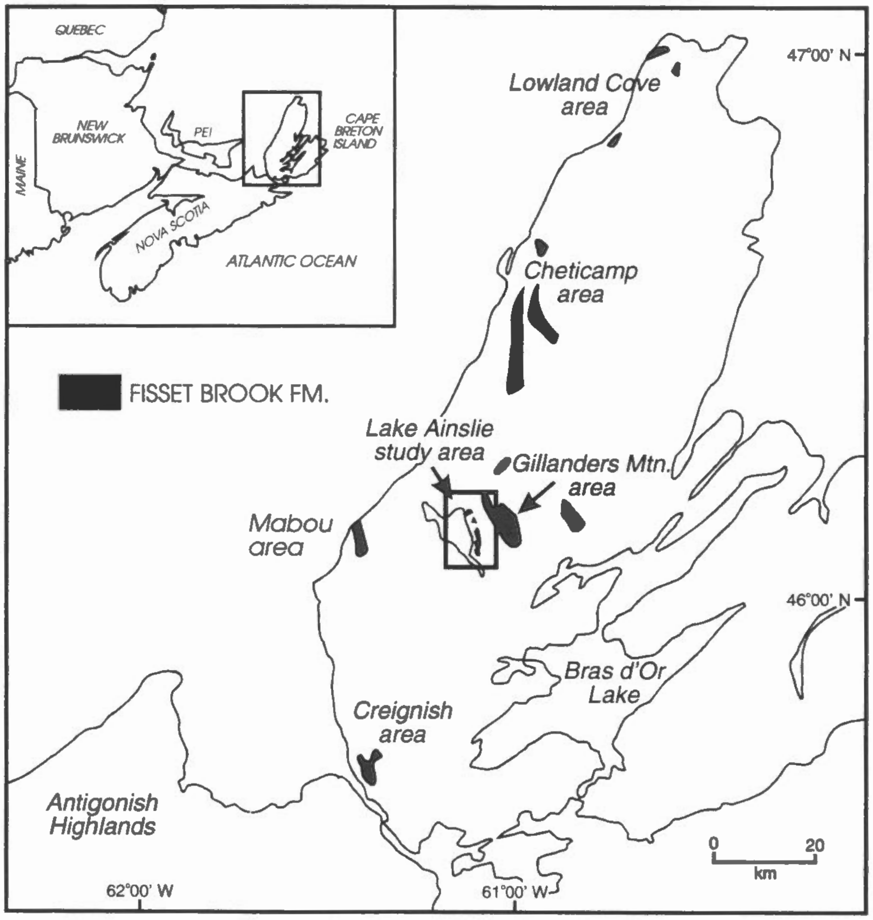

Figure 1. Location map showing Lake Ainslie study area in relation to outcrops of the Fisset Brook Formation and possible correlative rocks on Cape Breton Island, Nova Scotia.

GENERAL GEOLOGY

The results of geological mapping for this study (Fig. 2) show that the Lake Ainslie inliers are fault-bounded horst blocks which appear to have been pushed up through a cover of Horton and Windsor groups as a result of basin inversion. This contrasts with previous interpretations (e.g. Creed, 1968) that the inliers occupied the core of a large-scale anticlinal structure. The blocks themselves are made up of crystalline metamorphic and plutonic rocks, together with steeply dipping, faulted to nonconformable clastic, and bimodal volcanic rocks of the Fisset Brook Formation.

Crystalline Basement:

The crystalline rocks, which are presumably representative of the infrastructure, are comprised of mainly psammitic gneisses intruded by diorite and granite. The gneisses vary from relatively uniform, foliated quartzite, through quartzofeldspathic gneiss, to quartz-feldspar-biotite gneiss. Commonly they show a mylonitic and retrograde metamorphic overprint, characterized by grain size reduction, development of stretching lineation, and chloritization. Similar effects, within metre-scale shear zones, are seen in the diorite plutons which have intruded the gneisses. Ages of the gneisses and the diorite are not well constrained but, from correlation with similar rocks in the Gillanders Mountain block to the NE (French, 1983; Lynch *et al.*, 1993b; Giles *et al.*, 1995), they are inferred to be Ordovician to Silurian in age.

The age of the biotite-hornblende monzogranite which occurs in the southernmost fault block is not established and its contact relations with the Fisset Brook Formation were not observed but, again from relative age relations established in the Gillanders Mountain area, it is believed to be Silurian to Devonian in age (French, 1983, Lynch et al., 1993b, Barr et al., 1995).

Fisset Brook Formation:

In the Fisset Brook Formation, only the felsic volcanic rocks are reasonably well exposed, forming several distinctive, rubble-strewn "bald" hills with sporadic outcrops on their steep flanks. The stratigraphy of the formation has been compiled from restricted sections (especially along the access road to the MacInnis open-pit near Scotsville, and along Johnson Brook near East Lake

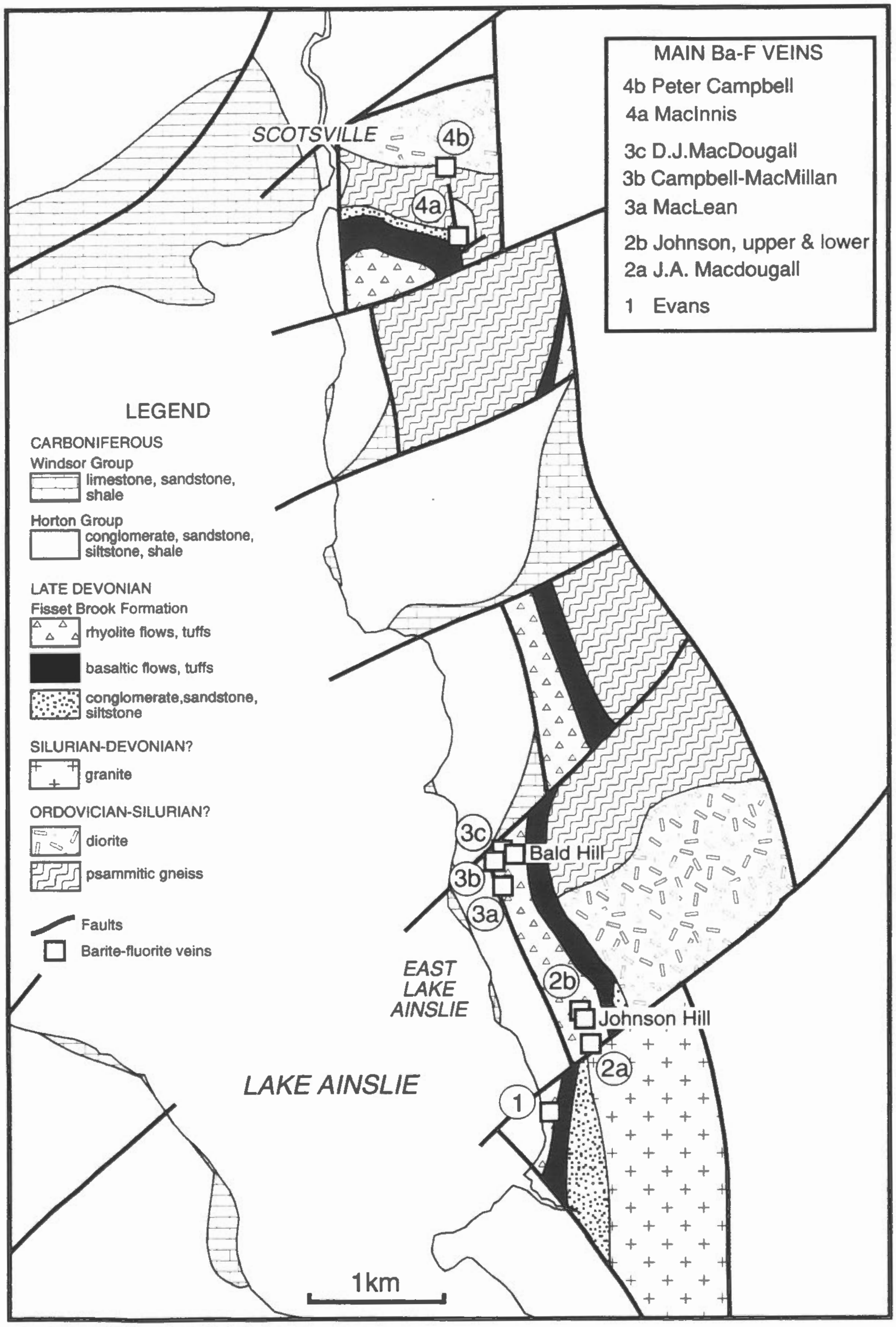

Figure 2. Simplified geologic map of the east side of Lake Ainslie (based on Map A) showing the locations of the main barite-fluorite veins.

Ainslie), from widely disparate outcrops, and from drill core. The sequence, which is ca. 500m in thickness, begins with brown polymictic breccia, followed by roundstone cobble conglomerate with abundant granitoid, quartzitic and metavolcanic clasts. These coarse clastic units are succeeded by red-brown lithic to arkosic, conglomeratic sandstones and siltstone interbedded with basalt layers. Some of the siltstone layers in contact with basalt show evidence of soft-sediment mixing with the basalt to form peperite, suggesting that the basalts were extruded locally into shallow lakes. The basalt sequence includes amygdaloidal flows and lesser amounts of lapilli tuff. Rare andesites are also present locally. Basalts are typically composed of ophitic to intergranular clinopyroxene and plagioclase (An_{50-70}), chlorophaeite-rich pseudomorphs after olivine(?), opaques, and minor secondary chlorite, calcite, and hematite. Where the basalts are amygdaloidal, zeolites such as prehnite and stilbite are the most common infilling.

Orange to pink rhyolite flows and lapilli tuffs overlie the basaltic sequence. The flows vary from massive to intricately flow-banded, and may include ash-flow tuffs (Huard, 1984). Typically, the rhyolites display patchy to banded spherulitic and micrographic textures. Resorbed quartz and K-feldspar phenocrysts are generally sparse. A few small biotite and(or) muscovite anhedral phenocrysts occur locally. Partial alteration of spherulitic and crystalline K-feldspar to clay (kaolinite?) is very common, biotite is chloritized, and secondary epidote is locally concentrated along fractures.

Based on spores and plant fossils from various localities (Fig. 1), the age of the Fisset Brook Formation has been suggested to be Late Devonian(?) to Early Carboniferous (Kelley and Mackasey, 1964; Smith and Macdonald, 1981; Blanchard *et al.*, 1984). However, U-Pb dating of rhyolite in the Gillanders Mountain area gave a Middle to Late Devonian age of 373 +\- 4 Ma (Barr *et al.*, 1995). The significance of an Early Carboniferous Rb-Sr 15-point isochron age of 344 +\- 7 Ma reported by Huard (1984) for rhyolite from the Lake Ainslie area is uncertain. A widespread thermal event occurred at this time: gabbro intrusions in the St. Peters area of southern Cape Breton Island have given a U-Pb zircon age of 339 +/- 2 Ma (Barr *et al.*, 1994), mafic flows of Early Carboniferous age occur in New Brunswick (Fyffe and Barr, 1986) and in the Magdalen Islands (Barr *et al.*, 1985), and mafic dykes intrude rocks of the Horton Group in many other locations.

Horton Group:

Rocks of the Horton Group exposed to the east of the fault-block inliers generally have not been subdivided (Giles *et al*, 1995), but from their coarse clastic nature and apparent conformity with the underlying Fisset Brook Formation in the Gillanders Mountain area (Barr *et al.*, 1995), they are believed to represent the lower part of the group, and are tentatively correlated with the Creignish Formation. The sequence, which is at least 1 km thick, consists primarily of coarse, pale pink arkosic pebbly sandstone and conglomerate.

Those rocks lying between, and to the west of the fault blocks are correlated with the Ainslie Formation which forms the upper part of the Horton Group. This unit is at least 500 m thick and consists of a sequence of laminated to thinly bedded grey/buff sandstone, with interbedded red and grey/buff laminated siltstone and lesser shale, which becomes more uniformly red in colour towards the base of the overlying Windsor Group. Small-scale cross bedding, ripple marks, and mud cracks are all common features. The outlier on top of the Scotsville fault block (Fig. 2 & Map A) has yielded spores of Tournasian age (upper 3B zone), as well as reworked Early Paleozoic achritarchs (see palynology report in Appendix).

Windsor Group:

Limestones are exposed intermittently along the shores of Lake Ainslie, and also at several localities inland close to the margins of the fault blocks (see Map A). Those exposed along the lake shore are correlated with the Macumber Formation of the Windsor Group as they consist of laminated, grey oolitic to peloidal microsparites (with thin sandstone interbeds), overlain by laminated limestone collapse-breccia. At Howard MacLean's Point, about 7 m of these limestones are separated from underlying grey to red sandstone and siltstone of the Horton Group by a 2 m thick basal conglomerate-breccia. No direct evidence of the Ainslie Detachment, whose locus is inferred to be within the upper part of the formation (Giles *et al*, 1995; Lynch and Giles, 1996), was observed at this locality.

Inland, two different limestone facies are present in outcrops adjacent to the fault-block inliers. These have been identified by R. Moore (pers. comm.) as (i) ostracodal, pelletal to oolitic, laminated microsparite, and (ii) thin to thick bedded oolitic, intraclastic sparite, both of which have thin sandstone interbeds/lenses. Neither of these facies contains recognizable marine fauna making correlation with the Windsor Group, as used in this study, slightly tenuous. Previously, these inland outcrops have been included, wholly or in part, in the Horton Group (Norman, 1935; Giles *et al.*, 1995). Evaporites are presumed to overlie the Macumber Formation but these are exposed only on the west side of Lake Ainslie.

GEOCHEMISTRY OF FISSET BROOK FORMATION VOLCANIC ROCKS

Ten samples of basalt and rhyolite from the Fisset Brook Formation were analyzed for major and trace elements (Table 1) to add to those previously analyzed from the area by Huard (1984), making a total of 21 analyses.

The sampled rocks from Lake Ainslie show distinctly bimodal, major element patterns (Fig. 3), like the equivalent volcanic rocks from Gillanders Mountain area to the east (Arnott, 1994; Barr et al., 1995). Both suites are also subalkalic, based on their Zr/TiO_2 vs. SiO_2 values (Fig. 4a). However, the Lake Ainslie samples, including most of the rhyolites and about half of the basalts, also show significant potassic enrichment compared to the Gillanders Mountain samples. This is considered to be the result of alteration, as their K_2O/K_2O+Na_2O values extend across and beyond the normal range for igneous rocks (Fig. 4b). Rubidium values are also elevated and show positive correlation with K_2O values. Barium values are variable from low to extremely high in the basalts showing good correlation with K_2O, Rb, and Zn (Table 1). However, the Ba values are surprisingly low in the rhyolites and do not show the same correlation.

The immobile elements, in general, do not show significant differences between the Gillanders Mountain and Lake Ainslie suites, except for Zr which appears to be elevated in the Lake Ainslie rhyolite samples (Figs. 4a, 5b). Based on their immobile element ratios, both the rhyolites and basalts appear to be of "within-plate" origin (Figs. 5a,b), and the basalts in particular appear to be tholeiitic rather than alkalic, based primarily on their low Nb contents (Fig. 5c). Such characterization of the volcanic rocks is compatible with field evidence for their deposition in association with red clastic sediments in graben or half-graben structures.

In terms of their overall chemistry, the Lake Ainslie volcanic rocks are typical of the Fisset Brook Formation elsewhere on Cape Breton Island but may be considered as anomalous on the

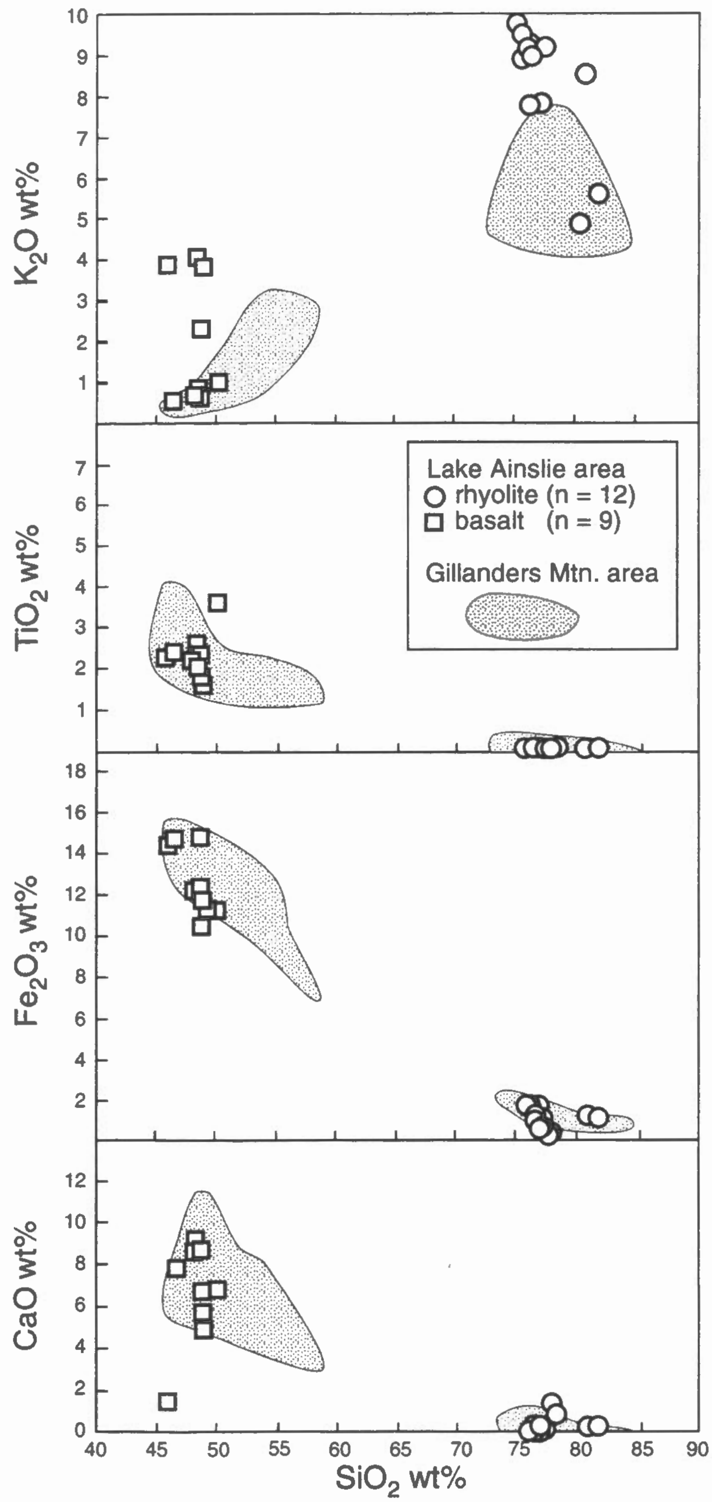

Figure 3. Plots of major elements versus SiO_2 illustrating chemical variations in volcanic rocks from the Fisset Brook Formation, compared to those from Gillanders Mountain area (Barr et al., 1995).

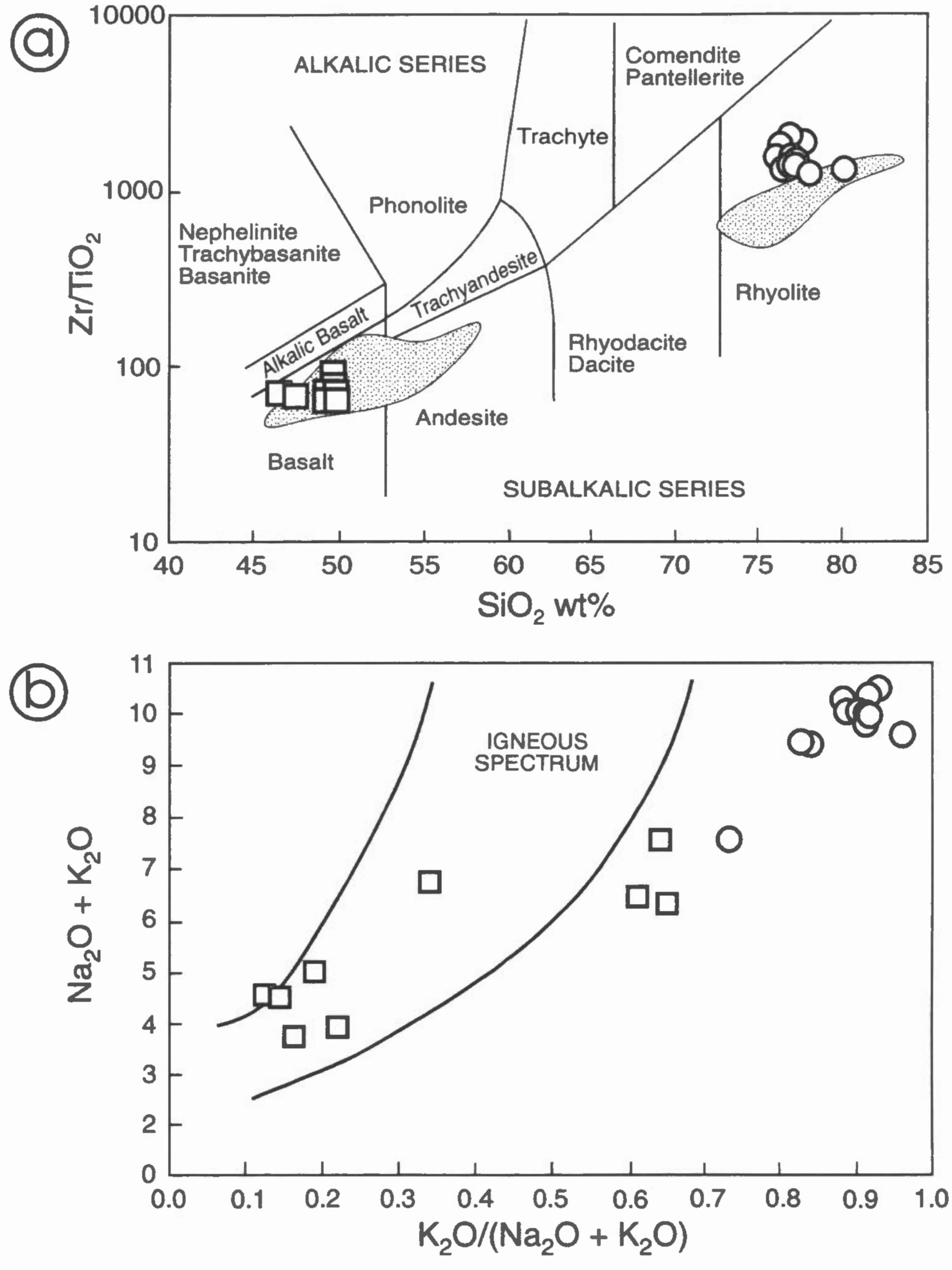

Figure 4. Plots of (a) Zr/TiO_2 versus SiO_2, with fields from Winchester and Floyd (1977), for volcanic rocks of the Fisset Brook Formation showing their subalkalic, bimodal character, and general similarity to equivalent rocks in the Gillanders Mountain area to the east (Barr et al., 1995); and (b) Na_2O+K_2O versus $K_2O/(Na_2O+K_2O)$, with fields from Hughes (1973), showing a distinct potassic alteration trend.

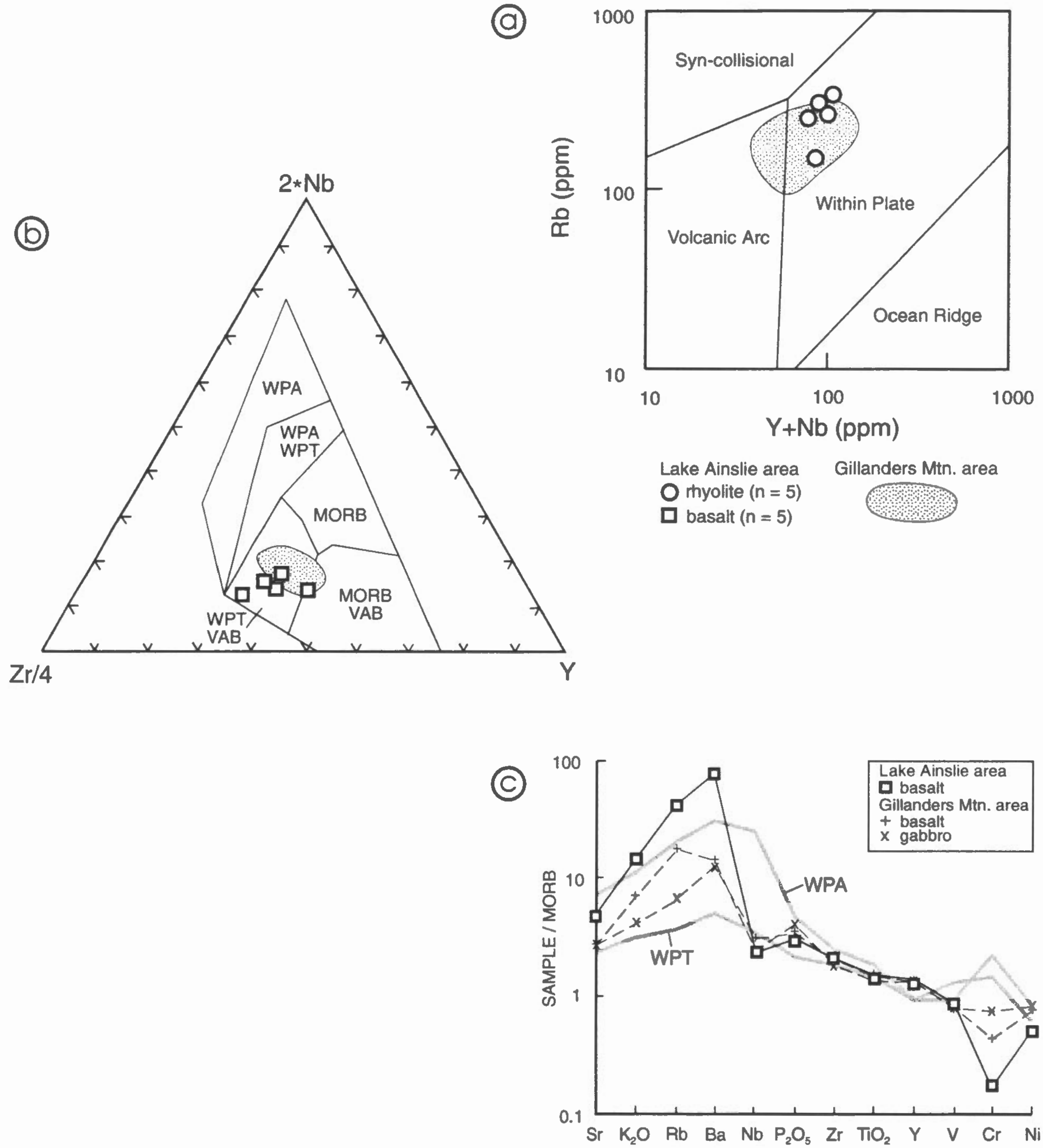

Figure 5. Tectonic discrimination diagrams for volcanic rocks of the Fisset Brook Formation: (a) Rb versus Y + Nb plot (Pearce et al, 1984) showing within-plate character of rhyolite, (b) Nb-Zr-Y plot (Meschede, 1986) showing the within-plate tholeiitic character of the basalt, and (c) normalized "spider" diagram of average basalt from the Fisset Brook Formation compared to basalt and gabbro from Gillanders Mountain (Barr et al., 1995), and to average within-plate tholeiitic basalt (WPT) and alkalic basalt (WPA) (Pearce, 1982); basalt from Lake Ainslie is enriched in Ba, Rb, and K_2O but has the low Nb, Zr, and TiO_2 contents of tholeiitic basalt.

basis of their potassic enrichment/alteration. Kaolinization(?) is the most obvious alteration observed petrographically in the rhyolites, but its origin is not clear. In the basalts, elevated K_2O values correlate with Ba and Zn values that are distinctly higher than in the rhyolites. Recognition of this led Huard (1984) to suggest a possible genetic link between basaltic volcanism, barite mineralization, and alteration.

DESCRIPTION OF THE BARITE-FLUORITE VEINS

The barite-fluorite veins occur in 4 main groups or locations within the fault-block inliers but commonly close to the faulted margins of the blocks (Fig. 2 and Map A). Those near East Lake Ainslie in the southern part of the area are hosted by rhyolite of the Fisset Brook Formation, whereas those near Scotsville in the north are hosted by gneiss and associated diorite.

The veins are developed on a wide variety of scales, from mm-scale microveinlets up to large veins 175-200 m in length by 5-6 m in maximum width, such as the MacInnis and Campbell-MacMillan veins. Although essentially tabular in form, large veins also pinch and swell, perhaps as a result of convergence/divergence caused by offset of curviplanar hanging-wall and footwall fault surfaces. They also tend to occur in subparallel sets, and commonly have satellite veinlets and offshoots occupying second-order shears. Drill logs also suggest that large veins bifurcate and splay at depth (Zurowski, 1971, 1972a).

MacInnis Vein:

The MacInnis vein (Fig. 6) is a large vein, oriented 358/60E with a well defined N-S surface trace extending about 175 m but only tested by drilling to a depth of ca. 80 m, and blocked out to a depth of 45 m (Potapoff, 1982; Felderhof and MacDonald, 1984). It has been partially mined by open pit method at its southern end, over a strike length of 75m to an estimated depth of 30-40m. It is located in the footwall zone of a N-S oblique-slip fault which downthrows lacustrine sediments of the upper Horton Group (zone 3B) to the east against quartz-feldspar-biotite gneiss, diorite, and pegmatite of the basement which is nonconformably capped by clastic and volcanic rocks of the Fisset Brook Formation. This vein has been interpreted as being parallel to the unconformity at the base of the Horton Group sequence (Felderhof and MacDonald, 1984)

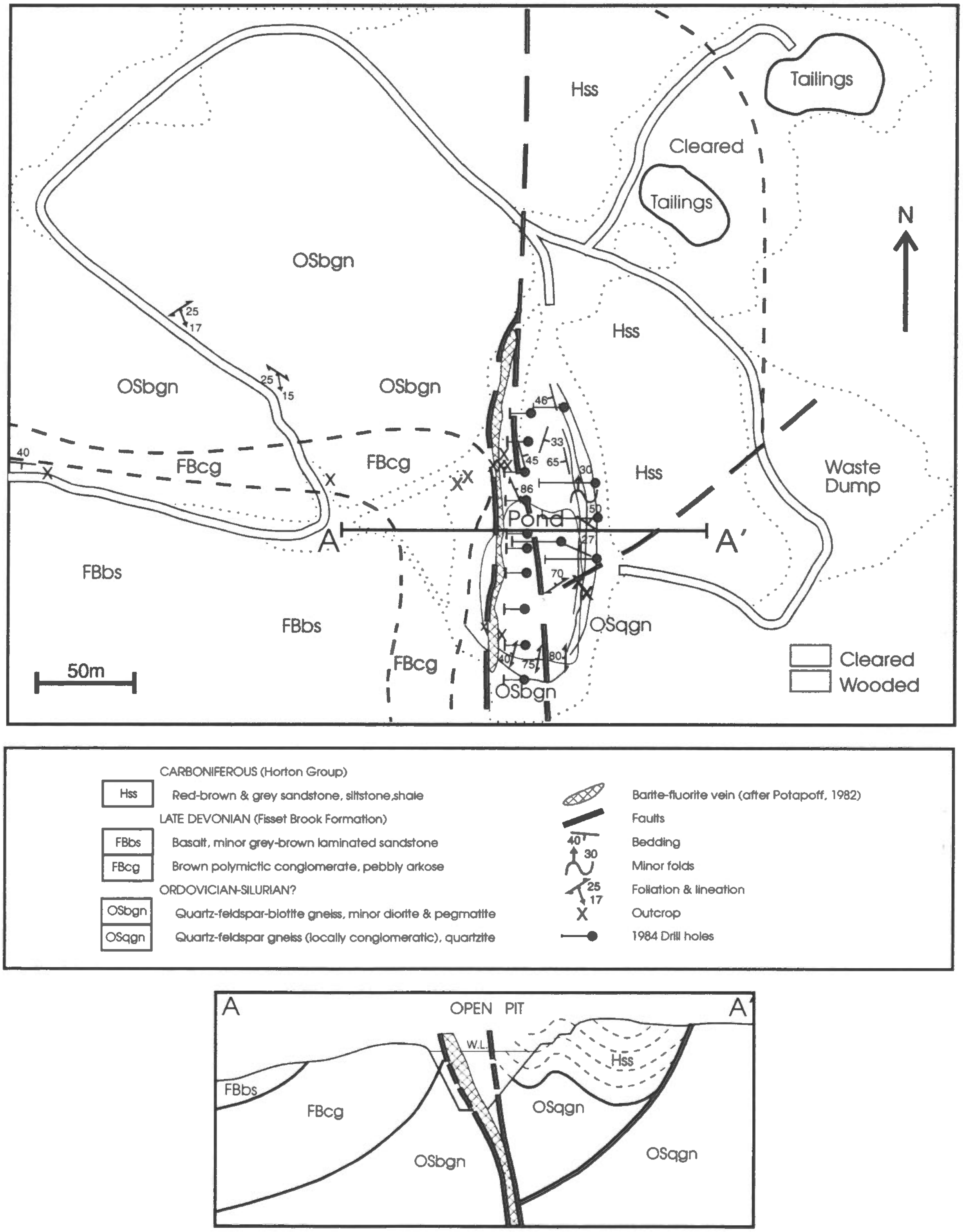

Figure 6. Detailed geological map and section of the MacInnis vein, near Scotsville. See Fig. 2 and Map A for location.

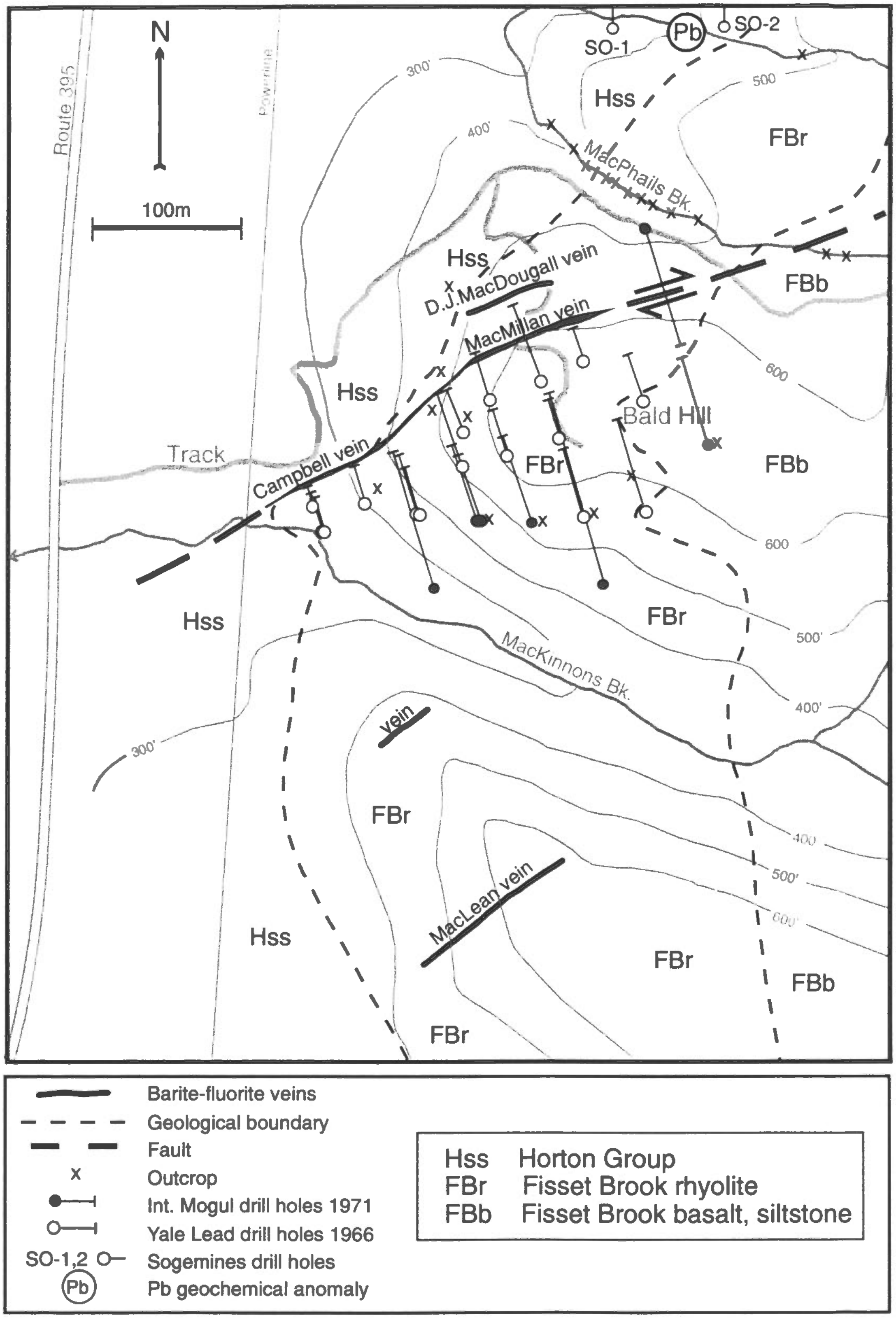

Figure 7. Detailed geological map of the Campbell-MacMillan and related veins, near East Lake Ainslie (after Zurowski, 1971, 1972a). See Fig. 2 and Map A for location.

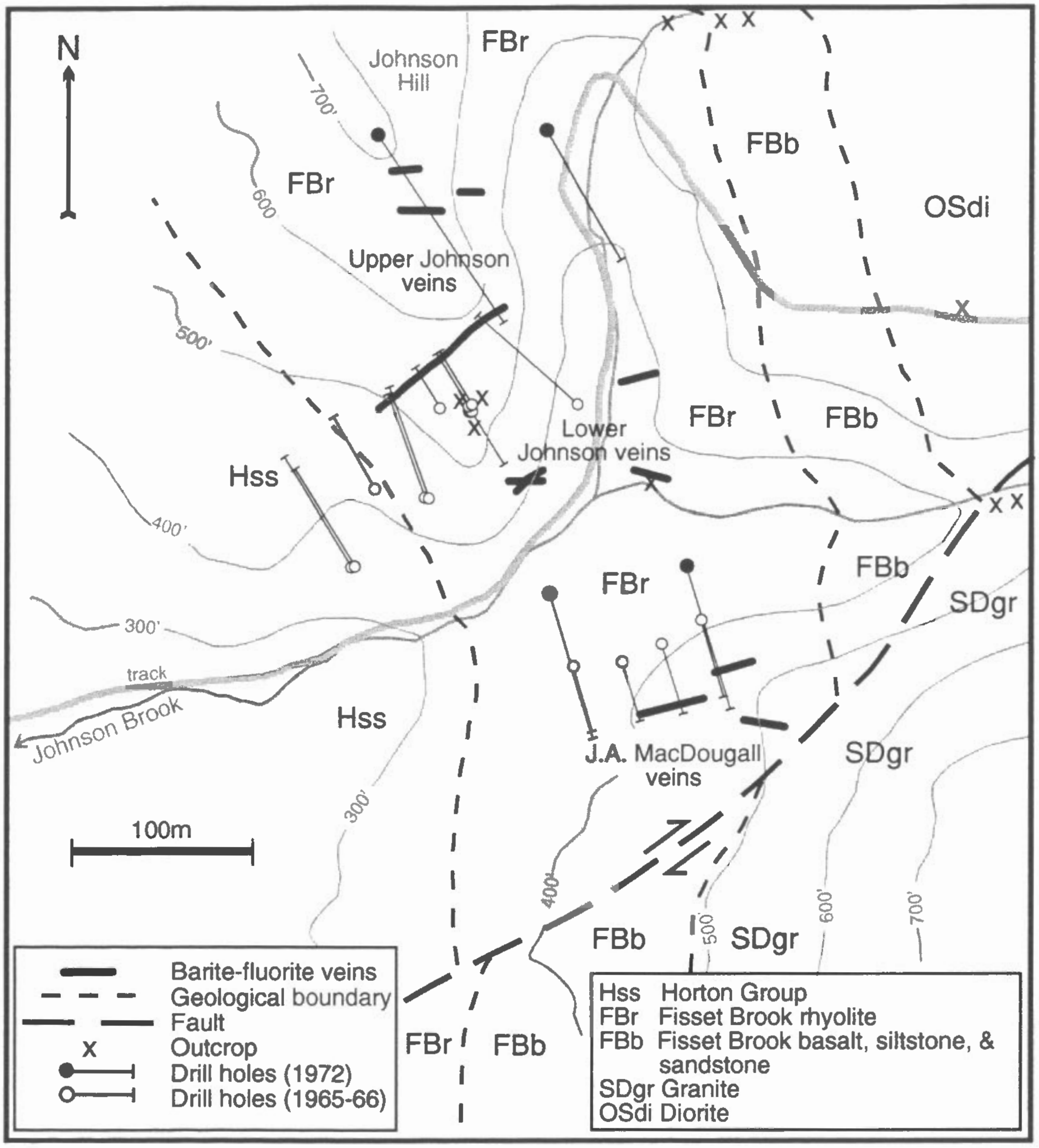

Figure 8. Detailed geological map of the Johnson and J.A. MacDougall vein systems near East Lake Ainslie (after Zurowski, 1971, 1972a). See Fig. 2 and Map A for location.

but mapping of the open pit area and re-examination of the drill core show that the stratigraphy of the hangingwall and footwall sections is complex. It is more likely that the vein is fault controlled (Fig. 6).

Campbell-MacMillan Vein:

The Campbell-MacMillan vein and its satellite, the D.J. MacDougall vein, occur within rhyolite, close to or in partial fault-contact with sandstone-siltstone of the upper Horton Group (Fig. 7). Two other lesser veins of similar orientation are located 200-300 m to the south. The Campbell-MacMillan vein is oriented 070\65SE and drilling has proven a strike length of 200 m, maximum thickness of 5-6 m, and a depth extension of ca. 125 m. Limited underground mining, via adits and a shallow shaft, has been done at the west and east ends of the vein respectively. Drill core shows that many small satellite barite-fluorite veins (1 to 10 cm in width) are formed in the rhyolite. They vary from regular simple or banded forms to irregular breccia-dominated forms containing orange equigranular barite, coarse white barite, and translucent green fluorite. Green fluorite is commonly developed at the margins of the more regular veins, and as matrix material to brecciated barite and rhyolite within the veins. Fine-grained purple fluorite also occurs but it is restricted to fracture coatings and vug fillings in the brecciated rhyolite of the wallrocks.

Johnson Vein:

The Johnson vein is the largest of a system of veins made up of the Johnson and J.A. MacDougall sets, oriented ENE to E, and located entirely within Fisset Brook rhyolite (Fig. 8). Trenching and drilling have shown the Johnson vein to be oriented 065/85N, at least 100 m in length, but open to the SW under the cover of Horton clastic rocks, and extending to a depth of ca. 200 m (Zurowski, 1972a,b). Potential reserves are probably considerably in excess of the proven 1 Mt.

Evans Vein:

The Evans vein, which is the most southerly of the veins, is poorly exposed but appears to be located within an ENE fault-zone between Fisset Brook rhyolite and grey laminated siltstone of the upper Horton Group (Map A). It is oriented 075/50N, but is highly lenticular with localized maximum thickness of 4 m. Proven strike length is only 40 m with a depth extension to 30 m (Douglas, 1944). However, it is distinctive in that it contains grey siltstone fragments within the barite-fluorite ore, and is also the most fluorite-rich of the Lake Ainslie veins.

Vein Mineralogy and Texture:

Mineralogy of the veins is simple, comprising white to orange barite, colourless to green fluorite, and variable, minor amounts of grey calcite. Trace amounts of very fine-grained sulphides, most commonly chalcopyrite and pyrite (or their oxidized equivalents) also occur, and black manganese oxide/hydroxide coatings (possibly psilomelane) are found in vugs and on some fracture surfaces. Waxy hydrocarbons in vugs have been reported also but their occurrence was only confirmed in very altered grey rhyolite, cropping out on the Twin Valley Road, which is not associated with barite-fluorite mineralization.

Grain size, especially of barite, varies widely and commonly attains sizes of 3-4 cm in large veins such as the MacInnis vein at Scotsville.

The veins are obviously deformed, their hanging wall and footwall surfaces being slickensided, fluted, and slip lineated, and their wallrocks heavily fractured and commonly brecciated (Fig. 9). As a result, their internal fabrics are hybrids of primary depositional and secondary defomational features (Fig. 10). Obvious primary features include:

(a) two or more generations of barite, coarse prismatic/tabular white barite (barite 1), and fine equigranular white or orange barite (barite 2) (Figs. 9a, 10a);

(b) coarse and fine grained calcite;

(c) "early" colloform, layered turbid fluorite (Fig. 10c) and "late" clear, zoned crystalline fluorite (Fig. 10d);

(d) crustiform, vuggy intergrowths of all 3 minerals.

Secondary features include essentially brittle structures such as shear bands, single- and two-stage breccias, as well as cataclastic mortar textures (Fig. 10b), and brittle-ductile microtextures such as kinks and deformation twinning shown particularly by barite and calcite. Pressure solution stylolites are also developed locally within the veins.

Because of the deformational overprint it is difficult to recognize primary, large-scale zoned or repeated patterns of mineral deposition such as would result from operation of a "crackseal" mechanism of complex vein generation. However, a generalized, inward zoning pattern can be synthesized from localized observations of many of the veins, both large and small:

1. Purple fluorite on wallrock fractures.
2. Green fluorite +/- calcite concentrated at vein margin.
3. Barite, pale green to white colloform fluorite, calcite.
4. Barite (coarse grained, vuggy) forming central part of vein

+/- clear fluorite as late crustiform infillings.

A similar zoning pattern was recognized by Creed (1968) who also interpreted it as a paragenetic sequence. However, the textural complexity in some breccia zones suggests that there was repeated deposition and deformation so that the paragenesis may not have been simple. For example, the localized occurrence of two-stage breccias in the Campbell-MacMillan vein (Fig. 9a), involving barite-calcite-fluorite could be the product either of hydrofracturing caused by boiling of the vein-forming fluid, or of brittle faulting during vein formation. There is also much textural evidence in all the veins for cataclasis and recementation, e.g. disrupted colloform fluorite in a matrix of fine-grained calcite.

Barite and calcite are essentially uniform in composition, both within and between veins. Electron microprobe analyses (Table 2) show that most barite contains 1 - 2 wt % SrO (1.62 +\- 0.39), and that calcite contains about 1 wt % MnO (0.96 +\- 0.25). No consistent compositional differences could be detected between the coarse- and fine-grained generations of barite (barite 1 vs. barite 2). Only samples from the Johnson Hill veins can be considered to be slightly richer in Sr (> 2 wt % SrO). The only truly significant compositional difference between the veins is shown by REE contents of fluorite which show a dramatically different pattern for the MacInnis vein at Scotsville compared to those for the other veins (Fig. 22). This difference is believed to result from the MacInnis vein being hosted by basement rocks rather than by rhyolite of the Fisset Brook Formation (see later discussion).

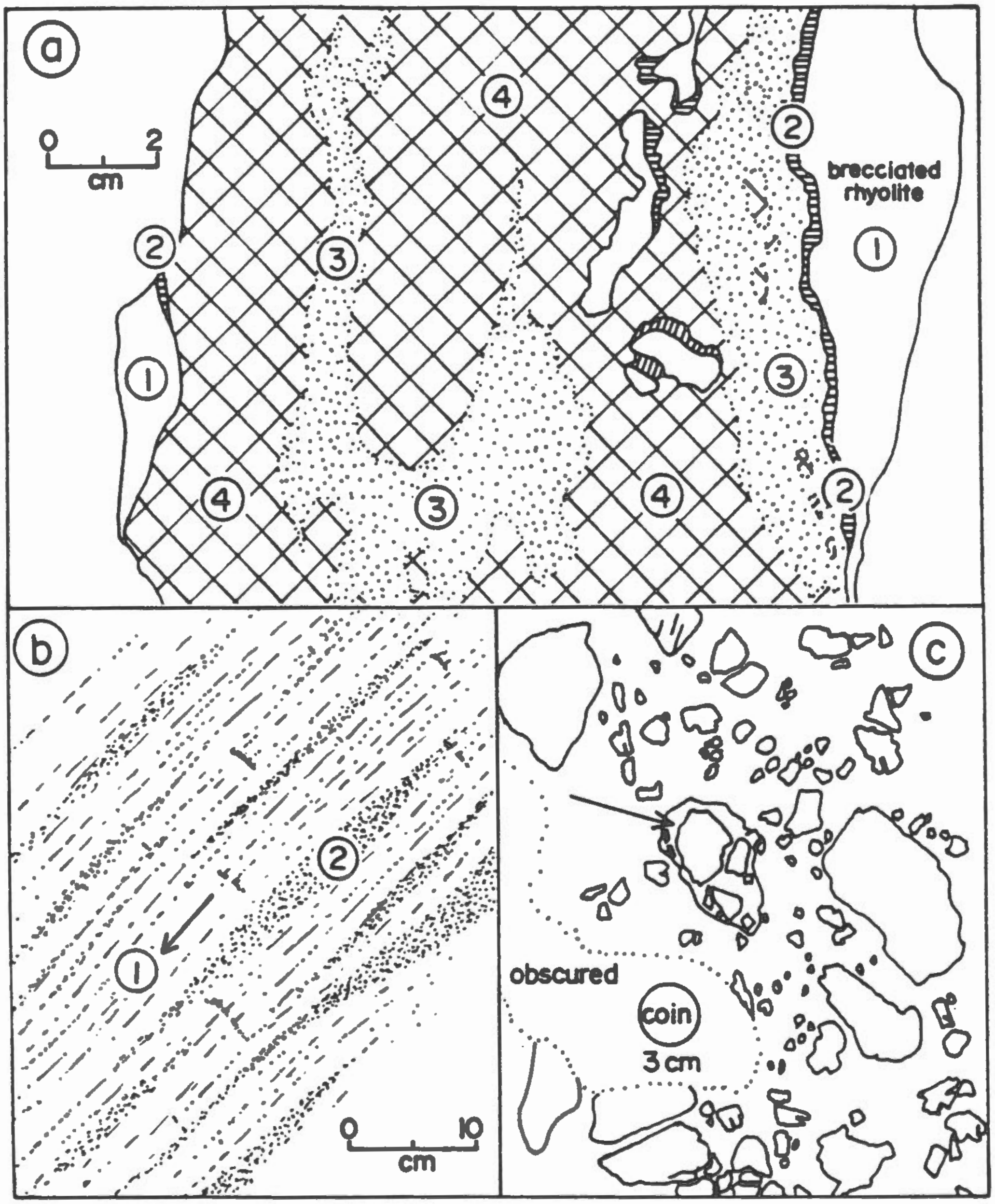

Figure 9. Some typical structural and textural features of the Lake Ainslie barite-fluorite veins: (a) satellite vein from Upper Johnson vein set showing brecciated wallrock (1), fluorite concentrated at margin (2), shear banding (3), and disrupted vuggy, crustiform texture (4); (b) slip-lineated (1) and fluted (2) footwall to the J.A. MacDougall vein; (c) two-stage breccia of possible hydrothermal origin (arrowed) involving barite, fluorite, and calcite, from Campbell-MacMillan vein. (Traced from photographs).

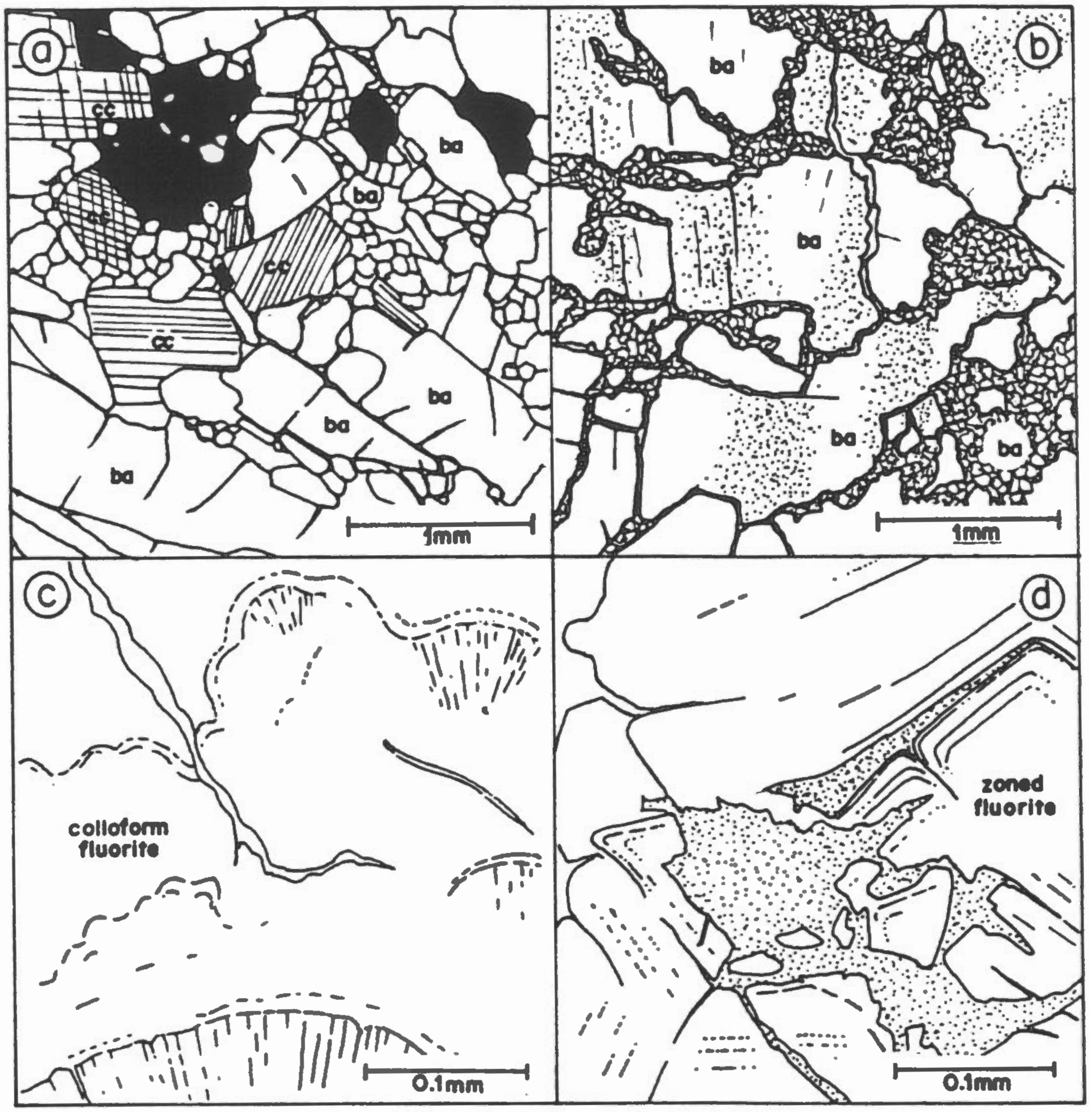

Figure 10. Details of typical mineral textures within the veins: (a) coarse tabular and fine granular barite, with minor calcite (cc) and fluorite (black); (b) deformed barite showing strain extinction and mortar texture; (c) "early stage" turbid, colloform fluorite; (d) "late stage" clear, growth-zoned crystalline fluorite. (Traced from photomicrographs).

STRUCTURAL GEOLOGY

Because of block faulting, structural features in the area are characterized and complicated by juxtapositioning of different structural levels, accompanied by a widespread brittle overprint (Figs. 2 & 11).

Basement Gneisses

The main paragneissic foliation (S_{0-1}) generally has a N to NNE trend and also appears to have been folded about gently plunging SW axes (Fig. 12a) but the scale and shape of such folding are not well constrained: minor folds are rare, perhaps due to transposition during subsequent mylonitization of the gneisses. The mylonitic foliation (S_m) subparallels the gneissic foliation (Fig. 12a) but is inhomogeneously developed, occurring in metre-scale shear zones, marked by intense grain-size reduction and chloritization. Mylonitic zones also cut the diorite which has intruded the gneisses, suggesting that the shear event must be significantly younger in age than the gneisses. Perhaps it is related to movement on the Margaree Shear Zone which crops out on the NE side of Gillanders Mountain (Fig. 11) and is believed to be an extensional shear zone of Devonian age (Lynch et al., 1994), although there may have been also earlier compressional movements (Perkins, 1995).

Fisset Brook Formation:

There are insufficient data to fully define the attitudes of the Fisset Brook Formation; contact relations are obscure due to poor exposure, and are also partly faulted. However, map patterns indicate that the rocks are generally moderately to steeply dipping towards the west and southwest off the margins of the basement blocks. The few bedding and regular flow-banding attitudes indicate that the Fisset Brook Formation may be partially folded about a moderately plunging SW axis (Fig. 12b). If real, this pattern more closely resembles the orientation of post-S_1 folding in the basement gneisses than the folding in the overlying Horton-Windsor package. The general competence of the volcanic rocks probably means that it behaved more like the adjacent crystalline infrastructure than the sedimentary cover rocks during folding.

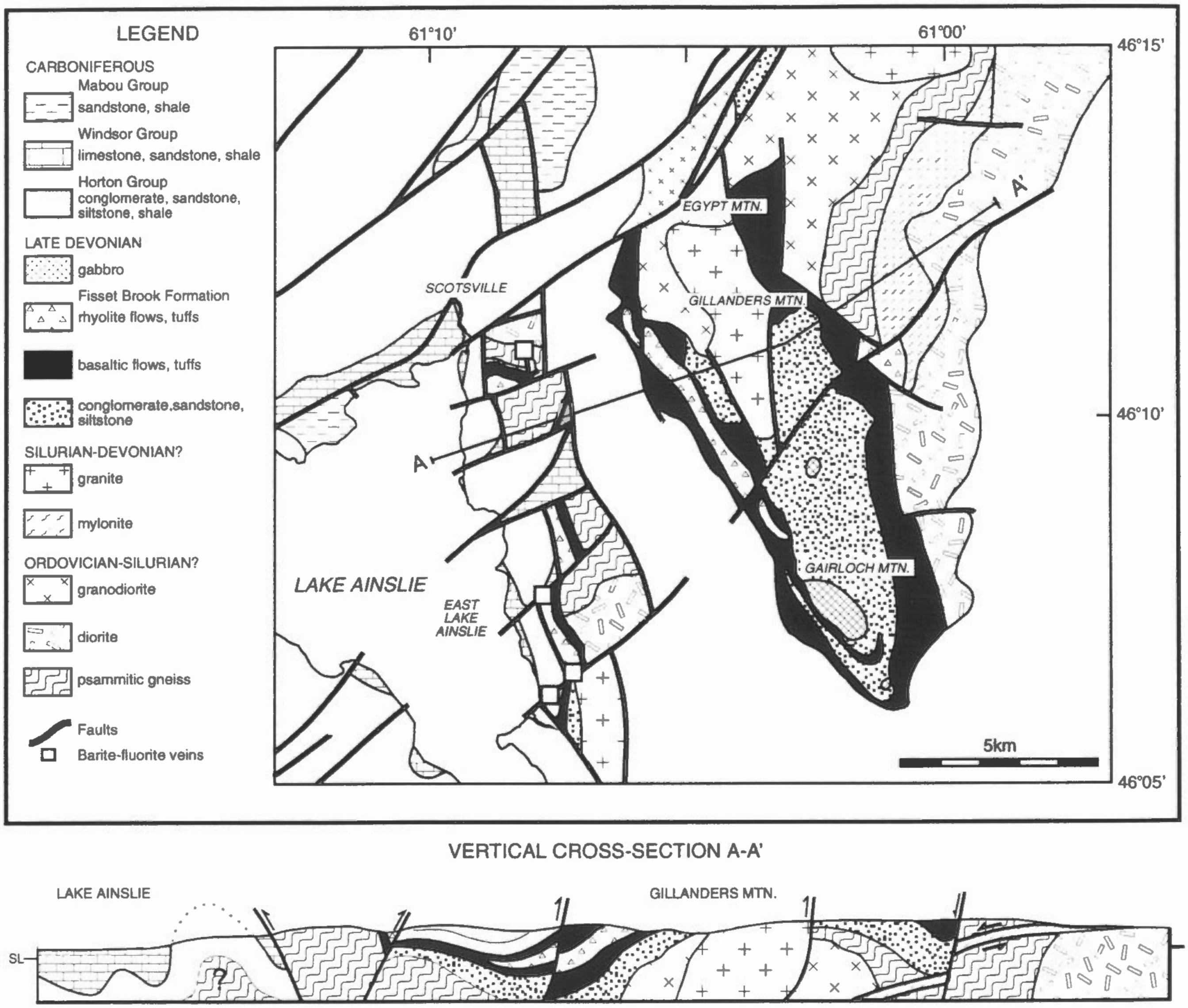

Figure 11. General geology of Lake Ainslie - Gillanders Mountain areas (Barr et al., 1995) with inferred structural relations illustrated in vertical cross-section

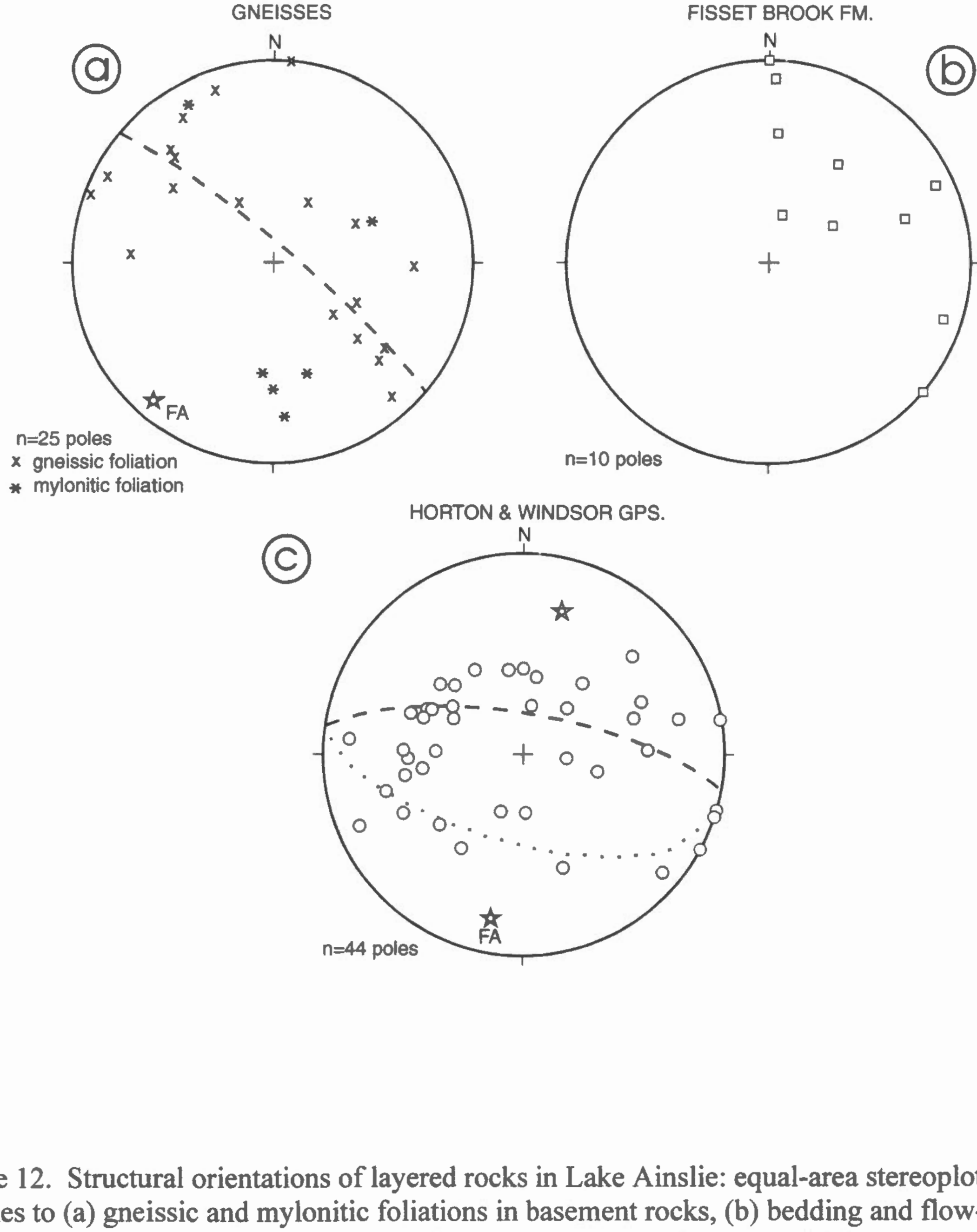

Figure 12. Structural orientations of layered rocks in Lake Ainslie: equal-area stereoplots of poles to (a) gneissic and mylonitic foliations in basement rocks, (b) bedding and flow-banding in the Fisset Brook Formation, and (c) bedding in the Horton and Windsor Groups. (Great circles represent best-fit pole girdles and FA's represent modal fold axes)

Horton and Windsor Groups:

Horton and Windsor groups have been folded together into relatively tight, upright to overturned folds along the margins of the inlier blocks (see Map A, and cross-section in Fig. 11). In general, the folds appear to be of large amplitude and to plunge gently both toward the north and the south, although the modal fold axis plunges at 10° toward the south (Fig. 12c). Good examples of such folding are exposed (a) at the open-pit in the MacInnis vein near Scotsville where folded rocks of the upper Horton Group, forming the hanging wall to the vein, are folded into N-plunging folds (Fig. 6), and (b) on the lake-shore at Howard MacLeans Point where a large fold involving basal Windsor rocks plunges NNW at 15° (Map A).

The faults bounding the uplifted blocks crosscut the folds thus establishing their relative ages, however their collective N-S distribution suggests a common origin, possibly as transpressional, push-up structures.

Local Fault Patterns:

The pattern of map-scale faulting (Fig. 11 and Map A) shows basically three sets of faults: (i) N-S faults, (ii) ENE-WSW faults, and (iii) NW-SE faults. Most of these faults cannot be observed directly so movement on them is inferred from map-scale offsets, and from similarly oriented, minor faults and their senses of motion as deduced from observed slip-lineation and release-step orientations.

The majority of the minor faults are oblique-slip to strike-slip fault surfaces, oriented ENE-WSW to ESE-WNW and commonly show dextral sense of motion (Fig. 13). Several sets of these oblique/strike-slip minor faults were developed, apparently because there was second-order and possibly also third-order movement (e.g. on riedel shears) in relation to the larger map-scale faults. Less common are N-S to NNW-SSE surfaces, some of which show dip-slip motion, and some sinistral(?) strike-slip motion (Fig. 13).

Modal minor faults (derived from a Kamb contoured plot of slip linears) suggest that there was consistent/coherent movement on, at least, three sets of these minor faults, essentially ENE-WSW directed (Fig. 13d). Therefore, they are interpreted to have formed largely as a synchronous array during formation of the map-scale fault blocks.

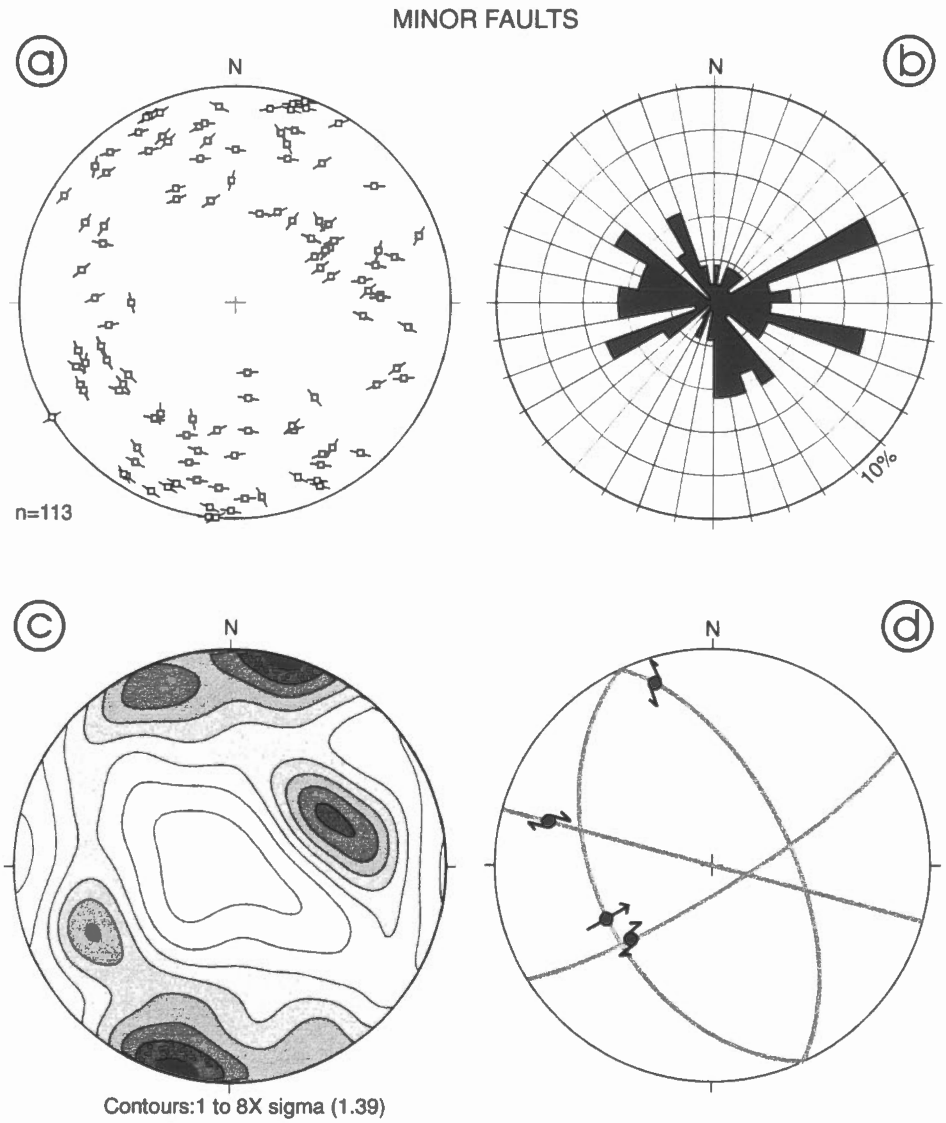

Figure 13. Minor fault patterns developed in Lake Ainslie area: (a) stereoplot of poles (with slip linears) to minor fault planes, (b) rose diagram of minor fault directions, (c) Kamb contoured stereoplot of poles to minor faults, and (d) stereoplot of modal fault planes and slip directions.

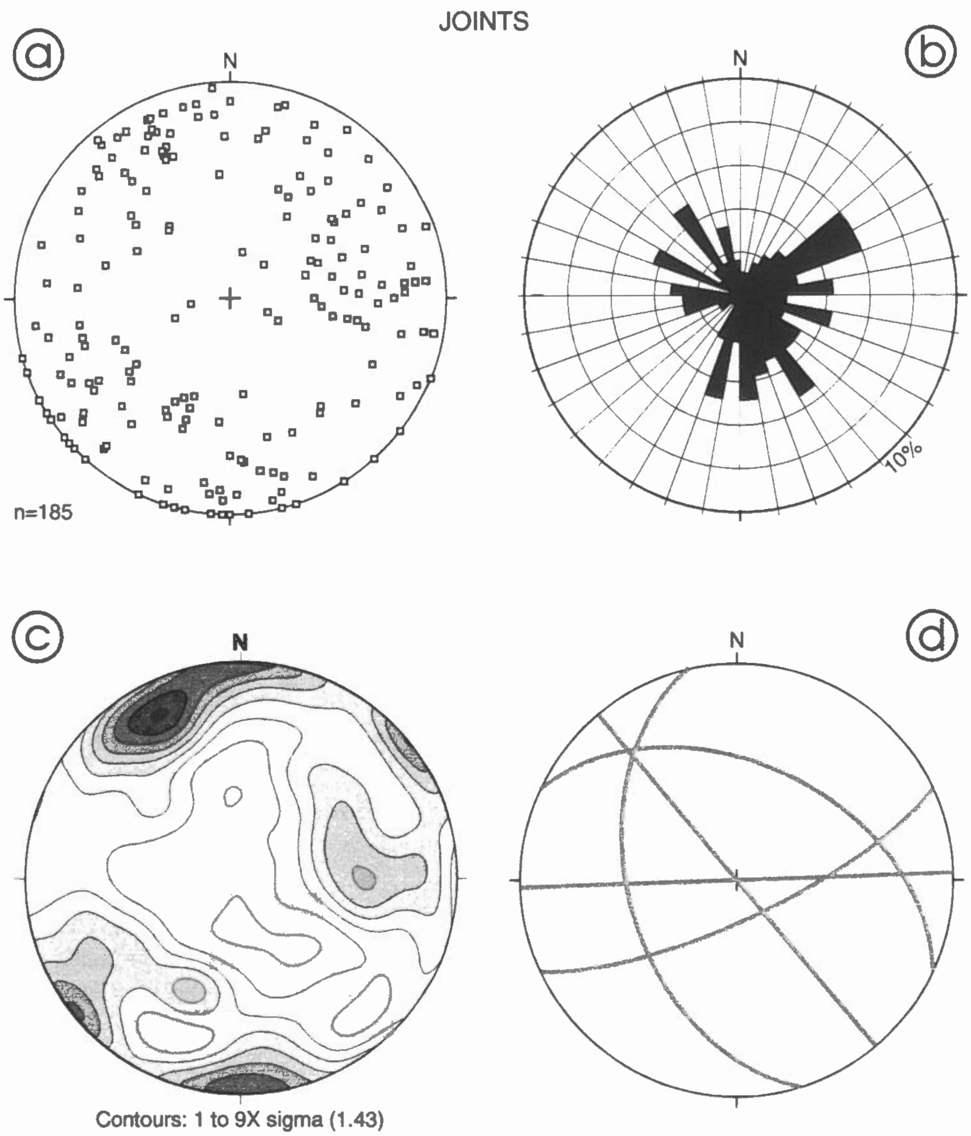

Figure 14. Joint patterns developed in Lake Ainslie area: (a) stereoplot of poles to joints, (b) rose diagram of joint directions, (c) Kamb contoured stereoplot of poles to joints, and (d) stereoplot of modal joint orientations.

Joint patterns (Fig. 14) broadly resemble those of minor fault planes except for a prominent set of subvertical NW-SE joints (Fig. 14d) which may be of younger age as it has no analog among the minor fault sets. This suggests that many of the minor faults represent joint surfaces that experienced later shear displacements.

Regional Fault Patterns:

On the larger scale, both east and west of Lake Ainslie, a similar pattern of faulting is developed (Figs. 11, 15). However, NE-SW faults predominate over N-S faults, and E-W faults are also developed. The NE-SW faults form a through-going system from which the E-W faults appear to branch/splay. The N-S faults, and the N-S folds in Carboniferous rocks, appear to be both offset and terminated by the NE-SW faults.

This pattern has many of the features of a NE-SW strike-slip fault regime, in this case one of dextral shear. The N-S folds and faults may be either transpressional structures of the same age as the strike-slip faults, or older structures re-activated during strike-slip faulting. Fold trends in the Carboniferous rocks are commonly subparallel to the NE-SW faults and appear to transect and interfere with N-S fold trends creating a basin-dome interference pattern to the west and southwest of Lake Ainslie (Fig. 15). Both the NE-trending faults and folds post-date deposition of the Mabou and Cumberland Groups and are therefore post-Westphalian in age, whereas the N-S faults and folds affect rocks of the Horton and Windsor Groups, and therefore are at least post-Visean in age. However, farther to the SW near Port Hood, rocks of the Mabou Group are folded with the Windsor Group into N-S folds adjacent to a N-S fault (Giles et al., 1995), implying that the N-S structures also could be significantly younger.

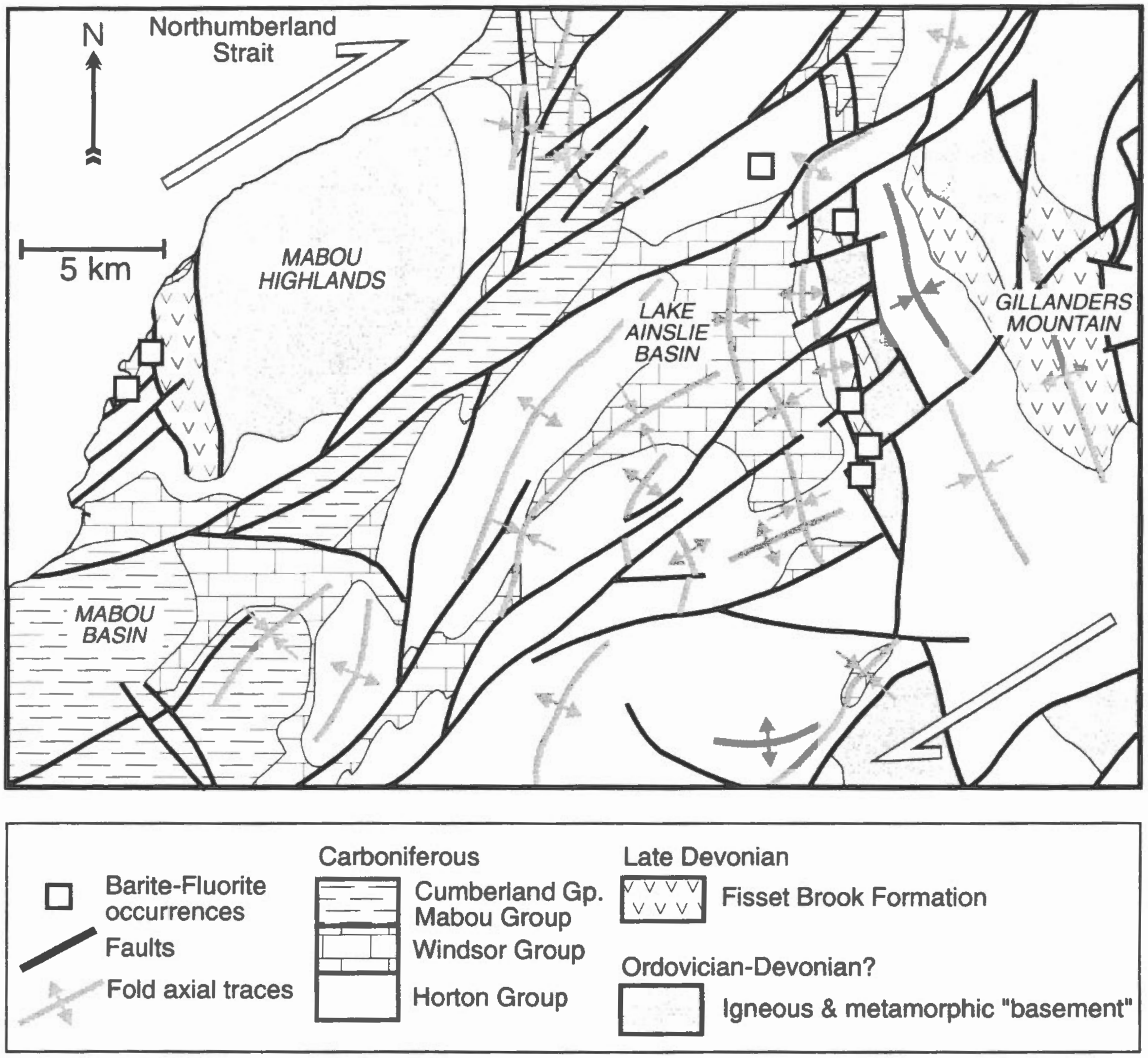

Figure 15. Inferred NE dextral strike-slip regime in the Mabou - Lake Ainslie area, with related interference folds and push-up fault blocks (mainly after Giles et al. (1995), with modifications in the area of the Mabou highlands from Barr and Macdonald (1989)).

STRUCTURAL GEOLOGY OF THE VEIN SYSTEMS

Vein Patterns:

The mean orientation of 21 measured veins is 065/70SE (Fig. 16a-c), and the majority of veins have orientations subparallel to this orientation which mimics prominent ENE-WSW fault directions in the general area (Fig. 11). But the large MacInnis vein near Scotsville, oriented 358/60E, and two other small veins clearly do not fit this general pattern; their orientations mimic prominent N-S to NNW-SSE fault directions (Fig. 11).

Kinematic & Dynamic Analysis

Slip-lineated minor fault surfaces associated with the veins suggest that movements affecting the veins were hybrid in nature. In the vicinity of the MacInnis vein, movements were a mixture of (i) sinistral(?), oblique-slip on steep N-S surfaces, (ii) reverse dip-slip on SW-dipping surfaces, and (iii) some associated dextral oblique-slip on transverse ENE-WSW surfaces (Fig. 16d). Whereas at the Campbell-MacMillan vein, movements on ENE-WSW to E-W surfaces were largely dextral oblique-slip, with some reverse dip-slip movement on W-dipping surfaces (Fig. 16e).

The kinematic history of the veins was determined from movement directions recorded by slip lineations developed on slickensided vein walls and adjacent shear fracture surfaces. Using the method of Marrett and Allmendinger (1990), movement planes and directions were used to deduce compressional and extensional directions of movement (Fig. 17a, b). These indicate for the Campbell-MacMillan vein at Bald Hill and for the Johnson vein that compressional movements were directed essentially NW - SE, and extensional movements NE - SW.

The graphic method of Alexandrowski (1985) was also used to determine the principal stress orientations responsible for the movement patterns shown by the vein walls and adjacent fracture surfaces. This method, which is derived from Arthaud's (1969) concept of movement planes (M-planes), is applicable to multiple fracture sets produced by a triaxial stress system. The results from the MacInnis, Campbell-MacMillan, and Johnson veins suggest that the maximum principal stress (σ_1) was oriented NW - SE, and the minimum principal stress (σ_3) oriented NE - SW (Fig. 17c). Such a stress configuration is compatible with the movement directions exhibited

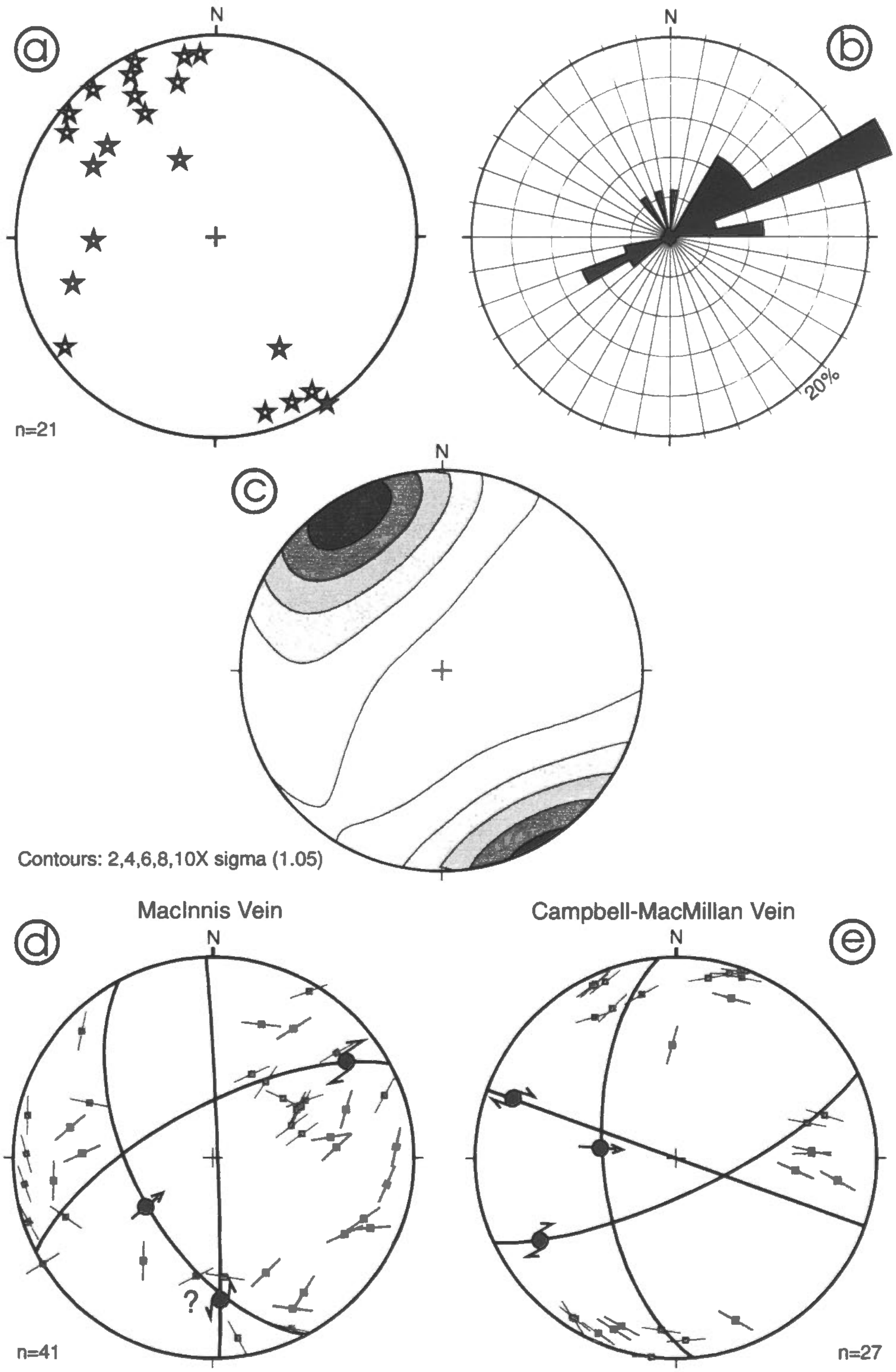

Figure 16. Orientations and movement directions of barite-fluorite veins: (a) stereoplot of poles to all veins, (b) rose diagram of all vein directions, (c) Kamb contoured stereoplot of poles to all veins, (d) and (e) stereoplots of slip linears associated with the MacInnis and Campbell-MacMillan veins showing modal movement planes and slip directions.

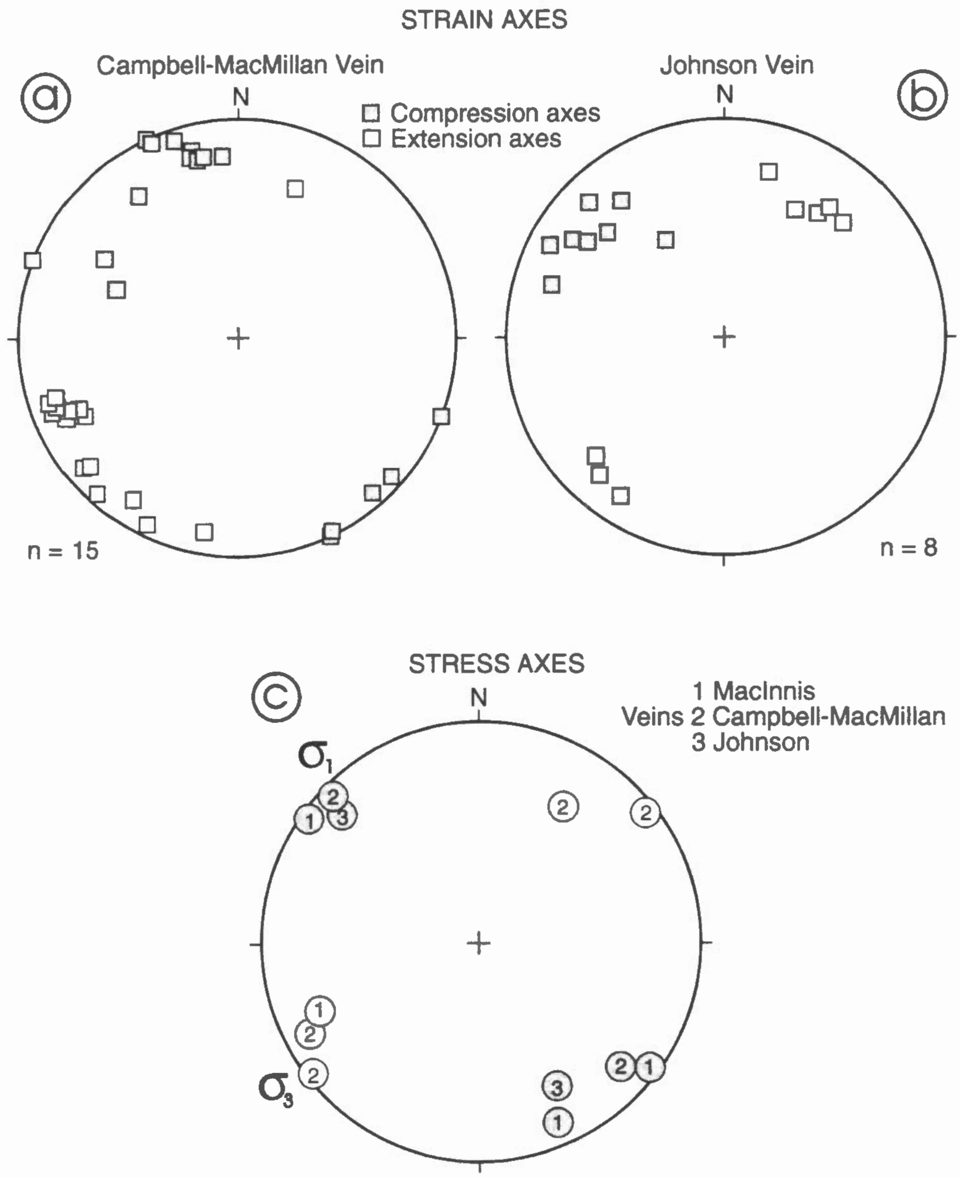

Figure 17. Orientations of stress and strain axes determined for the barite-fluorite veins: lower hemisphere projections of (a) and (b) compressional and extensional strain axes derived using the method of Marrett and Aldeminger (1990), and (c) stress axes derived using the graphic method of Aleksandrowski (1985).

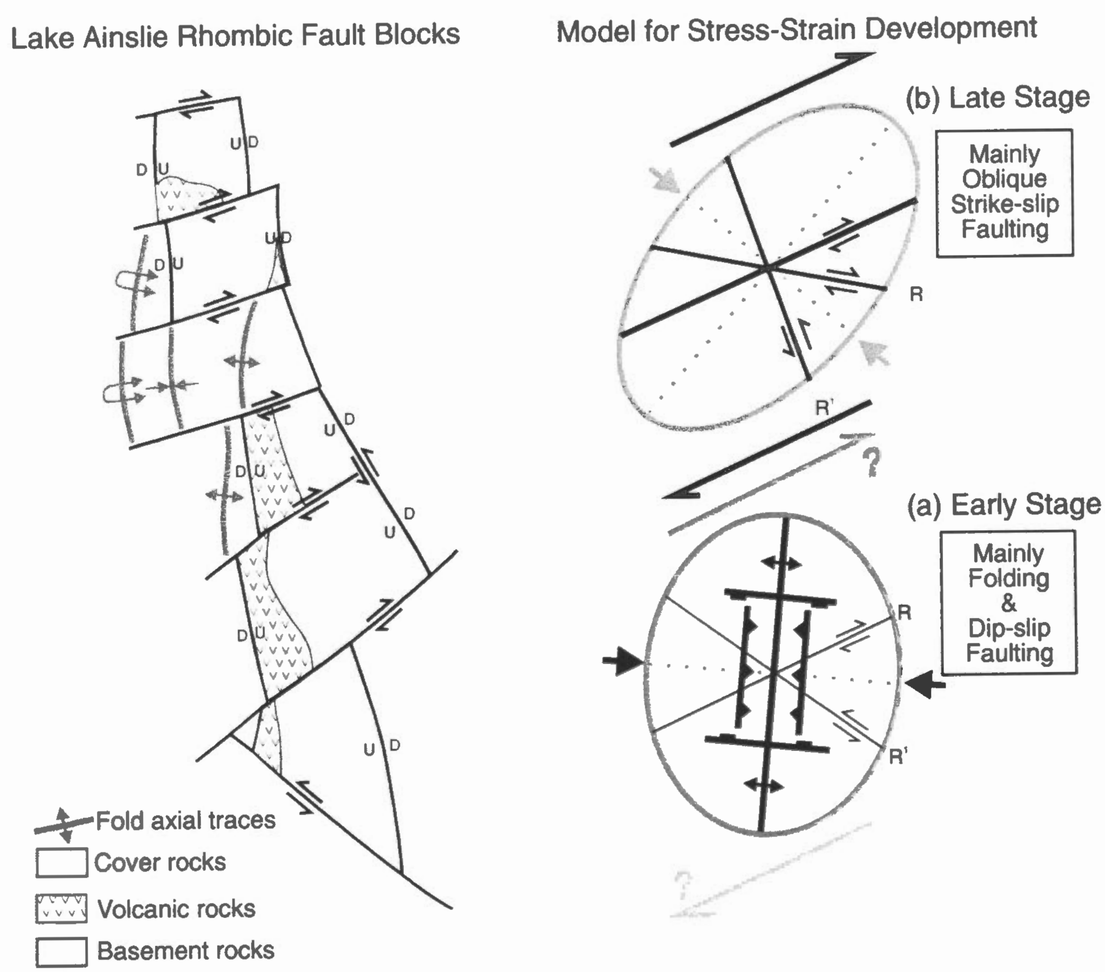

Figure 18. Structural model for the development of fracture and vein patterns in Lake Ainslie area within a transpressive regime.

by the fractures in general, and also with essentially dextral movement on the common ENE-WSW (065°) fault planes (Fig. 13d).

Model for Fracture Development in Lake Ainslie Area

A simple transpressional model for fracture development in the Lake Ainslie area (Fig. 18) has been compiled from modal minor fault data (Fig. 13), and from deduced stress-strain patterns (Fig. 17). While this model can explain the origin of the minor faults (and also some of the map-scale faults) reasonably well, it does not explain the development of the N-S folds and associated reverse faults that are cut by the faults. Compressional structures like the latter should be oriented NE-SW within such a prevailing stress field, so probably they were produced by a differently oriented precursor, stress system. If this too was transpressional, then the N-S array of cover folds and uplifted basement blocks was formed in the early stage, and then pervasively faulted and off-set at a late stage. It was at this late stage of transpression that the barite-fluorite veins were apparently emplaced.

FLUID INCLUSION STUDY

A study of the fluid inclusions was undertaken in collaboration with D. Kontak of Energy & Mines Branch, Department of Natural Resources, Halifax, N. S. Although some of this work has yet to be completed, preliminary results have been published (Kontak and Macdonald, 1995). The following represents a summary version of the results to date.

Twenty doubly-polished sections from six vein sets were examined for fluid inclusions. Although all samples show evidence of multiple stages of mineralization and are generally inundated with inclusions, syn- and post-vein brittle deformation has obscured and otherwise modified many inclusions. Thus the amount of material amenable to study is restricted to small relatively strain-free areas. Within these areas, small sub-populations of two-phase (L-V) aqueous inclusions, 20 - 45μm in size and showing consistent L:V ratios and essentially unmodified shapes were identified as appropriate for freezing and heating experiments. Many other groups of similar L-V inclusions displayed locally inconsistent L:V ratios, probably due to leakage and(or) knecking down as a result of deformational modification. More abundant and widespread than the two-phase (L-V) inclusions are planar arrays of monophase aqueous and vapour inclusions. These are considered to consist of L_{H2O} and V_{H2O} as no dissolved gases, such as methane, were detected on freezing to -196°C. Also found were two-phase (L-S) inclusions containing a birefringent solid, possibly barite or carbonate.

Only fluorite in samples from three different veins (Evans, J.A.MacDougall, and Campbell-MacMillan) was found to contain adequate numbers (n = 30-45) of useable two-phase aqueous inclusions, i.e. those with consistent L:V ratios and shape/orientation/distribution apparently unmodified by post-crystallization deformation, to warrant freezing and heating experiments.

Most of the inclusions displayed first melting temperatures at -70 to -58°C, indicating the presence of dissolved solutes other than NaCl. Most likely additional solute is $CaCl_2$ but as the eutectic for the $CaCl_2$-NaCl-H_2O system is -51°C, yet another dissolved phase, possibly gaseous, may be present. In many inclusions it was possible to determine the last melting of both hydrohalite and halite and so determine the NaCl/($CaCl_2$ + NaCl) ratio of the fluid (Fig. 19a). These ratios are variable indicating a compositional spectrum in fluid chemistry. Bulk salinities modelled in the system $CaCl_2$-NaCl-H_2O indicate salinities mostly in the range 20 to 28 wt. % eq. NaCl (Fig. 19b).

Homogenization temperatures (T_h) for two of the three samples range from 125°C down to 60°C (Fig. 19c). These temperatures are interpreted to be indicative of variable entrapment temperatures rather than secondary modification because within any sub-population of inclusions temperature variation is within 5°C. The colloform growth zoning commonly shown by fluorite may reflect in part such temperature and compositional fluctuations.

Assuming entrapment of the inclusions in fluorite occurred at a depth of 2.5 km from fluids with average salinity of 25 wt. % eq. NaCl, pressure corrected maximum temperatures can be estimated, from isochores calculated for the NaCl-H_2O system, to have been 170°C for lithostatic conditions versus 140°C for hydrostatic conditions. Such an emplacement depth for the veins appears compatible with the total stratigraphic thickness of the Carboniferous cover and its structural configuration at the time of vein formation (Fig. 11).

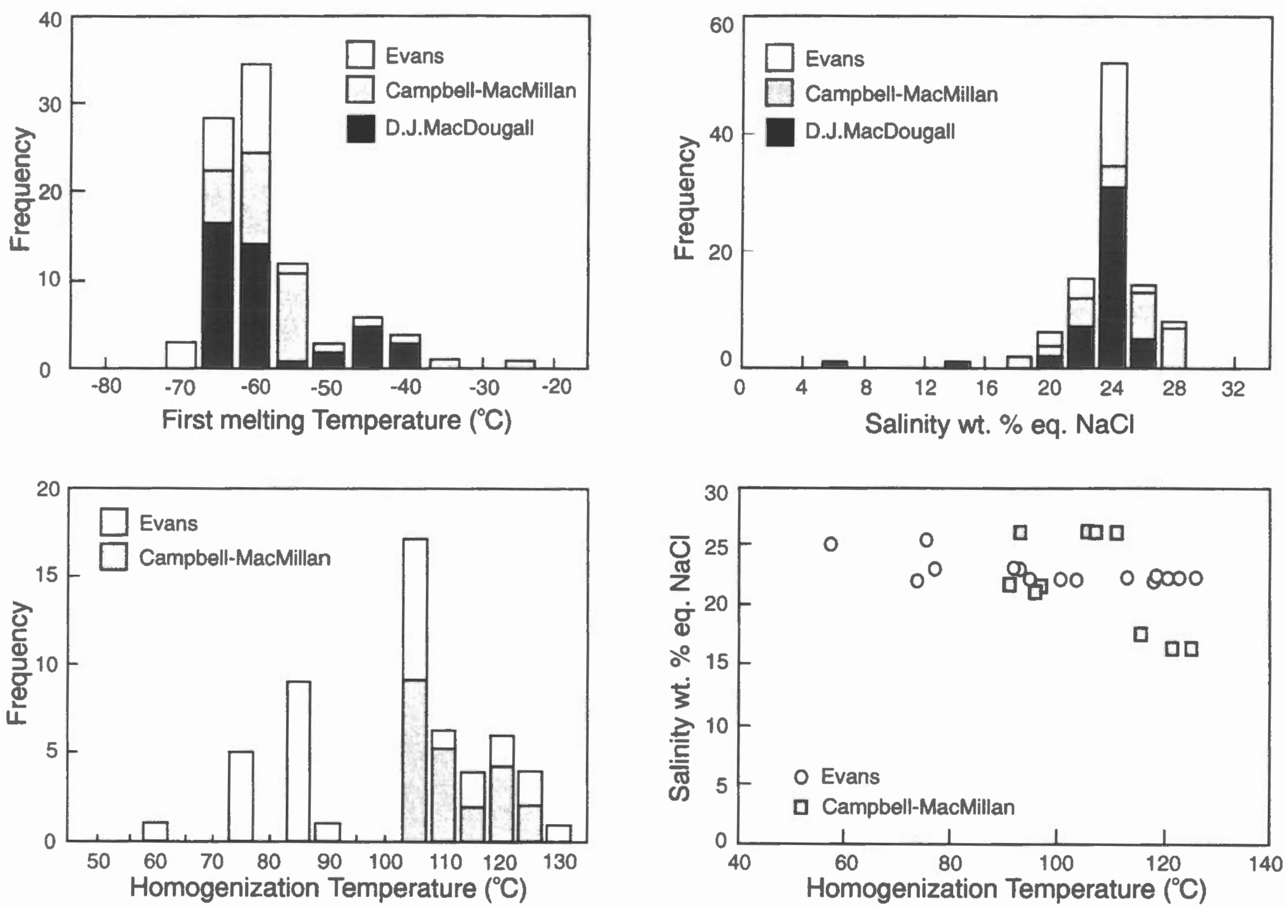

Figure 19. Fluid inclusion data from fluorite in three barite-fluorite veins: Campbell-MacMillan (Sample AM-48-1), D.J. MacDougall (Sample AM-75), and Evans (Sample AM-88-2). (a) first melting temperatures after freezing, (b) estimated salinities, (c) homogenization temperatures T_h, and (d) salinity vs. homogenization temperature.

STABLE ISOTOPE STUDY

Eighteen samples of barite were analyzed for S and O isotopes, seven samples of calcite for C and O isotopes, and seven samples of fluorite for H isotopes (Table 3).

Barite: $\delta^{34}S$ values in barite are relatively restricted (17.6 +\- 2.1‰) both within and between veins, and fall within the range of evaporitic sulphates of Mississippian age, 13.6 to 22.6 ‰ (Claypool *et al*., 1980). $\delta^{18}O$ values are low and also restricted in range (9.8 +\- 1.5‰).

Calcite: $\delta^{13}C$ values (-3.3 +\-0.5‰) and $\delta^{18}O$ values (14.3 +\- 0.3‰) are very restricted in their ranges. Such a close grouping of values, which is suggestive of a uniform hydrothermal source, resembles those shown by ore-stage calcites from other Ba and related Zn-Pb occurrences (Fig. 20) hosted by Mississippian clastic and carbonate rocks of the Horton and Windsor groups respectively (Ravenhurst *et al*., 1984). However, more highly negative $\delta^{13}C$ values, such as are shown by calcite from the Jubilee Zn-Pb deposit, are considered to be the result of involvement of organic carbon in crystallization of the calcite, e.g. from reduction of anhydrite by methane under anaerobic conditions (Armstrong *et al*., 1993; Chi *et al*, 1995). Also, higher temperatures of crystallization may be indicated by the higher $\delta^{18}O$ values of calcite found in many of the other occurrences.

Fluorite: δD values of fluid liberated from inclusions in fluorite were in the range -26 to -73 (mean & S.D. = -55 +\- 18‰) which spans the median range for most fluids except seawater (Fig. 21). However, when these values are combined with calculated values of $\delta^{18}O$ values for barite (+1.2 to -5.7 ‰) and for calcite (+4.2 to -5.7 ‰) which would be in equilibrium with aqueous fluid at temperatures from 170° down to 90°C (based on pressure-corrected, fluid inclusion T-X data), an isotopic compositional field for the ore-forming fluid can be inferred which falls within the general field for formation waters (Fig. 21).

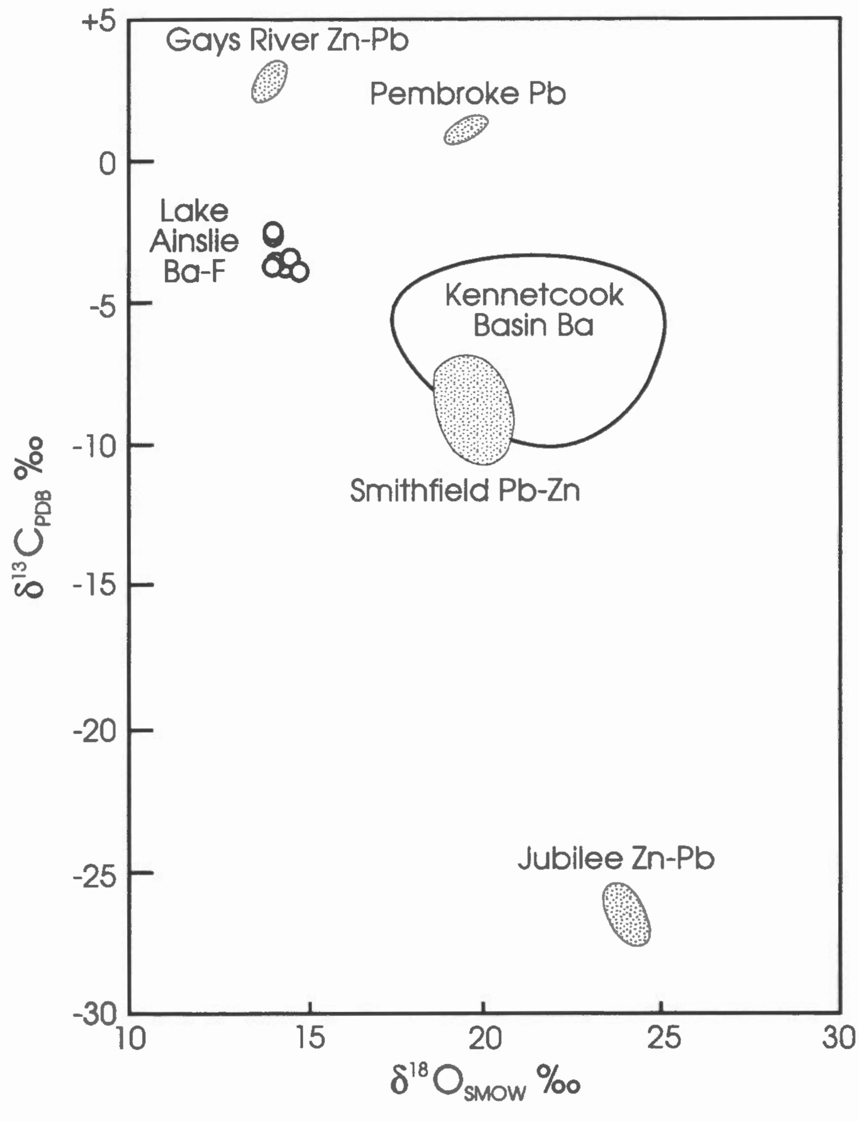

Figure 20. Stable isotope data for calcite from Lake Ainslie barite-fluorite veins, shown in relation to equivalent data from ore-stage calcite from other Ba and Zn-Pb-Ba mineral deposits in the Carboniferous Maritime Basin (from Ravenhurst et al., 1984; Armstrong et al., 1993).

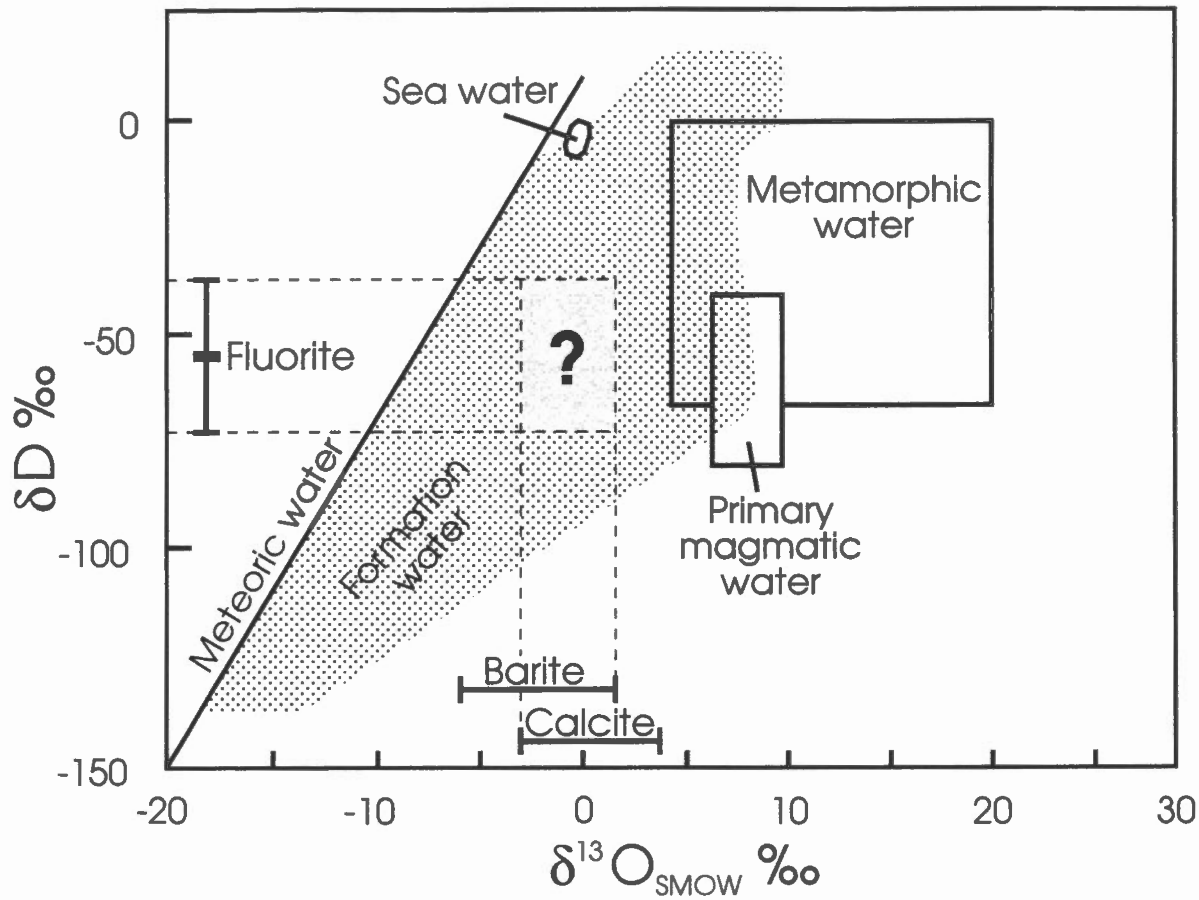

Figure 21. Inferred isotopic composition for Lake Ainslie fluid(s) based on δD values of fluid inclusions in fluorite (mean +/- standard deviation for 7 samples), and on calculated $\delta^{13}O$ values from barite and calcite assumed to be in equilibrium with the fluid(s) at T = 60-170°C.

RARE-EARTH ELEMENT STUDY

Fifteen samples of fluorite representing the main vein sets were analyzed for their REE contents by neutron activation (Table 4). When normalized to chondrite (Haskin *et al.*, 1968), they show distinctive patterns. Fluorite from the MacInnis vein (which is hosted by gneiss) shows flat patterns with slight depletion of LREE over HREE and no Eu anomaly. In contrast, fluorites from the other three vein sets (which are all hosted by Fisset Brook rhyolite) show slight enrichment of LREE and very strong Eu anomalies. As the fluorite in all these veins has a complex multistage crystallization history, indicated by their textural and zoning patterns, these results probably represent weighted averages of more complex internal patterns (Strong *et al.*, 1984).

Compared to REE patterns from the Fisset Brook rhyolite (Huard, 1984; Barr *et al.*, 1995), the latter group of vein fluorites which are hosted by the rhyolite show remarkably similar patterns (Fig. 22). This combined with the contrasting pattern of the MacInnis vein suggests that there may have been significant fluid/wallrock interaction during vein formation, although the only alteration identified is the pervasive kaolinization(?) of the host rhyolite.

It is not uncommon for fluorite from barite-fluorite vein districts to show variable bulk REE patterns, and these have been attributed variously to redox conditions and/or to fluid mixing (Jebrak *et al.*, 1985), and to changes in fluorine activity (Strong *et al.*, 1984). This aspect is being pursued further, in conjunction with on-going fluid inclusion studies.

GENETIC MODEL

Several lines of evidence can be combined to postulate a genetic model for the barite-fluorite veins.

The veins display textural and structural features indicative of syn- to post-kinematic brittle deformation. Much of this deformation was tectonic in which dextral oblique-slip ENE – WSW faulting played a dominant role, but there were also synchronous dip-slip and oblique-slip movements on N-S to NNW-SSE planes. Mineral deposition in the veins was largely by multistage open-space filling, as shown by colloform, crustiform and vuggy textures, and probably

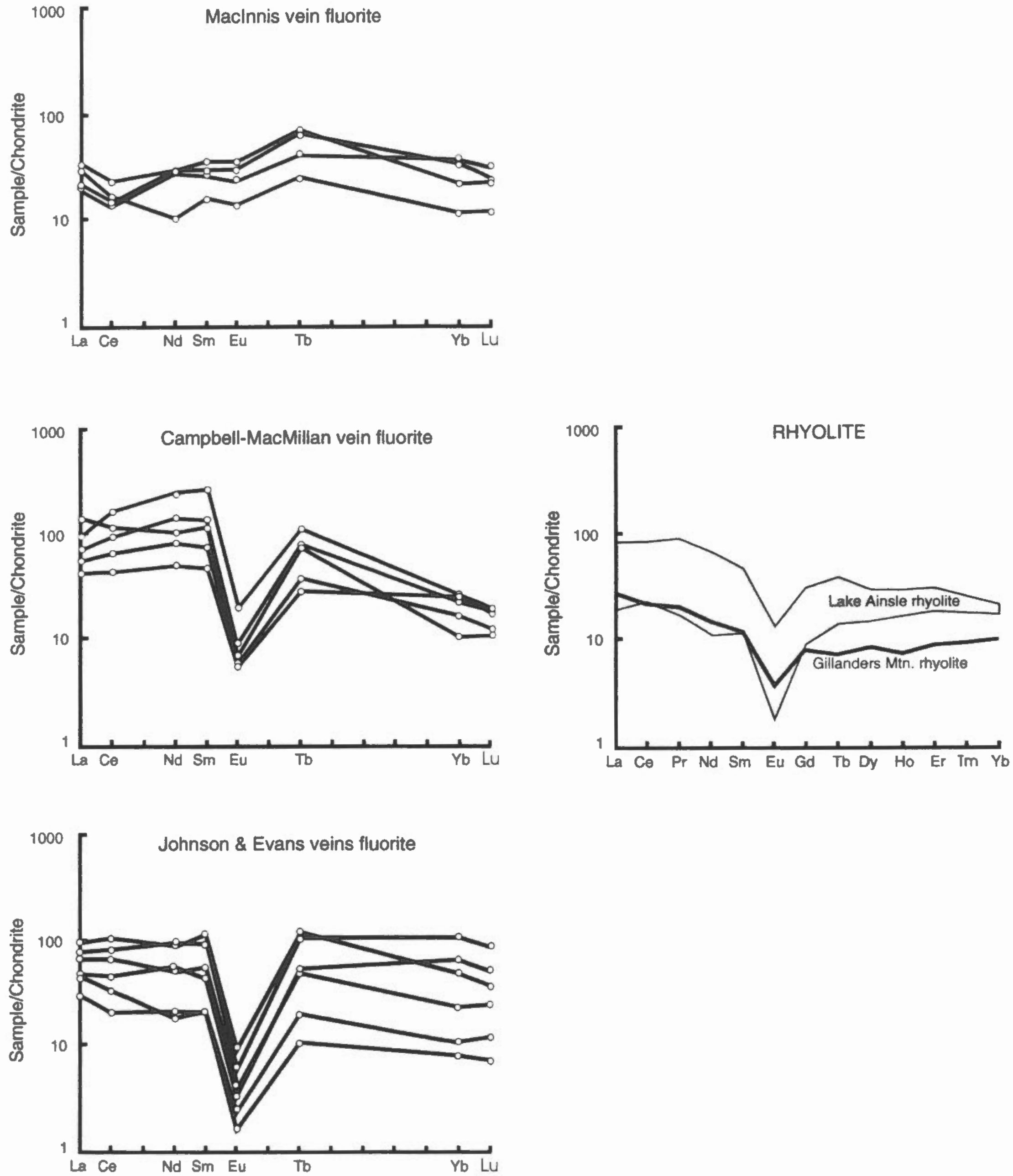

Figure 22. REE contents of fluorite from different vein sets, compared to those of rhyolite from the Fisset Brook Formation (from Huard, 1984; Barr et al., 1995).

occurred under relatively shallow lithostatic/hydrostatic conditions.

The ore fluid appears from fluid inclusion studies to have been highly saline (20-28 wt. % eq. NaCl) and to have approximated a $CaCl_2$-NaCl-H_2O system. With entrapment temperatures estimated to have been in the range of 90-170°C, such fluid resembles deep formational brines like those encountered at depths of more than 3-4 km in petroleum fields such as the Central Mississippi Salt Dome Basin (Kharaka and Thordsen, 1992). An origin for the ore fluid, as a formational brine expelled from a deep sedimentary basin, is supported also by the stable isotope data from barite-calcite-fluorite assemblages which suggest similarities in fluid composition with (i) formational waters in general (Fig. 21), and (ii) other Ba-Zn-Pb mineral deposits in the Carboniferous Maritime Basin (Fig. 20) (Ravenhurst *et al.*, 1984).

Vein formation in the Lake Ainslie area must be at least post-Visean in age as the faults with which the veins are directly associated cross-cut folds affecting both the Horton and Windsor Groups. They may even be post-Westphalian in age as similarly oriented faults of the Hollow Fault system cut younger stratigraphic units to the west in the Mabou area (Giles *et al.*, 1995). Given such timing, and the similarities to the other Ba-Zn-Pb occurrences of Carboniferous age (such as the Walton deposit and other smaller barite-rich vein occurrences in the Kennetcook sub-basin), the model of Ravenhurst *et al.* (1984) for compaction-driven expulsion of fluids from the Magdalen Basin via a Horton Group aquifer system beneath Windsor Group evaporites is probably also applicable to the Lake Ainslie area.

The veins were apparently emplaced in active fracture zones as they developed in competent crystalline rock units within pre-Carboniferous basement blocks when they were pushed up through the Carboniferous cover sequence near the margins of the basin during regional strike-slip faulting.

EXPLORATION CRITERIA

Other areas with potentially similar environments for barite-fluorite veins of the Lake Ainslie type, include:

(i) areas immediately to the north and south of Lake Ainslie (Fig. 11), where, although at a higher structural level, similar hydrologic and tectonic conditions may have prevailed marginal to the Mabou basin;

(ii) the Cheticamp area, farther to the north (Fig. 1), where the Fisset Brook Formation is again exposed between a younger cover and an older crystalline basement;

(iii) the SW margin of the Mabou Highlands (Fig. 15), particularly in the Mill Brook area where float blocks of barite occur close to the faulted contact between clastic rocks of the Horton Group and volcanic rocks which are possible equivalents of the Fisset Brook Formation.

The possibility also exists for stratabound replacements and infillings of barite and fluorite, in association with sulphides that are commonly found disseminated in the vicinity of the Horton-Windsor contact. These could involve either the Macumber Formation, especially its collapse-breccia facies, or the upper part of the Horton Group (Ainslie Formation). A potential example of this association might be the MacPhails Brook minor sulphide occurrence which lies just north of the Campbell-MacMillan and D.J. MacDougall veins (Figure 9).

Exploration techniques shown to be effective in Lake Ainslie area (Zurowski, 1971, 1972a,b) included (i) EM surveys which resulted in the discovery of satellite veins, and (ii) geochemical soil sampling for barium which proved to be partially effective in that it detected float barite in colluvial soil. Stream sediment sampling for barium, strontium, and possibly manganese might also prove useful at the recconnaissance level, as demonstrated in the Walton area (Boyle, 1972) where significant drainage dispersion trains are developed in an area of much more subdued topography. Another possible diffuse geochemical indicator might be the potassic alteration shown by volcanic rocks of the Fisset Brook Formation which host the veins, assuming that alteration is genetically linked to fluid migration into the area. Gravity surveys were also attempted but proved to be laborious to implement and the results difficult to model due the many topographic corrections which had to be applied (Zurowski, 1971, 1972a,b).

REFERENCES

Aleksandrowski, P. 1985. Graphical determination of principal stress directions for slickenside lineation populations: an attempt to modify Arnaud's method. Journal of Structural Geology, 7, pp. 73-82.

Armstrong, J.P., Longstaff, F.J., and Hein, F.J. 1993. Carbon and oxygen isotope geochemistry of calcite from the Jubilee Zn- Pb deposit, Cape Breton Island. Canadian Mineralogist, 31, pp.755-766.

Arnott, A.M. 1994. Petrology and geochemistry of the Fisset Brook Formation in the Gillanders Mountain area, Cape Breton Island, Nova Scotia. B.Sc. Honours Thesis, Acadia University, 117p.

Arthaud, F. 1969. Methode de determination graphique des directions de raccourcissement, d'allongement et intermediaire d'une population de failles. Bulletin Societe Geologique Francaise, 11, pp. 729-737.

Barr, S.M., Brisebois, D., and Macdonald, A.S. 1985. Carboniferous volcanic rocks of the Magdalen Islands, Gulf of St. Lawrence. Canadian Journal of Earth Sciences, 22, pp.1679-1688.

Barr, S.M., Jamieson, R.A., and Raeside, R.P. 1992. Geology, Northern Cape Breton Island, Nova Scotia; Geological Survey of Canada, Map 1752A.

Barr, S.M., Macdonald, A.S., Arnott, A.M., and Dunning, G.R. 1995. Field relations, structure, and geochemistry of the Fisset Brook Formation in the Lake Ainslie - Gillanders Mountain area, central Cape Breton Island, Nova Scotia. Atlantic Geology, 31, pp. 127 -139.

Barr, S.M. and Macdonald, A.S., 1989. Geology of the Mabou Highlands, western Cape Breton Island, Nova Scotia. Nova Scotia Department of Mines and energy, Paper 89-2, 65p.

Blanchard, M.-C. 1982. Geochemistry and petrogenesis of the Fisset Brook Formation, Western Cape Breton Island, Nova Scotia. M.Sc. Thesis, Dalhousie University, 225p.

Blanchard, M.-C., Jamieson, R.A. and More, E.B. 1984. Late Devonian - Early Carboniferous volcanism in western Cape Breton Island, Nova Scotia. Canadian Journal of Earth Sciences, 21, pp. 762-774.

Claypool, G.E., Holser, W.T., Kaplan, I.R., Sakai, H., and Zak, I. 1980. The age curves of sulfur and oxygen isotopes in marine sufate and their mutual interpretation. Chemical Geology, 28, pp. 199-260.

Chi, G. and Savard, M.M. 1995. Constraints from fluid-inclusion data on the origin of the Jubilee carbonate-hosted Zn-Pb deposit, CapeBreton, Nova Scotia. Canadian Mineralogist, 33, pp.709-721.

Creed, R.M. 1968. Barite-fluorite mineralization at Lake Ainslie, Inverness County, Nova Scotia. M.Sc. Thesis, Dalhousie University, Halifax, 158p.

Dawson, K.R. 1985. Geology of barium, strontium, and fluorine deposits in Canada. Geological Survey of Canada, Economic Geology Report 34.

Douglas, G.V. 1944. Barytesand fluorspar deposits at Lake Ainslie. Nova Scotia Department of Mines, Annual Report 1944, pp.132-151.

Felderhof, G.W. 1978. Barite, celestite and fluorite in Nova Scotia. Nova Scotia Department of Mines, Bulletin 4, 463p.

Felderhof, G.W and MacDonald, R.H. 1984. Report on the MacInnis Barite deposit, Scotsville, Cape Breton, Nova Scotia (for Scotsville Mineral Resources by A.C.A. Howe International Ltd.) Nova Scotia Department of Mines, Assessment Report 84-088, 102p.

French, V.A. 1985. Geology of the Gillanders Mountain Intrusive Complex and satellite plutons, Lake Ainslie area, Cape Breton Island, Nova Scotia. MSc. Thesis, Acadia University, 237p.

Fyffe, L.R. and Barr, S.M. 1986. Petrochemistry and tectonic significance of Carboniferous volcanic rocks in New Brunswick. Canadian Journal of Earth Sciences, 23, pp. 1243-1256.

Giles, P.S., Hein, F.J., and Allen, T.L. 1995. Bedrock geology of Port Hood - Lake ainslie (11k04, 11K03, 11F13), Cape Breton Island, Nova Scotia. Geological Survey of Canada, Open File xxxx, 1:50 000 map with marginal notes.

Haskin, L.A., Haskin, M.A. and Frey, F.A., 1968. Relative and terrestrial abundances of the rare earths. In Origin and distribution of the elements. *Edited by* L.H. Aherns. Pergamon, Oxford, United Kingdom, pp. 889-912.

Huard, A.A. 1984. The Carboniferous volcanic rocks at Lake Ainslie, Nova Scotia: implications for tectonic regime and barite mineralization. B.Sc. thesis, St. Francis Xavier University, Antigonish, Nova Scotia.

Hughes, C.J., 1973. Spilites, keratophyres, and the igneous spectrum. Geological Magazine, 6, pp. 513-527.

Jebrak, M., Smejkal, V., and albert, D. 1985. Rare earth and isotopic geochemistry of the barite-fluorite veins from the western Rouerge district, France. Economic Geology, 80, pp. 2030-2034.

Kelley, D.G. and Mackasey, W.O. 1965. Basal Mississippian volcanic rocks in Cape Breton Island, Nova Scotia. Geological Survey of Canada, Paper 64-34.

Kharaka, Y.K. and Thordsen, J.J. 1992. Stable isotope geochemistry and origin of waters in sedimentary basins. *In* Isotopic signatures and sedimentary records. *Edited by* Clauer, N. and Chaudhuri, S. Springer-Verlag, New York, pp. 441-466.

Kontak, D.J. and Macdonald, A.S. 1995. Initial results of a fluid inclusion study of fluorite from the Lake Ainslie barite-fluorite deposits, Inverness County, Nova Scotia. Annual Report of Activities, Mineral Resources Division, Nova Scotia Department of Natural Resources.

Luwick, G.D. 1990. Report on the production of barium chemicals from the Conwest barite deposit at Lake Ainslie, Cape Breton, Nova Scotia. Phase IIB, Laboratory Investigations. Nova Scotia Research Foundation for Conwest Exploration Co. Ltd. Nova Scotia Department of Mines and Energy, Assessment Report 90-163, 87p.

Lynch, J.V.G., and Tremblay C. 1994. Late Devonian - Carboniferous detachment faulting and extensional tectonics in western Cape Breton Island, Nova Scotia, Canada. Tectonophysics, 238, pp. 55-69.

Lynch, G., Tremblay, C., Rose, H. 1993b. Geological map (1:50,000) of Lake Ainslie area, Cape Breton Island, Nova Scotia (11K3 and west 11K2). Geological Survey of Canada, Open File 2613.

Marrett, R. and Aldeminger, R.W. 1990. Kinematic analysis of fault-slip analyses. Journal of Structural Geology, 12, pp. 973-986.

Meschede, M. 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram. Chemical Geology, 56, pp. 207-218.

Norman, G.W.H. 1935. Lake Ainslie map-area, Nova Scotia. Geological Survey of Canada, Memoir 177, 103p.

Pearce, J. A. 1982. Trace element characteristics of lavas from destructive plate boundaries. In Andesites: Orogenic Andesites and Related Rocks. Edited by R.S Thorpe. Wiley-Interscience, New York, pp. 525-548.

Pearce, J. A., and Cann J. R. 1973. Tectonic setting of basic volcanic rocks determined using element analyses. Earth and Planetary Science Letters, 19, pp. 290-300.

Pearce, J.A., Harris, N.B.W. and Tindle, A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology, 25, pp. 956-983.

Perkins, C.T. 1995. Deformational history of the Margaree Shear Zone, East Lake Ainslie area, Cape Breton Island, Nova Scotia. B.Sc. Honours thesis, Acadai University, 80p.

Potapoff, P. 1982. Barite, Lake Ainslie, Inverness County, Nova Scotia: report on geological mapping, a soil geochemical survey, a VLF-EM survey, trenching and drilling. CCH Mineral Ltd. Nova Scotia Department of Mines and Energy, Assessment Report 11K/03D 06-J-31(010)

Ravenhurst, C.E., Reynolds, P.H., Zentill, M., Kreuger, H.W., and Blenkinsop, J. 1984. Formation of Carboniferous Pb-Zn and barite mineralization from basin-derived fluids, Nova Scotia, Canada, Economic Geology, 84, pp. 1471-1488.

Smith, P.K. and Macdonald, A.S. 1981. The Fisset Brook Formation at Lowland Cove, Inverness County, Nova Scotia. Nova Scotia Department of Mines and Energy, Paper 81-1 18 pp.

Whalen, J.B., Currie, K.L., and Chappell, B.W. 1987. A-type granites: geochemical characteristics, discrimination, and petrogenesis. Contributions to Mineralogy and Petrology, 95, pp. 407-419.

Winchester, J.A. and Floyd, P.A., 1976. Geochemical magma type discrimination: application to altered and metamorphosed basic igneous rocks. Earth Planetary Science Letters, 28, pp. 459-469.

Winchester, J.A. and Floyd, P.A., 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chemical Geology, 20, pp. 325-343.

Zurowski, M. 1971. Report on the exploration and development activities conducted on the holdings of International Mogul mines Ltd. and Newcostigan Mines Ltd. for 1971 in the Lake Ainslie area, Inverness County, Province of Nova Scotia. Nova Scotia Department of Natural Resources, Assessment Report 11K/03A 06-J-31(12).

Zurowski, M. 1972a. Report on the exploration and devlopment activities conducted on the holdings of International Mogul mines Ltd. and Newcostigan Mines Ltd. for 1972 in the Lake Ainslie area, Inverness County, Province of Nova Scotia. Nova Scotia Department of Natural Resources, Assessment Report 11K/03A 06-J-31(13).

Zurowski, M. 1972b. Barite-fluorite deposits of Lake Ainslie - an appraisal from an economic viewpoint. CIM Transactions, 75, pp. 318-321.

APPENDICES

TABLE 1. Major and trace element analyses* (in wt. % and ppm respectively) for samples from Lake Ainslie.

	BASALT					RHYOLITE				
	AM-14	AM-16	AM-32	AM-49	AM-103	AM-17	AM-28	AM-31	AM-50	AM-100
SiO_2	46.55	46.66	47.31	46.46	48.05	75.62	76.05	75.49	75.85	81.55
TiO_2	2.55	2.26	2.13	1.99	3.42	0.11	0.09	0.08	0.09	0.10
Al_2O_3	16.66	15.71	14.9	17.51	14.48	11.64	11.28	11.77	11.69	9.32
$Fe_2O_3^T$	11.91	11.44	14.28	9.98	10.77	1.91	1.27	1.84	0.88	1.28
MnO	0.28	0.59	0.24	0.59	0.87	0.01	0.01	0.02	0.01	0.02
MgO	5.05	6.29	5.72	6.23	6.38	nd	nd	nd	0.04	0.04
CaO	8.42	6.34	5.55	8.37	6.44	0.06	0.06	0.04	0.07	0.22
Na_2O	3.77	2.11	4.32	2.9	4.04	1.12	0.82	0.07	0.94	1.86
K_2O	0.63	3.96	2.24	0.83	0.94	8.91	8.94	9.79	8.98	5.52
P_2O_5	0.37	0.34	0.32	0.30	0.86	0.01	0.02	0.01	0.01	0.01
LOI	4.20	3.60	3.50	4.10	4.00	0.50	0.50	0.40	0.80	0.80
TOTAL	100.39	99.3	100.51	99.26	100.23	99.9	99.05	100.14	99.36	100.72
Ba	432	1553	1553	281	886	265	387	367	384	640
Rb	6	99	194	21	29	346	413	418	429	140
Sr	502	1854	397	320	270	14	18	18	20	70
Y	37	38	38	35	58	47	59	52	62	51
Zr	210	257	195	172	218	249	158	148	153	157
Nb	8	7	7	8	9	29	43	47	42	35
Th	10	10	10	10	<10	23	25	38	31	28
Pb	10	29	28	10	25	17	21	12	61	<10
Ga	19	17	16	19	22	20	18	23	20	5
Zn	117	2226	161	556	447	13	24	13	26	12
Cu	30	12	25	50	29	5	5	5	19	<5
Ni	56	60	56	85	69	5	5	5	5	<5
V	260	265	265	251	323	11	12	5	12	8
Cr	17	44	54	57	91	7	12	12	5	<5

*Analyses by standard XRF techniques at the Nova Scotia Regional Geochemical Centre, St. Mary's University.
LOI = loss on ignition.

TABLE 2: Electron Microprobe Analyses* of Calcite and Barite from Lake Ainslie barite-fluorite veins.

n = number of spot analyses

	Calcite			Barite		
	n	CaO	MnO	n	BaO	SrO
MacInnis Vein				7		
AM-7-4	6	55.53 +/- 1.85	0.60 +/- 0.23	3	60.81 +/- 1.32	1.31 +/- 0.11
AM-84-6	2	54.82 +/- 0.02	0.83 +/- 0.23	4	61.20 +/- 0.68	1.73 +/- 0.31
AM-84-17	4	56.22 +/- 1.23	1.16 +/- 0.54	6	61.12 +/- 0.14	1.52 +/- 0.23
AM-92-1	3	56.80 +/- 2.83	1.30 +/- 0.09		60.61 +/- 1.15	1.84 +/- 1.03
Campbell-MacMillan Vein						
AM-48-5	2	57.42 +/- 0.52	0.90 +/- 0.01	8	61.03 +/- 0.35	1.52 +/- 0.52
Johnson Veins						
AM-25-1	0			4	61.67 +/- 0.45	1.15 +/- 0.31
AM-27-1	4	54.94 +/- 0.61	0.79 +/- 0.07	5	60.34 +/- 1.05	2.25 +/- 0.87
AM-30-1	0			11	60.81 +/- 0.80	2.11 +/- 0.69
Evans Vein						
AM-88-1	9	54.46 +/- 1.36	1.15 +/- 0.58	3	61.82 +/- 0.80	1.19 +/- 0.32
Mean Value	30	55.75 +/- 1.11	0.96 +/- 0.25	51	61.04 +/- 0.48	1.62 +/- 0.39

* Analyses performed at the Dalhousie Regional Electron Microprobe Laboratory, Dalhousie University.

TABLE 3. Stable isotope analyses* of barite, calcite, and fluorite from Lake Ainslie veins.

			BARITE		
Sample	Vein	mol/mg SO	$\delta^{34}S_{cdt}$	μmol/mg CO	$\delta^{18}O_{smow}$
7-2	MacInnis	2.8	16.9	5.1	8.7
7-4	"	2.8	17.6	2.6	8.6
92-1	"	3.0	18.1	5.5	9.8
92-2	"	3.3	18.3	6.3	10.8
DD84-6	"	3.0	20.4	6.5	11.0
DD84-11	"	3.0	20.9	7.2	11.5
48-3	MacMillan	2.7	18.5	6.3	10.8
48-5	"	2.8	18.6	6.7	10.5
DD72-C	"	3.1	19.0	7.2	10.8
75-1	D.J. MacDougall	2.9	20.2	6.7	11.0
25-1	Johnson	3.1	15.5	7.0	8.3
30-1	"	2.7	15.5	6.6	9.0
30-2	"	2.8	15.5	7.0	8.5
36-1	"	3.0	15.1	7.2	8.5
37-1A	"	2.4	14.6	4.6	8.6
37-1B	"	2.8	14.2	6.1	8.0
88-1	Evans	2.8	16.9	7.8	12.5
88-2	"	3.3	20.2	5.5	11.0

			CALCITE		
Sample	Vein	mol/mg CO	$\delta^{13}C_{pdb}$	$\delta^{18}O_{pdb}$	$\delta^{18}O_{smow}$
92-1	MacInnis	9.1	-2.6	-16.4	14.0
92-2	"	7.5	-2.5	-16.4	14.0
48-1	MacMillan	8.9	-3.6	-16.0	14.4
DD72-C	"	9.0	-3.4	-16.4	14.0
30-1	Johnson	8.8	-3.4	-15.9	14.6
88-1	Evans	9.2	-3.9	-15.7	14.7
88-2	"	8.7	-3.4	-16.4	14.1

		FLUORITE	
Sample	Vein	wt% H_2O	H/D
7-4	MacInnis	0.1	-71
92-1	"	0.2	-44
48-1	MacMillan	0.2	-42
48-5	"	0.2	-73
DD72-C	"	0.1	-69
75-1	D.J. MacDougall	0.1	-59
88-2	Evans	0.2	-26

* All analyses by Stable Isotope Laboratory, University of Saskatchewan.

TABLE 4: Rare earth and other trace element analyses* of fluorite from Lake Ainslie barite-fluorite veins.

	MacInnis Vein				Campbell-MacMillan Vein				D.J.MacDougall		Johnson Veins			Evans Vein	
	n = 4				n = 4				n =2		n = 3			n = 2	
	7-2	7-4	92	DD84-6	48-1	48-3	48-5	DD72-C	75	26	30-1	30-2	37-1	88-1	88-2
La	7.90	10.85	12.61	7.33	20.38	37.43	26.45	16.42	51.28	11.30	17.78	29.29	16.69	29.76	22.15
C	13.66	15.16	21.92	13.32	63.68	162.27	92.15	40.86	107.39	20.03	43.92	77.85	29.80	89.94	58.37
N	21.32	7.18	20.84	21.40	58.88	180.07	104.68	35.97	75.80	15.75	41.86	68.01	13.53	60.21	33.12
S	6.87	3.69	8.51	6.50	17.59	59.48	33.24	10.84	27.34	4.33	10.39	21.79	4.95	28.33	12.20
Eu	2.78	1.19	3.18	2.09	0.44	1.74	0.78	0.50	0.61	0.14	0.28	0.52	0.18	0.73	0.31
Tb	3.98	1.44	4.21	2.55	2.24	6.80	4.87	1.68	4.67	0.66	3.15	6.39	1.22	7.49	2.69
Yb	8.57	2.82	5.47	9.89	4.37	6.52	5.67	6.56	2.73	2.18	16.91	28.64	2.82	15.20	5.46
Lu	0.92	0.45	0.86	1.26	0.49	0.71	0.67	0.78	0.41	0.29	2.00	3.47	0.49	1.70	0.90
Hf	5.25	2.41	2.31	0.12	0.09	0.10	0.12	0.02	2.50	0.05	0.72	0.25	2.75	0.14	0.81
Ta	0.00	0.11	0.09	0.02	0.03	0.00	0.01	0.02	0.06	0.02	0.02	0.06	0.01	0.01	0.12
Th	0.00	0.00	0.00	0.20	0.06	0.04	0.03	0.14	0.00	0.29	0.00	0.01	0.19	0.01	0.01
U	0.04	0.00	0.00	1.91	1.08	2.08	2.18	0.26	0.00	1.11	11.67	3.52	0.00	0.00	0.00
Sc	0.05	0.12	0.10	0.16	0.07	0.07	0.06	0.06	0.12	0.07	0.07	0.08	0.14	0.04	0.14
C	0.04	0.07	0.19	0.26	0.07	0.12	0.08	0.07	0.22	0.08	0.06	0.12	0.34	0.14	0.53

* Analyses by neutron activation, Nova Scotia Regional Geochemical Centre, St. Mary's University.

COPY OF PALYNOLOGY REPORT BY DOLBY & ASSOCIATES

SAMPLES: AM-84-2 & AM-84-17

AGE: Tournasian

ZONE: upper 3B, Dolby (1993)

LOCATION: These two samples are from drill holes #84-2 and #84-17 (Scotsville Mineral Resources Ltd.) located on the MacInnis barite-fluorite vein, 1km SE of Scotsville, Lake Ainslie (11K/03 46°11'00"N, 61°08'20"W). They are grey shales from a depth of *ca.* 20m within a folded sequence of lacustrine shale/siltstone/sandstone forming a downfaulted inlier of the upper Horton Group in the hanging wall of the vein.

REMARKS: Both samples yielded similar species but in different proportions. *Schopfites claviger* is present in both samples which indicates that the samples are no older than upper 3B. *Crassispora trychera* is also present but in small numbers. *Vallatisporites vallatus* and *V. verrucosus* are numerous to abundant in #17 but fewer in in number in #2. A small number of *Spelaeotrilites pretiosus* is also present in both. An upper 3B age is favored.

Acritarchs are present in both samples. At least some some have been reworked from the Early Palaeozoic. There is also evidence in #2 of Strunian reworking.

Significant species:

Schopfites claviger (R)	*Crassispora trychera* (F)
Vallatisporites vallatus	*V. verrucosus* (C-A)
Spelaeotrilites pretiosus	*S. crenulatus*
Retusotrilites avonensis	*Rugospora polytycha*