Maritime Sediments and Atlantic Geology

Vol. 22 December, 1986 No. 3

Stratigraphy and Structure of the Southeastern Cape Breton Highlands, Nova Scotia

Robert P. Raeside and Sandra M. Barr
Department of Geology, Acadia University
Wolfville, Nova Scotia, BOP 1XO

The southeastern Cape Breton Highlands are composed of an eastern belt of predominantly granitoid rocks and a western belt of dioritic, granitoid and stratified rocks. The oldest unit is inferred to be the Cheticamp Lake gneiss, which outcrops in the western belt. This is in faulted contact with the most extensive stratigraphic unit, the McMillan Flowage Formation, which occurs throughout the western belt. It represents early Paleozoic or older continental margin accumulations of sandy and silty clastic sedimentary, volcanic, volcaniclastic and rare calcareous rocks. These stratified units have been folded and intruded by late Precambrian(?) to lower Paleozoic granitoid and dioritic plutons, and then have undergone a later strike-slip deformational event. In the eastern belt, the Barachois River unit preserves a section of siltstones and greywackes which have been largely metamorphosed to gneisses, and the Price Point unit includes a small section of volcanic rocks. A single pervasive foliation has been recognized in the eastern belt.

The two belts appear to represent components of two tectonostratigraphic zones, the western belt being part of the Highlands zone, and the eastern belt part of the Bras d'Or zone of Cape Breton Island. The western belt displays a pronounced Devonian thermal overprint, whereas the eastern belt has preserved late Precambrian or Siluro-Ordovician ages. Neither belt can readily be correlated with the Southeastern zone of Cape Breton Island or the Avalon Zone in Newfoundland. Based on lithologic similarities, both in the stratified units and in the nature of the plutonic rocks, the western belt (Highlands zone) can be correlated with the Gander zone. The eastern belt (Bras d'Or zone) is a possible manifestation of the Avalon zone at a deeper crustal level.

Le sud-est des Hautes-Terres du Cap-Breton se compose d'une chaîne orientale formée surtout de roches granitoïdes ainsi que d'une ceinture occidentale montrant des termes dioritiques, granitoïdes et stratifiés. On croit que le gneiss de Cheticamp Lake, qui affleure dans la chaîne occidentale, est l'unité la plus vieille. Il est en contact par faille avec l'unité stratigraphique la plus étendue, *i.e.* la Formation de McMillan Flowage qui se présente d'un bout à l'autre de la ceinture occidentale. Cette dernière représente l'accumulation, au début du Paléozoïque voire plus tôt, de roches terrigènes sableuses et limoneuses, volcanites, volcaniclastites et de rares roches calcaires sur la marge continentale. Ces unités stratifiées ont été plissées et injectées de plutons granitoïdes et dioritiques tardi-précambrien (?) à éo-paléozoiques. Elles ont par la suite subi un épisode de décrochement. Dans la chaîne orientale, l'unité de Barachois River préserve une assise de siltstones et de grauwackes qui ont été en grande partie métamorphisés en gneiss, alors que l'unité de Price Point comprend une petite section de volcanites. On a reconnu une seule foliation pénétrante dans la chaîne orientale.

Les deux chaînes semblent faire partie de deux zones tectonostratigraphiques; la ceinture occidentale appartiendrait à la zone de Highlands tandis que la ceinture orientale ferait partie de la zone de Bras d'Or de l'île du Cap-Breton. La chaîne occidentale accuse d'un épisode thermique dévonien prononcé alors que la ceinture orientale a préservé des âges tardi-précambriens ou siluro-ordoviciens. La corrélation de l'une ou l'autre de ces chaînes avec la zone sud-est de l'île du Cap-Breton ou la zone d'Avalon de Terre-Neuve est malaisée. Si l'on en juge par leur similitudes lithologiques, tant en ce qui regarde les unités stratifiées que la nature

MARITIME SEDIMENTS AND ATLANTIC GEOLOGY
22, 264-277 (1986)

0711-1150/86/030264-14$3.10/0

Received April 29, 1986
Revision Accepted August 4, 1986

des roches plutoniques, on peut corrêler la chaîne occidentale avec la zone de Gander. La chaîne orientale (zone de Bras d'Or) pourrait représenter la zone d'Avalon à un niveau cortical plus profond.

[Traduit par le journal]

INTRODUCTION

The Cape Breton Highlands occupy a significant situation in the Appalachian Orogen, between the larger and more intensely studied areas in Newfoundland and mainland North America. In the southwestern corner of Newfoundland, 150 km distant from the Cape Breton Highlands, four major tectonostratigraphic terranes (Williams and Hatcher 1983) of the Appalachian Orogen converge in an area of poorly defined tectonic relationships (Fig. 1). A fifth terrane, the Avalon, occurs 200 km to the east on the southern coast of Newfoundland.

The correlation of these tectonostratigraphic terranes identified in Newfoundland with Paleozoic and Precambrian crystalline rocks in Cape Breton Island has proved to be difficult (e.g. Barr and Raeside, this issue, Williams and Hatcher 1983, Keppie 1982). This has been in part due to limited mapping, especially of the Cape Breton Highlands, and a lack of radiometric or paleontological age data, and in part due to differences in the character of the rocks. Most authors have considered that all of Cape Breton Island belongs to the Avalon Terrane, based primarily on the similarities of lithologies in the southeastern part of the island to those of the Avalon Peninsula of Newfoundland (O'Brien *et al*. 1983, Rast and Skehan 1983). However, the largest block of crystalline basement rocks in Cape Breton Island, the Cape Breton Highlands, preserves lithologies distinctly different from those of southeastern Cape Breton Island and has the potential for providing evidence of the nature of either the deeper levels of the Avalon crust or of a separate terrane.

The Cape Breton Highlands form a plateau, with an elevation of about 400 to 500 m, which has been deeply incised

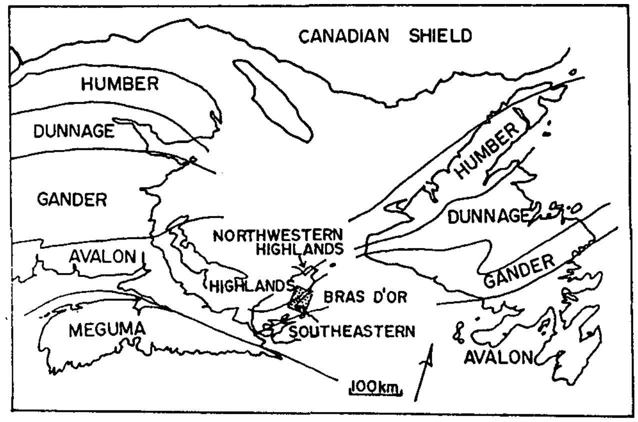

Fig. 1. Tectonostratigraphic subdivisions of Atlantic Canada. Zones in Cape Breton Island after Barr and Raeside (this issue); in other areas after Williams (1979). Area of study shown in stippled box.

by a radial drainage system. Around the perimeter of the plateau, coastal lowlands are underlain by Carboniferous sedimentary rocks, and areas of extensive outcrop of crystalline rocks are limited to rivers and streams. There is good access to the top of the plateau in the southern Highlands using private road networks of lumber and power companies.

Previous maps of the southern Cape Breton Highlands (MacLaren 1956a, 1956b, Kelley 1957, 1960, Murray 1977) are of a reconnaissance nature and serve to outline the approximate positions of major rock types. No detailed descriptions of stratigraphy, structure, plutonism or metamorphism were provided. These maps have been summarized in a regional compilation of the geology of Nova Scotia (Keppie 1979). Recent geological mapping has redefined the lithologic types and their distribution in the southern half of the Highlands (Jamieson and Craw 1983, Jamieson and Doucet 1983, 1984, Raeside *et al*. 1984, Barr *et al*. 1985).

The southeastern Highlands (Fig. 2) incorporate two major north-south trending belts of different lithological character. The eastern belt includes a variety of granitoid rocks

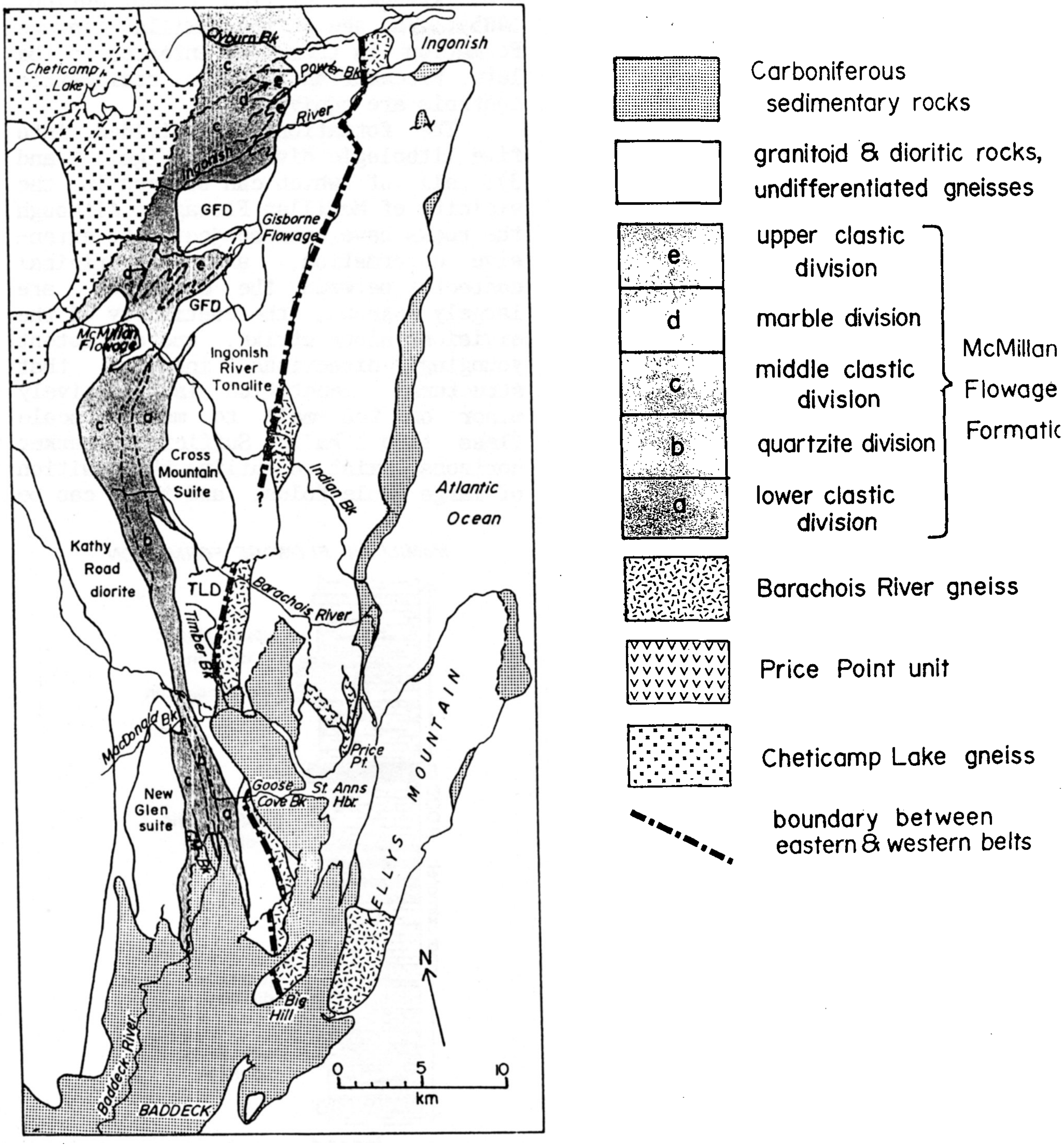

Fig. 2. Simplified geological map of the southeastern Cape Breton Highlands. GFD - Gisborne Flowage diorite, TLD - Timber Lake diorite; CM Bk - West Branch Christopher MacLeod Brook.

and subordinate isolated blocks of gneissic, volcanic and metasedimentary units. The western belt includes a variety of presumed Precambrian dioritic and granitoid rocks and a continuous belt of metasedimentary lithologies. The primary purposes of this paper are firstly to define and describe the most extensive stratified unit, the McMillan Flowage Formation, and to describe more briefly the other stratified units of the southeastern Highlands. Secondly, the paper aims to interpret the tectonic history which these rocks, together with the adjacent plutonic units, have undergone and to propose a tectonic model for the development of the southeastern Cape Breton Highlands.

STRATIGRAPHY

Four major stratified units are recognized in the southeastern Highlands, but only one, the McMillan Flowage Formation, has been mapped in sufficient detail to assign a formal name.

1. McMillan Flowage Formation

The most extensive stratified unit in the southeastern Highlands, the McMillan Flowage Formation, outcrops in a belt extending from Clyburn Brook in the north to Baddeck River in the south, a strike length of 60 km. The rock types are predominantly clastic, but include substantial amounts of mafic rocks, at least some of which are volcanic, and rare calcareous rocks.

The age of the McMillan Flowage Formation is not known precisely. In the south it is unconformably overlain by Carboniferous rocks of the Horton Group. It has been intruded by a variety of dioritic and granitoid bodies, some of which have been dated by radiometric methods. In the Gisborne Flowage area, an intrusive contact was observed, with xenoliths of semipelite of the middle clastic division of the formation incorporated in the Gisborne Flowage diorite which has yielded a KAr date on hornblende of 417 $\pm$ 16 Ma (H. W. Krueger, written communication, 1985). The age of the intrusion, however, may be substantially older. The McMillan Flowage Formation has also been intruded by the Ingonish River Tonalite which has yielded ages of 352 $\pm$ 13 Ma (Rb-Sr whole rock; J. Blenkinsop, written communication, 1985) and 420 to 485 Ma (K-Ar, whole rock; A. Hayatsu, written communication, 1984) and by the New Glen Suite which has yielded a somewhat dubious age of 708 $\pm$ 53 Ma (Rb-Sr, whole rock; H.W. Krueger, written communication, 1985). The age of the McMillan Flowage Formation is therefore inferred to be late Precambrian but the radiometric controls are equivocal.

The formation is subdivided into five lithologic divisions (Figs. 2 and 3), all of which can be seen in the vicinity of McMillan Flowage. Although the rocks have been subjected to extensive deformation, and the original contacts between the divisions are largely unknown, the continuity of the divisions along strike, and consistent younging directions indicate that structural repetition is relatively minor on the small to medium scale (less than 1 km). Sufficient marker horizons exist to outline the position of large scale folds, and these can be

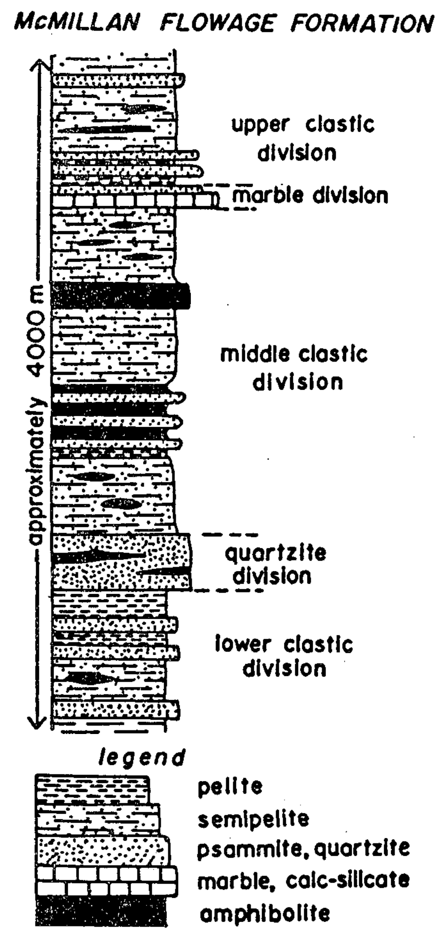

Fig. 3. Schematic stratigraphic section of the McMillan Flowage Formation. The width of the column is a general indication of average grain size.

confirmed by consistent graded and cross bedding observations.

Original stratigraphic thicknesses are difficult to determine because of the extensive folding - thicknesses quoted below are present structural thicknesses.

a. *Lower clastic division*

The lower clastic division is recognized only to the south of McMillan Flowage. It is particularly well exposed in the headwaters of Goose Cove Brook, where an 800 m thick section has been preserved displaying peak metamorphic conditions in the greenschist facies. Small sections of the lower clastic division have also been mapped in the central part of the area (West Branch Indian Brook and Barachois River) where metamorphic grade is in the sillimanite zone. Because of this relatively wide range of metamorphic conditions, the aspect of these rocks varies considerably. In the southern sections, they are a series of quartzites, semipelitic phyllites and black slates at the bottom and garnet phyllites interbedded with psammites at the top. Mafic layers occur sporadically throughout the unit, but are not laterally persistent. Small outcrops of calc-silicate rocks were observed in Barachois River in an area previously mapped as marble (Murray, 1977; Keppie, 1979). Marble horizons, up to 1 to 2 m thick, outcrop in the lowermost parts of the division (Goose Cove Brook to MacDonald Brook area). On the basis of poorly preserved fining upwards structures and consistently oriented tectonic structures, all sections of the lower clastic division are inferred to young from east to west. Nowhere has the base of the division been identified - its eastern margin has been intruded by the granitoid rocks of the Goose Cove Brook and Cross Mountain suites, and the Timber Lake diorite.

b. *Quartzite division*

Conformably overlying the lower clastic division is the quartzite division. It underlies a prominent northerly trending ridge, 30 km long and up to 1500 m wide, which tapers both to the north and south. As the rocks have a near-vertical dip, the quartzite division is inferred to have a maximum thickness of 1500 m. The rocks are typically monotonous medium grained quartzites, but include arkosic and psammitic varieties, which are finely bedded and preserve evidence of cross-stratification. Mafic layers within the quartzite can be traced laterally for up to 2 km. In the McMillan Flowage area, the quartzite division thins and pinches out, and a conformable stratigraphic relationship is inferred between the lower clastic division and the middle clastic division. Elsewhere, the quartzite division passes abruptly, but conformably, up into the lower semipelites of the middle clastic division.

c. *Middle clastic division*

The middle clastic division is the thickest division of the McMillan Flowage Formation, ranging up to 2000 m thick in the McMillan Flowage area. Like the lower clastic division, the appearance of the rocks varies considerably depending on metamorphic grade which ranges from chlorite in the south to sillimanite in the vicinity of McMillan Flowage. Complete exposure of a lower part of the division is found in the spillway cut at McMillan Dam, and the middle and upper parts of the division are moderately well exposed along logging roads south of McMillan Flowage. In the south, the most complete sections of the division occur in easterly flowing tributaries of West Branch Christopher MacLeod Brook.

In the McMillan Flowage area, the lower part of the division (approximately 500 m thick) is composed of pelitic schists and semipelitic gneisses with thin layers or boudins of amphibolites and calc-silicate rocks. Many of the clastic layers show migmatization, and in this area the division has been intruded by at least three phases of cross-cutting veins and granitoid dykes. At lower metamorphic grade in Clyburn and Christopher MacLeod Brooks, the lower part of the division occurs as well bedded green-grey to black slates, phyllites and garnet phyllites with common thin mafic layers.

The middle part of the division (approximately 400 m thick) is composed of a series of quartzites and amphibolites. Individual beds of quartzite range from 40 to 150 cm thick, and are very variable in their appearance - blue-white and rusty weathering orthoquartzites, micaceous, feldspathic and graphitic quartzites, and fine to coarse grained varieties of quartzite are present. Quartzite layers range from 15 to 60 m thick and are interlayered with 25 to 40 m thick amphibolite layers. Individual amphibolite layers can be traced for up to 4 km, but do not appear to be correlable throughout the middle clastic division. At lower metamorphic grades quartzites are interlayered with chloritic schists.

The upper part of the middle clastic division is poorly exposed and outcrops on logging roads southwest and east of McMillan Flowage. Its total thickness is about 1100 m, assuming no repetition by folding. It is composed of a series of semipelitic schists with discontinuous quartzite and amphibolite layers. A thick amphibolite unit, about 200 m thick, occurs near the middle of the section and can be traced for distances of 8 and 6 km in two separate areas. The upper part of the division is not found in the south where it has been cut out by the intrusion of the New Glen suite.

d. *Marble division*

The marble division is a thin, but laterally persistent, horizon which is an important marker in the upper part of the McMillan Flowage Formation. It outcrops in two areas - between McMillan and Gisborne Flowages, and on the ridge and brook north of Ingonish River. In both areas the division is characterized by a 25 to 35 m thick marble and calc-silicate horizon, with 1 to 2 m thick amphibolite layers included in it, overlain by a 25 to 70 m thick quartzite or feldspathic quartzite. The most complete exposure of the calcareous part of the marble division occurs in an access ramp to an adit to an aqueduct between McMillan and Gisborne Flowages. A detailed description of this outcrop has been made by Davis (1983). Correlation with the marble division in other localities, and detailed examination of the structural geology, has indicated that this outcrop preserves a duplicated section of the division, folded about a southwesterly plunging minor syncline in the core of a large synclinorial structure.

e. *Upper clastic division*

Small portions of the upper clastic division are preserved in the core of a large synclinorial structure in the Gisborne Flowage and Ingonish River areas. The top of the division has been removed by the intrusion of the Gisborne Flowage diorite and Ingonish River Tonalite, and a maximum thickness of 500 m is preserved. The base of the upper clastic division is gradational from the marble division, and consists of interlayered quartzites, feldspathic quartzites and semipelites. Further up-section, thin, lensoid amphibolites occur in a predominantly semipelitic sequence. The division has everywhere undergone metamorphism to the middle amphibolite facies.

Largely on the basis of limited reconnaissance mapping and correlation across areas of Carboniferous cover much of the area now recognized to be underlain by the McMillan Flowage Formation has been previously assigned to the George River Group (Murray, 1977; Milligan, 1970; Keppie, 1979; Wiebe, 1972). In other parts of Cape Breton Island, however, the George River Group is characterized by thick sequences of carbonates and quartzites (Milligan, 1970), whereas the McMillan Flowage Formation is predominantly semipelitic in composition with psammitic, quartzitic, pelitic and mafic components, and only very minor carbonates. The George River Group (carbonate-quartzite association) outcrops only in central Cape Breton Island and there are no extensive areas of outcrop of pre-Carboniferous carbonate rocks in the Cape Breton Highlands. Correlation between the McMillan Flowage Formation and the George River Group therefore appears tenuous. If the McMillan Flowage Formation is time-equivalent with any portion of the George River Group, it must represent a deeper water clastic deposit with a more significant volcanic component.

The correlation of volcanic and volcaniclastic layers in the northern part of the area with the volcanic and sedimentary Fourchu Group of south-eastern Cape Breton Island (Wiebe, 1972; Keppie, 1979) is yet more tenuous. There appears to be no separation between the volcanic and volcaniclastic layers and the clastic sedimentary layers in the Clyburn Brook area - the two are largely interbedded with each other throughout the section. Metamorphic grade increases gradually from chlorite grade to sillimanite grade up the Clyburn valley, and the entire section has been included in the middle clastic division of the McMillan Flowage Formation.

2. Cheticamp Lake gneiss

In the northwestern part of the study area, a belt of ortho- and para-gneisses occurs (Fig. 2). The major rock type is a monotonous felsic biotite-K-feldspar gneiss, with some garnet-bearing horizons. The gneiss is monzogranitic in composition, medium grained and moderately to poorly foliated. It contains lenses of pelitic material - some as migmatized biotite schists, others as pure biotite (or biotite and muscovite) rocks. Lenses of syenogranitic gneiss also occur in the unit. Possibly infolded into the predominantly orthogneiss is a 2 km wide pelitic gneiss belt which contains garnet, K-feldspar and sillimanite-bearing lithologies. Mapping has proceeded in this unit only to the northern edge of the map area in Figure 2 and it is likely that the unit underlies areas to the north. Mapping has not been sufficiently detailed to establish a stratigraphic order, and the entire unit is informally termed the Cheticamp Lake gneiss.

The relationship between the McMillan Flowage Formation and the Cheticamp Lake gneiss is not precisely known. South of the Clyburn Brook Fault, the contact between them is in a 100 to 500 m wide shear zone characterized by chloritic felsic mylonites. North of the fault, the contact is not exposed, but can be limited to a 150 m wide interval of no outcrop across which metamorphic grade increases from the sillimanite and muscovite zone to the sillimanite and K-feldspar zone.

The relationship between the Cheticamp Lake gneiss and other gneissic units in the Cape Breton Highlands is as yet unknown.

3. Price Point unit

A sequence of volcanic rocks described by Macdonald and Barr (1985) as the Price Point unit outcrops in the St. Anns Harbour area (Fig. 2). The unit is mostly fault-bounded, although it has been intruded by the Indian Brook granodiorite which in turn has been intruded by the St. Anns leucogranite which has yielded a Cambrian Rb-Sr age (Cormier 1980), indicating a probable Precambrian age for the Price Point unit. The Price Point unit is composed of intermediate crystal and lithic-crystal tuffs and andesitic-dacitic flows of calc-alkalic chemical affinity.

Based on similarities in geochemistry and mineralization, Macdonald and Barr (1985) considered the volcanic rocks of the Price Point unit to be equivalent to the Fourchu Group of southeastern Cape Breton Island. However, more recent tectonostratigraphic analysis (Barr and Raeside, this issue) places the Price Point unit in the Bras d'Or zone of Cape Breton Island, and does not correlate the unit with the Fourchu Group in the Southeastern zone. More radiometric age data are required to resolve this problem.

4. Barachois River gneiss and related rocks

A number of lenses of predominantly gneissic rock occur in the otherwise plutonic eastern half of the map area. Particularly well exposed sections exist in Timber Brook and Barachois River, but similar rocks are also found at the confluence of East and West Branches Indian Brook, and south of Goose Cove Brook. To the north, near Ingonish, a block of gneisses may be part of the same unit, and yet further north, the Coastal Gneiss of Wiebe (1972) also shows similarities to it. In all these sections except the Coastal Gneiss, the blocks of gneiss occur as screens between various plutonic bodies.

The Barachois River gneiss is typically composed of dark grey, K-feldspar augen gneisses, although more psammitic and some amphibolitic varieties have been noted. From Goose Cove Brook metamorphic grade decreases to the south, through zones of sillimanite schist, garnet phyllites and biotite siltstones to weakly metamorphosed greywackes which are exposed in the Big Hill inlier near Baddeck. These are likely correlative with the greywackes exposed in the southern end of the Kellys Mountain block (Barr *et al.* 1982).

The Barachois River gneiss occupies a critical position in the recently proposed tectonostratigraphic subdivision of Cape Breton Island (Barr and Raeside, this issue), lying at or near the boundary between the Bras d'Or and Highlands zones. To the west, both plutonic and stratified rocks preserve evidence of Devonian thermal activity in the form of extensive development of retrograde muscovite and epidote and $^{40}Ar/^{39}Ar$ dates on hornblende (Johnston, 1984) whereas K-Ar dating of rocks to the east has indicated that there has not been any significant thermal activity since the beginning of the Cambrian (Macdonald and Barr, 1985). The Barachois River gneiss may therefore represent the remains of oceanic or plate margin sedimentary rocks preserved in the predominantly intrusive terrane of this part of the Highlands.

STRUCTURAL GEOLOGY

The structure of the southeastern Highlands is relatively complex, although individual outcrops typically display simple patterns. Major trends vary from northerly in the south to northeasterly in the McMillan and Gisborne Flowages area. In the Clyburn Brook-Ingonish River area, trends are erratic. Structural measurements were made in the intrusive units as well as in the stratified units and the two generally show parallel patterns. The McMillan Flowage Formation is particularly important in the structural analysis as it extends throughout the study area and contains lithologies suitable for the development of a penetrative fabric as well as marker horizons to permit the construction of structural cross-sections and the analysis of the large scale structures.

The map area has been divided into seven structural domains, depending on the major rock types and dominant foliation trends. Three domains are recognized in the McMillan Flowage Formation (north, central and south), and two in the plutonic and metamorphic rocks to the east of the McMillan Flowage Formation. In addition the Cheticamp Lake gneiss and the plutonic rocks west of the McMillan Flowage Formation are considered as two separate domains.

McMillan Flowage Formation

1. *Central Domain*

In the area of McMillan and Gisborne Flowages, the marble division of the McMillan Flowage Formation outlines a series of near-isoclinal folds. The stratigraphic arrangement indicates that these folds are the core of a 5 km wide synclinorial structure (Fig. 4a). The foliation is axial planar to the folds (Fig. 5c). Mesoscopic folds are moderately inclined to upright, near-isoclinal folds which plunge at 30^o to 45^o to the southwest (Fig. 5d). The absence of refolded folds implies a relatively simple single-stage early deformational history.

2. *Northern Domain*

In the area between Gisborne Flowage and Clyburn Brook, the map pattern of the marker marble division is more complex. Foliation trends are essentially parallel to those in the central domain except in the extreme northeast where the structures have an east-west orientation (Fig. 5a). Although very few minor fold hinge lineations were noted, those measured indicate a near horizontal structure (Fig. 5b). In

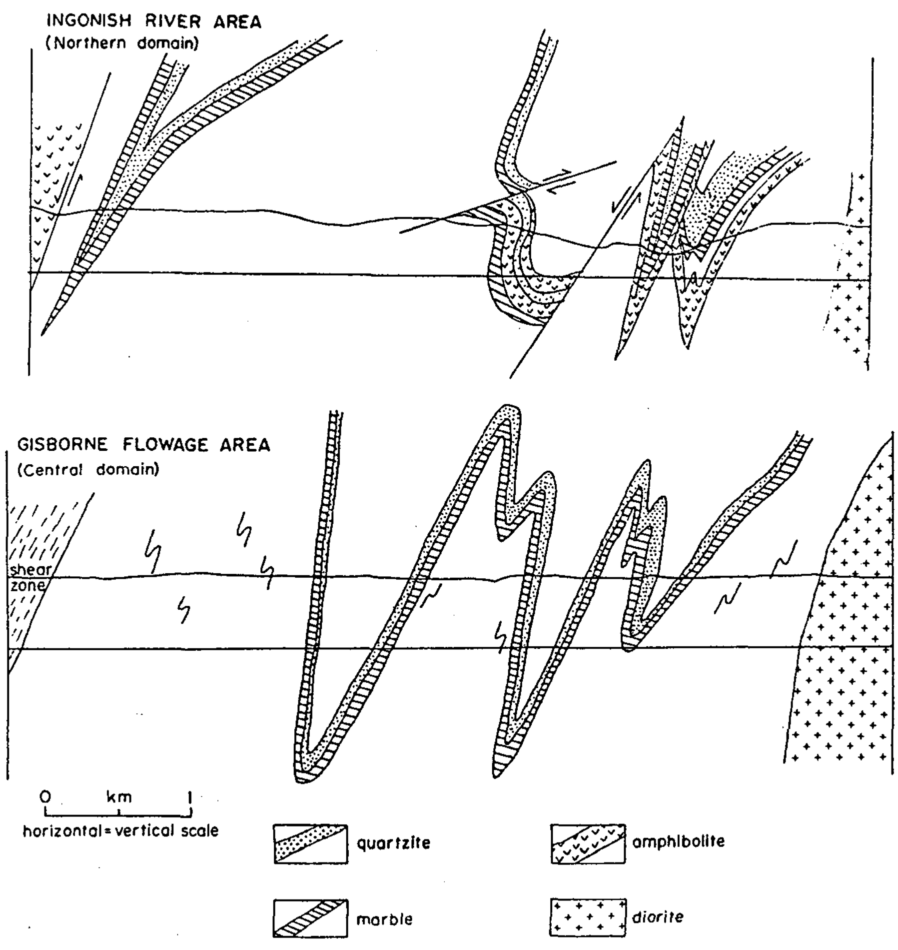

Fig. 4. Vertical structural cross-sections across the McMillan Flowage Formation illustrating the style of synclinorial folding in the northern and central structural domains.

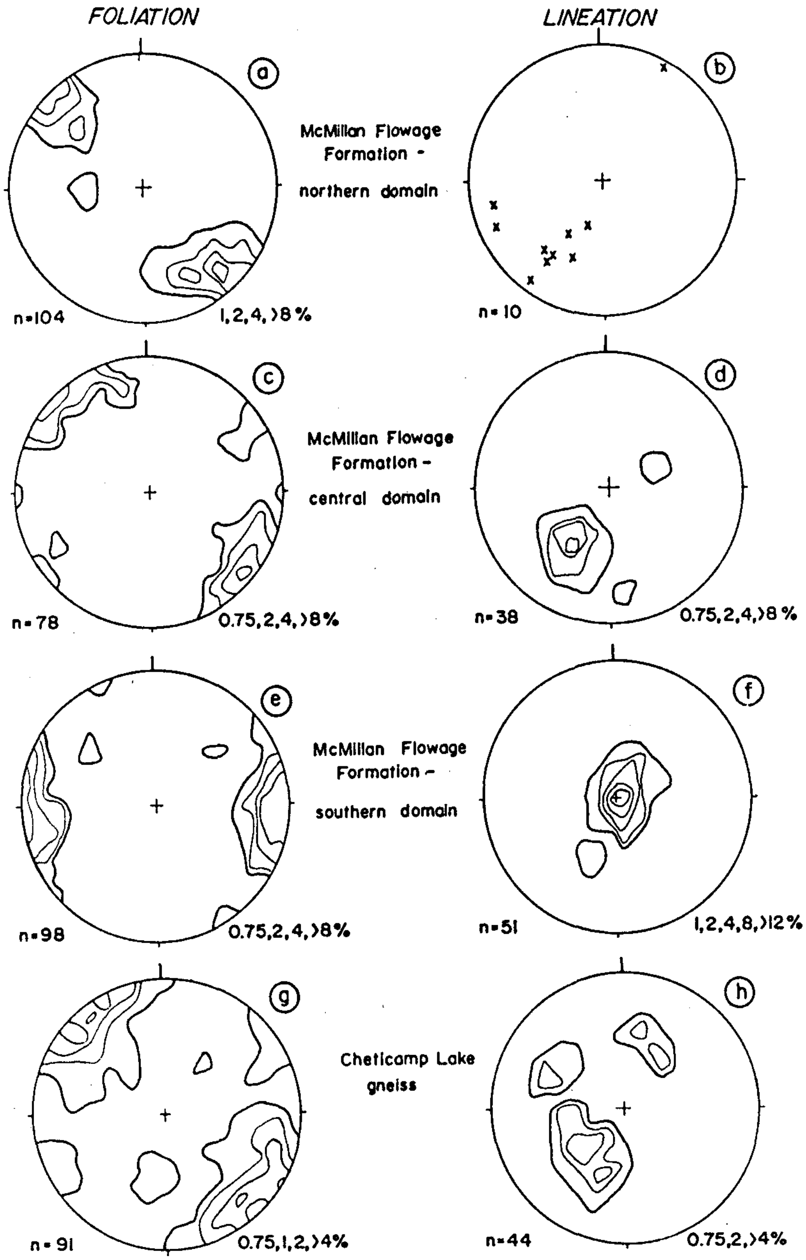

Fig. 5. Summary of structural data for the stratified units of the southeastern Cape Breton Highlands. Figures a to f - McMillan Flowage Formation, g and h - Cheticamp Lake gneiss. Figures a, c, e and g are plots of poles to foliations, figures b, d, f and h are plots of lineations (all minor fold hinge lineations, except figure h, which includes rodding lineations). Contour intervals are indicated below stereographic projections.
n - number of data points.

vertical section, the marble division clearly outlines a series of synclines but with some of the intervening anticlines sheared out. A thrust fault with a southerly transport direction, which outcrops in Power Brook, appears to dip gently to the north. The more complex behaviour of these rocks is likely related to greater competence contrasts between the layers as deformation proceeded at lower metamorphic grade conditions.

3. *Southern Domain*

In the area south of the prominent flexure in the trend of the map units, south of McMillan Flowage, a single stratigraphic section of the lower part of McMillan Flowage Formation is preserved with 30 km of lateral extent. Based on correlation with the central domain, this is interpreted to be the eastern limb of the synclinorial structure. Foliations and bedding orientations are more northerly (Fig. 5e) but the minor fold hinges cluster around vertical (Fig. 5f). Minor folds are developed on scales ranging from 2 cm wavelength to several metres wavelength. Because of the lack of late-recrystallizing micas, finer scale folds tend to be best preserved in quartzites. The origin of the vertically plunging minor folds is enigmatic. They are predominantly sinistrally asymmetric (S-shaped) when viewed down-plunge, although within individual outcrops, both sinistral and dextral asymmetry can be found. The presence of two orientations of vergence implies that two phases of co-planar deformation exist, the first presumably being the one responsible for the large-scale folding, and the second overprinting the earlier structures with the vertical minor fold hinges. The great lateral extent of consistently oriented minor structures and the 50 to 60^{o} change in orientation of plunge between the central and southern domains indicates that this major structure formed as a neutral fold rather than a moderately plunging fold, subsequently re-oriented. A possible means of generating the vertically plunging fold structures and the 30 km amplitude neutral fold is strike-slip movement in a north-south direction. The western limb of this fold has been removed by the intrusion of the Kathy Road diorite and the New Glen suite (Fig. 2).

Plutonic rocks

A tectonic foliation is exhibited by almost all the plutonic rocks east and west of the McMillan Flowage Formation. Foliations from these are plotted on Fig. 6, together with the limited number of measurements from the Barachois River gneiss. The foliations are parallel to those of the adjacent stratified rocks, superficially indicating a similar deformational history. However, some anomalies exist, for

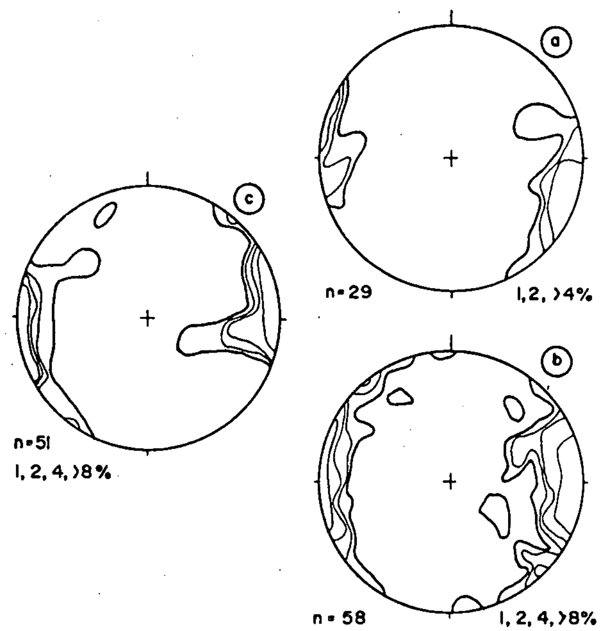

Fig. 6. Summary of foliation orientations in the plutonic rocks and Barachois River unit. Fig. a, plutonic rocks east of central domain (McMillan Flowage Formation); b, plutonic rocks (and Barachois River gneisses) east of southern domain; c, plutonic rocks west of southern domain.

example the Gisborne Flowage diorite. This pluton is particularly significant as it has been intruded into the core of the synclinorium, but it has not been deformed by that folding because its outline is clearly cross-cutting with respect to the internal boundaries in the McMillan Flowage Formation. The pluton, however, displays a tectonic foliation which is parallel to the foliation in the McMillan Flowage Formation, indicating a two phase deformational history - an earlier event responsible for the large-scale folding, and a later event which enhanced the axial planar foliation, and imparted a foliation to the diorite. As the two events are coplanar, they are probably the product of a single orogenic event and the intrusion of the diorite was penecontemporaneous with the second phase of the deformation.

Cheticamp Lake gneiss

A poorly to moderately developed foliation (oriented parallel to the foliation in the McMillan Flowage Formation) exists in the Cheticamp Lake gneiss (Fig. 5g). Because of the Absence of marker horizons, no larger folds have been recognized, although a broad pelitic belt may be an infolded section. The orientation of minor fold hinge and rodding lineations is more complex than in other domains (Fig. 5h), suggesting a more complex early history. In addition, some garnet porphyroblasts from the pelitic section of the gneiss preserve a crenulated internal schistosity. These indicate that the early deformational history of the Cheticamp Lake gneiss is more complex than that of the McMillan Flowage Formation and therefore that the Cheticamp Lake gneiss may have undergone deformation before the deposition of the McMillan Flowage Formation.

Younger deformation

Later deformational effects on the rocks of the southeastern Highlands appear limited to normal faulting and to open folding, which has not significantly affected the outcrop patterns of the crystalline rocks. The surrounding Carboniferous sedimentary rocks have undergone moderate deformation, producing folded (in places overturned) and faulted structures (Kelley, 1957, 1960). This late deformation may also be responsible for the normal faulting and open folding of the crystalline rocks of the Highlands.

A strong thermal overprint is responsible for Devonian K-Ar, $^{40}Ar/^{39}Ar$ and Rb-Sr ages in the granitoid rocks of the western part of the area, and elsewhere in the Cape Breton Highlands (Jamieson *et al.* in press). This is also manifested by the extensive development of retrograde, but coarse grained, muscovite in aluminous rock types and epidote in felsic lithologies. These effects have not been detected in the eastern part of the southeastern Highlands, where the rocks have retained late Precambrian or Siluro-Ordovician ages (Barr *et al.* 1985), and lack extensive development of retrograde metamorphic minerals.

DISCUSSION

The various stratified units of the southeastern Cape Breton Highlands represent a range of depositional situations, possibly separated both in time and in space. On the basis of the preservation of textures which appear to predate the main northeasterly trending foliation of the area, the oldest unit is inferred to be the Cheticamp Lake gneiss. However, insufficient mapping has as yet been done in this unit to correlate it with any other similar body in the Cape Breton Highlands or to postulate its origin. The preservation of mixed ortho- and paragneisses in the Cheticamp Lake gneiss implies that its early history involved both intrusive and depositional events, before the probable late Precambrian deposition of the McMillan Flowage Formation.

The McMillan Flowage Formation is a predominantly clastic unit, incorporating large amounts of semipelitic and psammitic or quartzitic material, and lesser amounts of pelitic, mafic and calcareous lithologies. Only in the extreme northeastern sections (Clyburn Brook area) is the metamorphic grade sufficiently low to observe many of the original depositional features, for example laminar sedimentary structures, volcaniclastic breccias and tuffs, and aphanitic flows. The preponderance of medium to coarse clastic material throughout the formation, its great thickness (at least 4000 m), and its considerable lateral continuity imply that it was deposited at a relatively stable continental margin. The numerrous quartzite layers, including the thick quartzite division, may represent periodic increased sediment supply, and the rare calc-silicate and marble horizons may represent periodic shallowing and carbonate deposition. The mafic rocks which occur throughout the formation have not yet been studied in detail. Although some are recognized as eruptive in the northeastern part of the formation, it is possible that many of these rocks may be intrusive.

The Price Point unit and Barachois River gneiss have not been studied in sufficient detail to determine their environments of deposition. The Price Point unit is volcanic and volcaniclastic with calc-alkalic affinities (Macdonald and Barr, 1985) and may represent active orogenic volcanism during the late Precambrian. Based on the correlation of the Barachois River gneiss with the lower grade metasiltstones of the Big Hill area, and the correlation of these rocks to those on Kellys Mountain, the Barachois River unit appears to have originated as a thick section of siltstones and greywackes, typical of continental margin sedimentation.

The stratigraphic continuity of the McMillan Flowage Formation from at least the latitude of Clyburn Brook south to the southern margin of the Cape Breton Highlands is particularly useful in the regional analysis of the role of the southeastern Highlands during the late Precambrian and Paleozoic tectonic events. Deformation of this unit has been effected in two stages - an early folding stage resulting in the extensive synclinorial structure, and later sinistral strike-slip tectonic activity, affecting only the southern part of the area.

The southeastern Highlands straddle the boundary between two of the tectonostratigraphic zones identified in Cape Breton Island (Barr and Raeside, this issue). The boundary between these zones is placed at the western margin of the belt of outcrops of the Barachois River gneiss. The Highlands zone, to the west, is characterized by a core of gneisses (for example, the Cheticamp Lake gneiss) flanked by lower grade stratified units (for example, the McMillan Flowage Formation). These rocks have been intruded by a variety of granitoid rocks, similar to those of the Gander Terrane of southwestern Newfoundland (Barr and Raeside, this issue; Chorlton and Dallmeyer, 1986). The Bras d'Or zone, to the southeast, is characterized by pre-700 Ma gneissic basement (Olszewski *et al.* 1981; Gaudette *et al.* 1985), overlain by carbonate and clastic rocks (for example, the George River Group) with minor volcanic rocks. It has been assumed to underlie the volcanic rocks of southeastern Cape Breton Island (for example, Rast and Skehan, 1983), although this relationship now appears uncertain (Barr and Raeside, this issue). This zone cannot be easily assigned to either the Gander or Avalon Terranes. Keen *et al.* (1986) reported that the Dover-Hermitage Bay Fault which separates these terranes in Newfoundland is a major crustal discontinuity. However, although no fault has yet been recognized in the southeastern Highlands, the juxtaposition of the eastern and western belts is thought to have been effected by sinistral strike- slip faulting. Sheared rocks have been observed at two localities on the western margin of the Barachois River gneiss and the effect of the fault is also demonstrated by the sinistrally vergent minor structures and neutral folding of the McMillan Flowage Formation.

ACKNOWLEDGEMENTS

We acknowledge with thanks the contributions made by other workers in the Cape Breton Highlands, in particular Alan Macdonald, who participated in much of the mapping. We also appreciate the co-operation of the Nova Scotia Power Corporation in the use of their private road network and Parks Canada for access to, and sampling privileges in, the Cape Breton Highlands National Park. To R.A. Jamieson and G. Pe-Piper we express our appreciation for suggestions for improvements from a previous version of the manuscript. This work was funded by Natural Sciences and Engineering Research Council operating grants to both authors.

BARR, S.M., JAMIESON, R.A. and RAESIDE, R.P. 1985. Igneous and metamorphic geology of the Cape Breton Highlands. Geological Association of Canada/ Mineralogical Association of Canada, Joint Annual Meeting, Excursion Guide 10, 48 p.

BARR, S.M., O'REILLY, G.A. and O'BEIRNE, A.M. 1982. Geology and geochemistry of selected granitoid plutons of Cape Breton Island. Nova Scotia Department of Mines and Energy, Paper 82-1, 176 p.

BARR, S.M. and RAESIDE, R.P. 1986. Tectonostratigraphic subdivision of Cape Breton Island. Maritime Sediments and Atlantic Geology, 22, pp. 252-263.

BARR, S.M., RAESIDE, R.P. and MACDONALD, A.S. 1985. Geological mapping of the southeastern Cape Breton Highlands, Nova Scotia. *In* Current Research, Part B, Geological Survey of Canada, Paper 85-1B, pp. 103-109.

CHORLTON, L.B. and DALLMEYER, R.D. 1986. Geochronology of early to middle Paleozoic tectonic development in the southwest Newfoundland Gander Zone. Journal of Geology, 94, pp. 67-89.

CORMIER, R.F. 1980. New rubidium/strontium ages in Nova Scotia. Nova Scotia Department of Mines and Energy, Report 80-1, pp. 223-234.

DAVIS, C.R. 1983. Metamorphism in the George River Group, Cape Breton Island, Nova Scotia. Unpublished B.Sc. thesis, McMaster University, Hamilton, Ont., 112 p.

GAUDETTE, H. E., OLSZEWSKI, W.J.,Jr. and JAMIESON, R.A. 1985. Rb-Sr ages of some basement rocks, Cape Breton Highlands, Nova Scotia. Geological Association of Canada - Mineralogical Association of Canada, Program with Abstracts, *10*, p. A20.

JAMIESON, R.A., VAN BREEMEN, O., SULLIVAN, K.A. and CURRIE, K.L. (In press) The age of igneous and metamorphic events in the western Cape Breton Highlands, Nova Scotia. Canadian Journal of Earth Sciences.

JAMIESON, R.A. and CRAW, D. 1983. Reconnaissance mapping of the southern Cape Breton Highlands - a preliminary report. *In* Current Research, Part A, Geological Survey of Canada, Paper 83-1A, pp. 263-268.

JAMIESON, R.A. and DOUCET, P. 1983. The Middle River - Crowdis Mountain area, southern Cape Breton Highlands. *In* Current Research, Part A, Geological Survey of Canada, Paper 83-1A, pp. 269-276.

JAMIESON, R.A. and DOUCET, P. 1984. Geology of the Crowdis Mountain area, southern Cape Breton Highlands, Nova Scotia. Geological Survey of Canada, open file map, scale 1:25,000.

JOHNSTON, K.A. 1984. Multifaceted study of an area of mainly dioritic rocks in the southern Cape Breton Highlands, N.S. Unpublished B.Sc. thesis, Dalhousie University, 134 p.

KEEN, C.E., KEEN, M.J., NICHOLS, B., REID, I., STOCKMAL, G.S., COLMAN-SADD, S.P., O'BRIEN, S.J., MILLER, H., QUINLAN, G., WILLIAMS, H. and WRIGHT, J. 1986. Deep seismic reflection profile across the northern Appalachians. Geology, 14, pp. 141-145.

KELLEY, D.G. 1957. Baddeck, Nova Scotia. Geological Survey of Canada, Map 14-1956.

KELLEY, D.G. 1960. St. Anns, Nova Scotia. Geological Survey of Canada, Map 38-1960.

KEPPIE, J.D. 1979. Geological map of the Province of Nova Scotia. Nova Scotia Department of Mines and Energy, scale 1:500,000.

KEPPIE, J.D. 1982. Terranes in the northern Appalachians. Nova Scotia Department of Mines and Energy, scale 1:5,000,000

MACDONALD, A.S. and BARR, S.M. 1985. Geology and age of polymetallic mineral occurrences in volcanic and granitoid rocks, St. Anns area, Cape Breton Island, Nova Scotia. Geological Survey of Canada, Paper 85-1B, pp. 117-124.

MACLAREN, A.S. 1956a. Ingonish. Geological Survey of Canada, Preliminary map 55-35.

MACLAREN, A.S. 1956b. Cheticamp River. Geological Survey of Canada, Preliminary map 55-36.

MILLIGAN, G.C. 1970. Geology of the George River Series, Cape Breton. Nova Scotia Department of Mines and Energy, Memoir 7, 111 p.

MURRAY, D.L. 1977. The structural relationship between rocks of the George River and Fourchu Groups in the Ingonish River-Clyburn Brook area, Cape Breton Island, Nova Scotia. Unpublished M.Sc. thesis, Queen's University, Kingston, Ontario, 271 p.

O'BRIEN, S.J., WARDLE, R.J. and KING, A.F. 1983. The Avalon Zone: a Pan-African terrane in the Appalachian Orogen of Canada. Geological Journal, 18, pp. 195-222.

OLSZEWSKI, W.J., GAUDETTE, H.E., KEPPIE, J.D. and DONOHOE, H.V. 1981. Rb-Sr whole rock age of the Kellys Mountain basement complex, Cape Breton Island. Geological Society of America, Abstracts with Program, 13, p. 169.

RAESIDE, R.P., BARR, S.M. and JONG, W. 1984. Geology of the Ingonish River - Wreck Cove area, Cape Breton Island, Nova Scotia. Nova Scotia Department of Mines and Energy, Report 84-1, pp. 249-258.

RAST, N. and SKEHAN, J.W. 1983. The evolution of the Avalonian Plate. Tectonophysics, 100, pp. 257-286.

WIEBE, R.A. 1972. Igneous and tectonic events in northeastern Cape Breton Island, Nova Scotia. Canadian Journal of Earth Sciences, 9, pp. 1262-1277.

WILLIAMS, H. 1979. The Appalachian orogen in Canada. Canadian Journal of Earth Science, *16*, pp. 792-807.

WILLIAMS, H. and HATCHER, R.D., Jr. 1983. Appalachian suspect terranes. *In* Contributions to the tectonics and geophysics of mountain chains. *Edited by* R.D. Hatcher, Jr., H. Williams, and I. Zietz. Geological Society of America Memoir 158, pp. 33-53.