Tectonics of Southern Nova Scotia

by J. Duncan Keppie

Nova Scotia Department of Mines

a joint project with the
Canada Department of
Regional Economic Expansion

Paper 77-1

PROVINCE OF NOVA SCOTIA

DEPARTMENT OF MINES

PAPER 77-1

TECTONICS OF SOUTHERN NOVA SCOTIA

by

J. DUNCAN KEPPIE

HALIFAX, NOVA SCOTIA

1977

HON. WILLIAM GILLIS, MINISTER

John C. Smith
Deputy Minister

F. S. Shea, Director of
Mineral Resources and
Geological Services

Contribution No. 1 to the Canadian I.G.C.P., Caledonide Orogen Project

PREFACE

This paper represents the first of a series on the tectonics of Nova Scotia. The final product will be a Tectonic Map of Nova Scotia.

This paper deals with southern Nova Scotia, and provides a tectonic model which can be applied to mineral exploration.

Funding for these investigations was provided by the Department of Regional Economic Expansion and the Nova Scotia Department of Mines.

F. S. Shea
Director
Mineral Resources

Halifax, Nova Scotia
May 1977

CONTENTS

LIST OF FIGURES

LIST OF TABLES

TECTONICS OF SOUTHERN NOVA SCOTIA

J. Duncan Keppie

ABSTRACT

The rocks of southern Nova Scotia are divided into three tectonic provinces: the Sonosco Pre-Cratonic Province, the Nova Scotia Epi-Cratonic Province, and the Blomidon Epi-Cratonic Province.

The Sonosco Pre-Cratonic Province is characterized by continental rise deposits, alkalic oceanic volcanics, widespread granitic plutonism, high grade metamorphism and polyphase deformation. These parameters are interpreted as indicative of an orthotectonic orogen. It ranges in age from (?)Cambrian to Devonian. It is deduced that the Sonosco Pre-Cratonic Province evolved from an Atlantic type continental margin during the Cambro-Ordovician to a Pacific type continental margin in the Silurian, followed by subduction of a spreading ridge complex, and culminating in continental collision during the Devonian. An origin off Gondwana is inferred from polarity indicators and geophysical data.

The Nova Scotia Epi-Cratonic Province is bounded by the Acadian Orogeny and the Maritime (Hercynian) Disturbance. The association of predominantly non-marine clastics, alkaline volcanism, rift structures and Mississippi Valley type Pb-Zn mineralization is interpreted in terms of the Fundy Aulacogene bounded by marginal platforms. Structures associated with this aulacogene were generated during lateral movements produced by dextral transcurrent movements between the North American and Gondwana cratons. These were terminated by the collision of Africa and North America during the Permian.

The Blomidon Epi-Cratonic Province is represented by cratonic cover rocks of Triassic and Cretaceous age. They were deposited on stable continental margins and in rift valleys accompanied by tholeittic volcanism. The Bay of Fundy graben is interpreted as an aulacogene produced during the initial stages in the formation of the Atlantic Ocean.

INTRODUCTION

Since Wilson (1966) introduced the Palaeozoic Proto-Atlantic (Iapetus) Ocean, plate tectonic reconstructions of the Appalachian-Caledonide Orogen have become progressively more elaborate, and different models have been put forward (e.g. Dewey, 1969a; Bird and Dewey, 1970; Rodgers, 1970; Schenk, 1971; McKerrow and Ziegler, 1972; Williams et al., 1972; Rast and Grant, 1973; Williams and Stevens, 1974; Hatcher, 1974; St. Julien and Hubert, 1975; Kennedy, 1975; Poole, 1976; Phillips et al., 1976; Lambert and McKerrow, 1976; McKerrow and Cocks, 1977; Keppie, 1977). Generally, all agree that the Iapetus Ocean existed between the Canadian Shield and the Baltic Shield. The Avalon Prong, extending from southern England through southern Ireland and eastern Newfoundland to Boston and possibly through the Carolina State Belt, is considered to be a peninsula of the Baltic Shield. Southern Nova Scotia lies to the south of the Avalon Prong. This paper addresses itself primarily to the

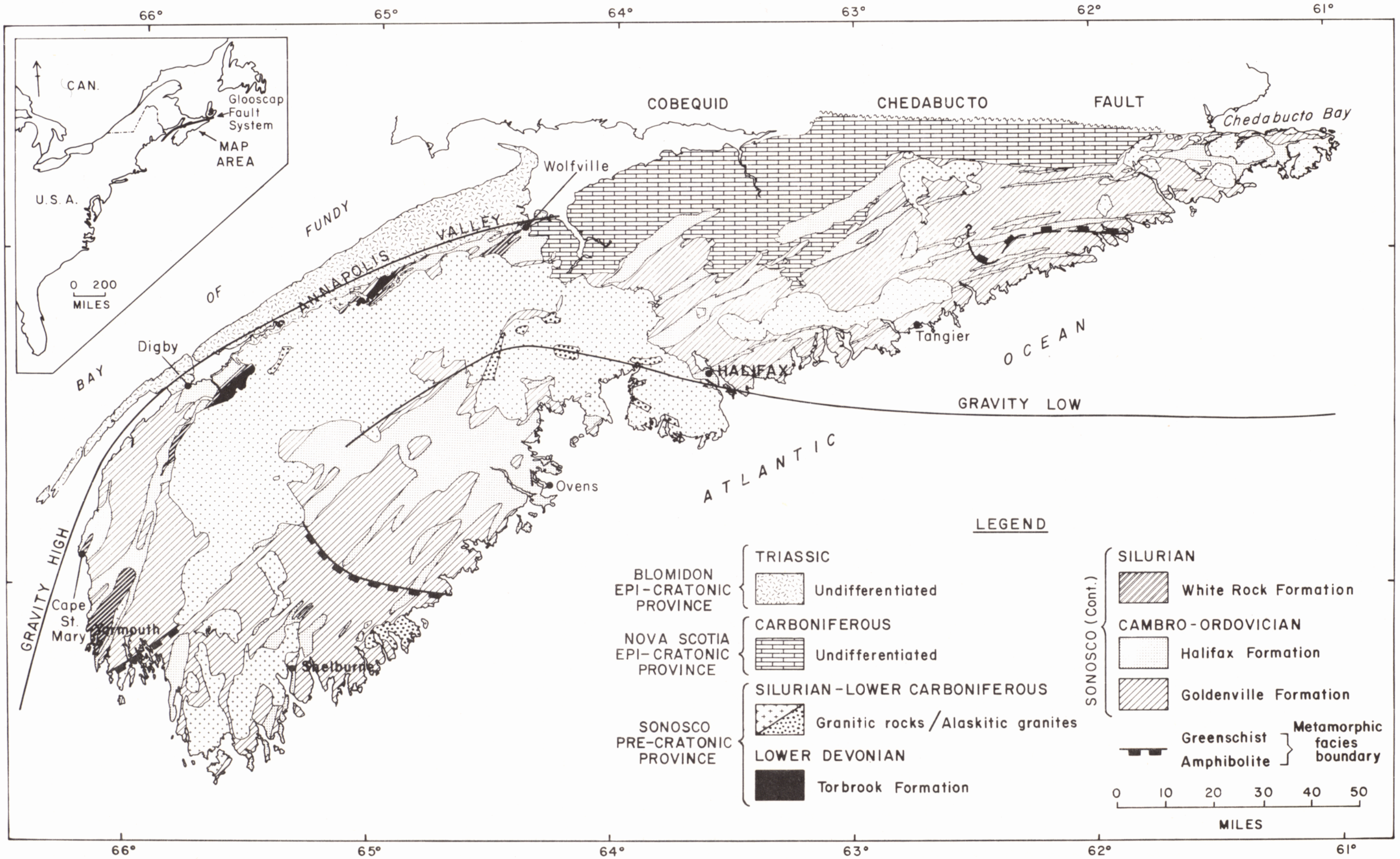

FIGURE 1. Geological map of southern Nova Scotia showing Tectonic Provinces.

tectonic interpretation of southern Nova Scotia and its relationship to the Avalon Prong. Based upon this interpretation the geology of southern Nova Scotia is subdivided into tectonic provinces using the scheme devised by Scheibner (1972). He distinguished three tectonic realms: oceanic, small ocean basin and continental margin, and continental. He defined a tectonic province as an area characterized by its tectonic realm and bounded by a terminal paroxysm. He recognized four tectonic provinces, namely, oceanic, pre-cratonic, transitional and epi-cratonic, of which the latter two provinces belong to the continental realm.

GEOLOGY AND TECTONIC INTERPRETATION OF SOUTHERN NOVA SCOTIA

Southern Nova Scotia is defined as that area of Nova Scotia lying to the south of the Glooscap Fault System (Fig. 1; King *et al.*, 1975). The geological history of southern Nova Scotia is summarized in Table 1 and is outlined below. The rocks of southern Nova Scotia can be divided into three tectonic provinces: the Sonosco Pre-Cratonic Province, the Nova Scotia Epi-Cratonic Province, and the Blomidon Epi-Cratonic Province. The Sonosco Pre-Cratonic Province ranges in age from (?)Cambrian to Devonian and was terminated by the Acadian Orogeny. The Nova Scotia Epi-Cratonic Province is bounded by the Acadian Orogeny and the Maritime (Hercynian) Disturbance. The Blomidon Epi-Cratonic Province is represented by Triassic and Cretaceous rocks.

SONOSCO PRE-CRATONIC PROVINCE

Stratigraphy

Meguma Group. The geological history begins with the deposition of the Goldenville and Halifax Formations which together make up the Meguma Group. If one includes the offshore areas (King and McLaren, 1974), the Meguma Group underlies an area at least 700 x 250 kilometres in size after deformation. Schenk (1970, p. 148) states that the Goldenville Formation underlies the Halifax Formation, but indicates that the boundary between them is probably diachronous. The Goldenville Formation consists of alternating layers of sandstone and finer grained beds and is interpreted as a submarine mid-fan deposit (Harris and Schenk, 1976, p. 31). The Halifax Formation consists of slate, siltstone, minor sandstone and Fe-Mn nodules and represents a number of environments of deposition, including distal turbidite fan, basin plain, interchannel areas of the inner fan, continental rise and slope and outer shelf (Harris and Schenk, 1976, p. 31; Lane, 1976, p. 93-94). Faribault (1914) recorded a thickness of at least 5,600 metres for the Goldenville Formation, and about 500-4,400 metres has been recorded for the Halifax Formation (Faribault *in* Malcolm, 1929; Taylor, 1967, p. 13-14). However, this does not take into account the possible presence of early recumbent folds, F_A (Table 1).

The age of the Meguma Group is only known at a few localities from which fossils have been recorded. The Tremadocian graptolite *Dictyonema flabelliforme* (Eichwald) has been found at several localities in the Halifax Formation between Wolfville and Digby (Fig. 1; Crosby, 1962, p. 19-21; Smitheringale, 1973, p. 20-21). A poorly preserved graptolite (probably *Didymograptus*) of possible Arenigian age has been

TABLE I. Summary of the geological history of southern Nova Scotia

Time+	Period	Stage (or) Series	Tectonic Province	Formation or Group	Environment of Deposition	Name of phase of mobility	Nature of mobility	Igneous activity Type, Chem. class, Series	Metamorphism Name, Type, Facies	Mineralization
65	CRETACEOUS	Upper		▨						
95		Lower		Clay, sand	non-marine					Si, Kaolin
135	JURASSIC	Upper		▨						
		Middle	BLOMIDON	▨						
		Lower		▨						
? 205	TRIASSIC	Upper	EPI-	⊛ Scots Bay	lacustrine	PALISADES	rifting	↕ lava/dyke-basic-tholeittic		Cu, Fe, V
				Ⓚ N. Mtn. Basalt		DISTURBANCE	faulting			
			CRATONIC	⊛ Annapolis	continental		gentle folding			
		Middle		▨						
		Lower		▨						
? 245	PERMIAN	Upper		▨			regional unconformity		↕ Burial V8 coal rank	
		Lower	NOVA	▨						
290	CARBONIFEROUS	Stephanian		▨		↕ MARITIME				
				⊛ Scotch Village	fluviatile					
		Westphalian	SCOTIA	▨		DISTURBANCE	faulting, recumbent folding, unconformity			
		Namurian		▨						
? 353		Visean	EPI-	⊛ Windsor	sub-aerial shallow marine			Ⓡ lava/sill-basic-alkaline		Pb, Zn, Ag, Cu, Ba Na Cl, KCl, gypsum Mn
				⊛ Horton	fluvial lacustrine			stock/dyke-alaskite		Sn, Mo, W, Be, F, Li
		Tournasian		▨				Ⓚ	contact	
? 380	DEVONIAN	Famennian	CRATONIC	▨				plutons 2 mica granite quartz monzonite grandiorite calc-alkalic acid	up to anatexis Buchan	
		Frasnian		▨						
? 394		Givetian		▨		↕ ACADIAN	regional unconformity, faulting, major F_B folds + cleavage	Ⓡ		Sb
		Eifelian		▨		OROGENY			Ⓚ greenschist ? Barrovian	Au
? 405		Emsian	SONOSCO	? ⊛						
		Siegenian		⊛ Torbrook	paralic - shelf					
		Gedinnian		⊛						
? 430	SILURIAN	Ludlovian		⊛ Kentville / New Cannan	neritic					Zn, Pb, Ag, Ni
		Wenlockian		White Rock	shelf	┆		lava / dyke / sill basic/acid alkaline		
		Llandoverian	PRE-	?			recumbent F_A folds + cleavage		greenschist	
? 460	ORDOVICIAN	Ashgillian		?	outer shelf	(unnamed)			? Barrovian	
		Caradocian			slope					
? 471		Llandeilian			rise			?		
		Llanvirnian		Ⓚ	abyssal plain					
		Arenigian	CRATONIC	Halifax ⊛	deep-sea fan					
? 530		Tremadocian		⊛ ⊛				? granite pluton (Brenton)		Fe, Mn
	CAMBRIAN	Upper		Goldenville						
		Middle						?		
		Lower								
? 610										

⊛ Fossil Ⓚ K/Ar age date Ⓡ Rb/Sr age date ↕ Probable age range ┆ Possible age range — — — Tectonic Province boundary ▨ No stratigraphic record

\+ Based upon ^{87}Rb half-life of 5.0×10^{10} y ($\equiv 1.39 \times 10^{-11}$ yr.$^{-1}$ decay constant)(Lambert, 1971) reported from the Goldenville Formation near Tangier, 100 kilometres east of Halifax (Schenk, 1970, p. 129; Poole, 1971). Tremadocian acritarchs have been recovered from the Halifax Formation near Wolfville, on the east side of Halifax Harbour, and at the Ovens, 100 kilometres west of Halifax (Jenkins, W. A. M., pers. comm.). K-Ar ages of 476±19 m.y. and 496±20 m.y. have been determined for muscovite from sandstones of Goldenville Formation near Tangier (Poole, 1971). About 15 m.y. is added to these and other K-Ar ages to allow direct comparison with the extended time scale used in Table 1 based upon an ^{87}Rb half-life of 5.0×10^{10} y. (Lambert, 1971). This muscovite was interpreted as detrital; however, it is possible that the age could have been more or less modified during the regional metamorphism associated with the deformation (Table 1). Thus, while an Early Ordovician age is established for part of the Meguma Group, it may range from Cambrian to Middle or Late Ordovician and possibly into the Silurian.

White Rock Formation. Rocks of the White Rock, Kentville, New Cannan and Torbrook Formations overlie those of the Meguma Group only between Yarmouth and Wolfville (Fig. 1). The White Rock Formation is typified by an orthoquartzite interbedded with siltstones, silty shales and dark shales which are sometimes phosphatic (Schenk, 1972; Taylor, 1965; Smitheringale, 1973, p. 21-34; Lane, 1976, p. 89-91). In some places, especially near Yarmouth and Cape St. Mary, acid and basic volcanic rocks associated with base metal mineralization, volcaniclastic rocks and paraconglomerates have been included in the White Rock Formation (Smitheringale, 1973). However, the inclusion of all of these volcanic rocks in the White Rock Formation is in some doubt (Keppie, in press). A paralic to nearshore environment of deposition influenced by glacio-eustatic effects is inferred for these rocks (Schenk, 1972, p. 98-102; Lane, 1976, p. 91-96). The glacial interpretation derives mainly from the rock unit immediately overlying the Halifax Formation at Cape St. Mary. Schenk (*op. cit.*) interprets it as a dropstone conglomerate; however, Taylor (1965) and Keppie (in press) deduce that it is an acidic tuff.

The contact between the White Rock and Halifax Formations along the Annapolis Valley is reported to be gradational and conformable (Crosby, 1962, p. 23-24; Taylor, 1965; Schenk, 1972, p. 96; Smitheringale, 1973, p. 32-33; Lane, 1976). On the other hand, at Cape St. Mary the contact is interpreted as an angular unconformity of local significance by Taylor (1969, p. 15-16). However, the contact is not observed elsewhere and it is possible that subsequent deformation may have obscured any angular discordance. The White Rock Formation is conformably overlain by the Kentville Formation in the eastern part of the Annapolis Valley (Crosby, 1962, p. 24; Smitheringale, 1973, p. 33). To the southwest, the biostratigraphic equivalent of the Kentville Formation is included in the White Rock Formation by Smitheringale (*op. cit.*) because the two formations are indistinguishable (Table 1).

The thickness of the White Rock Formation (*sensu lato*) increases gradually from 30 metres near Wolfville to 1,000 metres near Digby (Taylor, 1969, p. 24). In the Yarmouth area, the thickness of the White Rock Formation is greatly increased by the presence of volcanic rocks to about 4,500 metres although repetition by folding is not taken into account.

The age of the White Rock Formation is based upon the Ludlovian fauna recovered from the Kentville Formation and from facies equivalents in the White Rock Formation at Bear River near Digby (Smitheringale, 1973, p. 35-39). Lane (1976, p. 91) reported the occurrence of a costellate rhynconnellid brachiopod from the upper part of the White Rock Formation at Yarmouth. Its maximum age is Caradocian. A gastropod recovered from Cape St. Mary, while ranging in age from Early Ordovician to Devonian, may possibly be Middle Ordovician (Yochelson, E. L., pers. comm.). Thus the maximum age of the White Rock Formation is in some doubt.

Kentville Formation. The Kentville Formation occurs only in the eastern part of the Annapolis Valley. The Kentville Formation is predominantly graptolitic black shale with some interbedded horizons of silty shale, siltstone and limestones (Crosby, 1962, p. 24-25; Smitheringale, 1973, p. 36-39). Smithingale (*op. cit.*) suggests that the Kentville Formation was deposited in a neritic marine environment. The thickness of the Kentville Formation ranges up to 650 metres. The graptolites *Monograptus nilsonni* (Barr) and *M. Colonus* (Barr) indicate a Ludlovian age for the Kentville Formation (Smitheringale, *op. cit.*).

New Canaan Formation. The New Canaan Formation is limited to the area near Wolfville (Fig. 1). It may be equivalent to the upper part of the Kentville Formation (Table 1). It consists predominantly of breccia with volcanic fragments, siltstone, slate, limestone and volcanic rocks (Crosby, 1962, p. 26-28). A marine neritic environment of deposition is inferred. The thickness of the New Canaan Formation varies up to at least 300 metres. Fossils include crinoids, pentamerid brachiopods and a tabulate coral tentatively assigned to the Late Silurian (Crosby, 1962, p. 28-29).

Torbrook Formation. The Torbrook Formation crops out in the west-central part of the Annapolis Valley (Fig. 1). The contact between the Torbrook Formation and the Kentville and White Rock Formations is gradational and conformable (Table 1; Smitheringale, 1973, p. 41). The Torbrook Formation is a richly fossiliferous succession of silty shales, mudstones, sandstones and limestones deposited in a paralic marine environment (Smitheringale, 1973, p. 40-44; Jensen, 1976). It is at least 1,300 metres thick in the central Annapolis Valley. The shelly fauna ranges in age from Early Gedinnian to Siegenian and possibly Early Emsian, and has Rhenish-Bohemian affinities (Boucot, 1960).

Structural and Metamorphic History

An early set of recumbent folds, F_A, associated with an axial plane foliation, thrusting, and greenschist metamorphism, deforms the rocks of the Meguma Group (Keppie, in press). The axial plane foliation is defined by chlorite, muscovite and biotite, indicative of greenschist facies metamorphism. This early deformation is not observed in the Torbrook Formation. It affects the Yarmouth and Cape St. Mary parts of the White Rock Formation but dies out in the Annapolis Valley. This may be interpreted as either diachronous deformation or incorrect stratigraphic correlation. These latter data also suggest that the rocks at Yarmouth and Cape St. Mary may be older than the White Rock Formation (*senso strictu*). Until these problems are resolved the age of this early phase of deformation can only be loosely defined as post-Tremadocian and pre-Devonian (Table 1).

During the Acadian Orogeny all of these rocks, including the Torbrook Formation were deformed by upright, northeasterly trending, sub-horizontal folds, F_B, associated with an axial plane cleavage and gold mineralization (Faribault *in* Malcolm, 1929; Fyson, 1966, p. 933-934; Keppie, 1976a). This was accompanied by greenschist facies metamorphism (Taylor and Schiller, 1966). Reynolds *et al.* (1973) in discussing their K-Ar age dates, assign a lower limit of 390+6 m.y. (adjusted to 405±6 m.y. in Table 1) to the time of regional metamorphism accompanying the formation of this cleavage. However, all their samples came from the Halifax Formation and whole rock ages were determined. Any interpretation of the age of the regional metamorphism accompanying F_B should take into account the polygenetic origin of the muscovite in the slates of the Meguma Group: detrital, S_A muscovite, S_B muscovite and post-S_B muscovite (Keppie, in press).

Fyson (1966, p. 934-939) reported three sets of late minor folds and kink bands in the Meguma Group. Keppie (in press) recorded three sets of conjugate kink bands in the White Rock Formation at Bear River. Fyson (*op. cit.*) states that one set of these late folds predates the intrusion of the granites near Chedabucto Bay; however, some of these folds post-date the granite intrusion and may be post-Devonian in age (Keppie, in press).

Regional Buchan-type metamorphism ranging through the amphibolite facies to conditions close to anatexis followed the F_B deformation (Taylor and Schiller, 1966). Two areas of amphibolite facies metamorphism occur in the vicinity of Shelburne and Chedabucto Bay (Fig. 1). Contact metamorphism associated with a granite pluton is superimposed upon this regional metamorphism east of Cape St. Mary (Taylor, 1969, p. 45).

Intrusive Igneous Activity

Igneous intrusive activity began during (?) Middle-Late Ordovician or Silurian times with the intrusion of basic sills, sheets and dykes. Some may be related to the volcanic activity in the White Rock Formation (Taylor, 1967, p. 39-41). However, Smitheringale (1973, p. 46-47) reported that similar basic rocks cut the Torbrook Formation and are themselves intruded by granite. Generally, these basic rocks are foliated indicating that they are probably pre-F_B in age, although a syntectonic F_B age cannot be ruled out. These basic rocks are more common along the northwest side of southern Nova Scotia. The Brenton granite pluton near Yarmouth is foliated (Taylor, 1967, p. 48) suggesting a pre- or syn-tectonic time of intrusion. The spatial association of this pluton with the Yarmouth volcanic rocks may indicate a temporal relationship also. Most other granitic plutons cut across the major F_B folds and their metamorphic aureoles are superimposed upon them (Taylor and Schiller, 1966; Fyson, 1966). These granitic rocks range from quartz diorite to alaskite with a preponderance of granodiorite, granite and quartz monzonite. They underlie approximately one-third of southern Nova Scotia (Fig. 1). Cormier and Smith (1973) report that there are two separate phases of intrusion. The early phase consists of biotite granodiorite, quartz monzonite (Rb-Sr age of 417±38 m.y.) and muscovite-biotite granite (Rb-Sr age of 387±25 m.y.). Using the K-Ar method, Reynolds *et al*. (1973) determined an age of 367±6 m.y. (recalculated to 382±6 m.y. in Table 1) for this phase. The later alaskite phase has a Rb-Sr age of 355±6 m.y. (Cormier and Smith, 1973). The alaskites are more common in the southern half of the South Mountain batholith (Fig. 1) and are associated with Sn, Mo, W, F, Be and Li mineralization (Figs. 2 and 3).

Tectonic Interpretation

Southern Nova Scotia has been variously placed relative to the Avalon Zone. Dewey (1969a) infers, by analogy with the Welsh Basin, that the rocks of southern Nova Scotia were deposited in a trough that lay within the Avalon Zone. Schenk (1971) interpreted the Meguma Group of southern Nova Scotia as a continental margin deposit that lay northwest of the African Craton near Morocco. Rodgers (1970) suggests the rocks of southern Nova Scotia may have been deposited on the southeastern side of the Avalon Prong in the Gulf of Maine.

An interpretation of the pre-Carboniferous geology of southern Nova Scotia in terms of part of an orthotectonic orogen built up by a continental collision superimposed upon a cordilleran-type mountain belt (Dewey and Bird, 1970) follows (Table 2).

(i) The depositional environments and dimensions deduced for the Meguma Group by Harris and Schenk (1976) are consistent with, but not exclusive proof of their interpretation that it was part of an Atlantic type continental rise deposit. A deeply eroded, quartz-rich cratonic source is indicated by sandstone compositions and extraformational lithic clasts of gneiss, granite and metasediments (Harris and Schenk, 1976). The absence of volcanic detritus is noteworthy since volcanic rocks form a large part of the Avalon Zone. Using various sedimentary parameters, Schenk (1970) concluded that the source area lay to the south-southeast in the African craton. Since neither strain, thrusting nor recumbent F_A folds were taken into account in this latter study care must be exercised in applying conclusions based upon primary directional structures (Keppie, in press). Thus, considered alone, these data are enigmatic.

(ii) The alkalic nature of the volcanic rocks near Yarmouth (Muecke and Sarkar, 1977) suggests that they formed in either a continental rift, an oceanic island or an island arc. Their position structurally above the deep water slates of the Halifax Formation would seem to eliminate the first possibility. An oceanic origin for these volcanics which occur only along the northwestern margin of the Sonosco Zone is consistent with a paleogeographic view of an ocean lying to the northwest with an Atlantic type continental margin lying to the southeast (Fig. 4). It is important to note that a pre-orogenic Atlantic type continental margin is common to both cordilleran- and collision-type mountain belts.

(iii) The widespread granitic plutonism and the high grade T/P metamorphism in southern Nova Scotia are characteristic of a cordilleran-type mountain belt (Table 2; Dewey and Bird, 1970). They are not present

TABLE 2

Comparison of pre-Carboniferous geology of southern Nova Scotia with orthotectonic cordilleran-collision orogen and simple collision orogen

	PROPERTY	ORTHOTECTONIC CORDILLERAN-COLLISION OROGEN	PRE-CARBONIFEROUS SOUTHERN NOVA SCOTIA	SIMPLE COLLISION OROGEN
Structure	Sense of thrusting	Divergent	Unknown	Towards consumed plate
	Complex or simple structure	Complex	Complex-simple	Simple
	Gravity slides pre- or post-hard-rock thrusting	Pre	Pre	Post
Metamorphism	Low and/or high T/P metamorphism	Paired, low & high T/P	High T/P	Low T/P
Igneous	Early volcanicity	Basalts	↑? Basalt/rhyolite	Basalts
	Late volcanicity	Basalt/andesite/rhyolite	↓?	Absent
	Plutonism	Granite widespread	Granite widespread	Rare-absent
	Increase in plutonic $\frac{K_2O}{Na_2O}$ ratio	Towards continent	Towards south	Absent
	Time of plutonism	Younger towards continent	Younger towards south	Absent
Stratigraphy	Pre-orogenic continental margin	Atlantic type	Atlantic type	Atlantic type
	Polarity of flysch	Dual	(?) Single	Single

in the simple collision orogen. Heat sources inducing fusion of the lower crust may be (i) the rise of basaltic and calc-alkaline magmas from subducted oceanic plate at depths greater than 100 km (Dewey, 1969b), (ii) subduction of a ridge complex (Lambert and McKerrow, 1976), and (iii) thickening of the continental crust due to continent-continent collision (Burke and Dewey, 1969b). The thickness of the continental crust along the south coast of Nova Scotia is about 30 km (Dainty et al., 1966). Adding 5-10 km for post-Devonian erosion (c.f. McKenzie and Clarke, 1975) suggests that little or no thickening of the continental crust took place during the Acadian continental collision. It is inferred that both the two first mentioned heat sources were predominant in southern Nova Scotia. The first granitic plutonism in Early Silurian times is here related to subduction of oceanic crust (Fig. 4). It is deduced that subduction was initiated before this Early Silurian plutonism, possibly during the Late Ordovician. The continuation of granitic plutonism into the Early Carboniferous, 40 m.y. after the Acadian continental collision terminated subduction (Table 1), is interpreted in terms of slow thermal decay of a subducted ridge (Fig. 4). If the main Nova Scotia batholith marks the site of the subducted ridge, then the gravity low over the batholith suggests that it continues into the Atlantic Ocean east of Halifax (Fig. 2).

(iv) Polyphase deformation, with early recumbent folds interpreted as gravity slides in southern Nova Scotia (Keppie, in press), is typical of cordilleran-type mountain belts (Table 2; Dewey and Bird, 1970).

The dip direction of a subduction zone may be determined by the polarity of various parameters. This is hampered in southern Nova Scotia by the limited exposed width perpendicular to strike. However, the data that are available tend to indicate a southeasterly dip for a Benioff zone beneath southern Nova Scotia. Firstly, the younger and the more alaskitic granites occur towards the southeast (Figs. 1 and 2). Only Rb-Sr ages are considered here for the ages of plutons because loss of radiogenic argon means that K/Ar age dates (Reynolds et al., 1973) record cooling ages rather than times of emplacement. Secondly, in plutons in areas of greenschist facies metamorphism across the central part of southern Nova Scotia, the K_2O/Na_2O ratios, although somewhat complex, do indicate larger areas with higher ratios in the southeast than in the northwest (Figs. 1 and 2). The low K_2O/Na_2O ratios near Shelburne (Albuquerque, 1977), lie in the amphibolite facies suggesting that the higher temperatures caused potassium to migrate to higher levels. Thirdly, the high T/P metamorphism occurs towards the southern side of southern Nova Scotia (Fig. 1) which is consistent with a southeasterly dipping subduction zone. The absence of blueschist metamorphism may be due to either limited width of exposure, slow plate consumption inhibiting blueschist facies metamorphism (Dewey and Bird, 1970) possibly related to oblique subduction, or subsequent burial beneath the Triassic Bay of Fundy Graben. Fourthly, mineral occurrences temporarily associated with magmatic activity, while complex in detail, shows a broad zonal pattern with Be occurrences lying to the southeast of Mo and W which in turn lie southeast of Cu, Pb, Zn (Figs. 3 and 4). Similar patterns have been described by Sillitoe (1972) and Mitchell and Garson (1972 and 1976) in modern cordilleran-type mountain belts. These would suggest a southeasterly dipping Benioff zone in southern Nova Scotia. Finally, seismic data from the Scotian Shelf (Dainty et al., 1966; Keen et al., 1974) indicates that the continental crust is 30-35 km thick between the

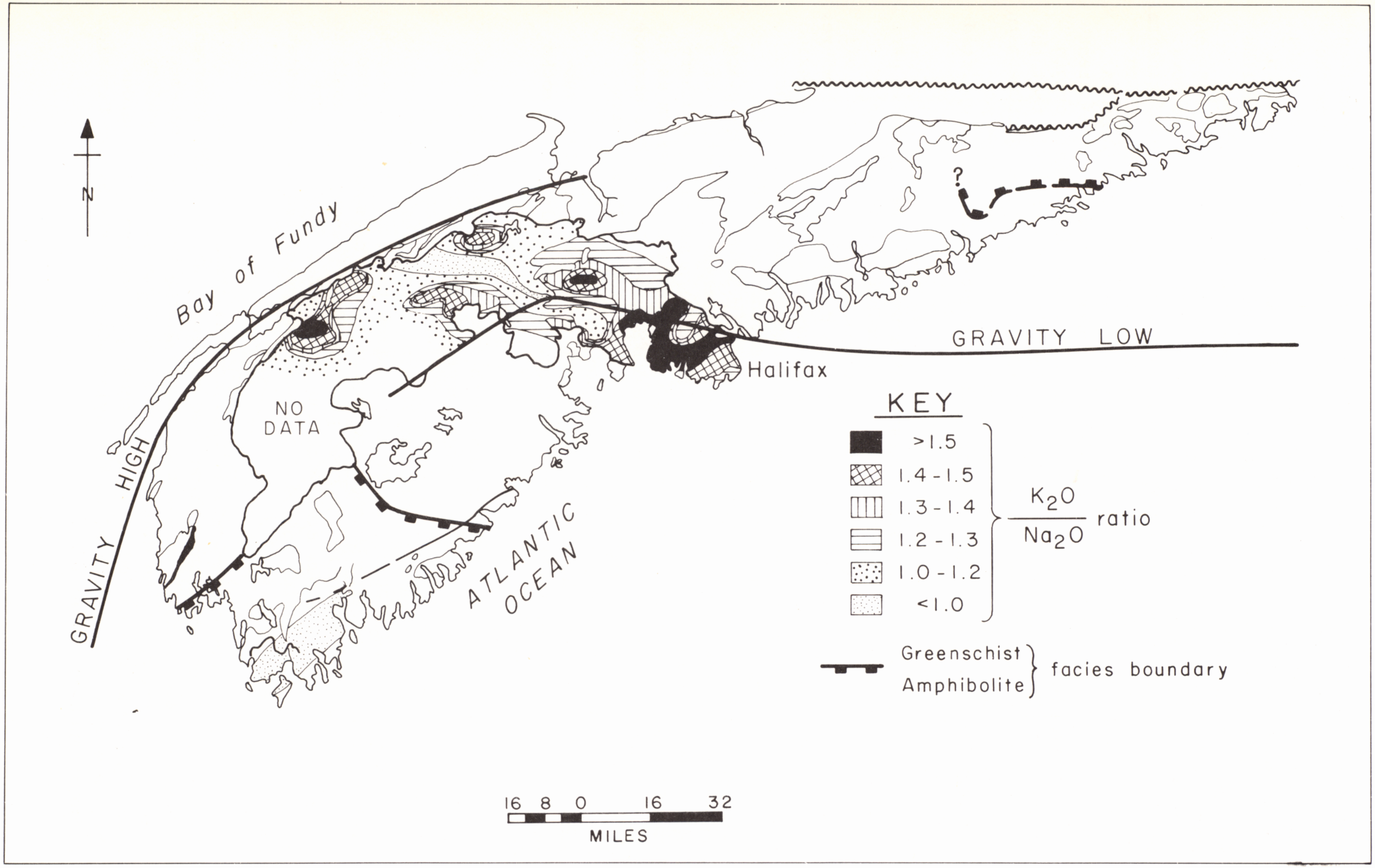

FIGURE 2. K_2O/Na_2O ratio in granitic plutons of southern Nova Scotia.

southern coast of Nova Scotia and the shelf margin. That this continental crust continues north beneath southern Nova Scotia is indicated by the low gravity anomaly (Fig. 2). However, a gravity high is located along the Annapolis Valley (Fig. 2; Haworth, 1974). Along the northwestern margin of the Appalachians a similar belt of positive gravity anomalies coincides with uplifted Grenville basement and the west Appalachian serpentinite belt, and it is interpreted as the transition from continental to oceanic crust (Williams and Stevens, 1974). Thus, in southern Nova Scotia, the gravity high may mark a similar transition between continental and oceanic crust. It cannot be attributed to volcanics of the White Rock or North Mountain Formations because they are not coincident in space. Such a transition from continent to oceanic crust is consistent with the conclusions deduced from sedimentology and the oceanic origin of the White Rock volcanics. In this respect it is interesting that the Brenton pluton near Yarmouth (Fig. 1) would lie close to the northwestern limit of continental crust. Although this pluton may be either pre- or syn-tectonic, the possibility exists that it might represent an uplifted block of basement.

These data together, suggest that southern Nova Scotia is part of an orthotectonic orogen (Table 2). It probably originated during Cambro-Ordovician time as an Atlantic type continental rise deposit off a craton lying to the south with ocean to the north (Fig. 4). Elsewhere, data are presented to show that this craton was probably southern Mexico and Central America adjacent to northwest Southern America, and the ocean was the Theic Ocean (Keppie, 1977). During Late Ordovician, Silurian and Early Devonian times, southeasterly subduction took place beneath southern Nova Scotia which eventually included subduction of a ridge complex (Fig. 4). The nature of the northern margin of southern Nova Scotia probably changed from oblique subduction to transform as the ridge reached the trench (c.f. Lambert and McKerrow, 1976). The absence of the ophiolite suite, marking the site of the former Theic Ocean between southern Nova Scotia and the Avalon Prong could be due to either burial beneath the Triassic Bay of Fundy Graben, complete subduction or removal by transcurrent faulting. Conceivably, these rocks may yet be recognized.

The proximity of South and North America by Emsian times is indicated by the appearance of Eastern Americas Realm brachiopods in northern South America (Boucot, 1975). The effects of continental collision between North and South America following closure of the Theic Ocean (McKerrow and Ziegler, 1972) are inferred to be the Middle Devonian, major F_B folds (Fig. 4). Donohoe and Pajari (1973) have demonstrated that the time of deformation becomes progressively younger from south to north across Maine and New Brunswick and into Quebec (Fig. 4). The suture between the Avalon Zone and Gondwana is postulated to lie beneath the Bay of Fundy (Fig. 4).

The Sonosco Pre-Cratonic Province has its lower boundary at the top of the basement beneath the Meguma Group, which is not observed in southern Nova Scotia, unless the Brenton pluton represents basement. The upper boundary is the diachronous Acadian Orogeny. This boundary should perhaps be extended to include those post-tectonic intrusions which are genetically related to the dying stages of the Siluro-Devonian ridge subduction (Table 1).

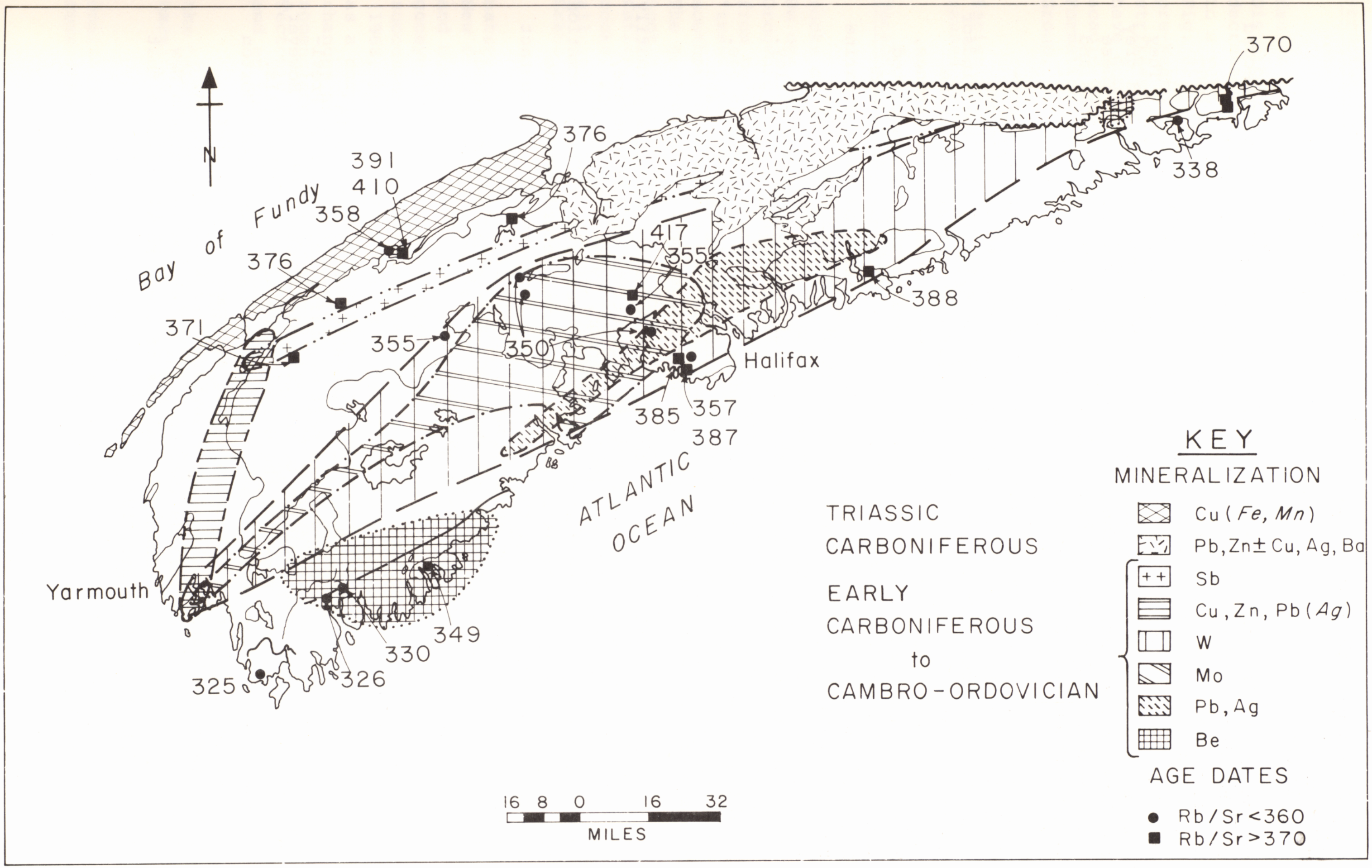

FIGURE 3. Rb/Sr ages of granitic plutons and patterns of mineral occurrences in southern Nova Scotia.

NOVA SCOTIA EPI-CRATONIC PROVINCE

Stratigraphy

Horton Group. In southern Nova Scotia, there is no stratigraphic record for the Middle and Late Devonian. This probably marks a period of uplift and erosion following the Acadian Orogeny. The oldest Carboniferous rocks in southern Nova Scotia belong to the late Tournasian stage of the Early Carboniferous Horton Group (Hacquebard, 1972). They consist primarily of non-marine, fluviatile and lacustrine, red and grey conglomerate, arkose, sandstone, siltstone, shale and rare coal. These rocks were deposited unconformably upon the pre-Carboniferous rocks and reach a thickness of 1,500 metres in the Windsor area.

Windsor Group. The Windsor Group rests either conformably or unconformably upon the Horton Group, overstepping onto pre-Carboniferous rocks in some areas (Stevenson, 1959; Giles and Ryan, 1976). The Windsor Group is unique in the Carboniferous succession in containing marine carbonates and evaporites, interbedded with red, non-marine sandstones, siltstones and shales. Pb-Zn (-Cu-Ag-Ba) mineralization is associated with the Windsor Group (Table 1, Fig. 3; Boyle, 1972; MacEachern and Hannon, 1974). The environment of deposition varied from shallow marine through supratidal to subaerial (Schenk, 1969). Boehner and Giles (1976) have established that during deposition of the Lower Windsor Group the palaeo-shoreline lay to the south of the Musquodoboit Valley. Thicknesses up to 1,000 metres have been recorded. On the basis of macrofauna, Bell (1958) believed the Windsor Group to be of Visean age. However, Mamet (1970), using microfauna, correlates it with the late Visean-earliest Namurian of Western Europe.

Scotch Village Formation. The Scotch Village Formation consists primarily of buff coloured sandstones with some intercalations of conglomerate, shale, gypsum and coal (Crosby, 1962; Stevenson, 1959). Hacquebard (1972) has assigned a late Westphalian age to the Scotch Village Formation based upon spores. The break in the floral/faunal record between the Scotch Village Formation and the Windsor Group suggests that the contact is either disconformable or unconformable. A fluviatile origin is envisaged. A minimum thickness of about 300 metres has been recorded; however, the top of the formation is missing.

Igneous Activity

Igneous activity during the Carboniferous is limited in southern Nova Scotia to a few sills east of Wolfville (Fig. 1). Previously, these sills were assigned to the Triassic (Crosby, 1962). However, a cleavage in the host rocks of the Horton Group also cuts the sills. The age of this cleavage is probably Carboniferous. Thus a post-Horton Group (Tournasian) and pre-Permian age is assigned to them. Early Carboniferous volcanic rocks occur elsewhere near Knoydart (Benson, 1974), on the Magdalen Islands (Sanschagrin, 1964) and in southern New Brunswick (Poll, 1967). Chemical analyses of these rocks indicate that they are alkaline (Durocher, 1974).

Structural and Metamorphic History

Deformation of Carboniferous rocks is manifested in folds, faults and local unconformities and is referred to as the Maritime Disturbance (Poole, 1976). The area generally affected by deformation decreases from the whole of the Fundy Basin in Early Carboniferous time to a very restricted area in the latest Carboniferous (Hacquebard, 1972, Fig. 3). Fyson (1967) believed that the main and cross folds in the pre-Westphalian are the result of gravity sliding related to normal and strike-slip faulting. In southern Nova Scotia, Giles and Ryan (1976) have demonstrated that deformation in the Windsor Group of the Shubenacadie area dies out southwards and does not affect the Scotch Village Formation. A similar lateral transition may be observed in the Horton Group.

Metamorphism of Carboniferous rocks is generally sub-greenschist facies reaching a maximum of V8 coal rank (Hacquebard, 1972). It is caused by the maximum depth of burial after folding.

Tectonic Interpretation

Various interpretations of the tectonics of the Carboniferous rocks of southern Nova Scotia and neighbouring areas have been advanced. On one extreme, Rast and Grant (1973) draw the Variscan (Hercynian) Orogenic Front through the Gulf of Maine and southern New Brunswick and from here they displaced it dextrally along the Cobequid-Chedabucto "transform" fault to a position east of Newfoundland. This implies that southern Nova Scotia lies totally within the Variscan Orogenic Belt. The geological evidence against such an interpretation in southern Nova Scotia is overwhelming. Thus, the predominantly continental sedimentation, the lack of significant metamorphism and calc-alkaline igneous rocks, and the relatively limited deformation which dies out southwards all argue strongly against the interpretation put forward by Rast and Grant (op. cit.).

Other tectonic interpretations are mainly based upon the nature of the stratigraphic record in the Fundy Basin and surrounding New Brunswick, Nova Scotia and Newfoundland Platforms. Kelley (1970) and Howie and Barss (1974) interpret the Fundy Basin as either an epieugeosyncline or a taphrogeosyncline. Poole (1976) regards it as a successor basin filled with molasse deposits. On the other hand, Belt (1968, 1969) presents strong evidence for interpreting the Fundy Basin as a complex rift valley based mainly upon stratigraphic and facies changes associated with large faults. Using plate tectonic concepts and nomenclature of Scheibner (1972), these correspond to a Transitional Tectonic Province (epieugeosyncline, taphrogeosyncline, successor basin) and an Epi-Cratonic Tectonic Province (rift).

In order to arrive at an objective tectonic interpretation of the Carboniferous rocks all aspects of the geological record will be examined. Table 3 summarizes these data.

The interpretation of the Horton Group as molasse and the continuation of granitic plutonism into the Early Carboniferous are consistent with placing at least the Early Carboniferous within a

TABLE 3. Comparison of Carboniferous geology of southern Nova Scotia with the properties of epi-cratonic and transitional tectonic provinces.

PROPERTIES OF TECTONIC UNITS	TECTONIC PROVINCE		FUNDY BASIN	
	EPI-CRATONIC	TRANSITIONAL	PROPERTY	AFFINITY*
Sedimentation: Terrestrial-Shallow Marine	√	√	√	
Molasse	-	√	√	T
Igneous: Calc-alkalic acid or intermediate	-	√	√	T
Alkalic-calcic	√	√	-	
Alkalic	√	-	√	E
Metamorphism: Sometimes burial metamorphism	√	√	√	
Structures: Germano-type structures	√	√	√	
Some Alpino-type structures	√	√	√	
Tectonism increases towards comtemporary pre-cratonic prov.	-	√	-	E
Deformed with underlying pre-cratonic prov.	-	√	~~√~~	
Mineralization: Mississippi Valley type	√	-	√	E

* E: Epi-Cratonic T: Transitional

transitional province as defined by Scheibner (1972). On the other hand, the alkalic nature of the Early Carboniferous volcanic rocks and the Pb-Zn (-Cu-Ag-Ba) mineralization are typical of an intra-continental rift zone in an epi-cratonic tectonic province (c.f. Scheibner, 1972; Mitchell and Garson, 1976). The southward disappearance of deformation and metamorphism in southern Nova Scotia is perhaps most significant because the Hercynian Orogenic Belt is inferred to lie south of Nova Scotia (Dewey, 1974; Keppie, 1977). Thus, the deformation in the Fundy Basin is spatially distinct from and is not transitional into the Hercynian Orogenic Belt. Therefore, it represents a deformed intra-cratonic rift valley. The author believes these latter factors outweigh the former. Therefore, the Carboniferous geology is interpreted as the Nova Scotia Epi-Cratonic Province. Within this tectonic province, the Fundy Basin developed as a long, secular, linear downwarp whose development was arrested at an early stage of rifting. Thus, the Fundy Basin is an aulacogene (c.f. Shatski, 1961), here named the Fundy Aulacogene. The small rate of crustal separation in the Fundy Aulacogene is probably a consequence of large dextral transcurrent movements on many of the faults (Fig. 4; Belt, 1968, 1969; Webb, 1969; Keppie, 1977). These movements, and possibly some closing of the Fundy Aulacogene, are responsible for the deformation suffered by the Carboniferous rocks. The recumbent folds in the Windsor Group were probably initiated by vertical movements, causing gravity sliding with the evaporites acting as thrust lubricants.

The negative gravity anomaly between the Magdalen Islands and southwestern Newfoundland (Haworth, 1974) coincides with the northeastern part of the Fundy Basin axis. This is comparable with the inactive Cretaceous Garoua Rift in Chad where the negative gravity anomaly is attributed to sediment fill (Louis, 1970). The absence of an axial positive gravity anomalies in both areas suggests that rifting did not progress far enough to produce axial basic intrusions. A similar explanation may be postulated for the negative gravity anomaly near the Nova Scotia-New Brunswick border. The intracratonic nature of the Fundy Basin is supported by seismic data which show that it is underlain by about 22 kilometres of continental crust in the area between the Magdalen Islands and Prince Edward Island (Dainty et al., 1966). The intermediate layer beneath this continental crust is probably a feature inherited from Lower Palaeozoic (Keen, 1972).

Belt (1969) has illustrated the close similarities in the stratigraphy between the Fundy Basin and the Midland Valley Rift of Scotland and Ireland. In addition, both the alkaline vulcanism and Pb-Zn-Cu-Ag-Hg-Cd-Ba mineralization in Scotland and Ireland are of Late Tournasian-Visean age (Russell, 1973) which reinforces the comparison with the Fundy Basin in both time and space (Table 1).

Other parallels may be drawn between the Fundy Basin and recent rift valleys. For example, the association of alkalic volcanic rocks and continental to shallow marine sediments is typical of the rift valleys of Africa (Burke and Whiteman, 1973). Also, the Pb-Zn(-Cu-Ag-Ba) mineralization associated with the Early Carboniferous rocks (Table 1, Fig. 2) are of Mississippi Valley type (MacEachern and Hannon, 1974). The recent interpretation of the Mississippi embayment as a failed rift or aulacogene (Burke and Dewey, 1973) provides a recent analog between Mississippi Valley type mineralization and rifting.

The Nova Scotia Epi-Cratonic Province is bounded by the Acadian Orogeny and the last movements of the Maritime (Hercynian) Disturbance represented by the regional unconformity beneath the Triassic rocks. The Hercynian Orogenic Belt is inferred to lie southeast of Nova Scotia. Its margin possibly intersects the North American coastline north of Boston, where the northern limit to Permian metamorphism and deformation has been outlined (Bird and Dewey, 1970; Keppie, 1977).

BLOMIDON EPI-CRATONIC PROVINCE

Stratigraphy

In the Atlantic Provinces, Permian rocks are rare and Early and Middle Triassic rocks are absent on land. A regional unconformity separates the Triassic rocks from the older rocks (Crosby, 1962). The Triassic rocks are divided into three formations (Table 1). The oldest, the Annapolis Formation consists of continental red conglomerate, sandstone and shale and has yielded reptilian remains of Late Triassic age (Baird in Klein, 1962). It is conformably overlain by the North Mountain Basalt Formation which is characteristically tholeittic (Sinha, 1970). Five K-Ar whole rock ages for the basalt give an average of 198 m.y. (Poole, 1970), which is very close to the Triassic/Cretaceous boundary (Table 1). The Scots Bay Formation disconformably overlies the North Mountain Basalt. It consists of lacustrine, sandy limestone and calcareous sandstone containing Late Triassic fossil fish (Klein, 1962). A total thickness of about 1,000 metres has been measured on land but the succession is considerably thicker in the Bay of Fundy.

The pre-Pleistocene stratigraphic record in Nova Scotia ends with the deposition of Cretaceous clay, sand, silt and lignite in the Shubenacadie area (Stevenson, 1959).

Structural History

The Triassic rocks are gently folded into a large syncline (Fig. 1). Ballard & Uchupi (1975) believe the Triassic rocks were deposited in a half-graben bounded on the north side by the Fundy fault system. The discovery of the Valley Lineament, interpreted as a fault, on the south side of the Annapolis Valley (Keppie, 1976b) suggests that the Bay of Fundy may be a true graben. It is probable that the development of both the graben and the syncline was synchronous during Late Triassic times (c.f. Burek, 1973).

Tectonic Interpretation

It is postulated that the ENE-trending Bay of Fundy Graben formed as one consequence of the initial rifting that eventually produced the present Atlantic Ocean. At the same time, movement occurred on the E-W Cobequid-Chedabucto-Guysborough County Fault System producing the Orpheus Graben (Jansa and Wade, 1974) and adding to the development of the St. Mary's and Guysborough Grabens (Keppie, 1976b). The direction of relative motion at this time was probably parallel to the seismicity belt (Sbar and Sykes, 1973) which is coincident with the mildly alkaline

White Mountain magma series and New England Seamount Chain (Ballard and Uchupi, 1975). This belt has been variously interpreted as either the result of migration of the North American plate over a fixed deep mantle plume (Wilson, 1965), a deep crustal fault or trausform fault (Drake et al., 1968), or a shear fracture (Ballard and Uchupi, 1975). The trend of the Bay of Fundy is approximately perpendicular to the seismicity belt suggesting a pure rift origin for the Bay of Fundy Graben. On the other hand, the E-W St. Marys-Guysborough-Orpheus Graben system is inferred to be the result of combined sinistral translation and normal faulting analogous to the Dead Sea Rift (Freund, 1965). It is significant that these Triassic grabens are superimposed upon an old line of weakness, namely a suture.

One anomalous feature in this general scheme is the tholeittic composition of the North Mountain Basalt Formation. Burke and Whiteman (1973) have shown that the initial stages of rifting are accompanied by alkaline volcanism followed by tholeittic volcanism as the rifts begin to widen and axial dykes are intruded (Gass, 1973). These basic axial intrusives are associated with axial positive gravity and magnetic anomalies. The absence of such anomalies along the Bay of Fundy (Haworth, 1974) suggests that it did not reach this latter stage. These considerations suggest that the tholeittic basalts in the Bay of Fundy originated in the main rift between North America and Africa, somewhere in the vicinity of the present Atlantic continental margin (Fig. 4). The amount of lateral separation required to produce the Bay of Fundy Graben is therefore deduced to be small. It follows that the degree of crustal thinning is also minimal. The failure of the Bay of Fundy to develop into an ocean indicates that it is an aulacogene, here termed the Bay of Fundy Aulacogene.

The association of continental Triassic sedimentary rocks with tholeittic volcanic rocks and rift structures is indicative of an epicratonic affinity. Thus, they are assigned to the Blomidon Epi-Cratonic Province. The Blomidon Epi-Cratonic Province extends from the regional unconformity representing the last phase of the Maritime Disturbance, to the present (Table 1). Its southeastern margin lies on the Scotian Shelf.

CONCLUSIONS

The rocks of southern Nova Scotia can be divided into three tectonic provinces: the Sonosco Pre-Cratonic Province, the Nova Scotia Epi-Cratonic Province and the Blomidon Epi-Cratonic Province. The Sonosco Pre-Cratonic Province records the changes from an Atlantic type continental margin through a Pacific type continental margin, followed by subduction of a spreading ridge complex and continental collision between the Avalon Prong and Gondwana during the Acadian Orogeny. The subsequent history is cratonic and aulacogenes are typical features, including the Fundy Aulacogene during the Nova Scotia Epi-Cratonic Province and the Bay of Fundy Aulacogene during the Blomidon Epi-Cratonic Province.

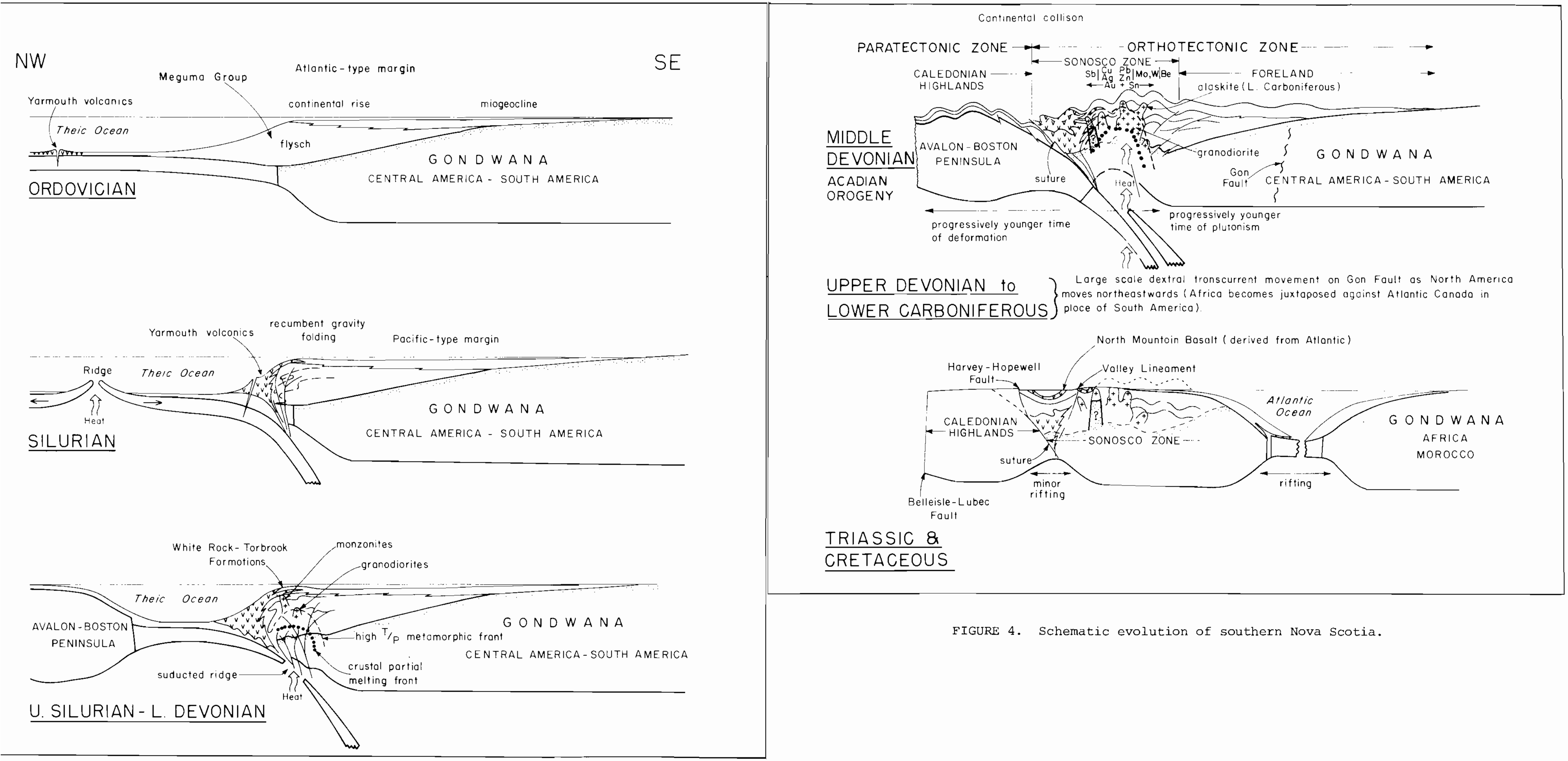

FIGURE 4. Schematic evolution of southern Nova Scotia.

ACKNOWLEDGEMENTS

I wish to thank J. C. Smith, F. S. Shea, P. S. Giles, A. K. Chatterjee, H. V. Donohoe and D. J. Gregory for critically reading the manuscript. Thanks are also extended to D. H. Bernasconi, G. McDonald, P. Belliveau, J. Campbell and R. Morrison for preparing the figures, and to J. Fahie for typing the manuscript.

Funds for this project were provided jointly by the Canada Department of Regional Economic Expansion and the Province of Nova Scotia.

REFERENCES

Albuquerque, C. A. R. de
1977: Geochemistry of the tonalitic and granitic rocks of the Nova Scotia southern plutons; Gecchim. et Cosmoch. Acta, v. 41, p. 1-14.

Ballard, R. D., and Uchupi, E.
1975: Triassic Rift Structure in Gulf of Maine; Am. Assoc. Petr. Geol. Bull., v. 59, p. 1041-1072.

Bell, W. A.
1958: Possibilities for the occurrence of petroleum in Nova Scotia; N. S. Dept. Mines, Halifax.

Belt, E. S.
1968: Post-Acadian rifts and related facies, Eastern Canada; in studies of Appalachian geology: Northern and Maritime; E-an Zen et al. (eds.), p. 95-113. Interscience Publ., N. Y., 475 p.

1969: Newfoundland Carboniferous stratigraphy and its relation to the Maritimes & Ireland; in North Atlantic--geology and continental drift; Kay, M. (ed.). Amer. Assoc. Petr. Geol., Mem. 12, p. 734-753.

Benson, D. G.
1974: Geology of the Antigonish Highlands, Nova Scotia; Geol. Surv. Can., Mem. 376, 92 p.

Bird, J. M., and Dewey, J. F.
1970: Lithosphere plate-continental margin tectonics & the evolution of the Appalachian Orogen; Geol. Soc. America Bull., v. 81, p. 1031-1060.

Boehner, R. C., and Giles, P. S.
1976: The Lower Carboniferous stratigraphy of the Musquodoboit Valley, Nova Scotia; N. S. Dept. Mines, Rept. 76-2, p. 99-100.

Boucot, A. J.
1960: Implications of Rhenish Lower Devonian brachiopods from Nova Scotia; 21st Int. Geol. Congress Rept., pt. 12, p. 129-137.

1975: Evolution and extinction rate controls; Developments in palaeontology & stratigraphy, 1. Elselvier Sci. Publ. Co., 427 p.

Boyle, R. W.
1972: The geology, geochemistry and origin of the barite, manganese, and lead-zinc-copper-silver deposits of the Walton-Cheverie area, Nova Scotia; Geol. Surv. Can., Bull. 166, 181 p.

Burek, P. J.
1973: Structural deduction of the initial age of the Atlantic Rift Systems; in Implications of continental drift to the earth sciences, v. 2, Tarling, D. H., and Runcorn, S. K. (eds.), p. 815-830.

Burke, K., and Dewey, J. F.
1973a: Plume-generated triple junctions: key indicators in applying plate tectonics to old rocks; J. Geol., v. 81, p. 406-433.

1973b: An outline of Precambrian plate development; in Implications of continental drift to the earth sciences; Tarling, D. H., and Runcorn, S. K. (eds.), v. 2, p. 1035-1045.

Burke, K., and Whiteman, A. J.
1973: Uplift, rifting and the break-up of Africa; in Implications of continental drift to the earth sciences; Tarling, D. H., and Runcorn, S. K. (eds.), v. 2, p. 735-755.

Cormier, R. F., and Smith, T. E.
1973: Radiometric ages of granitic rocks, south-western Nova Scotia; Can. J. Earth Sci., v. 10, p. 1201-1210.

Crosby, D. G.
1962: Wolfville map-area, Nova Scotia (21H/1); Geol. Surv. Can., Mem. 325, 67 p.

Dainty, A. M., Keen, C. E., Keen, M. J., and Blanchard, J. E.
1966: Review of geophysical evidence on crust and upper mantle structure of the Eastern Seaboard of Canada; Amer. Geophys. Union, Mono. 10, p. 349-369.

Dewey, J. F.
1969a: Evolution of the Appalachian/Caledonide Orogen; Nature, v. 222, p. 124-129.

1969b: Continental margins: a model for conversion of Atlantic type to Andean type; Earth and Planetary Sci. Letters 6, p. 189-197.

1974: The geology of the southern termination of the Caledonides; in the ocean basins and margins, v. 2, Nairn, A. E. M., and Stehli, F. G. (eds.), p. 205-232. Plenum Press, N. Y.

Dewey, J. F., and Bird, J. M.
1970: Mountain belts and the new global tectonics; Jour. Geophys. Res., v. 75, p. 2625-2647.

Donohoe, H. V., and Pajari, G.
1973: The age of the Acadian deformation in Maine-New Brunswick; Maritime Seds., v. 9, p. 78-82.

Drake, C. L., Ewing, J. I., and Stockard, H.
1968: The continental margin of the eastern United States; Can. J. Earth Sci., v. 5, p. 993-1010.

Durocher, A. C.
1971: Basic magmatism in Nova Scotia; Unpubl. M.Sc. thesis, Acadia Univ., Wolfville, N. S.

Faribault, E. R.
1914: Greenfield and Liverpool Town map-areas, Nova Scotia; Geol. Surv. Can., Summ. Rept. 1912, p. 334-340.

Freund, R.
1965: A model of the structural development of Israel and adjacent areas since Upper Cretaceous times; Geol. Mag., v. 102, p. 189-205.

Fyson, W. K.
1966: Structures in the Lower Paleozoic Meguma Group, Nova Scotia; Geol. Soc. Amer. Bull., v. 77, p. 931-944.

1967: Gravity sliding and cross folding in Carboniferous rocks, Nova Scotia; Amer. J. Sci., v. 265, p. 1-11.

Gass, I. G.
1973: The Red Sea depressions: causes and consequences; <u>in</u> Implications of continental drift to the Earth Sciences, v. 2, Tarling, D. H., and Runcorn, S. K. (eds.), p. 779-785.

Giles, P. S., and Ryan, R. J.
1976: A preliminary report on the stratigraphy of the Windsor Group in the Eastern Minas Subbasin, Nova Scotia; N. S. Dept. Mines, Rept. 76-2, p. 100-105.

Hacquebard, P. A.
1972: The Carboniferous of eastern Canada; 7th Congress Int. Carboniferous Strat. & Geol. Krefeld, 1971, v. 1, p. 69-90.

Harris, I. M., and Schenk, P. E.
1976: The Meguma Group; Maritime Seds., v. 12, p. 25-46.

Hatcher, R. D., Jr.
1974: North American Paleozoic foldbelts and deformational histories: a plate tectonic anomaly?; Amer. J. Sci., v. 274, p. 135-147.

Haworth, R. T.
1974: Paleozoic continental collision in the northern Appalachians in light of gravity and magnetic data in the Gulf of St. Lawrence; Geol. Surv. Can., Paper 74-30, v. 2, p. 1-10.

Howie, R. D., and Barss, M. S.
1974: Upper Paleozoic rocks of the Atlantic Provinces, Gulf of St. Lawrence, and adjacent continental shelf; Geol. Surv. Can., Paper 74-30, v. 2, p. 35-50.

Jansa, L. F., and Wade, J. A.
1974: Geology of the continental margin off Nova Scotia and Newfoundland; Geol. Surv. Can., Paper 74-30, v. 2, p. 51-105.

Jensen, L. R.
1976: The Torbrook Formation; Maritime Seds., v. 12, p. 107-118.

Keen, C. E., Keen, M. J., Barrett, D. L., and Heffler, D. E.
1974: Some aspects of the ocean-continent transition at the continental margin of eastern North America; Geol. Surv. Can., Paper 74-30, v. 2, p. 189-198.

Keen, M. J.
1972: The deep crustal structure of the Appalachian Province; Geol. Assoc. Can., Spec. Paper 11, p. 243-248.

Kelley, D. G.
1970: "Carboniferous and Permian" in southeastern Canada; <u>in</u> Geology and economic minerals of Canada; Douglas, R. J. W. (ed.), Geol. Surv. Can., Econ. Geol. 1, p. 284-296.

Keppie, J. D.
1976a: Structural Model for the saddle reef and associated gold veins in the Meguma Group, Nova Scotia; N. S. Dept. Mines, Paper 76-1, 34 p.

1976b: Interpretation of P.P.I. radar imagery of Nova Scotia; N. S. Dept. Mines, Paper 76-3, 31 p.

1977: Plate tectonic interpretation of Paleozoic world maps (with emphasis on circum-Atlantic orogens and southern Nova Scotia); N. S. Dept. Mines, Paper 77-3.

Keppie, J. D.
(in press) Structural history of pre-Carboniferous rocks of southern Nova Scotia; N. S. Dept. Mines, Paper.

Kennedy, M. J.
1975: Repetitive orogeny in the northeastern Appalachians, new plate models based upon Newfoundland examples; Tectonophysics, v. 28, p. 39-87.

King, L. H., Hyndman, R. D., and Keen, C. E.
1975: Geological development of the continental margin of Atlantic Canada; Geosci. Canada, v. 2, p. 26-35.

Klein, G. de V.
1962: Triassic sedimentation, Maritime Provinces, Canada; Geol. Soc. Am. Bull., v. 73, p. 1127-1146.

Lambert, R. St. J.
1971: The pre-pleistocene Phanerozoic time-scale--a review; in The Phanerozoic time-scale--a supplement; Part I, Spec. Publ., Geol. Soc. London, No. 5, p. 9-31.

Lambert, R. St. J., and McKerrow, W. S.
1976: The Grampian Orogeny; Scott. J. Geol., v. 12, p. 271-292.

Lane, T. E.
1976: Stratigraphy of the White Rock Formation; Maritime Seds., v. 12, p. 87-106.

Louis, P.
1970: Contribution geophysique a la connaissance geologique du bassin du lac Tchad; Mem. ORSTOM, v. 42, 311 p.

MacEachern, S. B., and Hannon, P.
1974: The Gays River discovery - a Mississippian Valley type lead-zinc deposit in Nova Scotia; Can. Inst. Min. Metall. Bull., v. 67, p. 61-66.

Malcolm, W.
1929: Gold fields of Nova Scotia; Geol. Surv. Can., Mem. 156, 253 p.

Mamet, B. L.
1970: Carbonate microfacies of the Windsor Group (Carboniferous), Nova Scotia and New Brunswick; Geol. Surv. Can., Paper 70-21.

McKenzie, C. B., and Clarke, D. B.
1975: Petrology of the South Mountain batholith, Nova Scotia; Can. J. Earth Sci., v. 12, p. 1209-1218.

McKerrow, W. S., and Ziegler, A. M.
1972: Paleozoic Oceans; Nature, Phys. Sci., v. 240, p. 92-94.

McKerrow, W. S., and Cocks, L. R. M.
1977: The location of the Iapetus suture in Newfoundland; Can. J. Earth Sci., v. 14, p. 488-495.

Mitchell, A. H. G., and Garson, M. S.
1972: Relationships of porphyry copper and circum-Pacific tin deposit to paleo-Benioff zones; Inst. Min. & Metall. Trans., Sect. B, v. 81, p. B10-B25.

1976: Mineralization at plate margins; Minerals Sci. Engng., v. 8, p. 129-169.

Muecke, G. K., and Sarkar, P.
1977: Rare earth mobility during amphibolite facies metamorphism of White Rock Formation metavolcanics, Nova Scotia; Geol. Soc. Amer., NE Section Abstracts, v. 9, no. 3, p. 303.

O'Reilly, G. A.
1976: The petrology of the Brenton pluton, Yarmouth County, Nova Scotia; Unpubl. B.Sc. Hons. thesis, Dalhousie Univ., Halifax, N.S.

Phillips, W. E. A., Stillman, C. J., and Murphy, T.
1976: A Caledonian plate tectonic model; J. Geol. Soc. Lond., v. 132, p. 579-609.

Poll, H. W. van de
1967(1968): Carboniferous volcanic and sedimentary rocks of the Mount Pleasant area, New Brunswick; N. B. Min. Res. Branch, Rept. Invs. 3, 52 p.

Poole, W. H.
1970: In Geology and economic minerals of Canada; Geol. Surv. Can., Econ. Geol. Rept. 1, p. 296-304.

1971: Graptolites, copper and potassium-argon in Goldenville Formation, Nova Scotia; Geol. Surv. Can., Paper 71-1A, p. 9-11.

1976: Plate tectonic evolution of the Canadian Appalachian region; Geol. Surv. Can., Paper 76-1B, p. 113-126.

Rast, N., and Grant, R.
1973: Transatlantic correlation of the Variscan-Appalachian Orogeny; Amer. J. Sci., v. 273, p. 572-579.

Reynolds, P. H., Kublick, E. E., and Muecke, G. K.
1973: Potassium-arson dating in slates from the Meguma Group, Nova Scotia; Can. J. Earth Sci., v. 10, p. 1059-1067.

Rodgers, J.
1968: The eastern edge of the North American Continent during the Cambrian and Early Orodovician, in Zen, E-an, et al., (eds.) Studies of Appalachian geology: northern and maritime; Wiley, N. Y., p. 141-149.

1970: The tectonics of the Appalachians; Wiley-Interscience, N. Y., 271 p.

1972: Latest Precambrian (post-Grenville) rocks of the Appalachian region; Amer. J. Sci., v. 272, p. 507-520.

Russell, M. J.
1973: Base-metal mineralization in Ireland and Scotland and the formation of Rockall Trough; in Implications of continental drift to the earth sciences; Tarling, D. H., and Runcorn, S. K. (eds.), v. 2, p. 581-597.

Sanschagrin, R.
1964: Magdalen Islands; Quebec Dept. Nat. Res., Geol. Rept. 106, 58 p.

Sbar, M. L., and Sykes, L. R.
1973: Comtemporary compressive stress and seismicity in eastern North America: an example of intra-plate tectonics; Geol. Soc. Amer. Bull., v. 84, p. 1861-1881.

Scheibner, E.
1972: Tectonic concepts and tectonic mapping; Rec. Geol. Surv., New South Wales, v. 14, pt. 1, p. 37-83.

Schenk, P. E.
1969: Carbonate-sulphate-redbed facies and cyclic sedimentation of the Windsorian stage (Middle Carboniferous), Maritime Provinces; Can. J. Earth Sci., v. 6, p. 1037-1066.

1970: Regional variation in the flysch-like Meguma Group (Lower Paleozoic) of Nova Scotia, compared to recent sedimentation off the Scotian Shelf; Geol. Assoc. Can., Spec. Paper No. 7, p. 127-153.

Schenk, P. E.
1971: Southeastern Atlantic Canada, Northwest Africa and continental drift; Can. J. Earth Sci., v. 8, p. 1218-1251.

1972: Possible Late Ordovician glaciation of Nova Scotia; Can. J. Earth Sci., v. 9, p. 95-107.

Shatski, N. S.
1961: Vergleichende Tektonik alter Tafeln; Fortschritte Sow. Geologie, v. 4, E. Berlin.

Sillitoe, R. H.
1972: Relation of metal provinces in western America to subduction of oceanic lithosphere; Geol. Soc. Amer. Bull., v. 83, p. 813-818.

Sinha, R. P.
1970: Petrology of volcanic rocks of North Mountain, Nova Scotia; Unpubl. Ph.D. thesis, Dalhousie Univ., Halifax, N. S.

Smitheringale, W. G.
1973: Geology of parts of Digby, Bridgetown and Gaspereau Lake map-areas; Geol. Surv. Can., Mem. 375, 78 p.

Stevenson, I. M.
1959: Shubenacadie and Kennetcook map-areas, Colchester, Hants and Halifax Counties, Nova Scotia; Geol. Surv. Can., Mem. 302, 88 p.

St. Julien, P., and Hubert, C.
1975: Evolution of the Taconian Orogen in the Quebec Appalachians; Amer. J. Sci., v. 275-A, p. 337-362.

Taylor, F. C.
1965: Silurian stratigraphy and Ordovician-Silurian relationships in southwestern Nova Scotia; Geol. Surv. Can., Paper 64-13, 24 p.

1967: Reconnaissance geology of Shelburne map-area, Queens, Shelburne and Yarmouth Counties, Nova Scotia; Geol. Surv. Can., Mem. 349, 83 p.

1969: Geology of the Annapolis-St. Marys Bay map-areas, Nova Scotia (21A, 21B East Half); Geol. Surv. Can., Mem. 358, 65 p.

Taylor, F. C., and Schiller, E. A.
1966: Metamorphism of the Meguma Group of Nova Scotia; Can. J. Earth Sci., v. 3, p. 959-974.

Webb, G. W.
1969: Paleozoic wrench faults in Canadian Appalachians; in North Atlantic-geology and continental drift; Kay, M. (ed.), Amer. Assoc. Petr. Geol., Mem. 12, p. 754-786.

Williams, H.
1964: The Appalachians in northeastern Newfoundland-a two-sided symmetrical system; Am. Jour. Sci., v. 262, p. 1137-1158.

Williams, H., Kennedy, M. J., and Neale, E. R. W., (Coordinators)
1972: The Appalachian structural provincc; in Price, R. A., and Douglas, R. J. W. (eds.) Variations in tectonic styles in Canada; Geol. Assoc. Can., Spec. Paper 11, p. 181-261.

Williams, H., and Stevens, R. K.
1974: The ancient continental margin of eastern North America; in Burk, C. A., and Drake, C. L. (eds.) The geology of continental margins; p. 781-796, Springer-Verlag, N. Y.

Wilson, J. T.
1965: Evidence from oceanic islands suggesting movements in the earth: a symposium on continental drift; Royal Soc. London Phil. Trans., Ser. A, v. 258, p. 145-167.

1966: Did the Atlantic close and then reopen? Nature, v. 211, p. 676-681.