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Acado-Baltic Volcanism In Eastern North America and Western Europe: Implications for Cambrian Tectonism

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Article abstract

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Acado-Baltic Volcanism in Eastern North America and Western Europe: Implications for Cambrian Tectonism

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Although small in volume, Cambrian volcanic rocks associated with Acado-Baltic sedimentary rocks in Newfoundland, New Brunswick, and Nova Scotia, Norway and Poland display characteristics indicating formation in a tensional tectonic setting. They generally form bimodal (basalt-rhyolite) suites. Mafic rocks are of both alkaline and tholeiitic affinities but all have within-plate major element and trace element characteristics. The small volume and low frequency of eruption suggests that in most cases the volcanic rocks resulted from only small amounts of lithospheric extension, and that rupturing and separation of plates may not have taken place. Volcanism over the Acado-Baltic province appears to have been less common in the Late Cambrian than in the Early and Middle Cambrian. This suggests that tension persisted throughout the Early and Middle Cambrian, but waned in the Upper Cambrian, possibly in direct or indirect response to processes which led to closing of the Iapetus Ocean.

Malgré un volume restreint, les volcanites cambriennes associées aux roches sédimentaires acado-baltiques à Terre-Neuve, au Nouveau-Brunswick ainsi qu'en Nouvelle-Ecosse, Norvège et Pologne montrent des caractéristiques qui suggèrent leur formation en régime tectonique de tension. Elles forment généralement des suites bimodales (basalte-rhyolite). Les roches mafiques ont des affinités tant alcalines que tholéiitiques bien qu'elles revêtent un caractère intraplaque au plan des éléments majeurs et en traces. Du volume restreint et de la faible fréquence éruptive, on retire l'impression que, pour la plupart, ces volcanites ne reulten que d'une extension lithosphérique de faible valeur et qu'aucune rupture ou séparation des plaques n'a eu lieu. La province acado-baltique aurait connu un volcanisme moins prononcé à l'éo-Cambrien et au Cambrien moyen qu'au tardi-Cambrien. Ceci semble indiquer que la tension a perduré de l'éo-Cambrien au Cambrien moyen et s'est, par la suite, atténuée au Cambrien supérieur, possiblement en réponse directe ou indirecte aux processus qui ont suscité la fermeture de l'océan Iapetus. [Traduit par le journal]

INTRODUCTION

Cambrian rocks from around the world can be divided into four provinces based on differences in their benthonic faunas at the generic level (e.g. Henningsmoen, 1969; Palmer, 1977; Burrett and Richardson, 1980). Cambrian rocks from the Avalon Zone (Williams, 1979) of eastern North America as well as from most of western Europe belong to the Acado-Baltic faunal province (Figure 1) and may have formed one continental block during the Cambrian. Based on differences in the fauna as well as lithological and

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stratigraphic differences (Figures 1 and 2) rocks of the Acado-Baltic province in Europe can be divided into two parts, northern and southern (cf. Brasier, 1980; Burrett and Richardson, 1980), and this subdivision appears applicable to the Appalachians as well (Skehan, *et al.* 1978).

Differences between the northern and southern portions of the Acado-Baltic province may be due to variations in climate over one continental block or could indicate that there were two separate continents (Brasier, 1980; Burrett and Richardson, 1980). In favour of the former hypothesis are the observations of numerous authors (Rast *et al.* 1976; Zoubek, 1977; Strong, 1979; Kaye and Zartman, 1980; O'Brien and King, 1982) that all areas in Figure 1, with the exception of Norway, display similar Late Precambrian stratigraphy and were therefore together for long periods of time prior to the Cambrian. Secondly, the numerous paleogeographic reconstructions for the Cambrian place both portions of the Acado-Baltic province at the lower to middle latitudes during the Cambrian (cf. Ziegler, 1981), and polar wander curves suggest that they moved together (Van der Voo *et al.* 1980). The evidence to date seems to favour a single continental block.

Most studies of Acado-Baltic Cambrian rocks have dealt with stratigraphy and paleontology of the sedimentary rocks and ignored the volcanic rocks, probably because the latter are volumetrically of minor importance. However, volcanic rocks occur within most of the Cambrian stratigraphic sections around the North Atlantic (caption Figure 1) and from a petrologic and tectonic point of view they are very important. In this paper we review information pertaining to the volcanic rocks associated with the Cambrian stratigraphy, with emphasis on the northern portion of the Acado-Baltic province.

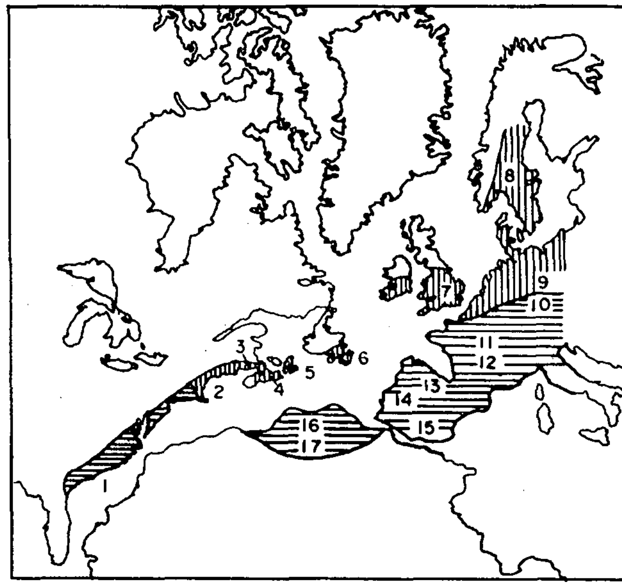

Fig. 1. Distribution of terranes bearing Acado-Baltic sedimentary rocks. Localities examined are numbered as follows: 1 southern Appalachians, 2 New England, 3 southern New Brunswick, 4 Antigonish Highlands, Nova Scotia, 5 Cape Breton, Nova Scotia, 6 Avalon Peninsula, Newfoundland, 7 southern British Isles, 8 central Norway, 9 Poland, 10 Czechoslovakia, 11 central France, 12 southern France, 13 northern Spain, 14 Portugal, 15 southern Spain, 16 Haut Atlas, Morocco, 17 Anti Atlas, Morocco. Cambrian volcanic rocks are found within all of the above areas except New England but the present study does not include Morocco or the southern Appalachians. Vertically ruled areas belong to the northern portion of the Acado-Baltic province and horizontally ruled areas the southern portion of the province. The Triassic reconstruction is from Bullard *et al.* (1965).

STYLE OF VOLCANISM

Volcanic rocks within the Acado-Baltic province show a bimodal (basalt-rhyolite) distribution of rock types at most localities (Table 1), with mafic rocks occuring alone at 30% of the locations. In the northern portion of the Acado-Baltic province basalts tend to predominate over felsic rocks (where both are present) but in the southern portion of the province felsic rocks appear more important. Czechoslovakia is unique in that the rocks show a unimodal distribution with felsic rocks dominant. The volcanic rocks commonly consist of only a few flows or tuffaceous beds representing single

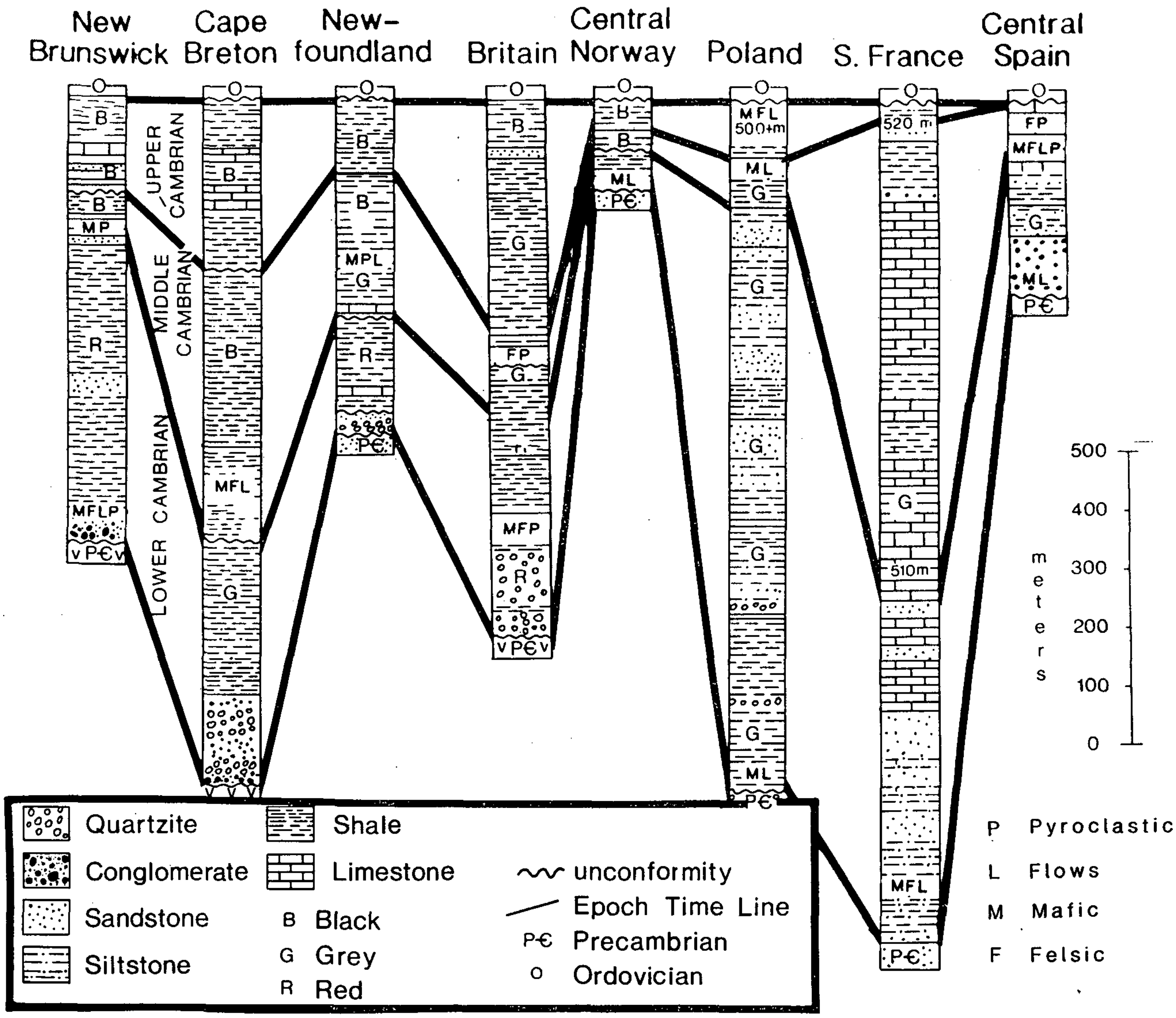

Fig. 2. Cambrian stratigraphic sections for areas with Acado-Baltic stratigraphy in eastern North America and western Europe. These sections do not represent particular localities but illustrate typical features of sections within each area. With the exception of France and Spain, all sections are from the northern portion of the Acado-Baltic province. The location of volcanic rocks in the stratigraphy is diagramatic in that their thicknesses are not shown and the volcanic rocks need not (and in most cases do not) occur at all localities (ie. outcrops) within a particular area. Sources: New Brunswick (southern), Hayes and Howell (1937); Cape Breton, Hutchinson (1952); Newfoundland (Avalon Peninsula), McCartney (1967); Norway, Henningsmoen (1956); Poland, Samsonowicz (1956); England, Rushton (1974); France, Geze (1956); S. Spain, Dupont and Vegas (1978). Sources for information on the volcanic rocks appear in Table 1.

eruptive episodes of limited areal extent. At most localities the rocks consist of both flows and volcaniclastic material with the proportion of volcaniclastic material exceeding that of flows in only 2 cases (15%). The volcanic rocks commonly show linear emplacement (e.g. Avalon) and in some areas are associated with normal faulting (e.g. Norway, Table 1).

Most of the above characteristics are common to rift-related rocks. For example, a bimodal distribution of rock types is commonly associated with rifting environments (Martin and Piwinskii, 1972). The small volume and localized nature of the volcanism distinguish the Acado-Baltic province from flood basalt provinces, volcanic arcs, and back-arc basins, all of which

Table 1. Summary of the characteristics of Cambrian volcanic rocks.

Location	Distribution of Rock Types	Dominant Rock Types	Chemical Affinities[3]	Proportion of flows to Volcaniclastic Rocks[1]	Local Thickness	Geographic Distribution[2]	Assoc. Tectonism	Age
Beaver Harbour, N.B.	Unimodal	Evolved Basalt	Tholeiitic	Equal	100 M	Local	?	Middle Cambrian
Long Reach, N.B.	Bimodal	Basalt	Tholeiitic	Flows Predominate	50 M	Local	Basins Formed	Eocambrian to Lower Cambrian
Cape Breton, N.S.	Bimodal	Basalt	Tholeiitic	Flows Predominate	600 M	Local	Basins Formed	Middle Cambrian
Avalon Pen.	Unimodal	Basalt	Alkalic	Equal	200 M	Local	Basins Formed	Middle Cambrian
Britain	Bimodal	Basalts	?	Mostly Volcaniclastic Rks.	1200 M	Local	?	Lower and Middle Cambrian
Norway	Unimodal	Basalts	Tholeiitic	Mostly Flows	50 M	Local	Faulting	Eocambrian Lower Cambrian
N & NE Poland	Bimodal	Basalts	?	Flows Predominate	100 M	Local	?	Eocambrian Lower Cambrian and Upper Cambrian
SW Poland	Bimodal	Basalts	Subalkaline	Flows Predominate	1000 to 2000 M	Wide	Late stage folding	Middle Cambrian
Czechoslovakia	Unimodal	Felsic Rocks	Subalkaline	Mostly Flows	1000M	Wide	Emplaced along faults, late folding	Middle to Upper Cambrian
N. France	Bimodal	Felsic Rocks	Subalkaline	Volcaniclastic Rks. Predominate	Approx. 500 M	Wide	?	Lower Middle Cambrian
S. France	Bimodal	Basalts	Subalkaline	Flows	Less than 100 M	Local	?	Lower Cambrian
Portugal & NW Spain	Unimodal	Basalts	Alkaline	Mostly Flows	50 M	Local	Faulting and Basin Subsidence	Lower, Middle and Upper Cambrian
Southern & Central Spain	Bimodal	Felsic Rocks	Subalkaline	Mostly Flows	50 M	Local	Faulting and Basin subsidence	Lower to Middle Cambrian

show copious volumes of volcanic rocks. However, this style of volcanism resembles some rifts (Segalstad, 1977; Basaltic Volcanism Study Project, 1981, p. 108, hereafter BVSP). The existance of some volcaniclastic rocks at most Cambrian localities distinguishes these rocks from ocean floor or marginal basin environments because high water pressures (great water depths) in these settings prevent the formation of pyroclastic rocks (Ayres, 1982: Ricketts *et al.* 1982). Most continental arc and island arc settings show high proportions of fragmental rocks (Ricketts *et al.* 1982). Only in some mid-plate settings are both flows and volcaniclastic rocks important (Ibid.). The linear placement of volcanic centers at some Cambrian localities, though also locally seen in arc environments, is common to rift axes where the location of volcanic centers tends to be fault controlled (e.g. Benue Trough, Fitton, 1980; Rio Grande rift, Baldridge, 1979).

Table 1 (Cont.)

1. Mostly 80%, Predominate 51% to 80%, Equal 50%.

2. Local means present only locally, wide implies present in most sections in area.

3. Chemical affinities determined from chemical data except SW Poland (Subalkaline) and Portugal & NW Spain from petrography. S. & Central Spain from our unpub. data.

Sources:

Beaver Harbour, N.B., Helmstaedt (1968), and Greenough et al., (1985).

Long Reach, N.B., Hayes and Howell (1937), McCutcheon (1981), and Greenough et al., (1985).

Cape Breton, N.S., Hutchinson (1952), Helmstaedt and Tella (1973), Cameron (1980), and Murphy et al., (1985).

Avalon Peninsula, Nfld., Hutchinson (1962), McCartney (1967), Fletcher (1972), and Greenough and Papezik (1985).

Britain, Rushton (1974, pp. 62, 67, 71, 78, 90) and Greenly (1944, 1945).

Norway, Henningsmoen (1956), Ramberg and Barth (1966), Bjorlykke (1978), Ramberg and Larsen (1978), Nystuen (1981, 1982), Furnes et al., (1983).

N and NE Poland, Znoska (1965), Juskowiak and Ryka (1967), and Chlebowski (1978).

SW Poland, Teisseyre (1968), Baranowski and Lorenc (1981), and Baranowski et al., (1984).

Czechoslovakia, Svoboda et al., (1966), Waldhausrova (1966, 1971), Palicova and Stovickova (1968), Vidal et al., (1975) and Fiala (1978 a, b).

N and Central France, Boyer 91966, 1974), Dore et al., (1972), Le Gall et al., (1975), Le Gall (1978), Boyer et al., (1979) and Chauvel (1979).

S France, Boyer (1974), Dore (1977) and Boyer et al., (1979)

N Spain and Portugal, Teixeira (1958) and Parga (1969).

S Spain, Dupont and Vegas (1978) and Guillou (1971).

CHEMICAL CHARACTERISTICS OF VOLCANIC ROCKS

Representative analyses of Cambrian basaltic rocks from New Brunswick, Nova Scotia, Newfoundland, Norway, Poland, and Czechoslovakia appear in Table 2. With the exception of Czechoslovakia, all show concentrations of TiO_2 in excess of 1 wt. %, suggesting that Fe-Ti oxide removal was not an important process in their evolution. The high TiO_2 concentrations distinguish the rocks from volcanic arc basalts (Gale and Pearce, 1982).

Some values for Mg' (Mg'=Mg/Mg+0.9Fe atomic) in the Newfoundland, Nova Scotia and New Brunswick basalts exceed 0.60 (Figure 3). The Newfoundland suite displays a negative correlation between Mg' and Al_2O_3 where as Long Reach basalts (New Brunswick) show a positive correlation. The Norwegian and Beaver Harbour (New Brunswick) basalts are characterized by high Al_2O_3 concentrations at low Mg' values.

In (unfractionated) primitive basalts Mg' values should equal about 0.70 (Hanson and Langmuir, 1978). Values greater than 0.60 (some Newfoundland, Nova Scotia, and New Brunswick basalts) are rare in flood basalts (BVSP, 1981, p. 67, 82, 103) but higher values do occur in basalts from other mid-plate settings (Oslo rift, Weigand, 1975; Hawaii, Macdonald, 1968; Ethiopian rift, Barberi *et al*. 1975; Di Paola, 1972). flood basalts rarely show a negative Mg' - Al_2O_3 correlation but some mid-plate basalt suites do (Ibid.; BVSP, 1981, p. 67, 82, 103). Differentiation (through olivine and/or pyroxene removal) probably raised Al_2O_3 values to produce the concentrations in the Norwegian and Beaver Harbour basalts because primitive basalts with equivalent Al_2O_3 concentrations usually yield a positive Mg' - Al_2O_3 correlation. In summary Mg' values

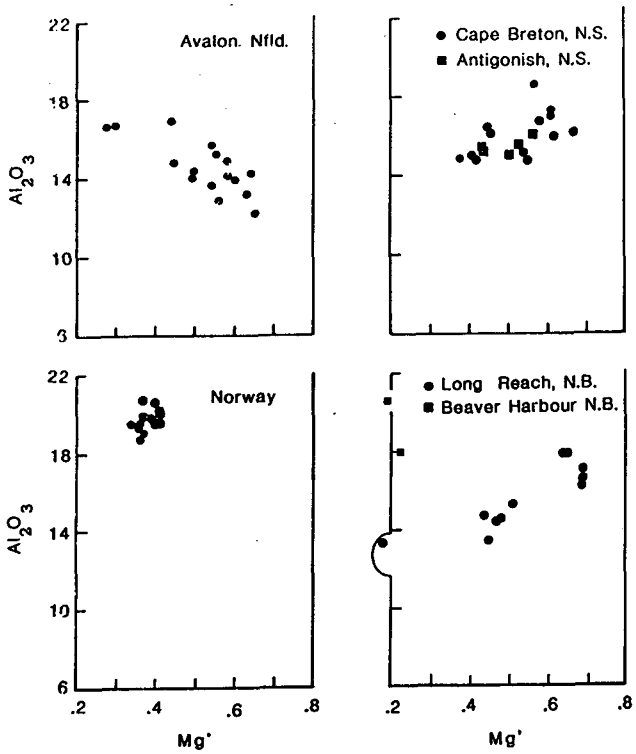

Fig. 3. Plot of Mg' versus Al_2O_3. Shown are data for Cambrian or Eocambrian mafic rocks from Newfoundland (Greenough and Papezik, 1985), New Brunswick (Greenough *et al.*, 1985), Nova Scotia (Antigonish, Murphy *et al.*, 1985; Cape Breton, Cameron, 1980) and Norway (Furnes *et al.*, 1983). Al_2O_3 in wt. % and Mg' = Mg/(Mg+0.9Fe) atomic.

and their relationship to Al_2O_3 concentrations indicate that the Cambrian basalts should not be compared with flood basalts.

Plots of Zr versus Nb, which give some indication of the alkaline versus tholeiitic nature of the Cambrian basalts (BVSP, 1981, p. 118), appear in Figure 4. All trace element alkalinity indicators (Table 2 and Figure 4) show that the Newfoundland basalts are alkaline (Greenough and Papezik, 1985). Baranowski *et al.* (1984) classified the Polish basalts as tholeiitic on the basis of their major element compositions. However, trace element ratios such as P/Zr (> 10 in alkaline rocks, Floyd and Winchester, 1975) indicate that they have alkaline tendencies as is typical of some continental tholeiites. Murphy *et al.* (1985) found that basalts from the Antigonish Highlands (Nova Scotia) are alkaline whereas those from Cape Breton (Nova Scotia) appear tholeiitic. All of the New Brunswick and Norwegian basalts show tholeiitic trace element characteristics (Greenough *et al.* 1985; Furnes *et al.* 1983) though in Norway there are also alkaline intrusive rocks (mafic) of Cambrian

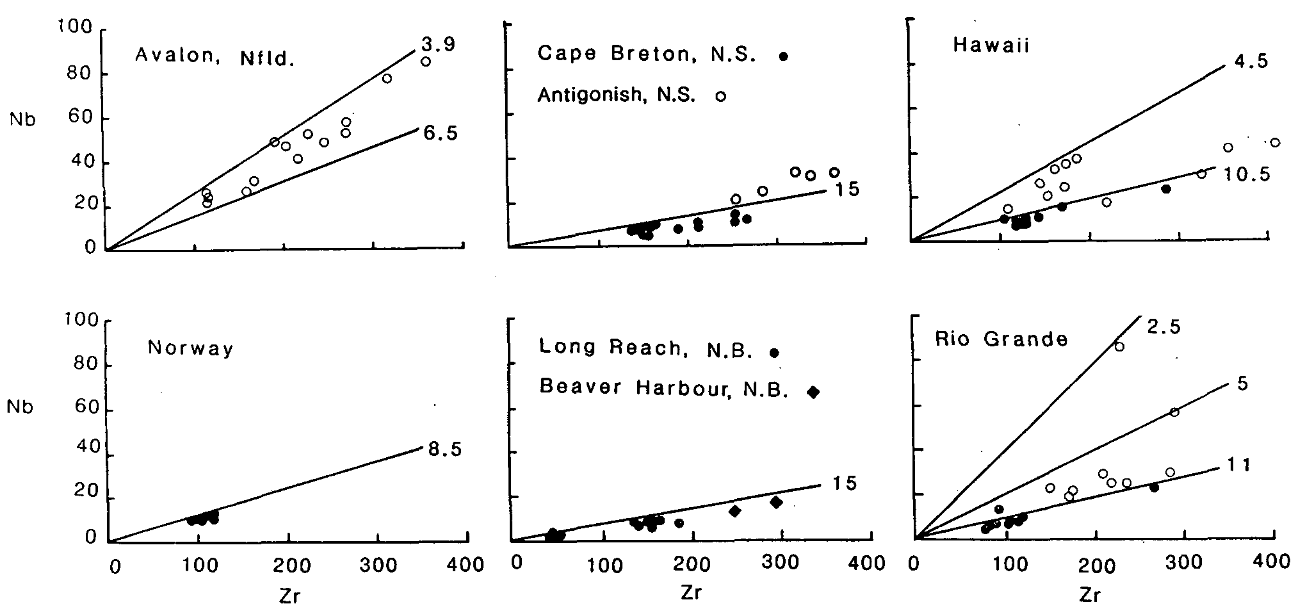

Fig. 4. Zirconium versus Nb diagrams. Closed symbols represent tholeiites and open circles alkali basalts. Sources for Cambrian rocks as in Figure 3; Hawaiian Islands, Greenough (1979); Rio Grande Rift, BVSP (1981), p. 115.

Table 2. Composition of representative Acado-Baltic Cambrian basalts from Newfoundland, New Brunswick, Nova Scotia, Norway, Poland and Czechoslovakia.

	Newfoundland		New Brunswick			Nova Scotia			Norway[1]		Poland[2]	Czech.
	LC15A	PL44	BHR3	GWD9	GWD8	KJC68	KJC73	475	G7	H8	Average	CZ34
SiO_2	51.60	47.60	51.70	47.20	50.70	48.00	50.30	44.0	48.06	47.29	49.4	42.88
TiO_2	2.60	2.64	2.08	2.36	0.75	1.69	3.88	3.53	3.21	2.96	2.6	0.61
Al_2O_3	13.30	13.50	19.80	12.80	16.20	16.20	14.30	15.1	20.36	19.30	16.1	15.92
Fe_2O_3	11.00	10.57	12.36	17.24	8.35	5.39	6.67	10.50	2.88	3.76	11.7	5.46
FeO	-	-	-	-	-	4.70	5.80	3.75	11.56	13.11	-	2.81
MnO	0.21	0.20	0.03	0.28	0.28	0.21	0.20	0.26	0.20	0.31	0.2	0.14
MgO	6.08	8.71	1.31	6.33	8.50	8.01	3.60	6.40	4.90	4.75	6.7	8.97
CaO	6.42	5.85	1.14	5.89	7.60	4.71	5.66	8.06	1.35	0.87	8.3	6.86
Na_2O	4.11	2.79	5.35	4.07	3.17	3.86	4.77	2.77	1.42	3.29	4.1	2.57
K_2O	1.96	2.80	2.54	0.42	0.16	1.82	0.27	0.88	5.50	3.80	0.4	0.50
P_2O_5	0.52	0.65	0.12	0.33	0.11	0.28	0.59	0.94	0.54	0.55	0.5	0.13
L.O.I.	2.90	3.70	3.12	2.59	4.50	4.55	3.42	3.14	2.68	5.50	-	12.58
Total	100.70	99.01	99.55	99.51	100.32	99.42	99.46	99.33	100.00	100.00	100.00	99.43
Mg'	0.55	0.64	0.18	0.45	0.69	0.62	0.38	0.49	0.41	0.36	0.56	0.70
Rb	21	28	73	14	3	81	11	48	267	173	5	9
Sr	345	429	274	323	344	334	324	946	136	144	274	104
Ba	1075	1488	327	346	111	499	127	-	616	839	65	269
Zr	205	277	296	149	54	131	257	317	116	97	187	83
Nb	47	57	16	8	3	5	9	34	13	11	-	3
Y	29	31	28	66	22	38	66	45	26	22	30	29
Ga	21	25	29	21	17	17	21	-	-	-	20	16
V	214	229	159	509	222	234	444	-	295	279	292	227
Cr	75	114	0	38	308	130	9	236	59	56	164	213
Ni	49	129	0	50	69	65	18	120	-	-	149	99
Cu	56	62	0	17	46	0	8	-	-	-	38	31
Zn	109	119	87	199	81	123	108	-	-	-	66	92
Ti/V	72.8	69.1	78.4	27.8	20.3	43.3	52.3	--	65.2	63.6	53.3	16.1
P/Zr	11.1	10.2	1.8	9.7	8.9	9.3	10.0	12.9	20.3	24.7	11.7	6.8
Nb/Y	1.6	1.8	0.6	0.1	0.1	0.1	0.1	0.8	0.5	0.5	--	0.1
Zr/Nb	4.4	4.9	18.5	18.6	18.0	26.2	28.6	9.3	8.9	8.8	--	27.7

Major element oxides in wt. %. Total Fe as Fe_2O_3 unless otherwise shown. LOI. = loss on ignition for N.B. and Nfld. samples; sum of H_2O and CO_2 for Norway, Czechoslovakia and Nova Scotia. Trace element concentrations in ppm. Mg' = Mg/Mg+0.9Fe atomic. 1 Norwegian analyses recalculated CO_2 and H_2O free to 100% in source paper. 2 Average of 17 analyses with average LOI. not given.

Sources: Newfoundland, Greenough and Papezik (1985). New Brunswick, Greenough et al., (1985). Nova Scotia, (Cape Breton), Cameron (1980) and Antigonish Highlands, Murphy et al. (1985). Norway, Furnes et al. (1983). Poland, Baranowski et al. (1984). Czechoslovakia, majors from Waldhausrova (1971), trace elements our unpublished data.

age. All of the papers mentioned above that examined tholeiitic basalts (with the exeption of Baranowski *et al.* 1984, which lacks REE data) noted that the rocks show slight light rare earth element enrichment (La/Yb normalized to chondrites = 1.5 to 4.7).

The association of alkaline rocks with rifting is well established (Bailey, 1974). The Newfoundland basalts as well as some of the Nova Scotia and Norwegian rocks can therefore be related to a rifting event. The remaining basalts are continental tholeiites, as indicated by (for example) their slight enrichment in the light REE, and characteristic of rift or flood basalt tensional environments.

The thickest volcanic sections occur in Czechoslovakia and Poland (1000-2000 M thick) where the volcanism is Middle Cambrian. Although this change in the style of volcanism implies that these rocks formed under a different tectonic regime, the geochemical composition of the rocks from Poland suggests a continuation of tensional tectonism.

RELATIONSHIP OF VOLCANISM TO TECTONISM

Associated with the volcanism at many localities are sedimentary basins. Isopach maps for various Cambrian formations on the Avalon Peninsula, Newfoundland can be interpreted in terms of at least one slowly subsiding trough about 50 km wide with its axis coinciding with the linear chain of Cambrian volcanism (Hutchinson, 1962; Butler and Greene, 1976). Sedimentary rocks in Cape Breton apparently formed in two basins (Hutchinson, 1952) and those in southern New Brunswick in eight or more basins with a total width of over 100 km (Hayes and Howell, 1937).

Cambrian sedimentation and volcanism in Spain was preceded by extensive rift-related block-faulting, subsidence and clastic sedimentation that continued into the Cambrian and produced a deep subsiding rift valley or basin in northern Spain (e.g. Vegas, 1978, 1980; Van Calstern and Den Tex, 1978; Den Tex, 1979). In Norway rifting started during the Late Precambrian, and resulted in N- to NNW-trending, fault-bounded grabens approximately 30 to 60 kilometers wide (Henningsmoen, 1956; Bjorlykke, 1978). The grabens filled with the "sparagmite" sediments , and continued to develop throughout Cambrian time, experiencing tholeiitic volcanism as well as alkaline plutonism (Ramberg and Larsen, 1978).

Non-Acado-Baltic stratigraphic sections of Cambrian to Ordovician age on both the eastern (Stevens, 1970) and western (Bond and Kominz, 1984) sides of North America have been related to rifting and breakup of a late Precambrian supercontinent. Acado-Baltic sections have as yet to be examined in terms of rifting-thermal subsidence models but stratigraphers have long recognized that the thin stratigraphic sections (1000-1500 m, Figure 2) and areal extensiveness of individual lithotypes suggests that the rocks are platformal as opposed to miogeoclinal (Williams, 1979; Dore, 1977). We therefore tentatively propose that the volcanism was produced as a result of small amounts of extension (or flexure) spread out over a broad continental area.

Models for basaltic volcanism in tensional zones (Jarvis and McKenzie, 1980; Le Pichon and Sibuet, 1981; Wendlandt and Podpora, 1982) suggest that small volumes of lava with low frequency of eruption (as seen for the Acado-Baltic rocks) indicate that only small amounts of lithospheric stretching took place. The alkaline nature of the volcanism at many localities is also in keeping with a small amount of stretching (Le Pichon and Sibuet, 1981). This suggests that the tension associated with the volcanic rocks may not have resulted in rupturing and separation of plates.

Superimposed on this general model for small-scale extension is the possibility that rifting actually reached the stage of sea-floor spreading in central Europe as proposed by Bard *et al*. (1980) and Matti and Burg (1981). These conclusions are based on the presence of an Ordovician-Silurian assemblage of island arc tholeiites, blueshcists and an ophiolite complex (Teisseyre, 1968; Narebski *et al*. 1981) that purportedly formed in response to closing of an ocean that formed during the Cambrian.

The most alkaline rocks generally occur on the flanks of rifts with the least alkaline rocks (in some cases tholeiites) appearing in the rift axis (Lippard, 1977; Neumann and Ramberg, 1978). Because it is impossible to reconstruct the paleogeography of the Acado-Baltic province in detail, and because an actual rift or rifted continental margin has not been identified within the province, it is impossible to determine if there was any spatial relationship between the composition of volcanism and possible focal points of tension in the Acado-Baltic province.

Volcanism was apparently most common in the Middle Cambrian (most number of localities), and least common in the Late Cambrian (Table 1). If volcanism can be used as an indicator (cf. Sengor and Burke, 1978: Baker and Morgan, 1982), it appears that tension persisted throughout the Early and Middle Cambrian, but may have waned in the Late Cambrian. This possibly occurred in direct or indirect response to closing of the Iapetus Ocean which primarily took place during the Ordovician (Stevens, 1970).

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