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Paleozoic supracrustal rocks near Cheticamp, Nova Scotia

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Near Cheticamp, northwestern Cape Breton Island, a sequence of supracrustal rocks overlies and cuts granite previously dated at 530±44 million years, as well as older, presumably Precambrian gneisses. Rhyolite dikes feeding the supracrustal sequence yielded zircons giving a U-Pb discordia age of 439±7 million years (late Ordovician or Silurian). The supracrustal rocks are overlain and cut by bimodal volcanics of the Fisset Brook Formation, previously dated by Rb-Sr isochron at 376±12 million years. Interpretation of the stratigraphic and geochronologic data, together with petrochemical data on the volcanic rocks, shows that the rocks of the Cape Breton Highland underwent repeated cycles of deformation, uplift and granitic intrusion, rapidly followed by subsidence and emplacement of bimodal volcanic rocks. The repetitive and cyclic nature of the process suggests that throughout late Precambrian and early Paleozoic time these rocks remained in a single, cyclic, tectonic environment, rather than passing from one tectonic environment to another.

Près de Chéticamp, dans le nord-ouest de l'île du Cap-Breton, une succession de roches supracrustales recouvre et coupe un granite daté antérieurement à 530±44 million d'années, ainsi que des gneiss plus vieux dont l'âge remonte vraisemblablement au Précambrien. Des dykes de rholite qui alimentent la succession supracrustale ont livré des zircons donnant un âge U-Pb "discordia" de 439±7 million d'années (Ordovicien tardif ou Silurien). Les roches supracrustales sont recouvertes et coupées par des roches volcaniques bimodales de la formation Fisset Brook, datées antérieurement à 376±12 million d'années par isochrone Rb-Sr. L'interprétation des données stratigraphiques et géochronologiques, ainsi que les données pétrochimiques des roches volcaniques, démontrent que les roches des hautes terres du Cap-Breton ont été soumises à des cycles répétés de déformation, de soulèvement et d'intrusion granitique, rapidement suivis par un affaissement et la mise en place de roches volcaniques bimodales. La nature cyclique et répétitive du processus suggère que du Précambrien tardif jusqu'au début du Paléozoique ces roches, plutôt que de passer d'un environnement tectonique à un autre, sont demeurées au sein d'un seul environnement tectonique cyclique.

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INTRODUCTION

The Cape Breton Highland forms a block of plutonic rocks some 100 by 50 km in dimensions, which rises abruptly to a height of 300 to 400 m above the Gulf of St. Lawrence and the Atlantic Ocean. Pioneer geologists considered all of this block to be of Precambrian age, with the exception of a discontinuous fringe of Carboniferous rocks along the sea coast (Fletcher 1885). However radiometric age determinations obtained by Neale (1963) showed that several of the granitic plutons were of Devonian, rather than Precambrian age, and later age dating work by Cormier (1972) demonstrated that plutons of Ordovician and late Precambrian to early Paleozoic age also occur in the Cape Breton Highland. Detailed mapping on the eastern edge of the highland by Wiebe (1972) demonstrated that at least two series of metamorphosed supracrustal rocks outcropped in that area. He did not establish the age of either sequence, but tentatively correlated them with the Helikian(?) George River Group and the late Hadrynian Fourchu Group of southeastern Cape Breton Island. Similar supracrustal sequences occur on the northern tip of the highland (Neale and Kennedy 1975), and along the western side of the highland near Cheticamp (Currie 1975), but the age of these sequences has remained uncertain.

Geological and geophysical compilations (Williams 1978, Haworth *et al.* 1980, Zietz *et al.* 1980) show that the Cape Breton Highland forms part of a chain of complexes extending from the north shore of Newfoundland through the

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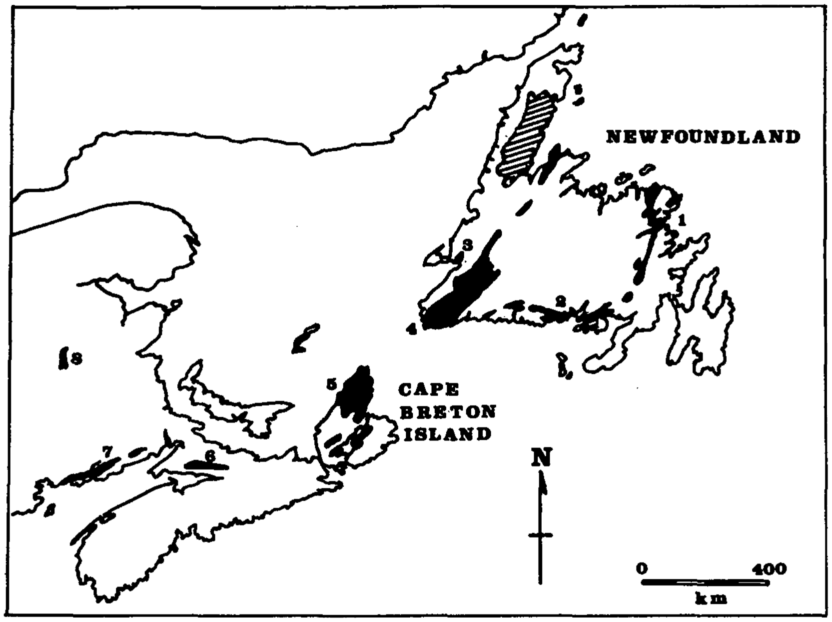

Fig. 1 - Complexes containing crystalline basement within the Canadian Appalachians. Crystalline basement is shown in black. Presumably younger Precambrian supracrustal rocks, such as those of the Avalon zone, not shown. Complexes are identified by number: 1 - Bonavista Bay gneiss complex, 2 - Hermitage Bay gneiss complex, 3 - Indian Head comlex, 4 - Port aux Basques gneiss complex, 5 - Composite gneiss complex of the Cape Breton Highland, 6 - Bass River complex, Cobequid Highland, 7 - Brookville gneiss, Saint John region, 8 - Granite gneiss, Miramichi region. Hachured area is the Precambrian block of the northern Long Range, an outlier of the Canadian Shield. Geology after Williams (1978).

Cape Breton Highland and Cobequid Highland of Nova Scotia, to the Caledonia Highland and the region of Saint John, New Brunswick. Although this chain of complexes, all of which contain Precambrian material, forms a crystalline core to the Canadian Appalachians (Fig. 1), models for the development of the Canadian Appalachians take little notice of their presence, and hence offer little explanation. Recent work suggests that the Cape Breton Highland underwent a long and complex development (Wiebe 1972, Neale and Kennedy 1975, Currie 1975, in press). The present communication fixes the timing and nature of the latest events in this development for the region around Cheticamp, and points out some constraints on the development of the Cape Breton Highland, which may be applicable to other crystalline complexes in the Appalachians.

GEOLOGY OF THE CHETICAMP REGION

In the Cheticamp region, the rocks may be conveniently divided into five major groups (Fig. 2), namely a composite gneiss containing a Precambrian protolith, a late Precambrian granite batholith, a late Ordovician to Silurian volcano-sedimentary assemblage (Jumping Brook complex), granitoid plutons of Devonian age, and a volcano-sedimentary assemblage of Late Devonian and Carboniferous age (Fisset Brook Formation, Horton, Canso, Riversdale Groups). The oldest and most abundant unit consists of composite gneiss containing within it schlieren, lits, screens and nebulous remnants of (a) semi-pelitic to pelitic gneiss, (b) pyroxene amphibolite, and (c) gneissic but homogeneous granitoid rocks, all contained within a heterogeneous, generally granodioritic, migmatitic gneiss. All mappers have assigned a Precambrian age to this terrane (Fletcher 1885, MacLaren 1955, Neale 1963, Wiebe 1972, Currie 1975, Neale and Kennedy 1975) although no radiometric determinations of Precambrian age have yet been obtained from it. Within this terrane, the pelitic enclaves commonly contain relicts of kyanite encased in muscovite, although the assemblage cordierite-garnet occurs in several kyanite-absent pelitic enclaves. Amphibolitic enclaves commonly contain the pair hornblende-clinopyroxene, but the pair hornblende-cummingtonite occurs in the upper Cheticamp River canyon. Detailed examination of the relations between the gneissic granites and their hosts, and between the amphibolitic schliers and their hosts, suggests that the composite gneiss terrane has been through at least two, and probably three, episodes of metamorphism and plutonism, each followed by injection of mafic dikes. Formation of kyanite took place during the second-last period of metamorphism.

East of Cheticamp, a highly fractured but unfoliated granodioritic complex, termed the Corney Brook complex (Currie 1975), cuts the composite gneisses, and is overlain and intruded by younger supracrustal rocks. The granodiorite complex now outcrops within a narrow, north-trending belt, probably part of a thrust slice. Typically the pluton consisted of white to pale pink biotite-hornblende granodiorite, but the mafic minerals are now largely chloritized, and some phases of the pluton contain

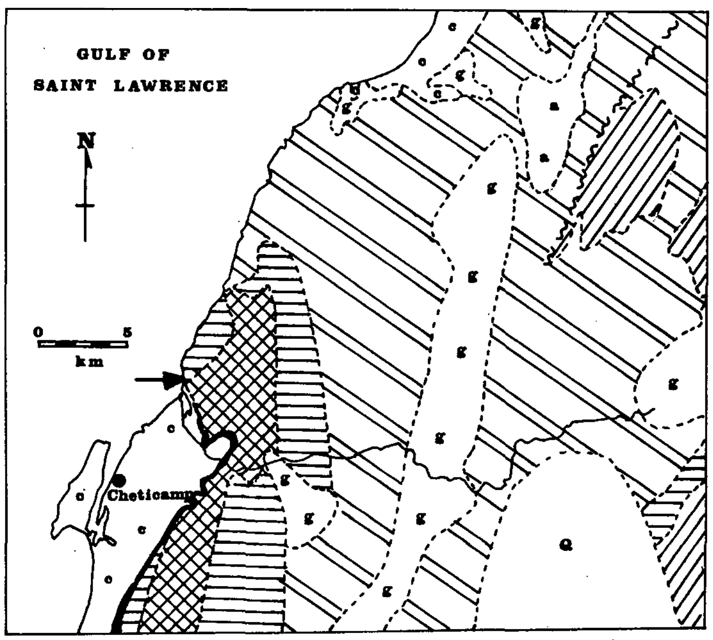

Fig. 2 - Geological sketch of the Cheticamp region, Nova Scotia. Q - drift covered; c - Carboniferous sedimentary rocks; solid black - Fisset Brook Formation, alkali basalt and rhyolite; horizontal hatching - Jumping Brook complex, basal alkali basalt and rhyolite, pelitic schist and gneiss, quartzofeldspathic schist and gneiss; cross-hatched - hornblende-biotite granodiorite complex; diagonal close hatching - supracrustal rocks of pre-Jumping Brook age (George River Group?); a - anorthosite; diagonal open hatching - composite gneiss complex, pelitic to semipelitic schist, amphibolite, granite gneiss, all in a migmatic matrix; g - granitoid plutons, mainly of Devonian age, but probably older in part. Geology after Neale (1963), Wiebe (1972), and Currie (in press). Site of zircon collection from the Jumping Brook complex is marked by an arrow.

large amounts of potash feldspar. South of Cheticamp, the Corney Brook complex locally contains large, ovoid alkali fèldspar crystals up to 10 cm long, a texture reminiscent of the 'megacrystic' plutons of the Gander zone of Newfoundland (Jayasinghe and Berger 1976).

Cormier (1972) obtained a Rb-Sr isochron age from the Corney Brook complex. When converted to current decay constants, the age is 530±44 million years (Keppie and Smith 1978). Similar ages occur in northern Nova Scotia and Cape Breton Island (Cormier 1972), and in the Avalon zone of Newfoundland. Keppie (1979) and Rast (1980) proposed to term the associated orogenic episode the Cadomian orogeny, by analogy with European usage. In the Cheticamp region, petrographic evidence suggests that this event produced relatively high-pressure, kyanite-grade metamorphism in the composite gneiss, reaching peak conditions of about 630°C at 6.5 kilobars (Fig. 3).

The granodiorite complex contains a strongly bimodal dike suite of amphibolitic gabbro and aplitic granite. Locally the mafic rocks approach hornblendite, and form small plugs. Unlike the granodiorite complex, the salic rocks are noticeably peraluminous, commonly containing muscovite and garnet. These rocks clearly cut the granodiorite complex, but appear to be older than the Jumping Brook complex, dikes of which consistently cut the gabbro and aplite.

North of Cheticamp, along the Cabot Trail highway, relatively low-grade sedimentary, volcanic and volcanogenic schists overlie the composite gneiss and the granodiorite complex. Variably tectonized unconformable contacts can be observed in several places (Fig. 4). The younger schists, termed the Jumping Brook complex (Currie, in press), consist of a basal unit of metamorphosed rhyolitic and basaltic flows and tuffs, interlayered with and overlain by black pelitic schist, and capped by a quartz-rich greywacke unit containing fragments of the composite gneiss. The sequence is about 400 m thick.

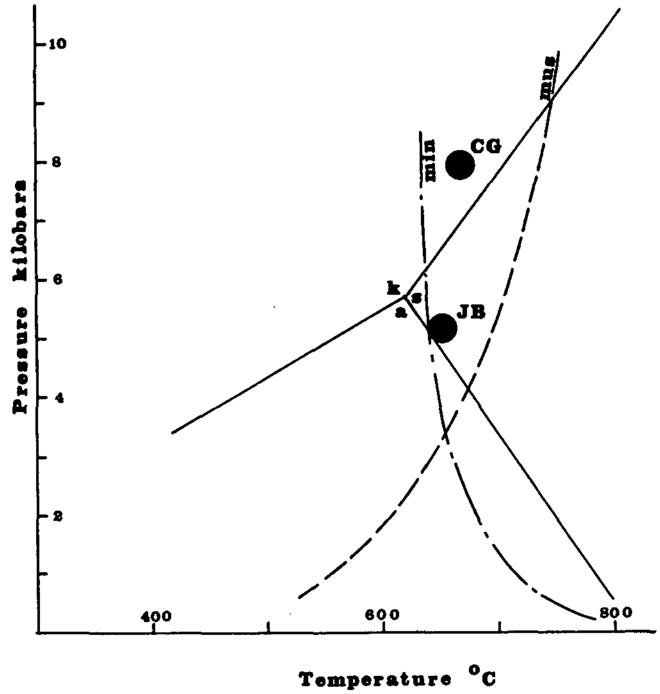

Fig. 3 - Peak temperature and pressure conditions for metamorphism of the composite gneiss (CG) and Jumping Brook complex (JB). The large dots give the calculated metamorphic conditions of the composite gneiss just prior to emplacement of the granodiorite complex, and prior to emplacement of Devonian granitoid rocks. The point CG lies in the kyanite field (k) above the minimum melting curve for water-saturated conditions (min) and below the muscovite+ quartz breakdown curve. The point JB is fixed by the coincidence of the andalusite(a) - sillimanite(s) transition with the onset of partial melting. These estimates have been confirmed by other geothermometers (Currie, in press).

The schists exhibit a spectacular progressive metamorphic sequence, passing from low-grade assemblages along the shore through a Buchans-type sequence with successive zones (in favourable lithologies) of prehnite, garnet, chloritoid, biotite, staurolite, cordierite and andalusite in that order. In contrast to the older composite gneisses, only one period of metamorphism can be recognized, which in the lower grades of metamorphism outlasted deformation

Fig. 4 - Composite gneiss containing a dike of granodiorite, truncated by schists of the Jumping Brook complex. Cabot Trail, 12 km north of Cheticamp. To the left, the massive dike cuts weakly foliated gneiss. The dike is truncated by schistose amphibolite in a dark rubbly area toward the right of the photograph. Note that for a meter below this truncation the composite gneiss is strongly foliated parallel to the overlying schist. A geology pick is stuck into the contact about a meter below the dike. About a meter above the contact, a pale coloured 30 cm rhyolite layer lies in the amphibolites of the Jumping Brook complex.

Fig. 5 - Porphyroblasts of chloritoid randomly oriented in schists of the Jumping Brook complex. Above staurolite grade the porphyroblasts are aligned and rotated into the schistosity.

(Fig. 5). The peak conditions of metamorphism reached about 630°C at 3.5 kilobars, which led to local anatexis in compositionally favourable beds. Along the coast north of Cheticamp, the metamorphic grade increases rapidly eastward, and isograds can be observed in canyons to dip westward. Along Cheticamp River, however, the isograds dip moderately eastward, so the metamorphic zones there are inverted.

Salic and mafic feeder dikes of the Jumping Brook complex cut the granodiorite complex at the site marked by

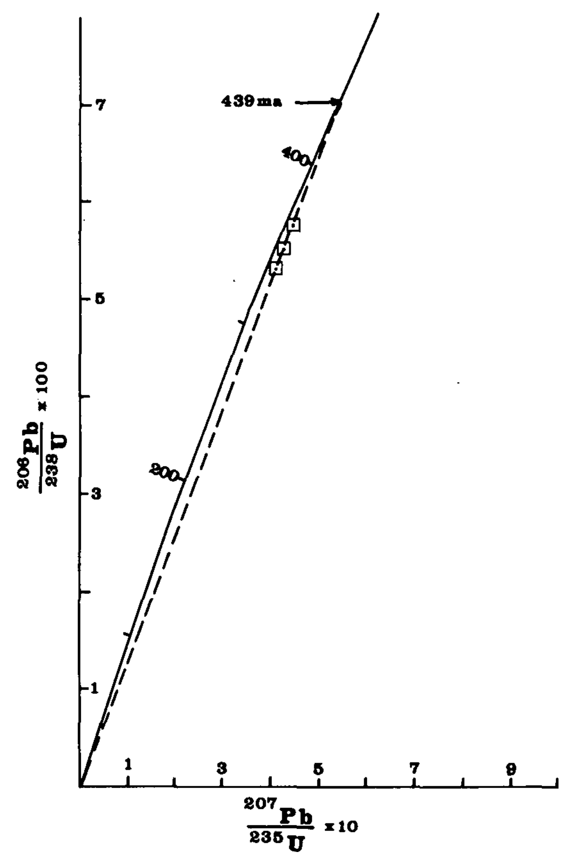

Fig. 6 - Concordia diagram of U-Pb isotope analyses for zircons from a rhyolite dike feeding the Jumping Brook complex. The three analyses defining the chord are shown by dots surrounded by squares. From top to bottom they are the -100+140 mesh non-magnetic fraction, the +100 mesh fraction, and the -100+140 mesh magnetic fraction. Decay constants assumed are $d_{238} = 1.55425{:}10^{-10}$/year, and $d_{235} = 9.84135{:}10^{-10}$/year.

an arrow in Figure 2. Zircons from a rhyolite dike gave the plot in Figure 6. Details of the analyses can be found in Loveridge and Currie (in press). Three points define a chord, for which the lower intercept passes essentially through zero, and the upper intercept through 439 million years. Since the points cluster near the upper intercept, and the morphology of the zircons is simple and consistent with an igneous volcanic origin, the rhyolite is interpreted to have been emplaced 439 million years ago, that is in late Ordovician or Silurian time. Assuming the chord to pass through zero, the 2σ error from the 207/206 age is 7 million years. Biotite concentrated from the same rock gave a K/Ar age of 369±12 million years, probably dating post-metamorphic cooling.

The Jumping Brook complex, granodiorite complex, and the composite gneiss all contain relatively young, essentially massive, granitoid rocks, commonly of potassic character. Dates on similar granites to the north and east of the mapped area suggests that these rocks are of Devonian (360±15) age (Neale 1963, Cormier 1972). A large body of megacrystic granite, thought to be of this age, occupies the central part of the Cape Breton Highland. Dikes of this body closely resemble porphyritic rhyolite associated with the base of the Upper Devonian and Mississippian Horton Group (Neale 1963). These rhyolites form part of the Fisset Brook Formation (Kelley and Mackasey 1965), a bimodal volcanic unit which lies at, or near, the base of the Horton Group. Cormier and Kelley (1964) obtained a Rb-Sr isochron age from the Fisset Brook Formation which in terms of current decay constants gives 376±12 million years, essentially identical to the metamorphic age of 369±12 million years obtained from the Jumping Brook complex, and to several dates obtained by Neale (1963) from the potassic granites of this region.

The similarity in dates shows that the Cape Breton Highland must have been very rapidly uplifted following Acadian metamorphism and plutonism, since Acadian plutons were unroofed and shed coarse and abundant debris into the Horton Group. Uplift in the Cheticamp region took place along a complex net of steeply dipping mylonite zones which bound the highland. Devonian and later uplift was merely the latest episode in the long history of these zones, most of which contain older blastomylonites and flaser gneisses of several ages. Uplift triggered lateral instability, so that large blocks slid from the uplifted highland, commonly along a lubricating film of carbonates and evaporites of the Mississippian Windsor Group (Currie 1977). Such movements had terminated by Pennsylvanian time.

PETROCHEMISTRY OF VOLCANIC ROCKS IN THE CHETICAMP AREA

Combined stratigraphic and geochronologic data for the Cheticamp region suggest an extended sequence of events. The three-fold repetition of bimodal igneous activity is of particular interest, since the tectonic interpretation of alkaline bimodal suites seems well understood (Pearce and Cann 1973, Floyd and Winchester 1975). In order to improve the interpretation of the tectonic history, the salic and mafic igneous rocks of the Fisset Brook Formation, the Jumping Brook complex, and the dike suite of the granodiorite complex were sampled and chemically analyzed.

In Table 1 are compiled averaged chemical analyses for these three suites as well as amphibolites from the older composite gneisses. The mafic rocks of all four units are remarkably similar with compositions of nepheline-normative alkaline basalts. The salic rocks likewise resemble each other. All are high silica, corundum-norma-

TABLE 1

Average Chemical Composition of Volcanic Rocks near Cheticamp

	1	2	3	4	5	6	7
SiO_2	47.75	47.79	47.17	50.91	77.12	75.96	73.61
TiO_2	2.09	1.37	0.95	1.24	0.35	0.20	0.12
Al_2O_3	16.01	16.03	17.68	16.85	10.94	12.63	14.78
Fe_2O_3	3.01	2.83	1.63	2.36	0.76	0.95	0.43
FeO	7.30	8.07	7.55	5.83	1.37	0.77	0.52
MnO	0.31	0.21	0.23	0.18	0.03	0.02	0.02
MgO	5.80	6.78	8.10	5.78	1.08	0.15	0.22
CaO	8.57	8.51	10.03	8.89	0.80	0.22	0.91
Na_2O	3.95	3.73	3.57	4.30	3.12	4.28	4.80
K_2O	1.42	1.41	1.06	1.77	3.33	4.11	3.94
H_2O	3.33	2.97	1.90	1.61	0.81	0.67	0.60
P_2O_5	0.46	0.30	0.12	0.28	0.09	0.04	0.05
n	7	11	4	8	5	3	4
OL	18.78	23.17	25.78	15.54			
NE	3.12	4.02	8.80	5.14			

Analyses by Rapid Methods Group, Geological Survey of Canada

n - gives the number of analyses averaged, OL and NE give the amount (in mol percent) of normative olivine and nepheline respectively

1 - Fisset Brook Formation, mafic volcanics; 2 - Jumping Brook complex, mafic volcanics; 3 - Mafic dikes in granodiorite complex; 4 - Amphibolites in composite gneiss; 5 - Fisset Brook Formation, salic volcanics; 6 - Jumping Brook complex, salic volcanics; 7 - Salic dikes in granodiorite complex.

tive compositions. Unfortunately the salic rocks cannot be compared to salic igneous rocks within the composite gneiss, because salic rocks correlative to the amphibolites, if present, have not been recognized.

The present results confirm and extend those of Keppie and Dostal (1980) for the Fisset Brook Formation. These authors found that their samples tended to straddle the alkaline-subalkaline boundary. The present results show that in some regions the Fisset Brook Formation is markedly alkaline. Bimodal suites with a mafic alkaline component indicate tensional conditions in a continental environment. Thus Keppie and Dostal (1980) argued from the chemistry of the Fisset Brook Formation that during Carboniferous time the Cape Breton Highland formed part of a craton which was undergoing some degree of tensional breakup. If this reasoning is persuasive for the Fisset Brook Formation, there seems no reason to reject it for the earlier bimodal suites.

REGIONAL INTERPRETATION

Stratigraphic, geochronologic and geochemical evidence suggests that the Cape Breton Highland has undergone three, or possibly four, cycles of metamorphism and plutonism, immediately followed by uplift and bimodal volcanism. In the Cheticamp region, the latest cycle of activity in Devonian and Carboniferous time included metamorphism and plutonism in mid-Devonian time (Acadian orogeny) immediately followed by uplift and bimodal volcanism (Fisset Brook Formation) in late Devonian and Carboniferous time. Presumably burial by sedimentation or tectonic downwarping preceded metamorphism. The Jumping Brook complex represents an older cycle of activity closely similar to the Fisset Brook Formation and the Horton Group. The Fisset Brook Formation contain numerous red shale and siltstone interbeds, analogous to the pelitic member in the Jumping Brook complex, while the greywacke part of the Jumping Brook complex formed from coarse clastic debris derived from nearby plutonic rocks, as did the Horton Group. To complete the analogy, plutons with ages of ±440 million years might be expected. Although such plutons have not been identified near Cheticamp, they do occur in the Cape Breton Highland (Cape Smoky pluton 447±37 million years, Keppie and Smith 1978).

The granodiorite complex and its dike suite represent a third cycle of activity. The granodiorite complex was emplaced near the climax of a metamorphic episode. Before initiation of the cycle leading to the Jumping Brook complex, bimodal igneous activity emplaced alkaline gabbroic dikes, and mildly peraluminous aplitic dikes. Surficial manifestations of this activity, analogous to the Fisset Brook Formation and the Jumping Brook complex, have not been found, presumably because they have been destroyed by erosion. Preservation of such supracrustal rocks when their subjacent plutonic rocks are exposed by uplift requires special circumstances, such as the network of faulted and slid blocks which have preserved much of the Fisset Brook Formation and Jumping Brook complex.

A fourth cycle of activity may be represented by the older alkaline amphibolites within the composite gneisses, although the stratigraphic control is too weak to be certain. However the presence of such alkaline mafic rocks strongly suggests a tensional episode older than the granodiorite complex, but younger than the composite gneiss, into which the amphibolites were emplaced as dikes.

The Cape Breton Highland appears to record all three deformational and intrusive episodes commonly recognized in the northern Appalachians, namely those termed Cadomian, Taconic and Acadian, plus an older Precambrian episode. Roughly comparable histories have been deduced from other sites along the chain of basement complexes shown in

Fig. 1. Currie *et al.* (1981) argued that the Saint John, New Brunswick region had undergone repeated episodes of acid and basic plutonism with accompanying diapirism, separated by intervals of sedimentary accumulation. They proposed four cycles, dated at roughly 370, 450, 600 and 750 million years, based on the dating of Olszewski *et al* (1980). Donohoe and Wallace (1979) showed that the Cobequid Highland experienced an intricate history of sedimentation, volcanism, deformation and metamorphism extending from Precambrian to Triassic time. Whalen and Currie (1982) showed that the Topsails region of Newfoundland underwent repeated bimodal igneous activity, probably extending from Precambrian to Carboniferous time, with the acid products becoming progressively more peralkaline with time.

The persistent cyclic nature of the history of the Cheticamp region suggests that throughout late Precambrian and early Paleozoic time the Cape Breton Highland remained in a single tectonic environment, of which the cyclic nature was an integral part. Although at present inadequate, the available evidence is compatible with the hypothesis that all, or most, of the basement complexes shown in Fig. 1 underwent a similar cyclic history, and hence represent parts of a single whole, rather than 'debris' accidently swept up during development of the Appalachians.

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