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Paleomagnetism of mafic dikes from the Avalon Peninsula, eastern Newfoundland

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As part of a major study of the Avalon zone in eastern Newfoundland, we describe the palromagnetism of two series of dikes located in the Bauline and Colliers-Harbour Main areas, respectively. Detailed alternating field (AF) and thermal experiments performed on these dikes indicate that they are characterized by two significantly different mean directions of magnetization: SE++(D = 153°, I = +62°; K = 46, N = 12 sites) and SW (D = 217°, I = +58°, K = 58, N = 12 sites) with corresponding paleopole positions at A (4°N, 34°W; d_p,d_m = 8°, 10°) and C (2°N, 81°W; d_p, d_m = 6°, 9°). Antipoles A and C are located in southerly latitudes, and a comparison with other poles of Avalonian rocks from New Brunswick, Nova Scotia and Newfoundland indicates a Silurian to Siluro-Devonian age for these dikes. Poles A and B are interpreted as representing rapid apparent polar wander with respect to eastern Newfoundland during Silurian time. Two components of magnetization, corresponding to two distinct geological events, are observed in the dikes investigated and this situation favours the following geological scenario for the evolution of the Avalon microcontinent: (a) intracratonic rift zone resulting in long-lived Late Hadrynian and Cambrian continental extension, (b) a very late phase of distension in separating miniplates during Silurian and Early Devonian time.

Dans le cadre d'une étude d'envergure de la zone d'Avalon menée dans l'est de Terre-Neuve, nous décrivons le paléomagnétisme de deux séries de dykes situées dans les régions de Bauline et de Colliers - Harbour Main respectivement. Des expériences détaillées de désaimantation par champ alternatif (CA) et par lavage thermique démontrent que deux directions moyennes de l'aimantation caractérisent les dykes: SE++ (D = 153°, I = +62°; K = 46, N = 12 sites de prélèvement) et SO (D = 217°, I = +58°, K = 58, N = 12 sites de prélèvement) avec des paléopôles correspondants aux positions A (4°N, 34°O; d_p,d_m = 8°,10°) et C (2°N, 81°O; d_p,d_m = 6°, 9°). Les antipôles A et C se situent à des latitudes méridionales et par comparaison avec d'autres pôles de roches avaloniennes du Nouveau-Brunswick, de la Nouvelle-Ecosse et de Terre-Neuve, on attribue aux dykes un âge Silurien à Siluro-Dévonien. On interprète les pôles géomagnétiques A et B comme le résultat de déplacements rapides du pôle par rapport avec l'est de Terre-Neuve durant le Silurien. On observe dans ces dykes deux composantes de magnétisation, correspondant à deux évènements géologiques distincts. Ceci suggère le scénario suivant pour expliquer l'évolution du microcontinent Avalon: (a) un rift intracratonique qui se traduit par une longue période d'extension continentale depuis l'Hadrynien tardif jusqu'au Cambrien; (b) du Silurien jusqu'au début du Dévonien, une phase tardive de distension lors de la séparation des miniplaques.

[Traduit par le journal]

INTRODUCTION

The eastern segment of the Appalachian orogen is largely underlain by Late Precambrian rocks. These rocks were labelled "Avalonian", after the Avalonian Peninsula of eastern Newfoundland (Kay 1967, Poole 1967) where they are typically exposed. Detailed studies in the eastern Avalon Peninsula have been carried out by Papezik (1972), Nixon and Papezik (1979) and King (1979). Systematic mapping programs of the Avalon Zone were first undertaken by Rose (1952), Hutchinson (1953) and McCartney (1956, 1967). The Precambrian stratigraphy was elucidate subsequently by Misra (1969), Brückner and Anderson (1971), Hughes and Brückner (1972), King *et al.* (1974), Anderson *et al.*(1975) and Strong (1979). The Avalon Peninsula was affected by two principal orogenies, a Late Precambrian "Avalonian orogeny" (Lilly 1966) and the "Acadian" orogeny of Middle to Late Devonian age (Strong 1979). Different tectonic models

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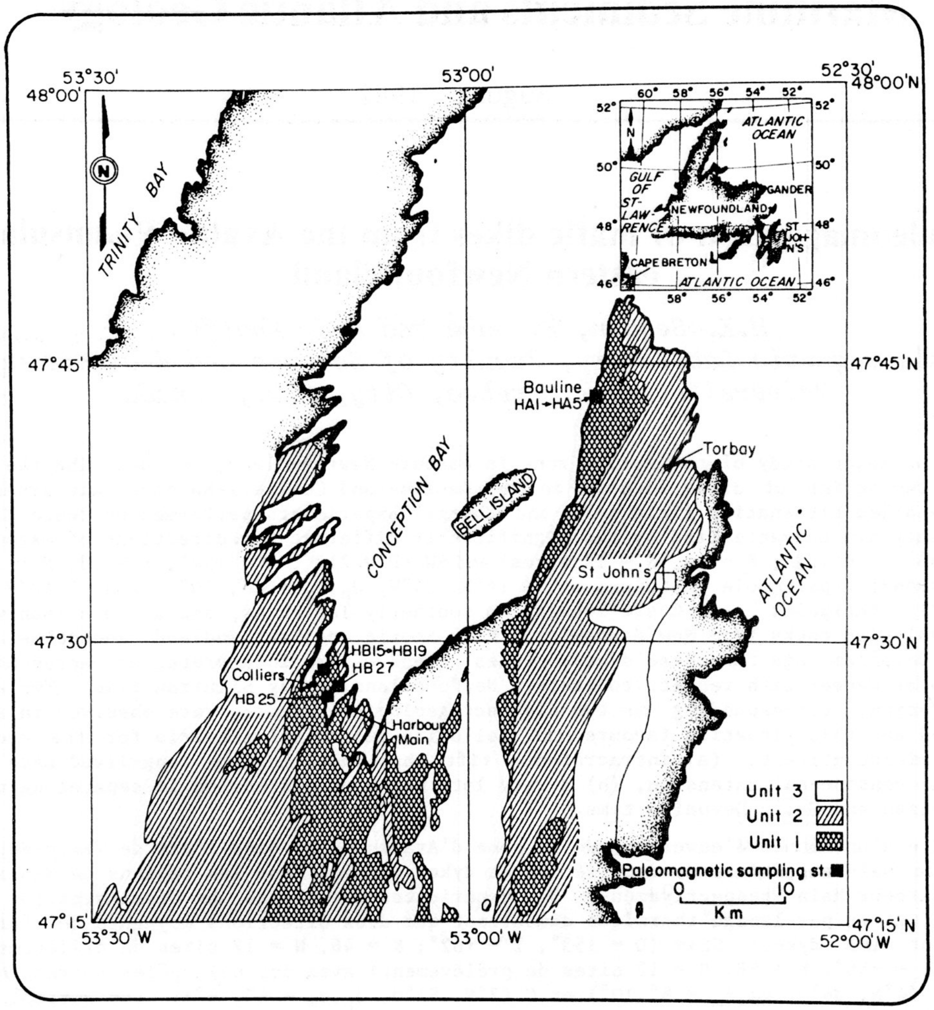

Fig. 1 - Distribution of paleomagnetic sampling sites (HA and HB) in eastern Newfoundland. Unit 1 = Harbour Main Group, Unit 2 = Conception Group, Unit 3 = upper sedimentary Group.

have been proposed for the origin of the Avalon mini-continent: 1) island arc (Hughes and Brückner 1972, Rast *et al.* (1976); 2) subduction and Basin and Range-type rifting (Schenk 1978); Strong *et al.* 1980; and 3) continental extension and rifting (Rankin 1976).

Precambrian rocks similar to the ones encountered in the Avalon Zone occur throughout the Applachian orogen, in Nova Scotia, New Brunswick, eastern Massachusetts, southeastern United States (Carolina State Bélt, Williams 1979) and on the eastern side of the Atlantic, i.e. Wales, Brittany, the Iberian Peninsula, Czechoslovakia and Turkey, as well as in northeast Africa (Choubert 1935, Schenk 1978, Cogné 1972, Rast *et al.* 1976, Strong 1979, Williams 1979).

GEOLOGICAL SETTING

In the Whitbourne (Colliers-Harbour Main) and Torbay-Bauline map areas (Fig. 1), the Late Precambrian rocks of the Avalon Zone are subdivided into three groups: 1) Harbour Main Group, 2) Conception Group, and 3) an upper sedimentary Group, all of which are overlain, in turn, by a small zone of Lower Cambrian sedimentary blocks. The Harbour Main Group is composed of marine and terrestrial volcanics, the Conception Group of volcaniclastic sedimentary rocks and the upper sedimentary Group of shallow continental sedimentary strata (Brückner and Anderson 1971, Williams and King 1979, King 1979, Williams 1979). The Harbour Main Group is intruded by the Holyrood plutonic series south of the study area (McCartney 1967). Generally, all the lithological groups are weakly metamorphosed to the subgreenschist facies (Nixon and Papezik 1979). Contact metamorphic effects near and within the Holyrood plutonic rocks have been recognized (McCartney 1967).

Small basic dikes (diabasic gabbro, diabase and trap) cut the Harbour Main Group in the Torbay map area (Rose 1952) and both Harbour Main and Conception Groups as well as Cambrian sedimentary units (up to lower Middle Cambrian) in the Whitbourne map area (McCartney 1967). In the Colliers Bay area (Fig. 1), these dikes cut all other Late Precambrian rocks including porphyrites and rhyolite sills (Nixon and Papezik 1979). The dikes present chilled margins to the rocks cut, they cut the Hadrynian rocks in all directions, they generally have a subvertical dip and their thickness vary from a few decimeters to tens of meters. No significant geological difference (mineralogical and textural) is observed between HA and HB dikes. The dikes are apparently older than Late Devonian - Early Carboniferous.

Consequently, the HA and HB mafic dikes sampled in the Bauline and Colliers-Harbour Main areas, respectively, have a possible age span extending from the Middle Cambrian to the Late Devonian. No radiometric data are available on these dikes.

SAMPLING PROCEDURE

Some 61 oriented samples (159 specimens were collected at 12 different sites (5 in HA and 7 in HB); the orientation was taken with a Brunton or a sun compass. The number of samples per site varied from 5 to 7 and the number of specimens per sample between 2 and 5. The majority of the samples were collected on the chilled margins of the dikes. The oriented hand samples were later cored in the laboratory. The locations were chosen with reference to detailed geological maps published by Rose (1952), Hutchinson (1953), McCartney (1967), Nixon and Papezik (1979) and King (1979). Efforts were made to select sites where there was adequate exposure and where the structural geology was simple and best understood. Great care was taken to avoid altered material. The locations of the sampling sites are shown on Fig. 1.

EXPERIMENTAL PROCEDURE

Equipment Used

The direction and intensity of remanent magnetization were measured with digital spinner magnetometer (model DSM-1) manufactured by Schonstedt Inst. Co. (sensitivity = 10^{-4} Am^{-1}). Alternating field (AF) demagnetization was carried out by using a demagnetizer built at Laval University which has a maximum peak-to-peak intensity of 90 milliTesla (mT). Its performance was improved by adding 3 large concentric mu-metal cylinders around the solenoid (Seguin 1975) and a Schonstedt AF specimen demagnetizer (model GSD-1). Thermal treatment of the specimens was done in a field-free demagnetizer (model TSD-1) manufactured by Schonstedt Inst. Co. The amount of residual ambient field present is 5 nT in the demagnetizer, and 10 nT in the electrical oven.

Remanent Orientation and Intensities

Individual specimen natural remanent magnetization (NRM) directions of HA and HB dikes (Fig. 2), although characterized by wide scatter caused by some positively and one negatively inclined shallow remanence, have a pronounced deviation away from the Present Earth's Field (PEF) (D = 334°, I = +71°) at the site localities. This indicates that HA and HB dikes carry some ancient remanence especially since the directions of the remanence of the few specimens (10-15%) that lie close to the PEF were found to move away from those initial directions during AF or thermal treatment. It is also noticeable that the majority of the directions of the remanence are lo-

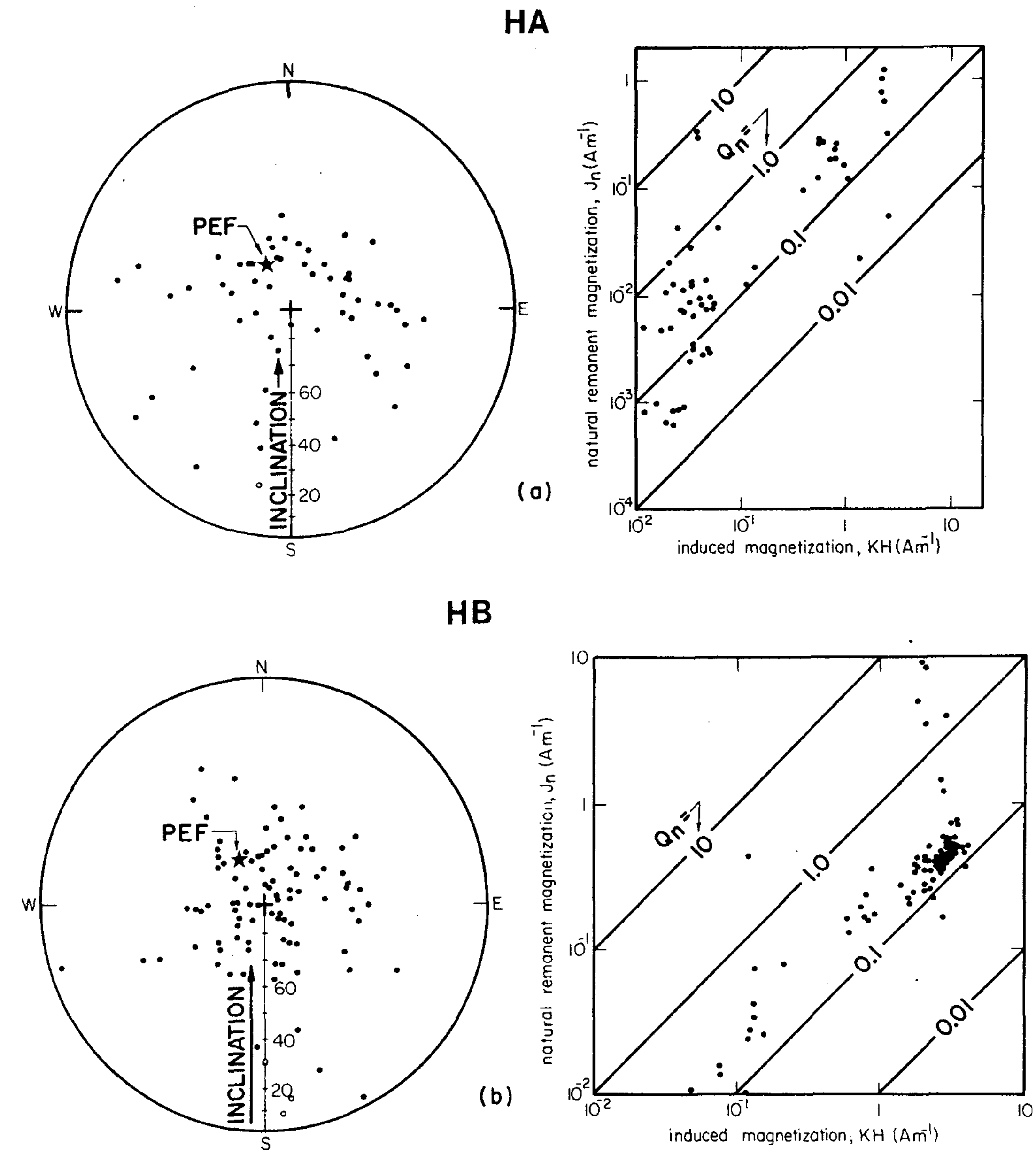

Fig. 2 - Individual specimen NRM directions plotted on Wulff net for HA (2a) and HB (2b) dikes (left). Solid (open) circles represent projections on lower (upper) hemisphere. The star represents the present earth's field (PEF) at the sampling locality. Plots of corresponding intensity of NRM (J_n in Am^{-1}) against the induced magnetization (KH in Am^{-1}) with resulting slope lines indicating the values of Koenigsberger ratio, Q_n (right).

cated in the southern quadrants on the stereonet. The wide scatter in NRM with occasional dual polarity of remanence is, therefore, indicative of the presence of both low and high coercivity components. The intensities of NRM (J_n) vary from 10^{-2} to 4 Am^{-1} with values of the Koenigsberger ratio ($Qn = J_n/KH$) between 0.07 and 8, with most ratios between 0.2 and 0.7 (Fig. 2).

The Qn values for both HA and HB dikes are similar; they are mainly located in the range 0.1 - 1.0. This observation suggests that they have more or less the same age and that they are probably consanguinous. The NRM orientations of

HA and HB dikes are also quite similar. Those directions which are not located close to the PEF plot preferentially in the two southern quadrants. The inclinations are predominantly downward.

PRELIMINARY DEMAGNETIZING STUDIES

AF Demagnetization

For the premininary AF study at least five specimens per HA and HB site were demagnetized in 14 steps up to 100 mT, and vector diagrams (Zijderveld 1967) were used in the subsequent analysis. For 95% of the HA (HB) samples, the intensities of magnetization at/or before the 60 (30) mT treatment had fallen to less than 10% of the NRM intensity. In almost 45% of the samples, the measurements indicated acquisition of spurious magnetizations at higher demagnetizing fields (70-100 mT) for HA and 30-50 mT for HB. Remanence behaviour during AF treatment typical of most samples from the five HA dike sites are shown by three specimens from three different sites. Vector trajectories are linear until stable end-points are reached at higher fields. The linear trajectory for specimen HA 4 - 3.B indicated the presence of two components (Fig. 3). One has a northeasterly directed magneti-

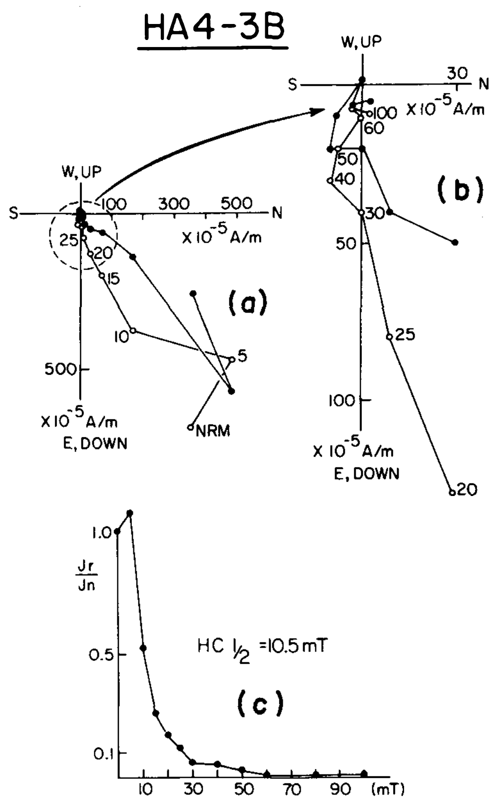

Fig. 3 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HA4-3.B dike specimen as indicated. Solid (open) circles represent projections on horizontal (vertical) plane. Numbers next to open circles represent the demagnetization steps (mT).

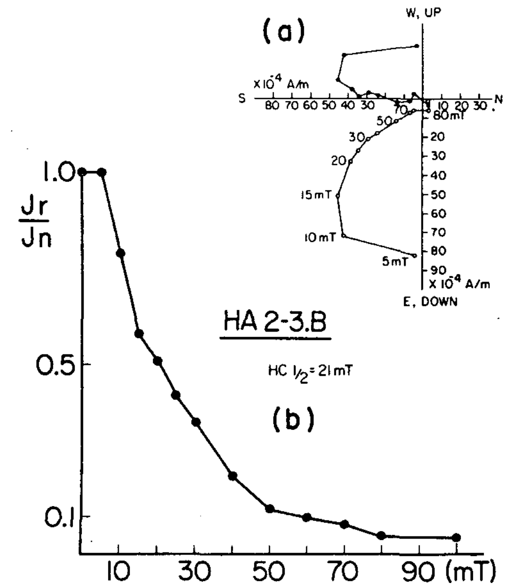

Fig. 4 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HA2-3.B dike specimen. The other symbols are as in Fig. 3.

zation having an intermediate to steep downward inclination (D = 50°), I = 60°), which is present in the 5-30 mT range (more generally 20 mT) and it is removed at an AF intensity of 40 mT. It is detected on sites HA-2, -3 and -4. The second component has a southeasterly directed magnetization having an intermediate downward inclination (D = 125°, I = 50°) which is isolated in the 40-80 mT range. This component is observed on sites HA-2 and -3 (eventually HA-5). The linear trajectory for specimen HA 2-3.B (Fig. 4) is characterized by two linear trajectories representing two different components. The first component has a southwesterly directed magnetization having an intermediate to steep downward inclination (D = 230°, I = 60°) which is present in the 0-20 mT range (more generally 10-15 mT) and it is removed above the 30 mT AF intensity level. This component is predominant on sites HA-2 and -3 (eventually HA-5). The second component has a southeasterly directed magnetization having an intermediate downward inclination (D = 170°, I = +40°) isolated in the 25-60 mT range. Occasionally, and this is the case for specimen HA 2-3.B, a third component is isolated in the high coercivity range (70-100 mT). This third component has a northeasterly magnetized direction with an intermediate downward inclination (D = 45°, I = 35°). This component is observed on two HA sites only. The linear trajectory for specimen HA 3-1.A (Fig. 5) shows the occurrence of two components. One has a southwesterly directed magnetization with an intermediate to steep downward inclination (D = 240°, I = 60°)

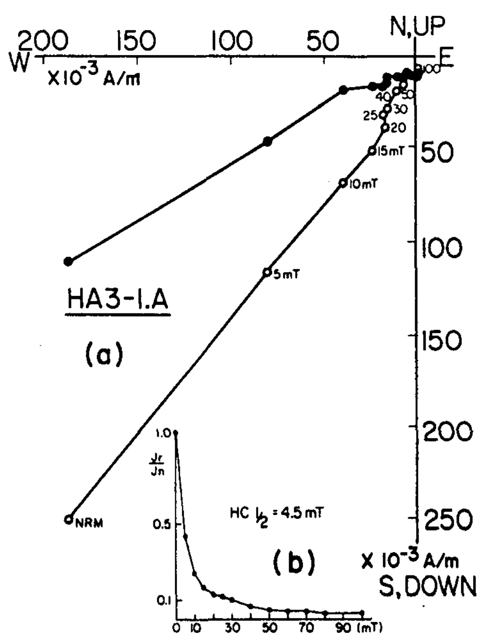

Fig. 5 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HA3-1.A dike specimen. The other symbols are as in Fig. 3.

present in the 5-60 mT range (generally 45 mT) which is removed at an AF intensity higher than 70 mT. It is present on sites HA-3 and -4. The second component has a magnetization directed to the south with an intermediate downward inclination (D = 170°, I = 45°) which is observed in the high coercivity range (70 - 100 mT). This component is occasionally isolated in sites HA-3, -4 and -5.

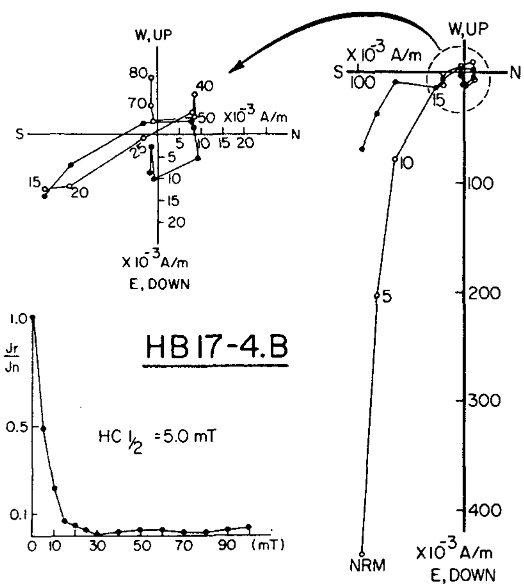

Fig. 6 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HB17-4.B dike specimen. The other symbols are as in Fig. 3.

Remanence behaviour during AF treatment typical of almost all samples from the seven HB dike sites are represented on Figures 6 and 7 by three specimens from three different sites. Vector trajectories for specimen HB-17-4.B (Fig. 6) indicate the presence of a stable, single component of magnetization with a southeasterly declination and intermediate downward inclination (D = 160°, I = 45°) in the 10-25 mT range. Acquisition of spurious ma_netization above 50 mT renders impossible the extraction of an eventual high coercivity component. This SE intermediate downward component is most common on sites HB-16, -17, -18 and -19. Specimen

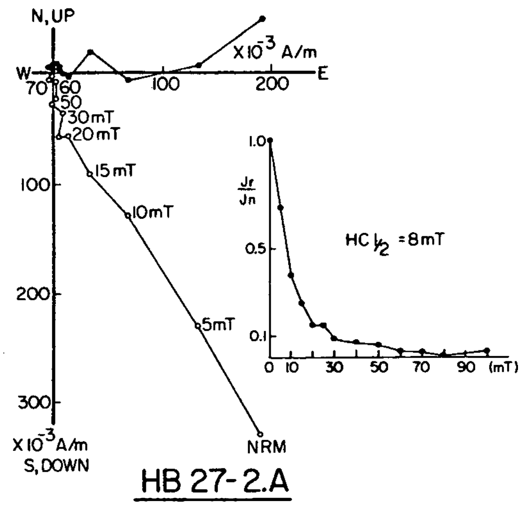

Fig. 7 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HB27-2.A dike specimen. The other symbols are as in Fig. 3.

HB 27-2.A (Fig. 7) is indicative of another stable, single component which has north-northeasterly directed magnetization with an intermediate to steep downward inclination (D = 75°, I = 60°). This component is best isolated in the 10-40 mT range and was commonly encountered on sites HB-16, -17, -18, -19 and -27. Finally, specimen HB 19-3.C (Fig. 8a) is characterized by two components of magnetization. The first component has a westerly directed magnetization having a steep to intermediate downward inclination (D = 270°, I = 65°) which is present in the 0-25 mT range (generally 15 mT) and is removed at an AF intensity of approximately 40 mT. This component is common on sites HB-15, -17, -19 and -25. The second component has a west-southwesterly directed magnetization having a shallow to intermediate downward inclination (D = 250°, I = 25°). This component, which is isolated in

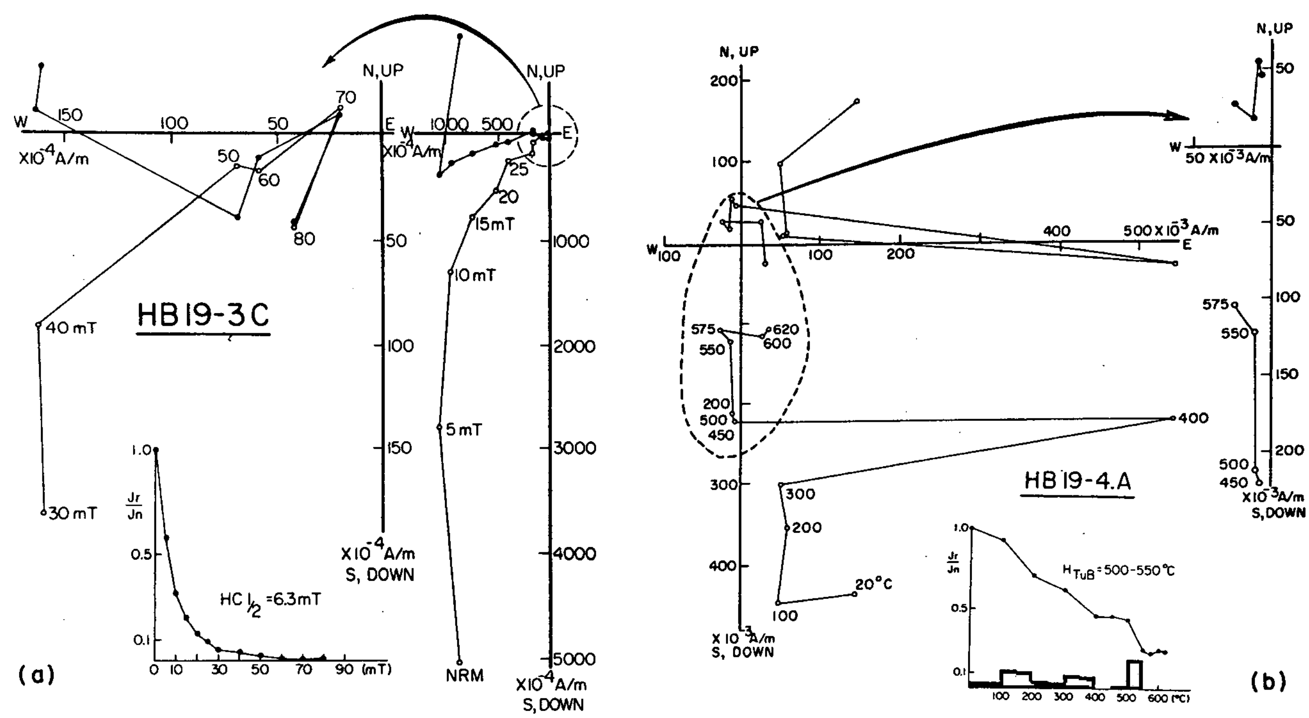

Fig. 8 - Representative orthogonal AF (a), and thermal treatment diagrams (b) (Zijderveld 1967) of successive end-points of magnetization vector for two HB dikes specimens as indicated. For specimen HB19-4.A (b), the numbers next to open circles represent the demagnetization steps (°C). The unblocking temperature ($T_{\mu B}$) in °C is indicated below the orthogonal plots. The other symbols are the same as in Fig. 3.

the 40-70 mT range, is very rare because the acquisition of a spurious magnetization interferes with its reliable extraction.

Thermal Treatment

For the preliminary thermal study, at least five specimens per HA and HB sites were demagnetized in 11 steps up to 620°C; vector diagrams were used in subsequent analysis. Most commonly, the unblocking temperature ($T_{\mu B}$) (Roy and Lapointe 1978) is located in the 500-575°C range. Typical behaviour of three HA samples during thermal treatment from two different sites is shown in Fig. 9. In the case of specimen HA 3-2.B (Fig. 9a), two components are seen on the linear vector trajectories. The first component is a SSW directed magnetization with a shallow downward inclination (D = 215°, I = 25°). This component is rarely observed and is definitely secondary - it is detected in the 20-500°C range of specimen HA 3-2.B. The second component is isolated in the 525-575°C range; its orientation is also SSW but its declination is intermediate to steep downward (D = 215°, I = 55°). This component is common to sites HA-1, -2, -3 and -5. A third component is possibly isolated in the 575-620°C range. Its direction of magnetization is ENE with intermediate to steep downward inclination (D = 80°, I = 60°). It is unusual to isolate this NE component in the high temperature range. Specimen HA 3-5.1 (Fig. 9b) also depicts two components. The first component has a southern to SSW direction of magnetization with steep downward inclination (D = 190°, I = 75°).

This direction is present in the 20-350°C range and corresponds to the second component of specimen HA 3-2.B. The second direction of magnetization isolated in this specimen is SSE with an intermediate downward inclination (D =

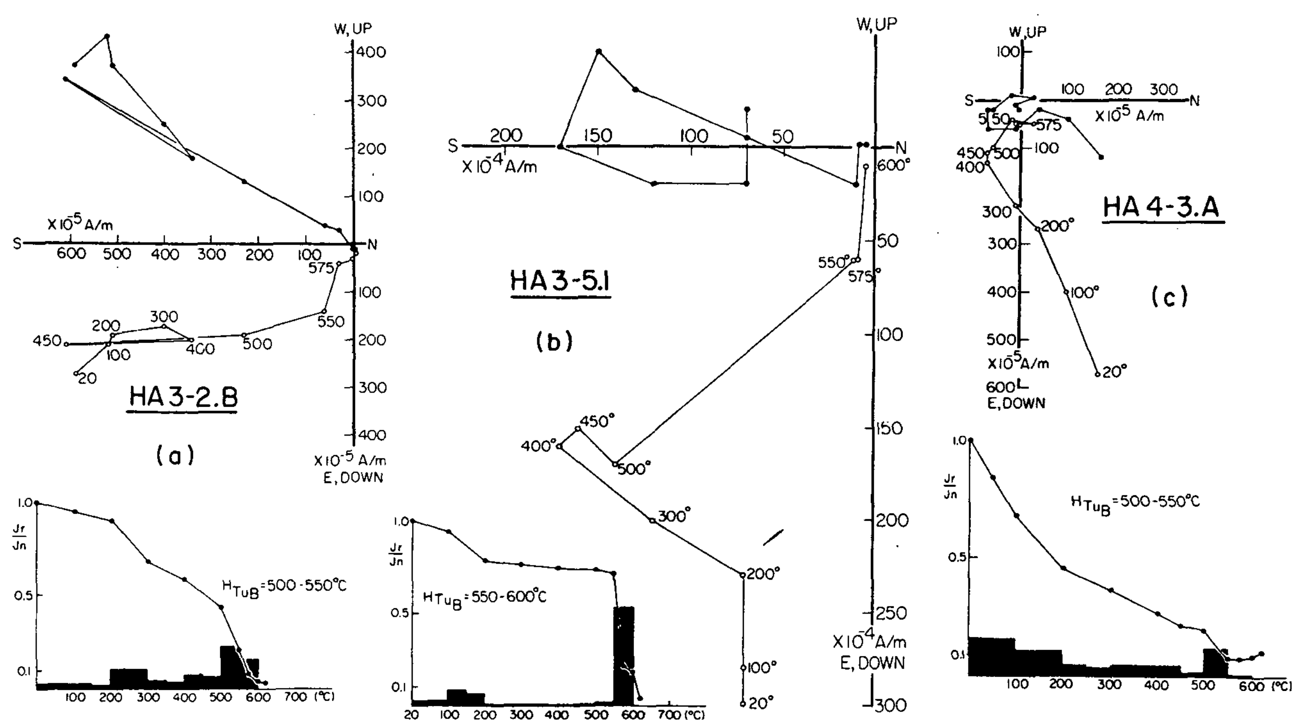

Fig. 9 - Representative orthogonal thermal demagnetization diagrams (Zijderveld 1967) of successive end-points of magnetization vector for three HA dike specimens as indicated. The other symbols are the same as in Fig. 3. The numbers next to open circles represent the demagnetization steps (°C). The unblocking temperature ($T_{\mu B}$) in (°C) are indicated below the orthogonal plots.

175°, I = 50°). This southeastern direction of magnetization, isolated in the 450-600°C range for specimen HA3-2.B is the most common at all HA dike sites. Two components of magnetization are also detected on specimen HA 4-3.A (Fig. 9c). The first one has a northeasterly directed magnetization with steep downward inclination (D = 35°, I = 75°) in the 20-400°C range. The second component, a southeasterly directed magnetization having an intermediate to steep downward inclination (D = 160°, I = 65°), is isolated in the 450-600°C range. This is the most common situation encountered and in particular, at sites HA-2, -3 and -4.

The typical behaviour of one HB sample during thermal treatment from site HB-19 (Fig. 8b) is compared with the one during the course of AF demagnetization. Two components of magnetization are detected on specimen HB 19-4.A. The first component has a northeasterly directed magnetization with steep downward inclination (D = 80°, I = 75°) and is observed in the 100-400°C range. This is the most common low and/or intermediate temperature component encountered on both HA and HB dike sites. The second component, isolated in the 450-575°C range, has a NNW declination with a steep downward inclination (D = 320°, I = 70°). The direction of this component corresponds to that of the first component obtained by AF demagnetization (specimen HB 19-3.C, Fig. 8b). This magnetization is encountered on sites HB-15, -17, -19 and -25.

STATISTICAL ANALYSIS OF SITE-MEAN DIRECTIONS

HA and HB dikes site-mean directions for both AF and thermally cleaned results are shown in Table 1. SE++(A), NE(B), SW(C), NW(D), SE++(E) and W remanence directions are observed in either HA or HB dikes and the corresponding group-mean directions based on sites are presented for both groups in the same table. A, B, C, D and E directions are common to both HA and HB dike suites. The W component is observed in only 2 specimens of the HA and is not significant. The same conclusion applies to the E component for HB dikes. The PEF component is relatively common in the HB dikes, but seldom observed in the HA dikes. As a result of these observations, only the A, B, C and D components are common to both HA and HB sites and thus considered reliable for paleomagnetic investigation. The E component is also significant, but for some HA sites only.

SEQUENCE OF THE COMPONENTS OF MAGNETIZATION

An attempt to classify the acquisition sequence of these components was made based on: a) the coercivity spectrum and unblocking temperature, b) frequency of distribution, c) precision parameter (K) of the mean direction. Based on criterion a) applied to specimens or samples of the different HA and HB sites, it is assumed that the components having the higher coercivity spectra (H_{cr}) and higher unblocking temperatures ($T_{\mu B}$) are the oldest. Clearly, this is not always true since the H_{cr} and the $T_{\mu B}$ depend on the nature of the magnetic carriers. By working out this relationship, the following sequence was established: B > A > D > E > C for the HA sites, where B > A tentatively means older than A, etc. The sequence B > A generally holds for both AF and thermally cleaned specimens; the sequence A > D > E was established from thermally cleaned results alone, whereas the sequence E > C was obtained from AF demagnetized results alone.

The above sequence is exactly the same as for the HA series when component E is removed. Sequence B > A was established from both AF and thermally cleaned specimens, while sequence A > D was deduced from AF demagnetized results. Finally, the relationship D > C is observed in both AF and thermally cleaned results.

On the basis of frequency distribution (number of specimens per component for both HA and HB dike series [see Table 1]), the sequence obtained is the fol-

Table 1

STATISTICAL SUMMARY OF SITE-MEAN DIRECTIONS

	SE++(A)					NE (B)					SW (C)				
Site	N(n)	D°	I°	K	α_{95}°	N(n)	D°	I°	K	α_{95}°	N(n)	D°	I°	K	α_{95}°
HA-1	4(8)	167	72	110	8.8	1(1)	022	73	-	-	2(3)	223	53	12.1	-
HA-2	4(6)	156	62	19.7	21.2	2(2)	050	58	30.1	-	2(3)	215	59	24.6	25.4
HA-3	5(6)	162	65	38.3	12.5	2(2)	053	69	9.9	-	4(5)	219	44	48.3	13.4
HA-4	4(9)	154	58	72.7	10.8	2(3)	034	57	108	24.3	1(1)	208	74	-	-
HA-5	2(2)	146	71	16.7	-	1(2)	070	80	-	-	2(4)	237	56	51.4	35.3
mean:	5(31)	157	66	153	6.2	5(10)	044	68	50.2	10.9	5(16)	222	57	44.5	11.6
%	41					13					21				
HB-15	2(3)	156	43	57.9	33.3	2(2)*	075	53	100	25.2	2(3)	201	59	774	9.0
HB-16	3(5)	144	69	30.7	22.8	3(3)	047	61	16.9	30.8	3(5)	219	47	55.9	16.7
HB-17	4(5)	143	53	9.7	31.3	4(5)	031	56	10.6	29.7	4(5)	220	48	59.3	12.0
HB-18	4(5)	162	49	19.6	21.4	4(6)	046	57	11.9	27.8	5(7)	229	65	47.3	11.2
HB-19	5(9)	143	65	28.3	14.7	3(6)	045	59	42.6	19.1	2(3)	224	61	29.5	-
HB-25	2(2)	161	54	-	-	1(1)	021	60	-	-	4(6)	200	61	20.9	20.6
HB-27	2(2)	104	75	-	-	2(4)	039	74	59.4	32.2	4(4)	199	67	77.9	10.5
mean:	7(31)	151	59	31	11.0	7(27)	044	61	54	8.3	7(33)	214	59	65	7.5
%	26					21					27				
HA+HB	12(62)	153	62	45.5	6.5	12(40)	044	64	51.9	6.1	12(49)	217	58	57.8	5.8

	NW (D)					SE+ (E)					W				
HA-1											1(1)	284	23	-	-
HA-2						1(2)	162	35	-	-					
HA-3	1(1)	296	61	-	-	3(4)	162	32	10.6	40	1(1)	261	12	-	-
HA-4	4(5)	334	55	41.8	14.4	1(2)	168	30	-	-					
HA-5	3(3)	327	73	22.9	26.4										
mean:	3(9)	319	64	34	20.3	3(8)	164	32	438	5.9	2(2)	272	18	22	-
%	12					10					3				
												PEF			
HB-15	2(3)	291	52	26.1	-	1(1)	125	13	-	-	1(1)	350	84	-	
HB-16											1(1)	299	83	-	
HB-17	3(3)	321	36	20.4	28.1						3(4)	328	68	27.4	
HB-18	1(1)	310	43	-	-						3(3)	325	66	58.1	
HB-19	3(4)	279	55	33.5	21.7						2(2)	340	71	73.5	
HB-25	2(2)	281	59	7.9	-						3(5)	338	70	123	
HB-27											2(2)	335	71	66.9	
mean:	5(13)	299	50	28	14.7	1(1)	135	13	-	-	7(18)	328	78	29	
%	10					1					15				
HA+HB	8(22)	305	56	25.3	11.3		149	23	12.5	-					

* = Reverse polarity
N = Number of samples
D = Declination
I = Inclination
K = Precision parameter (Fisher, 1953)
α_{95} = circle of confidence at 95% probability level (Fisher, 1953)

lowing: A > C > B > D > E for HA dikes and C ≥ A > B > D for HB dikes. Finally, when using the largest precision parameter (K) as a criterion, the sequence arrived at is: A > B > C > D > E for HA dikes and C > A > B > D for HB dikes. As the coercivity spectra of many components are superimposed in the same temperature or AF strength range, this mode of classification was eliminated. By comparing the two other modes of classification, it is noted that components A and C are predominant over components B, D and E for both HA and HB dikes. The common denominator obtained is A > C > B > D > E.

VECTOR SUBSTRACTION OF COMPONENTS

As the number of geological events is rather limited within the small age interval admissible from field evidence, it was clear that too many components of magnetization were isolated for both HA and HB dikes and that some of these components were composite rather than unique. In addition to Zijderveld diagrams, the vector subtraction technique was used (Roy and Park 1974). The results obtained with the help of vector subtraction indicated that the B(NE) component is composite and obtained by addition of the PEF to the A component in the low temperature range: 200-400°C for some HA sites, and 100-300°C for some HB sites. The same conclusion applies for AF demagnetization - the spectrum is then located in the 5-25 mT range for some HA dikes and 5-10 mT for some HB dikes (see Table 3). Thus, the B component does not represent a single geological event and is eliminated.

SIGNIFICANCE OF D AND E COMPONENTS OF MAGNETIZATION

The D(NW) component in both HA and HB dikes is responsible for only 10% of the frequency distribution of all the components (Table 1). In the case of HA dikes, the D component is encountered on only two sites and their mean direction (D = 331, I = 64) corresponds closely to the PEF (D = 334, I = 72). The specimens of HB dikes which contained only PEF magnetization were discarded. Four sites (HB-15, -17, -19 and -25) which contain the D component (mean: D = 300, I = 50) remained. The D component was never isolated by thermal treatment and so the existence of this component is rather suspect. The D component was usually isolated in a relatively high AF range (20-70 mT, mean 45 mT), and the PEF is most commonly present in the low AF range. These two observations suggest the occurrence of a fictitious D component which is poorly isolated and still contains a large fraction of the PEF magnetization. In conclusion, the D component has no paleomagnetic or geological significance for the HA or HB dikes.

The E(SE) component is encountered in the HA-3 site only with a frequency distribution of 10% (see Table 1). The E component is extracted by AF demagnetization in the higher coercivity range of the spectrum (40-100 mT) but never after thermal treatment. A comparison of AF and thermal treatments in the same samples of HA-3 site shows that thermal treatment which yielded the A component is more efficient on this specific site than AF demagnetization which yielded the E component. This suggests that the E component is not a real one and can be eliminated.

In conclusion, two reliable components (A and C) remain. Considering the variation in their angle of confidence (α_{95}), the components of magnetization are not significantly different in HA and HB dikes. The interpretation given to this situation is the following: HA and HB dikes have the same paleomagnetic signature, they have the same origin and they are of the same age.

PALEOPOLE POSITIONS AND THEIR RELATION TO POLES PREVIOUSLY DETERMINED

The A component (D = 153, I = +62) yields a paleopole of 4°N in latitude and 34°W in longitude, and the C component (D = 217, I = +58) a paleopole of 2°N in latitude and 81°W in longitude (see Table 2). Both components have a paleopole near the equator. The

Table 2

STATISTICAL SUMMARY OF GROUP-MEAN DIRECTIONS OF MAGNETIZATION AND PALEOMAGNETIC POLES

	HA Dykes					HB Dykes				
Group	N*	D°	I°	K	α_{95}°	N	D°	I°	K	α_{95}°
SE++(A)	5	157	66	153	6.2	7	151	59	31	11
NE (B)	5	044	68	50.2	10.9	7	044	61	54	8.3
SW (C)	5	222	57	44.5	11.6	7	214	59	65	7.5
NW (D)	3	319	64	34	20.3	5	299	50	28	14.7
SE+ (E)	3	164	32	438	5.9					

	HA and HB Dykes Combined					Paleopole			
Group	N*	D°	I°	K	α_{95}°	Lat.°	Long.°	d_p°	d_m°
SE++(A)	12	153	62	45.5	6.5	4N	34W	7.8	10.1
NE (B)	12	044	64	51.9	6.1	60N	24E	7.7	9.7
SW (C)	12	217	58	57.8	5.8	2N	81W	6.3	8.5
NW (D)	8	305	56	25.3	11.3	49N	138W	11.7	16.2
SE+ (E)						24S	37W	3.7	6.6

* N = number of sites

D°, I°, K, α_{95}° = same as for Table 1

d_p° = error in paleocolatitude

d_m° = polar error in the declination

antipoles of components A and C are 4°S, 146°E and 2°S, 99°E respectively. Both geological events related to these components of magnetization occurred in a period of reversal of the paleofield. The paleopole of component A lies close to pole BD-1 and CB-1 (Fig. 10), i.e. in the 400-460 Ma time interval (≃430 Ma) or early Silurian. The paleopole of component C lies close to pole JF (Fig. 10), i.e. in the 400-420 Ma time interval (≃410 Ma) or late Silurian to Siluro-Devonian. According to Kent and Opdyke (1978), the coastal Maritime Provinces-New England region was not an integral part of North America until the late Carboniferous. However, the large angular deviation in longitude between the A and C poles during this relatively small time interval highly suggests an apparent rapid polar wander with respect to the Avalon microcontinent in the Silurian Period.

DISCUSSION AND CONCLUSION

The hypothesis of a Japan-type island-arc and consequently a system in compression during most of the time interval of this geological event implies a rather short-lived phenomenon which should be characterized by a single magnetic signature, this is not the case. The hypothesis of an intracratonic rift zone would imply that the Avalonian microcontinent was still in distention during the Silurian Period. This hypothesis is plausible and then the A component of magnetization would correspond to the period of intrusion of the HA and HB dikes (thermoremanent component) while the C component would be an overprint. One of the reviewers (P. Lapointe, written communication 1982) suggested that the C component overprint is possibly related to the St. Lawrence granite in the southern Avalon Peninsula. In the Gander Zone of northeastern Newfoundland, Jayasinghe and Berger (1976) described basic dikes (diabases) which have similar petrographic and textural features to the dikes of this study. These dikes are truncated by the Newport granite which yielded a Rb-Sr isochron of 332 Ma (Bell *et al.* 1979), i.e. early Carboniferous. Thus a phase of extension was proposed in the Gander Zone at approximately the

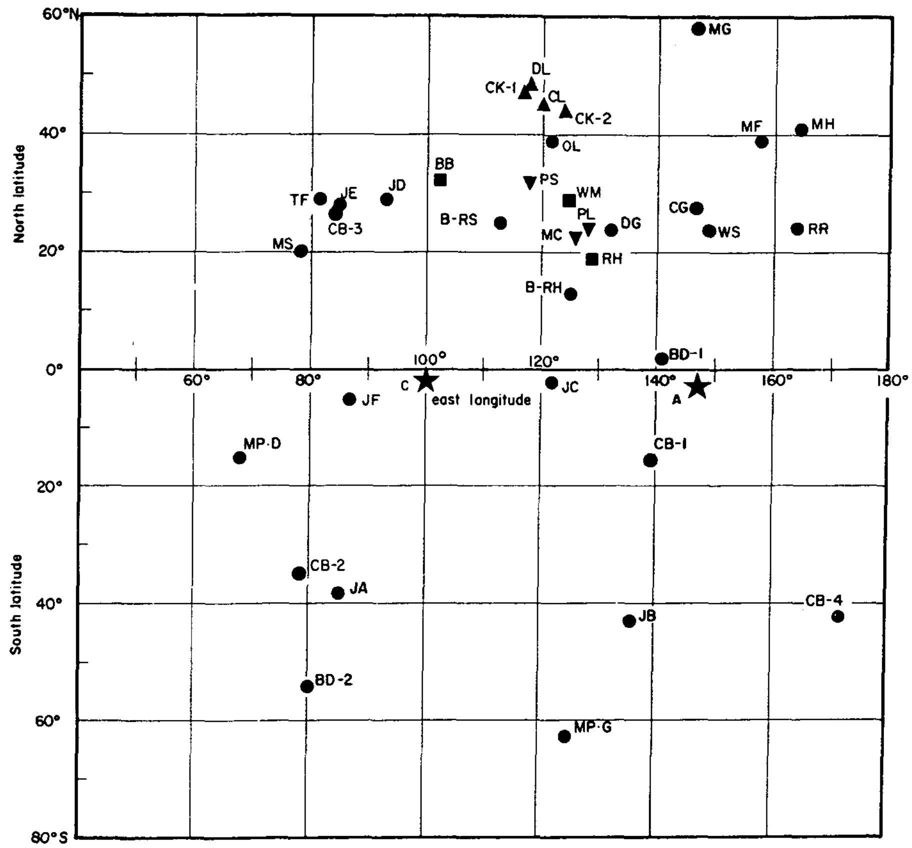

Fig. 10 - Poles obtained from paleomagnetic studies of Silurian and Devonian rock units from Appalachians. Pole symbols are as in Rao *et al.* 1981. The solid squares represent Silurian poles (BB, RH) obtained from interior North America. The solid upright (inverted) triangles represent, respectively, the paleopoles derived from north (south) of Kent and Opdyke's (1978) hypothesized shear zone. The solid circles represent the other Devonian or Siluro-Devonian poles. The stars represent the poles obtained in the present study (Table 2).

same time as ours in the Avalon Zone. More data are needed to prove or disprove this hypothesis. Such a geological situation has a younger equivalent as overprints have been interpreted to have occurred with the rifting and opening of the present Atlantic Ocean in Middle Jurassic time (Seguin *et al.* 1981). This would mean that the Avalon microcontinent was separated from the North American plate during the Silurian period (acquisition of A). As the late Precambrian rocks were deformed during the middle to late Devonian (acquisition of C) Acadian Orogeny (Williams and King 1979) and intruded by Early Carboniferous continental granites, it is clear that the Avalon microcontinent (AVM) was docking on the North American plate by middle Devonian time. It is thus plausible that the AVM was in compression from Middle Devonian to Middle Jurassic time but in extension before that age span.

One proposed scenario of evolution of AVM is the following:

1) formation of an intracontinental basin or continental margin (Poole 1976), 2) long-lived Hadrynian continental extension (King 1979), 3) local rupture(s) and sea floor spreading by very late Precambrian to early Cambrian (Williams 1979), 4) possible occurrence of several

Table 3

VECTOR SUBTRACTION

Specimen No.	T range (°C)	AF strength range (mT)	D (°)	I (°)	J_{r-n} x10 (Am^{-1})	ΔD (°)	ΔI (°)	ΔJ_{r-n} x10 (Am^{-1})
HA5-2.A	200		60	68	5.07			
						37.1	53.1	1.80
	300		85	73	3.41			
						2.5	56.3	1.01
	400		116	66	2.65			
						295.4	15.9	0.71
	450		117	80	2.26			
HA4-3.A	200		23	80	0.56			
						326.1	37.4	0.18
	300		103	75	0.46			
						356.9	57.7	0.22
	400		140	54	0.32			
						271.1	26.0	0.08
	450		161	56	0.27			
HA4-2.A	100		34	77	0.68			
						20.8	59.6	0.23
	200		66	84	0.47			
						279.8	61.0	0.33
	300		92	41	0.27			
						41.4	-7.3	0.12
	400		133	51	0.25			
HB17-2.B	100		31	82	1.12			
						314.0	69.3	0.46
	200		351	70	0.72			
						355.9	38.6	0.17
	300		344	79	0.59			
						45.2	35.3	0.27
	400		255	65	0.47			

Specimen No.	T range (°C)	AF strength range (mT)	D (°)	I (°)	J_{r-n} x10 (Am^{-1})	ΔD (°)	ΔI (°)	ΔJ_{r-n} x10 (Am^{-1})
HA4-3.B		10	38	61	0.87			
						27.1	48.7	0.23
		15	44	65	0.65			
						19.0	63.7	0.23
		20	57	64	0.43			
						18.6	61.9	0.16
		25	78	61	0.28			
						56.8	58.3	0.09
		30	89	61	0.19			
HB18-2.C		0	50	50	7.13			
						284.9	72.5	4.70
		5	33	14	4.04			
						34.5	-4.4	1.57
		10	32	25	2.61			
HB18-4.B	200		51	62	5.96			
						36.1	63.2	1.82
	300		57	61	4.16			
						7.7	-13.4	1.67
	400		109	69	4.34			
HA1-1.A		5	337	76	0.89			
						303.0	59.2	0.34
		10	30	79	0.58			
						338.9	61.7	0.14
		15	68	79	0.45			
						15.5	66.3	0.09
		20	92	78	0.37			

ΔD = Declination of magnetic vector removed, ΔI = Inclination of magnetic vector removed, ΔJ = Intensity of magnetic vector removed.

separated microcontinents by Cambro-Ordovician time, 5) ongoing extension on detaching miniplates during the lower Paleozoic time up to the middle Devonian.

Our data set pertains to item 5. The previous phases of the scenario may be modified. Williams (1979), amongst others, maintain that the main collision between the North American and the Avalonian continents occurred in the Ordovician. Taking the existing facts into account, the events of the Cambrian to Devonian interval are complex when the geological evidence from Newfoundland to the west of the Avalon Zone is taken into consideration.

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