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PALEOMAGNETISM OF THE SAINTE-CECILE AND SAINT-SEBASTIEN GRANITIC INTRUSIVE

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RESUMEN

Se presentan resultados paleomagnéticos de muestras de un intrusivo ácido de edad Devónica Media-Tardía, localizado en el sur de Quebec, Canadá. Las direcciones de magnetismo remanente determinadas son diferentes de las direcciones correspondientes a la plataforma estable de Norte América o a la zona de Avalón. Las direcciones medias obtenidas de 31 sitios colectados en tres tipos diferentes de granitos son: 045°, −14°, α_{95} = 11° y 102°, 48°. Las posiciones polares correspondientes son: 164°E, 31°N (016°W, 31°S) y 170°E, 13°S (010°W, 13°N). Al parecer el cuerpo intrusivo no fue afectado por la Orogenia 'Acadian' del Devónico Medio ni por rotación local. Evidencias geológicas indican que intrusiones graníticas como las de Ste. Cécile y St. Sébastien representan la última fase de la Orogenia 'Acadian'. Considerando la cantidad de datos disponibles, se estima aún prematuro establecer una subdivisión entre los polos correspondientes a la zona de Avalón (micro-continente) y los del Cinturón móvil central, durante el Devónico Medio al Tardío. Se sugiere la ocurrencia de un movimiento polar aparente durante este período. Dicho movimiento se infiere de los resultados de direcciones de desmagnetización para las diferentes fases de intrusión, que representan un período relativamente corto; dichas direcciones muestran importantes discrepancias. Se considera prematuro dar una conclusión sobre la posible presencia de una zona de esfuerzo tangencial paralela a alguna de las zonas tectono-estratigráficas.

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ABSTRACT

A middle to Upper Devonian acidic intrusive from southern Quebec yields paleomagnetic directions unlike those determined for the stable North American platform or the Avalon Zone. Thirty one (31) sites from the three different types of granites give mean residual magnetizations of 045°, −14°, α_{95} = 11° and 102°, 48°. The corresponding paleopole positions are 164°E, 31°N (antipole: 016°W, 31°S) and 170°E, 13°S (antipole: 010°W, 13°N). This granite appears to be unaffected by the mid-Devonian Acadian orogeny and by local rotation. Geological evidences indicate that granitic intrusions like the one of Ste-Cécile and St-Sébastien represent the very last phase of the Acadian orogeny. Considering the quantity of data available, it is still premature to make clear subdivision between the poles corresponding to the Avalon microcontinent and the ones from the central Mobile Belt at Middle to Late Devonian times. Because an important disparity of the cleaned NRM orientations is observed for different phases of intrusion which occurred in a relatively short span of time, a rapid APW is presumed to have taken place during this time interval. No definite statement can be made on the possibility of the presence of a shear zone parallel to some of the tectonostratigraphic zones.

GEOLOGY

The area investigated is located in the southern sector of the Quebec Appalachians (long: 71°W, lat: 45°40'N). The rocks of this area are made up of a folded sedimentary sequence which has been intruded by a granitic stock and associated dikes and sills of felsic rocks and molybdenum mineralization. The sedimentary rocks are only slightly metamorphosed (sub-greenschist facies) except near the granitic intrusion where they are altered to hornfels. The sedimentary sequences are correlable with the ones mapped by Béland (1951), Gorman (1954, 1955), and MacKay (1923) to the north and northwest and by Marleau (1957, 1958) and McGerrigle (1955). These metasediments are assigned to the Early or Middle Devonian. The region investigated was mapped in part by Lord (1938) and later completely by Kelly (1975).

The granitic stock has an areal extent of about 35 km^2. The flank of the intrusion under the cover of the sedimentary rocks appear to dip steeply at the northeast and southwest extremities where the slope is more gentle. The chilled margin is narrow and does not exceed 10 cm in many places. The granitic body is elongated in the NNE direction, has an elliptical shape in plan view and subvertical walls. The stock contains numerous aplite dikes but few pegmatite dikes.

The granite which is constituted mainly of quartz potash feldspars and albite has been subdivided into three easily recognizable types in the field by Kelly (1975): medium-grained, fine-grained and aplitic. The colour of the medium-grained granite is usually grey. The fine-grained granite occurs as islets dispersed here and there in the central part of the stock. Over short distances, heavy concentrations of biotite impart a foliated structure. Aplitic granite occurs mainly in the northeast and southwest extremities of the stock. It is pink on the weathered surface and grey on the fresh surface. Many dikes and sills of felsic rocks (quartz porphyry and occasionally granite and aplite) are found in the sedimentary rocks around the granitic stock. These intrusions are rarely greater than 5 m thick and occur in the cleavage planes of the less competent beds. The dikes are generally short.

AGE OF THE GRANITE

The Sainte-Cécile and Saint-Sébastien granitic intrusive is one of a series of stocks encountered in the central sector of the Appalachian domain. The Aylmer and Winslow intrusives are located to the west, the Scotstown to the southwest, the Spider Lake to the south and the Hereford, Stanhope and Stanstead to the southwest. The age of these nearby granites varies from Middle to Late Devonian. According to a potassium-Argon data (Lowdon, 1960), the granite is 362 million years old, that is Late Devonian.

The composition and texture of the Sainte-Cécile and Saint-Sébastien granite is somewhat different from the other nearby acidic intrusions. Its composition and texture are more variable in space and its potash content higher. Besides, molybdenite is associated with quartzofeldspathic veins which cut the sedimentary rocks and this is not the case for the nearby granites.

There is no geological evidence of post intrusion tectonics (rotation) in the granite investigated here and in the nearby granites either (Kelly, 1975).

SAMPLING PROCEDURE

Some 118 oriented samples (342 specimens) were collected on 33 different sites; the orientation was done with a Brunton compass. The number of samples per site varied between 2 and 5 and the number of specimens per sample between 2 and 6. Seven (7) sites were located on aplitic granite, 11 on fine-grained biotite granite, 14 on medium-grained biotite granite and finally 1 on a felsic dike. The samples were cored on the field with a portable diamond drill. The sample locations were chosen by reference to a detailed geological map published by Kelly (1975) at a scale of 1:12,000 (figure 1). Efforts were made to select sites where there was an adequate exposure and great care was taken to avoid altered material.

EQUIPMENT USED

The direction and intensity of remanent magnetization were measured with a digital spinner magnetometer (model DSM-1) manufactured by Schonstedt Inst. Co. Alter-

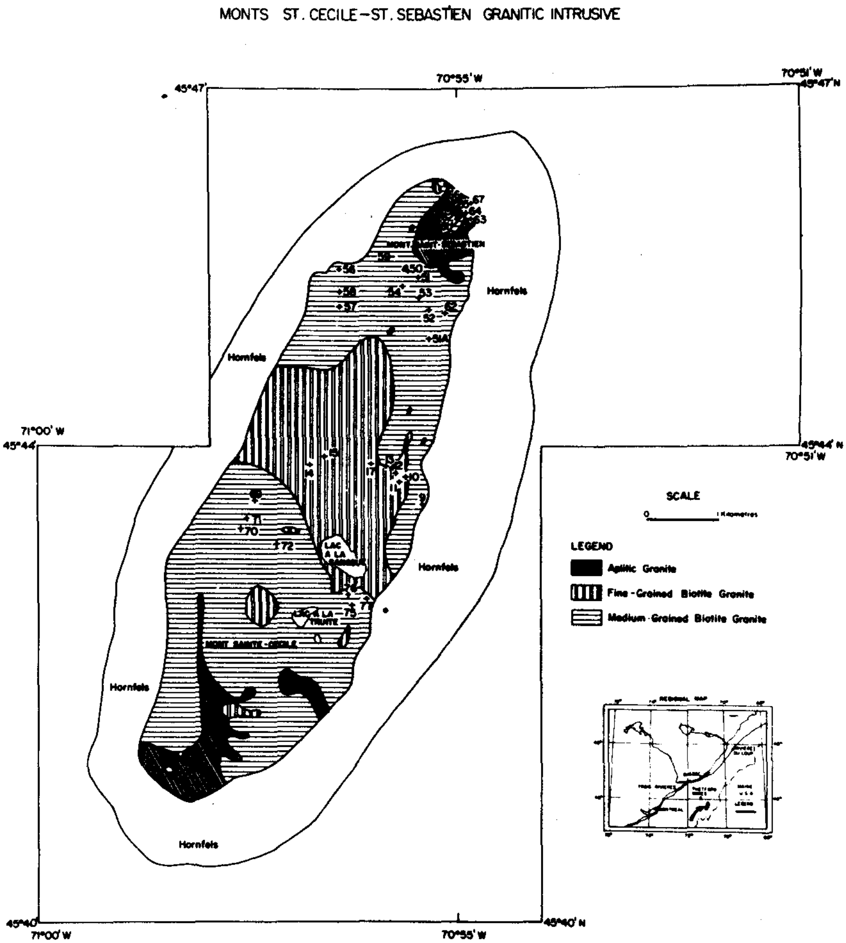

Fig. 1 Location and geologic map of the Sainte-Cécile and Saint-Sébastien granitic intrusive.

nating field (AF) demagnetization was carried out using a demagnetizer built at University Laval (maximum intensity of 75 mTesla) the performance of which was largely improved by adding 3 large, concentric mu-metal cylinders around the solenoïd (Seguin, 1975). Thermal treatments of the specimens were done in a field-free specimen demagnetizer (model TSD-1) manufactured by Schonstedt Inc. Co. The amount of residual ambient field present is 5 to 18 nT in the AF and thermal demagnetizer respectively.

REMANENT MAGNETISM OF THE GRANITES

The NRM intensities range from 2×10^{-3} to 7×10^{-1} Am^{-1} (2×10^{-6} - 7×10^{-7} emu cm^{-3}). The low intensity values are most frequently found in the aplitic granite (range = 2×10^{-3} – 10^{-1} Am^{-1}) and the highest intensity values in medium-grained granite (range: 10^{-2} – 5×10^{-1} Am^{-1}). The intensity is very low in the felsic dikes (2 - 6×10^{-3} Am^{-1}) and intermediate in the fine-grained granite (range: 2×10^{-3} - 10^{-1} Am^{-1}). The NRM orientation (mean values: 351, −66) is very different from the actual declination and inclination of the Earth's field; this means that a large fraction of the remanence is of ancient origin. The NRM site mean directions are characterized by statistical parameters of the following order: α_{95}: 22°, K = 7. The mean NRM orientation for all the sites is scattered as indicated by the values of $\alpha_{95} = 19°$ and K = 11.

THERMAL AND AF DEMAGNETIZATION

Specimens were thermally demagnetized at 100, 200, 300, 400, 450, 500, 550, 600 and sometimes 650°C. About 32% of the samples yielded a stable remanent component in the process of thermal demagnetization. Two distinct components (one NNE and shallow, another ESE and intermediate to steep) could be isolated on the whole of the sites of this study. The magnetization directions and intensities of pilot samples representative of each component are presented in figure 2. Pilot tests show that the temperature at which the residual component is most thoroughly isolated is variable and generally located in the 450-500°C range. The variations in the magnetic vector orientations are occasionally accompanied by increases in intensity indicating the presence of two components (one NNE and one ESE) in different specimens of the same sample. In some specimens, the intensities increase slightly (15 to 20%) in the 400-450°C range and then decrease substantially (40 to 50%) in the 450-500 or 550°C range. Thereafter, the intensities increase again in (sometimes up to 15%). This last increase is apparently caused by chemical changes such as oxidation and/or noise since the intensities are frequently low (1 to 3×10^{-3} Am^{-1}) in the 550-650°C range. No polarity inversions were observed in the heating process. Sample 75A which represents the

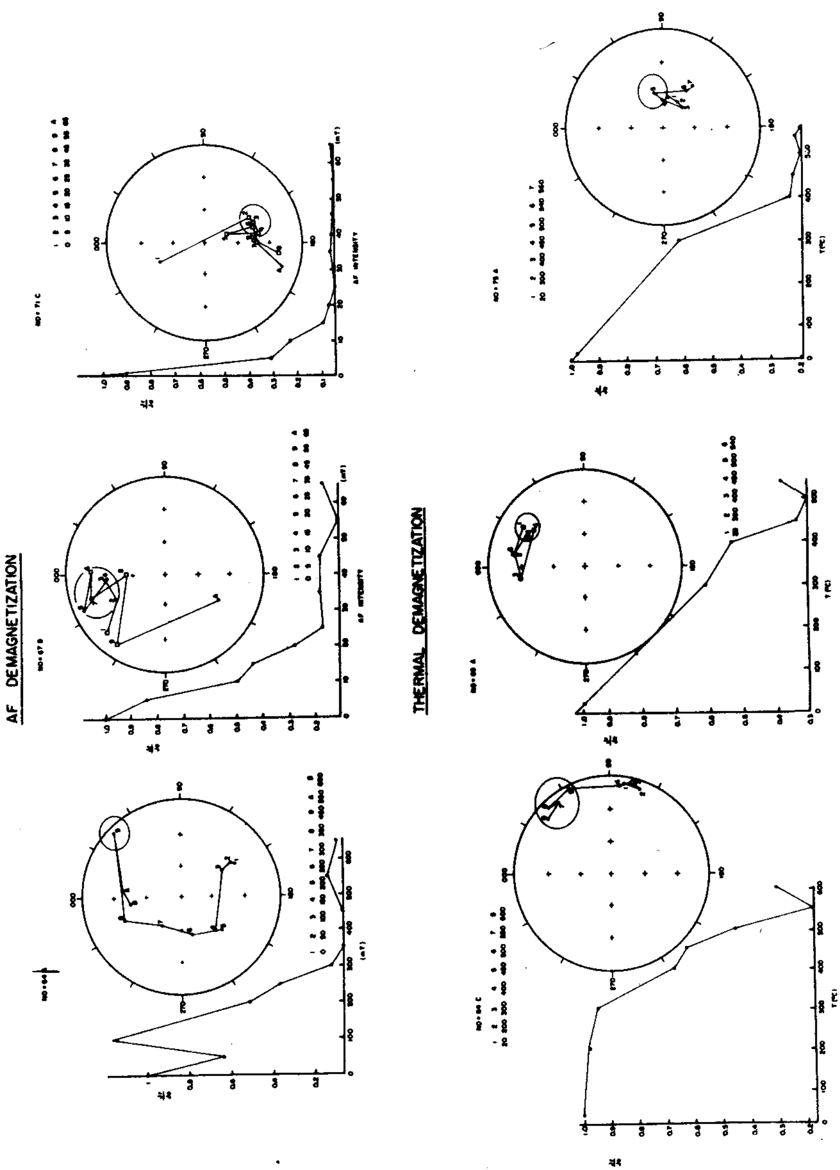

Fig. 2 Variation of the residual magnetization directions and intensities of typical pilot samples of the geological formations investigated as a function of temperature and increasing demagnetizing AF strength.

average of 3 pilot specimen studies is characteristic of the ESE component obtained by thermal demagnetization and sample 64C of the NE component.

A minimum of 2 specimens (usually 3 to 5 per site) on 22 sites were usually demagnetized in steps of 5 mTesla in a shielded area (5-10 nTesla). Guided by the stepwise change in orientation and intensity of remanence and occasionally the trend of Zijderveld plots, the remaining specimens from a site were AF demagnetized at optimum fields. The components were successively isolated after remeasuring the residual remanences. Two components (one NNW and another NNE) were isolated using the AF technique. Occasionally, the two components were detected on the same site. Figure 2 shows typical examples of the behaviour of the granites in the course of AF demagnetization. Sample 64A which is the average of 3 pilot specimen tests is typical of the NNE component isolated at high field. The AF demagnetized results of sample 64A can be compared with the thermally demagnetized results of sample 64C (figure 2). Occasionally, both low AF (15-30 mT) and high AF (45-60 mT) components were encountered in the granites. Generally, the mean destructive field is of the order of 10 to 20 mT suggesting that the largest fraction of the memory is carried by magnetite.

For the aplites, the declination of both low and high AF residual components are scattered and their inclinations small. The relatively weak initial intensities and the large degree of instability of the remanence explain this situation.

MAGNETIC MINERALOGY OF GRANITES

Some 20 polished sections were observed with a Reichert reflecting microscope; the magnification varied from 150 to 700. The microscopic studies indicated that the reflecting and opaque minerals are rutile, magnetite, ilmenite and hematite. Magnetite is present in large rounded grains clustering around rutile and occasionally ilmenite. Ilmenite occurs as euhedral medium to coarse grains and contain some rare exsolutions of hematite as thin parallel rods. No hemoilmenite was observed. The most important volume of opaque minerals is made up of magnetite. The demagnetization results indicate that magnetite is the only magnetic memory carrying more than one component.

DISCUSSION OF THE RESULTS

The directions of the residual components obtained are grouped according to the three (3) types of granites using both AF and thermally demagnetized data (see Table 1). A mean direction was then calculated for the AF demagnetized results (unit weight to samples). The mean directions are $D = 39.5^{o}$, $I = 22.6^{o}$, $\alpha_{95} =$

30.4°, K = 18 and D = 329.5°, I = 23.1°, α_{95} = 27.2°, K = 22 respectively for the AF demagnetized components and D = 44.9°, I = 14.2°, α_{95} = 11.3°, K = 15 and D = 102.1°, I = 47.7°, α_{95} = 9.3°, K = 43 for the thermally cleaned components respectively. The residual remanence directions are significantly different in the case of the AF and thermally cleaned results (figure 3). However, in many samples investigated, the NNE component of the AF and thermally cleaned data is often similar. When all the sites are considered, the mean inclination of the thermally cleaned component is negative whereas the one of the AF cleaned component is positive (see figure 3). The other AF and thermally cleaned components are definitely different. The NNW component obtained by AF demagnetization is seldom found by thermal cleaning and vice versa the intermediate to steep ESE component obtained by thermal cleaning is rarely observed in the AF demagnetized results.

Table 1

Residual remanence directions after cleaning for the different types of granites

Site	AF cleaning						Thermal cleaning					
No.	D_1	I_1	D_2	I_2	α_{95}	K	D_1	I_1	D_2	I_2	α_{95}	K
			A) Aplitic granite (Younger?)									
61	035	07					032	−08				
62	044	−02					044	−02				
63			352	12(?)								
64	064	07	(stable)				064	06	091	34		
65			309	11			028	−18				
66			337	30								
67			327	03								
	48,	04			24	27						
			331	15	24	15						
			B) Fine-grained biotite granite (Intermediate age?)									
10			310	17								
11			322	04								
12			288	19			064	−06	098	56		
14			347	16					104	47		
15			322	03								
17	056	22					057	07				
69	046	48(?)					045	−33	094	61		
	033	02(R)										
71			252	13 (∓ stable)			041	−28				
76			316	30(?)			031	−04				
	45,	31			29	19						
			318	16	18	15						

Table 1 (Continued)

C) Coarse-grained biotite granite (Older?)

1	025	33							105	46 (R)		
9	036	36										
13			286	05(?)								
50			351	13			055	−37				
51			346	34(?)			028	−26				
52	034	51										
53			328	28								
54	003	01(R)					057	06	094	46		
56	017	23										
57	045	39										
58			348	47								
59	011	23										
70			351	47								
			334	42(R)								
72			327	43			035	−40				
			344	30(R)								
75	043	28(R)							126	40		
	24	32			13	17	45	−14			11	15
			342	39	09	31			102	48	9	43
Average:	39	23	330	23								

(R)* = reverse polarity

Considering the large α_{95} solid angles of the AF components, it is concluded that: 1) the NNW component is a secondary component which was only partially isolated and 2) that the AF cleaning technique is not as efficient as thermal cleaning to isolate the primary remanence component of the granites. Consequently, the two thermally cleaned components are retained. The NNE shallow component is much more frequent and is interpreted as the primary component. The less common steep ESE component is probably secondary.

The significance and stability of magnetization of the Sainte-Cécile and Saint-Sébastien is demonstrated by the departure of the residual remanence from the present Earth's field direction (341°, 75°) and the concordant results obtained after AF and thermal treatment.

SAINTE-CECILE, SAINT-SEBASTIEN GRANITIC INTRUSIVE

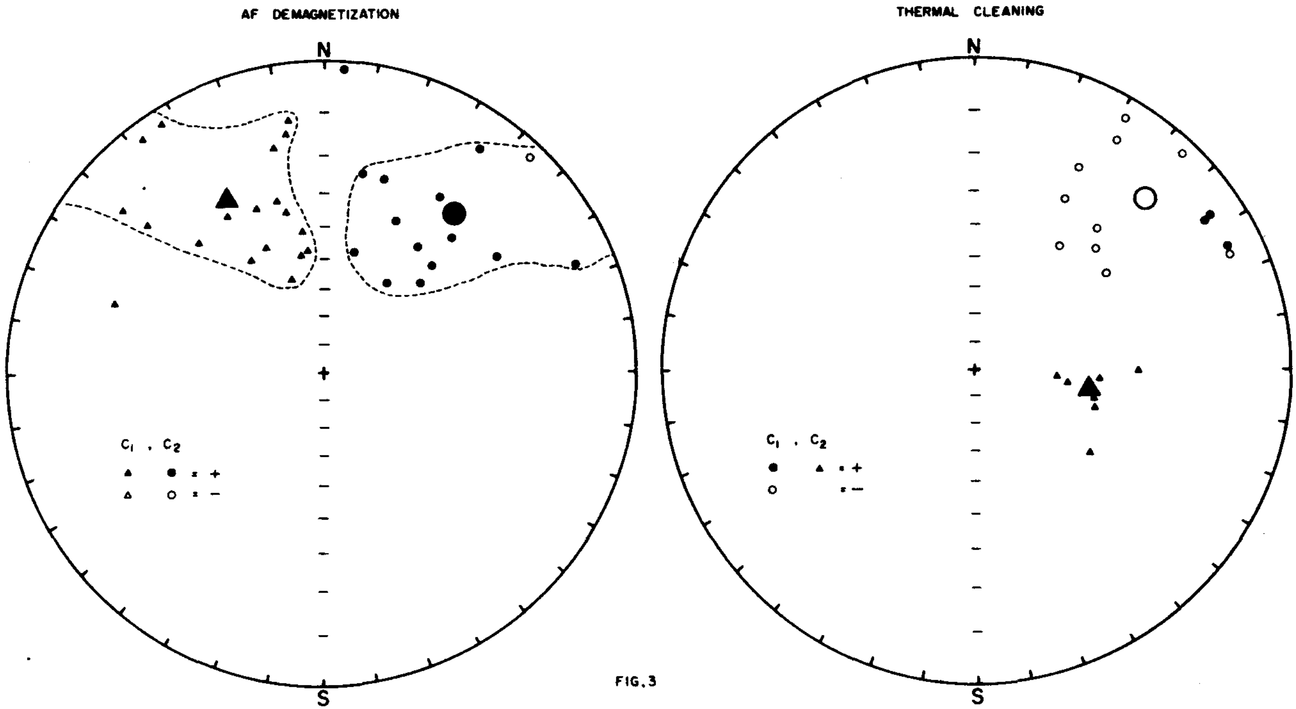

Fig. 3 Site mean directions of residual remanence after AF and thermal treatment. C1 and C2 represent the components isolated by both treatments.

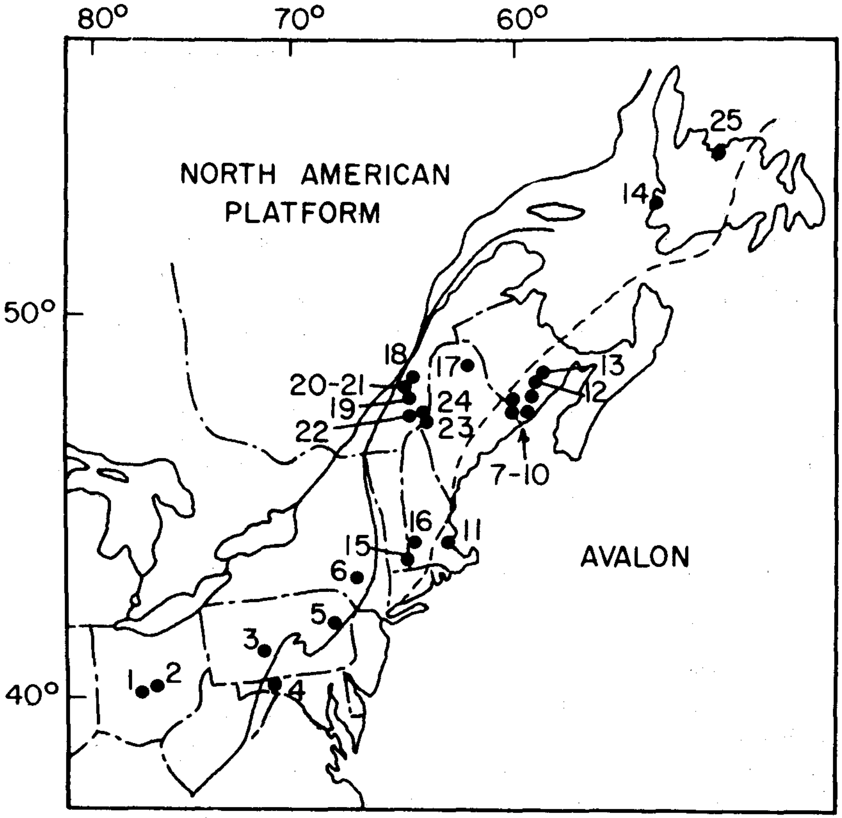

Fig. 4 Location of sampling sites for paleomagnetic studies on Devonian rocks of eastern North America. Numbers refer to data in Table 2. Solid line is the western margin of the Appalachian orogen, dashed line is the western limit of Avalon microcontinent. (Modified after Brown, 1979).

PALEOPOLES AND GEOLOGICAL SIGNIFICANCE OF THESE RESULTS

The paleopole position corresponding to the thermally cleaned predominant component ($D = 045°$, $I = -14°$) is 164°E, 31°N (antipole: 016°W, 31°S). The other pole position which corresponds to the less frequent thermally cleaned component ($D = 102°$, $I = 48°$) is 170°E, 13°S (antipole: 010°W, 13°N). Compared to all the other paleopoles obtained from Devonian granites in Quebec located north of the Ste-Cécile and Saint-Sébastien intrusive (Seguin 1979a, b, c, 1980b), the paleopoles obtained from this study are anomalous (Table 2, figure 5).

Table 2.
Devonian Paleomagnetic Poles, Eastern North America

	Location		Age	Pole E (°)	Pole N (°)	Reference
	North American Platform					
1	Columbus lm,	Oh	Dm	120	25	Martin, 1975
2	Delaware lm,	Oh	Dm	118	48	Martin, 1975
3	Catskill fm,	Pa	Du	130	43	Phillips, 1966
4	Catskill fm,	Pa	Du	123	41	Liebes and McDonald, 1977
5	Catskill fm,	Ny	Du	117	47	Kent and Opdyke, 1978
6	Catskill fm,	Pa	Du	124	44	Van der Voo *et al.*, 1979
	Avalon Microcontinent					
7	Perry lavas,	NB	Du	109	26	Black, 1964
8	Perry seds,	NB	Du	121	35	Black, 1964
9	Perry lavas,	Me	Du	128	24	Phillips and Heroy, 1966
10	Perry seds,	NB	Du	118	32	Robertson *et al.*, 1968
11	Mafic Complex,	Ma	370	126	23	Schutts *et al.*, 1976
12	St George Pluton,	NB	387	085	38 S	Roy *et al.*, 1979
				093	29	" " " "
13	St. Stephen Pluton	NB	382	136	43 S	Roy *et al.*, 1979
	Intermediate locations					
14	Clam Bank Gp,	Nfld	De	146	28	Black, 1964
15	Belcherton Int.	Ma	380	147	48	Ashwal and Hargraves, 1977
16	Hartwick Diorite,	Ma	400	084	36	Brown and Kelly, 1977
17	Dockendorff Cp	Me	406	132	24	Brown, 1979
18	Mt. Aylmer,	Qc	Dm-u	118	57	Seguin, 1979b
19	Scotstown,	Qc	Dm-u	131	39	Seguin, 1979a
20	Winslow Granite,	Qc	Dm-u	133	56	Seguin, 1979c
21	Winslow Hornfels,	Qc	Dm-u	131	59	Seguin, 1979c
22	Mégantic,	Qc	Dm-u	122	17(?)	Seguin, 1980a
23	Spider Lake,	Qc-Me	Dm-u	138	37	Seguin, 1980b
24	Ste-Cécile & St-Sébastien	Qc	362	164	31	This Study
				170	13S	
25	Mount Peyton,	Nfld	420	068	15S	Lapointe, 1979
			380	125	63S	Lapointe, 1979

North American Platform:	Average, N = 6	122°E,	44°N
Avalon Microcontinent:	Average, N = 8	117°E,	15°N
Intermediate locations:	Average, N = 13	123°E,	27°N

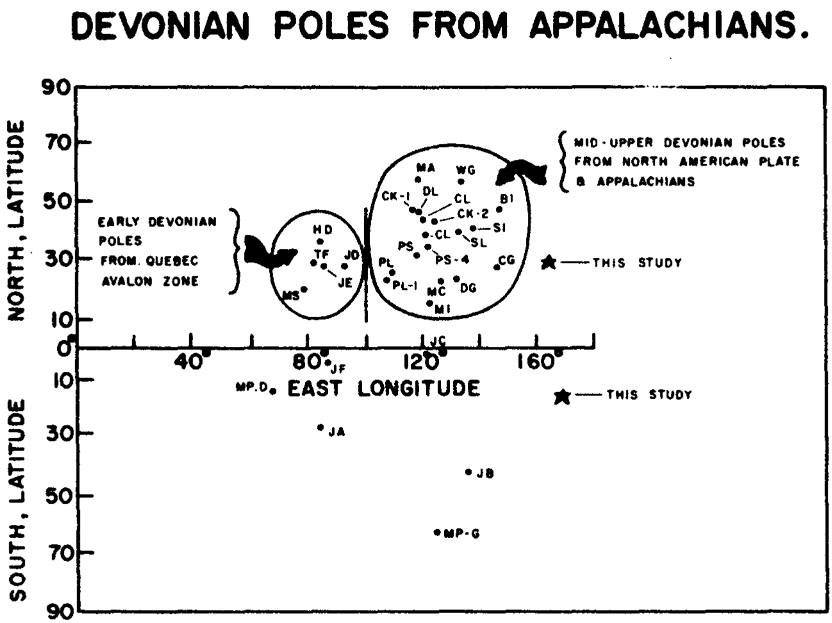

FIGURE 5

Fig. 5 Positioning of all Devonian paleopoles obtained from the Appalachians to date. The new results presented in this study are shown as stars.

In view of the uncertainty of the paleomagnetic results on Devonian rocks (Table 2 and figure 4) of eastern North America (Kent and Opdyke, 1978; Roy *et al.*, 1979; Lapointe, 1979), it is premature to make any final statement on the subject because of the possibility of the presence of a shear zone parallel to some of the tectonostratigraphic zones as proposed, for example, by Williams (1979). It is noted on figure 5 that the Early Devonian poles from the Quebec Appalachians and the Avalon zone (Newfoundland and New England) are located in the 85°E of longitude and 30°N of latitude. The Mid to Late Devonian North American continental poles are all clustered around 120°E, 45°N. Poles of about the same age from the Appalachians are scattered around this cluster of poles; their position varies from 100 to 145°E of longitude and 15° to 55°N of latitude. The paleopoles obtained in this study are located much further to the east. They suggest either a rapid polar wandering at Late Devonian time or the occurrence of an important shear zone between all the other granitic intrusions of the Quebec Appalachians located further northwest.

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