The Bécancour—Yamaska Area, Québec: A Paleomagnetic Study

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We report paleomagnetic results from 45 oriented samples collected at 8 sites from the fossiliferous marine Pontgravé Formation (3 sites) and continental Bécancour Formation (5 sites) of the gently dipping Late Ordovician Richmond Group sediments in the St. Lawrence Lowlands of Quebec. Stepwise thermal and alternating field demagnetization studies revealed the presence of two groups of coherent magnetization (components: A and B) before and after tilt correction. The group A magnetization is characterized by a stable direction ($D=175^\circ$, $I=-22^\circ$, $\alpha_{95}=8.2^\circ$) with unblocking temperatures (T_{UB}) between 500° and 630°C and coercivities (H_C) generally larger than 100 mT; this direction is a secondary chemical remanence probably acquired during the uplift related to the Acadian orogeny (Middle to Late Devonian). Component B ($D=184^\circ$, $I=20^\circ$, $\alpha_{95}=9.1^\circ$) is characterized by H_C spectra of 10 to 30 mT and T_{UB} s in the range: $300\text{--}540^\circ\text{C}$. This component is interpreted as the oldest and it is possibly primary. The paleopoles of components A and B are 116°E , 55°N ($d_p=59^\circ$, $d_m=10.8^\circ$) and 105°E , 33°N ($d_p=5^\circ$, $d_m=9.5^\circ$), respectively. This last pole position could characterize the Late Ordovician depositional event. A comparison of this pole with paleomagnetic data of the same age from cratonic North America suggests a small apparent polar motion from Early to Late Ordovician. Pole of the same age obtained from the northern Appalachians are significantly different. A 50° clockwise rotation of the mountain chain is a possible solution to the problem if component B is not an overprint. However, deformation of the Appalachians characterized by a mosaic of small blocks or else magnetic overprinting still remain the two better alternatives.

1. Introduction

It is clear from recent literature on Ordovician paleomagnetic results from North America (SEGUIN *et al.*, 1981; VAN DER VOO, 1981; DANKERS, 1982) that the data set is not only too limited in number to make Paleozoic continental restorations but also suffers from several ambiguities related to: (1) geologic age,

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(2) type and extent of tectonic movements of the rock units studied, (3) likely possibility of events such as Late Paleozoic remagnetization, and (4) breakdown in the dipole nature of the geomagnetic field during Ordovician times. These factors (1 to 4) impose problems in the determination of the time of acquisition of different magnetic components.

The present paleomagnetic study is from the Upper Ordovician Richmond Group sediments located in the St. Lawrence Lowlands of Quebec. The tectonically undisturbed and temporally uninterrupted Upper Ordovician platform succession of the St. Lawrence Lowlands provides an ideal laboratory in which to collect samples to measure sections and to develop and test various geologic concepts and models. The objective of the study are three-fold: (1) to obtain a new Ordovician result from the northern part of the craton, (2) to compare this result with those obtained from other contemporaneous sediments of the North American platform, (3) to obtain and define more accurately the apparent polar wander path (APWP) of North America in early Paleozoic time.

2. Geological Setting

The first geological studies of this area were carried out by LOGAN (1849, 1863) and FOERSTE (1916, 1924). Additional geological information came from the studies of PARKS (1930, 1931), CLARK (1944, 1947, 1951, 1964, 1974), BELYEA (1952), DEAN (1958), DEAN and WEBBER (1961), and the MINISTÈRE DE L'ÉNERGIE ET DES RESSOURCES DU QUÉBEC (1947a, b). The latest publications are by CLARK and GLOBENSKY (1976) and HARLAND and PICKERILL (1982).

The sedimentary rocks of the area belong to the Ordovician System of the St. Lawrence Lowlands. The exposed rocks belong to the Lorraine and Richmond Groups. The main structure of the Bécancour-Yamaska area is an open syncline (Chambly-Fortierville) striking northeast-southwest and bounded on its southeastern side by a thrust zone (Logan's line) with folded and faulted Appalachian rocks to the south (Fig. 1). The synclinal structure plunges gently to the southwest and the dips on the flank of the syncline are small.

The Richmond Group is composed of two formations: Pontgravé and Bécancour. The Pontgravé Formation has a marine origin and the Pontgravé a continental origin.

The Pontgravé Formation is composed of silty limestone interbedded with shale, sandstone and thin beds of fossiliferous limestone; it is the equivalent of the Upper Ordovician Waynesville Formation in New York State. The Bécancour Formation is the highest formation exposed in the Chambly-Fortierville syncline. It consists mainly of red silty shales and sandstones, minor amounts of green and grey shales and sandstones, and thin veins of gypsum. This formation is the equivalent of the Upper Ordovician Queenston Formation in the Niagara Peninsula of southern Ontario and of New York State. On the Nicolet and Bécancour rivers, there is a nearly continuous section of 900 m of Ordovician beds. According to CLARK (1964), such sections, unparalleled elsewhere in Quebec,

Fig. 1. Simplified geological map of a sector of the St. Lawrence Lowlands from the province of Québec centered on the Bécancour—Yamaska region showing locations of the eight sampling sites.

give the only sure key to the stratigraphic succession within the Lorraine and Richmond Formations. The age of the formations is known with certainty; it is Upper Ordovician (CLARK, 1974; HARLAND and PICKERILL, 1982).

3. Sampling Procedure and Measurements

In the present paleomagnetic study, 40 oriented block samples from the Pontgrivé and Bécancour Formations were collected at 8 sites on unaltered outcrops where the stratigraphic relations and the structures are well known. Site 1 is located on the bank of Gentilly river, sites 2, 3 and 4 on the banks of Bécancour river, site 5 on the bank of Orignaux river, sites 6 and 7 on the banks of Chêne river and site 10 on the bank of Nicolet river. Five sites (2, 3, 4, 7 and 10) are within the Bécancour Formation and the three others (1, 5 and 6) within the Pontgrivé Formation (Fig. 1). Magnetization was measured with a digital spinner magnetometer (DSM-1). Two methods of demagnetization were carried out using (1) an AF demagnetizer with three-axis tumbler operating in residual fields of about 5 nT (SEGUIN, 1975) and (2) a field-free electrical oven (SEGUIN, 1973/74) and a Schonstedt thermal demagnetizer (STD-1) with residual fields less than 15 nT. Stepwise alternating field (AF) and thermal procedures were used up to 100 mT and 660°C, respectively. Natural remanent magnetization (NRM) of each oriented core sample was obtained from the mean of at least two specimens (diameter 2.5 cm, height 2.2 cm). Single measurements of NRM were usually repeated to within 4% in intensity (J) and within 3° in direction (declination D , inclination I).

4. NRM Intensities and Directions

Individual specimen NRM directions, although characterized by wide scatter as a result of positively inclined shallow and positively inclined steep and shallow remanences have a pronounced deviation (SSE, shallow negative inclination; $D=156^\circ$, $I=-23^\circ$, $\alpha_{95}=28^\circ$, $K=5$) away from the present Earth's field (PEF) ($D=343^\circ$, $I=75^\circ$) at the site localities. This significant deviation from the PEF indicates some ancient remanence. The wide scatter in NRM with dual polarity of remanences in 4 sites is therefore indicative of the presence of both low and high coercivity components. NRM site mean directions are shown in Fig. 2. The NRM intensity (J_n) varies between 2×10^{-4} and $8 \times 10^{-3} \text{ Am}^{-1}$.

5. AF Demagnetization

For the preliminary AF demagnetization study, at least five but usually six to fourteen sedimentary specimens from each of the eight sites were demagnetized in 7 to 12 steps by intervals of 5 milliTesla (mT) up to 25 mT and intervals of 10 mT to 80 mT (sometimes 100 mT). For 60% of the samples of sedimentary units, the intensities of magnetization fall off to less than 10% of the original

Fig. 2. Natural remanent magnetization (NRM) for the Pontgravé and Bécancour Formation of the Richmond Group directions plotted on Wulff net. Solid (open) circles represent projections on lower (upper) hemisphere. The star represents the present Earth's field (PEF) at the sampling region.

NRM intensity in the interval 15–70 mT (average $\approx$ 30 mT). All the samples of sites R-1, R-5 and R-6 (Pontgravé Fm) have intensities of magnetization falling off to less than 10% of the original intensity in this interval while samples from sites R-4 and R-10 have no significant drop. Samples from sites R-2, R-3 and R-7 have a coercivity spectrum higher than 100 mT in 70% of the cases. This observation suggests that the majority of the magnetic memory in the grey shaly limestones of the Pontgravé Fm is found in magnetite while in the grey and red shales and sandstones of the Bécancour Formation it is preserved in hematite. As a good fraction of the specimens remained unchanged after AF demagnetization; they were used again for thermal cleaning.

Two components: one (A) oriented SSE with a shallow negative inclination and the other (B) oriented S with a shallow positive inclination were isolated through AF and thermal demagnetizations. Component A is found mainly on sites R-2, R-3, R-4 and R-10, that is exclusively in the Bécancour Formation. Component B is found mainly on sites R-1, R-5 and R-6, that is exclusively in the Pontgravé Formation. It is worth noting that site R-7 which contains both components in about the same proportion straddles the boundary of the two geological formations. Having established the relationship between the spatial distribution of the components and the geological environment, we shall proceed to the description and interpretation of the physical characteristics of these components of magnetization.

After AF demagnetization, component A is isolated on sites R-2, R-3, R-4

Table 1. Magnetic Characteristics of the A and B components.

Component No.	Site Nos:	Coercivity (mT)	Unblocking temperature (°C)	Magnetic minerals	Polarity
A	R-2, 3, 4, 7, 10	≥ 100	540–650	Hematite + little Magnetite	Normal
B	R-1, (2), 5, 6, 7	10–30	450–540	Magnetite	Mainly reverse

and R-10. On all these sites, the magnetization directions are very stable, depict a high coercivity (> 100 mT) characteristic of a hematitic carrier and the polarity is reverse (Table 1). Table 2 shows a summary of the important characteristics for the components of magnetization after AF and thermal treatments and Fig. 3A a typical example of the magnetic behaviour of specimens containing this component upon AF demagnetization. Component B is isolated on sites R-1, R-2, R-5, R-6 and R-7. It is the common component encountered on sites R-1, R-5, R-6 and R-7; it is not frequent on site R-2. This component is characterized by (1) a low coercivity ($H_C = 10\text{--}30$ mT) indicating that magnetite is the memory carrier, (2) a stable direction and (3) a reverse polarity (Table 1). A typical example of its magnetic behaviour during AF demagnetization is shown in Fig. 3B. Normal polarities were detected in only one sample of sites: R-1, R-2 and R-5. The normal polarities of sites R-1 and R-5 are antiparallel to the direction of component A while the direction of site R-2 is antiparallel to the one of component B (Table 3). Thus, a mixed A component is found on sites R-1 and R-5 and site R-2 is characterized by a mixed polarity B component.

6. Thermal Cleaning

Six to fifteen specimens for each of the eight sites of sedimentary units were thermally cleaned in a maximum of 12 steps up to 670°C by steps of 100°C up to 400°C and 50°C up to 660°C .

After thermal treatment, component A is isolated on all 8 sites investigated. Component A is the most important on all these sites except for R-5 and R-6 (Table 2). It is characterized by (1) a high unblocking temperature (T_{UB}) ranging from 540 to 650°C indicating that hematite is the most important memory carrier of this component and (2) a reverse polarity (see Table 1). T_{UB} s ranging from 540° to 650°C cannot be attributed to hematite only, the lower end T_{UB} could well be a magnetite component. Figure 4A shows a typical example of the behaviour of this component in the course of the thermal treatment. Component B (reverse polarity) is present as a principal component (Fig. 4B) on sites R-5 and R-6 and as a less common one on sites R-1, R-2, R-3, R-4, R-7 and R-10. This component is characterized by an intermediate T_{UB} ($450\text{--}540^\circ\text{C}$) suggesting that magnetite is its memory carrier (Table 1). Normal polarities were isolated

Fig. 3. Equal-area projections of directions of magnetizations (left) of two specimens after stepwise AF demagnetization. The numbers next to the circles represent the demagnetization steps in mT as indicated. The respective AF decay curves are shown on the right side. Fig. 3A) illustrates an example of the extraction of the A component and Fig. 3B) an example for the extraction of the B component.

Table 2. Site means for cleaned characteristic directions of magnetization.

Site	Strike	Dip	Treatments used		N	In-situ		α_{95}	Tilt-corrected				
			AF(mT)	T(°C)		D°	I°		K	D°	I°	K	
Component A													
R-1	047	13 SE	20-50	500-600	3	168	-16	42	8.3	171	-27		
R-2	065	06 SE	45-100	600	4	167	-29	15	34.1	177	-26		
R-3	061	02 NW	80	570-630	5	178	-28	17	20.1	168	-30		
R-4	043	03 NW	80	540-600	5	163	-22	09	71.1	162	-19		
R-5	090	08 N	30-60	500	3	194	-14	40	10.1	194	-06		
R-6	070	06 SE	30	≥ 540	3	172	-13	37	10.9	172	-19		
R-7	118	02 SW		570-660	4	174	-16	26	12.5	174	-17		
R-10	038	04 NW	40-100	500-570	5	180	-31	25	12.3	178	-29		
								8.2	46.4	175	-22	8.3	45.3
Component B													
R-1			15-25	300	4	185	27	38	6.3	181	18		
R-2			15-30		3	183	17	29	16.9	173	41		
R-3			50	500	3	172	41	37	10.8	182	18		
R-4			80-100		1	186	07	—	—	186	09		
R-5			5-10	540-600	4	189	13	40	5.6	189	21		
R-6			15-40	450-525	5	188	17	06	15.6	187	12		
R-7			15-40	500-540	4	179	20	23	16.9	179	18		
								9.1	44.5	183	20	8.7	48.3

N is number of samples used in statistics.

D°, I° are declination and inclination of remanent magnetization.

α_{95} is semi-angle of cone of 95% confidence for mean direction.

K is the estimate of Fisher's precision parameter.

Table 3. Examples of reverse polarities for the A and B components in the course of AF demagnetization.

mT	Component A			R5-1B				Component B			
	R1-1B							R2-2C			
	<i>D</i>	<i>I</i>	<i>J_r</i>	<i>D</i>	<i>I</i>	<i>I</i>		<i>D</i>	<i>I</i>	<i>J_r</i>	
	(°)	(°)	(A m ⁻¹)	(°)	(°)	(A m ⁻¹)		(°)	(°)	(A m ⁻¹)	
10	336	25	5E ⁻²	5	8	12	2E ⁻²	5	348	-51	2E ⁻²
20	340	18	8E ⁻³	10	8	23	E ⁻²	10	356	-45	E ⁻²
30	342	19	5E ⁻³	15	9	25	8E ⁻³	15	345	-42	E ⁻²
40	348	24	4E ⁻³	20	8	15	7E ⁻³	20	357	-40	9E ⁻³
50	350	26	3E ⁻³	30	6	22	6E ⁻³	25	358	-41	8E ⁻³
60	334	35	5E ⁻⁴	40	10	18	4E ⁻³	40	356	-36	7E ⁻³
				50	9	10	2E ⁻³	60	357	-29	5E ⁻³

Fig. 4(A and B). Equal-area projections of directions of magnetization of two specimens after step-wise thermal demagnetization. The numbers next to the dots (circles) represent the demagnetization steps in °C indicated. Dots=positive inclinations and circles=negative inclinations.

sample; this is never the case in the course of AF demagnetization. The same comment applies to sites R-1, R-2, R-3 and R-5 upon thermal treatment. Two components were detected (using vector subtraction technique) in specimen R-4-4 of sample R-4 and two samples of R-6, R-7 and R-10. Figures 5A and 5B show four examples of multicomponents of magnetization detected in the same sample. The most common situation encountered in the successive removal of the components in order of increasing temperatures is $B \rightarrow A$ and $A \rightarrow A$ (N). In only two instances was the sequence of removal $A \rightarrow B$ found. Thermal treatment appears to be more efficient than AF demagnetization for the majority of the sites.

7. Statistical Analysis of Site-Mean Directions and Origin of Magnetizations

Site-mean directions for combined AF and thermally cleaned results are shown in Table 1 for both the Pontgravé and Bécancour Formations of the Richmond Group. A PEF component is observed in only one of the 40 oriented samples. Figures 6A and 6B show the sample-mean directions of magnetization for each

Fig. 6. Sample-mean directions of magnetization after AF and thermal treatments and before tilt correction, plotted on an equal-area projection for the Bécancour and Pontgravé Formations. Figure 6A shows the A component of magnetization and the small circles represent negative inclinations; Figure 6B shows the B component and the dots represent positive inclinations. The mean directions are indicated with triangles and the angle of cone of 95% confidence with the large circles.

Table 4. Examples of reverse polarities for the A and B components in the course of thermal demagnetization.

Component A R5-3B				R6-2A				Component B R3-5C			
°C	<i>D</i> (°)	<i>I</i> (°)	<i>J_r</i> (Am ⁻¹)	°C	<i>D</i> (°)	<i>I</i> (°)	<i>J_r</i> (Am ⁻¹)	°C	<i>D</i> (°)	<i>I</i> (°)	<i>J_r</i> (Am ⁻¹)
100	21	-2	2E ⁻²	100	27	15	2E ⁻²	100	17	-24	2E ⁻²
300	18	9	6E ⁻³	300	11	17	E ⁻²	300	13	-23	2E ⁻²
400	17	8	5E ⁻³	400	359	16	E ⁻²	400	5	-25	E ⁻²
450	10	10	3E ⁻³	450	357	17	9E ⁻³	450	4	-18	6E ⁻³
500	9	17	3E ⁻³	500	356	14	5E ⁻³	500	2	-17	3E ⁻³
540	4	17	2E ⁻³	540	349	18	3E ⁻³	540	357	-19	2E ⁻³
575	6	15	2E ⁻³	575	344	17	E ⁻³	575	359	-16	E ⁻³
585	6	17	E ⁻³	590	353	20	9E ⁻⁴				
600	3	18	9E ⁻⁴								

component of magnetization. Component A characterized by high coercivities and high T_{UBS} has a mean direction of 175° , -22° which is not significantly different from the one of NRM except for the dispersion which is significantly smaller after demagnetization and this means that the cleaning was efficient. Tilt correction fold test is inconclusive. Mixed polarities of the A component (Table 4) were detected in 5 sites (R-1, 3, 5, 6 and 7); the other sites are characterized by reverse polarities, low to intermediate coercivities and intermediate T_{UBS} . Component B has a mean direction of 180° , $+20^\circ$ which is significantly different from the mean NRM direction (Table 2). The degree of dispersion of the mean direction of the B component is about the same as the one of the A component. The tilt correction decreased slightly the degree of dispersion but the fold test is also inconclusive. Except for sites R-2 and R-3, the polarity of this component is decidedly reversed (Table 5).

The mean direction of reversed component A (175° , -22° , $\alpha_{95}=8^\circ$) is not statistically different from that of the normal (343° , $+18^\circ$, $\alpha_{95}=12^\circ$) on a 95% confidence level. The mean directions of reversed components A and B (184° , 20° , $\alpha_{95}=9^\circ$) is statistically different on a 95% confidence level. The criterion used for testing whether two mean directions are significantly different necessitates that their cones of confidence do not intersect (McELHINNY, 1973). This condition is fulfilled in this study (see Figs. 6A and 6B). Blocking temperatures (T_{UBS}) and median destructive fields ($H_{1/2} \cong H_C$) also provided good guidance in the separation of components A and B; for A and B, T_{UBS} are generally $>540^\circ\text{C}$ and $<590^\circ\text{C}$ and $H_{CS} > 40\text{ mT}$ and $>40\text{ mT}$, respectively (Table 1).

Independently of the components isolated, the tilt correction changes very little the group-mean directions of magnetization (Table 2) because the dips of the formation are small and also because magnetization directions are often sub-parallel to the strike of the formations. For all practical purpose, the fold test is not really informative.

Table 5. List of magnetization for each site.

Site	Most important component		Less common component	
	No:	Polarity	No:	Polarity
R-1	B	R	A	R + N
R-2	A	R	B	R + N
R-3	A	R + N	B	R + N
R-4	A	R + (N)?	B	R + (N)?
R-5	B	R	A	R + N
R-6	B	R	A	R + N
R-7	A	R + N	B	R + N
R-10	A	R	B	R

R = Reverse polarity.

R + N = Predominantly reverse polarity and minor normal polarity.

R + (N)? = Normal polarity questionable.

8. Age of the Magnetizations

In order to sort out the sequence of acquisition of the magnetizations, it must be clarified whether the magnetizations overlap in thermal and AF magnetizations or whether they do not occur simultaneously. In order to separate primary and secondary components in these sedimentary formations, the best criterion is the fold test but this test failed in this specific study. Other criteria which are not as stringent include H_{CS} , T_{UBS} , relationships between reverse and normal polarities of the components of magnetization and changes of directions and polarities in relation to the stratigraphic position of the geological formations. On the basis of higher H_{CS} and T_{UBS} , it could be concluded that component A is older than component B (Table 1) but there is definitely no relation in this case. Indeed, these physical parameters are related to the magnetic mineralogy; component A detected predominantly on sites R-2, 3, 4, 7 and 10 reflects a continental environment of deposition (hematite) while component B mainly present in sites R-1, 5 and 6 reflects a marine environment (magnetite). This relatively simple interpretation becomes complicated by the reversals. On sites R-1, 5, and 6 of the Pontgravé Formation, component B is always reverse while it is mixed on sites R-2, 3, and 7 of the Bécancour Formation; on site R-4, it is found in only one sample (Table 5). It is thus most probable that in the middle portion of the Bécancour Formation, a period of reversals of the B component took place. If this interpretation is correct, the B component is almost primary (period of diagenesis) rather than secondary (subsequent alteration). The A component is found with mixed polarities on all sites (of both Pontgravé and Bécancour formations) except on sites R-2 and R-10 (Table 5); this suggests a long period of acquisition of this component (chemical remanence in the course of a slow alteration process).

In summary, although the evidence that component B is always reversed and component A is characterized by mixed polarities on all sites sounds a little weak, the sequence of acquisition of the magnetic events would be the following (1) component B is the oldest and possibly primary (Late Ordovician) and (2) component A is secondary. The choice of the sequence is based on the arguments presented above and on the well-known fact that the youngest geological event recorded is masking (or erasing) partly or completely previously recorded geological events. Consequently, the memory (component) of this older event is not as frequent. The Late Ordovician sea regression is thus characterized by a period of polarity changes of the Earth's field without significant changes in the mean direction of magnetization.

Unresolved components due to a reversal may also be a solution to the difficulty of resolving the sequence of magnetizations. Attempts to solve this problem by core splitting and cutting did not yield different results.

9. Paleopole Positions and Their Relation to Poles from North America

The paleopole corresponding to component A is 116°E , 54°N ($d_p = 5.9^{\circ}$, $d_m = 10.8^{\circ}$). The paleopole is comparable to paleopole positions for the Late Devonian period (SEGUIN *et al.*, 1982; DANKERS, 1982) or for younger age (e.g., Permian). Component B yields a paleopole of 105°E , 33°N ($d_p = 5^{\circ}$, $d_m = 9.5^{\circ}$) which is located slightly to the West of a main group of Ordovician poles available from North America and centered on longitude 120°E and latitude 35°N (Fig. 7) and in particular on the Upper Ordovician pole (Juniata Fm). At this time and place, the paleolatitude was 15° to 20°N of the magnetic equator. In the Quebec Appalachians to the south, it is known that the sedimentary environment changed from marine to continental towards the end of Early Devonian time (SEGUIN *et al.*, 1982). Consequently, component A may represent the magnetic record of the uplift related to the Acadian orogeny (Middle to Late Devonian).

Figure 7 shows the Ordovician poles available from the North American continent. A large scatter is observed. As a first approximation, it is quite evident that most of the paleomagnetic poles obtained from (1) intrusives in the craton, (2) platform sediments and (3) Appalachian metasediments affected only by the Alleghanian Orogeny (Permian) are located within the range of longitudes 105° – 150°E and latitudes 25° – 40°N (within dashed circle on the western side of Fig. 7). All Ordovician paleopoles obtained from Appalachian sedimentary and igneous rock units affected by the Taconic (Late Ordovician) and sometimes Acadian (Middle to Late Devonian) orogenies are located in the zone of longitudes: 160° – 200°E and latitudes: 10° – 30°N (within dashed circle on the eastern side of Fig. 7).

A minimum large scale rotation of 50° could have taken place between the Northern Appalachians and the stable craton during or after Ordovician times. Because of the status of Appalachian paleomagnetic data, a rotation of 50° scale should leave significant geological signatures but this is not observed. In addi-

NORTH AMERICAN ORDOVICIAN PALEOPOLES

Fig. 7. Paleopoles obtained from paleomagnetic studies of Ordovician rock units from eastern North America and proposed apparent polar wander path (APWP) for the Ordovician period on North America. Pole symbols and references are as follows: BD (DANKERS and LAPOINTE, 1981), BC (PROKO and HARGRAVES, 1973), CH (SEGUIN *et al.*, 1981), CR (WATTS and VAN DER VOO, 1979), GD (MURTHY, 1971), JU (VAN DER VOO and FRENCH, 1977), MA (HOWER, 1979), MB (WATTS and VAN DER VOO, 1979), MH (DEUTSCH and RAO, 1977), QF (IRVING *et al.*, 1976), QV (SEGUIN, 1977), RG (B component in this study), SG1 (BEALES *et al.*, 1974), SG2 (DEUTSCH and RAO, 1977), SD (PALMER *et al.*, 1977), TR (McELHINNY and OPDYKE, 1973), SL (SEGUIN, 1981a), WG (SEGUIN, 1980), AL (SEGUIN, 1981c), WL1 and WL2 (SEGUIN, 1981b), VE (SEGUIN and PETRYK, 1984); O₁ = Lower Ordovician; O_m = Middle Ordovician, O_u = Upper Ordovician; S₁ = Lower Silurian.

tion, these are a few exceptions to the above mentioned generalization. In the St. Lawrence Lowlands, SEGUIN and PETRYK (1984) obtained a paleopole of 189°E, 37°N for the Late Ordovician Vauréal Formation of Anticosti Island. In the vicinity of the St. Lawrence Lowlands, slightly to the southwest of the present study area, SEGUIN (1977) obtained a paleopole position of 165°E, 20°N in Middle to Late Ordovician volcanic rocks.

Excluding the poles obtained in basic dykes (BD, SD and GD, Fig. 7) from the craton, the available data do not show any specific trend from Lower to Upper Ordovician. A preliminary study of the uppermost levels of the Châteauguay Formation in the St. Lawrence Lowlands (SEGUIN *et al.*, 1981) suggests that the

paleopole was located in the vicinity of 110°E , 40°N at very Early Ordovician time. If these results are correctly interpreted and later confirmed with further paleomagnetic studies in the St. Lawrence Lowlands, it can then be concluded that no or a very small apparent polar motion occurred during the Early to Late Ordovician time span. A similar conclusion is reached for the Ordovician paleomagnetic data from the Appalachian regions which were affected by the Taconic orogeny.

Nevertheless, the more reliable Ordovician poles may be subdivided into two groups. The first group is centered at 125°E , 30°E and the second at 165°E , 25°N ; these two groups are represented by the two circles in dotted lines on Fig. 7.

10. Conclusion

The paleomagnetic results of this study and their comparison with available paleomagnetic data from North America for the same age span (Fig. 7) indicate that the apparent polar wander path (APW) for the Ordovician period on the N.A. craton and the Appalachians (northern at least) is more complex than the one suggested by VAN DER VOO (1981). Considering the fact that; (1) more than one component are usually present in most of the Lower Paleozoic lithological units investigated, (2) the relative age of these components are generally unknown, (3) the errors involved in the determination of the older components are commonly quite large, many more individual paleomagnetic studies are needed before a reliable APWP may be obtained for this period. The most puzzling problem is the divergence in the paleopoles obtained from the craton and the southern Appalachians on the one hand and from the northern Appalachians on the other hand. Either a Carboniferous or Permian overprint is general in Ordovician rock units of the N.A. craton and the south central Appalachians or a clockwise rotation of approximately 50° for the northern Appalachians with respect to the N.A. craton took place at very Late or Post-Ordovician time, this rotation occurred without significant change in paleolatitude. It is worth noting that the scattering of the poles from the northern Appalachians underwent a deformation characterized by the differential motion of a mosaic of small blocks rather than a large scale rotation of the whole northern Appalachian block.

The present study constitutes a small fragment of a program of regional paleomagnetic investigations being undertaken in the St. Lawrence Lowlands of the province of Quebec. The determination of this new paleomagnetic Upper Ordovician data is a significant contribution to the very restricted list of existing paleopoles from unmetamorphosed, relatively unaltered and structurally undisturbed sedimentary sequences from North America.

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