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A paleomagnetic reinvestigation of the Upper Devonian Perry Formation: evidence for Late Paleozoic remagnetization

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In view of the recent recognition of widespread Late Paleozoic remagnetization of Devonian formations across North America, we undertook a reinvestigation of the Upper Devonian Perry Formation of coastal Maine and adjacent New Brunswick. Thermal demagnetization of samples from the redbeds yielded a characteristic direction ($D = 166°$, $I = 4°$) that fails a fold test. Comparison of the corresponding paleopole (312°E, 41°S) with previously published Paleozoic poles for North America suggests that the sediments were remagnetized in the Late Carboniferous. After the removal of a steep, northerly component, the volcanics also reveal a shallow and southerly direction ($D = 171°$, $I = 25°$ without tilt correction). No stability test is available to date the magnetization of the volcanics; however, similarity of several of the directions to those seen in the sediments raises the suspicion that the volcanics are also remagnetized. Although the paleopole without tilt correction (303°E, 32°S) could be taken to indicate an early Carboniferous age for the remagnetization, scatter in the data suggests that the directions are contaminated by the incomplete removal of a steeper component due to present-day field. Thus, it is more likely that the volcanics were remagnetized at the same time as the sediments. Isothermal remanent magnetization (IRM) acquisition curves, blocking temperatures, coercivities and reflected light microscopy indicate that the magnetization is carried by hematite in the sediments and by both magnetite and hematite in the volcanics. It is therefore likely that the remagnetization of the Perry Formation involved both thermal and chemical processes related to the Variscan/Alleghenian orogeny. Our results indicate that previously published directions for the Perry Formation were based on the incomplete resolution of two magnetic components. These earlier results can no longer be considered as representative of the Devonian geomagnetic field.

1. Introduction

Recent recognition of widespread Permocarboniferous remagnetization of several Devonian formations across North America [1–6] has led to a re-evaluation of the existing Devonian paleomagnetic data presented in earlier studies. Because many of the earlier studies did not recognize or completely remove secondary components of magnetization, the results of these studies have had to be revised. One of the results of this re-evaluation has been a decrease in the number of reliable Devonian paleomagnetic poles for North America. In fact, in a recent review of North American Paleozoic paleomagnetism, Van der Voo [7] lists only two reliable Devonian poles for the craton of North America. It has been shown that many of the existing cratonic reference poles are in fact based on Kiaman remagnetizations [7,8]. Although the causes of these widespread remagnetizations are currently not well understood [9], documenting the extent of the remagnetization in terms of the lithologies and the regions affected may lead to better understanding of the mechanisms of remagnetization.

Clearly it has become increasingly important to reinvestigate the published Devonian results from the 1960s in order to determine the reliability of the poles. Modern laboratory and data-analytical techniques have improved our ability to isolate components of magnetization and to identify rocks that carry secondary magnetizations. The published paleomagnetic poles from Devonian rocks in North America are listed in Table 1 [2–5,10–23]. Of the sixteen formations that have been studied, eleven yield poles that fall on the Permocarboniferous section of the North American Apparent Polar Wander Path. Two of those formations, the Catskill Formation and the St. Lawrence granite, also yield second components of magnetization

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that are likely to be of Devonian age. Five formations yield magnetic directions corresponding to paleomagnetic poles that do not appear to be Permocarboniferous in age. Of these five, the only cratonic poles that pass the quality critera of Van der Voo [7] are the one from the Peel Sound Formation [20] and the revised poles for the Catskill Formation [2,3].

We undertook a reinvestigation of the Upper Devonian Perry Formation for several reasons. The earlier studies [13–15] indicated the presence of stable, yet poorly resolved ancient magnetizations. The availability of stability tests (fold and contact tests) to date the magnetization makes the Perry Formation well suited for a paleomagnetic investigation. Finally, the reported paleomagnetic poles for the Perry Formation (see Table 1) are of a lower latitude than the well-documented Carboniferous remagnetized poles of other Devonian formations, which led us to hope that a modern study would reveal a primary Devonian direction.

2. Regional geology

The geology of the Upper Devonian Perry Formation has been described in detail by Smith and White [24] and Schluger [25,26]. One of a series of post-Acadian basin fillings found in the northern Appalachians, the Perry Formation was deposited in two separate basins—the St. Andrews and Blacks Harbour basins (Fig. 1). According to Schluger [25], during Late Devonian time the basins were separated by a highland area and had different source areas. In the St. Andrews basin the dips of the Perry Formation range from nearly

TABLE 1

Paleomagnetic results from Devonian rocks of North America

Formation	Location	Age	Pole position (lat. ° N, long. ° E)	Remagnetized	Reference
1 Columbus Is.	Ohio	Dm	45, 120	yes	Martin [10]
2 Delaware Is.	Ohio	Dm	48, 118	yes	Martin [10]
3 Catskill Fm.	Pa., Md	Du	44, 124	yes	Van der Voo et al. [11]
4 Catskill Fm.	N.Y.	Du	47, 117	yes	Kent and Opdyke [12]
5 Perry lavas	Maine	Du	24, 128 [a]	yes	Phillips and Heroy [13]
6 Perry lavas	New Brunswick	Du	26, 109 [a]	yes	Black [14]
7 Perry sediments	New Brunswick	Du	35, 121 [a]	yes	Black [14]
8 Perry sediments	New Brunswick	Du	32, 118 [a]	yes	Robertson et al. [15]
9 Perry lavas	Maine, N.B.	Du	32, 123	yes	this study
10 Perry sediments	Maine, N.B.	Du	41, 133	yes	this study
11 Martin Fm.	Arizona	Du	56, 109	yes	Elston and Bressler [16]
12 Temple Butte Fm.	Arizona	Du	53, 115	yes	Elston and Bressler [16]
13 Onondaga Ls.	N.Y.	Dl	40, 121	yes	Kent [4]
14 Helderberg sequence	N.Y.-Va	Su-Dl	49, 115	yes	Scotese [17]
15 Dockendorff Complex	Maine	406	24, 84	yes	Brown and Kelly [18]
16 Belchertown Intrusive	Mass.	380	48, 147	?	Ashwal and Hargraves [19]
17 St. Lawrence Granite	Newfoundland	Du-Cl	a) 47, 129	yes	Irving and Strong [5]
			b) 12, 120	?	
18 Catskill Fm.	Pa.	Du	a) 48, 124	yes	Miller and Kent [2]
			b) 33, 90	no	
19 Catskill Fm.	Pa.	Du	a) 43, 127	yes	Miller and Kent [3]
			b) 26, 124	no	
20 Traveler Felsite	Maine	Dl	29, 82	no	Sparisou and Kent [20]
21 Compton metaseds.	Quebec	D	20, 79	no	Seguin et al. [21]
22 Peel Sound Fm.	Northwest Terr.	Dl	25, 99	no	Dankers [22]
23 Hersey Fm.	Maine	Su-Dl	20, 129	?	Kent and Opdyke [23]
24 Eastport Fm.	Maine	Dl	24, 114	?	Kent and Opdyke [23]

A question mark (?) indicates that the direction and age of the magnetization are not constrained owing to the lack of a conclusive field test or structural correction.

[a] Not plotted in Fig. 7.

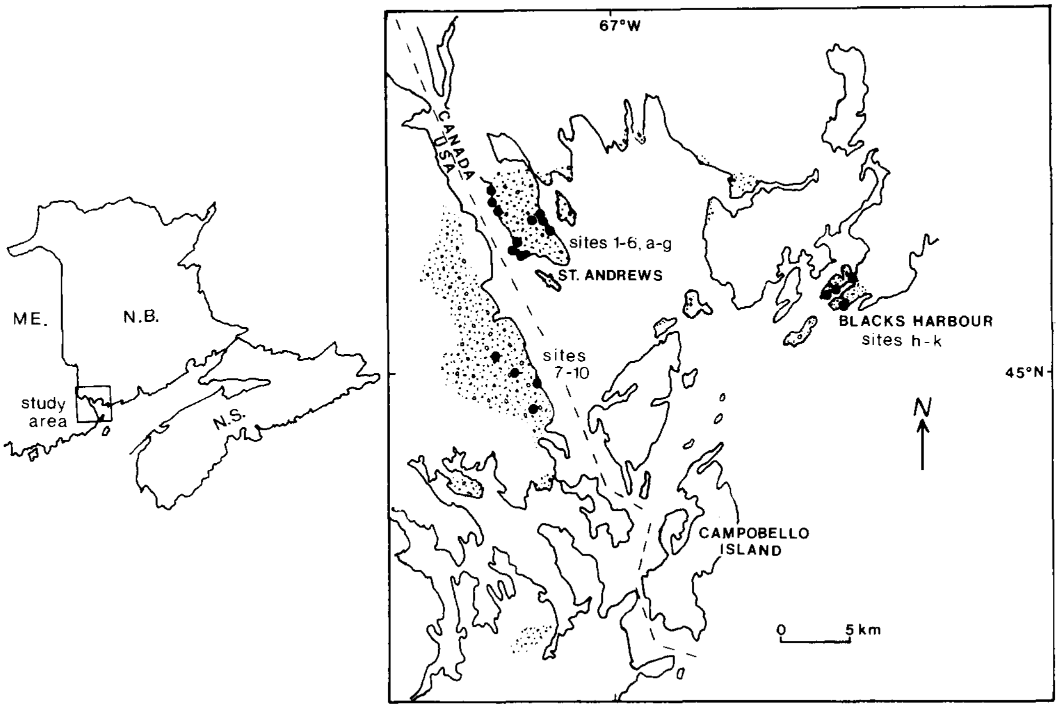

Fig. 1. Sampling locality map showing outcrops of the Perry Formation of Maine and New Brunswick in the stippled pattern. Sites in the sediments are indicated by letters, in the volcanics by numbers.

flat-lying to 30° to the northeast and southeast. In contrast, the beds in the Blacks Harbour region are steeply inclined to the northwest, and they have some fracture cleavage [25]. Direct stratigraphic correlations between the two basins are not possible because of the lack of continuous exposure and the facies changes associated with alluvial fan sequences. However, Schluger [25] correlates the Perry Formation in the St. Andrews Basin to that in the Blacks Harbour Basin on the basis of similar stratigraphic position and depositional environments.

Lithologically, the Perry Formation consists of red and green conglomerates, sandstones and siltstones that are interbedded with basalts and minor amounts of limestone [25,26]. The age of the Perry Formation was determined by the presence of some abraded plant fragments found in the easternmost part of the St. Andrews Basin [25]. No plant fossils have been identified in the Blacks Harbour Basin.

3. Previous work

The Upper Devonian Perry Formation of coastal New Brunswick and adjacent Maine was previously studied by Black [14], Robertson et al. [15] and Phillips and Heroy [13]. Black's early work was based on low-field alternating field demagnetization (< 300 mT) of redbeds and volcanics from New Brunswick. Robertson et al. reported results from the redbeds and volcanics of the Perry Formation in the St. Andrews and Blacks Harbour basins of New Brunswick (Fig. 1). They reported unstable behavior for the basalts, random directions from a rhyolite, and two poorly resolved components of magnetization from the redbeds. A primitive fold test suggested that the redbeds carried both pre- and post-folding components of magnetization. Phillips and Heroy [13] reported intermediate downward and southerly directions from Perry basalts from two sites near Eastport, Maine. The published poles from the three studies are listed in Table 1 along with other previously published Devonian data for North America.

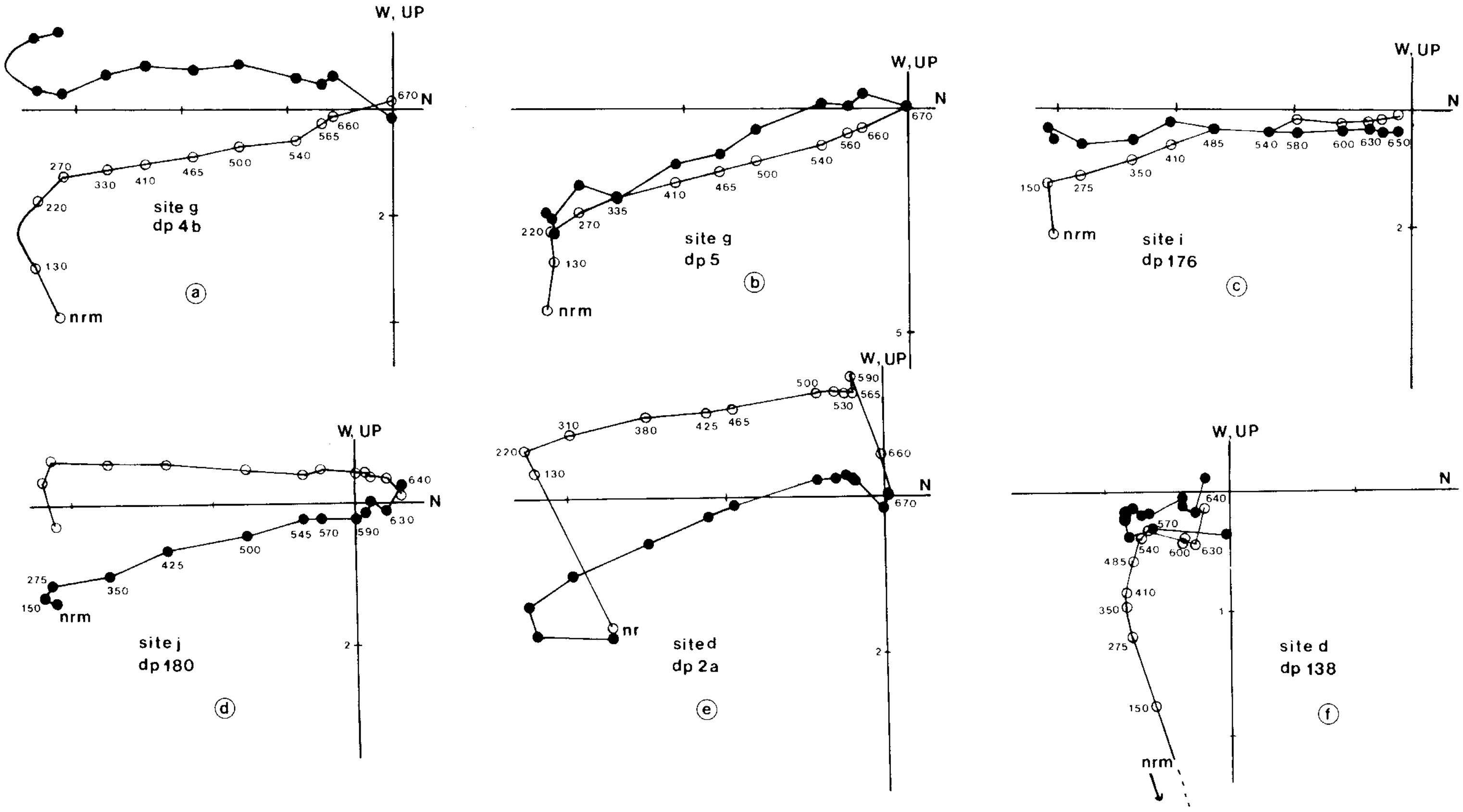

Fig. 2. Representative in-situ orthogonal demagnetization diagrams for thermal treatment of the redbeds of the Perry Formation. Open (closed) symbols represent projections of the end points of the magnetization vectors on the vertical (horizontal) planes. Treatment steps are labeled in °C. Intensities are labeled on the axes in mA/m.

4. Sampling and laboratory techniques

The sampling localities illustrated in Fig. 1 include eleven sites in the sediments and ten sites in the volcanics. Most of the samples were drilled in the field with a portable gasoline-powered drill and oriented in place with a Brunton compass and inclinometer. An additional 35 hand samples were collected and later drilled in the laboratory.

The natural remanent magnetization (NRM) of the samples was measured using a Schonstedt SSM1-A spinner magnetometer or a Superconducting Technology (ScT) cryogenic magnetometer at the University of Michigan. The samples were stored and treated in a magnetic-field-free room to reduce the possible effects of viscous magnetizations. To isolate secondary and characteristic components of the NRM, stepwise thermal demagnetization procedures were carried out using a Schonstedt TSD-1 model oven. Pilot studies using alternating field, thermal and chemical [27] demagnetization procedures indicated that for both the sediments and the volcanics thermal demagnetization was the best procedure to decompose the NRM. Alternating field demagnetization was only successful on the samples from the lava flow exposed near Bar Road (sites 1, 2 and 3 in Fig. 1). Chemical demagnetization of the sediments failed beause the samples disaggregated in acid before the magnetization could be removed. To determine the characteristic magnetic components, principal component analysis [28] was applied after visual inspection of orthogonal demagnetization diagrams. Great circle analysis was applied to results from samples with curvilinear demagnetization trajectories [29]. Isothermal remanent magnetization (IRM) experiments were done using a Varian Associates V-4005 Magnet assembly with a maximum field strength of 1.4 T.

5. Paleomagnetic results

5.1. The sediments

Typical Zijderveld diagrams for the redbeds of the Perry Formation are shown in Fig. 2. Thermal demagnetization of 40 samples yielded an in-situ southerly and shallow component ($D = 166°$, $I = 4°$). We will refer to this magnetization as the characteristic component. Unblocking temperatures range as high as 670 ° C which indicates that hematite carries all or part of the magnetization. The behavior of individual samples varied during demagnetization. Many of the coarser-grained sediments had a steep, northerly viscous component that was removed by 500 ° C (Fig. 2f). Although some samples showed nearly univectorial behavior at temperatures above 200 ° C (Fig. 2a, b and c), the demagnetization trajectories of many samples clearly bypassed the origin as is shown in Fig. 2d and e. This suggests the presence of an additional component of magnetization. However, we have not been able to detect any systematic directional behavior at high temperatures. Samples with trajectories bypassing the origin show high temperature directions that are highly variable. Moreover, many samples became unstable at high temperatures. Great-circle analysis revealed only intersections at the low temperature direction without yielding convergence at any additional components of magnetization. If there is an additional systematic component of magnetization preserved in the sediments, it appears that it cannot be resolved with standard demagnetization techniques.

The in-situ characteristic directions for all the demagnetized sediment samples are shown in Fig. 3 along with the site means in both field and tilt corrected coordinates. The site means are also listed in Table 2 with their associated statistical parameters. The site means cluster well in field coordinates, but application of the tilt correction dramatically increases the scatter of the data because of the steep dips of the strata of Blacks Harbour. Thus, the fold test is negative indicating that the characteristic southerly and shallow direction was acquired after the rocks were folded.

In summary, the sediments of the Perry Formation yielded a characteristic direction ($D = 166°$, $I = 4°$) that failed the fold test. Although stepwise demagnetization did not always yield univectorial Zijderveld diagrams, we have not been able to document any consistent high-temperature behavior despite detailed geometric analysis of demagnetization diagrams.

5.2. The volcanics

A tuffaceous rhyolite was sampled near St. Andrews. However the samples were weakly magnetized with NRM intensities ranging from 0.4 to 1.0 mA/m. Upon thermal demagnetization, the

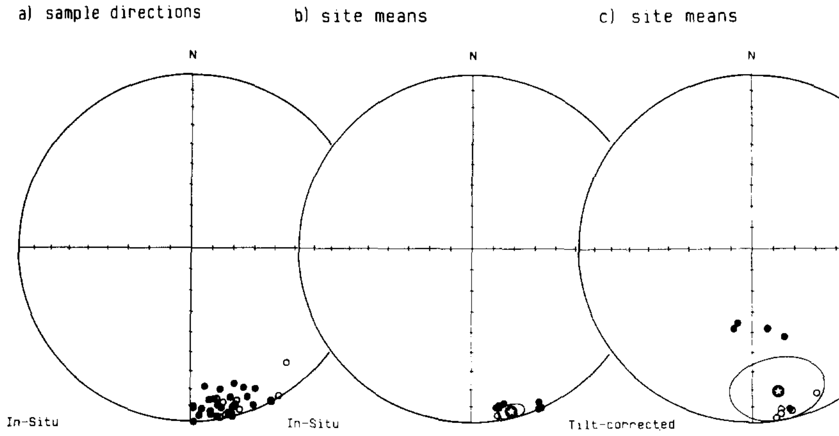

Fig. 3. Equal area projections of (a) in-situ characteristic directions from individual samples, (b) in-situ site means and (c) tilt corrected site means for the redbeds. Open (closed) symbols represent negative (positive) inclinations. In (b) and (c), the enclosed stars are the means of the site means with the associated α_{95} shown as ellipses about the means.

samples displayed viscous acquisition of magnetizations with random directions. We conclude that the rhyolites are unsuitable for paleomagnetic study, and the results are not included in this study.

Samples of the basalts were taken from two flows in New Brunswick—one exposed near Bar Road and one at Joe's Point (sites 1–3 and 4–6, respectively). In addition, samples were collected from four locations near Perry, Maine (sites 7–10). In Maine, the lack of continuous outcrop makes the precise stratigraphic relationships of the four sites difficult to determine. Typical Zijderveld diagrams for the volcanics are shown in Fig. 4. Thermal demagnetization yielded a characteristic southerly and intermediate to shallow directions ($D = 171°$, $I = 25°$) above 300 °C. Although alternating field demagnetization was not successful with most of the samples, a southerly and shallow component was obtained from the few samples for which the treatment worked (Fig. 4a, b). In addition to the characteristic direction, many of the samples (Fig. 4b, d, e, and f) yielded a steep and northerly component presumably acquired in the present-day field. Note that the removal of this component caused Robertson et al. [15] to think that the volcanics were magnetically unstable. We feel that because of overlapping stability spectra, we were not always able to isolate completely the steep and the shallow components. This will be discussed further below. The blocking temperatures for the characteristic directions ranged up to 590 °C in most of the sites, indicating that magnetite may be the magnetic carrier. However in sites 6 and 10 the magnetization remained up to 670 °C, indicating that hematite is carrying part or all of the magnetization.

The characteristic directions for the volcanics are shown in Fig. 5 and listed in Table 2. The mean direction seen in the volcanics is a little steeper than that in the sediments, but the dispersion of the data seen both within and between sites is higher than that in the sediments. Whereas some site mean directions with inclinations up to +45° are significantly steeper than those of the redbeds, other sites have the same shallow inclinations, even negative, as the redbed remagnetizations. It is likely that the directions are contaminated by the incomplete removal of the steeper component mentioned above as indicated, for instance, by the curvilinear nature of the Zijderveld diagrams in Fig. 4d and f. It is important to note that the method of demagnetization, i.e., thermal or alternating field, does not appear to result in differences in directions. Two specimens taken from the same sample but demagnetized either with alternating field or with thermal techniques yield the same direction. We are forced to conclude that overlapping stability spectra of two components makes it impossible to isolate them with standard demagnetization techniques.

No field test was available to date the magneti-

TABLE 2

Paleomagnetic results of this study

Site	n/N	S/D	D/I	D/I*	k	α_{95}
(a) The sediments						
a	6/6	348/20	171/−3	172/−2	60.4	8.7
b	3/4	25/15	167/5	167/−4	77.6	14.1
c	5/5	50/15	170/9	170/−4	78.2	8.7
d	3/5	83/17	156/4	156/−10	208.0	8.6
e	[a]		[a]			
f	4/4	35/5	168/10	168/6	88.7	9.8
g	5/6	60/17	170/8	170/−8	54.8	10.4
h	3/3	231/54	168/10	191/54	98.7	12.5
i	4/4	231/54	171/8	193/51	60.7	11.9
j	4/4	231/54	157/0	167/51	23,0	19.6
k	3/3	235/46	156/0	160/45	79.6	13.9
(b) The volcanics						
1	5/5	30/22	165/17	163/1	27.9	14.7
2	8/9	30/22	170/17	167/2	15.9	14.3
3	[a]		[a]			
4	4/6	25/16	155/32	150/19	49.6	13.2
5	6/7	25/16	163/37	155/26	65.4	8.3
6	4/4	42/16	170/17	168/4	114.6	8.6
7	4/4	346/15	170/45	155/44	50.1	13.1
8	4/4	346/15	185/−13	188/−8	132.6	8.0
9	4/4	18/10	201/32	195/32	82.9	10.1
10	5/6	347/10	160/29	155/27	197.9	5.5

[a] These sites were excluded owing to lack of within-site consistency

Site means

	D/I	k	α_{95}	Paleomagnetic pole
Sediments only (10/11 sites):				
in situ	166/4	108.0	4.7	312° E, 41° S
tilt corrected	169/16	7.5	18.8	
Volcanics (9/10 sites):				
in situ	171/25	15.0	13.7	303° E, 32° S
tilt corrected	166/17	13.0	14.8	
Combined (19 sites):				
in situ	168/14	20.0	7.6	
tilt corrected	168/17	10.0	11.0	

n/N is the ratio of samples used to samples analysed; *S/D* the strike and dip of the beds (left-hand rule) used for the tilt correction; *D/I* the in-situ declination/inclination; *D/I** the tilt corrected declination/inclination; *k* and α_{95} are the associated statistical parameters.

zation of the volcanics. The lava flows are not exposed in the steeply dipping beds in the Blacks Harbour area, and as a result the fold test was inconclusive. Since the sediments are remagnetized, no contact test is possible. In addition, we found no basalt cobbles in the interbedded conglomerates, so a conglomerate test was not possible either. However, because many of the characteristic directions are similar to those seen in the sediments, we conclude that the volcanics are also remagnetized. We argue that the apparently steeper directions are a result of the incomplete resolution of a steep component related to present-day field. We note that if the tilt correction is applied to the mean direction, the resultant direction ($D = 166°$, $I = 17°$) yields a pole (310° E, 35° S) that falls near the Late Carboniferous section of the North American APWP rather than near published Devonian poles. Thus we conclude that the volcanics are remagnetized and that the characteristic direc-

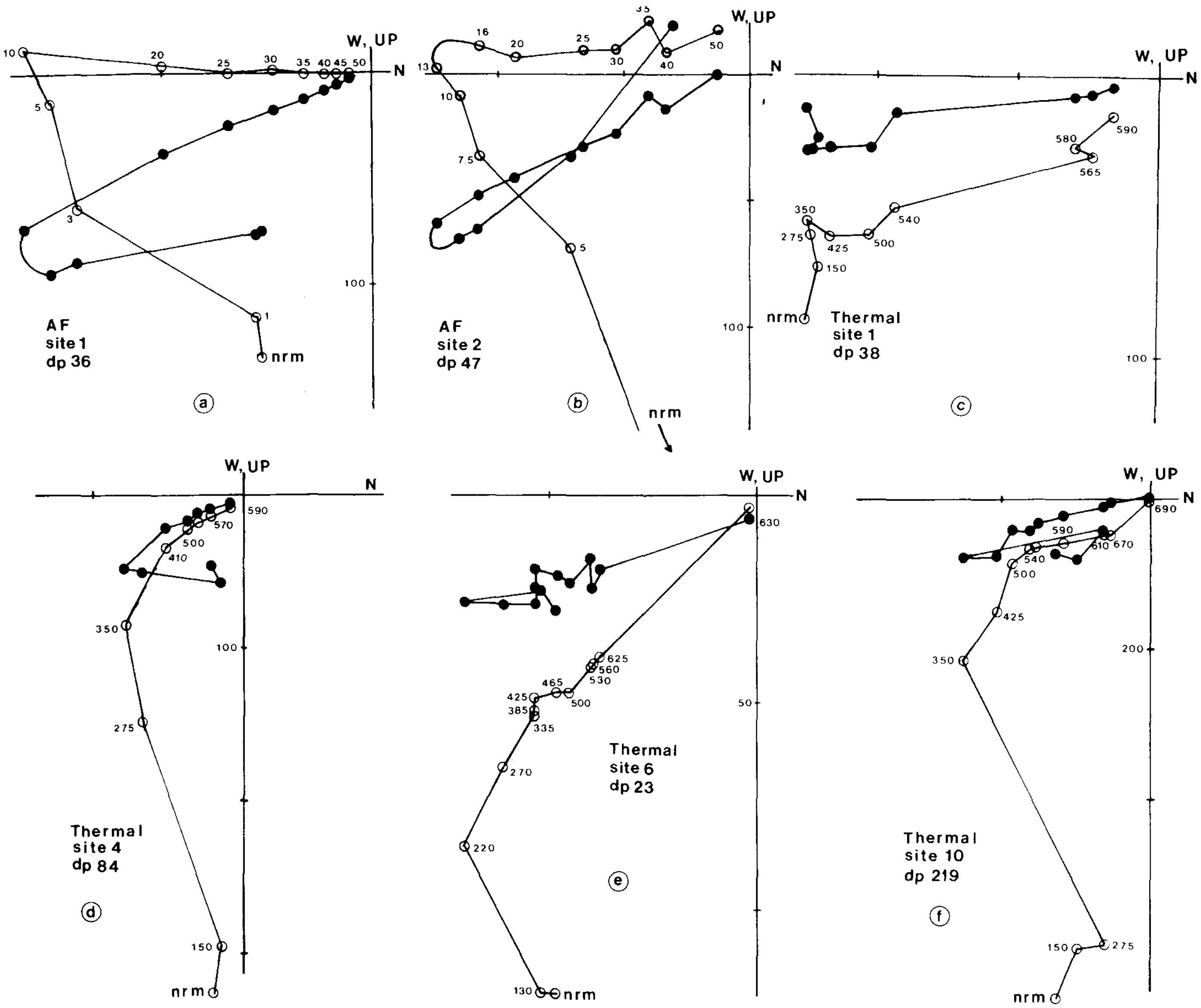

Fig. 4. Typical in-situ demagnetization diagrams for the volcanics of the Perry Formation. Treatment steps are labeled in °C for thermal demagnetization, and in mT for alternating field treatments. Open (closed) symbols represent projections on the vertical (horizontal) plane. Intensities are labeled in mA/m on the axes.

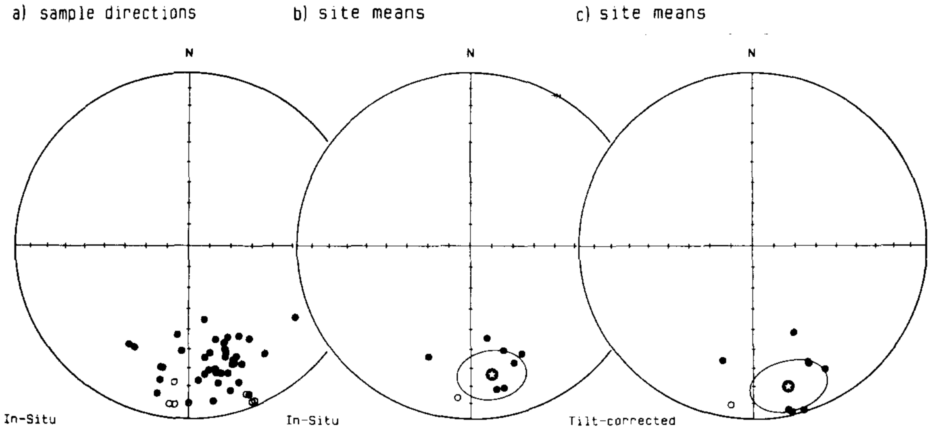

Fig. 5. Equal area projections of the (a) in-situ characteristic directions from individual samples, (b) in-situ site means and (c) tilt corrected site means for the volcanics (symbols as in Fig. 3).

tion ($D = 171°$, $I = 25°$) is likely to be contaminated.

6. Magnetic mineralogy

The high unblocking temperatures of the redbed samples indicate that hematite is a magnetic carrier. Schluger [26] has previously suggested that there are two generations of hematite in the sediments of the Perry Formation, one a depositional component that was derived from the underlying lithologic units and the other a post-depositional component formed by the alteration of mafic minerals by intrastratal fluids. Our results indicate that this secondary hematite formed during Late Carboniferous time.

The magnetic behavior of the volcanics is more complicated. Reflected-light microscopy reveals an abundance of iron oxides in the volcanic rocks of the Perry Formation. The samples from Bar Road (sites 1, 2 and 3) have large grains of magnetite and hematite with minor amounts of secondary hematite and magnetite seen as exsolution lamellae and/or needles within some of the larger grains. The samples from the exposures at Joe's Point (sites 4–6) and from Maine (sites 7–10) have large grains of hematite but much less magnetite. Exsolution features and needles can be seen in these rocks as well. The presence of more than one magnetic phase in the samples makes it difficult to determine which grains are in fact the carriers of the remanence.

Isothermal remanent magnetization (IRM) acquisition curves for the basalts are shown in Fig. 6. The samples from the flow at Bar Road (sites 1, 2 and 3, Fig. 6a) saturate by 0.1 T suggesting that magnetite is the magnetic carrier. A magnetite carrier for the remanence is also indicated by the blocking temperatures and the coercivities (Fig. 4a, b, c and d). Samples from site 10 in Maine yield IRM acquisition curves (Fig. 6c) indicative of hematite which agrees with the hematite blocking temperatures seen in the samples. The determination of the remanence carriers in the samples from the remaining sites in Maine and those from Joe's Point is less straightforward. Although many samples saturate by 0.3 T (Fig. 6b), theoretically the highest saturation point for magnetite, this does not preclude the presence of an additional phase in the rocks which may be contributing to the remanence. If magnetite is the carrier of the remanence in these samples, it remains unclear as to why alternating field demagnetization would not decompose the NRM. For this reason we suspect that an additional phase may be contributing to the NRM. We conclude that magnetite is the magnetic carriers in sites 1–3, that hematite is the magnetic carrier in the samples from site 10, and that it is likely that two phases are contributing to the magnetic remanence in the rest of the samples. The hematite would then be a chemical remanent magnetization (CRM) that is perhaps related to the same intrastratal fluids that formed the secondary hema-

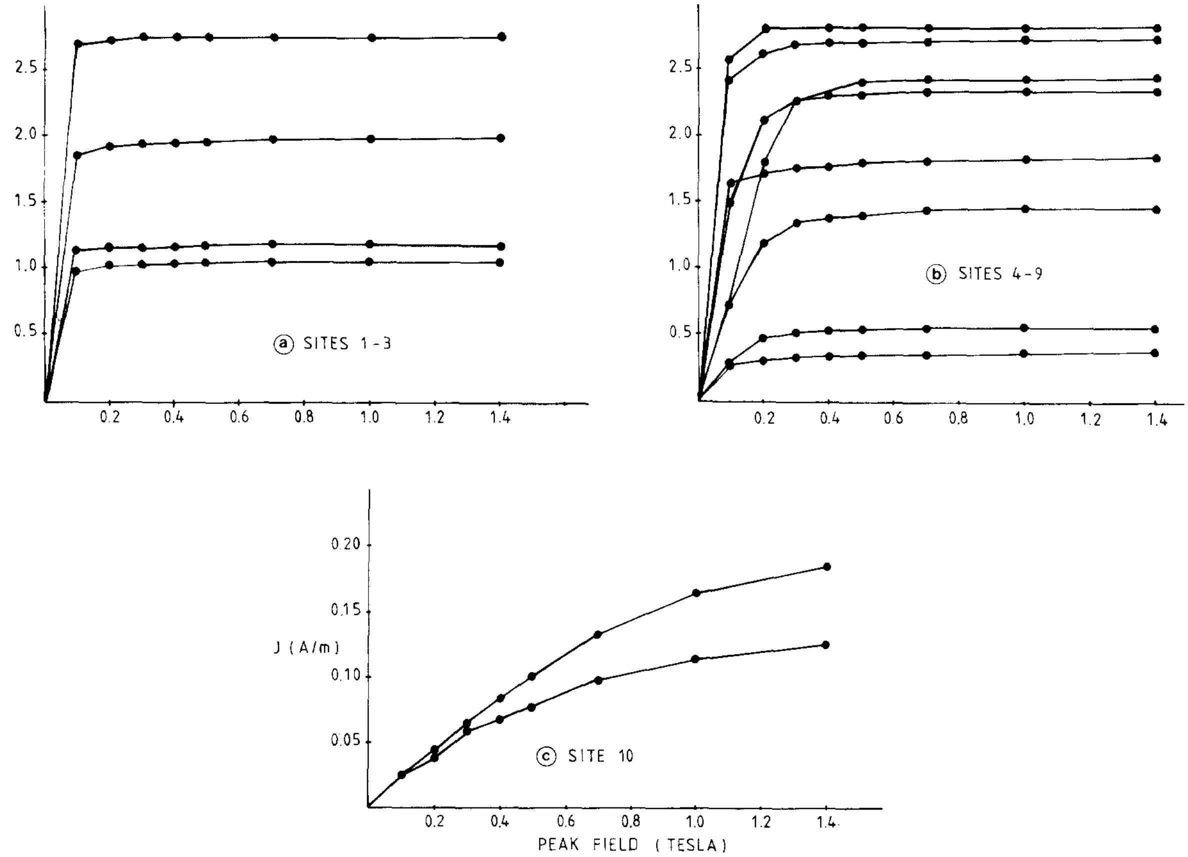

Fig. 6. Isothermal remanent magnetization acquisition curves for (a) samples from sites 1–3, (b) sites 4–9, and (c) samples from site 10 in Maine.

tite in the sediments. The magnetization carried by the magnetite is likely to be a viscous partial thermal remanent magnetization (VpTRM) related to thermal processes of the Alleghenian/Variscan orogeny.

7. Discussion

This paleomagnetic reinvestigation of the Perry Formation yielded a characteristic southerly and shallow direction from the redbeds that fails a fold test. The volcanics revealed a similar characteristic direction but no stability test is available to date the magnetization of the volcanics. However, dispersion of the data both within and between sites in addition to curvilinear demagnetization trajectories leads us to conclude that the directions of the volcanics are contaminated by the incomplete removal of a steep component presumably related to the present-day field. Overlapping stability spectra make it impossible to better resolve the components seen in the volcanics. It is likely that the volcanics are also remagnetized.

The corresponding paleopoles for the sediments and the volcanics of the Perry Formation are plotted in Fig. 7 along with previously published poles for other Devonian formations of North America. The pole for the redbeds (R) falls among the group of poles from other rocks that were remagnetized in the Late Paleozoic. This suggests further that the Perry Formation was also remagnetized in the Permocarboniferous. Because of the contamination problem discussed above we do not feel that the pole for the volcanics (V) can be considered representative of the geomagnetic field at the time of remagnetization. Comparison of our pole for the volcanics with previously published poles for the Perry Formation suggests that the earlier results were also based on incomplete reso-

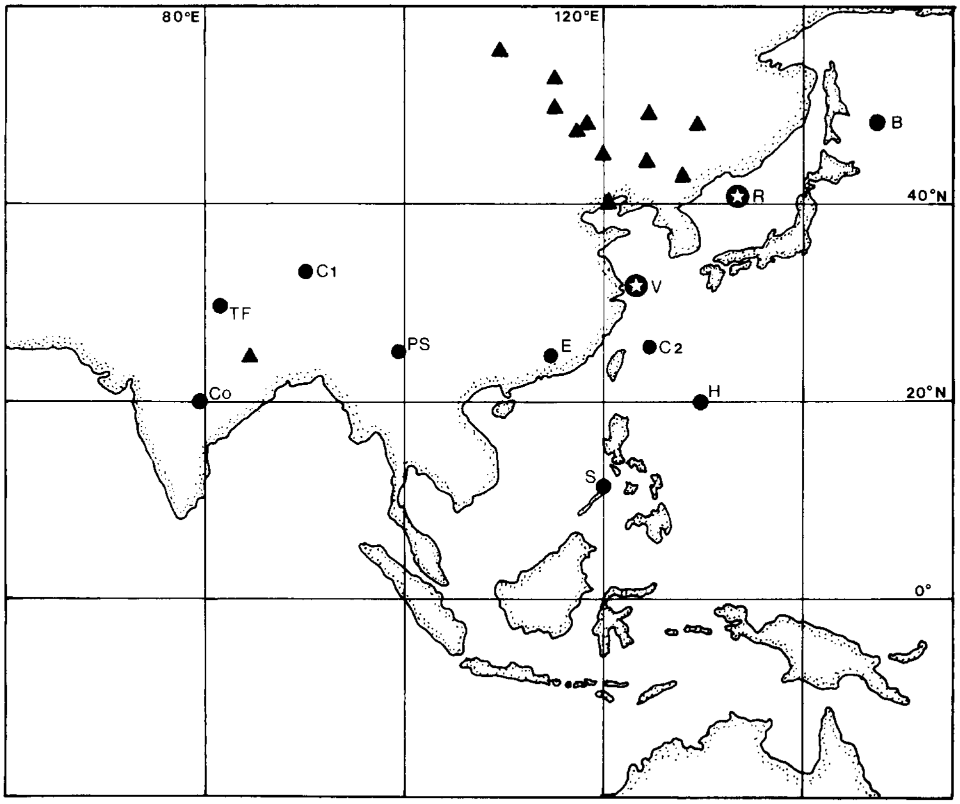

Fig. 7. The paleopoles for the redbeds (*R*) and the volcanics (*V*) are plotted along with the previously published paleomagnetic poles of Devonian rocks from North America listed in Table 1. Solid triangles represent poles from remagnetized rocks, solid circles possible Devonian poles. Labels are as follows: *Co* = Compton metasediments, *TF* = Traveler Felsite, *C1* = Catskill Formation, *C2* = Catskill Formation, *PS* = Peel Sound Formation, *E* = Eastport Formation, *H* = Hersey Formation, *B* = Belchertown Intrusive and *S* = St. Lawrence Granite.

lution of two components of magnetization.

With the exclusion of all the remagnetized poles, including those for the Perry Formation, the scatter in the available North American Devonian paleomagnetic poles is reduced (Fig. 7). The Devonian poles generally are located at the same latitude, but there remains a spread in longitude. This spread in longitude may be due to tectonic rotations or apparent polar wander. However, we note that the ages of the Hersey and Eastport poles (*H* and *E*, respectively), are not well constrained [30,31] owing to an inconclusive fold test. In addition, there are no structural corrections for the pole for the St. Lawrence granite (*S*) or the Belchertown Intrusive (*B*). In other words, the poles for which conclusive stability tests exist cluster between 80–125°E and 20–30°N (poles *Co*, *TF*, *C1*, *C2* and *PS* in Fig. 7).

8. Conclusions

A paleomagnetic reinvestigation of redbeds and volcanics of the Upper Devonian Perry Formation of coastal New Brunswick and adjacent Maine has yielded a characteristic direction in the redbeds that fails a fold test. Comparison of the corresponding paleopoles with published North American APWP indicates that the Perry Formation was remagnetized in Permocarboniferous times. This suggests that previously published data from the Perry Formation [13–15] were based on insufficient laboratory treatments and can no longer be considered as representative of the Devonian geomagnetic field. The characteristic direction seen in the basalts of the Perry Formation is thought to be contaminated by the incomplete removal of a steep overprint related to the present-day field. Reflected light microscopy, IRM acquisition experiments, unblocking temperatures, and coercivities indicate that the magnetic carrier is hematite in the sediments, and that both hematite and magnetite carry the magnetization in the volcanics. The remagnetization is thought to be related to both chemical and thermal processes of the Alleghenian/Variscan orogeny.

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