67-39

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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1. PALAEOMAGNETIC DIRECTIONS OF A BASIC SILL IN PRINCE EDWARD ISLAND

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A. Larochelle

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CONTENTS

1. PALAEOMAGNETIC DIRECTIONS OF A BASIC SILL IN PRINCE EDWARD ISLAND

ABSTRACT

Palaeomagnetic directions were obtained for 12 oriented samples collected from the only known occurrence of igneous rocks in Malpeque Bay, Prince Edward Island. These results suggest that the igneous rocks intruded the red beds in the area during Upper Permian time, prior to a period of mild folding.

INTRODUCTION

The Prince Edward Island red beds are presently believed to have been deposited as early as late Pennsylvanian or early Permian (Langston, 1963) but the age of the uppermost of these beds has not been definitely established because no fossil remnants have so far been found in them. The only known occurrence of igneous rocks within these beds is that at the eastern tip of George Island (part of Hog Island), Malpeque Bay. These rocks appear to have been injected as a sill into the red sandstones while the latter were still undisturbed and apparently unconsolidated. As the age of the red sandstone in this area is somewhat uncertain, any information pertaining to the intrusive would be of geological interest.

GEOLOGICAL SETTING

Milligan (1949) described the igneous rock as a dyke that "... strikes in a general NNW direction and dips eastward at about 15 degrees, though the contact is not clearly defined. The hanging-wall sandstones have been eroded away, but the remnants of the dyke appear to be at least 10 feet thick." The fine-grained blackish part of the intrusive mass is an olivine basalt. Milligan regards the exposures of sheared and brecciated intrusive along the northwest side of the outcrop as denoting a fault zone. V.K. Prest (pers. comm.) on the other hand, regards the rock body as a sill. The hanging-wall sandstone, which appears "baked" was seen at the southeastern tip of the point. The intrusive beneath the contact varies from a black, aphanitic rock through a vesicular breccia containing xenoliths which give it a maroon tinge. In fact, much of what appears to be a reddish vesicular part of the dyke is a baked sandstone profusely spotted with light coloured, 'foreign' rock fragments. Prest considers that the sandstone was unconsolidated at the time of the intrusion. This deduction is in harmony with Milligan's statement that the dyke probably predates the warping observed in the sediments.

SAMPLING AND MAGNETIZATION MEASUREMENTS

Sixteen independently oriented samples were collected from the only known outcrop of the sill by R.F. Black in 1960. The sampling points

Manuscript Received: June 5, 1967.

TABLE I: MAGNETIZATION DIRECTIONS

SAMPLE NO.	NATURAL REMANENT MAGNETIZATION		AFTER 300 Oe. CLEANING			
	D°	I°	D°	I°	θ°	$\Delta J / J_{300}$
1 - B	186.7	-17.5	190.7	-19.1	9.1	2.6
1 - K	172.7	-16.2	172.0	-14.1	1.9	2.2
2 - B	175.8	12.3	176.7	-14.2	2.0	0.5
2 - K	189.8	-8.3	185.6	-14.4	3.3	0.6
3 - B	163.6	78.2	192.9	32.5	19.9	4.0
3 - K	216.2	43.5	211.8	12.4	29.4	5.0
4 - B	1.3	31.4	49.7	-51.3	--	85.5
4 - K	1.5	24.5	38.1	-41.0	3.6	76.5
6 - B	168.2	39.6	176.3	-11.9	8.7	2.1
6 - K	201.9	27.5	196.5	-13.1	12.4	1.6
7 - B	179.8	11.8	174.0	-28.8	9.4	4.7
7 - K	209.2	12.4	194.2	-16.1	5.0	8.6
8 - B	173.7	15.3	173.4	-14.9	4.7	4.2
8 - K	185.8	8.6	186.9	-10.2	1.9	7.2
9 - B	185.7	-5.8	184.7	-18.1	3.8	5.5
9 - K	163.1	-14.2	174.1	-20.2	3.1	6.0
Mean	182.8	5.5	182.1	-16.4	--	--

D: declination relative to True North.
I: inclination relative to horizontal plane.
θ: angular deviation between the two magnetization vectors of a pair of cubes.
J_{300}: intensity of magnetization after cleaning in peak field of 300 oersteds.
Mean directions calculated with the omission of inhomogeneous samples 3-B and 3-K and unstable samples 4-B and 4-K.

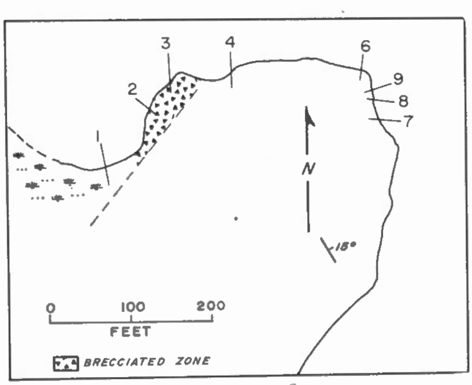

Figure 1.
Map showing location of sample points (numbers), northeast tip of George Island, Malpeque Bay, N.S.

were distributed over a distance of about 500 feet along the north and east shore of the northeast tip of George Island (Fig. 1) a part of Hog Island. A solar compass was used for the orientation.

The mean direction of remanent magnetization left in the two one-inch cubes cut from each of these samples was determined before and after the cubes had been subjected to an alternating field cleaning treatment in a peak field of 100, 200 or 300 oersteds. The magnetization of 14 of these samples (samples 3-B and 3-K being excepted) was considered stable by Black (unpublished data, Geological Survey of Canada) who computed their mean direction as having a declination of 180.6° and an inclination of -18.9°. The precision index of Black's data is relatively low however (k = 11.3, or angular standard deviation (A.S.D.) = 24°), considering that the samples come from a single site.

An independent series of measurements was carried out recently on a new set of one-inch cube pairs cut from the left-overs of Black's samples which were still available. The magnetization of these cubes was determined with a biastatic automatic magnetometer (Larochelle and Christie, 1967) and the alternating field cleaning treatments imposed on the individual cubes were carried out with the apparatus described by Larochelle and Black (1965).

RESULTS AND DISCUSSION

The mean directions of magnetization of the cube pairs (enough material was available for only one cube of sample 4-B) are listed in Table I. Denoting by J_{300} the mean remanent magnetization intensity of a sample after it has been submitted to a 300 oersted alternating field treatment and by ΔJ the difference $(J_0 - J_{300})$, the ratio $\Delta J/J_{300}$ was computed for each sample. These values are also listed in Table I along with the angles θ between the remanent magnetization directions obtained for each cube of a pair. These two parameters were used as criteria for magnetization stability and homogeneity respectively. On this basis, samples 3-B and 3-K were rejected as inhomogeneously magnetized and samples 4-B and 4-K, as unstably magnetized. The mean directions of the other 12 samples prior to and after the cleaning treatment are listed on the last line of Table I.

It is interesting to note that the mean direction of magnetization of the cleaned samples diverges by less than 3° from that obtained by Black and reported earlier. However, the precision of the new data is considerably higher (k = 69.9 or A.S.D. = 9.7°) and is more acceptable as a within-site precision. An explanation for the greater clustering in the present data can only lie in the improved measuring and cleaning techniques developed in this laboratory over the past few years.

Assuming a geocentric dipole field at the time the Malpeque Bay sill was magnetized and assuming that the latter has not been disturbed since the time of its emplacement, a pole position was computed on the basis of the mean direction of magnetization of the cleaned stable samples (112.8E, 51.7N). If, on the other hand, it is assumed that the sill has been tilted 15° east-northeasterly, the corresponding pole position turns out to be at the point of 111.0°E longitude and 50.4°N latitude. It is thus immaterial whichever assumption is made concerning the possible tilting of the sill. It is

TABLE II: POLE POSITIONS DERIVED FROM TRIASSIC AND PERMO-CARBONIFEROUS FORMATIONS OF NORTH AMERICA

			POLE POSITION					
	FORMATION	AGE	E longitude	N latitude	N	$\delta\chi$ (deg)	$\delta\psi$ (deg)	REFERENCE
1	Newark Series (New Jersey)	Upper Triassic	108	63	29	4	3	Opdyke (1961)
2	Manicouagan Group	Lower Triassic	88 1/2	60 1/2	11	6	3 1/2	Larochelle and Currie (1967)
3	Pennsylvania dykes	Upper Triassic	105	62	20	3	2	Beck (1965)
4	Great Shelburne dyke	Upper Triassic	98	69	2	4	2 1/2	Larochelle and Wanless (1966)
5	North Mountain Basalt	Upper Triassic	113	66	17	10 1/2	6	Larochelle (1967)
6	Prince Edward Island *	Permo-Carb.	127	42	70	7	4	Roy (1966)
7	Red Beds (East) *	Permo-Carb.	122	41	59	5	3	Black (1964)
8	Red Beds (Centre) *	Permo-Carb.	128	39	69	5	3	Black (1964)
9	Red Beds (N.W.) *	Permo-Carb.	129	40	26	5	3	Black (1964)
10	Bonaventure fm. *	Permo-Carb.	133	38	21	10	5	Roy (1966)
11	Bonaventure *	Permo-Carb.	131	34	22	7	3	Black (1964)
12	Dunkard Series *	Permian	123	44	101	5	2	Helsley (1965)
13	Malpeque Bay sill *	---	111	50 1/2	12	5	2 1/2	This paper

N: number of sites (* samples) on which mean directions and error limits ($\delta\chi$ and $\delta\psi$) are based at the .95 probability level.

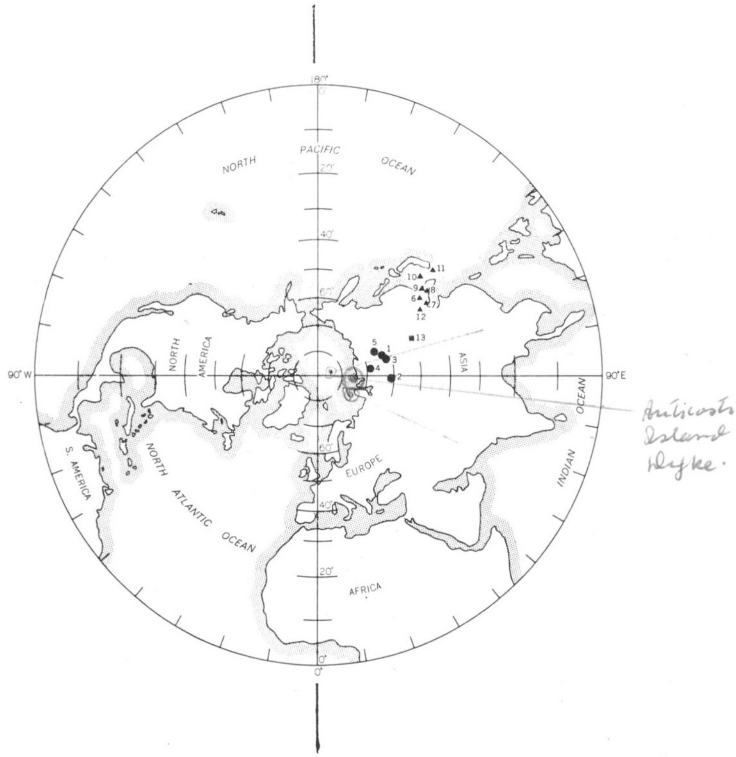

Figure 2. Pole positions derived from Triassic (circles), Permo-Carboniferous (triangles), and P.E.I. sill (square). Numbers refer to entries in Table II.

pointed out however that either one of the two pole positions given above are necessarily virtual geomagnetic pole positions since it is unlikely that the sill took more than a few years to cool entirely through its Curie point.

Dating rocks on the basis of their palaeomagnetism is still somewhat speculative unless the rocks dealt with form a continuous sequence in the upper part of the Quaternary. It is however possible to suggest in the present case that the Malpeque Bay sill is more likely Permian in age rather than Triassic or younger because its magnetization is southerly directed unlike that of other Triassic rocks in the area.

Figure 2 is a stereographic plot of pole positions derived from the North American Triassic, Permo-Carboniferous and Permian formations listed in Table II. It is interesting to note that both of the pole positions given above for the Malpeque Bay sill fall about half-way between the Triassic and the Permo-Carboniferous and Permian poles. This suggests, in accordance with the presently available geological information, that minor igneous activity took place in Prince Edward Island toward the closing of the Permian.

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2. PRELIMINARY DATA ON THE PALAEOMAGNETISM OF THE NORTH MOUNTAIN BASALT, NOVA SCOTIA

ABSTRACT

A palaeomagnetic pole position was obtained from 28 stably magnetized oriented samples collected from 17 sites along the North Mountain Basalt, Nova Scotia. This point differs substantially from that previously obtained from another suite of samples from the same rocks and it is in much better agreement with poles derived from other North American Triassic formations. These data suggest again that the mean North American Triassic pole was at least 10 degrees farther north than generally thought on the basis of early palaeomagnetic measurements.

INTRODUCTION

A virtual palaeomagnetic pole position and a whole rock K/Ar age were recently published (Larochelle and Wanless, 1966) for the Shelburne dyke along the southeast coast of Nova Scotia. As it has been suggested from time to time that this dyke may be genetically and chronologically related to the North Mountain Basalt, it is somewhat intriguing that the only available palaeomagnetic pole (Bowker in Cox and Doell, 1960) for the North Mountain Basalt (75 1/2°E, 77°N) is significantly distinct from that obtained by the writer for the Shelburne dyke (98°E, 69°N), although the ellipses of confidence about the two poles do overlap. It recently occurred to the writer that a preliminary investigation of the problem could possibly be made with a suite of 38 oriented samples collected from 19 sites in 1958 by P.M. DuBois and R.F. Black from the North Mountain Basalt between Cape Blomidon and Margaretville. They had measured the directions of natural remanent magnetization (NRM) of the 38 samples but attempts to submit the latter to an alternating field cleaning treatment in a peak field of 300 oersteds had proved unsuccessful. With the availability of an improved alternating field cleaning apparatus in this laboratory, the 38 samples were recently cleaned in a peak field of 350 oersteds. This paper describes the results of this work.

GEOLOGIC SETTING

The North Mountain Basalt forms a 200 kilometer ridge along the southeastern shore of the Bay of Fundy. The black and dark reddish tholeiitic lavas have been separated in the field into at least 16 parallel basalt or dolerite flows (Klein, 1962) totalling 875 feet in thickness at the type section in Kings county. The flows lie between the Blomidon Formation and the Scots Bay Formation, both of late Triassic age. The sequence dips between 1 and 10 degrees northwesterly toward the Bay of Fundy. The remarkable parallelism of the flows suggests that they were extruded probably from a fissure within and parallel to the long axis of the Bay of Fundy.

Manuscript Received: May 28, 1967.

SAMPLING PROCEDURE AND PRELIMINARY MEASUREMENTS

It is indicated in DuBois and Black's notes that the samples were oriented in situ with a solar compass when possible and with a Brunton compass held away from the outcrop. With two exceptions, two 1-inch cubes were cut from each sample and their natural remanent magnetization was measured. The direction of magnetization of a sample was taken as that of the mean of the magnetization vectors obtained for each cube. Results of these measurements extracted from a report by Black (1965) are reproduced below in columns 2 and 3 of Table I.

ALTERNATING FIELD CLEANING

The predominant magnetic mineral in the rocks studied being magnetite (Klein, 1962) it appeared likely that the NRM vectors bore a component of viscous or isothermal magnetization. The directions obtained by DuBois and Black after they had submitted their samples to an alternating field of 300 oersteds were highly scattered and apparently considered unreliable by Black who did not include them in his report.

The 38 samples were recently treated by the writer in a 350 oersted field with the apparatus described by Larochelle and Black (1965). The residual magnetization of each cube was then determined with an automatic astatic magnetometer (Larochelle and Christie, 1967) allowing the directions of magnetization to be determined at an accuracy better than 1 degree. The internal deviation (I.D.) between the magnetic vectors of the pair of cubes representative of each sample was taken as a criterion for magnetization homogeneity and when this angle exceeded 23 degrees, the sample's magnetization was considered inhomogeneous even though the resultant vector did not diverge appreciably from that of some of the homogeneously magnetized samples in most cases. As it turned out, 10 samples were rejected on that basis and the data obtained for the remaining 28 are listed in columns 6 and 7 of Table I. An appreciable amount of pyrrhotite was noted in some of the inhomogeneous samples.

ANALYSIS OF RESULTS AND DISCUSSION

In columns 4 and 5 of Table I the within-site angular standard deviations (A.S.D.) are listed respectively for the directions of natural and cleaned magnetizations. An overall estimate of the same statistic (Larochelle, 1967) for the two groups of data respectively is given on the last line of the table. In both instances it was found that the between-site A.S.D. was significantly larger than the within-site A.S.D., which indicates that the sites were likely picked on different flows and/or have undergone different degrees of tilting. The field information required to assess the relative importance of these two factors is not available, however, and the analysis may not be carried further along this line. Nevertheless, the precision of the present data being slightly greater than that of Bowker, it is suggested that at least the North Mountain Basalt palaeomagnetism should be re-examined if the present data are to be regarded only as provisional.

TABLE I: MAGNETIZATION DIRECTIONS AND DEVIATIONS (DEGREES)

SAMPLE NO.	N.R.M. VS HORIZONTAL D	I	ASD	AFTER CLEANING IN 350 OERSTEDS VS HORIZONTAL ASD	D	I	VS PALAEOHORIZONTAL D	I	I.D.
1 - B	18.0	57.5	12.5	4.6	23.1	48.5	18.9	45.4	13.6
1 - P	45.0	49.5			17.4	53.9	12.8	50.4	16.6
2 - B	6.5	32.5	7.5	6.0	19.5	33.1	17.2	29.8	8.0
2 - P	11.0	42.5			22.9	41.2	19.7	38.1	13.8
4 - B	335.0	43.0	--	--	349.3	33.7	348.3	29.0	17.5
6 - B	24.0	41.0	10.0	2.4	25.6	46.4	21.6	43.4	5.3
6 - P	13.5	53.5			21.7	44.5	18.1	41.3	2.7
7 - B	13.0	36.5	3.8	6.6	11.0	33.5	9.0	29.7	1.5
7 - P	19.5	35.0			22.3	34.3	19.8	31.2	0.6
8 - B	348.0	45.5	19.7	3.6	23.2	48.5	19.0	45.4	2.4
8 - P	20.5	32.5			24.2	43.4	20.6	40.3	0.9
9 - P	291.0	23.0	--	--	34.7	43.3	30.7	41.0	2.6
10 - B	10.5	54.0	5.5	3.5	31.3	45.0	27.2	42.4	5.3
10 - P	22.5	51.0			25.0	47.4	20.9	44.4	1.3
11 - B	327.5	60.0	--	--	0.0	53.1	357.1	48.7	2.1
12 - B	25.5	44.0	15.3	1.1	21.9	41.1	18.7	37.9	1.3
12 - P	0.5	34.0			23.6	40.2	20.4	37.1	1.8
13 - B	0.5	46.5	14.2	18.6	4.7	35.0	2.9	30.8	9.4
13 - P	332.0	53.5			331.9	38.1	331.8	33.1	3.6
14 - B	351.5	40.5	--	--	3.7	30.4	2.2	26.2	11.3
15 - B	331.5	35.5	4.9	1.5	348.9	31.2	348.0	26.5	--
15 - P	331.5	42.5			330.2	37.3	330.2	32.3	1.1
16 - B	337.0	38.0	7.8	5.4	337.8	32.4	337.4	27.4	3.4
16 - P	339.0	49.0			332.9	38.9	332.7	33.9	2.6
17 - B	349.5	49.0	20.6	20.8	348.8	47.4	347.3	42.6	0.1
17 - P	34.0	47.5			31.1	43.9	27.1	41.3	0.3
18 - P	4.0	54.0	--	--	343.3	41.4	342.4	36.5	--
19 - P	16.0	63.0	--	--	313.3	20.4	313.8	15.6	13.5
Mean	356.0	48.5	13.7	11.7	3.3	42.2	1.1	38.0	--

D: declination east of True North.
I: Inclination below horizontal or estimated palaeohorizontal plane.
ASD: Angular within-site standard deviation.
I.D.: Within-sample deviation
Estimated palaeohorizontal plane strike 60°, dip 5° N.W.
The overall mean directions are based on site mean directions.

TABLE II

	FORMATION	E longitude (degrees)	N latitude (degrees)	N	$\delta\chi$ (deg.)	$\delta\psi$ (deg.)	REFERENCE
1	Newark Series (New Jersey)	108	63	29	4	3	Opdyke (1961)
2	Manicouagan Group	88 1/2	60 1/2	11	6	3 1/2	Larochelle and Currie (1967)
3	Pennsylvania dykes	105	62	20	3	2	Beck (1965)
4	Shelburne dyke	98	69	2	4	2 1/2	Larochelle and Wanless (1966)
5	North Mountain Basalt	113	66	17	10 1/2	6	This paper

N is the number of sites.
$\delta\chi$ and $\delta\psi$ are the axes of the ellipses of confidence about the poles at the 95% probability level.

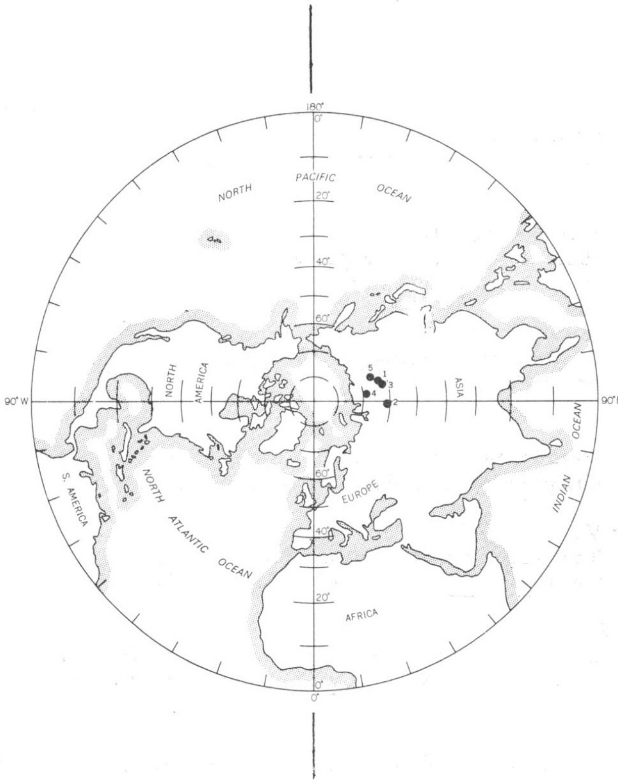

Figure 1. Palaeomagnetic pole positions derived from North American Triassic formations. Numbers correspond to entries in Table II.

Assuming that the flows dip northwesterly by an angle of 5° and that their surface corresponds to the palaeohorizontal plane, the site mean directions of magnetization were related to it. A palaeomagnetic pole position (113°E, 66°N) computed on this basis is in surprisingly good agreement with that obtained previously for the Shelburne dyke and substantially different from that derived from Bowker's data. This pole is listed in Table II along with apparently reliable palaeopole positions derived from other North American Triassic formations (Fig. 1).

With the exception of the Manicouagan Group (Lower Triassic) the formations listed in Table II have been dated as Upper Triassic either on faunal evidence and/or by isotopic methods. Their computed centre of gravity is at 102°E longitude and 64°N of latitude and their angular standard deviation is 5.4°, which is remarkably small. These results suggest that the mean position of the north pole in Triassic time may have been at least 10 degrees farther north than generally thought (Irving, 1964) on the basis of early measurements and that either the Upper Triassic units listed in Table II were contemporaneous or the secular variation was not as important during the Triassic as it is today.

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