71-24

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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2. PALEOMAGNETIC NOTES ON THE KARMUTSEN BASALTS, VANCOUVER ISLAND, BRITISH COLUMBIA

D. T. A. Symons

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Illustrations

PALEOMAGNETIC NOTES ON
SOME MINOR TERTIARY IGNEOUS BODIES,
VANCOUVER ISLAND, BRITISH COLUMBIA

ABSTRACT

Paleomagnetic measurements on 130 core specimens from 13 sites in known or presumed Tertiary igneous bodies indicate that all tested bodies have a stable primary remanence of probable Tertiary age. The Kennedy Lake and Tofino quartz diorite stocks, dated radiometrically at 59 ± 3 and 50 ± 5 m.y. respectively, represent two distinct intrusive events on the basis of remanence direction. The Mount Washington quartz diorite stock (35 ± 6 m.y.) is contemporaneous with surrounding porphyritic dacite sills such as those sampled near Anderson Lake and Bevan, and nearly contemporaneous with the porphyritic dacite sills in the Englishman River area such as the one beside Dash Creek which gives an antiparallel remanence direction. On northern Vancouver Island the rhyolite flow and tuff adjacent to the Cluxewe River may be contemporaneous with the Mount Washington intrusive event while the basalt flow on Twin Peaks is tentatively thought to represent a younger event.

RÉSUMÉ

Les mesures paléomagnetiques effectuées sur 130 échantillons de carottes provenant de 13 emplacements dans des formations de roches ignées, connues ou présumées du Tertiaire, indiquent que toutes les formations étudiées possèdent une rémanence primaire stable, datant probablement du Tertiaire. Les massifs de diorite à quartz du lac Kennedy et de Tofino, datés au radiomètre (respectivement 59 ± 3 et 50 ± 5 millions d'années) représentent deux phases intrusives distinctes, d'après la direction de la rémanence. Le massif de diorite à quartz du mont Washington (35 ± 6 millions d'années) est contemporain des filons-couches de dacite porphyritique environnants, par exemple ceux dont on a prélevé des échantillons près du lac Anderson et de Bevan, et presque contemporain des filons-couches de dacite porphyritique de la région de la rivière Englishman, comme celui qui se trouve au-delà de Dash Creek et qui indique une direction de rémanence antiparallèle. Dans le nord de l'île Vancouver, la coulée et le tuf de rhyolite adjacents à la rivière Cluxewe peuvent être contemporains du massif intrusif du mont Washington, alors que la coulée de basalte de Twin Peak est, pour autant que l'on puise penser, beaucoup plus jeune.

PALEOMAGNETIC NOTES ON SOME MINOR TERTIARY IGNEOUS BODIES, VANCOUVER ISLAND, BRITISH COLUMBIA

INTRODUCTION

There are several igneous bodies of known or presumed Tertiary age on Vancouver Island (Fig. 1). Most of the bodies sampled are described by Muller and Carson (1969). The Kennedy Lake quartz diorite stock on the west coast of the island (site 5) is about 10 miles long by 1 mile wide with several small satellite stocks. It gives a Paleocene date of 59 ± 3 m.y. The similar Tofino quartz diorite stock (site 4), 20 miles to the northwest, outcrops over an area of 1 mile in diameter on the north end of Esowista Peninsula, Felix Island and Stubbs Island where it gives an Eocene date of 50 ± 5 m.y. An adjacent stock on Catface Mountain gives a similar age of 48 ± 12 m.y. The Mount Washington quartz diorite stock (sites 8 and 9) is about 1 mile in diameter and gives an Oligocene date of 35 ± 6 m.y. It is thought to be genetically related to some surrounding porphyritic dacite sills such as those capping the butte by Anderson Lake (sites 6 and 7) some 6 miles to the east, and the one (sites 10 and 11) outcropping immediately north of the town of Bevan some 10 miles southeast of Mount Washington. Another very small but similar diorite stock some 10 miles to the southwest of Mount Washington

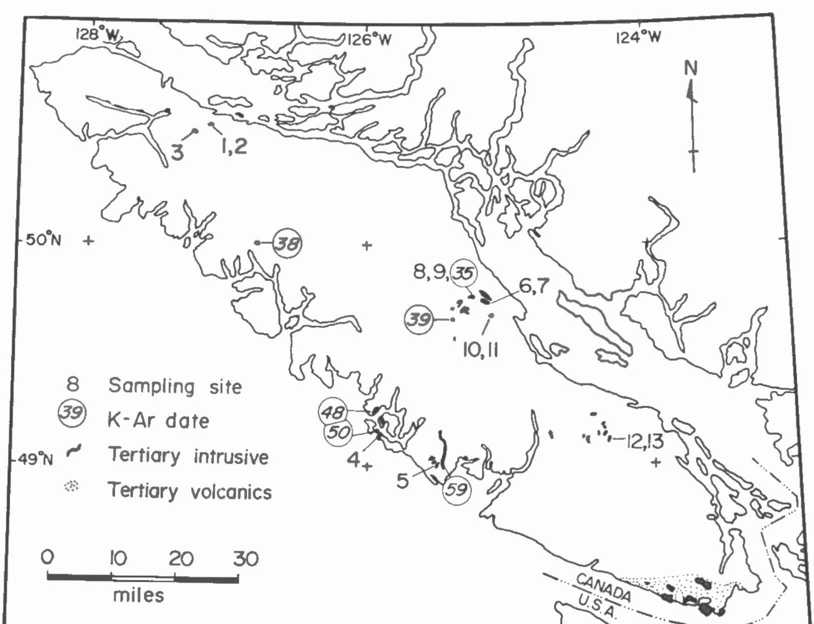

Figure 1: Location of sampling sites and Tertiary igneous rocks on Vancouver Island.

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TABLE 1: SITE REMANENCE STATISTICS

Site	Location	Geology	n	SI	H_{af}	Site mean remanence direction			
						D	I	R	SE
1	Cluxewe River	rhyolite flow	5	10.0	100	182.5	-81.8	4.9988	0.6
2	Cluxewe River	rhyolitic tuff	5	7.7	200	170.1	-82.1	4.9959	1.2
3	Twin Peaks	basalt flow	5	30.7	200	182.9	-57.5	4.9904	1.8
4	Tofino	quartz diorite stock	2	6.1	200	32.1	45.5	1.9954	2.8
5	Kennedy Lake	quartz diorite stock	3	19.2	100	216.4	-64.2	2.9941	2.5
6	Anderson Lake	porphyritic dacite sill	0	2.4	300				
7	Anderson Lake	porphyritic dacite sill	5	28.6	100	118.2	-78.9	4.9951	1.3
8	Mt. Washington	quartz diorite stock	5	11.6	100	184.2	-81.1	4.9977	0.9
9	Mt. Washington	quartz diorite stock	3	0.4	100	156.7	-82.7	2.9900	3.3
10	Bevan	porphyritic dacite sill	5	7.1	100	148.4	-71.8	4.9936	1.4
11	Bevan	porphyritic dacite sill	5	2.4	200	125.9	-73.3	4.9790	2.6
12	Dash Creek	porphyritic dacite sill	5	12.3	200	301.3	72.0	4.9936	1.4
13	Dash Creek	porphyritic dacite sill	5	5.9	200	295.2	79.7	4.9871	2.1

Notes:

n — number of cores representing site, each with two specimens

SI — stability index

H_{af} — AF demagnetizing field intensity used to "clean" remanence

D, I, SE — declination, inclination and standard error in degrees

R — resultant giving each core vector unit length gives an age of 39 $\pm$ 7 m.y. In addition, a number of mountains in the headwaters of the Englishman River are also capped by porphyritic dacite sills which are thought to be of Eocene age also. One sill of this cluster was sampled (sites 12 and 13) on a butte just west of Dash Creek. The radiometric dates have all been made by the K-Ar method on biotite (Wanless et al., 1967, 1968).

The remaining two sampled bodies are at the north end of Vancouver Island (Muller, 1970) and on the basis of stratigraphic and topographic position they are presumed by J.E. Muller (pers. comm.) to be Tertiary in age. One is a rhyolite flow about 20 feet thick (site 2) overlain by a rhyolitic tuff (site 1) which caps a small butte ($\simeq$1/3 mile in diameter) surmounted by a forestry lookout beside the Cluxewe River. The second, 8 miles to the west, is a 10-foot-thick basalt flow (site 3) outcropping on the upper eastern flank of Twin Peaks.

Two other Tertiary igneous formations on the south end of Vancouver Island are presently being studied paleomagnetically. E. Irving (pers. comm.) finds that the Metchosin volcanics are dominated by unstable remanence components. The author finds that the Sooke gabbro is magnetically very stable and may contain a normal to reverse transition zone, and he is now working on a more extensive collection of cores from this body.

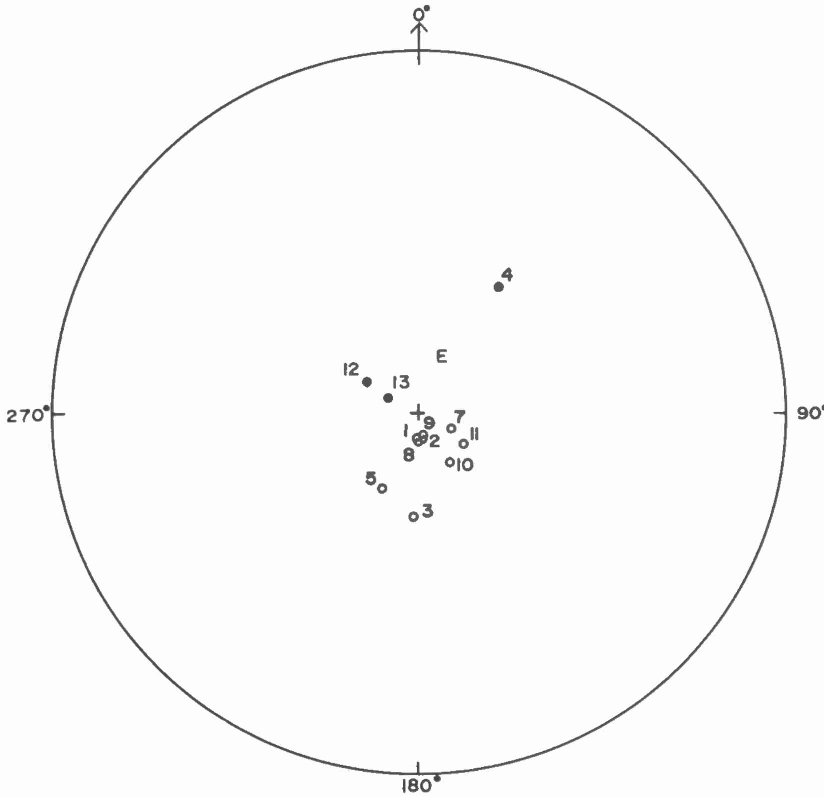
The purpose of this study was to determine whether or not these scattered igneous bodies retained a stable primary remanence which could be used to correlate between them and to confirm their presumed Tertiary age particularly for those bodies which are not suitable for radiometric dating.

METHOD

Five cores, each oriented in situ by sun compass and yielding two specimens, were collected from each of the 13 sites. After measuring the natural remanent magnetization (NRM) of all the specimens, one pilot specimen from each site was demagnetized stepwise in alternating field (AF) peak intensities of 50, 100, 200, 300, 400, 500, 650 and 800 Oe and its remanence remeasured after each step. Based on the results of the pilot specimen, the remaining specimens from each site were AF demagnetized in a selected field (Table 1). After demagnetization, two cores from site 5 gave remanence intensities below the level of reliable remanence direction determination (i.e. $< 5 \times 10^{-7}$ emu/cc) and were rejected. In 10 cores (3 from site 4; all 5 from site 6; and 2 from site 9) with rather low remanence intensities (i.e. $< 5 \times 10^{-6}$ emu/cc), the angle between the remanence directions of the two specimens exceeded 20°. In the present context, these cores were considered to be insufficiently homogeneously magnetized and were also rejected. The site mean remanence direction and dispersion statistics were then calculated for the 12 valid sites (Table 1).

DISCUSSION

Except for site 9, the stability index (SI) values for all the pilot specimens indicate stable remanence (Tarling and Symons, 1967). The presence of homogeneous primary stable remanence is further indicated by the low standard errors of $<$3.3° for all 12 valid sites, the presence of



1 and 2 - Cluxewe River tuff and rhyolite;
3 - Twin Peaks flow;
4 - Tofino stock;
5 - Kennedy Lake stock;
7 - Anderson Lake sill;
8 and 9 - Mount Washington stock;
10 and 11 - Bevan sill;
12 and 13 - Dash Creek sill;
E - is the earth's present magnetic field direction.

Figure 2: Stereographic equal-area projection of site mean remanence directions. Solid (open) circles indicate positive (negative) or downwardly (upwardly) inclined directions.

reversed remanence in 9 of 12 sites, and the non-alignment of any of the sites with the earth's present magnetic field direction (Fig. 2). Although a few cores proved unreliable because of low remanence intensities probably reflecting too low a magnetite concentration, most sites and all bodies tested yield reliable remanence directions.

A few conclusions are apparent from the site mean remanence directions and the analysis of their variance ratios. First, the Mount Washington quartz diorite stock and adjacent Anderson Lake and Bevan porphyritic dacite sills give a consistent cluster of reversed remanence directions (Fig. 2) and are almost certainly contemporaneous as Muller and Carson (1969) suggest.

TABLE 2: VARIANCE RATIO TESTS

Remanence Directions Compared	δ_b^2/δ_w^2	$F_{.05}$
Within-body		
Mt. Washington stock - site 8 to site 9	2.35	3.88
Bevan sill - site 10 to site 11	5.28	3.63
Dash Creek sill - site 12 to site 13	9.60	3.63
Cluxewe River - rhyolite flow (site 2) to tuff (site 1)	1.80	3.63
Between-bodies		
Kennedy Lake stock (site 5*) to Tofino stock (site 4)	18.53	5.14
Mt. Washington stock (sites 8, 9) to Anderson Lake (site 7) and Bevan (sites 10,11) sills	18.80	3.22
Cluxewe River flow (sites 1, 2) to Twin Peaks flow (site 3)	244.92	3.37
Mt. Washington complex (sites 7 to 11) to Dash Creek sill (sites 12*, 13*)	(1.07)	4.10
Mt. Washington complex (sites 7 to 11) to Cluxewe River flow (sites 1,2)	(1.61)	4.10

Notes:

* polarity of remanence reversed

δ_b^2, δ_w^2 between-site and within-site angular variances using mean core (site) remanence directions

$F_{.05}$ theoretical value at the 95% confidence level of the statistic F

TABLE 3: POLE POSITIONS BY SITE UNIT WEIGHT

Body	Age	N	Lat. °N	Long. °E	d_ψ d_χ	P
Kennedy Lake stock	Paleocene (59 ± 3 m.y.)	1 (3,6)	65.5	317.5		-
Tofino stock	Eocene (50 ± 5 m.y.)	1 (2,4)	56.8	354.2		+
Mt. Washington complex	Oligocene (37 ± 5 m.y.)	5 (23,46)	64.3	202.9	9.6, 10.2	-
Dash Creek sill	Oligocene - probable	2 (10,20)	54.9	192.5	11.5, 12.5	+
Cluxewe River flow and tuff	Oligocene - probable	2 (10,20)	66.3	230.4	2.9, 3.0	-
Twin Peaks flow	Oligocene - Recent (?)	1 (5,10)	77.5	42.4		-

Notes:

N — number of sites (cores, specimens)

$d\psi$, $d\chi$ — semi-axes of oval of 95% confidence in colatitude direction and perpendicular to it

P — polarity of earth's magnetic field indicated

Variance ratio analysis indicates that the two sites on Mount Washington are not statistically significantly different (i.e. $\delta_b^2/\delta_w^2 < F_{.05}$, Table 2) whereas those from the Bevan sill are different. The probable explanation is that minor post-intrusion tectonic movements have not deformed the stock but have caused slight between-site rotation in the more extensive sills. Further, the fact that the variance ratio test between the stock and the sills is not statistically significant is thought to reflect the abnormally high consistency of the Mount Washington stock sites and the probability of minor post-intrusion differential tilting of the sills during subsequent minor block faulting. The same between-site effect is seen in the Dash Creek sill (i.e. $\delta_b^2/\delta_w^2 < F_{.05}$, Table 2).

Second, the Dash Creek sill gives remanence directions that are almost exactly antiparallel to the Mount Washington group which suggests that they are very similar in age but not precisely contemporaneous since sufficient time for reversal of the earth's magnetic field must have elapsed between the two intrusive events.

Third, the rhyolite flow and overlying tuff by the Cluxewe River are absolutely contemporaneous giving reversed remanence directions which are barely 1° apart ($\delta_b^2/\delta_w^2 \ll F_{.05}$) and their directions fall within 1° of those from the Mount Washington stock suggesting that these two intrusive events are nearly contemporaneous if not exactly contemporaneous.

Fourth, the Twin Peaks basalt flow and Cluxewe River rhyolite flow give divergent remanence directions and therefore probably represent different periods of extrusion. Very tentatively, the Twin Peaks flow may be the younger event as it gives a pole position closer to present earth's geographic pole. Alternatively these two extrusive events could differ in age by only a few hundred years with secular variation accounting for the divergence.

Fifth, the remanence directions for the Kennedy Lake stock and Tofino stock differ in polarity, diverge from antiparallelism by some 20°, and give a variance ratio excluding polarity which indicates that they are statistically different and hence that they clearly represent two distinct intrusive events. This result supports the radiometric evidence for the two stocks which yield age dates of 59 $\pm$ 3 and 50 $\pm$ 5 m.y. respectively.

Finally, all of the bodies tested give pole positions (Table 3) which are reasonably consistent with positions determined for other Tertiary rock formations of North America (Irving, 1964).

SUMMARY

The results of this study have shown that: (1) all of the igneous bodies studied retain a stable remanence of probable primary origin; (2) the remanence in all bodies studied was most likely acquired during the Tertiary thereby confirming the available radiometric and limited geological evidence; and (3) the paleomagnetic method is eminently suited for establishing correlations between these bodies and the other similar bodies found in the Englishman River, Mount Washington, Kennedy Lake and Tofino areas (Fig. 1).

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REFERENCES

Irving, E.
1964: Paleomagnetism; J. Wiley & Sons, New York, 399 pp.

Muller, J. E.
1970: Northern Vancouver Island, British Columbia; in Report of Activities, April to October 1969; Geol. Surv. Can., Paper 70-1, Part A, pp. 44-49.

Muller, J. E., and Carson, D. J. T.
1969: Geology and mineral deposits of Alberni map-area, British Columbia; Geol. Surv. Can., Paper 68-50, 52 pp.

Tarling, D. H., and Symons, D. T. A.
1967: A stability index of remanence in palaeomagnetism; Geophys. J. Roy. Astr. Soc., vol. 12, pp. 443-448.

Wanless, R. K., Stevens, R. D., Lachance, G. R., and Edmonds, C. M.
1967: Age determinations and geological studies, K-Ar isotopic ages, Report 7; Geol. Surv. Can., Paper 66-17, 120 pp.

1968: Age determinations and geological studies, K-Ar isotopic ages, Report 8; Geol. Surv. Can., Paper 67-2, Part A, 141 pp.

PALEOMAGNETIC NOTES ON THE KARMUTSEN BASALTS, VANCOUVER ISLAND, BRITISH COLUMBIA

ABSTRACT

The 19,000-foot-thick Karmutsen Formation contains 2- to 50-foot-thick basalt and andesite flows with minor sedimentary interbeds deposited in a Late Triassic eugeosyncline. They have been slightly metamorphosed to pumpellyite facies by burial, gently folded probably during the Early Jurassic, and slightly tilted by Tertiary block faulting, however dips rarely exceed 25 degrees. After alternating-field demagnetization, a reliable stable remanence was isolated in 12 of 24 flow sites (119 cores tested). The 12 site mean remanence directions form two distinct groups, one positively inclined (normal), and the second at right angles to it and negatively inclined (reversed). The normal sites are found in the lower part of the Karmutsen Formation in the Buttle Lake section and the reverse sites in the upper part suggesting potential for paleomagnetic correlation in the formation. Thermomagnetic analysis suggests that relatively pure magnetite is the sole remanence carrier in both groups. The fold test indicates that both groups preferably represent a pre-folding remanence. None of the hypotheses examined to explain the origin of both remanence groups in terms of time, tectonics, secondary remanence and/or aberrations of the magnetic paleofield is without objection.

RÉSUMÉ

La formation de Karmutsen, d'une puissance de 19,000 pieds, contient des coulées de basalte et d'andésite, d'une épaisseur de 2 à 50 pieds, dans lesquelles sont intercalées des couches plus petites de sédiments déposés dans un eugéosynclinal de la fin du Trias. Elles ont été légèrement métamorphisées en un faciès pumpellyite par enfouissement, faiblement plissées, probablement au début du Jurassique, et légèrement basculées par des failles en blocs produites au Tertiaire; toutefois, les pendages n'excèdent que rarement 25 degrées. Après démagnétisation à l'aide d'un champ alternatif, on a pu isoler une rémanence stable et sûre dans 12 des 24 emplacements de coulée (essais effectués sur 119 carottes). Les directions de la remanence moyenne des 12 emplacements forment deux groupes distincts, l'un étant incliné positivement (normal) et l'autre étant perpendiculaire au premier et incliné négativement (inversé). Les emplacements à orientation normale se trouvent dans la partie inférieure de la formation de Karmutsen, dans la section du lac Buttle, et les emplacements à orientation inversée de trouvent dans la partie supérieure, ce qui laisse penser à une corrélation paléomagnétique possible dans la formation. L'analyse thermomagnétique permet de penser que de la magnétite, relativement pure, est seule porteuse de la rémanence dans les deux groupes. L'essai de plissement indique que les deux groupes présentent une rémanence très probablement antérieure à tout plissement. Toutefois, toutes les hypothèses envisagées pour expliquer l'origine des deux groupes du point de vue temps, tectonique, rémanence secondaire ou aberration du champ paléomagnétique, sont sujettes à objection.

PALEOMAGNETIC NOTES ON THE KARMUTSEN BASALTS, VANCOUVER ISLAND, BRITISH COLUMBIA

INTRODUCTION

The Karmutsen Formation, lowermost portion of the Vancouver Group (Muller and Carson, 1969), underlies about one-half of Vancouver Island (Muller, 1970). The formation, up to 19,000 feet thick, is composed of dark grey to black basalt and andesite flows with minor interbedded argillite, limestone and aquagene tuff members. The pillowed, brecciated, and massive flows are commonly amygdaloidal and occasionally porphyritic. They vary in thickness from 2 to 5 feet in the lower part of the formation to 20 to 50 feet in the upper part (Surdam, 1968). The sediments in the upper part contain Late Triassic (Karnian) fossils (Muller and Carson, 1969; Muller, J.E., pers. comm.). The formation was deposited as an early event in the submarine environment of an early Mesozoic Cordilleran eugeosyncline. Subsequent burial to a depth of 5,000 to 20,000 feet has resulted in regional metamorphism up to the subgreenschist pumpellyite facies only. The formation has been gently tilted in broad open folds with dips of generally less than 25 degrees except immediately adjacent to north-striking, vertically dipping faults produced by block faulting.

The study was undertaken to test the potential of paleomagnetism in assisting in regional correlation between flow sequences throughout Vancouver Island, to check on the age of the lower Karmutsen which could be as old as Permian, and to see if Vancouver Island has moved as a tectonic block since the Triassic.

METHOD

Two specimens were cut from each of 119 cores, each oriented in situ by sun compass and collected from 24 sites on Vancouver Island (Fig. 1). After measuring the natural remanent magnetization of each specimen, one pilot specimen from each site was demagnetized step-wise in alternating-field (AF) peak intensities to 50, 100, 200, 300, 400, 500, 650 and 800 Oe with its remanence remeasured after each step. Based on the results from the pilot specimen, a field intensity was selected in which the remaining specimens from the site were AF demagnetized. For 8 sites a second higher field intensity was also used to "clean" the remanence (Table 1).

ANALYSIS

Step demagnetization of the pilot specimens indicates that the remanence in the Karmutsen basalt is dominated by unstable components, i.e. the stability index (SI) values (Tarling and Symons, 1967) (Table 1) indicate that a stable remanence is isolated in less than one-half of the specimens. Also,

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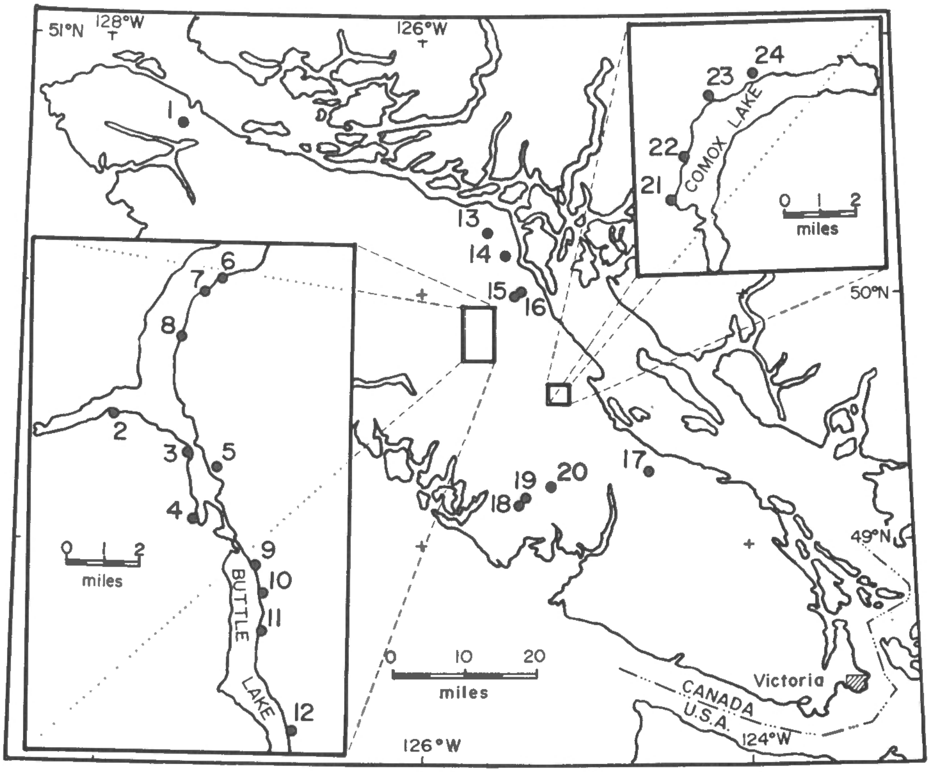

Figure 1: Location of sampling sites in the Karmutsen basalt on Vancouver Island.

anhysteretic remanence (ARM) is apparently introduced by the demagnetization process (Doell and Cox, 1967) above the 300 Oe step in nearly all the specimens as their remanence directions start to scatter randomly and their remanence intensities show irregular variations. ARM is also evident in sites which were AF demagnetized in two field intensities. Except for site 16 which was already well scattered by 300 Oe, the higher field cleaning greatly increased the within-core scatter (Table 2). Except for site 16, the remanence directions for the higher field cleaning are not considered further.

The 16 cores with remanence intensities after cleaning below the instrumental limit of 5×10^{-7} emu/cc for consistently reliable remanence direction determination, were rejected (Table 1). Next, the 15 cores were rejected for which the angle θ between the remanence directions of the two contained specimens exceeded 40 degrees. The plots of the mean remanence directions for the remaining 88 cores both before and after tectonic correction proved widely scattered both positively and negatively to the north (Fig. 2) without forming a consistent cluster. Tectonic corrections for the dip in the flows were made by simple rotation about the strike through the dip angle to the horizontal. In addition the cores in more than half of the sites give within-site remanence directions with a smeared, "mixed-polarity" but never

TABLE 1: SITE REMANENCE STATISTICS

Site	Str	Dip	N	SI	H_{af}	Reject			n	Site Mean Remanence					
						a	b	c		D	I	R	SE	D_c	I_c
1	105	35	6	4.6	300		5	1	0						
2	290	15	5	6.3	300	3	1	1	0						
3	305	25	5	7.2	300		1		4	23.8	40.8	3.7412	11.9		
4	275	25	5	9.3	300				5	301.6	63.6	4.9428	4.3	329.6	46.7
5	275	20	5	1.7	400		1		4	19.6	-10.0	3.9751	3.7	21.5	-29.3
6	270	2	5	1.7	200		2		3	329.3	-22.3	2.9694	5.8	328.9	-24.0
7	360	0	5	3.2	300		2		3	338.7	-38.1	2.2962	27.7		
8	280	10	5	6.6	300		1		4	0.3	10.2	1.9240	33.7		
9	265	20	5	7.9	300	3	2		0						
10	290	20	5	1.7	500		5		0						
11	330	25	5	2.0	300				5	0.3	62.9	4.9819	2.5	26.1	45.2
12	280	25	5	2.2	300		2		3	10.6	73.7	2.9685	5.9	10.2	48.7
13	270	20	5	5.9	300		2		3	12.1	68.5	2.9710	5.7	6.7	48.8
14	5	10	5	1.4	300		2		3	26.0	-42.1	2.9754	5.2	16.9	-44.9
15	360	10	5	1.5	200				5	15.0	30.6	3.2855	23.7		
16	360	10	5	0.7	650		3		2	10.2	-51.7	1.9778	8.7	357.3	-52.3
17	310	17	5	1.0	200	4	1		0						
18	270	2	5	1.0	200		3		2	23.6	36.7	1.9948	4.1	23.0	34.9
19	330	3	5	8.0	300		2		3	334.3	41.1	2.9769	5.0	336.9	40.8
20	315	15	3	2.5	400		2	1	0						
21	85	20	5	2.1	300	2	2	1	0						
22	85	20	5	14.2	200		3		2	82.7	-39.0	1.9917	5.2	83.1	-47.0
23	320	15	5	1.0	400	1	2		2	32.6	52.8	1.9998	0.8	13.7	46.1
24	350	10	5	5.2	500	3	1	1	0						

Notes:

Str, Dip — strike and dip of flows in degrees using the right-hand convention

N — number of cores collected

SI — stability index value

H_{af} — intensity of AF demagnetization field in oersteds

Reject — cores rejected because (a) intensity of remanence $<5 \times 10^{-7}$ emu/cc, (b) angle between specimens $\theta > 20°$, and (c) sole remaining core to representing site

n — number of cores given unit weight

D, I, SE — declination, inclination and standard error in degrees

R — length of resultant vector

D_c, I_c — declination and inclination after tectonic correction

TABLE 2: Average within-core scatter on AF demagnetization

Site	H_1	θ_1	H_2	θ_2
5	400	12.3	650	34.4
7	300	20.1	800	79.5
8	300	8.2	650	58.5
15	200	8.0	500	82.7
16	300	41.5	650	39.2
18	200	21.4	500	44.5
22	200	13.7	650	54.5
23	400	32.0	650	74.7

Notes:

H_1, H_2 AF demagnetization field intensity in oersteds

θ_1, θ_2 mean of the θ angles for the site;
θ for a core is the angle between the remanence directory of its two specimens in degrees

TABLE 3: Sites having cores with smeared or "mixed-polarity" remanence directions

Site	Positive Cores	Intermediate Cores	Negative Cores
1	2	4	
3	3	2	
5		2	3
6	2		3
7		2	2
8	3		2
12	3	1	1
13	4		1
14		1	3
15	3	1	1
21	1	1	1
22	3		2
23	2	1	2

Notes: Positive cores have inclinations of (>+30°), Intermediate (+30° to -10°), and Negative (>-10°) before tectonic correction.

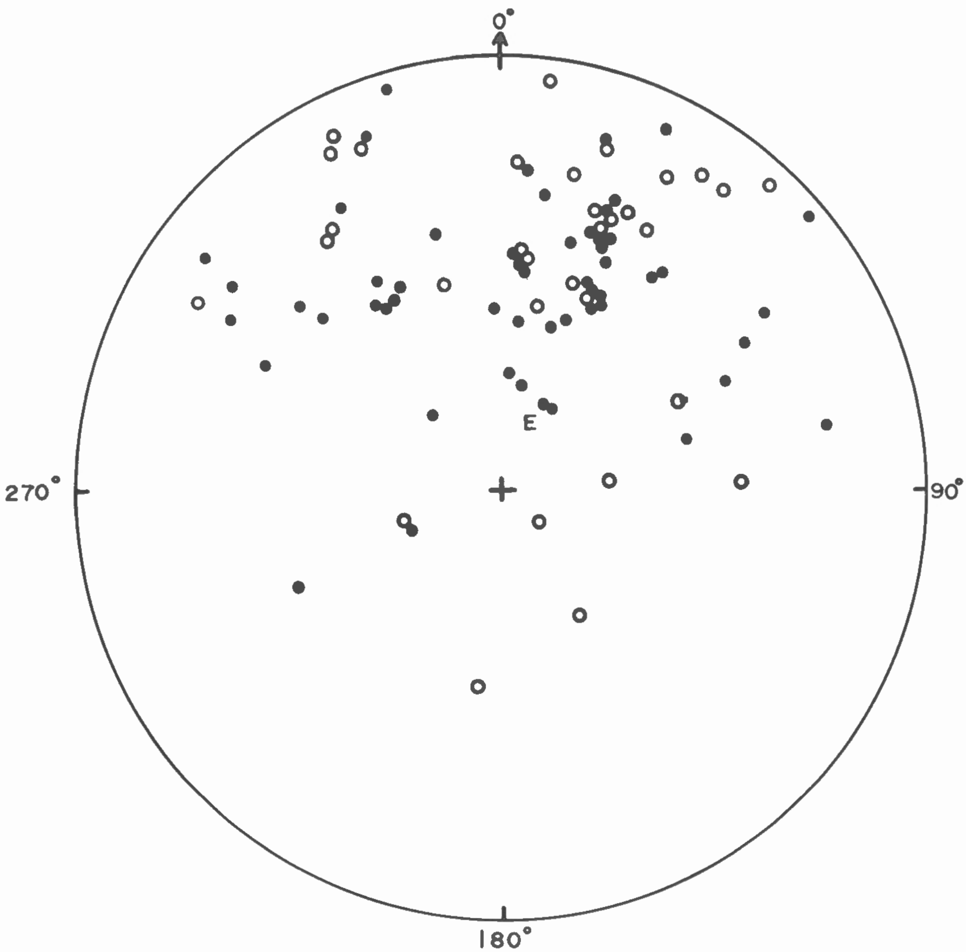

Figure 2: Equal-area stereographic projection of 88 core mean remanence directions with $\theta < 40°$; positive (negative) or downward (upward) inclinations are shown as solid (open) circles and E is the earth's present magmatic field direction for Vancouver Island.

dipolar distribution (Table 3) suggesting the presence of two relatively stable remanence components. This possibility was examined by testing four representative samples from specimens with positive, intermediate or negative remanence inclinations up to 630°C and then cooling them in a saturating magnetic field. None of the samples produced irreversible changes in saturation magnetization suggesting the presence of only one significant ferromagnetic mineral (Fig. 3). Further, all samples have similar thermomagnetic saturation curves with single Curie Point temperatures close to 600°C indicating that relatively pure magnetite was the sole significant remanence carrier; and these results were consistent with the results of E. Irving (pers. comm.)

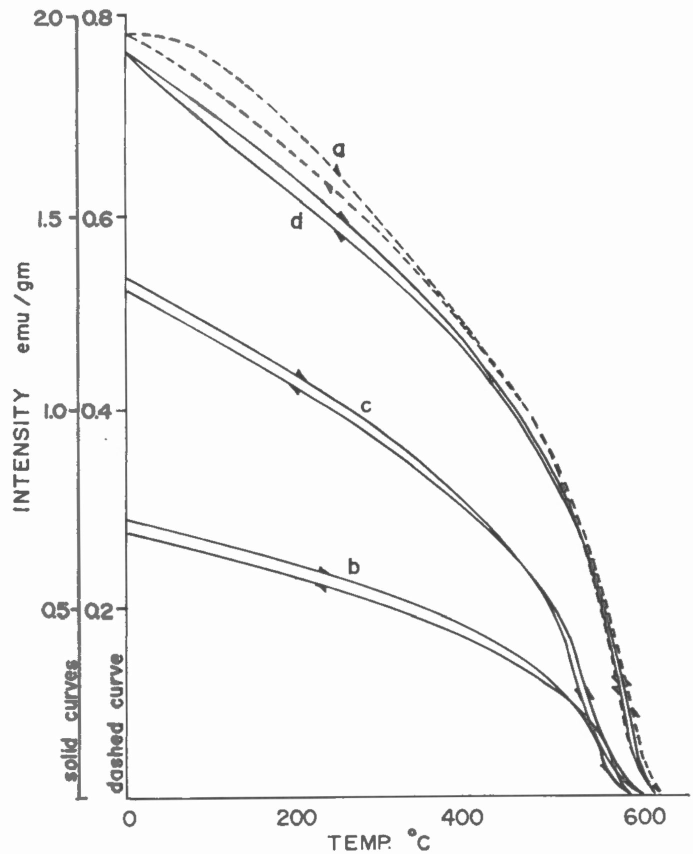

Figure 3: Thermomagnetic curves obtained during heating and cooling at a rate of 5° C/min. of 20 mg samples for ferromagnetic mineral concentrates from (a) site 6 (positive remanence inclination), (b) site 3 (intermediate), (c) site 5 (intermediate and (d) site 6 (negative) in an applied field of 3210 oersteds and an air pressure of 2 x 10^{-2} torr. within the instrument.

who found that both AF and thermal demagnetization yield similar remanence-directional distributions. Thus the mineral magnetic evidence does not support the presence of two relatively stable remanence components.

Based on observation that the cores with distinctly negative remanence inclinations tended to have greater within-core consistency and remanence intensity, it was decided to reject all 45 cores in which the angle θ exceeded 16 degrees as insufficiently homogeneously magnetized. Also the 5 cores which were the sole remaining cores to represent their site were rejected. The site mean remanence statistics were then calculated for the 16 sites having 2 or more homogeneous cores by giving each core unit weight. The 4 sites giving a standard error (SE) in excess of 10 degrees were rejected leaving 12 reliable sites.

DISCUSSION

The site mean remanence directions for the 12 remaining reliable sites form two groups - one of 7 normal directions and one of 5 reverse directions (Fig. 4) - both before and after tectonic correction (Table 4). In both groups the site mean remanence directions are statistically significantly different, i.e. $\delta_b^2/\delta_w^2 \gg F_{.05}$ (Larochelle, 1969) as would be expected for flows extruded at different times. Also the dispersion of both groups is decreased by applying tectonic corrections suggesting that both acquired their remanence prior to folding although the improvement is not statistically significant and the mean directions are not moved by a statistically significant amount by making tectonic corrections.

Despite the high incidence of remanence instability, there is some evidence that remanence polarity could be used for correlation in the Karmutsen basalts. In the Buttle Lake section, sites in the lower portion of the section (sites 12, 11 and 4) have positive remanence inclinations whereas those in the upper portions (sites 5, 6 and 16) have negative inclinations. In the Comox Lake section sites 22 (negative) and 23 (positive) are separated by a fault so that their interpretation is in doubt.

There is no unequivocal explanation for the origin of the two groups of remanence directions in the Karmutsen basalts. Both directions are of equal stability but are about 90 degrees apart. The negative or reversed group gives a pole position that is clearly discordant from those of other Upper Triassic formations from tectonically stable areas in North America (Fig. 5). There are several possible explanations for this discordance.

First, the Upper Triassic magnetic pole may have made a prolonged excursion from its usual Upper Triassic position into the equatorial area. Grommé and Gluskoter (1965) and Saad (1969) invoked this hypothesis to explain aberrant paleomagnetic results from the late Mesozoic Franciscan Formation and Red Mountain ultramafics respectively in California. However, the synoptic lists of pole positions (Irving, 1964; Khramov and Sholpo, 1967; McElhinny, 1968a, 1968b, 1969) reveal no other potential examples of such an Upper Triassic excursion which would have had to last long enough for several thousand feet of basalts to be extruded.

Second, the reversed sites could contain a stable secondary remanence such as the chemical remanent magnetization (CRM) found by Schaeffer and Schwarz (1970) to be replacing the original thermoremanence in suboceanic basalts. Unfortunately for this possibility, the thermomagnetic curves show no evidence for such CRM replacement. Also, the reversed sites come from the upper part of the flow sequence and therefore they are less likely to have been thermally metamorphosed than are the normal sites which have similar ferromagnetic mineralogy in any case. Finally, the reversed sites give a pole position which is totally inconsistent with known post-Triassic pole positions for North America.

Third, and requiring that the normal flows possess a stable secondary remanence, the whole of Vancouver Island could have been tectonically translated and/or rotated. A time limit is placed on possible tectonic movements by paleomagnetic results from the mid-Jurassic Island Intrusions of Vancouver Island which indicate that the island has not moved appreciably since their emplacement except possibly for minor clockwise rotation (Symons, 1971). Sufficient vertical rotation to account for the discordance is incompatible with the generally horizontal attitude of the Karmutsen flows. Horizontal

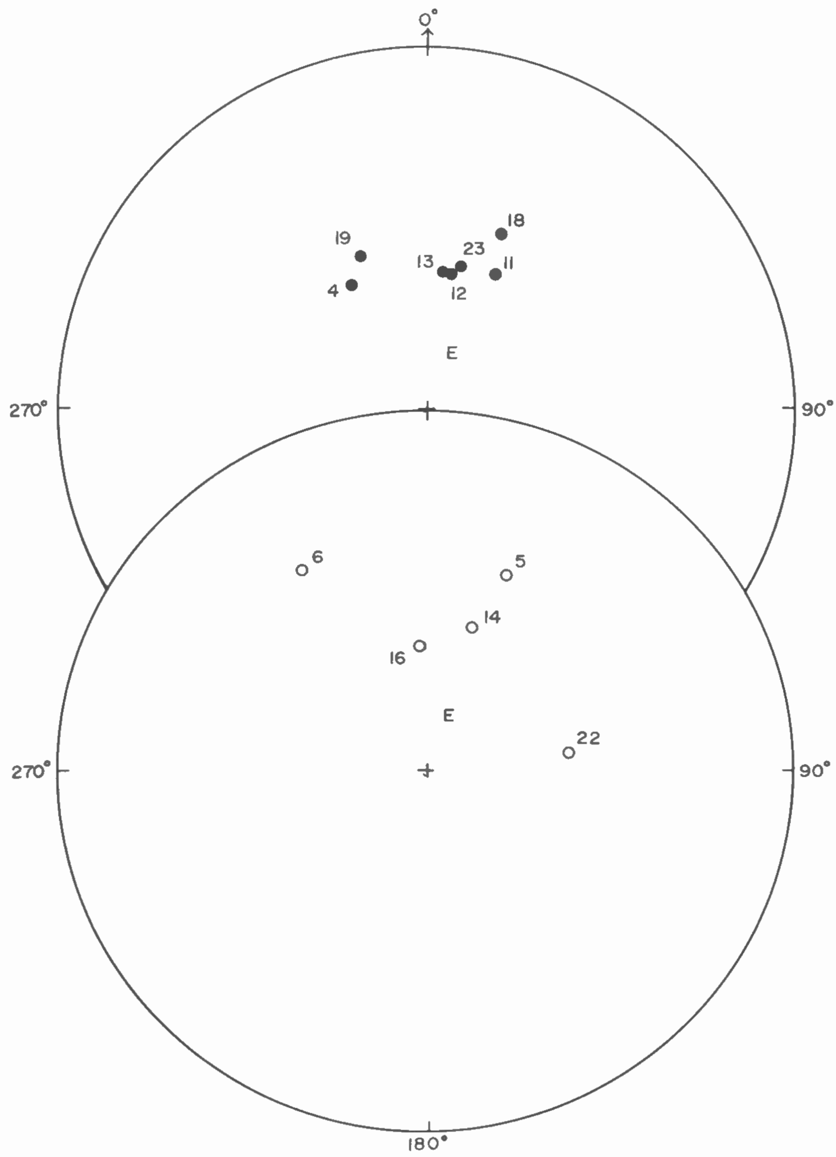

Figure 4: Equal-area stereographic projection of the stable site mean remanence directions after tectonic correction with positive (negative) inclinations shown as solid (open) circles, and the earth's present magnetic field direction (E) for Vancouver Island.

TABLE 4: Group mean remanence directions and pole positions

Group		N	B	Group Mean Remanence				δ_b^2/δ_w^2	$F_{.05}$	Pole Position			
				D	I	SE	R			Long.	Lat.	$d\psi$	$d\chi$
Normal sites	-U	23	7	1.3	60.5	8.0	6.5837	20.1	2.1	48.0	81.7	16.2	21.3
	-C	23	7	8.0	45.8	7.1	6.6759	17.6	2.1	36.3	66.7	10.0	15.7
Reversed sites	-U	14	5	18.9	-38.8	16.1	4.2059	42.4	2.5	36.5	16.5	19.8	33.3
	-C	14	5	10.4	-45.6	10.2	4.4892	27.1	2.5	45.4	12.8	18.2	28.6

Notes:

U, C	uncorrected and corrected site mean remanence directions for flow attitude
N, B	number of cores and sites represented
D, I, SE	declination, inclination and standard error in degrees
R	length of vector resultant giving each site unit weight
δ_b^2/δ_w^2	between-site and within-site angular variance
$F_{.05}$	theoretical statistic $F_{2(B-1),\ 2(N-B),\ .05}$ at 95% confidence level
Long. Lat.	longitude and latitude in degrees east and north respectively
$d\psi$, $d\chi$	semi-axes of oval of 95% confidence perpendicular to and in the colatitude direction.

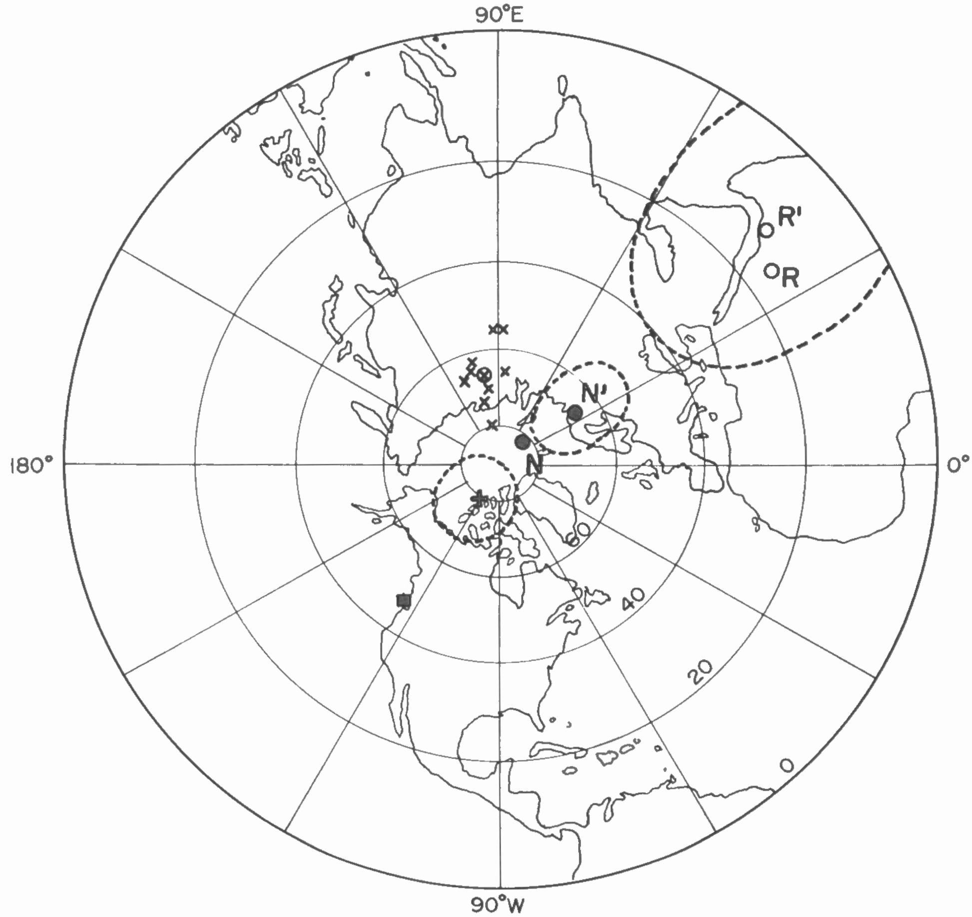

Figure 5: Projection of the northern hemisphere showing the sampling site (solid square); the pole positions of the Karmutsen basalt's normal and reversed groups both before and after tectonic correction (N, R, N', R' respectively) are shown as circles and the Jurassic Island Intrusions as a cross with their cones of 95% confidence by dashed lines; the mean pole position for the Upper Triassic is shown as a circled X and the represented poles by an X using date from the Chinle Formation (Collinson and Runcorn, 1960), North Mountain basalt (Larochelle, 1967; Carmichael and Palmer, 1968), Grand Manan lava (Carmichael and Palmer, 1968), Great Dyke of Nova Scotia (Larochelle and Wanless, 1966), and the Newark Group from Massachusetts (Irving and Banks, 1961), Connecticut (de Boer, 1968), New Jersey (Opdyke, 1961) and Pennsylvania (Beck, 1965).

rotation would require that the island be swung around through 180 degrees. Translation of the island requires, in addition to some 30 degrees of clockwise rotation, about 50 degrees of movement over the earth's surface within the late Triassic - mid-Jurassic interval of about 40 m.y. which is a rate of about 13 cm/yr. This slightly exceeds the maximum rate for crustal separation (and presumably for convergence also) given by Vine (1969) for the Pacific crustal plate from the Cenozoic sea-floor magnetic record. If translation of the island from the southern to northern hemisphere has occurred, then the pre-Jurassic geological records for the island and adjacent mainland should produce incompatible lithologies, faunal assemblages, etc. This does not appear to be the case as Yole (1963) for example, correlates fauna from the early Permian Sicker Group in the Buttle Lake area with fauna from formations in central Oregon, northwestern Washington, and central British Columbia. Another difficulty is that tectonic movements of the necessary magnitudes would almost certainly have caused more severe deformation of the Karmutsen flows than appears to be the case.

Explanations for the origin of the remanence in the normal sites are considered next.

First, they could retain a primary remanence in which case a simple clockwise rotation of the island of about 25 degrees would bring its tectonically-corrected pole position into coincidence with poles from Upper Triassic formations in tectonically-stable North America (Fig. 5). This is consistent with the possibility of minor clockwise rotation suggested by paleomagnetism for the Island Intrusions (Symons, 1971), and it requires that the remanence of the reversed sites originate by either the first or second mechanism given above.

Second, the normal sites could retain a post-folding secondary remanence acquired during burial or intrusion of the mid-Jurassic Island Intrusions. The overlap in the cones of 95 per cent confidence about the uncorrected normal-sites pole and the Island Intrusions pole favours this hypothesis, however the apparently identical ferromagnetic mineralogy of the normal and reversed groups does not.

Thirdly, the normal sites may be retaining an unusually stable secondary viscous remanence. This is unlikely because reversed sites with apparently identical ferromagnetic mineralogy are unaffected, and because the cones of 95 per cent confidence for only 2 of the 7 normal sites encompass the earth's present magnetic field direction.

In summary, none of the explanations for the origin of both normal and reversed non-dipolar remanence in the Karmutsen basalt are without objection.

CONCLUSIONS

1) The Karmutsen basalts possess significant components of unstable remanence. In this study a stable remanence was isolated in only one-half of the sites.

2) Remanence instability is sufficiently common to militate against the use of paleomagnetism in studies on detailed correlation between flows and on block-faulting tectonics. However, there is evidence in the Buttle Lake section to suggest that a normal-reversed paleomagnetic stratigraphy can be successfully employed in the Karmutsen basalts.

3) The basalts possess two equally-stable remanence directions, one positively inclined or normal, and a second negatively inclined or reversed but perpendicular to the normal direction.

4) Fold-test results indicate that it is marginally probable that both normal and reversed remanences originated before the flows were folded. Except for minor tilting associated with Tertiary block faulting, paleomagnetic evidence from the Island Intrusions (Symons, 1971) indicates that the folding occurred before the mid-Jurassic cooling of the Intrusions.

5) Thermomagnetic analysis suggests that both normal and reversed flows have similar ferromagnetic mineralogy. Their remanence likely resides in relatively pure magnetite only, and is likely thermal in origin.

6) None of the hypotheses examined to explain the origin of both remanence directions in the flows in terms of time, tectonics, secondary remanence, or aberrations of the magnetic paleofield is without objection. Logical extensions of this study to attack the problem include study of the magnetic mineralogy of the flows especially in relation to thermal effects, and of the paleomagnetism of Karmutsen flows from the Queen Charlotte Islands.

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REFERENCES

Beck, M.E.
1965: Paleomagnetic and geologic investigations of magnetic properties of the Triassic diabase of southeastern Pennsylvania; J. Geophys. Res., vol. 70, pp. 2845-2856.

Carmichael, C.M., and Palmer, H.C.
1968: Paleomagnetism of the Late Triassic, North Mountain Basalt of Nova Scotia; J. Geophys. Res., vol. 73, pp. 2811-2822.

Collinson, D.W., and Runcorn, S.K.
1960: Polar wandering and continental drift: evidence of paleomagnetic observations in the United States; Bull. Geol. Soc. Am., vol. 71, pp. 915-958.

de Boer, J.
1968: Paleomagnetic differentiation and correlation of the Late Triassic volcanic rocks in the Central Appalachian (with special reference to the Connecticut Valley); Bull. Geol. Soc. Am., vol. 79, pp. 600-626.

Doell, R.R., and Cox, A.
1967: Analysis of alternating field demagnetization equipment; in Methods in Paleomagnetism, D.W. Collinson et al., ed.; Elsevier, Amsterdam, pp. 241-253.

Grommé, C.S., and Gluskoter, H.J.
1965: Remanent magnetization of spilite and diabase in the Franciscan formation, western Marine County, California; J. Geol., vol. 73, pp. 74-94.

Irving, E.
1964: Paleomagnetism; J. Wiley and Sons, New York, 399 pp.

Irving, E., and Banks, M.R.
1961: Paleomagnetic results from the Upper Triassic lavas of Massachusetts; J. Geophys. Res., vol. 60, pp. 1935-1939.

Khramov, A.M., and Sholpo, L. Ye.
1967: Synoptic tables of U.S.S.R. paleomagnetic data; translated by E.R. Hope; Defence Research Board, Canada, Publ. T510 R, 1970, 24 pp.

Larochelle, A.
1967: Preliminary data on the paleomagnetism of the North Mountain Basalt, Nova Scotia; Geol. Surv. Can., Paper 67-39, pp. 7-12.

1969: L'application de la statistique au paléomagnétisme; Geol. Surv. Can., Paper 68-59.

Larochelle, A., and Wanless, R.K.
1966: The paleomagnetism of a Triassic diabase dyke in Nova Scotia; J. Geophys. Res., vol. 71, pp. 4949-4953.

McElhinny, J.W.
1968a: Paleomagnetic directions and pole positions - VIII; Geophys. J. Roy. Astr. Soc., vol. 15, pp. 409-430.

1968b: Palaeomagnetic directions and pole positions - IX; Geophys. J. Roy. Astr. Soc., vol. 16, pp. 207-224.

1969: Palaeomagnetic directions and pole positions - X; Geophys. J. Roy. Astr. Soc., vol. 19, pp. 305-327.

Muller, J.E.
1970: Northern Vancouver Island, British Columbia, in Report of Activities, April to October 1969; Geol. Surv. Can., Paper 70-1, Part A, pp. 44-49.

Muller, J.E., and Carson, D.J.T.
1969: Geology and mineral deposits of Alberni map-area, British Columbia (92F); Geol. Surv. Can., Paper 68-50, 52 pp.

Opdyke, N.D.
1961: The paleomagnetism of the New Jersey Triassic: a field study of the inclination error in sediments; J. Geophys. Res., vol. 66, pp. 1941-1949.

Saad, A. H.
1969: Paleomagnetism of Franciscan ultramafic rocks from Red Mountain California; J. Geophys. Res., vol. 74, pp. 6567-6578.

Schaeffer, R. M., and Schwarz, E. J.
1970: The Mid-Atlantic Ridge near 45° N. - IX. Thermomagnetics of dredged samples of igneous rocks; Can. J. Earth Sci., vol. 7; pp. 268-273.

Surdam, R. C.
1968: The stratigraphy and volcanic history of the Karmutsen Group, Vancouver Island, B. C.; Contributions to Geology, Univ. of Wyoming, vol. 7, pp. 15-26.

Symons, D. T. A.
1971: Paleomagnetism of the Jurassic Island Intrusions of Vancouver Island, British Columbia; Geol. Surv. Can., Paper 70-63.

Tarling, D. H., and Symons, D. T. A.
1967: A stability index of remanence in palaeomagnetism; Geophys. J. Roy. Astr. Soc., vol. 12, pp. 443-448.

Vine, F. J.
1969: Sea-floor spreading - new evidence; J. Geol. Education, vol. 17, pp. 6-15.

Yole, R. W.
1963: An early Permian fauna from Vancouver Island, British Columbia; Bull. Can. Petrol. Geol., vol. 11, pp. 138-149.