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DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 68-72

GEOLOGICAL IMPLICATIONS OF PALEOMAGNETIC STUDIES IN THE BELLA COOLA AND LAREDO SOUND MAP-AREAS, BRITISH COLUMBIA (93D and 103A)

(Report, 2 figures and 5 tables)

D. T. A. Symons

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ABSTRACT

The Coast Mountains are underlain mostly by a complex assemblage of granitic plutonic rocks with few time-markers. The paleomagnetism of 533 specimens from 70 sites representing several geological units of basic igneous origin in the Bella Coola-Laredo Sound map-areas was studied to assess their value as time-markers. The stable partial NRM of the specimens was isolated by alternating field demagnetization. Only 31 sites yielded remanence data of sufficient stability and homogeneity to be considered acceptable according to preset criteria. These data confirm and in part refine the geological time-scale established for the map-areas by reconnaissance mapping. The late Paleozoic or Early Mesozoic greenstone complex and the Lower or Middle Tertiary blue porphyritic dykes proved unsuitable for paleomagnetic study. The Middle or Upper Jurassic gabbroic plutons, the Cretaceous gabbroic dykes, the Paleocene or Eocene granodiorite intrusives, the Upper Miocene or Lower Pliocene basalt flows, and the Upper Miocene to Pleistocene brown basaltic dykes were found to have a primary TRM acquired during intrusion. The Mesozoic greenstone dykes were found to have a secondary pTRM acquired during the late stages of an Upper Cretaceous-Paleocene orogeny.

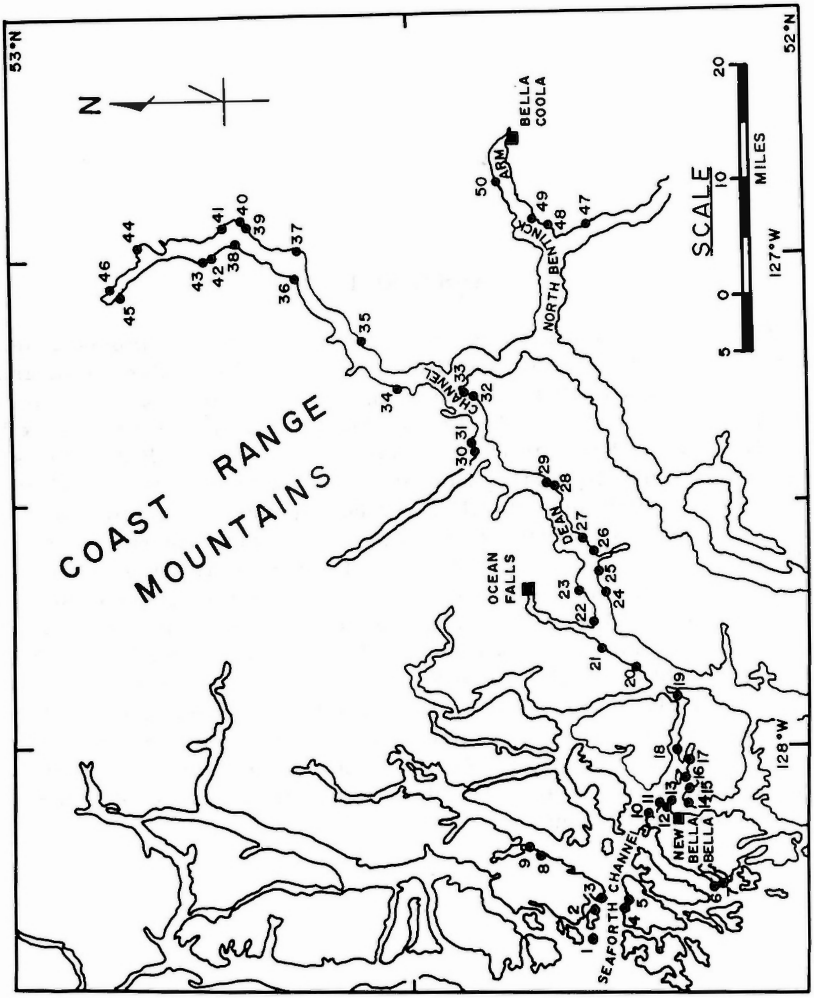

Figure 1. Site location map

GEOLOGICAL IMPLICATIONS OF PALEOMAGNETIC STUDIES IN THE BELLA COOLA AND LAREDO SOUND MAP-AREAS, BRITISH CLUMBIA (93 D and 103 A)

INTRODUCTION

Bella Coola and Laredo Sound map-areas span the Coast Mountains in west-central British Columbia (Fig. 1). The geology, which has been mapped at a scale of one inch to four miles by Baer (1967), is complex and difficult to interpret because the area is underlain mainly by various ages of granitic plutonic rocks of similar composition with very few time-markers (Table 1). However, there are numerous dykes, a few plutons, and some flows of basic composition in the area and it was thought that paleomagnetism could help in classifying and dating the various periods of intrusion. Fundamentally, the procedure consists in deriving the pole position from the stable primary remanence direction of the pluton, dyke swarm or lava sequence, and to compare it with pole positions derived from North American rock formations of known age (e.g. de Boer, 1967; Larochelle, 1967 and 1968a).

The rock units sampled are underlined in Table 1 and listed here in chronologic order starting with the oldest: (1) greenstone complex, (2) gabbroic intrusives, (3) green andesitic dykes, (4) granodiorite intrusives, (5) blue porphyritic dykes, (6) basaltic flows, and (7) brown basaltic dykes. Short geologic descriptions of these units will be given later in the paper.

The results of this study are not as diagnostic as hoped for at the outset, mainly for two reasons. First, the rocks themselves show a high incidence of remanence instability or inhomogeneity leading either directly or indirectly to the rejection of the data from over half of the collected cores. Second, the mean remanence directions for the various geological units are subject to broad error limits which are likely caused by: (a) regional tectonic rotations during mountain building and uplift for which corrections cannot be made in this dominantly intrusive geological environment, and (b) secular variation during intrusion of the basic igneous phases which may not be removed by averaging because of the high rejection rate noted above. Nevertheless some worthwhile results emerge which are discussed below.

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TABLE 1. Summary of the geology after Baer (1967, 1968, personal communication). The underlined units are discussed in this paper.

AGE	MAP-UNIT (Baer, 1967)	LITHOLOGY	Unit Numbers This Paper
Pleistocene and Holocene	16	Glacial drift, silt, and alluvium.	
" " "	15	Basaltic flows with scoria and ash; some flows are postglacial.)) brown basaltic dykes are probably equivalent	7
Upper Miocene or Lower Pliocene	14	Basaltic flows with olivine basalt, tuff, and minor rhyolite.)	6
Lower or Middle Tertiary	13	Rhyolitic flows with tuff, breccia, and quartz-feldspar porphyry; turquoise-blue porphyritic dykes are probably equivalent.	5
" " " "	12	Syenite, granite (commonly miarolitic), and minor quartz monzonite; massive biotite granite intrusions (map-unit A) are probably equivalent.	
Upper Cretaceous or Lower Tertiary	--	Deformation: foliation trend-NW strikes and vertical dips; fault shears strike NW; vertical faults strike N and NE.	
Upper Cretaceous and/or Eocene	11	Quartz monzonite and granodiorite; K-Ar age determinations of 47, 51, 57, 70 and 77 m.y.; massive quartz monzonite (map-unit B) and possibly some granodiorite (map-unit C) intrusions are probably equivalent.	4
Upper Cretaceous and/or Paleocene	10	Andesitic lava and agglomerate with greywacke, slate, and conglomerate; contains probable Upper Cretaceous plant remains.)	
Lower Cretaceous	9	Andesitic lava with agglomerate, tuff, and black slate; correlative units contain Lower Cretaceous fossils.) several generations of green andesitic dykes and gabbroic (map-unit F) intrusives are probably equivalent	3 2
Middle Jurassic	8	Andesitic lava with agglomerate and tuff, and minor rhyolite and greywacke; contains fossils of Middle Jurassic age.)	
Lower or Middle Jurassic (?)	7	Black slate and argillite with conglomerate; contains Jurassic fossils.	
Triassic or Lower Jurassic	--	Deformation: foliation trend - NE to E strikes and steep dips.	
Pre-Middle Jurassic	6	Granodiorite; most granodiorite (map-unit C) intrusions are probably equivalent.	
" "	5	Quartz diorite with granodiorite, diorite, and greenstone lenses; quartz diorite (map-unit D) are probably equivalent.	
" "	4	Diorite Complex: gneissic diorite with quartz diorite and greenstone, and minor quartzite and limestone; diorite (map-unit E) intrusions are probably equivalent.	
Upper Paleozoic or Lower Mesozoic	3	Greenstone Complex: greenstone from andesitic lavas chlorite schists, metadiorite, and andesitic dykes.	1
Upper Paleozoic and/or younger	2	Metasedimentary rocks: biotite-hornblende schist with garnet, sillimanite and kyanite locally; minor limestone, quartzite, metavolcanics, and conglomerate.	
Upper Paleozoic (?) or older	1	Gneisses: feldspar-quartz-biotite-hornblende gneiss, garnet gneiss, and amphibolite.	

SAMPLING AND REMANENCE MEASUREMENT

The samples were collected in June 1967 by boat from shoreline outcrops along or adjacent to Seaforth Channel, Dean Channel and North Bentinck Arm (Fig. 1). The outcrops are situated approximately on a 90-mile section trending northeast-southwest across the Coast Mountains. The selection of sampling sites was greatly facilitated by the advice of A. J. Baer.

A total of 291 individually oriented core samples were collected from 70 sites with generally 4 cores per site. The cores were collected with a portable drill (Gaucher and Meilleur, 1965) and they were oriented in situ using a solar compass (Larochelle, 1964) and/or mountain peak triangulation. Wherever possible, the cores at each site were drilled several feet apart. From each core, 1 or 2 cylindrical specimens (1 1/4 inches in diameter, and 1 3/16 inches in height) were cut, yielding a total of 533 specimens.

The natural remanent magnetization (NRM) of each specimen was measured using an automated biastatic magnetometer with a lower sensitivity or noise level limit of 5×10^{-8} emu/cc (Larochelle and Christie, 1967).

DEMAGNETIZATION

From each of the 59 sites having specimens with measurable remanence, one specimen was selected to test its remanence stability by alternating-field (AF) step demagnetization. The specimen was selected on the basis of: (1) its having an approximately average NRM direction and intensity for the site, and (2) its being from a core with two specimens. The AF demagnetization was done using the apparatus described by Larochelle and Black (1965). Each specimen was demagnetized in steps at AF peak intensities of 25, 50, 100, 200, 400, and 800 oersteds, and the specimen's remanence was measured after each step. Its remanence direction and intensity were plotted after each step, and the stability index (Tarling and Symons, 1967) was calculated. Guided by the plots and indexes (Tables 2 and 3), the author decided to partially demagnetize the remaining specimens at a peak AF field of 100 oersteds except for those specimens from sites 1A, 7, 13A, 18, 19, and 42 which were demagnetized at 200 oersteds. Following partial demagnetization, the remanence was remeasured.

DATA SELECTION

The following criteria were set to assess the acceptability of the remanence data for statistical analysis.

First, the NRM or second, the partial NRM (i.e. the remanence after partial demagnetization) of some cores was not sufficiently intense to be measured reliably and they were rejected (Table 2, columns I and II respectively).

SITE	U	N	CORES REJECTED I	II	III	IV	V	VI	R	SI
37	1	4			1	1		2		1.8
38	1	5	2		2		1			3.2
45	1	4	1						3	1.6
46	1	4	2	1	1					1.2
6	2	5			1				4	4.5
23	3	4	4							-
27	3	4	4							-
29A	3	4						4		16.0
34	3	5			3				2	1.1
36A	3	3			1	1	1			.33
36B	3	3			3					.88
36C	3	3			2		1			1.7
36D	3	4		1	3					.66
39	3	4	3	1						2.2
41B	3	4		1					3	3.6
49A	3	4	4							-
49B	3	4	4							-
50	3	4	1					3		1.3
25	4	5		1	1	1		2		2.5
48	*4	4			1			3		3.9
13B	5	4	4							-
15	5	4	4							-
16B	5	4		2		2				2.6
16D	5	4	4							-
17C	5	4				2		2		3.8
19	5	4						4		5.8
28	5	4	4							-
42	5	4			1				3	32.
5C	6	4			2	1	1			5.2
1A	7	4			2			2		3.0
2	7	4						4		1.2
3	7	5						5		.49
4	7	4	4							-
5B	7	4	4							-
11A	7	4			2			2		4.7
13A	7	4			4					2.5
14	7	4			1	1		2		3.9
16C	7	4			2			2		1.0
17A	7	4			1			3		3.1
17B	7	4			2				2	38.
18	7	4						4		1.25
21	7	5						5		2.0
24	7	3						3		3.4
40	7	4	4							-
47	7	5				1		4		5.3
TOTAL		183	53	7	36	10	4	56	17	

U GEOLOGIC UNIT (NUMBERED AS IN TEXT)
N NUMBER OF CORES COLLECTED AT SITE
I NRM INTENSITY TOO WEAK TO BE MEASURED
II REMANENCE INTENSITY TOO WEAK TO BE MEASURED AFTER AF CLEANING
III INHOMOGENOUS MAGNETIZATION BY O TEST
IV FAILS SINGLE SPECIMEN RELIABILITY TEST
V RELIABLE CORE REJECTED BY SOLE CORE PER SITE TEST
VI SITE MAGNETIZATION INHOMOGENOUS BY ALPHA 95 TEST
R REMAINING RELIABLE CORES AT SITE
SI STABILITY INDEX (TARLING AND SYMONS, 1967)(- NOT DETERMINABLE)

Table 2. Summary of the rejected remanence data.

S	U	STR	DIP	W	N	C	SI	RANGE	F	D,	I,	A95
45	1	330	65W	M	3	6	1.60	25-100	1	2	73	6.7
6	2	-	-	P	4	8	4.5	25-100	1	23	62	3.5
7	2	-	-	P	5	10	14.8	100-800	2	17	41	5.6
8A	2	-	-	P	5	10	10.3	25-200	1	317	59	4.5
9	2	-	-	P	5	9	7.4	25-800	1	358	48	8.4
8B*	2	280	90	7	4	8	24.	100-400	1	295	70	8.6
43 *	2	340	90	12	4	8	3.4	25-100	1	310	63	6.9
1B	3	120	80N	1	4	8	24.0	25-400	1	94	58	6.6
11B	3	120	80S	1	4	6	4.7	50-200	1	143	-64	3.9
20A	3	55	70S	1	4	7	12.0	25-200	1	69	52	3.9
20B	3	5	80W	4	4	8	16.0	25-400	1	40	53	6.2
22A	3	90	90	*4	4	8	38.	25-400	1	7	70	5.8
29B	3	335	75E	2	5	10	21.	25-100	1	318	80	13.5
30	3	140	70E	2	4	8	16.2	25-100	1	77	71	6.0
34	3	60	80W	4	2	4	1.07	25-100	1	55	75	18.5
35	3	30	75E	*8	4	8	16.0	25-200	1	7	75	2.0
41A	3	155	85W	2	4	8	4.5	25-400	1	331	70	7.5
41B	3	155	85W	10	3	6	3.6	50-200	1	82	78	19.1
32	4	-	-	P	5	10	74.	25-800	1	27	66	3.3
33	4	-	-	P	5	10	187.	25-800	1	18	67	18.3
42	5	320	87E	1	3	6	32.	25-800	1	101	-76	4.2
5A	6	330	35W	4	5	7	15.8	25-100	1	214	-55	12.5
1C	7	200	90	24	4	8	3.1	25-100	1	65	66	4.9
10	7	340	80W	18	5	10	15.3	50-400	1	92	-68	8.9
12	7	350	90	12	4	8	1.92	25-100	1	27	85	15.8
16A	7	5	80E	11	4	8	6.3	25-100	1	1	67	5.1
17B	7	350	90	6	2	4	38.	25-200	1	10	63	14.2
22B	7	190	70W	24	4	7	4.0	50-200	1	2	66	4.5
26	7	335	85E	24	4	8	2.3	25-100	1	187	-54	8.9
31	7	325	82E	18	4	8	32.	50-200	2	12	84	1.6
44	7	40	80W	8	4	8	11.0	50-200	2	346	80	13.1

S	SITE NUMBER
U	GEOLOGIC UNIT (NUMBERED AS IN TEXT AND IN TABLE 4)
STR	STRIKE IN DEGREES
DIP	DIP IN DEGREES (N-NORTH, E-EAST, S-SOUTH, W-WEST)
W	WIDTH OF DIKE OR FORMATION IN FEET (P-PLUTON, *-INCHES, M-METAMORPHOSED)
N	NUMBER OF CORES
C	NUMBER OF CYLINDRICAL SPECIMENS
SI	STABILITY INDEX OF TARLING AND SYMONS(1967)
RANGE	RANGE OF MAXIMUM STABILITY (TARLING AND SYMONS,1967) IN OERSTEDS
F	FIELD IN OERSTEDS EMPLOYED FOR ALTERNATING FIELD (AF) CLEANING (1 - 100 OE, 2- 200 OE) CLEANING
I,	INCLINATION IN DEGREES OF MEAN REMANENCE DIRECTION (DOWN UNSIGNED, UP -) OF N CORES AFTER AF CLEANING
D,	DECLINATION IN DEGREES OF MEAN REMANENCE DIRECTION OF N CORES AFTER AF
A95	RADIUS OF CONE OF 95 PER CENT CONFIDENCE

Table 3. Summary of the accepted remanence data by sites.

Third, the magnetization of a single core must be homogeneous or the core was rejected (Table 2, column III). Homogeneity in a core was considered satisfactory if the angle between the remanence directions of the two specimens from the core did not exceed 23°, which means that the minimum within-core precision estimate of Fisher (1953) is 25 or greater (Larochelle, 1966).

SITE	NUMBER	STABILITY INDEX		
		LOWER QUARTILE	MEDIAN	UPPER QUARTILE
REJECTED TEST I	11			
REJECTED TESTS II TO V	10	.88	1.9	2.6
REJECTED TEST VI	18	1.3	3.0	3.9
PARTIALLY REJECTED	6	1.6	4.0	32.0
ACCEPTED	25	4.6	14.8	22.5

Table 4. Relation between the rejection criteria and stability index. The rejection criteria are noted by Roman numerals and specified further in Table 2 and in the text.

Fourth, when only a single specimen was available to represent a core, its remanence direction had to fall within the cone of the angular standard deviation given by the other cores from the site, and the stability index for the site had to indicate remanence stability for the core to be acceptable (Table 2, column IV).

Fifth, when only one acceptable core remained to represent a site, it was rejected because the results from one core cannot represent the site on a statistically reliable basis (Table 2, column V).

Sixth, the magnetization of a site had to be homogeneous or the cores from the site were rejected (Table 2, column VI). Homogeneity of a site was considered satisfactory if the value of α_{95} (Fisher, 1953) did not exceed 20° using each core as an independent observation (Table 3).

Finally, no cores were observed to have anomalously high remanence intensities which is often indicative of a lightning-induced remanence component, and which would require rejection of the cores.

Following the above criteria, 31 of 70 sites (44 per cent) were judged acceptable, and they were represented by 125 of 291 cores (43 per cent) or 242 of 533 specimens (45 per cent). The selectivity of this procedure in rejecting data based on remanence of low stability is shown in Table 4 where the stability index falls in the metastable to poorly stable range for sites rejected by tests II to V, in the poorly stable to stable range for sites rejected by test VI, in the stable to very stable range for partially rejected sites, and in the very stable to extremely stable range for wholly accepted sites.

U	GEOLOGIC DESCRIPTION	N	R	P	DM	IM	AL95	LONG	LAT	OP	OM
		CLEANED REMANENCE DIRECTION						POLE POSITION			
1	GREENSTONE COMPLEX	)		N	2.4	72.8		113.9W	84.5N		
2	GABBRO INTRUSIVE-A	2	1.966	N	19.1	51.2	47.7	9.8E	65.5N	64.6	43.8
2	GABBRO INTRUSIVE-B	2	1.950	N	340.2	55.2	59.1	99.8E	68.3N	84.1	59.8
2	GABBRO INTRUSIVE-BOTH	4	3.835	N	0.7	54.8	22.1	49.9E	73.1N	31.3	22.4
*2	GABBROIC DIKES	2	1.993	N	303.4	66.5	20.9	160.1E	55.0N	34.4	28.3
3	GREEN ANDESITIC DIKES	10	9.569	N	46.4	73.1	10.8	68.7W	63.8N	19.3	17.3
3	GREEN ANDESITIC DIKES	1		R	323.4	64.1		142.2E	64.9N		
3	GREEN ANDESITIC DIKES	11	10.456	A	37.7	74.1	10.9	72.2W	68.2N	19.8	17.9
4	GRANODIORITE	2	1.999	N	22.8	66.8	8.7	34.5W	75.4N	14.3	11.8
5	BLUE PORPHYRITIC DIKE	1		R	281.1	75.8		170.3W	49.7N		
6	OLIVINE BASALT FLOW	1		R	321.0	76.0		157.0W	68.0N		
7	BROWN BASALTIC DIKES	7	6.859	N	15.5	74.3	8.1	86.2W	78.5N	14.8	13.4
7	BROWN BASALTIC DIKES	2	1.860	R	332.9	68.8	37.1	153.0E	73.5N	62.8	53.3
7	BROWN BASALTIC DIKES	9	8.675	A	4.5	74.0	9.4	112.2W	81.7N	17.0	15.4

U GEOLOGIC UNIT (NUMBERED AS IN TEXT)
N NUMBER OF SITES (*-CORES)
R VALUE OF RESULTANT MEAN VECTOR WITH N UNIT VECTORS
P POLARITY (N-NORMAL,R-REVERSED,A-MIXED)
DM DECLINATION OF MEAN VECTOR IN DEGREES
IM INCLINATION OF MEAN VECTOR IN DEGREES
AL95 ALPHA 95,RADIUS CONE OF CONFIDENCE IN DEGREES
LONG LONGITUDE IN DEGREES EAST(E) OR WEST(W) OF GREENWICH OF POLE
LAT LATITUDE IN DEGREES IN NORTHERN(N) HEMISPHERE OF POLE
OP SEMI-AXIS OF OVAL OF 95 PER CENT CONFIDENCE PARALLEL TO SITE-POLE GREAT CIRCLE
OM SEMI-AXIS OF OVAL OF 95 PER CENT CONFIDENCE PERPENDICULAR TO OP

Table 5. Summary of remanence data by geological units.

Having established that the partial NRM directions for each of the remaining sites (Table 3) were acceptable for statistical analysis, the sites were segregated into geological units. The remanence directions of the geological units were analyzed statistically on the basis of each site having unit weight (Table 5).

DISCUSSION OF RESULTS

Greenstone Complex (1)

The rocks were originally andesitic lavas extruded during the upper Paleozoic or Lower Mesozoic. Severe regional metamorphism during two orogenies has converted them to greenstone with steeply-dipping north-south axial planes.

Only 1 to 5 sites of these greenstone flows yielded a remanence direction acceptable for statistical analysis. Its pole position (113.9°W., 84.5°N.) is close to the earth's present geographic pole and geomagnetic pole (101°W., 75°N.) (Fig. 2a). This polar coincidence suggests that the remanence was acquired during the Cenozoic, possibly as a secondary partial thermal remanent magnetization (pTRM) during the last orogeny.

Gabbroic Intrusives (2)

Several gabbroic plutons are found on the western side of the Coast Mountains. These plutons are massive though possibly somewhat deformed. According to Baer (1968, personal communication), they were intruded after the first orogeny, which on paleontological evidence had apparently ended by Middle Jurassic time, and before the second orogeny which started in the Upper Cretaceous and/or Paleocene.

Two sites were sampled from each of 2 plutons and the remanence of all 4 sites proved acceptable. Following the method of statistical analysis of Larochelle (1968b), Snedecor's F-ratio test shows that the dispersions of the core remanence directions about their respective site mean directions within each pluton and of the site mean directions about the pluton mean directions are not significantly distinct at the .05 probability level. Similarly, the angular variance ratio test shows that the pluton mean directions based on the site mean directions are not significantly distinct at the .05 probability level so that results from the two plutons can be combined to represent a single unit. The resulting pole position (49.9°E., 73.1°N.) for the gabbro as shown in Figure 2a is much closer to the existing reliable Triassic pole positions for North America (Larochelle, 1967) than to the reliable Permo-Carboniferous and Cretaceous poles (Larochelle, 1968a) and it is in the best

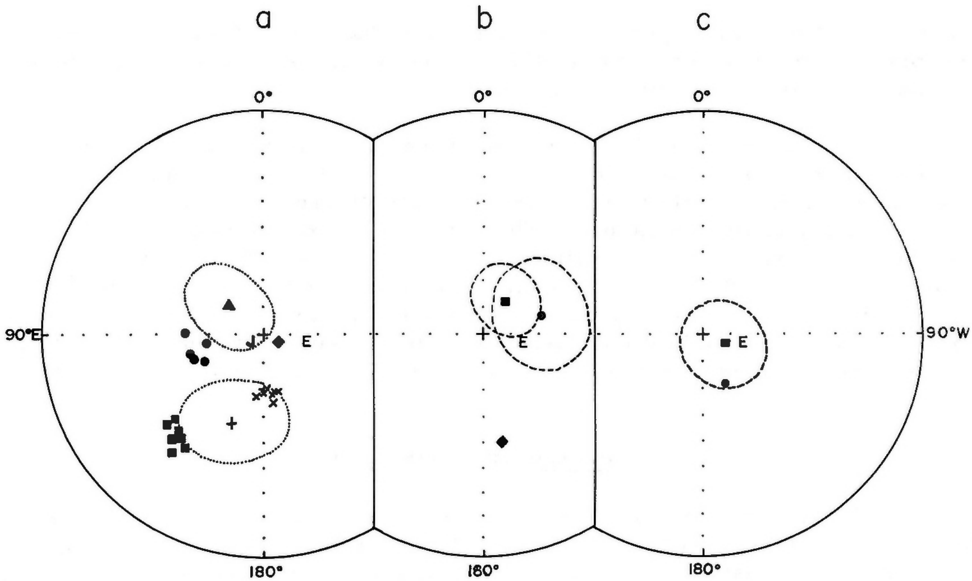

Figure 2. Pole position diagrams. The poles are plotted on the upper hemispheres of Schmidt equal-area polar projections with the unit symbol giving the mean pole position and its α_{95} (α_{63}) oval of confidence by the dashed (dotted) line. E is the earth's present geomagnetic pole.

a) The single site of the greenstone complex (unit 1) is represented by a diamond, the gabbroic plutons (unit 2) by a triangle, and the gabbroic dykes (unit *2) by a + cross. The known reliable pole positions for North America are shown by squares for the Permo-Carboniferous, circles for the Triassic, and J for the Jurassic and X crosses for the Cretaceous (Larochelle, 1967, 1968a).

b) The greenstone dykes (unit 3) are represented by a circle, the granodiorite intrusives (unit 4) by a square, and the single blue porphyritic dyke (unit 5) by a diamond.

c) The single basaltic flow (unit 6) is represented by a circle and the brown basaltic dykes (unit 7) by a square.

agreement with sole reliable Lower Jurassic pole available (Opdyke and Wensink, 1966). Therefore, it appears that these gabbro plutons were intruded before the Cretaceous as close in time to the Triassic-Early Jurassic as possible which combined with the paleontological evidence suggests a Middle or Upper Jurassic age, and that they retain their primary thermoremanent magnetization (TRM) without significant subsequent metamorphic alteration or tectonic rotation.

A gabbroic dyke (*2)* cuts one of the Jurassic gabbroic plutons and another one occurs on the extreme eastern side of the Coast Mountains. Both dykes are in fairly stable tectonic areas, and both are composed of massive and apparently unaltered gabbro. They yielded acceptable and consistent paleomagnetic data. The resulting pole position (160.1°E., 55.0°N.) diverges from the Triassic pole positions and the earth's present magnetic pole, and aligns most closely with reliable Cretaceous pole positions (Fig. 2a). This evidence, admittedly based on only two sites, is consistent with a Cretaceous period of intrusion and with the dykes retaining a primary TRM.

Green Andesitic Dykes (3)

The green andesitic dykes were intruded in several generations during the time interval Middle Jurassic to Upper Cretaceous and/or Paleocene. They are found mostly in the core of the Coast Mountains where they have been metamorphosed during one orogeny so that they are now severely deformed and composed of foliated rocks of the greenschist facies.

Of 22 sites in 22 dykes, 11 yielded reliable paleomagnetic data. Of the 11 sites, the site mean remanence directions were normally polarized in 10 and reversely polarized in 1 which was reversed to the normal position for analysis. The resulting mean pole position (72.2°W., 68.2°N.) diverges significantly from known reliable Cretaceous pole positions and it is moderately close to the earth's present geomagnetic and geographic pole positions without including them in the cone of 95 per cent confidence (Fig. 2b). Because the dykes intrude plutonic rocks, it is not possible to apply tectonic corrections for the fold-test of remanence stability; however, the deformations observed in the dykes in the field suggest that such corrections would be very large (i.e. several tens of degrees) and would increase the scatter in the remanence directions significantly. Therefore, it is thought that these dykes have a stable post-folding secondary remanence acquired during the final stages of the Upper Cretaceous-Paleocene orogeny which is probably a pTRM.

Granodiorite Intrusives (4)

Geological evidence (Baer, 1967) indicates that numerous granodiorite plutons were intruded during the interval Upper Cretaceous and/or Eocene. Five K-Ar radiometric ages between 47 and 77 m.y. have been

* The asterisk denotes the separate statistical analysis of the plutons and of the dykes of similar composition.

determined on rocks from these plutons. They occur in the central part of the Coast Mountains and so are probably somewhat deformed despite their massive appearance. There are a few granitic dykes (*4) which may be comagmatic.

Two sites from one pluton yielded reliable remanence data whereas one site from a second pluton and one site from a granitic dyke were rejected. The dispersion test and angular variance ratio test indicate that there is no reason to suppose that the two accepted site mean remanence directions have not been drawn from the same population at the .05 probability level. The pole position (34.5°W., 75.4°N.) derived from the site mean remanence directions may well be biased because two sites were probably insufficient to average out the effects of secular variation, however, it is significantly divergent from known reliable Cretaceous pole positions and moderately close to the earth's present geomagnetic and geographic pole positions without including them in the oval of 95 per cent confidence. Based on the one pluton, it appears that these plutons have a stable primary TRM acquired during intrusion in the Paleocene-Eocene rather than in the Upper Cretaceous which is consistent with the radiometric evidence. The pole position for the granodiorites agrees closely with that of the green andesitic dykes suggesting the heat associated with the granodiorite intrusive period may have impressed the pTRM on the dykes.

Blue Porphyritic Dykes (5)

The blue porphyritic dykes were probably intruded during the Lower or Middle Tertiary. They strike southwest to northwest and dip moderately south to steeply north. They are unmetamorphosed with minor gentle deformation.

Only 1 of 7 sites representing 7 dykes yielded acceptable remanence data which clearly demonstrates that they are not suitable for paleomagnetic study because of remanence instability or inhomogeneity. The magnetic north pole position (170°W., 49°N.) derived from the single site with reverse remanence polarity is close to the known reliable Cretaceous poles (Fig. 2) which favours the hypothesis of a Lower rather than Middle Tertiary age of intrusion with the dyke retaining a primary TRM.

Basaltic Flows (6)

According to Baer (1967), these olivine-rich basaltic flows were extruded during the Upper Miocene or Lower Pliocene. They are unmetamorphosed with minor deformation. Of the two flows tested, one yielded remanence data acceptable for analysis. It gives a reasonable mid-Tertiary pole position (157°W., 68°N.) after tectonic correction. This single result is consistent with the hypothesis that the flow retains a primary TRM which was acquired during extrusion in the Upper Miocene or Lower Pliocene.

Brown Basaltic Dykes (7)

The brown basaltic dykes form an extensive swarm of north-south-striking and vertically dipping dykes which are prominent in these map-areas on the western side of the Coast Mountains. The dykes are unmetamorphosed and undeformed, and consequently they are thought to have been intruded since the Upper Miocene and most likely during the Holocene (Baer, 1967).

Only 9 of 24 sites representing 24 brown basaltic dykes yielded acceptable remanence data of which 7 were normally polarized and 2 reversely polarized. Application of the dispersion test and angular variance test indicates that there is no reason to suppose that the site mean remanence directions of the normally and reversely (reversed for statistical analysis) polarized dykes have not been drawn from the same population at the 0.05 probability level. The resulting pole position (112.2°W., 81.7°N.) for these dykes derived from the site mean remanence directions is close to the earth's present geographic and geomagnetic poles which are encompassed by the oval of 95 per cent confidence about the dykes' pole (Fig. 2c). This position indicates an Upper Tertiary or Quaternary age of remanence acquisition. The presence of reversed remanence, the fresh appearance of the rocks and their geological relationships indicate that these dykes retain their primary TRM. The presence of reversed remanence also indicates that intrusion of the dykes occurred over a sufficiently long period of time (10^5 to 10^7 years) for the earth's magnetic field to reverse its polarity. This evidence favours the averaging of any bias in the pole position caused through secular variation, and an Upper Miocene to Pleistocene rather than Holocene age of intrusion.

CONCLUSIONS

The results of this study indicate that:

1. the greenstone complex is not suitable for paleomagnetic study; one site indicates that it may have a secondary remanence of Cenozoic age which is possibly a pTRM acquired during the Upper Cretaceous-Paleocene orogeny;

2. the gabbroic plutons have a primary TRM acquired during intrusion in the Middle or Upper Jurassic, and the gabbroic dykes have a primary TRM acquired during intrusion in the Cretaceous;

3. the green andesitic dykes have a secondary remanence which is probably a pTRM acquired during the late stages (Paleocene) of the Upper Cretaceous-Paleocene orogeny;

4. the granodiorite intrusives probably have a primary TRM acquired during intrusion in the Paleocene-Eocene;

5. the blue porphyritic dykes are not suitable for paleomagnetic study; one site indicates that they may have a primary TRM acquired during intrusion in the Lower Tertiary;

6. the single olivine-rich basaltic flow appears to have a primary TRM with a direction consistent with its postulated Upper Miocene or Lower Pliocene age; and,

7. the brown basaltic dykes have a primary TRM acquired during intrusion which probably occurred in the interval Upper Miocene to Pleistocene and probably not in the Holocene, and which occurred over a sufficiently long period of time (i.e. 10^5 to 10^7 years) to allow for reversal(s) in the earth's geomagnetic field.

The pole positions derived from the various geological units should be treated cautiously for comparison with other map-areas because most are based on insufficient acceptable remanence data so that errors from regional tectonic effects or secular variation are possible. When work on the radiometric ages presently in progress is completed, the pole position derived for the brown basaltic dykes (unit 7) should be reliable for the determined age. Also, the results from the gabbroic plutons (unit 2) and granodiorite plutons (unit 4) are encouraging and should yield reliable pole positions for such comparisons with additional paleomagnetic and radiometric work.

Four radiometric age dates from three units discussed in this paper have been completed by the Geochronology Section of the Geological Survey of Canada. One sample from the green andesitic dyke (3) at site 20B yielded a K-Ar age of 81 ± 4 m.y. on hornblende and of 87 ± 5 m.y. on biotite. These ages are concordant and reflect the mid Upper Cretaceous orogeny which metamorphosed the dyke. Thus, they support the conclusion of this study that the green andesitic dykes acquired a pTRM during the Upper Cretaceous-Paleocene orogeny, and they suggest that the orogeny was essentially terminated during the Upper Cretaceous. One sample from the blue porphyritic dyke (5) at site 16D yielded a whole rock K-Ar age of 14.5 ± 1 m.y. which, because the dyke is unmetamorphosed, is thought to date the time of intrusion as Middle Miocene. The remanence of all but one of the blue porphyritic dykes proved unsuitable for paleomagnetic study, and its time of intrusion was interpreted as probably Lower Tertiary or possibly Middle Tertiary. The Middle Miocene age for intrusion is now thought correct. Finally, one sample from the brown basaltic dyke (7) at site 10 yielded a whole rock K-Ar age of 12.5 ± 2.7 m.y. which, because the dyke is unmetamorphosed, is thought to date the time of intrusion as Upper Miocene. Thus, it supports the conclusion of this study that the brown basaltic dykes acquired a primary TRM upon intrusion during the Upper Miocene to Pleistocene, and it suggests that their intrusion was confined to the Upper Miocene.

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