Paleomagnetism of the Flores volcanics, Vancouver Island, in place by Eocene time[1]

E. IRVING AND M. T. BRANDON[2]

Pacific Geoscience Centre, Geological Survey of Canada, P.O. Box 6000, Sidney, B.C., Canada V8L 4B2

Received September 6, 1989

Revision accepted February 13, 1990

The Eocene Flores volcanics of the Insular Belt of southwestern Vancouver Island have U–Pb zircon ages of 51–50 Ma and a mean direction of magnetization (D, I) of 349.8°, 69.6° (12 collecting sites, $k = 41$, $\alpha_{95} = 7.0°$). The paleopole (81.1°N, 188.0°E, $K = 20$, $A_{95} = 9.9°$) agrees well with Early to Middle Eocene (54–48 Ma) paleopoles from cratonic North America and with two Early to Middle Eocene paleopoles (49 and 52 Ma) from the Intermontane Belt of the Canadian Cordillera. This shows that both the Vancouver Island section of the Insular Belt and the Intermontane Belt were in their present positions with respect to ancestral North America at that time. The data can be used as a reference for estimating tilts in bodies that themselves contain no geological evidence of paleohorizontal; as an illustration, tilts of two Eocene intrusions on Vancouver Island are estimated.

Les volcanites de Flores, d'âge éocène, de la ceinture Insulaire du sud-ouest de l'île de Vancouver, fournissent des âges U–Pb sur zircon de 51–50 Ma et une direction d'aimantation moyenne (D, I) de 349,8°, 69,6° (12 sites d'échantillonnage, $k = 41$, $\alpha_{95} = 7{,}0°$). Le paléopôle (81.1°N, 188.0°E, $K = 20$, $A_{95} = 9.9°$) est voisin des paléopôles de l'Écocèce moyen à précoce (54–48 Ma) de l'Amérique du Nord cratonique et de deux paléopôles de l'Éocène moyen à précoce (49 et 52 Ma) de la ceinture Intermontane de la Cordillère canadienne. Ceci démontre que la section de l'île du Vancouver de la ceinture Insulaire ainsi que la ceinture Intermontane occupaient en ce temps leurs positions actuelles par rapport l'Amérique du Nord ancienne. Les résultats peuvent servir de référence pour évaluer les inclinaisons dans les corps pour lesquels il y a absence d'indication géologique de paléohorizontalité; à titre d'illustration, des inclinaisons de deux intrusions éocènes sur l'île de Vancouver sont estimées.

[Traduit par la revue]

Can. J. Earth Sci. 27, 811–817 (1990)

Introduction

Previous paleomagnetic data from Eocene rocks of the Omineca (Fox and Beck 1985) and Intermontane (Symons and Wellings 1989; Bardoux and Irving 1989) belts show that by Eocene time they had reached their present latitude relative to cratonic North America (Fig. 1). The purpose of this paper is to describe paleomagnetic data from Eocene rocks of the Insular Belt, the westernmost element of the Canadian Cordillera.

The Eocene Flores volcanics rest unconformably on Mesozoic rocks of the Wrangellian terrane of southwestern Vancouver Island (Fig. 2). Its paleomagnetism is of interest because, by comparison with data from rocks of comparable age from the craton, it ought to be possible to determine whether Vancouver Island, the major component of the Insular Belt, had become fixed relative to North America by the Early Eocene. These volcanics generally are silicic and in a low to intermediate oxidation state. As a consequence, although a number of flows have been found to be good recorders of the paleofield, most have low magnetic stability and do not record the paleofield.

Symons (1971) studied two small stocks, which probably are coeval with the Flores volcanics and which he found to have normal (Tofino stock) and reversed (Kennedy Lake stock) magnetizations. However, these data cannot be used to determine the Eocene paleofield because the attitudes of the stocks, which may have been tilted after emplacement, are not known. The possibility of using their paleomagnetism to reconstruct their attitude will be considered at the end of this paper.

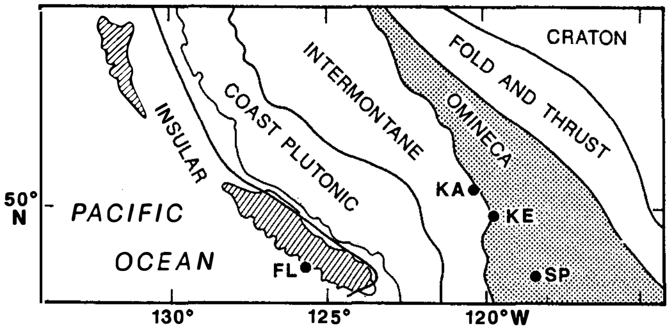

FIG. 1. Tectonic belts of the Cordillera and general locations of study area of Eocene rocks as follows: FL, Flores volcanics; KA, Kamloops Group volcanics; KE, Kelowna volcanics; SP, Sanpoil volcanics.

Geology

The Flores volcanics are composed primarily of welded and massive ash-flow tuff and tuff breccia, with subordinate flows and hypabyssal intrusions. A section of the unit having a stratigraphic thickness of about 730m is exposed on the southwest side of Flores Island. Modal quartz is present in the tuff, indicating a dacitic composition. Chemical analyses have however shown them to be mostly moderately potassic calc-alkaline andesites and dacites, with minor low-potassium tholeiitic basalts (Massey 1989). The rocks were originally mapped as part of the Jurassic Bonanza Group (Muller 1977), but their fresh appearance suggested to one of us (MTB) that they were probably younger. Accordingly, three samples were collected for dating. Fission-track studies (J. A. Vance, unpublished data, 1983, 1986) indicate ages of 51–55 Ma for their crystallization. Two of these three samples, one from Cow Bay, Flores Island, and one from Mount Ozzard, were also

---

[1] Geological Survey of Canada Contribution 21789; Lithoprobe Contribution 106.

[2] Present address: Department of Geology and Geophysics, Yale University, P.O. Box 6666, New Haven, CT 06511, U.S.A.

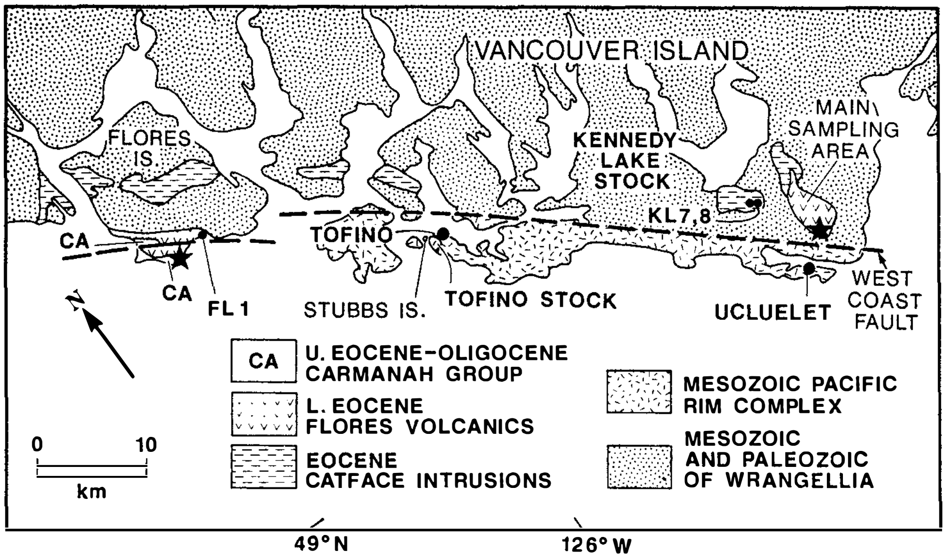

FIG. 2. General geology of sampling region (from Brandon 1989). The stars at the southern tip of Flores Island and in the main sampling area are localities from which samples for U–Pb studies were collected. An enlargement of the main sampling area is given in Fig. 4.

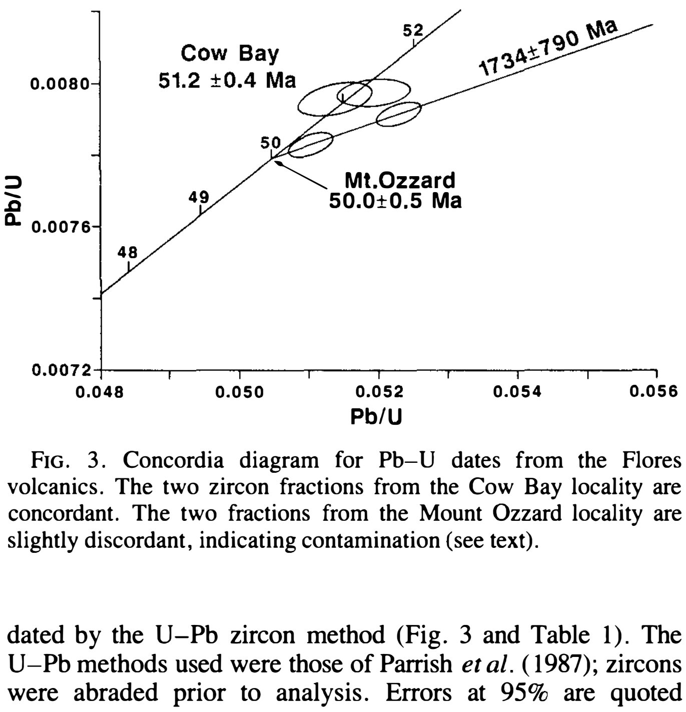

FIG. 3. Concordia diagram for Pb–U dates from the Flores volcanics. The two zircon fractions from the Cow Bay locality are concordant. The two fractions from the Mount Ozzard locality are slightly discordant, indicating contamination (see text).

dated by the U–Pb zircon method (Fig. 3 and Table 1). The U–Pb methods used were those of Parrish *et al.* (1987); zircons were abraded prior to analysis. Errors at 95% are quoted throughout.

The Cow Bay sample is a tuff from the basal part of the sequence and its zircons yield overlapping concordant analyses and an age of 51.2 ± 0.4 Ma. The Mount Ozzard sample is also a tuff from the basal part of the sequence. Its zircons are slightly discordant, indicating the presence of a minor inherited component, derived, presumably, by assimilation at depth, or surface intermixing of foreign material. The lower intercept of a two-point array of data is 50.0 ± 0.5 Ma, which is taken as the best estimate of the time of crystallization. Fission-track dates on zircons from these two samples are 50.7 ± 5.8 and 55.2 ± 6.4 Ma respectively. A third fission-track date from basal tuff near Mount Frederick is 54.7 ± 5.8 Ma. The U–Pb dates are the more precise and indicate an age of 51–50 Ma (early Middle Eocene on the DNAG (Decade of North American Geology) time scale of Palmer 1983). A summary of these and other Cenozoic isotopic ages for the Pacific Rim area is given by Brandon (1989).

There are numerous small Tertiary stocks in the Tofino-Ucluelet area (Carson 1973; Armstrong 1988), which Muller (1977) mapped as the Catface intrusions. These stocks range in age from 67 to 33 Ma (Fig. 2 in Brandon 1989). Two are relevant to our study: the Tofino stock, 51.6 ± 5 Ma (K/Ar biotite), and the Kennedy Lake stock, 67.4 ± 4 Ma (K/Ar hornblende) and 45.7 ± 2.3 Ma (K/Ar biotite). These ages are all from Wanless *et al.* (1967, 1968) and have been recalculated using modern decay constants.

Paleomagnetic results

Measurements were made on a Schonstedt spinner magnetometer controlled by IBM PC's. Thermal demagnetization was carried out using a Schonstedt TSD-1 furnace and alternating-field demagnetization, a Schonstedt GSD-5 tumbling demagnetizer. Principal-component analysis (Zidjerveld 1967; Kirschvink 1980) was used to isolate stable magnetizations using the programme LINEFIND (Kent *et al.* 1983), Directions of stable magnetizations of each specimen have been averaged to obtain the mean direction for each site (Table 2).

Most samples obtained in a trial collection had variable directions of remanent magnetization. Intensities of magnetization varied by two orders of magnitude. These samples were pale grey or buff in colour and silicic in composition. They include lavas, tuffs, and lithic tuffs from Flores Island, Mount Frederick, and Mount Ozzard, and quartz dioite from the Tofino stock exposed on Stubbs Island and at Tonquin Park (Fig. 2). The magnetization at some sites had random directions, and demagnetization yielded no significant grouping. Other sites had complex magnetizations that appeared to result from an intermixing of normal and reversed components, but detailed demagnetization studies were unsuccessful in separating them. Fortunately, however, a few sites yielded coherent mgnetizations, and during later collections their number was increased to 13, distributed among three localities: Flores Island (1 site, Fig. 2), Mount Frederick (8 sites, Fig. 4), and Mount Ozzard (4 sites, Fig. 4). After removal of small, soft components of magnetization, probably imposed by the present Earth's field,

TABLE 1. U–Pb ages of zircons from Flores volcanics

	Cow Bay (49°15.88′N, 126°10.62′W)		Mount Ozzard (48°57.22′N, 125°29.07′W)	
	8817-2A	8817-2B	81813-2A	81813-2B
Weight (mg)	0.557	0.415	0.649	0.689
U (ppm)	584.5	528.3	569.5	515.6
Pb (ppm)[a]	4.639	4.192	4.509	4.023
$^{206}\mathrm{Pb}/^{204}\mathrm{Pb}$[b]	451	378	779.6	670.4
Pb$_c$ (pg)[c]	377	306	242	269
$^{208}\mathrm{Pb}$ (%)[a]	9.8	9.5	9.9	9.5
$^{206}\mathrm{Pb}/^{238}\mathrm{U}$[d]	0.007954±.29%	0.007973±.22%	0.007912±.22%	0.007826±.20%
$^{207}\mathrm{Pb}/^{235}\mathrm{U}$	0.5140±.55%	0.5196±.52%	0.05232±.33%	0.05105±.33%
Correction coefficient	0.51	0.30	0.66	0.54
$^{207}\mathrm{Pb}/^{206}\mathrm{Pb}$[d]	0.04690±.47%	0.04727±.50%	0.04796±.24%	0.04731
$^{207}\mathrm{Pb}/^{206}\mathrm{Pb}$ age[e]	42.4±22.4	62.8±23.7	97.4±11.4	64.7±13.4
$^{206}\mathrm{Pb}/^{238}\mathrm{U}$ age[e]	51.1±0.2	51.2±0.2	50.8±0.2	50.3±0.2
$^{207}\mathrm{Pb}/^{235}\mathrm{U}$ age[e]	50.9±0.6	51.4±0.5	51.8±0.3	50.6±0.3
Interpreted age	51.2±0.4 Ma, average of two concordant Pb/U ages		50.0±0.5 Ma, lower intercept 1734±790 Ma, upper intercept	

NOTE: Analyses courtesy of D. Parkinson and R. Parrish, Geochronological Laboratories, Geological Survey of Canada.

[a] Radiogenic Pb.

[b] Measured ratio, corrected for spike and fractionation.

[c] Total common Pb.

[d] Radiogenic Pb, errors are 1σ % corrected for25 pg Pb blank, 20 pg U blank, and 50 Ma Stacey–Kramers common Pb.

[e] Radiogenic Pb, errors are 2σ.

TABLE 2. Data by sites

Site	Lat. N, long. W	Rock type	$c(s)$	M (A/m)	D, I (°)	k	α_{95} (°)
FL01	49°15.9′, 126°10.8′	Red breccia	7(11)	0.232	310, 69	37	8
FR07	48°59.9′, 125°29.6′	Plagioclase porphyry dyke	8(16)	0.005	165, −68	59	5
FR21	49°00.1′, 125°30.9′	Granodiorite dyke	7(10)	0.001	330, 61	28	9
FR24	49°00.6′, 125°31.1′	Mafic incl. in dyke	3(5)	0.498	340, 73	21	14
FR26	49°00.5′, 125°31.1′	Basalt Flow	6(6)	0.005	163, −76	46	10
FR27	49°00.5′, 125°31.2′	Basalt flow	7(10)	0.005	157, −65	73	6
FR28	49°00.3′, 125°31.4′	Andesite flow	5(9)	0.082	342, 80	98	5
FR29	49°00.6′, 125°30.8′	Granodiorite	3(5)	0.002	345,60	48	9
FR31	49°00.2′, 125°29.5′	Andesite flow	4(5)	0.258	26,77	16	19
OZ32	48°58.0′, 125°28.7′	Breccia	3(6)	0.009	344,75	42	10
OZ33	48°58.0′, 125°28.8′	Red breccia	7(12)	0.103	24, 46	61	6
OZ34	48°57.7′, 125°29.5′	Dacite flow	6(9)	0.015	195, −67	46	8
OZ35	48°57.5′, 125°29.6′	Hornblende porphyry sill	9(15)	0.057	273, −52	59	5
KL07	49°00.8′, 125°34.1′	Fine-grained dyke	2(4)	0.001	257, −64	95	10
KL08	49°00.8′, 125°34.1′	Quartz diorite	4(7)	0.019	230, −66	36	10
KL[a]	49°00.0′, 125°34.0′	Quartz diorite	(3(6)	—	216, −64	339	4
TP[a]	49°09.2′, 125°56.8′	Quartz diorite	2(4)	—	32, 46	217	7

NOTES: (1) $c(s)$ are the number of oriented cores and number of cylindrical specimens cut from these cores; M is the mean intensity of magnetization; D, I are the declination and inclination of the mean direction of magnetization, k and α_{95} are Fisher estimates of precision and radius of confidence circle ($P = 0.05$). (2) Geological dips are as follows: Flores Island (FL site) down 49° in the direction 267°; Mount Frederick (FR sites) 20° in rhe direction 220°; Mount Ozzard (OZ sites) 12° in the direction 215°. Directions given with respect to paleohorizontal for FL, FR, and OZ sites. For the Kennedy Lake intrusion (KL sites) the directions are given with respect to present horizontal. (3) The demagnetization ranges used for calculating the principal magnetizations are as follows: FL01 50–70 mT (8 specimens), 10–100 mT (2 specimens), 100–700°C (1 specimen); FR07 40–80 mT (15), 100–700°C (1); FR21 10–100 mT (1), 20–80 mT (8), 150–600°C (1); FR24 10–100 mT (1), 20–80 mT (3), 300–700°C (1); FR26 10–100 mT (1), 20–80 mT (4), 300–550°C (1); FR27 20–100 mT (1), 20–80 mT (8), 300–550°C (1); FR28 10–90 mT (1), 20–80 mT (6), 150–550°C (2); FR29 400–650°C (3); FR31 200–600°C (5); OZ32 10–50 mT (3), 200–600°C (2); OZ33 20–80 mT (11), 500–700°C (1); OZ34 20–100 mT (1), 20–80 mT (7), 400–650°C (1); OZ35 20–100 mT (1), 20–80 mT (13), 150–600°C (1); KL 7 10–40 mT (1), 100–650°C (1), 500–600°C (1); KL8 10–100 mT (1), 40–60 mT (5), 100–700°C (1).

[a] From Symons (1971).

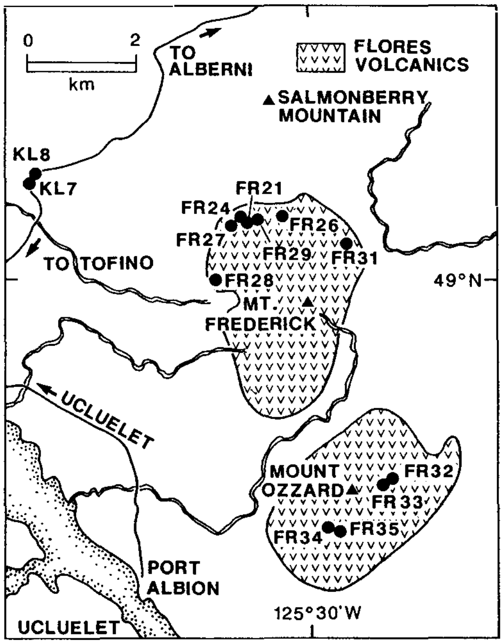

FIG. 4. Main sampling area, whose general location is given in Fig. 2.

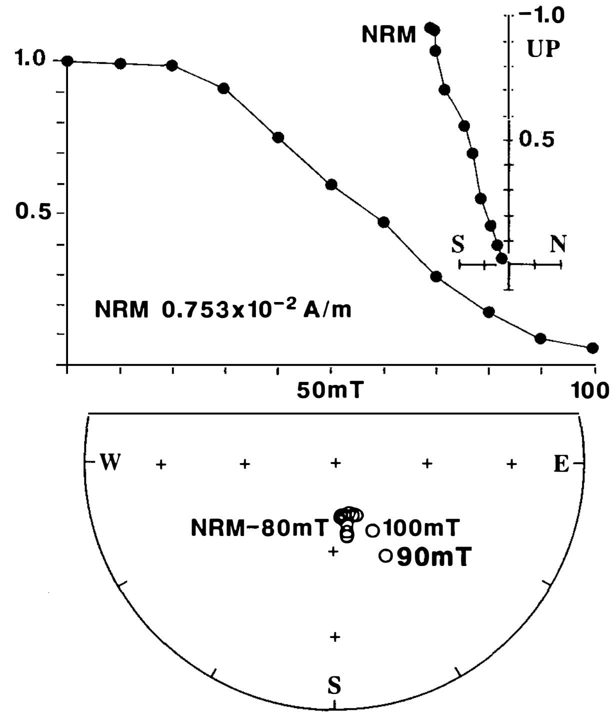

FIG. 5. Alternating field demagnetization of reversely magnetized plagioclase porphyry dyke (site FL7). Top, decay of intensity and normalized orthogonal plot in the north–south vertical plane; bottom, direction changes with respect to paleohorizontal.

the magnetizations at these 13 sites were single component, as illustrated in Figs. 5–8.

Very well defined single-component magnetizations were found in a grey-coloured plagioclase porphyry dyke (Fig. 5), a fine-grained black basaltic lava (Fig. 6), and red hematitic breccia (Fig. 7). Both thermal and alternating field demagnetization yielded excellent end points, high discrete unblocking temperatures, and linear decay to the origin on orthogonal plots.

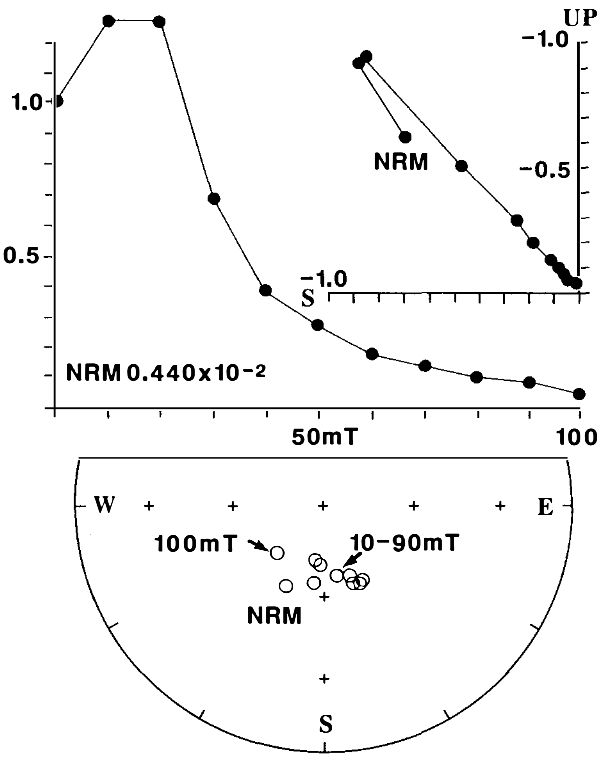

FIG. 6. AF demagnetization of reversely magnetized fine-grained basaltic lava (site FL27). See caption Fig. 5.

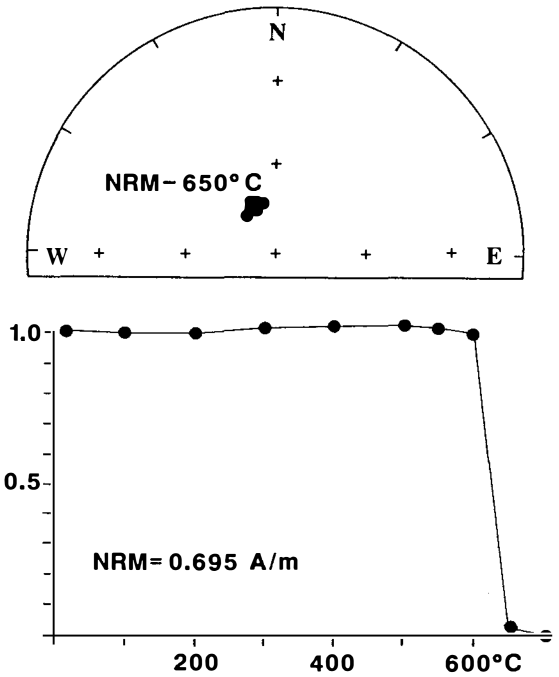

FIG. 7. Thermal demagnetization of normally magnetized red breccia from Flores Island (site FL1). See caption Fig. 5.

The intensity of magnetization in the porphyry dyke is low, as expected from its composition, but that in the basaltic lava is surprisingly weak (natural remanent magnetization (NRM) 0.4 × 10^{-2} decreasing to 0.2 × 10^{-3} A/m after demagnetization at 100 mT). All retain the same direction throughout the demagnetization range. Other samples have less well defined single-component magnetizations (an example from a pale grey

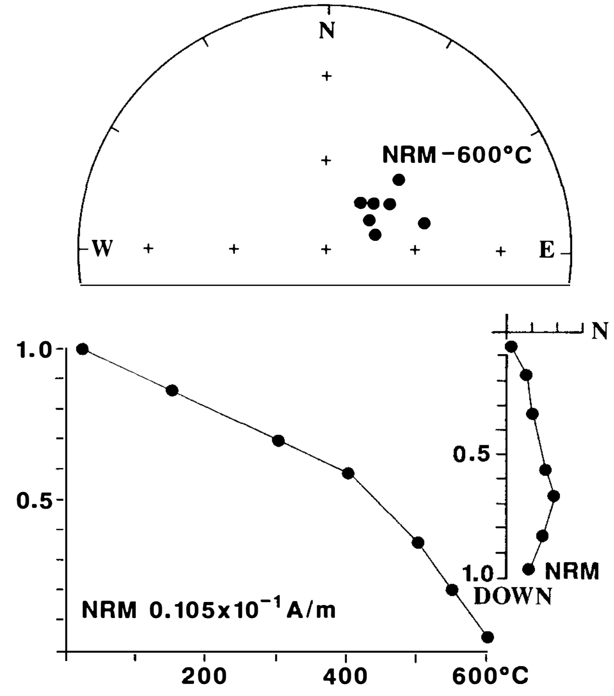

FIG. 8. Thermal demagnetization of normally magnetized grey-coloured breccia (site OZ32). See caption Fig. 5.

breccia is given in Fig. 8). Their end points are less well defined, unblocking temperatures are more widely distributed, and decay to the origin is less regular than in the examples just described. Nevertheless, line fitting, in this instance between 200 and 600°C, allows the direction of stable magnetiztion to be determined quite accurately.

At many sites it was impossible to obtain reliable bedding attitudes, nor could reliable attitudes be obtained by projection from nearby well-stratified exposures. However, mapping of contacts and bedding attitudes over the area of outcrop by M. T. Brandon (unpublished fieldwork, 1980–1982) and BP Minerals Limited (B.E. Marten, written communication, 1982) indicates that, to a good approximation, the two main sections (mounts Ozzard and Frederick) are uniformly tilted panels, whose dip can be estimated by averaging bedding attitudes observed throughout the panel. Consequently, "panel" dip corrections, given in Table 2, have been applied to data from each of the two main sections (12 sites). At the remaining site (FL01), bedding attitude is well established locally.

The mean site directions fall into two groups of normal and reversed polarity. Site 35 is exceptional; it has westerly declination with shallower inclination, and possibly records the field during reversal. Structural corrections produce only marginal improvement in the coherence of the data (Fig. 9, Table 3). Reversed and normal sites give essentially identical mean directions. The circular standard deviation θ_{63} for all corrected site poles (virtual geomagnetic poles or VGP's) is 18.1°, which is comparable to 20° for Eocene cratonic VGP's (Gromme *et al.* 1986). These tests show that the data is internally consistent and that the 12 VGP's provide an adequate sample of secular variation. The overall mean, irrespective of signs, is 349.8°, 69.6° (k = 41, α_{95} = 7.0°, 12 sites, 102 specimens). The paleopole, calculated as a mean of 12 VGP's, is at 81.1°N, 188.0°E (K = 20, A_{95} = 9.9°).

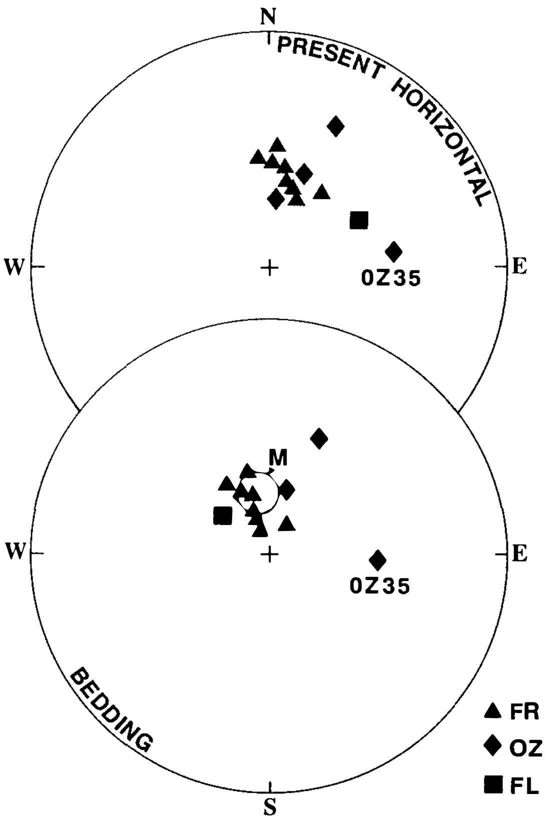

FIG. 9. Site directions. Reversed directions are inverted so all are plotted on the lower hemisphere. Top, directions uncorrected; bottom, corrected to paleohorizontal. The circle is the 95% error of the mean (M) of corrected data.

TABLE 3. Summary of data

	N	D_m, I_m (°)	k	α_{95} (°)
Normal corrected	8	349.6, 69.6	29	10.4
Reversed corrected	4	170.3, −69.7	105	9.0
All corrected	12	349.8, 69.6	41	7.0
All uncorrected	12	017.0, 55.3	37	7.2

NOTES: Corrected (uncorrected) data with respect to paleohorizontal (present horizontal). Paleohorizontal surfaces specified in footnote to Table 2. N is the number of sites, 102 specimens all told; D_m, I_m are the declination and inclination of the mean direction; k and α_{95} are Fisher precision and radius of circle of confidence (P = 0.05). The paleopole, calculated as a mean of 12 site poles for corrected data, is 81.1°N, 188.0°E (K = 20, θ_{63} = 18.1°, A_{95} = 9.9°).

Comparison with Cordilleran and cratonic data

The paleopole obtained from the Flores volcanics agrees very well with those from the Lower Eocene volcanics of the Kelowna inlier (Bardoux and Irving 1989) and from volcanics of the Kamloops Group (Symons and Wellings 1989) of south-central British Columbia (Table 4, Fig. 10). The latter are situated on Quesnellia, near the eastern border of the Intermontane Belt (Fig. 1). All three paleopoles from within the Canadian Cordillera are in excellent agreement with those from east of the Cordillera in Wyoming and Montana. The latter have been obtained from rock units ranging in age from 54 to 48 Ma (Table 4, Fig. 10). There is excellent agreement among paleopoles from six rock units spread over a distance of 1200 km from Montana to Vancouver Island. Evidently, the Vancouver Island section

TABLE 4. Summary of Early to Middle Eocene data

Rock unit (reference)	N	D_m, I_m (°)	k	α_{95} (°)	Lat. N, long. E	A_{95} (°)
Flores volcanics, 50–51 Ma (1)	12	350,70	41	7	81°, 188°	10
Kamloops Group, 49 ± 2 Ma (2)	24	355,73	20	7	81°, 222°	12
Kelowna volcanics, 52 ± 2 Ma (3)	28	352,69	21	6	85°, 197°	10
Sanpoil volcanics, 53–48 Ma (4)	83	013,69	12	5	80°, 296°	8
Bearpaw Mountains volcanics, 50–54 Ma (5)	30	349,67	34	5	82°, 189°	6
Absaroka volcanics, 48 Ma (6)	19	350,62	15	8	84°, 177°	10
Highwood Mountains volcanics, 49–53 Ma (7)	30	349,64	27	5	82°, 163°	7
Craton mean, 54–48 Ma (5–7)	3	—	—	—	83°, 176°	3

NOTES: N is the number of sites or rock units; D_m, I_m is the mean direction irrespective of sign; k and α_{95} are Fisher precision and cone of confidence ($P = 0.05$). Paleopoles and their errors, A_{95} at $P = 0.05$, are also given. References are as follows: (1) herein; (2) Symons and Wellings (1989); (3) Bardoux and Irving (1989), data mainly from the Marron Formation; (4) Fox and Beck (1985) as recalculated in Bardoux and Irving (1989, Table 4, entry *s*); (5) and (7) Diehl *et al.* (1983); (6) Shive and Pruss (1977). Craton mean is average of the three previous entries.

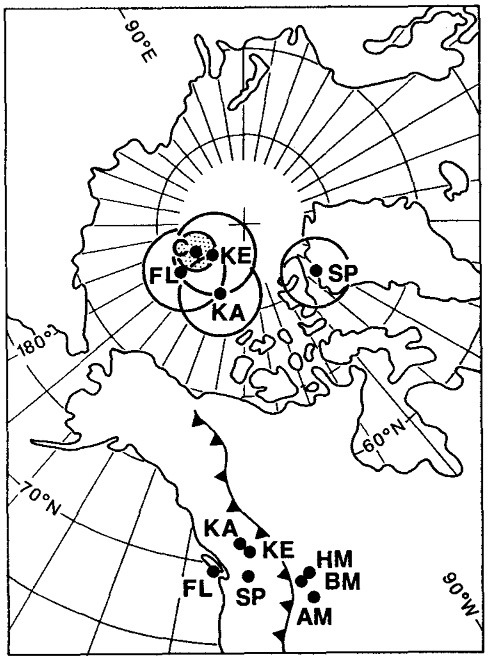

FIG. 10. Early to Middle Eocene paleopoles. Paleopole for the Flores volcanics (FL) compared with those from volcanics of the Kelowna outlier (KE), the Kamloops Group volcanics (KA), the Sanpoil volcanics (SP), and the craton mean (C) of data from Highwood Mountains (HM), Bearpaw Mountains (BM), and Absaroka Mountains (AM) (last entry of Table 4). Standard-error circles are drawn ($P = 0.63$), which have approximately one-half the radius of the 95% errors ($P = 0.05$) listed in Table 4. Standard errors are used because they indicate the significance of differences more clearly than the corresponding 95% errors; to a good approximation, paleopoles whose standard-error circles do not overlap are significantly different at $P = 0.05$. The Cordilleran thrust front is marked.

of the Insular Belt and the southern Intermontane Belt had attained their present relative position by Early Eocene time (about 50 Ma). In these data there is no indication of significant rotations about local vertical axes, although small rotations of up to about 7° would be permissible within experimental errors. Data, available as an abstract only, from Eocene volcanics further north in the Intermontane Belt yield paleolatitudes concordant with cratonic values (Vandall and Palmer 1988).

A study of the Sanpoil volcanics of Washington, which are of comparable age to the volcanics of Kelowna and Kamloops, has yielded a paleopole displaced clockwise from those indicated by the above data (Table 4, Fig. 10); the inclination (and hence, paleolatitude) agrees with determinations from the craton, but the declination does not, and a clockwise rotation of 25° has been inferred by Fox and Beck (1985).

Determining tilt of intrusions

As already noted, Symons has obtained data from the Tofino and Kennedy Lake stocks. Incidental to our study, the Kennedy Lake stock was resampled (Figs. 2 and 4). The direction (D, I) for the Tofino stock given by Symons (1971) is 32°, 46° ($\alpha_{63} = 3°$). That for the Kennedy Lake stock is 216°, −64°, which, when combined with data from our sites KL7 and KL8, becomes 234°, −66° ($\alpha_{63} = 6°$). No field determinations of attitude are available for either body, but estimates can be made by rotating paleodirections through small circles into the mean direction of the Flores volcanics (350°, 69° or 170°, −69°). The tilt obtained for the Tofino stock is down 33° in the direction 242°E and that for the Kennedy Lake stock is down 27° at 283°E with an uncertainty of about 10°. Data from the stocks is insufficient to average out the secular variation and these tilt estimates may suffer as a consequence. If it should become desirable to do so, it would be feasible, by undertaking detailed studies, to obtain similar estimates of tilt for Early to Middle Eocene intrusions across the entire Cordillera, since the reference paleofield is now well established for this time interval.

Acknowledgments

We gratefully acknowledge geological advice during fieldwork from N. W. D. Massey. We are very grateful to Judith Baker for making the magnetic measurements, to J. A. Vance of the University of Washington for allowing us to cite fission-track ages, to D. Parkinson and R. Parrish of the Geological Survey of Canada for providing the information on U–Pb zircon ages, to B. E. Marten of BP Minerals Limited for providing an unpublished reconnaissance map of the Mount Ozzard – Mount Frederick area, to C. R. Yorath for discussions, and to N. W. D. Massey, R. Parrish, M. E. Beck, Jr., C. S. Grommé, and C. R. Yorath for very helpful reviews.

ARMSTRONG, R. L. 1988. Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera. Geological Society of America, Special Paper 218, pp. 55–91.

BARDOUX, M., and IRVING, E. 1989. Paleomagnetism of Eocene rocks of the Kelowna and Castlegar areas, British Columbia: studies in determining paleohorizontal. Canadian Journal of Earch Sciences, **26**: 829–844.

BRANDON, M. T. 1989. Deformation styles in a sequence of olistostromal mélanges, Pacific Rim Complex, western Vancouver Island, Canada. Geological Society of America Bulletin, **101**: 1520–1542.

CARSON, D. J. T. 1973. The plutonic rocks of Vancouver Island, British Columbia: their petrography, chemistry, age, and emplacement. Geological Survey of Canada, Paper 72–44.

DIEHL, J. F., BECK, M. E., JR., BESKE-DIEHL, S., JACOBSON, D., and HEARN, B. C., JR. 1983. Paleomagnetism of the Late Cretaceous – Early Tertiary north-central Montana alkalic province. Journal of Geophysical Research, **88**: 10 593 – 10 609.

FOX, K. F., and BECK, M. E., JR. 1985. Paleomagnetic results for Eocene volcanic rocks from northeastern Washington and the Tertiary tectonics of the Pacific Northwest. Tectonics, **4**: 323–341.

GROMME, C. S., BECK, M. E., JR., WELLS, R. E., and ENGEBRETSON, D. S. 1986. Paleomagnetism of the Tertiary Clarno Formation of central Oregon and its significance for the tectonic history of the Pacific Northwest. Journal of Geophysical Research, **91**: 14 089 – 14 103.

KENT, J. T., BRIDEN, J. C., and MARDIA, K. V. 1983. Linear and planar structure in ordered multivariate data as applied to progressive demagnetization of palaeomagnetic remanence. Geophysical Journal of the Royal Astronomical Society, **75**: 593–621.

KIRSCHVINK, J. L. 1980. The least-square line and plane and the analysis of palaeomagnetic data. Geophysical Journal of the Royal Astronomical Society, **62**: 699–718.

MASSEY, N. W. D. 1989. The Eocene Flores Volcanics-transform-fault volcanism on Vancouver Island [abstract]. Geological Society of America, Abstracts with Programs, **21**: 112.

MULLER, J. E. 1977. Geology of Vancouver Island. Geological Survey of Canada, Open File Map 463.

PALMER, A. R. 1983. The DNAG time-scale. Geology, **11**: 503–504.

PARRISH, R. R., RODDICK, J. C., LOVERIDGE, W. D., and SULLIVAN, P. W. 1987. Uranium–lead analytical techniques at the Geochronological Laboratory, Geological Survey of Canada, Paper 87–2, pp. 3–7.

SHIVE, P. N., and PRUSS, E. F. 1977. A paleomagnetic study of basalt flows from the Absaroka Mountains, Wyoming. Journal of Geophysical Research, **82**: 3039–3048.

SYMONS, D. T. A. 1971. Paleomagnetic notes on some minor Tertiary igneous bodies, Vancouver Island, British Columbia. Geological Survey of Canada, Paper 17–24, pp. 1–10.

SYMONS, D. T. A., and WELLINGS, M. R. 1989. Paleomagnetism of the Eocene Kamloops Group and the cratonization of Terrane I of the Canadian Cordillera, Canadian Journal of Earth Sciences, **26**: 821–828.

VANDALL, T. A., and PALMER, H. C. 1988. Paleomagnetism of the Middle Eocene Ootsa lake volcanics in the Stikine Terrane, B.C. Eos, **97**: 1165.

WANLESS, R. K., STEVENS, R. D., LACHANCE, G. R., and EDMONDS, C. M. 1967. Age determinations and geologic studies, K–Ar isotopic ages, report 7. Geological Survey of Canada, Paper 66–17.

——— 1968. Age determinations and geologic studies, K–Ar isotopic ages, report 8. Geological Survey of Canada, Paper 67–2.

ZIDJERVELD, J. D. A. 1967. A.C. demagnetization of rocks: analysis of results. *In* Methods in palaeomagnetism. *Edited by* D. W. Collinson and S. K. Runcorn, Elsevier, Amsterdam, pp. 254–286.