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Myrl E. Beck Jr.
Western Washington University, myrl.beck@wwu.edu

Russ R. Burmester
Western Washington University, russ.burmester@wwu.edu

Ruth Schoonover
Western Washington University

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TERTIARY PALEOMAGNETISM OF THE NORTH CASCADE RANGE, WASHINGTON

Myrl E. Beck, Jr., R. F. Burmester, Ruth Schoonover

Department of Geology, Western Washington University
Bellingham, Washington 98225

Abstract. We have obtained paleomagnetic data for the southern tip of the middle Tertiary Chilliwack Composite Batholith, located on the Canada-United States border about 125 km E of Vancouver, B.C. Thirty-four separately oriented samples were collected along a road traverse 1.5 km long located along State Highway 22, about 20 km NE of Marblemount, Washington. The mean direction after magnetic cleaning is: D, 182.8°; I, -65.0°; α_{95}, 1.5°. This corresponds to a paleomagnetic pole at 87.5°N, 267.5°E, close to other poles for Tertiary plutons from the North Cascades and only slightly displaced from Tertiary reference poles from the craton. We conclude that the North Cascades block has not been rotated or suffered major internal disruption since perhaps late Eocene time, in marked contrast to all the terranes that surround it.

Introduction

The Chilliwack Composite Batholith [Misch, 1966, 1979] ranges from diorite to granodiorite in composition and Miocene to Eocene in age. It is one of several plutons of similar age and lithology in the crystalline North Cascades block, the complicated geology of which is summarized by Misch [1966]. The North Cascades block is thought to be a displaced terrane by many investigators (for instance, Coney et al., 1980), and indeed available paleomagnetic data [Beck and Noson, 1972; Beck et al., 1981] suggest, but do not prove, that it was far south of its present location until late Mesozoic time. The North Cascades block is bordered on the west by the Olympic Mountains and the Washington Coast Range, on the south and southeast by young volcanic rocks of the Cascades and the Columbia Plateau, respectively, and on the east by the Okanogan Highlands, a southern extension of the Cassiar-Omineca crystalline belt. All of these provinces have experienced deformation in the Tertiary, in some cases into the late Tertiary. Some of this deformation was quite profound. One consequence of our work on the Chilliwack Batholith is that we can test whether similar deformation has affected the North Cascades.

Methods and Results

We collected 34 oriented samples along 1.5 km of nearly continuous exposure provided by Washington State Highway 22, about 20 km E of Marblemount (Fig. 1). Samples were collected in pairs (roughly one meter apart) spaced at equal intervals of approximately 100 m from one side of the exposure to the other. Details of the local geology, including radiometric ages (30-36 m.y. B.P., K/AR) can be found in Misch [1979]. The rocks are medium-grained, massive, isotropic granodiorites or diorites, and appear to be very fresh. Test samples were demagnetized by the alternating field method to 100 mT, thermally to temperatures above which the remanent magnetism became too weak to measure, and by cooling in liquid nitrogen and rewarming in field-free space. No trace of any hard secondary magnetization was detected in the test samples. Accordingly, we demagnetized the entire site at 20 mT, which was sufficient to remove the small amount of viscous remanent magnetization some samples had acquired. Results are presented in Table 1; the cluster of individual directions is circularly symmetrical and probably Fisherian.

Fig. 1 shows the location of other Tertiary plutons in the North Cascades for which paleomagnetic data are available; Table 2 gives a summary. In this compilation data for the Twin Sisters dunite of northwest Washington [Beck, 1975] are excluded. The Twin Sisters body may have been emplaced tectonically along the Shuksan thrust [Misch, 1966], and if so probably acquired its magnetization during emplacement at upper crustal levels, most likely in earliest Tertiary time. It has a strongly discordant direction of remanent magnetization, interpreted by us to represent clockwise rotation during tectonic emplacement. Rotation in this sense is compatible with right-oblique convergence between the Farallon and North American plates, such as apparently prevailed at the time (D. C. Engebretson, personal communication, 1981).

Fig. 2 shows site-VGP (virtual geomagnetic poles) for the six plutons of Table 2. They form a tight cluster with no obvious elongation, even though their sampling sites are spread over a distance of roughly 200 km N-S and their ages range over approximately 20-25 m.y. Only the Mt. Barr sites (which may be partly unstable) fall outside the group. In Table 3 we give mean middle Tertiary poles for the North Cascades based on these data, with and without the Mt. Barr sites. Also listed are the appropriate reference poles for the North American craton.

Interpretation

The homogeneous grouping of VGP in Fig. 2 suggests that there has been no important internal deformation affecting the basement of the central North Cascades since perhaps late Eocene or Oligocene time. As shown (Fig. 1), the important Straight Creek fault traverses the line of batholiths; this fault is thought to have had right-lateral displacement of several hundred kilometers in pre-Chilliwack time (J. Vance, personal communication, 1981), with perhaps some subsequent dip-slip displacement. Apparently any such late deformation did not tilt or rotate the plutons

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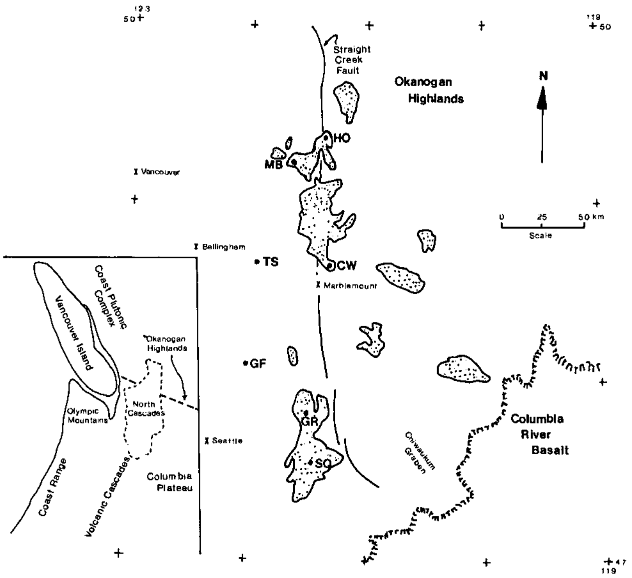

Fig. 1. Location map showing sampling localities. Stippled pattern shows major Tertiary plutons. HO, Hope Plutonic Complex Symons, 1972; MB, Mt. Barr Plutonic Complex [Symons, 1973]; TS, Twin Sisters Dunite [Beck, 1975]; CW, Chilliwack Composite Batholith (this paper); GF, Granite Falls Stock [Beske et al., 1973]; GR, Grotto Batholith [Beske et al., 1973]; SQ, Snoqualmie Batholith [Beske et al., 1973]. Insert shows geological provinces mentioned in text.

relative to one another to any significant extent.

Fig. 2 also indicates that polar wandering relative to the North Cascade block was minimal during the period 16-43 m.y.B.P. This is not consistent with observations by Diehl et al. [1980] to the effect that polar movement relative to North America was practically nonexistent during the period 35 to 15 m.y.B.P., but was apparently rapid during a preceding interval from 44 to 35 m.y.B.P. Our contrary results may well be an artifact of insufficient sampling of the North Cascade plutons, or perhaps the magnetizations of these slowly-cooled rocks is considerably younger than their K/Ar dates. It seems possible, however, that the Diehl et al. chronology may need to be modified to consist of a polar stillstand during much of the Cretaceous (120-75 m.y.B.P.), a period of rapid movement in latest Cretaceous and Paleocene time, and a period of slow polar movement thereafter.

Fig. 2 indicates that the North Cascade terrane has not moved significantly relative to the interior of the continent since late Eocene time. A slight "near-sided" effect is observed; that is, North Cascade Tertiary poles tend to be slightly closer to the sampling area than are the North American reference poles. In terms of directions of remanent magnetization, this means that the inclinations observed in North Cascade plutons are slightly steeper than expected. The

TABLE 1. Paleomagnetic Results for the Southern Chilliwack Batholith, Washington

N	D	I	K	α_{95}
34	182.8°	-65.0°	284	1.5°

N, number of samples; D, I, declination and inclination of remanent magnetization; K, precision parameter; α_{95}, radius of circle of 95% confidence.

TABLE 2. Paleomagnetic Data for Intrusive Rocks of Tertiary Age from the North Cascades, Washington

Unit	N	λ'	Ø'	Age	Reference
HO	5	87.5 N	210.0 E	35-41	Symons [1973]
MB	5	72.5	274.5	16-21	Symons [1973]
CW	1	87.5	9.5	30-37	This paper
GF	1	87.5	267.5	43	Beske et al.[1973]
GR	3	86.5	184.5	25-27	Beske et al.[1973]
SQ	5	80	207.0	17-18	Beske et al.[1973]

Units: HO, Hope Plutonic Complex; MB, Mt. Barr Plutonic Complex; CW, Chilliwack Composite Batholith; GF, Granite Falls Stock; GR, Grotto Batholith; SQ, Snoqualmie Batholith; age based on K/AR results, in m.y.B.P. λ', Ø' are north latitude and east longitude of the paleomagnetic pole.

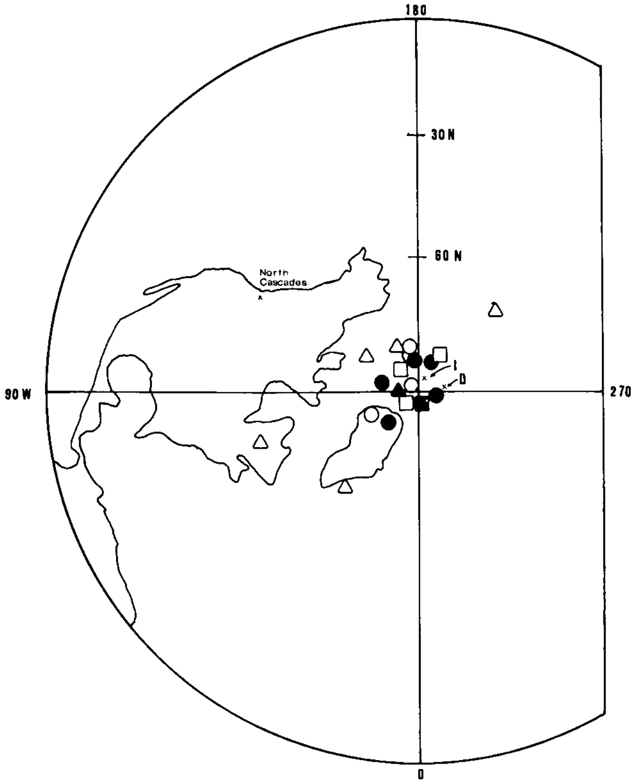

Fig. 2. Site VGP for Tertiary granitic plutons from the North Cascades. Open symbols indicate data for younger sites (< 27 m.y.B.P.). Open triangles, MB; open squares, GR; open circles, SQ; closed triangle, GF; closed square, CW; closed circles, HO. D, I are reference poles from Diehl et al. [1980] and Irving [1977], respectively. For references see captions to Fig. 1 or Table 2.

differences are not significant at the 95% confidence level, however. A similar "near-sided" aspect is seen in preliminary paleomagnetic data for Eocene volcanic rocks from the Republic graben, in northeastern Washington [Schwimmer et al., 1979]. We suspect that this represents a slight error in locating the reference pole, or perhaps the result of persistent non-dipole effects [Coupland and Van der Voo, 1980], rather than the effect of tectonics.

In view of the histories of surrounding terranes, the fact that the North Cascade block has not experienced regionally significant post-Eocene tectonic rotation is surprising. The Olympic Mountains were created during this time, by underthrusting of the Farallon plate, probably accompanied by oroclinal bending [Tabor and Cady, 1978; Beck and Engebretson, 1982]. During the same interval the Washington and Oregon Coast Ranges were apparently accreting to North America, a process that involved large amounts of clockwise rotation [Simpson and Cox, 1977; Beck and Plumley, 1980; Magill et al., 1981; Wells and Coe, 1980]. Graben formation on the eastern edge of the North Cascade block took place during the middle Tertiary [Gresens, 1980], possibly accompanied locally by large amounts of rotation (R. F. Burmester, personal communication, 1979). Finally, R. Bentley (personal communication, 1980) and others have mapped structures implying N-S compression and NW-SE dextral shear throughout large areas of the Miocene Columbia Plateau. However, the paleomagnetic data indicate that throughout all of this the North Cascade block remained substantially intact and immobile, at least insofar as its major batholiths are concerned.

The paleomagnetic data also indicate that there is an important tectonic boundary, active until at least as late as Miocene time, cutting through the Cascade Range somewhere between the Snoqualmie Batholith and the southern edge of Mt. Rainier National Park. This zone conveniently contains the trace of the mysterious Olympic-Wallowa lineament [Raisz, 1945], the true tectonic significance of which has never been determined. The paleomagnetic evidence for the Cascade tectonic discontinuity is simple: from Snoqualmie Pass northward plutons of Eocene to Miocene age are *in situ* and undeformed, whereas from Mt. Rainier southward Cascade and Columbia Plateau volcanic rocks of Oligocene to Miocene age have undergone very large-scale block rotations, ranging to as much as 25 or 30° [Bates et al., 1981; Beck and Burr, 1979; Simpson et al., 1980; Sheriff and Bentley, 1980]. Inliers of pre-Tertiary crystalline rock in west-central Washington show that the older volcanics of the region, which are the precursors of the modern volcanic Cascades, rest at least locally on ancient nonvolcanic basement. The tectonic discontinuity at the southern end of the underformed North Cascades block thus is an extremely important feature.

TABLE 3. Mean Middle Tertiary VGP for North Cascade Plutonic Rocks

Calculation	N	λ'	ϕ'	α_{95}	Reference
1	20	84.7°N	227.0°C	5.9°	This paper
2	15	85.1	206.4	4.7	This paper
D		83.8	91.6	5.2	Diehl et al. 1980
I		86	152	5	Irving, 1977

Calculation 1 includes all stable sites from the Hope, Mt. Barr, Chilliwack, Granite Falls, Grotto and Snoqualmie plutons. Calculation 2 excludes the Mt. Barr sites. Calculations D and I are reference poles for the North American craton, covering the periods 35-15 m.y.B.P. and 20-40 m.y. B.P., respectively. N, λ', ϕ' and α_{95} as defined in Tables 1 and 2.

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