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PALEOMAGNETISM OF THE MIDDLE CRETACEOUS GERMANSEN BATHOLITH, BRITISH COLUMBIA (93N/9, 10)

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INTRODUCTION

Paleomagnetic data from intrusive rocks of the Coast Belt are aberrant (Symons, 1977; Monger and Irving, 1980; Beck *et al.*, 1981a, b; Irving *et al.*, 1985). The aberrancies can be interpreted as tilting, 30° to the southwest (Symons, 1977; Beck and Noson, 1972; Irving *et al.*, 1985; Butler *et al.*, 1989); as northward displacement of about 2000 kilometres and clockwise rotation of 60° about a vertical axis (Beck and Noson, 1972; Irving, *et al.*, 1985; Umhoefer, 1987; Umhoefer *et al.*, 1989) or as a combination of these two processes (Irving and Wynne, 1990; Irving and Thorkelson, 1990; Umhoefer and Magloughlin, 1990). One result from the Axelgold intrusion (Monger and Irving, 1980; Armstrong *et al.*, 1985) also shows a similar aberrancy, indicating that this phenomenon extends eastward into the Intermontane Belt. The purpose of this paper is to describe results obtained from a study of the Germansen batholith (Figure 1-10-1), also in the Intermontane Belt, which was undertaken to further investigate this aberrancy.

The rocks of the Germansen batholith are generally, but not everywhere, too felsic to serve as good recorders of the paleofield. Also, as this work shows, many outcrops have been struck by lightning which has affected their magnetization. The results presented here, therefore, are not definitive, but provide information pertinent to the "tilt versus translation" debate regarding the origin of aberrant paleomagnetic results from mid-Cretaceous plutons in the Cordillera.

GEOLOGY AND SAMPLING

The Germansen batholith intrudes Upper Triassic to Lower Jurassic sedimentary and volcanic rocks of the Takla Group (Figure 1-10-2). It is a large body (600 km^2) composed mainly of foliated hornblende biotite granodiorite. It commonly contains large (3 cm) potassium feldspar phenocrysts aligned parallel to foliation. Ferri and Melville (1989) suggest that, because the foliation parallels the intrusive contact and is also associated with a steep mineral lineation, it may be related to the emplacement of the batholith. Hence the fabric is probably a "hot" phenomenon, predating the acquisition of magnetization.

Granodiorite near Mount Germansen (the locality here informally referred to as Radiometric Ridge) has been dated at 106±3 Ma and 86±3 Ma (K-Ar ages from hornblende and biotite respectively; Meade, 1975). The younger age may reflect partial resetting by Tertiary intrusions nearby. Biotite from a two-mica granite from near Mount Gillis yielded a K-Ar age of 107±4 Ma (Ferri and Melville, 1989). Hence the batholith is considered to be mid-Cretaceous in age.

We sampled the batholith in three localities, collecting 18 hand samples from the apophysis on the southeast margin, 23 drill cores on Radiometric Ridge, and 12 hand samples from an isolated knoll west of Mount Gillis (Figure 1-10-2). Samples from the apophysis are fine to medium grained, weakly foliated, equigranular hornblende biotite granodiorite. The foliated hornblende biotite granodiorite from Radiometric Ridge and the knoll west of Mount Gillis contains large potassium feldspar phenocrysts (2 by 5 cm) and is more leucocratic than the apophysis granodiorite.

METHOD

In the laboratory, up to three cores were taken from each hand sample and two specimens were cut from each core; about 100 cores or 180 specimens altogether. After the natural remanent magnetization (NRM) of the specimens was measured, a pair of specimens from one out of three hand samples was chosen for detailed stepwise demagnetization. One specimen was thermally demagnetized, the other was demagnetized using alternating fields. The response of these specimens to demagnetization was used to determine the treatment for the remainder; namely, three levels between 20 and 100 milliteslas. A line fitting program (LINEFIT) was used to calculate the direction of magnetization removed over the treatment steps.

PALEOMAGNETIC OBSERVATIONS

WELL-GROUPED MAGNETIZATION

Interpretable data were obtained from 55 per cent of the collection (100 specimens). The majority of these specimens are from the apophysis and all are normally magnetized. After the removal of a small, low coercivity component, the directions become well grouped, defining an end-point, and the magnetization decays along a straight line to the origin (Figure 1-10-3). The direction of the magnetization removed along the straight-line segment, from 10 to 100 milliteslas, is labelled RV in Figure 1-10-3 and was calculated using LINEFIT.

Low coercivity components are common in the collection and are interpreted to be the product of lightning. They are best removed using alternating field demagnetization. To illustrate this the demagnetization of two specimens from the same core is shown in Figures 1-10-4 and 1-10-5. During thermal demagnetization the direction of the B specimen starts to migrate towards the northeast quadrant but no end point is achieved (Figure 1-10-4). During AF demagne-

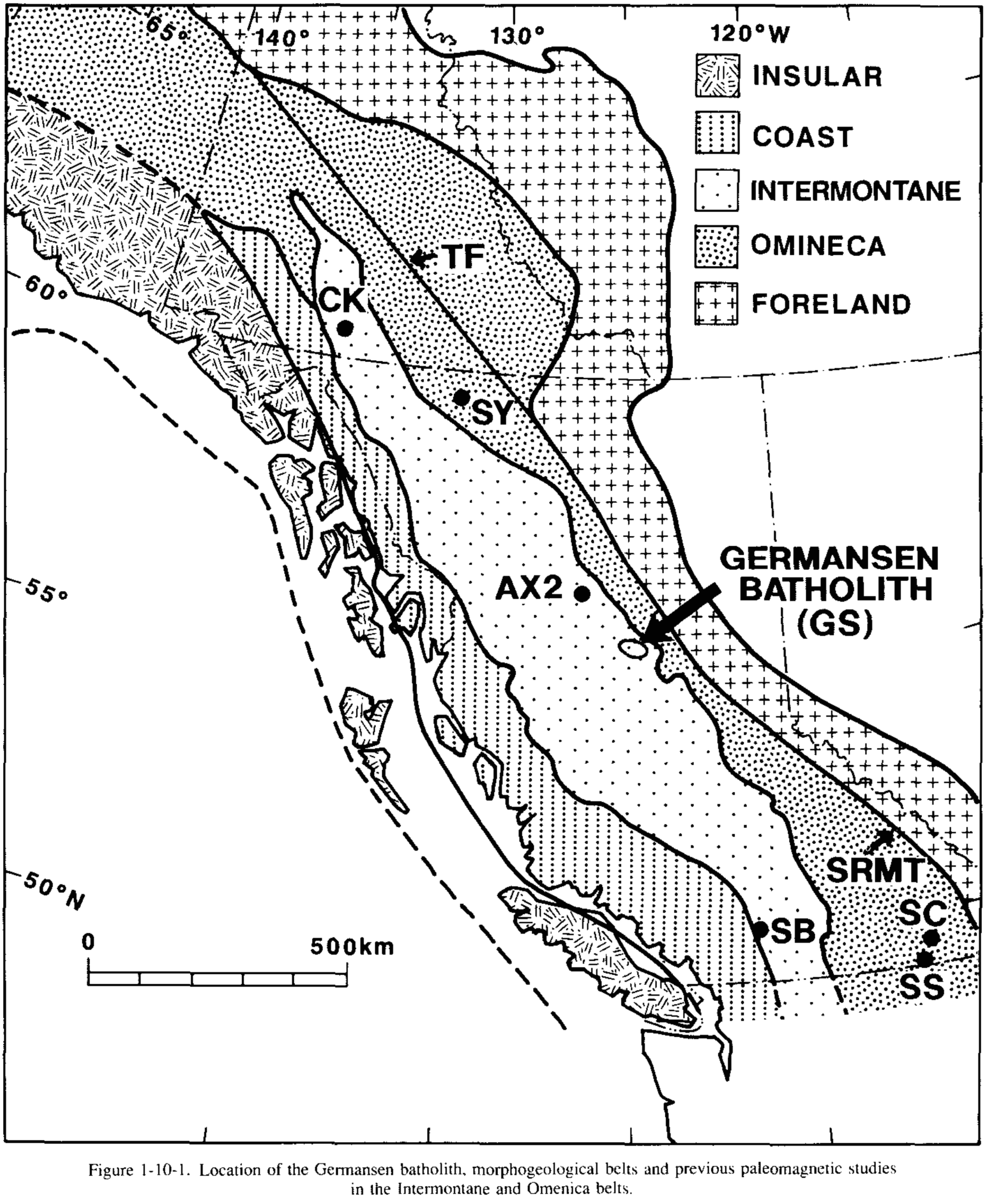

Figure 1-10-1. Location of the Germansen batholith, morphogeological belts and previous paleomagnetic studies in the Intermontane and Omenica belts.

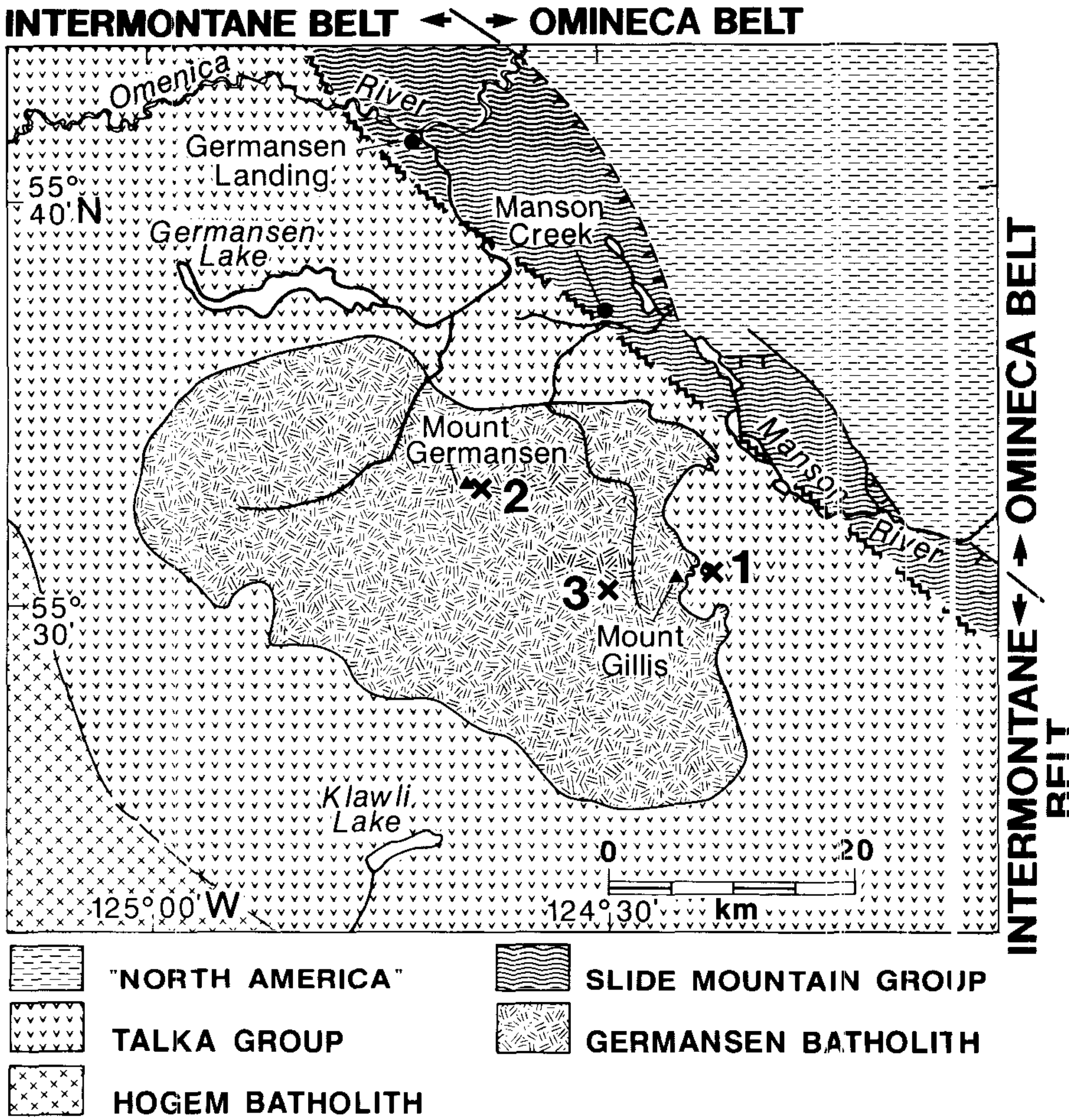

Figure 1-10-2. Local geology map and sampling localities as follows: (1) apophysis, (2) Radiometric Ridge, (3) knc l west of Mount Gillis. Geology modified from Armstrong, 1949; Ferri and Melville, 1988, 989.

tization, by 30 milliteslas, the intensity of the A specimen dropped to 10 per cent of the NRM intensity as the lightning-induced component was removed (Figure 1-10-5). The orthogonal plct shows a sharp change in direction between 10 and 20 milliteslas. Between 30 and 90 milliteslas a rough end-point is attained and a linear decay to the origin of the orthogonal plot is defined. Apparently, lightning has superposed a magnetization but has not destroyed the underlying stable magnetization.

Figure 1-10-6 illustrates more generally the effec: of removing the lightning component. D sparate clusters of NRM directions, corresponding to specime is from three hand samples, are shown. These move into a well-defined group after alternating field demagnetiz tion (Figure 1-10-6). Each point in the clt ster of clear ed direct ons represents the magnetization removed from a single specimen in the range 10 to 100 mil iteslas, as ca culated using LINEFIT.

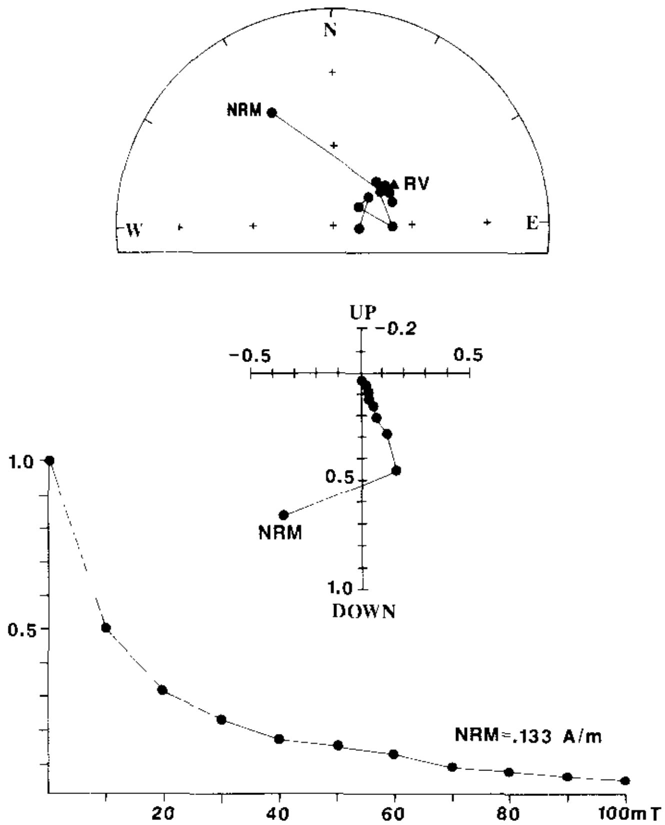

Figure 1-10-3. Alternating field demagnetization of a specimen from the apophysis. Changes in direction (top), orthogonal plot (centre), changes in intensity (bottom) are shown. **RV** is the magnetization removed along the straight-line segment going to the origin of the orthogonal plot.

The results for specimens with interpretable magnetization, organized by localities, are summarized in Table 1-10-1. Averages were calculated giving unit weight to the mean direction of specimen pairs from each core.

Random Magnetization

Twenty-four per cent of the collection (44 specimens) have very strong NRM intensities (3.39 A/m) that fall to a few per cent after demagnetization in alternating fields of 10 to 20 milliteslas. While some specimens show end-points, the directions are inconsistent within a single hand sample. For this reason they were not included in the analysis. Lightning has apparently completely overprinted the magnetization and no underlying stable magnetization could be retrieved.

Ill-defined Magnetization

The remainder of the specimens in the collection (22%, 38 specimens) have a non-linear decay. The strong NRM intensity (1.5×10^{-1} A/m) decreases sharply to 10 per cent at 10 milliteslas and remains little changed for the rest of the treatment interval. For a given specimen the directions at subsequent treatment steps remain in one quadrant, forming a loose cluster. The specimens appear to have a small stable magnetization, but it is not well defined and consequently they were not included in the analysis. The majority of these specimens are from the two more felsic localities, Radiometric Ridge and the knoll west of Mount Gillis.

TABLE 1-10-1
SUMMARY OF MEAN DIRECTIONS

Location	H(S)C	D°, I°	k	α_{95}	α_{63}
1. Apophysis	16(64)48	045,72	14	6	3
2. *Radiometric Ridge*	−(16)9	030,67	6	22	11
3. Knoll east of Mt. Gillis	10(20)17	060,74	6	16	8
Germansen Average					
4. Cores	−(100)74	045,72	10	6	3
5. Localities	−3	043,71	189	9	3
6. *K expected*	−	328,78	—	3	—

NOTES: H(S)C, number of hand samples (specimens) cores, unit weight given to cores. Cores were drilled at Radiometric Ridge. D°, I° are declination, inclination of the mean direction, k, precision parameter for directions; α_{95}, radius of the circle of confidence ($P = 0.05$); α_{63} is the standard error $= 81\,(kN)^{1/2}$, where N is the number of data used in the average (number of cores or localities in this table). K expected is the direction for the Germansen batholith predicted using the mid-Cretaceous cratonic reference paleopole of Globerman & Irving (1988).

RESULTS - TILT OR TRANSLATION?

The mean directions of the three localities have normal polarity. Their standard error circles overlap so the directions are not significantly different from one another (Figure 1-10-7) but are significantly different from the expected Cretaceous direction (Table 1-10-1). This difference can be accounted for either by post-emplacement tilt, by northward displacement and rotation about a vertical axis, or some combination of these two. No mapping has been done of bathozonal mineral assemblages in the contact aureole of the Germansen batholith so no estimate of paleohorizontal is available.

Table 1-10-2 summarizes, in terms of both apparent tilts and apparent displacements and/or rotations, the paleomagnetic results obtained from Cretaceous rocks in the Omineca and Intermontane belts. Ninety-five per cent errors are quoted. The two entries for the Axelgold intrusion have been calculated first with respect to present horizontal (AX1) and then (AX2) after correction for tilt using crystal layering as an estimate of paleohorizontal (Monger and Irving, 1980; Armstrong *et al.*, 1985). The latter yields the more modest aberrancy and is used in the following discussion.

Results from two studies in the Omineca Belt indicate that no tilting had occurred (SC, SY). The aberrancy in paleomagnetic directions of the Summit stock (SS) is that expected from the tilt of bathozones mapped in the metamorphic aureole around the batholith. The tilt has been considered to be a product of Eocene extension (Irving and Archibald, 1990). In the Intermontane Belt the dips of the two bedded sequences (CK, SB) are variable. When these are corrected to paleohorizontal, the paleomagnetic directions remain aberrant. The Axelgold (AX2) and Germansen (GS) aberrancies can be expressed as the product of 18 to 20° tilts down to the west-southwest. The apparent tilts are smaller but are in the same direction as those required to produce the observed magnetization directions in plutons of the Coast Plutonic Complex and the North Cascades Range (30° to the west-southwest) (Beck and Noson, 1972; Irving *et al.*, 1985; Butler *et al.*, 1989; Irving and Wynne, 1990).

If the results are cast as the product of rotation and displacement then in the southern Omineca Belt the Skelly Creek batholith suggests a clockwise rotation; Summit stock (after tilt correction indicated by bathozones) shows a small counter-clockwise rotation; neither show any significant displacement. In the north the Sylvester allocthon shows displacement but no significant rotation. Within errors, the SY result is consistent with an estimate of 900 kilometres dextral offset along the Tintina and Northern Rocky Mountain Trench fault which is situated just to the east of the Sylvestor allocthon (Figure 1-10-1).

In the Intermontane Belt results from the Late Cretaceous Carmacks Group show no rotations. The rotations observed in the mid-Cretaceous studies are remarkably similar; clockwise, between 58° and 75°, with the Germansen showing the greatest rotation. An apparent northward displacement of the Germansen batholith is indicated, but it is of borderline significance at $P = 0.05$. The rest (AX2, CK, SB) show northward displacements which are again very similar. Figure 1-10-8 shows the aberrances calculated as displacements. The error arrows of the figure give the probability distribution. The probability is highest at the mean (centre) and decreases away from it. It is interesting to note that if the compositional layering is a reasonable estimate of paleohorizontal, then the aberrancy of the Axelgold direction is the product of both tilt and northward translation with rotation. The directions obtained from bedded rocks SB and CK are best explained as the product of translation with and without rotation, respectively (Irving and Thorkelson, 1990; Marquis and Globerman, 1988).

These new data indicate that a second pluton in the Intermontane Belt is aberrant and confirms that paleomagnetic aberrancies are a feature of intrusions in both the Intermontane and the Coast belts. Although each result is

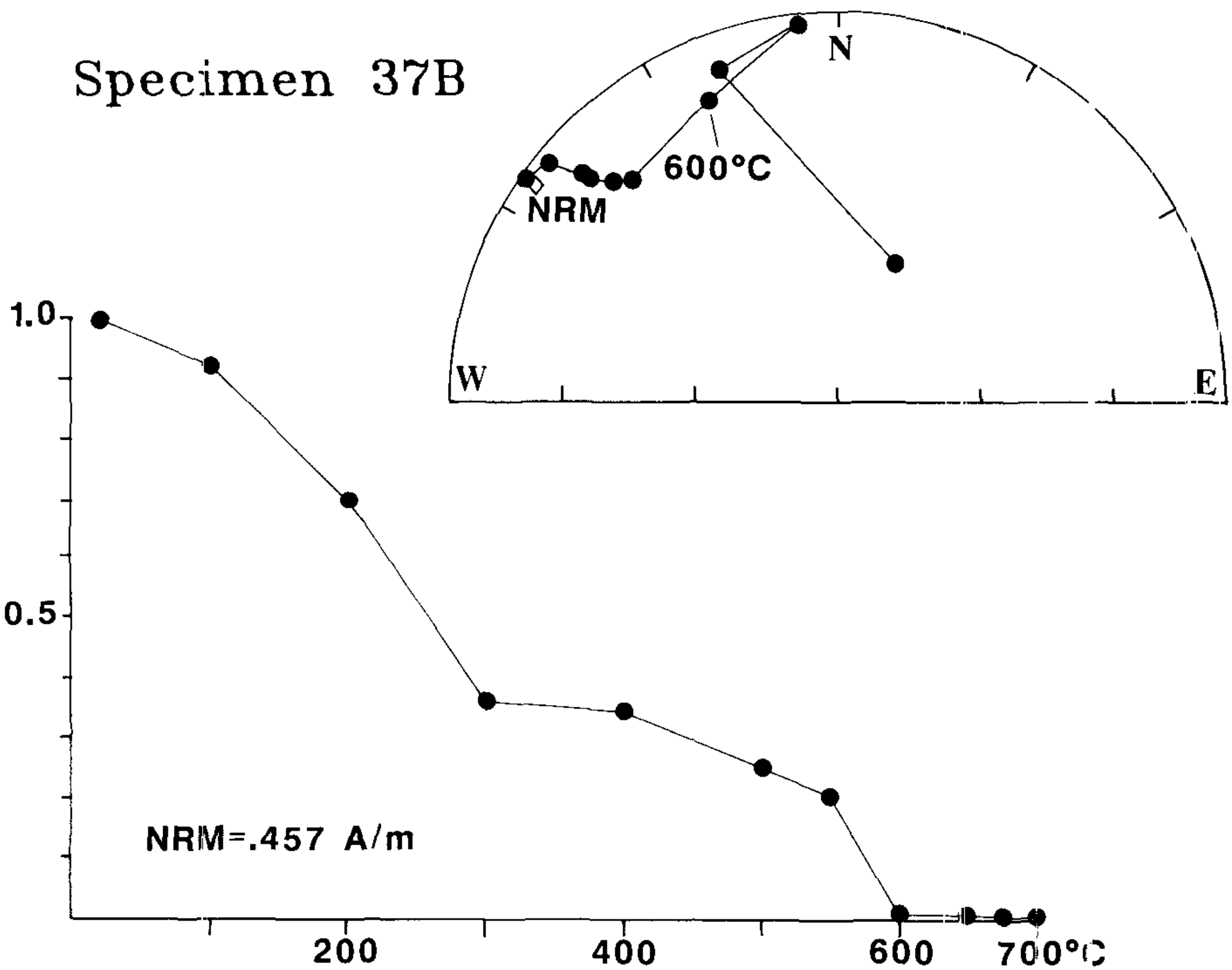

Figure 1-10-4. Specimen 37B, from the apophysis: thermal demagnetization with changes in direction above, changes in intensity below. An end-point is not achieved.

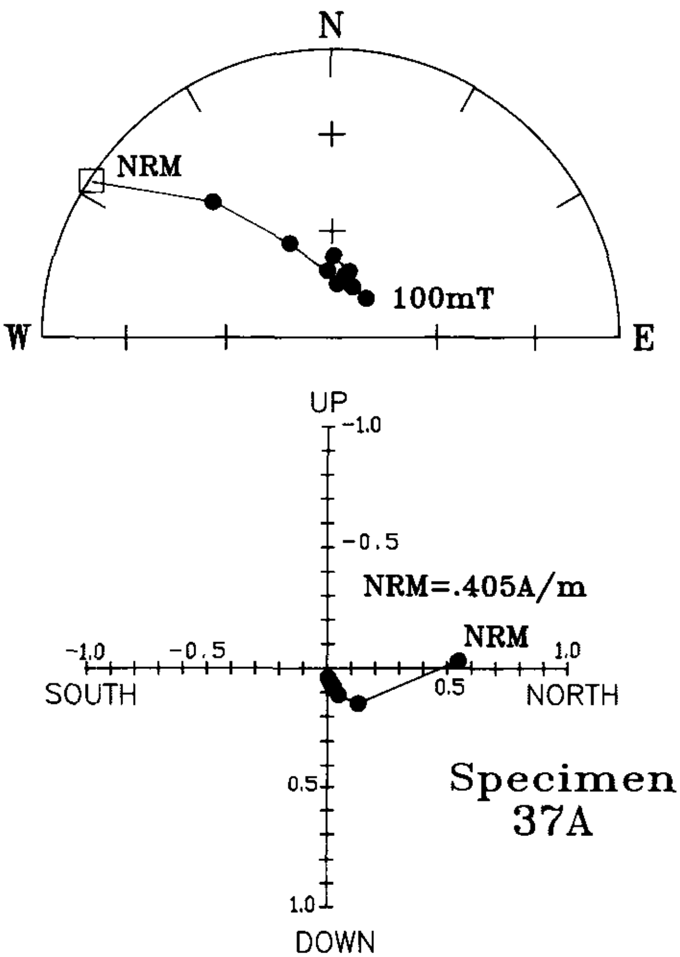

Figure 1-10-5. Specimen 37A, from the apophysis: alternating field demagnetization with changes in direction above, orthogonal plot below. An end-point is achieved.

TABLE 1-10-2
SUMMARY OF PALEOMAGNETIC WORK ON CRETACEOUS ROCKS DONE IN THE INTERMONTANE AND OMENICA BELTS

Rock Unit	Belt	Apparent tilt Dip°,DDA°	Apparent displacement RR°	RPD°
SC Skelly Creek	OM	<5,–	–17±17	–01±08
SS Summit Stock	OM	24,west	14±11	–01±06
SY Sylvester Allocthon	OM	flat lying	–05±20	08±07
AX1 Axelgold 1	IM	28,234	–65±14	27±06
AX2 Axelgold 2	IM	18,237	–58±12	16±07
CK Carmacks	IM	variable	–06±20	14+07
SB Spences Bridge	IM	variable	–66±12	16±07
GS Germansen	IM	20,256	–75±23	12±12

NOTES: OM, IM Omineca, Intermontane belts; Apparent tilt is given as the dip and down-dip azimuth (DDA) of the tilt required to produce the observed directions from that expected (down 28° at 234°); Apparent displacement is given as RR, relative rotation (clockwise rotation is negative) and RPD, relative paleolatitudinal (northward relative motion is positive). RR and RPD errors (P = 0.05) have been calculated using the method of Demarest (1983). Calculations for this table were made using the mid-Cretaceous cratonic reference paleopole of Globerman and Irving 1988 (71°N, 196°E, A_{95}=4.9) except for the Carmacks. For the Carmacks a late Cretaceous cratonic reference paleopole, 79°N, 190°E, N=5, K=326, A_{95}=4.2° (Wynne *et al.*, 1992) was used. To convert RPD from degrees to kilometres, multiply by 111.3. References: SC, SS Irving and Archibald, 1990; SY, Butler *et al.*, 1988; AX1, AX2 Monger and Irving, 1980, Armstrong *et al.*, 1985; CK, Marquis and Globerman, 1988; SB, Irving and Thorkelson, 1990. GS is calculated using localities unit weight, line 5, Table 1-10-1. The GS paleopole is 66°N, 054°W, A_{95} = 15°, K = 70.

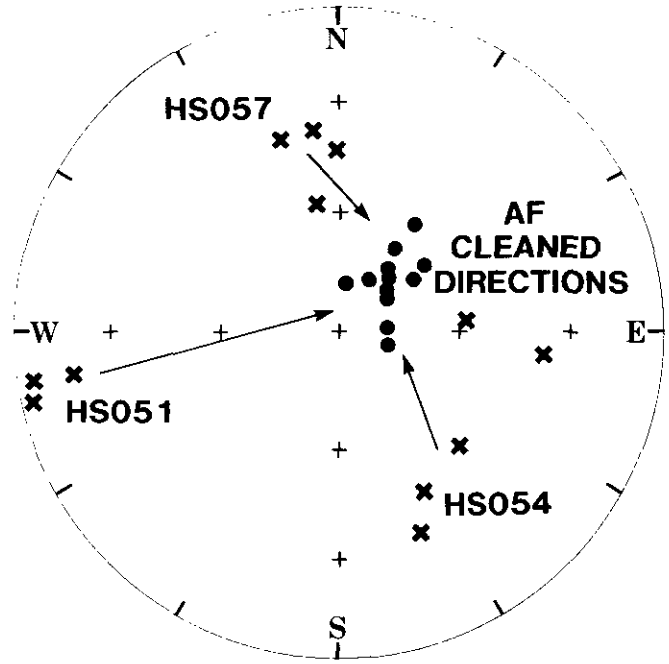

Figure 1-10-6. Directions of magnetization in specimens from three hand samples. NRM directions (crosses) are widely scattered, the "cleaned" directions (solid dots) are well grouped. All are down directions, plotted on the lower hemisphere.

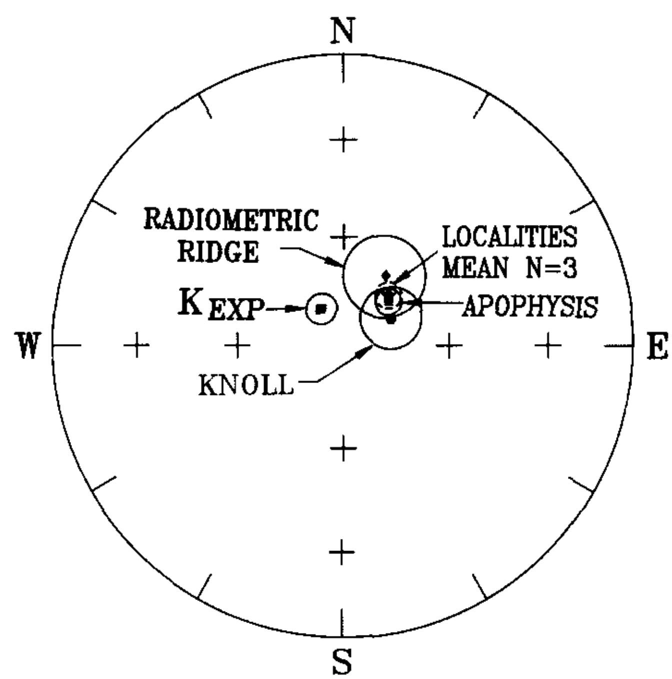

Figure 1-10-7. Locality mean directions. Specimen pair given unit weight. All three are significantly different (P=.05) from K_{exp}, the expected mid-Cretaceous direction (Globerman and Irving, 1988). Standard error (63) ellipses are shown.

subject to considerable error, the apparent displacements within the Intermontane Belt are all from the south and of similar magnitude (>1000 km). The apparent displacements are comparable to those observed in bedded Cretacous rocks. An alternative explanation (which does not agree with data from bedded rocks) is that tilts 20° to the west-southwest have taken place. This is about 10° less than the apparent tilts for Coast Belt plutons. Finally the Germansen data could be the product of both tilt and rotation/displacement like its neighbour (AX2), 100 kilometres to the northwest.

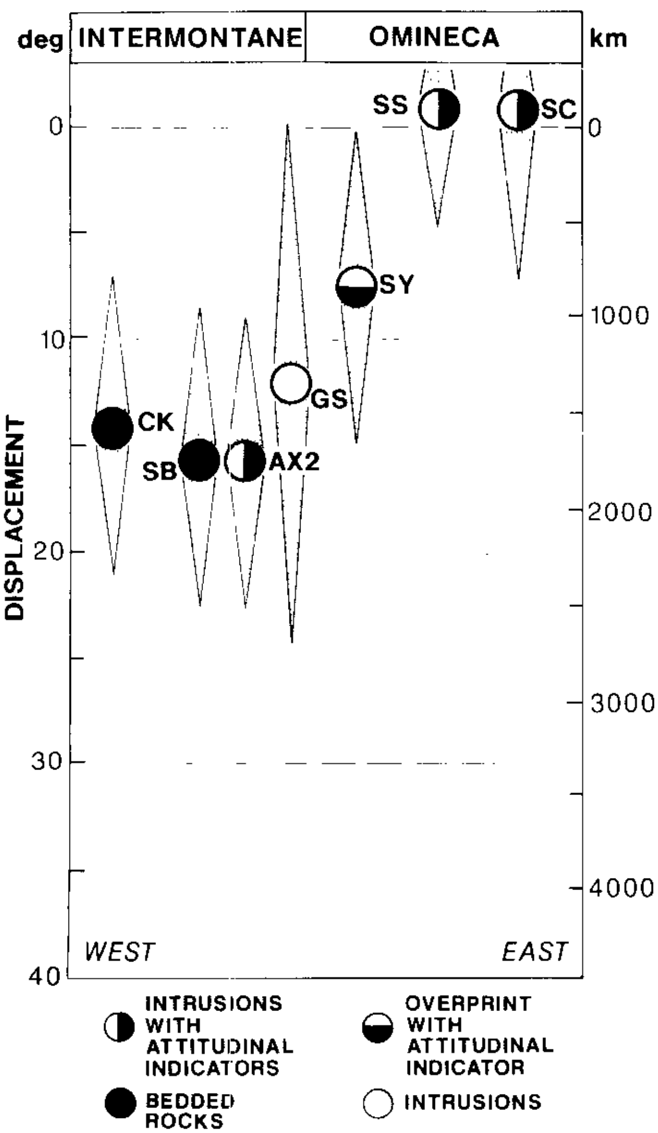

Figure 1-10-8. Displacement diagram showing paleomagnetic studies from the Intermontane and Omenica belts. Labelling is the same as in Figure 1-10-1. GS calculated using the combined localities average, line 5, Table 1-10-1. $P=0.05$ error arrows are shown as calculated using Demarest's (1983) method.

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