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Postfolding Remagnetization that Passes the Fold Test

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Post-folding remagnetization that passes the fold test

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SUMMARY

The palaeomagnetism of folded Cretaceous redbeds in the Methow–Pasayten belt of Washington was studied in an attempt to resolve the tilt versus translation origin of shallow inclinations found in most Cretaceous plutonic rocks of the Pacific Northwest. After elimination of results from apparently strained, overturned beds, correction to palaeohorizontal of the high-temperature, dominant components produced two distinct directions, one from each of two areas. Treated separately, the magnetizations from these two areas appear to pass the fold test. Both directions are anomalously shallow which is typical of the region, but the discrepancy between them casts doubt that both could have been acquired when the strata were horizontal. Instead we propose that they date from at least two episodes of remagnetization after the planar strata were tilted but before development of the tighter folds observed today. Our caution is that a positive fold test only establishes that a magnetization likely was acquired when strata in an area were planar. Other arguments are required to demonstrate that this planar surface was in fact horizontal during magnetization.

Key words: fold test, Methow, redbeds, remagnetization, synfolding.

1 INTRODUCTION

The case for poleward transport of terranes (Coney, Jones & Monger 1980; Debiche, Cox & Engebretson 1987) along the western margin of North America since the Cretaceous is convincing, largely because of the consistency of the evidence in the form of shallow palaeomagnetic inclinations (Monger & Irving 1980; Irving *et al.* 1985; Beck 1990). However, most palaeomagnetic evidence for the existence and timing of northward displacement of western Washington and British Columbia has come from plutons which lack palaeohorizontal indicators (Beck 1980; Beck, Burmester & Schoonover 1981; Irving *et al.* 1985). This produces an ambiguity because the observed shallow magnetic inclinations can be interpreted as the result of either post-magnetization southward tilting or northward transport (Beck *et al.* 1981).

The Cretaceous Mount Stuart batholith in the Cascade terrane of central Washington (Fig. 1) is such a pluton; its inclination is some 28° too shallow. The Late Jurassic and Cretaceous rocks of the Methow–Pasayten belt, located on the east side of the Cascade terrane and tied to it since 88 Ma by a 'stitching' pluton (Black Peak batholith, Fig. 1; Misch 1964) are nicely layered, and so appeared likely to provide a reference of palaeohorizontal that would allow resolution of the northward transport versus tilting ambiguity. Furthermore the rocks are folded which suggested that the classic fold test of Graham (1949) might be used to date the magnetization relative to deformation. It was for these promising reasons that we undertook a palaeomagnetic study of the Methow–Pasayten belt. Unfortunately, our results have proved to be far from simple. We found two areas whose magnetizations separately pass fold tests but whose palaeoinclinations imply significantly different palaeolatitudes, 17 °N and 39 °N, respectively. This of course renders the palaeolatitudes highly suspect; both may be artifacts of remagnetization during folding, or between folding events. Our experience indicates that a 'positive' fold test does not guarantee that magnetization pre-dates folding in areas of complicated deformation and magnetic history.

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2 GEOLOGIC SETTING

2.1 Rock units

The Methow–Pasayten belt is a fault-bounded structural depression that contains a stratigraphic section approxim-

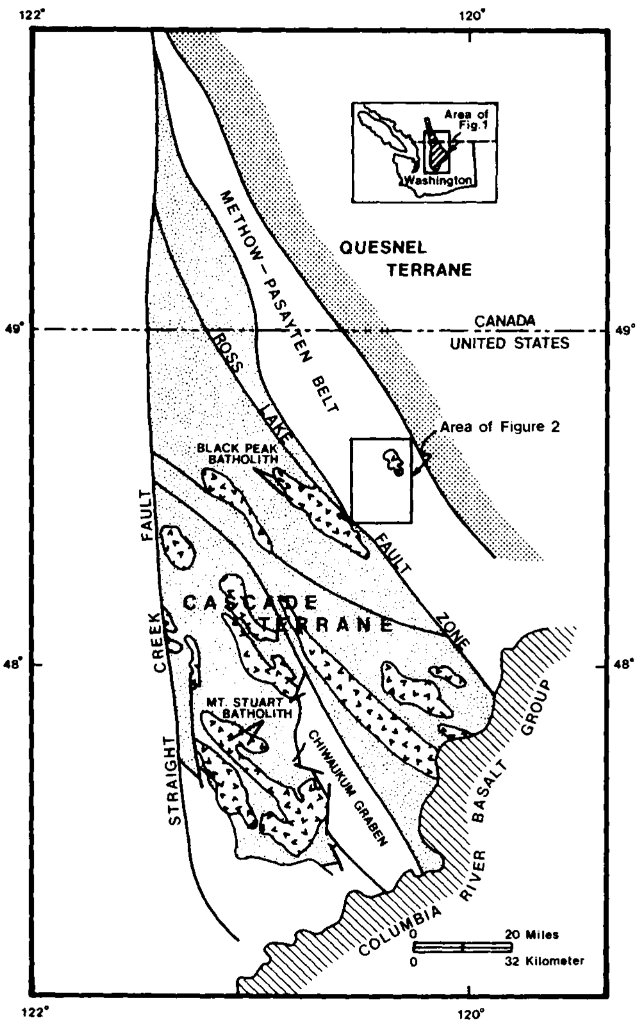

Figure 1. Regional location map showing tectonostratigraphic terranes and structures boardering the Methow–Pasayten belt of northern Washington and British Columbia. Cretaceous intrusions are shown by the 'v' pattern. After Tabor, Zartman & Frizzell (1987).

ately 15 km thick of Jurassic through Early Tertiary sedimentary and volcanic rocks that are intruded by Cretaceous and Tertiary plutons (Fig. 2). The Midnight Peak Formation (Cole 1973; Tennyson 1974; Barksdale 1975; Trexler & Bourgeois 1985) sampled for this study consists of volcanics and redbeds that overlie (both conformably and with local unconformity) clastic sedimentary rocks of the Winthrop Sandstone and Virginian Ridge Formation (McGroder, Garver & Mallory 1990). These, in turn, unconformably overlie an older section that is broken by two other unconformities (Trexler & Bourgeous 1985). Locally, very gently north dipping Palaeocene (?) conglomerates and arkosic sandstones of the Pipestone Canyon Formation unconformably overlie folded strata of the Methow–Pasayten belt (Ryason 1959), indicating that the major deformation was probably completed in the Cretaceous. The unconformities indicate that there were at least five episodes of deformation since the early Jurassic (Barksdale 1975). While this was expected to pose problems in correcting magnetizations from the older units, initially we expected that deformation of the Midnight Peak Formation was due to a single event and would be easily correctable.

The youngest and potentially most useful sedimentary unit of the Pasayten Group is the Ventura Member at the base of the Midnight Peak Formation. A local unconformity between this unit and the overlying Volcanic Member (McGroder *et al.* 1990) suggests that deformation and partial erosion of the Ventura Member preceded volcanism. Although the Ventura Member is unfossiliferous, its age is constrained to Late Cretaceous (probably Cenomanian to Turonian) by fossil dates from the Winthrop Sandstone and Virginian Ridge Formation (Barksdale 1975) and by radiometric dates from post-depositional dikes (Tabor, Engels & Staatz 1968; Todd 1987; V. R. Todd, personal communication 1987). This places the Midnight Peak Formation in the Cretaceous normal superchron (Harland *et al.* 1982) so its magnetizations are expected to have normal polarity exclusively.

The Ventura Member is composed of reddish conglomerate, sandstone, siltstone, and shale that vary in relative

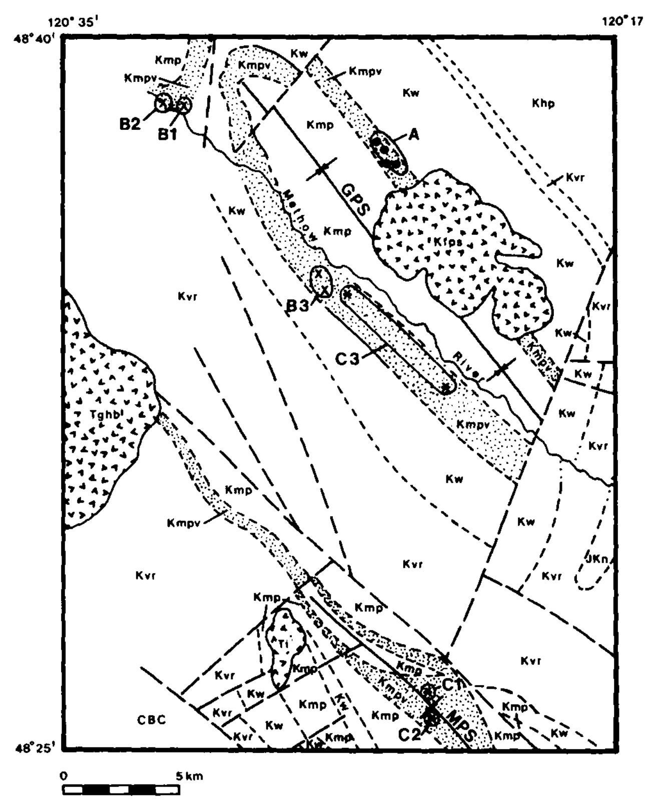

Figure 2. Simplified geologic map of the study area showing major stratigraphic units, structures, and intrusions. Kmp: Upper Cretaceous Midnight Peak Formation, Kmpv is its redbed Ventura Member; Kw: middle Cretaceous Winthrop Sandstone; Kvr: middle Cretaceous Virginian Ridge Formation; Khp: Lower Cretaceous Harts Pass Group; JKn: Lower Jurassic–Cretaceous Newby Group; Ti: Tertiary intrusion; Tghb: Tertiary Golden Horn batholith; Kfps: Late Cretaceous Fawn Peak stock; GPS: Goat Peak syncline; MPS: Midnight Peak syncline. Locations of sites are $^{\times}$ for group B, * for group C and filled circles for group A. Modified after Barksdale (1975).

abundance; thickness ranges to a maximum of 600 m (Barksdale 1975). Ventura strata are interpreted as locally derived, channel and floodplain deposits that represent progradation of an alluvial system from volcanic and sedimentary sources to the east (Mohrig & Bourgeois 1986). While the conglomerates may well have had an original dip, samples and attitudes were obtained exclusively from the finer grained beds a few centimetres to several metres in thickness whose original layering was very likely horizontal.

Thin sections show the redbeds to be generally poorly sorted, subangular, subspherical, haematite and calcite cemented lithic wacke with clay and crushed rock fragments partially supporting framework grains. Mafic mineral grains are completely oxidized to skeletons of haematite, and magnetite grains in most samples are oxidized to martite. The lithology, poor sorting, angular and non-spherical grains, and general immaturity of the Ventura indicate rapid transport from local magmatic arc and uplifted sedimentary sources (Tennyson & Cole 1978; Granirer 1985). It is probable therefore that much of the oxidation post-dates deposition and produced a chemical remanent magnetization over several million years (see e.g. Larson & Walker 1975).

2.2 Structure

The area of the Methow Valley where we sampled seemed ideal for fold tests. The Jurassic through Late Cretaceous rocks are folded into two structures, the Goat Peak and Midnight Peak synclines (GPS and MPS in Fig. 2). Asymmetry of bedding attitudes and overturned portions of NE limbs of these synclines indicate SW vergence of the structures. Analysis of bedding attitudes taken from these synclines by Barksdale (1975), Granirer (1985), and Bazard (1987) indicate that, overall, the Midnight Peak and Goat Peak synclines plunge less that 5°, to the southeast. The fold geometry is locally complicated where the folds are cut by high angle faults. Closures of the map patterns in the NW portion of the Goat Peak syncline (Fig. 2) is partly due to local warping near such faults and partly an artifact of topography. Therefore, plunge was taken as negligible everywhere, and correction to palaeohorizontal was accomplished simply by rotating each site mean direction about the local strike.

3 PREVIOUS WORK IN THE METHOW

Palaeomagnetic investigation of the Methow region was begun by Schwarz (1984) with a broad-ranging reconnaissance study that included sites in the Virginian Ridge, Winthrop, Midnight Peak and older units. No fold test was possible because of the distribution of sites, but apparently stable components from the Midnight Peak Formation and lower units had a mean direction after correcting for bed tilt that agreed well with the discordant Mount Stuart direction (Schwarz 1984; Schwarz, Beck & Burmester 1984). This provided encouragement that more detailed work would uncover pre-folding remanence in at least some of these rocks.

Granirer (1985) and Granirer, Burmester & Beck (1986) concentrated on the Late Cretaceous sediments that Schwarz had shown to be the most reliable palaeomagnetic recorders. Granirer (1985) isolated a stable magnetization in 10 sites from the Midnight Peak Formation and Winthrop Sandstone in a small part of the Goat Peak syncline. He found that the remanence of opposing limbs agreed best when corrected for 46 per cent of total tilt. Granirer interpreted this as evidence that the magnetization had been acquired midway through folding; that is, it was 'synfolding' (e.g. McCabe *et al.* 1983; Kent & Opdyke 1985). The mean of the 46 per cent corrected directions also was consistent with the discordant Mount Stuart direction. This raised the possibility that the deformation occurred prior to northward transport, although the loss of palaeohorizontal through remagnetization makes the results no less ambiguous than directions from plutons. Also encouraging was the demonstration that the magnetization was not completely post-folding.

Bazard (1987) concentrated on the redbeds of the Ventura Member of the Midnight Peak Formation because of its stable magnetization and relatively simple structural history (Barksdale 1975; Granirer 1985). Sampling was widely distributed over a variety of structures and bed attitudes with the intent of using fold tests locally to recognize unremagnetized regions. Use of small areas to document local structural histories has worked well in other studies (Reidel *et al.* 1984; Wells & Coe 1985). We report here on a subset of results from Bazard (1987) that gives two positive fold tests from what appears to be post-folding remanence. Use of the complete results to map previous structures and constrain the tectonic history of the Method–Pasayten belt is presented in Bazard *et al.* (1990).

4 METHODS

Collection, orientation and preparation of three to 13 cores per site (bed) were by standard methods. Non-magnetic drill bits and saw blades were employed throughout. Agreement of azimuths measured by magnetic and sun compasses indicates that orientations are accurate to within about 2°. All specimens were measured using a Schonstedt model SSM1-A spinner magnetometer interfaced with a microcomputer. After initial measurement for natural remanent magnetization (NRM) the samples were progressively demagnetized within magnetic shields using either a Schonstedt model GSD-5 alternating field tumbling specimen demagnetizer, an open-air furnace, or a chemical demagnetization solution [10 per cent HCl or a non-corrosive reducing agent (Kirschvink 1981)]. Measurements were made after each demagnetization step; the number and size of steps was dictated by each specimen's coercivity spectrum, unblocking temperature range, or reaction to chemical treatment (solution spectrum) as viewed on orthogonal projections. Measurements were accepted if the magnetometer's signal-to-noise ratios for each of the six spin positions was greater than 10, and estimates of each measurement's precision (γ_{95}; Briden & Arthur 1981) were, with few exceptions, less than 10°.

Measurements after the highest levels of demagnetization that formed straight line segments on orthogonal diagrams were used to define the most stable component. Directions and maximum angular deviations (MADs) of these components were obtained using a least-squares method (Kirschvink 1980). Directions with MADs greater than 10°

were not accepted. Site-mean directions were calculated using the method of Fisher (1953); two sites with $\alpha_{95} > 15°$ were rejected as having unacceptable precision. Three tests were applied to the data: McFadden's (1982) procedure to determine the appropriateness of averaging site-mean directions to get an overall mean direction, and the fold tests of both McElhinny (1964) and McFadden & Jones (1981).

Representative specimens also were measured for anisotropy of magnetic susceptibility using a low field torque meter (King & Rees 1962) to check for possible effects of strain. Susceptibility minima at all sites tended to be normal to bedding, i.e. vertical after correcting for tilt. Susceptibility maxima from upright beds had no preferred direction. However maxima from overturned beds tended to be aligned northwest, parallel to the fold axes, which may be due to strain and incipient formation of axial plane foliation with unknown effects on remanence. To eliminate uncertainty of directions due to this and to large tilt corrections, sites from vertical and overturned beds (Fig. 2, Group A; Bazard 1987) were omitted from this study. They are, however, presented in Bazard *et al.* (1990).

5 RESULTS

After rejection of samples and omission of sites according to the criteria above, there remain 16 sites from the Ventura Member. Magnetizations generally are strong (magnetic moments 0.01–0.1 A m^{-1}) and are dominated by a single high unblocking-temperature magnetization. Neither thermal nor chemical demagnetization could resolve this into separate components (Fig. 3). Table 1 lists the temperature ranges over which sample directions were obtained for each site as well as site-mean directions and statistics, and tectonic corrections.

For the purpose of further analysis, these sites are divided into two groups, B and C. It is the conflict between the directions of these groups that we wish to use to illustrate the fallibility of the fold test. Group B consists of sites in the northern part of the Goat Peak syncline whereas group C sites occupy the southern part as well as the centre of the Midnight Peak syncline (Fig. 2). Each group is further divided into three 'limbs', 1, 2, 3, based on common location and attitude (Table 1). Of these, three (B2, B3, C3) have sufficient number of sites to test for between-site

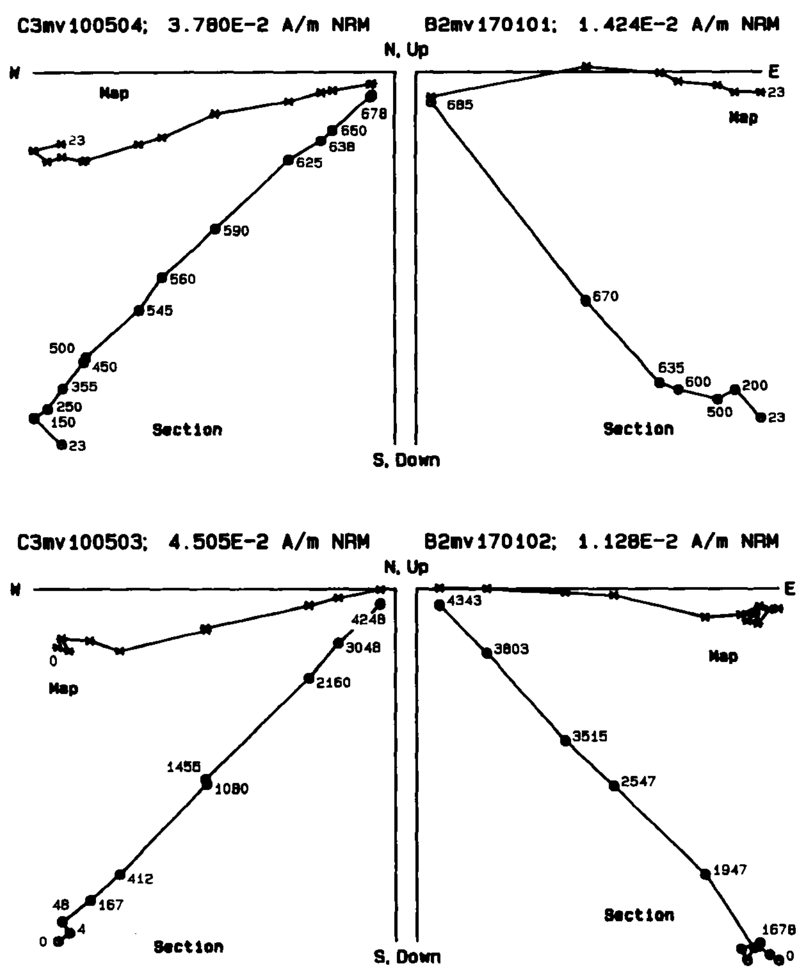

Figure 3. Orthogonal projection of demagnetization paths for representative samples. Asterisks represent the map view; circles show the projection of magnetizations on W–E sections. The left two plots show that the same component is obtained with thermal (upper) and chemical (lower) demagnetization, respectively, for a pair of specimens for a core from Group B. The right pair of plots show similar behaviour but a distinctly different direction for a core from group C. Points are labelled with demagnetization level in °C or hours in HCl.

Table 1. Site-mean directions and statistics.

Gp	Site	Attitude	D	I	N	Result.	k	alpha-95	Levels
C1	85MV04	240/37	25.1	+36.2	5	4.966	117.8	7.1	585-670
C2	85MV05	87/21	322.7	+51.8	5	4.965	113.2	7.2	595-670
B1	85MV09	330/35	79.6	+17.2	4	3.992	397.9	4.6	635-680
C3	85MV10	50/65	248.8	+42.2	4	3.993	438.6	4.4	590-670
C3	85MV11	40/61	264.3	+49.7	5	4.990	406.9	3.8	590-680
C3	85MV12	48/58	262.7	+51.0	5	4.997	1492.5	2.0	590-680
C3	85MV13	47/60	254.5	+50.2	5	4.985	258.7	4.8	590-680
C3	85MV14	47/60	268.1	+50.2	5	4.995	821.4	2.7	600-680
B2	85MV15	28/44	83.5	+61.0	4	3.996	689.7	3.5	600-680
B2	85MV17	32/39	89.7	+58.3	4	3.990	302.4	5.3	600-680
B2	85MV18	29/41	97.6	+58.8	4	3.991	334.8	5.0	600-680
B3	86MV19	58/55	177.6	+85.4	6	5.948	96.4	6.9	600-670
B3	86MV20	52/60	152.3	+78.7	5	4.956	91.5	8.0	600-685
B3	86MV21	50/61	185.7	+74.5	4	3.979	139.7	7.8	600-670
B3	86MV22	50/60	159.6	+80.0	5	4.986	288.4	4.5	550-670
B3	86MV23	62/58	165.9	+87.1	5	4.989	352.7	4.1	550-670

Notes: Gp: group and limb; Site: site name; Attitude: azimuth and plunge of bedding down dip vector; D and I: mean declination and inclination of high stability component uncorrected for bed tilt; N: number of specimens used to calculate site mean direction; Result.: sum of N unit vectors used to calculate site mean direction; k: estimate of Fisher precision parameter; alpha-95: semiangle of cone of 95% confidence about the mean direction; Levels: range of thermal demagnetization (in $^{\circ}$C) used to isolate high-stability components.

dispersion. Two of these 'limbs' (B2 and B3) that occur in the same group permit application of McFadden & Jones' (1981) fold test.

Before using the data in fold tests or other analyses it is necessary to determine whether sample or site-mean directions should be used as independent estimates of the palaeomagnetic field direction. Dispersion of sample directions within sites (high *k*, Table 1) and between sites collected over 10 m stratigraphically apart in a continuous section are low compared to the dispersion expected for Cretaceous palaeomagnetic secular variation (McFadden & McElhinny 1984). This is probably because magnetization spanned sufficient time to average much of the secular variation within the sample. Therefore, sites are unlikely to represent palaeomagnetic field directions that differ because of secular variation and it is tempting to use sample directions, because of their greater number, to perform the fold tests. However, the procedure of McFadden (1982) clearly demonstrates that within-site dispersions are significantly different between sites and that site-mean directions are sufficiently different within 'limbs' (significant between-site dispersion), both before and after correction, to require calculation of limb-mean directions from site-mean directions. Mean directions so calculated for multisite limbs and the groups B and C are listed in Table 2 along with pertinent statistics.

Table 2. Mean directions for multisite limbs and folds.

Gp	Limbs	Dec-g	Inc-g	Dec-t	Inc-t	N	R	k	a-95
B	2	90.4	+59.5			3	2.995	443.46	5.9
				60.0	+28.9	3	2.992	249.07	7.8
B	3	169.1	+81.4			5	4.981	206.13	5.3
				63.7	+34.7	5	4.992	483.68	3.3
B	2,3	114.0	+76.4			8	7.722	25.20	11.1
				62.3	+32.5	8	7.971	243.07	3.5
B	1,2,3	102.4	+71.2			9	8.243	10.57	16.6
				62.7	+31.7	9	8.962	214.11	3.5
C	3	259.4	+48.9			5	4.975	159.74	6.1
				3.8	+58.2	5	4.967	122.14	7.0
C	1,2,3	280.8	+57.2			7	6.098	6.65	25.3
				0.3	+58.8	7	6.958	141.88	5.1

Notes: Gp: group; Limbs: limb number(s); Dec-g, Inc-g, Dec-t and Inc-t: mean declination and inclination uncorrected (-g) and corrected (-t) for bed tilt (Attitude given in Table 1); N: number of sites used to calculate mean direction; R: sum of N unit vectors used to calculate mean direction; k: estimate of Fisher precision parameter; a-95: semiangle of cone of 95% confidence about the mean direction.

6 FOLD TESTS

Correcting the site-mean directions to palaeohorizontal produces a dramatic convergence within each group (Fig. 4). McElhinny's (1964) version of the fold test poses that improvement in precision of directions due to correction can be tested by comparing the ratio of estimates of precision parameters with a critical *F* statistic. For example, the ratios of precision parameters calculated after tilt correction and before for $N = 9$ sites from Group B (*k* from Table 2 for B 1, 2, 3) is 20.26. This is much larger than the *F* statistic 2.33 for 16×16 degrees of freedom so the hypothesis that these two configurations have the same precision can be dismissed at the 95 per cent confidence level. Recently, investigators of synfolding magnetizations have used this test for intermediate corrections as well (e.g. McClelland-Brown 1983; Schwartz & Van der Voo 1984; Kent & Opdyke 1985;

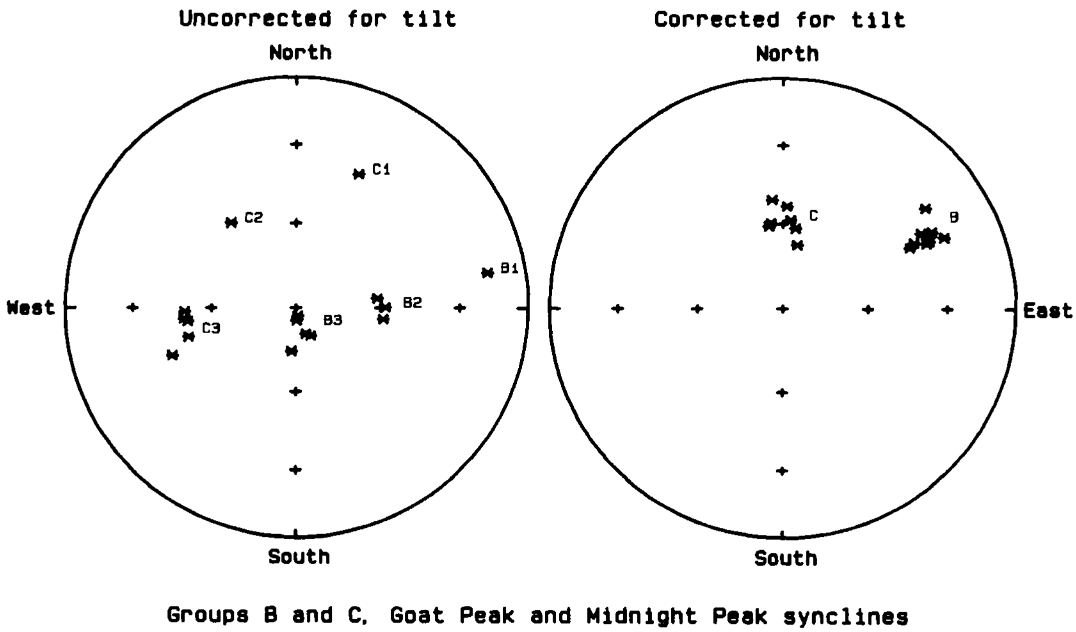

Figure 4. Stereographic projections of site-mean directions for groups B and C (a) before and (b) after untilting of beds to horizontal. Notice the dramatic improvement in clustering within groups with untilting yet remaining difference between groups. Improper structural correction might contribute to the difference in declination but not in inclination if the magnetization were primary (e.g. MacDonald 1980; Scott 1984).

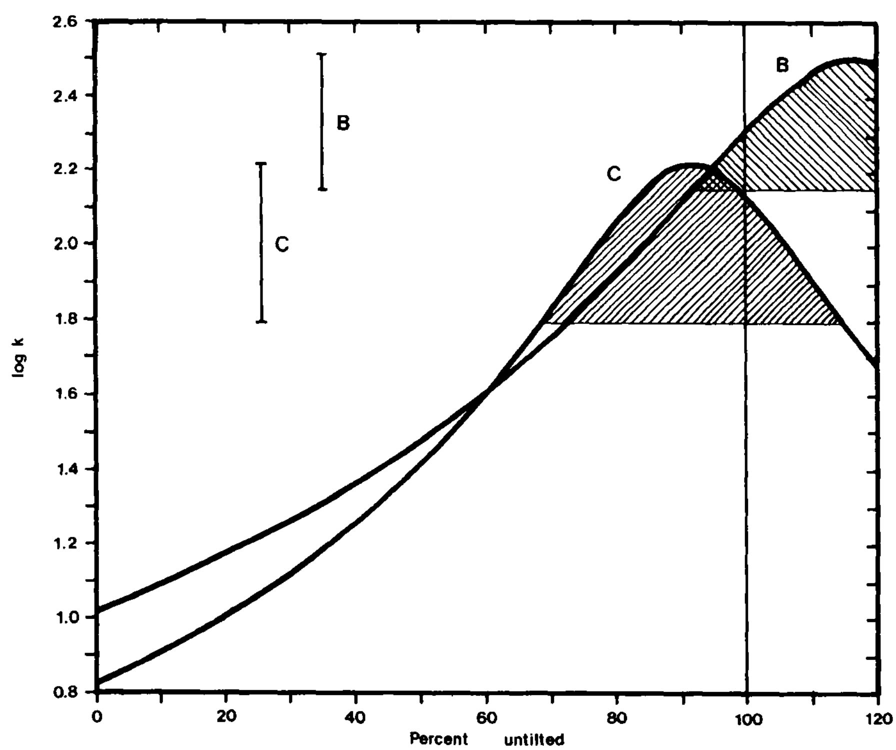

Figure 5. Change of precision (k) of mean directions for groups B (nine sites) and C (seven sites) with incremental untilting. Plotting $\log k$ (after Miller & Kent 1986) allows the 95 per cent confidence limits for McElhinny's (1964) fold test, represented by the bars on the left side, to be valid anywhere on the diagram. The shaded regions show that the peak precisions obtained at 115 and 93 per cent untilting for groups B and C respectively are not significantly higher than precisions obtained with 100 per cent untilting so the hypothesis that the rocks were magnetized when flat cannot be rejected.

Miller & Kent 1986). Fig. 5 shows that precisions of the means for groups B and C are significantly higher after correction than before. Although both curves peak at corrections other than 100 per cent, the precisions at the peaks are not significantly higher than at 100 per cent correction. Therefore, the hypothesis that the rocks were magnetized before any folding cannot be rejected.

The more stringent test of McFadden & Jones (1981) compares the mean directions of two or more limbs. If, for instance, the corrected limb-mean directions are not significantly different, then the hypothesis that the limbs were in their corrected attitude when magnetized can be accepted. One condition is that within-limb dispersions be similar; otherwise it is unlikely that the limbs averaged the same palaeomagnetic field. The dispersions are compared using the F test in a manner similar to McElhinny's (1964) fold test above. Dispersions of sample directions within sites are not similar according to this test (this was part of the test for whether sample directions could be used to calculate limb-mean directions). Therefore single-site limbs cannot be used. However, multisite limbs B2 and B3 may be used since dispersions of their site-mean directions are not significantly different according to the F test, either before or after untilting.

Whether these two limbs have the same direction is calculated using the resultants of the limbs separately (B2, B3; Table 2) and combined (B2, 3). For the exact procedure see McFadden & Jones (1981); for an example see Sandberg & Butler (1985). As one would guess from Fig. 4, which shows that these two limbs have distinct directions before correction, the hypothesis that the rocks were magnetized in their present attitudes can be rejected. The test statistic (10.41) is much greater than the critical value for 95 per cent confidence (0.65).

The hypothesis that the magnetization was acquired before tilting is tested similarly. Using site-mean directions corrected for locally measured tilt, the test statistic (0.81) is still larger than the critical value so we should reject this hypothesis also. However, the values are close and, considering that the intralimb variation of attitude is on the order of measurement accuracy, we should ask how errors in measurement of attitude might have affected the results. If the errors are random, we can reduce the uncertainty in the tilt correction by averaging attitudes. An alternative, therefore, is to assume that the limbs are homoclinal and to correct *in situ* limb-mean directions for mean limb attitude. Doing so reduces the test statistic (0.21) well below the critical value (0.65) so that the hypothesis that the two limbs had a common true mean direction before interlimb deformation cannot be rejected.

7 DISCUSSION

A positive fold test in which dispersion of site- or limb-mean directions is decreased after correction to palaeohorizontal has generally been interpreted to indicate that the magnetizations analysed were acquired before folding. Palaeohorizontal is, therefore, assumed to be the valid reference plane. Given the positive sense of the fold tests above, our first inclination is to follow this tradition. The fact that the rocks were formed and deformed in the mid-to-late Cretaceous when there was little apparent polar wander (Irving & Irving 1982) makes the interpretation insensitive to the exact time of magnetization.

Irving *et al.* (1985) have suggested that shallow inclinations of Cretaceous magnetizations and remagnetizations in Cordilleran batholiths originated at palaeolatitudes in the range of 31°–41°N, with 37°N–41°N being most common. The palaeolatitude from the Mount Stuart batholith [41°N when corrected for 15° block tilting independently determined by Haugerud (1987)] is consistent with this. The palaeolatitude from group C (39°N) also falls in this range. If data from only group C were available, poleward transport of the Methow–Pasayten belt along with the batholiths would appear to be an acceptable explanation. The positive fold test from C would settle the translation versus tilt debate about the origin of the shallow inclinations. However, adding the results from group B whose much shallower inclination predicts a 17°N palaeolatitude introduces near-fatal complications.

The same fold test used to support the magnetization of C as pre-folding can be used for B; both directions are shown to be pre-folding, and both are from overlapping levels in the same stratigraphic unit—but they do not agree. If both magnetizations were acquired when the strata were horizontal, they could not have been acquired at the same place and time; in this situation B must have been magnetized earlier when the terranes were farther south, and C must have been remagnetized after considerable translation. However, such a southerly origin and the extremely rapid poleward motion it would require are inconsistent with plate motion models (Debiche, Cox & Engebretson 1987). Also difficult to reconcile with any hypothesis that relies on greatly different times of magnetization is the lack of any obvious difference in the magnetic carriers or magnetizations of the two groups that one could use to rationalize why the older one (B) survived remagnetization. The only alternative is that the strata in group B were not horizontal when magnetized. But if strata in group B were not horizontal when magnetized, what evidence is there that those from C were? One possible clue is that C includes sites from beds with the gentlest dips, beds which might have magnetizations least affected by strain. This argument is weak on two counts. One is that strain, except in the overturned limbs which were excluded, appears negligible. The other is that a present horizontal attitude does not guarantee lack of strain. Consider that strata on a flat in a thrust system may have been strained then unstrained when climbing a ramp (Sanderson 1982).

What, then, can we learn from this study? The analysis above appears to us to demonstrate that the fold test depends only on the geometry of the limbs with respect to each other; it determines whether remanent directions agree if the beds are restored to a parallel orientation, but does not assure that the orientation was horizontal. Once this is recognized, there is a simple way to explain the divergent directions of groups B and C: planar strata in the two groups were oriented differently with respect to the palaeomagnetic field when remagnetized. One plausible mechanism is that the two groups were remagnetized at different times during progressive tilting of planar strata. Simultaneous remagnetization when the two groups were in different attitudes is unlikely given their close proximity. Another paper (Bazard *et al.* 1990) explores how the magnetizations in the

Methow–Pasayten belt can be used to constrain the geometry and development of earlier structures.

8 CONCLUSION

Our results serve as a useful cautionary note on interpretation of the fold test. Rocks in the upper levels of the Mesozoic section in the Methow–Pasayten belt are not complexly, nor even strongly deformed, nor do they bear any obvious lithological scars (alteration, baking) that might point to remagnetization. Applying the fold test to the best of our ability in the least deformed rocks produced a positive ('magnetized before folding') result; in fact it produced *two* such positive results, with mean directions that differ from one another dramatically. Apparently the simple Methow structure conceals a complicated Cretaceous history involving deposition of the Ventura Member of the Midnight Peak Formation, initial deformation, then at least two episodes of remagnetization during a second phase (or continuation) of deformation. The timing of deformation and magnetization varied enough over the area that the magnetizations do not exhibit minimum dispersion upon proportional partial correction, which has been used to recognize synfolding magnetization. Only because we sampled widely and applied fold tests locally were we able to detect complications in the region's history. If we had restricted our sampling to a smaller area we would have missed the initial remagnetization, and perhaps enunciated a potentially erroneous tectonic interpretation (e.g. Granirer *et al.* 1986). Could such a complicated history have been recognized from other data? The anomalously low within-site and between-site dispersions in this study are consistent with remagnetization but also with prolonged acquisition of original chemical remanence. The simple structure also was no help. In this regard it is worth emphasizing that present gentle attitudes of rocks, especially in convergent regions laced with thrust faults, should not be taken as proof that the rocks were always flat and unstrained. Finally, consistent polarity is no guarantee of a single magnetization. The problem of resolving remagnetizations in complexly deformed terranes is especially acute if remagnetization is suspected to have occurred during a long interval of constant polarity (e.g. mid-Cretaceous, late Palaeozoic), both because many events can occur during such long times and because the useful 'reversal test' is inoperative. Unfortunately, these are precisely the times during which large-scale remagnetization is most likely (e.g. by viscous processes; Moon & Merrill 1986).

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