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U.S. Nuclear Regulatory Commission
ATTN: Mrs. Deborah DeMarco
Office of Nuclear Material Safety and Safeguards
Two White Flint North
Mail Stop 8A23
Washington, DC 20555

Dear Mrs. DeMarco:

The enclosed manuscript entitled Late Cretaceous Paleogeography of Wrangellia: Paleomagnetism of the MacColl Ridge Formation, Southern Alaska, Revisited is not a NRC deliverable and is sent for programmatic review. The work was done as part of Professional Development activity by Dr. John Stamatakos. The manuscript will be submitted to Geology. The enclosed manuscript is the final version and has been through CNWRA review. Some of the techniques used to develop the rotational history of the MacColl Ridge are similar to those used in determining the tectonic history of Bare Mountain. This work provides Dr. Stamatakos with additional experience in the interpretation of the tectonic history of a mountain range and enhances his professional reputation.

If you have any questions please contact Dr. John Stamatakos at (210) 522-5247 or me at (210) 522-5183.

Sincerely,

Budhi Sagar
Technical Director

BS/re

Enclosure

cc:					
	E. Whitt	D. Brooks	B. Leslie	J. Stamatakos	K. Ridgway
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Late Cretaceous Paleogeography of Wrangellia: Paleomagnetism of the MacColl Ridge Formation, Southern Alaska, Revisited

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ABSTRACT

Volcanic and sedimentary strata of the Late Cretaceous MacColl Ridge Formation were sampled and demagnetized to re-evaluate the paleomagnetically derived paleolatitude of the allochthonous Wrangellia terrane. Characteristic directions from 15 sites representing ~750 m of the MacColl Ridge Formation (80 Ma) reveal a reversed-polarity primary magnetization with a mean direction of D=140°, I=-69°, α_{95}=6°, corresponding to a paleomagnetic pole at 126°E, 68°N, A_{95}=9°. Comparison of this pole with the Late Cretaceous reference pole for North America indicates 15°±10° of latitudinal displacement (northward) and 26°± 25° of counterclockwise rotation. In contrast to previously reported low paleolatitudes (32° ± 9°N) for the MacColl Ridge Formation, these new results place the Wrangellia terrane at a moderate paleolatitude (53° ± 8°N) in the Late Cretaceous.

INTRODUCTION

Although there is general agreement that much of the northwest Cordillera including southern Alaska is composed of allochthonous terranes, the nature and timing of terrane accretion and subsequent tectonic modification of the accreted margin remain equivocal (see Cowan et al., 1997 for a comprehensive summary of the debate). The central question is whether allochthonous terranes of southern Alaska and western Canada were positioned at relatively low paleolatitudes, offshore present-day Baja California, or much closer to their present latitudinal positions with respect to North America, offshore present-day British Columbia, Oregon, and Washington during the Late Mesozoic and Early Tertiary.

A critical and often cited paleomagnetic result important to the debate about the Mesozoic paleogeography of the Cordillera (e.g., Umhoefer, 1987; Irving et al., 1996) was derived from sedimentary strata of the Late Cretaceous MacColl Ridge Formation (Panuska, 1985). The MacColl Ridge Formation is particularly significant to paleogeographic studies because it was deposited on rocks of the Wrangellia composite terrane (WCT). The WCT is a subcontinent-scale amalgamation of allochthonous crustal fragments (Fig. 1a), including the Peninsular, Wrangellia (at least the fragments now exposed in Alaska), and Alexander terranes, that shared a common tectonic history since the end of the Paleozoic (Plafker and Berg, 1994). Fragments of Wrangellia are also exposed along western British Columbia and Washington (Fig. 1a), and possibly in eastern Oregon (Hillhouse et al., 1982). Paleomagnetic results from Panuska (1985) place the MacColl Ridge Formation, and thus the WCT, more than 4000 km south from its present position relative to North America in the Late Cretaceous and suggest 120° of counter-clockwise or 240°of clockwise vertical-axis rotation.

The reliability of the paleomagnetic results from the MacColl Ridge Formation has been questioned, however, because of a high sample rejection rate (75% of the original demagnetized samples were deemed unusable), small sample size (20 specimen directions defined the formation mean), poor demagnetization quality (alternating fields to a peak of 40 mT), and possible inclination error (e.g., Coe et al., 1985; Hillhouse and Coe, 1994; Butler et al., 1997). Inclination error occurs when the detrital or post depositional remanent magnetizations in the sedimentary rocks record inclinations much shallower than the inclination of the ambient magnetic field (e.g., Anson and Kodama, 1987).

Recent detailed studies of the MacColl Ridge Formation document previously unreported crystal vitric tuffs interbedded within the uppermost MacColl Ridge Formation (Trop et al., 1999). These interbedded tuffs and associated volcaniclastic sandstones provide ideal lithologies to re-evaluate the paleomagnetism of the MacColl Ridge Formation because volcanic strata typically carry a stable thermo-remanent magnetization not susceptible to inclination error. These new paleomagnetic results from the MacColl Ridge Formation redefine the paleogeographic position of the MacColl Ridge Formation in the Late Cretaceous and by inference delimit northward transport of the Alaskan segment of Wrangellia in the Late Cretaceous and early Tertiary.

GEOLOGIC SETTING AND SAMPLING

The MacColl Ridge Formation represents the stratigraphically youngest unit of a 7 km thick Mesozoic sedimentary sequence deposited in the Wrangell Mountains basin of southern Alaska. Lowermost strata of the MacColl Ridge Formation conformably overlie Cretaceous strata that in turn rest unconformably on Paleozoic-Mesozoic rocks of the Wrangellia terrane (Fig. 1b). The MacColl Ridge Formation consists of 1150 m of generally upward-fining sequences of conglomerates, lithic arkosic sandstones, and mudstones deposited by a northward-prograding (present coordinates) submarine fan system within the Wrangell Mountains forearc basin (Trop et al., 1999). Sediment was derived from uplifted source terranes exposed in the hanging wall of the south-vergent Border

Ranges thrust-fault system that juxtaposed the forearc basin against the subduction complex (Chugach terrane in Fig. 1a). Uppermost strata include 10 to 40 cm thick vitric tuffs and volcaniclastic sandstones. The tuffs were derived from volcanic eruptions of the Kluane Arc, that developed in the Late Cretaceous inboard of the forearc basin (Trop, 2000). Palynologic studies of mudstones in combination with $^{40}Ar/^{39}Ar$ radiometric dates from two interbedded tuff samples of the MacColl Ridge Formation (79.4+0.7 Ma, 77.9+2.1 Ma) indicate a middle to late Campanian age (Trop et al., 1999).

Strata of the MacColl Ridge Formation are exposed in a large syncline along the modern Chitina River (Fig. 1b). The syncline forms an impressive, broadly-topped topographic ridge 10 km wide, 24 km long, and several thousand meters high. Paleomagnetic samples were collected from 21 sites on both limbs of the MacColl Ridge syncline (Fig. 1b). Three different lithologies were targeted; vitric tuffs, volcaniclastic sandstones, and lithic arkosic sandstones. Samples were collected from the uppermost 750 m of the section (Fig. 1c), in contrast to Panuska (1985), who sampled only lithic arkosic sandstones and siltstones from a different part of the ridge where only the lowermost 30 m of stratigraphy is exposed (Figs. 1b and 1c).

METHODS

Samples were cored in the field or collected as oriented blocks and cored in the laboratory. Pilot samples were subjected to progressive thermal and alternating field (af) demagnetization. Thermal demagnetization proved the more reliable technique and the remaining samples were thermally demagnetized to a peak temperature of 575 °C. In addition, af experiments were made on several sandstone samples using procedures similar to those of Panuska (1985) to test the reliability of the paleomagnetic results from that earlier study.

Remanence measurements were made at the University of Michigan on a three-axis cryogenic magnetometer housed in a magnetically shielded room with a peak ambient field of less than 600 nT. Remanence components isolated during demagnetization were determined from visual inspection of linear segments on vector end-point diagrams (Zijderveld, 1967). Component directions were determined from a least squares fit of the observed linear trajectories (e.g., Kirschvink, 1980). Sample directions were combined to site means using simple vector addition, giving unit weight to each sample direction. Statistical parameters were calculated using the method of Fisher (1953). The fold test (Graham, 1949; McElhinny, 1964; McFadden and Jones, 1981) was used to establish the relative age of the magnetization.

PALEOMAGNETIC RESULTS

Thermal demagnetization of vitric tuff samples produced the best paleomagnetic results (Figs. 2a and 2b). After unblocking of a viscous present-day overprint by demagnetization temperatures up to 350 °C, stable characteristic remanent magnetization (ChRM) directions were removed. Maximum unblocking temperatures reached 570 °C, suggesting magnetite as the dominant carrier of the ChRM. Many of the volcaniclastic sandstone samples also produced well-behaved and stable ChRM. In contrast, all lithic arkosic sandstone samples produced noisy and poorly defined demagnetization trajectories, often characterized by remagnetization circles (Fig. 2c). Af demagnetization produced erratic demagnetization behavior and possible growth of a rotation remanent magnetization antipodal to the first removed component (Fig. 2d); an observation also noted in the original alternating field demagnetization of Panuska (1985).

Stable site mean directions were obtained for 15 of the 21 sites (73% of all samples; 86% of the tuff and volcaniclastic sandstone samples, Table 1). Demagnetization of samples from sites 3, 6, 9, and 21 did not produce stable ChRM directions. Only a few samples from sites 2 and 16 produced ChRM directions, but because of the small sample size and large α_{95} values, these sites were also excluded from calculation of the formation means. None of the lithic arkosic sandstone sites produced coherent ChRM site-mean directions. Of the 15 sites with reliable ChRM directions, all site mean directions have east to south declinations and moderate to steeply up inclinations (Fig. 3a). The site mean directions cluster better in tilt-corrected coordinates (Fig. 3b). The McElhinny (1964) fold test is positive at the 90% confidence level but statistically inconclusive at the 95% confidence level (Fig. 3c). The precision parameter (kappa) increases from 26.2 ($k1$) in in-situ coordinates to 47.2 ($k2$) in tilt-corrected coordinates, reaching a peak of 50.8 at 80% unfolding. The $k2/k1$ ratio is 1.80, compared to the critical ratios of 1.88 (95%) and 1.64 (90%). In contrast, the McFadden and Jones (1981) fold test is positive at the 95% confidence level. The hypothesis of a common true mean direction is rejected in the in-situ coordinates ($f = 4.99$) and accepted in tilt-corrected coordinates ($f = 1.58$), [number of sites (N) =15, number of limbs (m) = 6, critical value of the F distribution at 95% significance level = 3.94].

PALEOLATITUDE

Several lines of evidence indicate that the ChRM in the MacColl Ridge Formation is primary (acquired during deposition) and that secular variation has been averaged. (1) The directions cluster better in tilt-corrected coordinates. (2) The samples do not show evidence for extensive thermal or geochemical alteration. Mudstone samples from the sampled stratigraphy contain palynomorphs and spores with Batten's Thermal Alteration Scale values of 2 and 3 (A.R. Sweet, personal communication, 2000; Batten, D.J. 1996). This color range implies a maximum postdepositional paleotemperature of 80°C. (3) Campanian radiometric and biostratigraphic ages (Trop et al., 1999) place deposition of the MacColl Ridge Formation during reversed chron C33r (Palmer and Geissman, 1999), consistent with the pervasive reversed-polarity ChRMs. (4) The approximately 750 m of section represented by the paleomagnetic samples constitutes deposition over several hundred thousand years or more. The indication from the fold tests that the magnetization may be synfolding (and thus secondary) does not alter conclusions about the paleolatitude of the MacColl Ridge Formation in the Late Cretaceous. Bedding dips progressively decrease upsection toward the center of the syncline, indicating that folding coincided with deposition of the MacColl Ridge Formation; an observation consistent with the interpreted tectonic evolution of the Wrangell Mountains forearc basin (Trop, 2000). Thus, if the ChRM is secondary and was acquired during folding, it is still Late Campanian in age.

Given these lines of evidence, the mean direction (D = 140°, I = -69°, k = 47, α_{95} = 6°) and corresponding paleopole (lat. = 68° N, long. = 126° E, A_{95} = 9°) is a representative measurement of the Late Cretaceous paleopole for the Wrangellia terrane. The North American reference pole closest in age to the MacColl Ridge Formation is the 80 Ma Elkhorn Mountains Volcanics (80° N, 190°E, A_{95} = 10°) of Diehl (1991). Similar-age North American reference poles from the Upper Cretaceous Carmacks Group (78° N, 185°E, A_{95} = 8°) of Marquis and Globerman (1988) and the Rocky Mountain diatremes reference pole (79°N, 190°E, A_{95} = 4°) of Wynne et al. (1992) are compatible. Comparison of the revised MacColl Ridge Formation pole with the Elkhorn Mountains reference pole, including error procedures of Demarest (1983), indicates 15°±10° (1650±1100 km) of latitudinal displacement (northward) and 26°±25° of counterclockwise rotation. These results place Wrangellia at moderate paleolatitudes (53°± 8°N), near present-day British Columbia, Washington, and Oregon in the Late Cretaceous (Fig. 4), in contrast to the previously reported paleolatitudes (32° ± 9°N), near Baja California (Panuska, 1985). We attribute this discrepancy to the unreliable paleomagnetic signature and limited demagnetization of the lithic arkosic sandstones analyzed in the Panuska (1985) study.

The paleolatitudes for Wrangellia from our results are consistent with palynoflora data (Trop et al., 1999), which show affinities with cratonic North American floras of the western Canadian foreland basin as opposed to those found farther south. Moreover, the moderate counterclockwise rotation recorded by our results are easily explained by our proposed reconstruction (Fig. 4). In contrast, the large 240° clockwise vertical-axis rotations suggested by Panuska (1985) restores the longitudinal axis of the Wrangell Mountain forearc basin (present-day axis trend is 300°) to an orientation that is nearly perpendicular to western North America (restored-basin axis trend is 60°) and it places the subduction complex (Chugach terrane) inboard of the forearc basin. This restored orientation of the forearc basin and subduction complex is hard to reconcile with the west-to-east convergence and subduction that characterized western North America in the Late Cretaceous (e.g., Engebretson et al., 1987).

DISPLACEMENT HISTORY

The Late Mesozoic-Early Cenozoic northward translation and accretion of the allochthonous Wrangellia terrane along the western margin of North America is an important element in the tectonic development of the Cordillera (Plafker and Berg, 1994; Cowan et al., 1997). Numerous geologic and paleomagnetic results place the WCT at low paleolatitudes (~10°N) during the Late Triassic (~220 Ma) and at or near its present position (60-63°N) by 45 Ma (Hillhouse and Coe, 1994; Butler et al., 1997). Results of our study show that the WCT was at moderate paleolatitudes (53° ±8°N) during the Late Cretaceous (~80 Ma) and thus, was displaced northward 15°±10°(1650 ±1100 km) during the latest Cretaceous to Eocene (80-45 Ma). Northward translation was most likely accomplished by cumulative displacement along coast-parallel dextral strike-slip faults (Plafker and Berg, 1994). Using the above constraints, the minimum average displacement rates for the WCT from 80-45 Ma was 5 cm/yr (1650 km over 35 Ma). The 5 cm/yr rate is a minimum because latitudinal displacements record only the northward component of terrane motion and because displacement is assumed to take place throughout the entire 35 m.y. interval between 80 and 45 Ma.

The 5 cm/yr rate is consistent with plate interaction models (e.g., Debiche et al., 1987) which suggest coast-parallel rates from 9 to 11 cm/yr, assuming 100 percent coupling between the ocean plates and North America (Harbert, 1990). The calculated 5 cm/yr rate is also comparable to geodetic rates along active strike-slip systems such as the San Andreas fault (e.g., 3.5 cm/yr of Dixon et al., 2000).

Our results are consistent with paleomagnetic results from the 110 Ma Duke Island Ultramafic Complex (Bogue et al., 1995), which place the WCT 3000 ±1300 km south of its present position in southeastern Alaska (Fig. 4) in the Early Cretaceous. The results of Bogue et al (1995) indicate a minimum average displacement rate of 4.6 cm/yr (3000 km over the 65 m.y. interval between 110 and 45 Ma). In contrast, our results appear incompatible with paleomagnetic results from other terranes in the Cordillera (Fig. 4); namely the 98-74 Ma Mount Tatlow strata (Wynne at al., 1995) and the 93-82 Ma Mount Stuart batholith (Beck et al., 1981; Ague and Brandon, 1996) of the Coast Plutonic Complex, and the 83-70 Ma Nanaimo Group sedimentary strata of the fragment of Wrangellia expose on Vancouver Island (Ward et al., 1997). These paleomagnetic results place their associated terranes 3000 km south of their present position with respect to North America in the Late Cretaceous.

If the WCT was associated with these other terrane fragments in the Late Cretaceous (e.g., Umhoefer, 1987), and if the aforementioned paleomagnetic results are assumed reliable indicators of paleolatutude, then the displacement history of the WCT requires intervals of anomalously rapid northward displacement in the Late Cretaceous. For example, the Mount Tatlow magnetization, with a mean age of magnetization of 86 Ma, indicates 2960 ±450km of latitudinal displacement (data from table 1 of Cowan et al, 1997). Given our results for the MacColl Ridge Formation (53° ± 8°N), the Mount Tatlow results suggest 1300 km of northward displacement for the WCT between 86 and 80 Ma, yielding a minimum average displacement rate of 21 cm/yr of northward motion (1300 km in 6 m.y.), followed by the 5 cm/yr rate between 80 to 45 Ma (1650 km in 35 m.y.) as described above. Similarly, the Mount Stuart batholith magnetization, with a mean age of 88 Ma indicates 3100 ±600km of latitudinal displacement, thus yielding a minimum average displacement rate of 18 cm/yr (1450 km in 8 m.y.). These 18 to 21 cm/yr rates rival the fastest known plate velocities (e.g., Meert et al., 1993), are 6 to 7.5 times faster than the 3.5 cm/yr displacement rate for the San Andreas fault system (Dixon et al., 2000), and do not match predicted rates based on plate motion models, even assuming 100 percent coupling between the ocean plates and North America. These Mount Stuart and Mount Tatlow results fit with predicted plate motion models only if the magnetization age at the older extremes of the published age ranges are used (e.g., Housen and Beck ,1999).

Butler et al. (1989,1997), among others, questioned the reliability of the Mount Tatlow, Mount Stuart, and Duke Island results as faithful indicators of paleolatitude. In particular, Butler et al., (1989, 1997) argued that for these igneous rocks, paleohorizontal can not be unequivocally established and thus, that the low paleolatitudes may simply be artifacts of incorrect tilt corrections. Kim and Kodama (1999) suggest that the shallow inclinations of the Nanaimo Group are an artifact of inclination error related to sediment compaction.

Until these outstanding questions about the age and reliability of these paleomagnetic studies are resolved, we propose an alternative and simpler displacement model in which Wrangellia remained at moderate paleolatitudes (offshore present day Oregon, Washington, and British Columbia) throughout most of the Cretaceous and was displaced northward to its present position in Alaska in the latest Cretaceous and Early Tertiary. This simpler displacement model is in agreement with paleontologic data that place the Alaska segment of Wrangellia north of 30°N during the Middle Jurassic (Smith and Tipper, 1986; von Hillebrandt, 1992) and north of 50°N during the Late Jurassic to latest Cretaceous (von Hillebrandt, 1992; Trop et al., 1999).

CONCLUSION

Paleomagnetic analyses of vitric tuffs and volcaniclastic sandstones of the MacColl Ridge Formation shows that these strata carry a stable, Late Cretaceous remanent magnetization. Site mean directions are reversed, consistent with the reversed polarity of the geomagnetic field at the time of deposition. The paleomagnetic pole indicates that Wrangellia was at moderate paleolatitudes (offshore present-day British Columbia, Washington and Oregon) and not low paleolatitudes (offshore present-day Baja California) in the Late Cretaceous (~ 80 Ma). Displacement of the terrane from these moderate paleolatitudes to its present location in southern Alaska probably occurred along coast-parallel dextral strike-slip faults in the latest Cretaceous and earliest Tertiary.

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TABLE 1. PALEOMAGNETIC DATA FROM THE MACCOLL RIDGE FORMATION, ALASKA

Site	Lith.	n/N	S/D	D_g	I_g	D_s	I_s	*K*	α_{95}	ϕ	θ
1	VC	4/8	124/40	189	-43	137	-72	11.7	28	136	68
2	Tuff	4/9	124/40	(017)	(-80)	(28)	(-39)	(5.1)	(46)	-	-
3	SS	0/7	120/40	-	-	-	-	-	-	-	-
4	Tuff	8/8	95/16	144	-58	118	-68	19.6	13	139	56
5	SS	3/8	95/16	155	-68	112	-79	34.0	22	172	62
6	SS	6/8	95/16	-	-	-	-	-	-	-	-
7	Tuff	8/8	150/20	187	-73	117	-73	17.4	14	151	60
8	Tuff	5/5	150/20	159	-73	106	-66	41.0	12	145	48
9	SS	0/6	271/05	-	-	-	-	-	-	-	-
10	Tuff	8/9	271/05	119	-56	125	-53	30.6	10	115	46
11	Tuff	10/10	271/05	103	-73	118	-72	20.2	11	148	59
12	VC	6/9	Horz.	178	-61	179	-61	21.5	15	40	71
13	VC	9/15	Horz.	152	-60	153	-60	19.1	12	89	64
14	Tuff	6/7	Horz.	123	-59	125	-59	18.1	16	120	51
15	Tuff	7/7	Horz.	165	-65	166	-64	21.5	13	72	73
16	SS	3/6	Horz.	(008)	(-76)	(009)	(-77)	(13.5)	(35)	-	-
17	Tuff	13/14	Horz.	159	-65	159	-65	29.8	8	87	71
18	Tuff	13/13	Horz.	162	-76	162	-76	72.8	5	151	81
19	Tuff	12/12	27016	057	-76	125	-76	12.4	13	160	65
20	Tuff	17/17	270/16	168	-79	175	-64	22.3	8	50	74
21	SS	0/8	270/16	-	-	-	-	-	-	-	-
$Mean_g$		14/21		153	-69			26.7	8		
Mean (80%)		14/21				143	-69	50.8	5		
$Mean_s$		14/21				140	-69	47.2	6		
Paleopole								19.7	9*	126	68

Notes: Lith. is the lithology of the site (SS = sandstone, VC = volcaniclastic sandstones). n is the number of samples that produced ChRM direction, and N is the number of samples demagnetized. S and D are the strike and dip of bedding (dip direction +90° from strike). Horz. is horizontal bedding. D_g and I_g (D_s and I_s) are the declination and inclination of the site mean in in-situ (tilt-corrected) coordinates, in degrees. *K* is the Fisher (1953) precision parameter, and α_{95} is the 95% confidence region about the mean in degrees. ϕ and θ are the longitude and latitude of the corresponding palomagnetic pole, in degrees. Bracketed values were not used to calculate the formation means.

* For mean paleopole, the confidence interval is reported as A_{95}, in degrees.

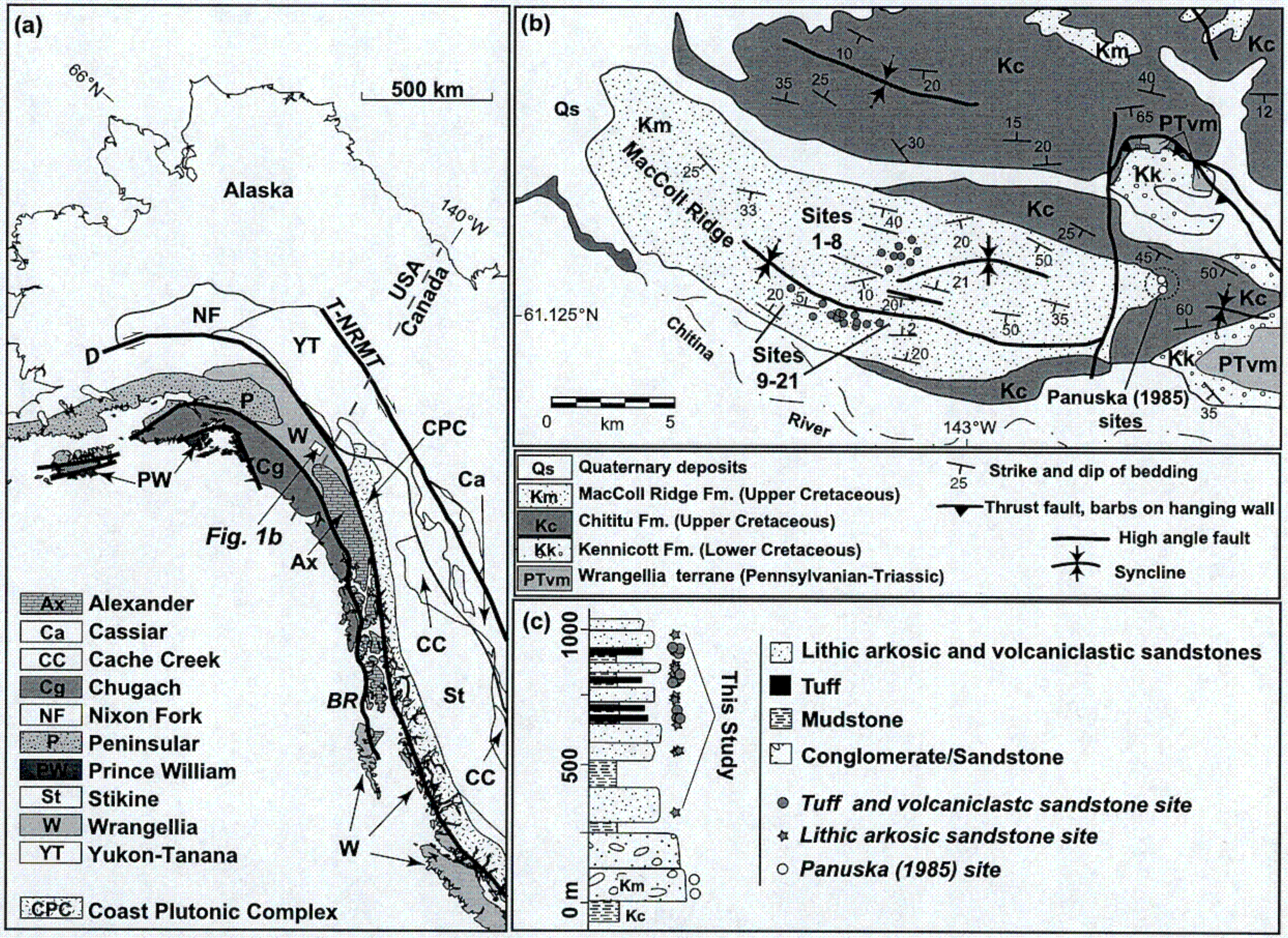

Figure 1. (a) Generalized map of northwestern Cordillera showing the major terranes (adapted from Umhoefer, 1987). Terrane-bounding fault systems, the Border Ranges (*BR*), Denali (*D*), and Tintina-Northern Rocky Mountain Trench (*T-NRMT*), are shown as heavy black lines. (b) Geologic map of MacColl Ridge, Alaska after Miller and MacColl (1964) and MacKevett (1978) showing paleomagnetic site locations. (c) Generalized stratigraphic column of the MacColl Ridge Formation (Km) and uppermost Chititu Formation (Kc) after Trop et al. (1999) showing the stratigraphic distribution of the paleomagnetic sites.

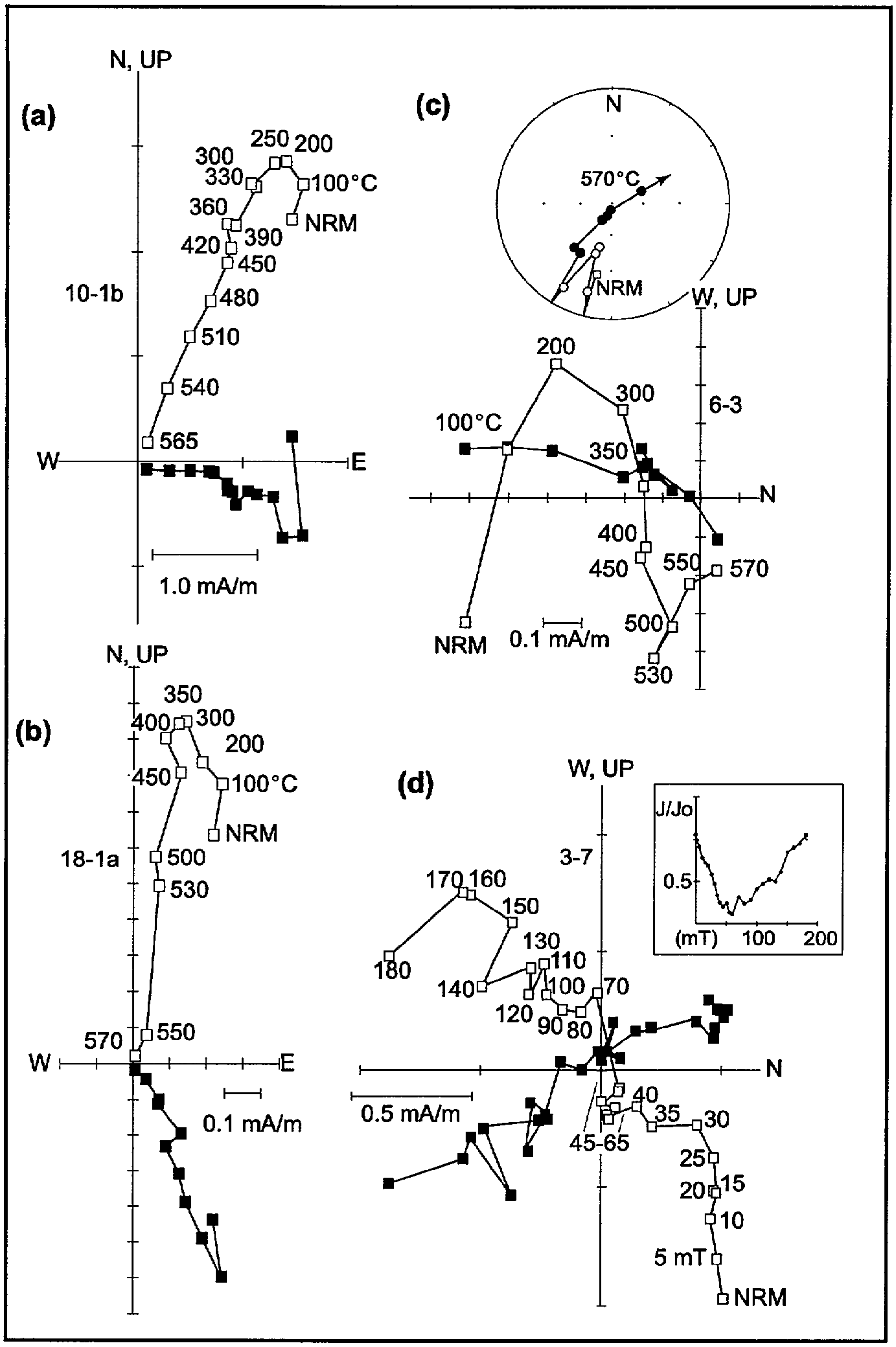

Figure 2. Sample vector end-point diagrams showing thermal and alternating field demagnetization, in in-situ coordinates. Open and closed symbols are projections onto the vertical and horizontal planes, respectively. NRM is the natural remanence magnetization. (a) and (b) show demagnetization of typical tuff samples. (c) and (d) show demagnetization of typical lithic arkosic sandstone samples. Insert in (c) is an equal-angle projection of the demagnetization showing remagnetization-circle trend. Insert in (d) shows the relative change in the magnetization intensity as a function of alternating field intensity.

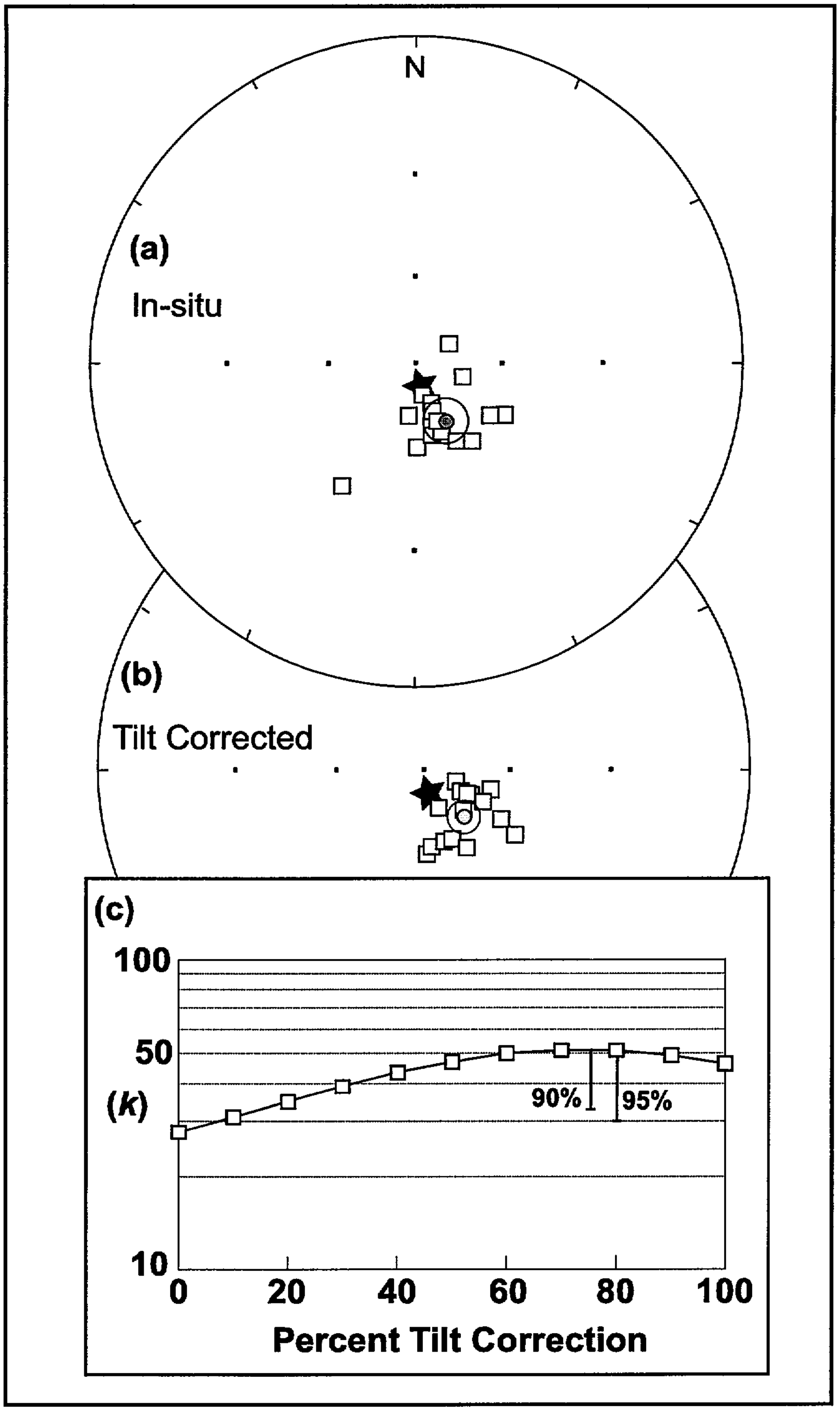

Figure 3. Equal angle projections in (a) in-situ and (b) tilt-corrected coordinates showing the site mean directions (squares), MacColl Ridge Formation-mean direction (small gray circles) and associated formation-mean 95% confidence area (larger circles). The star is the expected 80 Ma reference direction based on the North American reference pole of Diehl (1991). (c) Incremental fold test showing the variation in the precision parameter kappa (*k*) as a function of percent tilt correction. Statistical significance of the relative change in *k* with tilt correction (McElhinny, 1963) can be evaluated against the 95% and 90% confidence intervals, shown as solid black bars on the curve.

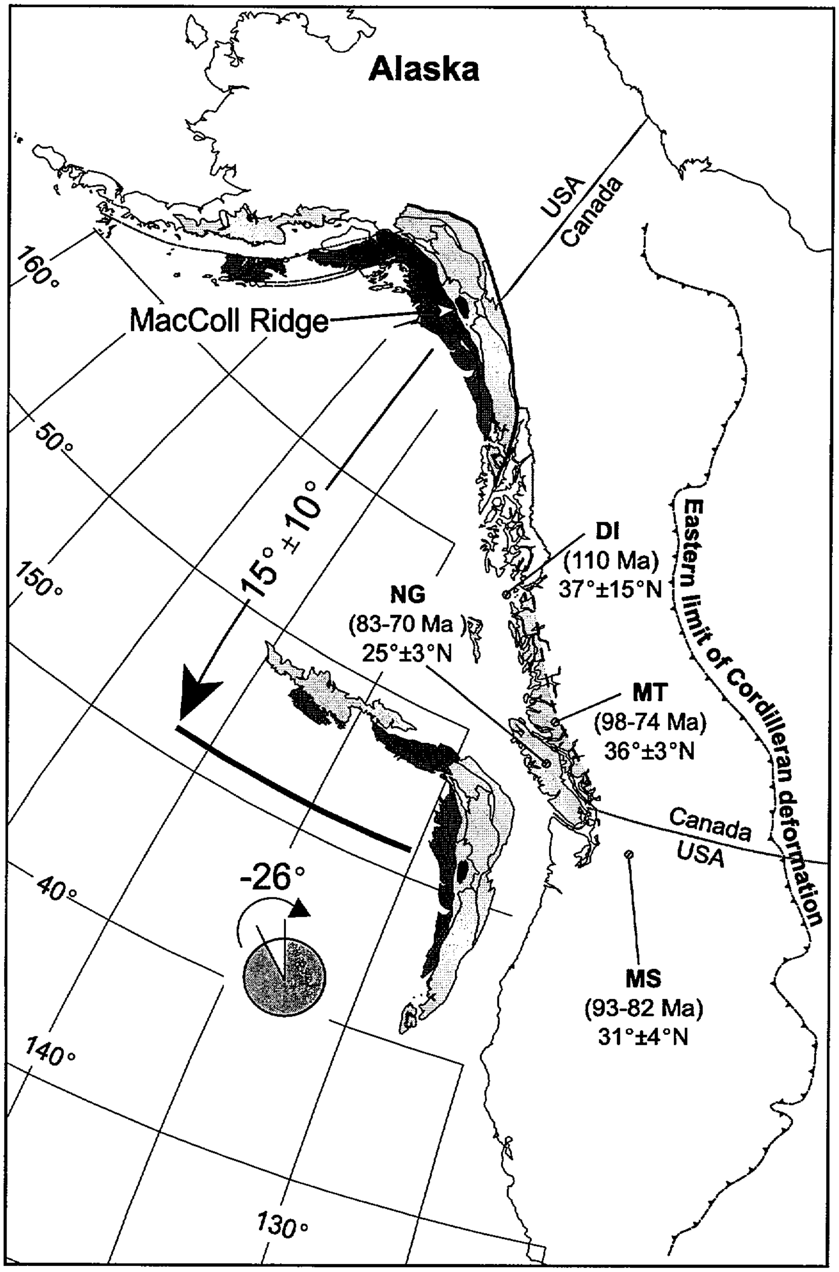

Figure 4. Map of western North America showing the present day and restored positions of Wrangellai composite terrane. The restored position show the correction for 15°of latitudinal displacement and 26° of counter-clockwise rotation indicated by the paleomagnetic data from the MacColl Ridge Formation. Also shown are the locations of other Cretaceous results discussed in the text; MS-Mount Stuart (Beck et al., 1981; Ague and Brandon, 1996), MT-Mount Tatlow (Wynne et al., 1995), DI-Duke Island (Bogue et al. 1995), NG-Nanaimo Group (Ward et al., 1997). For each location the published range of magnetization ages and paleolatutude are given .