Brandon and Ague's reply follows after this discussion, which is included for completenesss.

Regional tilt of the Mount Stuart batholith, Washington, determined using aluminum-in-hornblende barometry: Implications for northward translation of Baja British Columbia: Discussion and reply

Discussion

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INTRODUCTION

Ague and Brandon (1996) calculated a best-fit surface through Al-in-hornblende paleobarometric data to determine the paleohorizontal in the Mount Stuart batholith, North Cascades, Washington, and thus attempted to provide a means to better interpret paleomagnetic results obtained from this pluton. Ague and Brandon (1996) then used these results to reach conclusions about the tectonics of the northwestern Cordillera. We think that this is a useful approach and applaud their attempt to refine this technique. However, application of this technique to the Mount Stuart batholith remains problematic for reasons outlined in the following, and thus raises uncertainties about their tectonic conclusions. We address the following issues: (1) Ague and Brandon's attempt to determine a paleobarometric surface in the Mount Stuart batholith; (2) regional relationships that may bear on possible tilt directions; (3) direction of motion of the Windy Pass thrust; and (4) interpretation of existing paleomagnetic data. We hope that our comment emphasizes the complexity of data sets from the Mount Stuart region and thus the need for caution when interpreting its geologic history.

PALEOBAROMETRIC SURFACES

Ague and Brandon (1996) noted that for their technique to work the following three assumptions must be met: (1) reliable measurements of crystallization pressures must be available; (2) barometric surfaces are planar and roughly parallel to paleohorizontal; (3) tilting of the batholith did not occur during cooling. We suggest that all three of these assumptions may fail for the Mount Stuart batholith. First, there remain considerable problems with calculations of crystallization pressures in this batholith, as outlined by Anderson (1996, 1997). Anderson, using mineral equilibria, and Francis et al. (1996), using oxygen isotopic data from the batholith and host rocks, concluded that mineral compositions and calculated paleopressures in the batholith reflect both magmatic and subsolidus processes. We have concerns about whether any barometric data in the Mount Stuart batholith should currently fit a single plane. We have documented that much of the batholith was folded during final crystallization and that folding and ductile shear continued in four domains during subsolidus cooling of the batholith (Miller and Paterson, 1992, 1994; Paterson et al., 1994). Although the magnitude of displacement in these domains is generally unknown, at least in one case (Tumwater Mountain shear zone described by Miller and Paterson, 1992, 1994) it was enough to change pressures across the zone by >2 kbar (Paterson et al., 1994; see also Magloughlin, 1994). Existing paleomagnetic and structural data (see the following) also indicate that the batholith may have undergone subsolidus rotations, but not as a single rigid block (e.g., Beck et al., 1981; Lund et al., 1993, Paterson et al., 1994). Data summarized in Paterson et al. (1994) and Davidson and Evans (1995) indicate that a pressure increase caused by loading of the batholith and its host rock probably began during emplacement and certainly was active during cooling, suggesting that tilting was occurring during cooling of the batholith. Paterson et al. (1994) specifically noted that cordierite porphyroblasts in the hanging wall of the Tumwater Mountain shear zone (which deforms and displaces the northeast margin of the batholith) are partially pseudomorphed by staurolite, sillimanite, and kyanite. These mineral relations indicate a pressure increase, analogous to the loading history of the Chiwaukum Schist. Since this shear zone was active during and only for a short time after emplacement, this pressure increase (and thus loading) must have occurred prior to or during emplacement of the 93 Ma phase of the batholith.

REGIONAL RELATIONSHIPS

The only "regional relationships" that Ague and Brandon (1996, p. 482) offered in support of their proposed tilt direction is that "From north-northwest to south-southeast across the Mount Stuart area, one moves in an [stratigraphic] up-section direction from the Chiwaukum Schist through the Ingalls ophiolite into the unconformably overlying sedimentary strata of the Swauk Formation." However, the contact between the Chiwaukum Schist and Ingalls Complex is the Windy Pass fault, which was active during emplacement of the Mount Stuart batholith, and likely displayed major ramps rather than forming a single, subhorizontal planar surface (Paterson et al., 1994). The Ingalls-Swauk contact represents a basin margin that formed well after emplacement, and the Swauk

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Formation was unlikely to have extended for any significant distance laterally over the Ingalls Complex and Chiwaukum Schist (cf. Taylor et al., 1988). Furthermore, significant segments of the Ingalls-Swauk contact have been modified by Eocene or younger faulting (Tabor et al., 1982; Miller et al., 1990). Thus, the Chiwaukum-Ingalls-Swauk complex is largely a structural sequence that in part reflects lateral variations in geology and may easily record effects other than tilting. In addition, one may also move from the Chiwaukum Schist through the Ingalls ophiolite and into overlying Tertiary sedimentary strata in a southwest, southeast, east, and northeast direction rather than only to the south-southeast, as stated by Ague and Brandon.

We were disappointed that Ague and Brandon (1996) did not discuss regional structural patterns, metamorphism, and in part geochronologic data sets, which have been used previously to argue for a northeast-up tilt (e.g., Beck et al., 1981; Haugerud, 1987). Without at least some mention of these data sets, and discussion of why they conclude that their paleobarometric data set is more reliable, we feel that it leaves readers with an overly simplistic view of regional relationships and thus possible tilt scenarios. It would be particularly helpful to know the nature and location of structure(s), given their conclusion of a northeast-trending tilt axis, that caused their proposed tilt so that others may look for and examine the structure(s).

DISPLACEMENT OF WINDY PASS FAULT

Ague and Brandon (1996) assumed that the Windy Pass fault is a single, planar, "near-horizontal" structure "that extended across the entire Mount Stuart area." On the basis of these assumptions, they suggested northeast-directed motion for this fault because it cut up their paleobarometric contours to the northeast. We question this conclusion because the northeastern segments of the Windy Pass fault lie at the base of detached klippe either present in a >40° plunging synform, or uplifted in the hanging wall of the Tumwater Mountain shear zone. Furthermore, the fault is certainly not planar; the original geometry was significantly modified by folding during northeast-southwest contraction and batholith emplacement (Miller, 1985; Paterson et al., 1994). Ague and Brandon also ignored a great deal of structural data and regional considerations summarized by Miller (1985) and Paterson et al. (1994), which suggest an uncertain but probable north direction of early motion with some late southwest displacement. Some discussion of why they disregarded these observations would help in evaluating their conclusions.

PALEOMAGNETIC DATA

As noted by Ague and Brandon (1996), Lund and coworkers (Lund et al., 1993, 1994; Paterson et al., 1994) collected new paleomagnetic data from the Mount Stuart batholith. This study (as stated in Paterson et al., 1994) was able to reproduce, and is completely compatible with, the Beck et al. (1981) results. We thus find it surprising that Ague and Brandon chose to accept only the older and less-extensive results of Beck et al. (1981). In addition, we urge caution in interpretation of either data set. Magnetic remanence values are weak in this batholith and questions remain about the magnetic carrier, the timing of magnetic remanence, and the significance of patterns of the paleomagnetic values. However, initial conclusions using both data sets are intriguing. In contrast to statements made by Ague and Brandon (1996), these data indicate that (1) paleomagnetic results are available for the northern loaded part of the batholith; (2) widespread pyrrhotite and in local domains magnetite dominate the magnetic mineralogy; (3) paleomagnetic results preserve both normal polarity (southeast "unloaded" domain) and reversed polarity (northwest "loaded" domain); and (4) the paleomagnetic results require vertical axis rotation of 20°–40° between at least two crustal blocks, separated by a poorly defined northwest-striking structure (Beck et al., 1981; Lund et al., 1993; Paterson et al., 1994, 1996), which has not been recognized in any previous mapping (e.g., Tabor et al., 1982, 1987; Paterson et al., 1994). At this time these data do not support or refute the tilt suggested by Ague and Brandon (1996), but they strongly support the conclusion that tilt and/or rotation scenarios for this batholith are not simple and did not occur as a single block rotation (Paterson et al., 1996).

CONCLUSIONS

Our work to date and that of others indicate that the geology of the Mount Stuart region formed by complex processes, resulting in complex data sets. For example, there is an intriguing but poorly understood correlation between the zones of elevated oxygen isotope values noted by Francis et al. (1996), the domains of subsolidus deformation in the batholith noted by Miller and Paterson (1994), and the zones of remanent magnetism preserved in magnetite instead of pyrrhotite noted by Lund et al. (1993). There is also an excellent correlation between loaded regions (marked by late staurolite-kyanite assemblages) and the region where reversed paleomagnetic results are preserved. We encourage readers to treat all these data sets with caution: some remain incompatible or poorly understood. However, we also believe that the greatest understanding of the geology of this region will eventually come from an integration of these data sets rather than an emphasis on a single set.

Ague and Brandon (1996), emphasizing a single data set, reached conclusions about paleobarometric surfaces in the Mount Stuart batholith, possible tilt directions, direction of motion of the Windy Pass thrust, and interpretations of existing paleomagnetic data that we feel are not justified given evaluation of all data sets. However, we support two of the main points of their paper: (1) when certain assumptions are met, calculation of paleobarometric surfaces is a useful tool for evaluating geologic and paleomagnetic data; and (2) available data do not require large tilts of the Mount Stuart batholith, thus permitting large latitudinal displacement since Cretaceous time.

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Reply

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INTRODUCTION

Our use of Al-in-hornblende (AH) barometry to determine regional tilting of granitic plutons (Ague and Brandon, 1992, 1996) has generated much argument and disagreement. Most of this exchange has been informal, so we welcome this opportunity for a published discussion of our work.

We focus here on geologic and tectonic issues raised in Paterson and Miller's discussion. In a separate discussion, Anderson (1997) argued that the AH barometer may commonly fail to produce reliable pressure estimates, a point underscored in Paterson and Miller's discussion. We rely on Ague and Brandon (1997) and Ague (1997) to address this part of the disagreement.

Paterson and Miller's discussion concerns two themes: (1) our planar-tilt interpretation is too simple given the complex history of the Mount Stuart batholith, and (2) we have tended to gloss over certain geologic relationships that might undermine our interpretation. We suspect that these disagreements are further fueled by differences in the scale of the problems that our groups are studying. Paterson, Miller, and coworkers have been studying the processes of pluton emplacement as revealed by local deformation and metamorphism of the Mount Stuart batholith and surrounding country rock (e.g., Miller and Paterson, 1992, 1994; Paterson et al., 1994). Our work has focused on a regional-scale study of the pressure field in the batholith at the time of emplacement with the goal of using this information to restore a batholith-scale paleomagnetic data set (Beck et al., 1981). We believe that AH barometry is well suited for this task and has provided us with a robust data set that can be interpreted independent of other geologic information.

Our primary tectonic interpretation is that the Mount Stuart, at its present level of exposure, preserves a set of nearly planar isobaric surfaces that were formed when the batholith cooled through its solidus and that those surfaces currently dip about 7° to the southeast (133°). This interpretation represents a well-defined testable hypothesis. We maintain that it is fully consistent with our AH data and the published geology of the region. Our AH data provide information about the cumulative tilt of the batholith, but nothing about its incremental tilt history. A full synthesis of the tilt history of the batholith would require a massive integration of igneous and metamorphic barometry, thermochronology, paleomagnetic data, and Cenozoic stratigraphy, a task well beyond the scope and objective of our paper.

Much of Paterson and Miller's discussion focuses on what they see as conflicts between our AH–based results and regional geologic relationships. None of their points is new to us. We have given considerable thought to each and have decided that there is no available geologic evidence that refutes our planar-tilt hypothesis. Paterson and Miller acknowledge that much of their evidence is ambiguous with respect to the tilt question, but conclude that our interpretation is likely flawed, given the large number of contrary points that they have identified. We fail to see how the evidence becomes any stronger in aggregate. We support these broad statements below with a point-by-point reply to the four specific issues raised by Paterson and Miller, i.e., (1) Estimation of paleobarometric surfaces, (2) conflicts with regional geologic relationships, (3) inferences about the displacement history of the Windy Pass thrust, and (4) reliability and interpretation of the Mount Stuart paleomagnetic data.

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PALEOBAROMETRIC SURFACES

Paterson and Miller suggest that all three assumptions underlying our planar-tilt model may fail for the Mount Stuart batholith. The quoted headings below refer to Paterson and Miller's summary descriptions of our assumptions.

1. "*Reliable measurements of crystallization pressures must be available.*" We evaluated this assumption at great length (Ague and Brandon, 1996, 1997). We remain confident of our results because careful attention was paid to the established guidelines for the AH barometer: bulk rock with a tonalitic composition and rim compositions of unaltered hornblende in textural equilibrium with other phases of the specified critical assemblage. We cannot vouch for Anderson's (1997) results (as variously reported in Paterson et al., 1994; Anderson and Smith, 1995) because he generally disregarded the accepted guidelines for the barometer. His AH determinations came from samples that had a wide variety of bulk compositions and commonly lacked such critical minerals as potassium feldspar and sphene. Furthermore, it is unclear whether he was careful to avoid hydrothermal alteration in the hornblendes. His nominal pressure estimates are different from ours in that they do not follow a planar trend and show local variations, especially near the northeast margin of the batholith (e.g., Paterson et al., 1994, Fig. 11).

Ague and Brandon (1992) recognized that the northeast lobe of the Mount Stuart showed extensive subsolidus alteration, so we are not surprised that Paterson et al. (1994), Anderson (1996,

1997) and Francis et al. (1996) have come to the same conclusion. Our paper showed that hydrothermal alteration of hornblende was patchy, and that with careful use of back-scattered electron imaging, primary igneous compositions could be recovered.

The alteration history of the northeast lobe of the Mount Stuart is important for understanding the tectonic history of the entire batholith, but it is not relevant to restoring the controversial paleomagnetic data of Beck et al. (1981), which came from the relatively unaltered southern half of the batholith. Paterson and Miller do not address this important distinction.

2. "*Barometric surfaces are planar and roughly parallel to paleohorizontal.*" Paterson and Miller's main point is that "much of the batholith was folded during final crystallization and that folding and ductile shear continued in four domains during subsolidus cooling of the batholith. . . ." Closure of the AH barometer is thought to occur at or slightly below the solidus (see Ague and Brandon, 1996, for details), so magmatic structures are not relevant to our study.

Paterson et al. (1994, p. 2F–12F) stated, "Most of the Mount Stuart batholith only shows minor subsolidus deformation (e.g., undulose extinction, deformation twins) and recrystallizations (e.g., hornblende and biotite locally replaced by sericite). Exceptions occur in three domains along the northeast margin of the batholith . . . and one domain within the batholith where gently dipping magmatic foliations exist. . . ." (See Miller and Paterson, 1992, 1994, for further details.)

Using Figure 14 in Paterson et al. (1994), we estimate that these deformed domains account for <5% of the batholith. The three domains along the northeast margin of the batholith are not relevant to issues about deformation within the batholith. The Tumwater Mountain shear zone lies along the northeast margin of the batholith and is included in one of these domains. The only deformed domain within the batholith (Pioneer Creek) is described as having a strong magmatic foliation and a weak subsolidus fabric (Paterson et al., 1994). None of these details are relevant to our study.

Paterson and Miller also stated, "We have concerns about whether any barometric data in the Mount Stuart batholith should currently fit a single plane." We were also worried that the batholith may have a more complex subsolidus internal structure. We closely examined (Ague and Brandon, 1996) the spatial distribution and the magnitude of the misfit between our AH data and the best-fit planar-tilt model. We also examined more restricted parts of the batholith to see if we could detect differential tilts. None of these tests revealed the presence of more complex regional-scale structure, such as broad folds or widely spaced faults.

3. "*Tilting of the batholith did not occur during cooling.*" This summary of our assumption is misleading. In our words (Ague and Brandon, 1996), we assumed that "the batholith underwent no significant tilting until after it cooled through the magnetic block temperature. . . ." When restoring paleomagnetic data, the AH–determined paleohorizontal is only useful if the batholith did not tilt significantly between the closure time of the AH barometer and the blocking time of the measured magnetization. This assumption is difficult to evaluate because the blocking temperature for the Beck et al. (1981) magnetization remains poorly constrained (see discussion of paleomagnetism in Ague and Brandon, 1996, for details). However, concordant K-Ar ages for hornblende and biotite pairs from the western and southern parts of the Mount Stuart indicate rapid cooling in those areas (Ague and Brandon, 1996, Fig. 2). About half of the paleomagnetic sites of Beck et al. (1981) come from those parts of the batholith. There was probably not enough time at those sites for much tilting to occur between closure of the AH barometry and blocking of the reported magnetization.

REGIONAL RELATIONSHIPS

In Ague and Brandon (1996), we argued that our tilt interpretation for the Mount Stuart batholith was reasonably consistent with the surrounding geology at a regional scale. Paterson and Miller question our arguments on this matter. We hope that the expanded discussion below helps to clarify the disagreement.

The Mount Stuart batholith and associated Mesozoic country rock (e.g., Ingalls ophiolite and Chiwaukum Schist) collectively make up a fault-bounded block, which we call the Mount Stuart block (Haugerud, 1987, used the term Wenatchee block). We contend that the southern half of the Mount Stuart block—from the northern margin of the Mount Stuart batholith to the southern limit of the Ingalls ophiolite—has seen relatively little internal deformation since the emplacement of the batholith. Our inference is based on the preservation of planar isobaric surfaces in the Mount Stuart and the relatively static nature of the post-intrusion load-related metamorphism that affected the Chiwaukum Schist (Evans and Berti, 1986; Brown and Walker, 1993; Paterson et al., 1994). The block is bounded by major north- and northwest-striking high-angle faults on its east side (e.g., Leavenworth fault) and along at least part of its west side (e.g., Evergreen, and Deception Pass faults) (e.g., see Fig. 2a in Ague and Brandon, 1996, or Fig. 1 in Paterson et al., 1994). We acknowledge that relationships are poorly exposed on the west side of the block and remain disputed (Miller et al., 1990; Butler et al., 1989, 1990; Tabor et al., 1993). Nonetheless, the southern margin of the block is overlapped by a thick, well-stratified sequence of Paleogene sediments and volcanic rocks (e.g., Swauk Formation, Teanaway basalts, and Roslyn Formation described in Tabor et al., 1987). Published mapping (Frizzell et al., 1984; Tabor et al., 1987) clearly shows that this sequence was deposited unconformably on the Mount Stuart block. The unconformity is marked by Ni-rich lateritic sediments derived from weathering of the underlying Jurassic Ingalls ophiolite (iron sandstone unit of Frizzell et al., 1984; Tabor et al., 1987). At a regional scale, the Paleogene sequence youngs to the south and ultimately dips beneath the Miocene flood basalts of the Columbia River Plateau. Paterson and Miller are correct in saying that the Paleogene sequence is folded and faulted and that the basal unconformity is locally faulted as well, but these features are important only at the local scale. They do not change the fact that the Paleogene sequence has a general southward dip at the regional scale. We (Ague and Brandon, 1996) also noted that the Windy Pass thrust and Ingalls ophiolite show a similar generally southward dip (Miller, 1985).

Our intent in citing these relationships is to show that the southeast dip of the Mount Stuart batholith is not totally unexpected. However, it is important to note that available geologic data provide no hard evidence concerning the tilt geometry of the batholith. Many authors have attempted to deduce tilt of the batholith using the patterns of metamorphism and cooling ages within the Mount Stuart block (Beck et al., 1981; Haugerud, 1987; Umhoefer and Magloughlin, 1990; Miller et al., 1990; Beck, 1991). We believe that these approaches are problematic because the Mount Stuart block has a complex metamorphic and thermal history. The most significant event is the Late Cretaceous load-related metamorphism that postdated intrusion of the Mount Stuart batholith and affected the northeast lobe of the batholith and the surrounding Chiwaukum Schist (see Ague and Brandon, 1996, for summary). Following Evans and Berti (1986) and Brown and Walker (1993), we argued that a tectonic or magmatic load caused prograde metamorphism of the Chiwaukum Schist and widespread hydrothermal alteration of the northeast lobe. This load is completely gone now, so one can only speculate whether it was a higher thrust sheet (Evans and Berti, 1986; McGroder, 1991) or a massive high-level intrusion (Brown and Walker, 1993). The critical point for us is that metamorphic isograds in the Chiwaukum Schist and cooling ages in the Chiwaukum Schist and the northern part of the Mount Stuart batholith are related primarily to this younger event and provide no direct evidence of the cumulative tilt experienced by the batholith. It is interesting to note that this loading event appears to have caused no detectable distortion of the isobaric surfaces within the batholith, which implies that the batholith moved as a rigid body during emplacement and removal of the higher level load.

Paterson and Miller encourage us to specify the nature and location of structures responsible for the proposed southeast-down tilting. First, we note that a tilt axis is not a structure, but rather a geometric pole of rotation. Therefore, our definition of a tilt axis does not predict any specific structure, in much the same way that a fold axis does not predict the geometry and location of a fold. Second, it should be obvious that our estimated tilt for the Mount Stuart is the sum of several poorly understood incremental tilts, including the load-related metamorphism, postmetamorphic exhumation, the formation of regional angular unconformities at the base and top of the Paleogene sequence, and the modern uplift of the Cascade Range. It would be naive on our part to ascribe all of the observed tilt to a single event and a single structure.

Given this disclaimer, we suggest that much of the tilt might be due to the uplift of the Mount Stuart block. This style of deformation has been referred to as "piano-key tectonics," a term of J. Rodgers (1996, personal commun.). Fault-bounded sedimentary sequences east and west of the Mount Stuart block have dropped down, while the Mount Stuart block has rotated up by south-down tilting of the block. This deformation probably started in Eocene time and may have been reactivated during late Cenozoic uplift of the modern Cascade Range.

DISPLACEMENT OF WINDY PASS FAULT

Paterson and Miller cite Paterson et al. (1994) for the conclusion that the Windy Pass thrust "was active during emplacement of the Mount Stuart batholith, and likely displayed major ramps rather than forming a single, subhorizontal planar surface. . . ." We agree that the strong magmatic and weak subsolidus deformation recognized by Miller and Paterson (1994) and Paterson et al. (1994) in the Pioneer Creek domain of the Mount Stuart batholith might have been formed by motion on the Windy Pass thrust. This deformation seems relatively minor compared to the very large slip that occurred during obduction of the Ingalls ophiolite, which overlies the Windy Pass thrust. In fact, deformation in the Pioneer Creek domain could be due to reactivation of the Windy Pass thrust after ophiolite obduction.

Paterson et al. (1994) are cited as the source for observations about ramp structures along the Windy Pass thrust, but we found no discussion there of this point. Furthermore, we do not see how Paterson and Miller can make inferences about thrust ramps without some stratigraphic or paleohorizontal reference. The footwall and hanging wall of the Windy Pass thrust are a polyphase-deformed schist and serpentinized ultramafite, respectively.

Paterson and Miller question our proposal of a ramp structure in the Windy Pass thrust, but their summary is misleading. We stated that "the Windy Pass thrust and superjacent Ingalls ophiolite probably originated as a near-horizontal structural sequence that extended across the entire Mount Stuart area." Thus, the isobaric surfaces in the Mount Stuart batholith can be used, in a rough way, to infer the climb direction of the Windy Pass thrust relative to paleohorizontal (Fig. 2a in Ague and Brandon, 1996). The western exposed end of the thrust starts at the 7 km contour and then climbs rapidly to the northeast to the 6 km contour, which it follows for some 10 to 20 km to the east. This relationship suggests a ramp-flat geometry, the Windy Pass thrust climbing to the northeast relative to our estimated isobaric surfaces for the Mount Stuart batholith. This geometry implies top-to-the-northeast motion of the Ingalls ophiolite over the Chiwaukum Schist, which was the interpretation favored by McGroder (1991) in his regional-scale cross section.

Paterson and Miller argue that the top-northeast motion on the Windy Pass thrust is inconsistent with "a great deal of structural data and regional considerations summarized by Miller (1985) and Paterson et al. (1994) which suggest an uncertain but probable north direction of early motion with some late southwest displacement." In our paper, we acknowledged Miller's (1985) preference for a top–north slip direction on the Windy Pass thrust but omitted further review because the existing structural data seemed vague and inconclusive regarding the main transport direction associated with ophiolite obduction. Our exchange here highlights the need for a modern kinematic analysis of this important structure.

PALEOMAGNETIC DATA

Paterson and Miller question that we did not use more recent paleomagnetic data from the Mount Stuart batholith. We chose to rely on the older study of Beck et al. (1981) because it was fully published. The work of Lund et al. is available only in abstract form (Lund et al., 1993, 1994). Paterson et al. (1994) provided a brief summary but directional data for sites and demagnetization plots were not reported. A modern paleomagnetic study of the Mount Stuart batholith is clearly needed, including step-wise demagnetization and component analysis. Perhaps the work of Lund et al. will fill this gap, but we cannot evaluate their results until they are fully published.

Paterson et al. (1994) claimed that they replicated the study of Beck et al. (1981) because they sampled near some of the Beck et al. sites, but there is no assurance that the same lithologies were sampled or that the replicated sites had the same magnetization. Thus, we considered it unwise to judge the published work of Beck et al. (1981) using the preliminary results of Lund et al. (1993, 1994).

Most of Paterson and Miller's criticisms of the Beck et al. (1981) paleomagnetic data (numbered 1–3 in their Discussion) were already addressed in several long paragraphs in our paper (Ague and Brandon, 1996, p. 483–484). The last comment (number 4 in their Discussion) is incorrect on several counts. There is a small discordance in paleomagnetic directions for the eastern and western sites of Beck et al. (1981), but Beck et al. noted that the discordance was just at the limit of statistical significance. So differential motion within the batholith is suggested, but not required, by the paleomagnetic data. Furthermore, the discordance between the two sets of directions does not require a vertical-axis rotation. The discordance could have been produced by rotation on any axis that lies in the plane that bisects the two sets of directions. For example, a +10° rotation around a horizontal axis lying at about 165° would bring the eastern site directions into coincidence with the western site directions.

CONCLUSIONS

The main objective of our study was to restore the paleomagnetic data of Beck et al. (1981) in order to estimate the northward offset of Baja British Columbia (Cowan et al., 1997). Wynne et al. (1995) published a high-quality paleomagnetic study for Baja British Columbia based on sedimentary and volcanic rocks of the Tatlow syncline in southwest British Columbia (located ~475 km north of Mount Stuart). They isolated a well-defined high-coercivity prefolding magnetization, which can be restored to paleohorizontal using local bedding. If Mount Stuart was incorrectly restored, then we should see a difference in the northward offsets estimated by these studies. For instance, a degree of inclination error would produce an error in the estimated northward offset of ~98 km. Wynne et al.'s (1995) results indicate a northward offset of 3000 ± 500 km, which is in very good agreement with our estimate of 3100 ± 600 km. Recent paleomagnetic results of Ward et al. (1997) indicate a similar northward offset (~3500 km) for Campanian strata (~80 Ma) of the Nanaimo Group, which was deposited on the southwest part of the Baja British Columbia block.

We conclude that our results from the Mount Stuart batholith show that AH barometry can be used to provide an independent measure of the regional-scale structure of a large batholith. We thank Paterson and Miller for their critical comments, which have allowed us a context and a forum to clarify some important questions about our work.

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