FORUM

An 1161 Ma suture in the Frontenac terrane, Ontario segment of the Grenville orogen: Comment and Reply

COMMENT

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Hildebrand and Easton (1995) claimed to have recognized a fundamental suture, expressed as a northwest-directed thrust fault, in the southwestern Grenville orogen. The suture separates marble (lower plate carbonate platform) and gneiss, quartzite, and ~1.17 Ga plutonic rocks (upper plate "arc basement"). The upper plate was tectonically emplaced after intrusion of the plutonic rocks (youngest quoted age, 1162 Ma), and the "thrust" was folded into recumbent isoclines and coaxially refolded before introduction of ~1160 Ma diabase dikes. On the basis of similarities "too numerous to be mere coincidence," the authors extrapolate their upper plate nearly 400 km west across the Central Metasedimentary belt into the Central Gneiss belt. Given the proposed severe shortening between 1162 and 1160 Ma, as well as that associated with later Grenvillian thrusting (cf. Hanmer and McEachern, 1992), the postulated thrust surface must have had a much greater extent. The short time allowed for its propagation (<2 m.y.) makes this hypothesis tectonically unrealistic.

Several aspects of Hildebrand and Easton's reinterpretation of Frontenac geology are at odds with published observations and maps. Critical to the upper and lower plate hypothesis are the following interpretations.

1. *A single, major marble unit lies structurally below granulite and quartzite of the upper plate.* Wynne-Edwards (1967) suggested that there may be two, even three, marble units in Frontenac terrane (Hildebrand and Easton, 1995, Fig. 2, inset A). However, even if there is only one marble unit, the authors have not addressed the published evidence that quartzite faces toward and grades via a transitional unit into adjacent marble (Wynne-Edwards, 1967). Geologic maps quoted by the authors show quartzite lying concordantly between gneiss and the "main marble" unit; thus if the quartzite lies unconformably on the gneiss, and if the gneiss-quartzite upper plate was thrust over the marble, then the entire upper plate in the Frontenac region, plutons included, must have been upside-down at the time of its emplacement.

2. *The marble is not intruded by ~1.17 Ga plutonic rocks, which are restricted to the upper plate.* Although the authors "could find no evidence" (p. 919) that plutons of this age intrude marble, intrusive relationships have been clearly mapped. For example, Hildebrand and Easton (1995, Fig. 2, caption) interpreted one of these plutons, the 1166 Ma Lyndhurst granite, to be a "pluton-dominated klippe," although it cuts across the quartzite-marble contact and includes screens of marble and calc-silicate rock (Wynne-Edwards, 1967). On the other hand, similar plutons that the authors acknowledge to intrude marble, but which have not yet been dated, are assigned a post-thrust age (1080–1060 Ma).

3. *The marble lower plate was cool at the time of emplacement of the hot, "pluton-riddled" upper plate.* Marble in most of Frontenac terrane (as originally defined; see below) contains diopside, and commonly forsterite or chondrodite, and pelitic gneiss units enclosed by marble contain assemblages with garnet, sillimanite, cordierite, or orthopyroxene (Wynne-Edwards, 1967). These assemblages occur at locations well removed from silicate gneiss and plutonic rocks of the postulated hot upper plate. Low-grade assemblages in marble in this region (Ewert, 1977) can be attributed to altogether younger alteration at or near the pre-Paleozoic erosion surface. Moreover, Hildebrand and Easton do not consider U-Pb ages determined on titanite from marble in Frontenac (oldest, 1178 ± 2 Ma; Mezger et al., 1993) that point to metamorphism predating crystallization of most of the plutonic rocks (~1165 Ma; Marcantonio et al., 1990), which we have indicated intrude both upper and lower plate units. The published metamorphic and geochronologic evidence thus does not support the idea of a cool carbonate platform overridden by a hot upper plate.

The northwest boundary of Frontenac terrane was formerly placed at a southeast-dipping ductile thrust zone (Easton, 1988; Davidson and Ketchum, 1993), separating it from Sharbot Lake terrane (Fig. 1). Corfu and Easton (1995, p. 960) related Sharbot Lake terrane to Elzevir terrane to the northwest, not to Frontenac. However, Hildebrand and Easton (1995, Figs. 1 and 2) placed the northwest boundary of their Frontenac terrane farther northwest along a late, extensional fault (Robertson Lake shear zone), incorporating Sharbot Lake terrane within an enlarged Frontenac terrane. Hildebrand and Easton (1995, p. 920) suggested that "the area of the Central Metasedimentary belt lying to the northwest of Frontenac terrane [their definition] contains mostly lower-plate basement and cover overridden by upper-plate rocks," and in the northwest part of this area, marble in Bancroft terrane (Fig. 1) is equated with marble in Frontenac and is thus lower-plate cover. In their last sentence, however, they state that "the majority of rocks between Bancroft and Frontenac terranes [i.e., Elzevir terrane] are ... upper-plate rocks," this "majority" comprising deformed carbonate metasediments and volcanic rocks intruded by ~1.25 Ga plutons. The authors suggest that these rocks are either "... remnants of the overriding magmatic-arc system or possibly an earlier arc accreted to the overriding plate ...." Similar rocks of similar age in northwestern Frontenac (Sharbot Lake terrane), however, are in the lower plate, where they are cut by ~1.17 Ga plutons. How then can one distinguish the upper and lower plates? The mapped geology and extant "terrane" correlations cannot be reconciled with either of the authors' concluding suggestions.

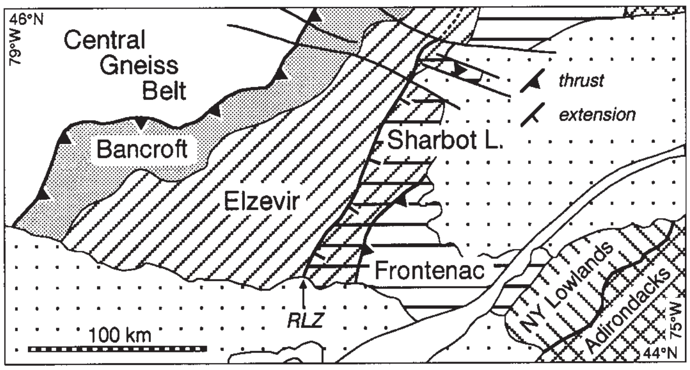

Figure 1. Terranes in the Central Metasedimentary belt, Ontario and New York. The northwest boundary of Frontenac terrane as defined by Hildebrand and Easton (1995) coincides with the Robertson Lake shear zone (*RLZ*).

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Wynne-Edwards, H. R., 1967, Westport map area with special emphasis on the Precambrian rocks: Geological Survey of Canada Memoir 346, 142 p., and Map 1182A, scale 1:63 360.

REPLY

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We thank Davidson and Carmichael for taking the time to comment on our paper in which we presented a new model to explain Grenvillian geology; however, we hope that they and others will test the predictions that it made. To date we are unaware of any new data that preclude our general model. Here we refute their criticisms in the order they were presented.

Davidson and Carmichael extracted the small quote “too numerous to be mere coincidence,” but in our paper (p. 920) we stated the similarities exactly: intrusions of the same age, similar marble melange, a quartzite containing similar-age detrital zircons, similar sense of shear from shear-sense indicators, syntectonic pegmatites documenting thrusting at about 1160 Ma, and similar-age mafic dikes. On the basis of such similarities, we suggested that both packages of rocks are part of the same thrust plate. As far as we are aware, the similarities were never recognized before.

Additionally, they question the extent and temporal emplacement of our proposed thrust, which, in reality, are poorly constrained because (1) there are no rigorous reconstructions of younger extension *or* thrusting in the Grenville orogen; (2) we know little, if anything, about tectonic rates at 1170 Ma; and (3) the zircon data constrain the age of thrusting to be between 1165 and 1159 Ma, not <2 m.y. as they state.

1. Wynne-Edwards (1967) suggested the possibility of two or three marble units, but he also allowed that there might be only one: the point being that he didn’t know and he admitted it. Secondly, Davidson and Carmichael suggest that if there is only one marble unit, it is in a conformable stratigraphic sequence—a possibility that we once considered ourselves, but ruled out because (i) there are no top determinations anywhere with the marble unit; (ii) except for tiny inliers of marble within gneiss and small inliers of gneiss and quartzite within marble, one highly contorted marble contact can be traced throughout the entire region and it is everywhere marked by marble melange, typically comprising crystalline blocks floating in a disrupted marble matrix; and (iii) the contacts between other rock types are commonly truncated, in many places at high angle, along the marble contact. This is not a normal stratigraphic contact: such relations are more typical of faults.

2. The maps of Wynne-Edwards show that the vast majority of the pre–1160 Ma plutons do not contact marble and that should be enough to awaken curiousity; however, we also examined many of the short stretches where pre–1160 Ma plutonic rocks are in contact with marble and found no unambiguous crosscutting relationships. The comment seems to imply that we arbitrarily assigned nondated plutons to a post-thrust age. This was not the case. All the post-thrust plutons have unequivocal evidence for intrusion, such as crosscutting dikes and sills or contact aureoles, or they are actually dated.

3. Low-grade metamorphic areas in the marbles cannot be explained as younger alteration as Davidson and Carmichael suggest, because there is ample data to the contrary (cf. Ewert, 1977). As we carefully pointed out and referenced in our paper, metamorphic lows with unreacted quartz + dolomite preserve primary sedimentary features and the assemblage potassium feldspar + dolomite in places contains unequivocal textures to indicate prograde reaction to the assemblage phlogopite + calcite. These lows represent nonmetamorphosed carbonate that underwent prograde metamorphism, not younger alteration of high-grade rocks.

Davidson and Carmichael are incorrect in stating that we did “not consider U-Pb ages determined on titanite from marble in Frontenac,” although we acknowledge that space limitations in the original article prevented elaboration on the relationship of these ages to our model. The titanite ages reported by Mezger et al. (1993) range from 1157 to 1178 Ma, with 4 of the 11 titanites dated by Mezger et al. (1993) yielding ages greater than 1169 Ma. Interpretation of the significance of the older ages is because all the titanites come from marble melange, which contains a variety of upper plate gneisses and plutonic rocks in a marble matrix. Therefore, it is quite possible that the marble melange contains titanites derived from upper plate rocks, as well as those formed in situ as the result of metamorphism related to overthrusting of hot upper plate rocks on the cool marbles. In other words, the 1171 Ma titanite age reported by Mezger et al. (1993) near the Lyndhurst granite does not necessarily mean that the marbles were metamorphosed at 1171 Ma by the Lyndhurst granite. This view is further supported by detailed geochronologic studies on the marble melange (Corfu et al., 1995). At least two generations of titanite are present, dated at 1159 Ma and 1153 Ma, as well as metamorphic zircon dated at 1168 ± 3 Ma. The latter is within error of the 1165–1159 Ma age constraint on thrusting. Geochemical studies of clast-free marble from the matrix of these melanges (Easton, 1995) show elevated Zr, Ti, Ba, and Sr contents relative to typical, nondisrupted Grenvillian marbles found in Elzevir, Sharbot Lake, and Frontenac terranes, a feature most easily explained by the introduction of these elements during metamorphism. Thus, the published metamorphic and geochronologic data remain consistent with the idea of a cool carbonate platform overridden by a hot upper plate.

Finally, Davidson and Carmichael were confused by what we hypothetically termed lower and upper plates between Bancroft and Frontenac terranes. In order to make the paper understandable to most readers, it was necessary to use the existing terrane terminology for the region. However, most terrane boundaries developed late in the history of the orogen (e.g., Mezger et al., 1993) and thus do not necessarily match older structures such as the suture we proposed. This is most evident in an area such as the Sharbot Lake terrane, which contains some rock units such as (i) the Lavant gabbro and associated metavolcanic rocks, which may be part of Elzevir terrane (upper plate?); (ii) metamorphic and plutonic rocks of Wolf Grove, which are most similar to upper plate rocks in Frontenac terrane; and (iii) the marbles, which resemble the nondisrupted marbles of the lower plate in Frontenac terrane. Although the terrane framework has proven useful as a means of making sense of the regional geology and late tectonic history of the Central Metasedimentary Belt, its inability to generate predictive tectonic models led us to a different approach. Our more regional hypothesis was simple: the marble autochthon is beneath the possible arc complexes of the Elzevir terrane and reemerges to the northwest in Bancroft terrane. Volcanic and other crystalline rocks of Frontenac (Sharbot Lake) also lie structurally atop the marble. We see no inconsistency.

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Kisseynew metasedimentary gneiss belt, Trans-Hudson orogen (Canada): Back-arc origin and collisional inversion: Comment and Reply

COMMENT

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Ansdell et al. (1995) have reviewed the geology of the Kisseynew domain (KD) and its tectonic setting in the Paleoproterozoic Trans-Hudson orogen (THO). Their discussion led to a tectonic model, i.e., a back-arc basin and fold-thrust belt, that may apply to other high-grade metasedimentary terranes associated with ancient granite-greenstone belts. However, more constraints need to be placed on this model because the present crustal architecture is a product of terminal continental collision (Lucas et al., 1994). The fold-thrust systems that had formed in the early stages of collision were severely modified by crustal delamination and inversion when the internal zone of THO was wedged between three Archean blocks (Hearne, Superior, and “Sask” cratons). Moreover, the present map pattern is probably not closely related to the original geometry of plate boundaries. A tectonics model derived from the geochemistry of the igneous rocks and from the pattern of sedimentation in the KD may prove to be more rigorous.

I agree with Ansdell et al. (1995) that F_1 folding and thrusting in the KD were coeval with sedimentation and can be attributed to early collision between juvenile volcano-plutonic domains and “Sask craton.” However, tectonic transport was probably unrelated to the southwest-verging structures to which they allude. Such structures (F_2–F_4) formed during terminal collision under high-grade metamorphic conditions ca. 15–40 m.y. after sedimentation in the KD (Parent et al., 1995). If the earlier vergence had been southwest, then the critical taper controlled by the fold-thrust system would have been southwest. This was clearly not the case because the fining, prograding, and transition from alluvial to turbidite facies of the syntectonic sediments, and therefore paleoslope, were toward the KD. Detrital zircon provenance was from the 1.89–1.85 Ga juvenile rocks surrounding the KD and from the >2.4 Ga Sask craton, which must have been exposed in contiguous highlands, not on a microplate separated by a trench or foredeep (cf. Fig. 3, D–E, Ansdell et al., 1995). Deformation of the fluvial-alluvial sediments started before 1842 Ma, but turbidite deposition continued in the KD after 1842 Ma (Machado and Zwanzig, 1995). This is consistent with an active margin that faced and overrode the marine deposits in the KD, not with a back-arc basin. Northeast-dipping F_1 structures can be interpreted as thrust sheets that were overturned during F_2, as indicated by inverted sills and an inverted unconformity (Zwanzig, 1995). An early southerly vergence is accepted by other workers (cited in Ansdell et al., 1995), but this may illustrate the difficulty of analyzing early structures that were caught up in large-scale recumbent folds during continental collision.

The geochemistry of igneous rocks within the KD is also more consistent with magmatism on an active margin than in a back-arc basin. Continental arc metavolcanic rocks are intercalated with the nonmarine metasandstones on the south flank of the KD. They are high-K calc-alkaline rocks to low-K tholeiites with low Ti and Nb, La/Nb = 1–4, and Th/Yb = 0.2–4 (Gordon and Lemkow, 1987). Felsic to ultramafic intrusions in the sedimentary rocks throughout the KD are similar to calc-alkaline, Alaskan or Appinitic plutons, which are found in the adjacent volcano-plutonic domains (O’Hanley and Kyser, 1994). U-Pb zircon ages of these igneous suites are 1837–1824 Ma in the KD and >1.84 Ga in the adjacent domains. They are coeval with clastic sedimentation, as indicated by the youngest detrital zircons (1.842–1.83 Ga). The igneous suite is interpreted to represent a diachronous transition from subduction- to asthenosphere-induced magmatism in a Mediterranean-type setting. Subduction rollback from the greenstone domains into the KD probably led to terminal collision with the Superior craton.

Evidence for arc-related extension is generally restricted to amphibolites derived from basalt, gabbro, and ultramafic volcanics from the margin of the greenstone basement adjacent to the KD (Zwanzig, 1990). These occur north of the turbidites and have N-MORB to plume-related chemistry, apparently, formed in a separate marginal basin. They are disconformably overlain by the youngest nonmarine sediments, which are intruded by alkaline–calc-alkaline sills (Nb/Yb = 8–11). The sills delimit an extensional subbasin developed on the greenstone basement north of the KD. No basement has been found for the turbidites.

The assembly of KD from precollisional paleogeography probably involved thousands of kilometres of translation that occurred during the docking of the last-arc, back-arc, and fore-arc segments. The present northern and southwestern margins of the KD may have lain along strike and faced the same ocean during early stages of collision. Now they represent the roof and footwall of a collision zone that has an architecture dominated by the enclosing cratons. By analogy, other deeply eroded collisional orogens may also fail to provide directly the polarity of subduction or configuration of early tectonic plates.

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