FORUM

Comment and Reply on "Comments on the growth of accretionary wedges"

COMMENT

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The paper by Silver et al. (1985) is one of the first (also see Brandon, 1984; Cowan, 1985) to propose that underplating in subduction complexes occurs with the formation of thrust duplexes, a structure commonly found in on-land thrust belts (Boyer and Elliott, 1982). Their proposal heralds a growing consensus (Moore et al., 1985) that the structure and progressive development of on-land thrust belts might be more directly analogous to their submarine counterparts at subduction zones.

My comments here are directed at two other conclusions of Silver et al. which I think are in conflict with our present understanding of thrust tectonics. These are (1) the suggested presence of an actively growing duplex beneath the Costa Rica trench slope, and (2) the geometry and role of a "backstop" behind accretionary wedges.

Costa Rica Duplex. To account for the lack of deformation of the trench-slope apron at the Costa Rica margin, Silver et al. (1985) proposed that a large duplex is forming beneath the frontal region of the Costa Rica accretionary wedge (see their Fig. 3). Therefore, the slope apron shows no fault offsets because imbricate thrust faulting is confined to the base of the wedge. The problem with this interpretation is that if the duplex is growing, the slope apron should be actively folding or distorting above the decollement ramp (i.e., ramp-bend folding—Suppe, 1983). In their Figure 3, Silver et al. showed a 0.6-km-high decollement ramp. Imbricate slices detached from this ramp would cause the overlying slope apron to bulge upward with a relief comparable to the size of the underlying ramp, and yet the slope apron over this area remains planar and undistorted. This relationship supports the original suggestion of Shipley et al. (1982), that the sedimentary cover on the downgoing plate is not being accreted at the front of the Costa Rica margin, but instead is subducted some unknown distance beneath the margin. This conclusion is not unexpected; Deep Sea Drilling Project drilling (Aubouin et al., 1982) has demonstrated that a similar situation is occurring at the Guatemala segment of this subduction zone, about 650 km to the northwest.

Geometry of the Backstop. Silver et al. argued that accretionary wedges are built against forward-sloping backstops (Fig. 1A here)—i.e., the relatively rigid, leading edge of the overriding plate. (Terms such as forward and rearward refer to seaward and landward directions, respectively.) This interpretation implies that subduction accretion processes, such as underplating, are confined to the region in front of this backstop. Their interpretation is reminiscent of past debates concerning the role of the overriding crustal plate in on-land thrust belts. Seismic reflection profiles and structural studies (see review by Seeber, 1983) have since shown the thin-skinned nature of these overriding crustal plates, indicating that the backstop in on-land thrust belts is generally a relatively thin thrust sheet that dips *rearward* (Fig. 1B) at a low angle.

A similar structural configuration has been determined for the Vancouver Island convergent margin (Fig. 2). Several deep seismic reflection

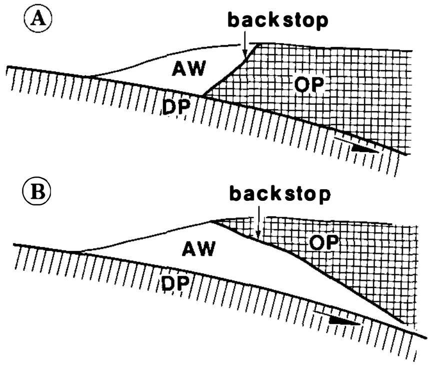

Figure 1. Two configurations for backstop behind subduction accretionary wedges. A: Forward-dipping backstop as proposed by Silver et al. (1985); B: rearward-dipping backstop as advocated here. AW = accretionary wedge, OP = overriding plate, and DP = downgoing plate.

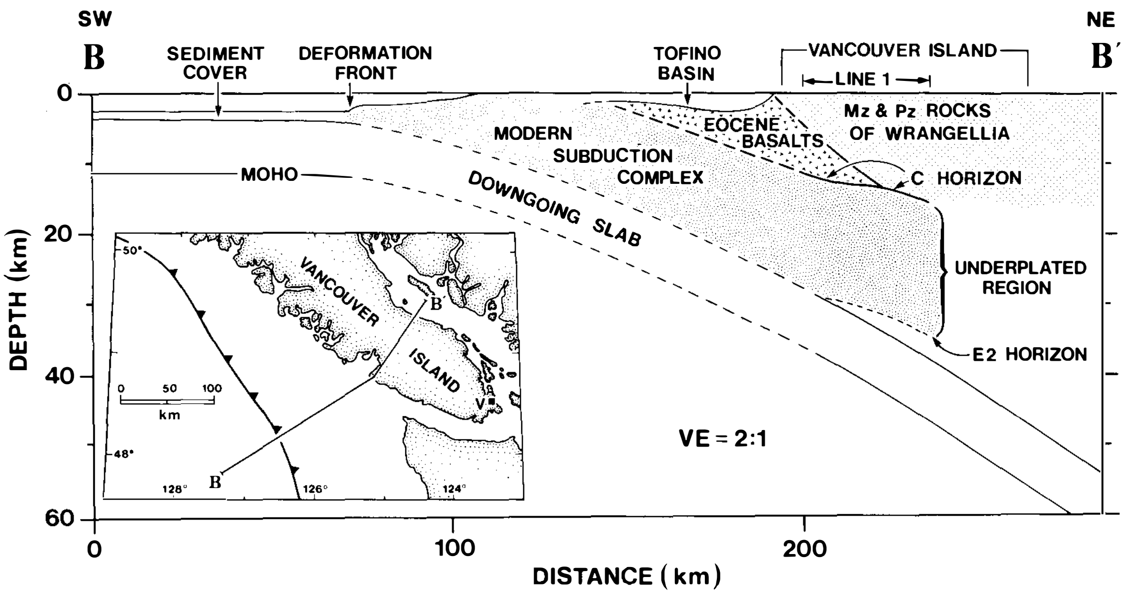

Figure 2. Cross section across Vancouver Island convergent margin modified from Brandon et al. (1984) to include results from Line 1 of Lithoprobe seismic reflection study (Yorath et al., 1985a, 1985b). In reflection profiles, underplated region lies beneath prominent reflection horizon (C horizon in figure), which is regionally extensive beneath southern half of island, underlying Mesozoic and Paleozoic rocks of Wrangellia terrane as well as accreted slab of Eocene basalts. Depth-velocity data are from Spence et al. (1985); position of downgoing slab is based on compilation of Benioff zone seismicity by G. Rogers (1985, written commun.).

profiles across Vancouver Island (Yorath et al., 1985a, 1985b) indicate that the overriding continental plate is a relatively thin thrust sheet, about 10–15 km thick. The modern (Eocene to Holocene) accretionary complex can be traced beneath this continental plate into an underplated region characterized by gently dipping reflectors (shaded region in Fig. 2). Geologic relations indicate that this underplated region started to form during the Eocene (Tabor and Cady, 1978) and probably has grown by steady-state accretion of thrust slices from the downgoing plate (Clowes et al., in prep.). This example clearly illustrates the close correspondence between on-land thrust belts and submarine accretionary wedges, both with rearward-dipping backstops.

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REPLY

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The observation that convinced us of duplexing beneath the Costa Rica margin is that incoming sediments are imbricated, not at the base of the slope, but beginning about 15 km inboard from it (Silver et al., 1985, Fig. 3). The sediment does not completely bypass the wedge, as would be the case for nonaccretion. The slope apron is not "planar and undistorted" but undulating, and the lowermost slope is deformed. The undulations on this profile are small, as pointed out by Brandon (Comment above), but profiles adjacent to this one, that have not been depth migrated and are therefore not as clearly imaged, show significant surface relief on the lower slope (Crowe and Buffler, 1983, Fig. 7) above the inferred duplex. Figure 3 of Silver et al. (1985) crosses the outer edge of one such high. Section balancing is not yet possible here, but we plan a three-dimensional seismic experiment that should provide a clear enough image of ramp heights and orientations to tell us whether or not the surface undulations are in dynamic equilibrium with an active duplex.

Brandon prefers Shipley's (and co-workers) earlier interpretations of the structure of the Costa Rica seismic lines, which were in support of nonaccretion. But those interpretations were not made in our Figure 3 (Silver et al., 1985), which represents a depth migration. The older interpretations were on nonmigrated versions, on which the imaged data are much less clear.

Brandon raises the issue of drilling results on the Guatemala margin, 650 km northwest of Costa Rica, and states that the two regions are similar. We must be very careful about long-distance extrapolation of structures determined in one local region, without evidence for structural continuity. Such evidence is lacking between Guatemala and Costa Rica, and it is questionable along the Guatemala margin itself. Ibrahim et al. (1979) showed two seismic profiles, GUA 13 and GUA 2, that are 20 km apart (their Fig. 7). GUA 13, located along and below San Jose canyon, shows a relatively steep lower slope, little sediment cover, and no penetration to the top of the downgoing plate. All of the drilling off Guatemala was focused on the region of GUA 13. In contrast, GUA 2 shows penetration to the top of the downgoing plate, a relatively low slope, and more sediment cover than its neighbor 20 km away.

Seely et al. (1974) showed a seismic profile off Guatemala, taken to the north of the drilling transect, in which they could trace the downgoing plate about 20 km inboard from the trench axis. They interpreted this line as indicating accretion. Has the drilling proved them wrong or does the structure change significantly over a length of 50–100 km? Also sharing the common trench is the Deep Sea Drilling Project leg 66 region off Mexico; this region lies 650 km northwest of Guatemala and is considered a type region for accretion (Moore et al., 1981). But 50 km south of the drilling area off Mexico the landward-dipping reflectors—so significant on the lines of the drilling transect—are not imaged. To extrapolate 650 km when structures as close as 20–50 km away appear to be so different is without foundation. The final word concerning the deep structure off Costa Rica is not in, but Brandon's arguments make no change in our paper.

Brandon's second point, however, concerning the geometry of the backstop, raises a good question that was not fully developed in our paper. We are not aware of a well-documented example where the backstop for an accretionary wedge is well imaged with seismic reflection data. Thus, all arguments, including ours, are based on incomplete data. Our emphasis was on the development of the ubiquitous pairing of forearc basin and outer high that is found in accretionary wedge settings. A rear-dipping backstop does not explain the pairing, but, as Le Pichon et al. (1982) first proposed and we have discussed, a forward-dipping backstop does. But what *is* a "backstop"? It is envisaged as a discontinuity in mechanical properties, and such a discontinuity is not expected to remain constant throughout geologic history. The example we showed (Fig. 1 of Silver et al., 1985) is a very young wedge, and the contact between the arc basement and the accretionary wedge may be expected to show sufficient contrast in mechanical strengths.

The Vancouver example, however, is very different, though clearly of great importance. This region has probably been a zone of convergence since the Paleozoic. It has undergone at least two major episodes of collision: the emplacement of Stikinia followed by the emplacement of Wrangellia. Vancouver might have appeared as a young arc system in the Triassic, but by the Cenozoic the collisions would have overprinted the original structure, and later accretion would have added thrust sheets to the very large "toe," as well as underplated material beneath the system. The original contact between forearc basin and outer high has long since been overprinted.

Evidence for underplating or duplexing beneath Vancouver Island, as alluded to by Brandon, is not an observation germane to the development of the forearc basin–outer ridge pair. Vancouver is actually part of the uplifting wedge, complex though it is. Observations that might relate to our arguments concern the mechanical contrasts beneath the outer high that bounds the Tofino basin, an aspect not dealt with in Brandon's Comment. In the careful refraction study by Spence et al. (1985), their ray paths do not pass through the region in question (see their Fig. 14). The fact remains that observations on Vancouver Island do not necessarily bear on the mechanism for the development of the modern accretionary wedge and the Tofino basin, and the existing offshore data are not sufficient to resolve the critical structure.

An example of a large, modern accretionary wedge that would have had a long and complex history but that apparently has not undergone a major collision event is the Lesser Antilles forearc. Interpretation of deep seismic refraction studies here (Westbrook, 1975) is consistent with a forward-sloping backstop. In this case both the wedge and forearc basin have evolved together, whereas in the case of Vancouver the present margin is an extension of an older mountain system, in which the original structural development has been extensively overprinted.

The field and seismic studies being carried out by Brandon and others on Vancouver Island are producing exciting and important results for furthering our sketchy knowledge of the deep structure of complex mountain systems and collision zones. For an understanding of the mechanical factors that produce the ubiquitous pairing of forearc basins and outer highs, we require high-quality seismic studies of the deep structure of modern forearcs that have not been grossly overprinted. In any case, it is important to focus on the structure and mechanical contrasts beneath the boundary between the forearc basin and the outer high.

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Comments and Reply on "Implications of magmatic epidote-bearing plutons on crustal evolution in the accreted terranes of northwestern North America" and "Magmatic epidote and its petrologic significance"

COMMENT

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Zen and Hammarstrom (1984) and Zen (1985) have used the occurrence of epidote to estimate emplacement depths of 25–30 km for plutons of northwestern North America and from this have calculated uplift rates and other aspects of crustal history. Similar epidote is a common accessory mineral in I type and intermediate I-S type granitoids of the Separation Point batholith and the Rahu Suite in New Zealand (Tulloch, 1983), and elsewhere. While I agree that this variety of epidote is probably magmatic, at least some of the plutons bearing this mineral in New Zealand have been emplaced at much shallower depths than that corresponding to 8 kbar (25–30 km), and I question the validity of using epidote as an indicator of emplacement depth.

Plutonic rocks of the Rahu Suite in the Victoria Range, New Zealand (Tulloch, 1979a), commonly contain epidote texturally similar to the epidote described in Zen and Hammarstrom (1984). Compositions are also similar, in the range Ps 25.2–28.5 (18 analyses from 5 plutons), and little or no correlation with host rock composition is apparent. Where the epidote projects from the enclosing biotite, it is invariably corroded against the felsic phases. Occasionally the epidote contains a euhedral core of allanite which is not corroded. This variety of epidote is texturally and compositionally distinct from that formed in the same rock by sudsolidus alteration of plagioclase (Ps 0–24) and biotite (Ps 36–48) (Tulloch, 1979b).

Epidote-bearing plutons in the Victoria Range (Ripsaw, Mount Ross, Waitahu, Rocky Creek, and Macey) are mostly massive, undeformed, and relatively highly oxidized granites and granodiorites (62%–74% SiO_2), containing green biotite and accessory magnetite, sphene ± Mn-ilmenite. Hornblende is a major phase in the Macey Granite, but otherwise occurs only in trace amounts in the Ripsaw Granodiorite. The Mount Ross pluton in particular shows features characteristic of relatively shallow emplacement: sharp, strongly discordant, chilled contacts that are controlled by the regional fracture pattern. But the strongest argument against a deep emplacement is the intrusion of the plutons into sedimentary rocks of the Greenland Group (Rocky Creek, Macey plutons) or into older granitoids that intrude the Greenland Group (Mount Ross, Ripsaw, Waitahu plutons). The latter has a maximum regional