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Structure of the Havallah sequence, Golconda allochthon, Nevada: Evidence for prolonged evolution in an accretionary prism: Discussion and reply

Discussion

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For many years, workers have debated whether the highly deformed upper Paleozoic rocks of the Golconda allochthon represent the remnants of a broad ocean basin that closed in front of a continentward-migrating island arc or the deposits of a back-arc basin (Burchfiel and Davis, 1975; Speed, 1979). Structural studies indicate that the tightly folded and disrupted rocks of the allochthon form a stack of imbricate east-vergent thrust plates, which is consistent with both of these models. The recent study by Brueckner and Snyder (1985) attempted to resolve this question by studying the detailed structural fabric of these rocks and specifically by addressing the interplay between the diagenetic and early tectonic structural history of the siliceous sediments of the allochthon. They concluded that their data indicates a prolonged (Mississippian to Permian) evolution for the structures in the Golconda allochthon accretionary prism, supporting the first of the models above. We applaud their detailed description of structures in the allochthon and their novel approach to the problem, but we find that their conclusions are incompatible with what is presently known about the geology of the Golconda allochthon.

Brueckner and Snyder (1985) provided four arguments in favor of a prolonged structural evolution for rocks of the allochthon. We discuss each of these four arguments below.

1. Brueckner and Snyder's (1985) first argument is that their recognition of a large number of thrust faults in the allochthon increases the estimates one must make for the total amount of structural shortening represented by the allochthon and thus increases the plausibility of the far-traveled accretionary prism model. We disagree, because the number of thrust faults is, by itself, insufficient information for estimating the total amount of shortening. In general, the degree of structural disruption of an accretionary wedge is not a measure of the amount of underthrusting represented by the wedge (Scholl and Vallier, 1983). Instead, one needs stratigraphic, paleomagnetic, or paleobiogeographic data to properly document large displacements between the overriding plate and the offscraped sediments of the overridden plate.

2. Their second argument is based on the observed similarity of structural style in chert sequences of the allochthon regardless of the age of the cherts. Brueckner and Snyder (1985) argued that had deformation in the Golconda allochthon entirely postdated deposition of the youngest cherts then the oldest diagenetically mature cherts at the bottom of the deforming sedimentary pile would have behaved in a more brittle fashion compared to the younger diagenetically immature cherts at the top of the sedimentary pile. As a difference in deformational style is not observed, they suggest that the cherts deformed within a few tens of millions of years after their deposition. Chert sequences within the allochthon must therefore have deformed diachronously, with the oldest sequences deforming in the Early Mississippian long before the youngest were deposited. The argument hinges, however, upon simple assumptions regarding the diagenesis of siliceous sediments and consequent time-dependent changes in rheological properties which are not obviously in accord with observation outside the Golconda allochthon. For example, in Franciscan Complex exposures north of San Francisco in the Marin Headlands, 100 m.y. of bedded radiolarian chert deposition is preserved within an imbricate stack of thrust sheets (Wahrhaftig, 1984; Murchey, 1984). The entire 100 m.y. of deposition is recorded within single thrust sheets and therefore entirely predates thrusting. Yet, irrespective of age, the cherts deformed in a similar fashion during folding and thrusting.

As Brueckner and Snyder pointed out, one of the uncertainties in their silica diagenesis-deformation model lies in the initial stratigraphic thickness of the Havallah sequence. A thin siliceous sequence may remain at low diagenetic states for long periods of time (Pisciotto, 1981). Despite Brueckner and Snyder's reservations about estimating the initial thickness, they failed to reference two independent studies that have estimated it to have been as thin as a kilometre or less (Miller and others, 1984; Stewart and others, 1986). Similarly, a study on potentially correlative rocks in British Columbia found 100 m.y. of chert and basalt stratigraphy recorded in less than 300 m (Struik and Orchard, 1985).

3. Brueckner and Snyder's third argument is based on their observation that Early Permian calcareous turbidites at Hoffman Canyon in the Tobin Range lack the tight folds seen in older chert sequences. They suggest that the Early Permian calcareous turbidites may represent trench-slope deposits resting unconformably on more highly deformed strata and

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The article discussed appeared in the *Bulletin,* v. 96, p. 1113–1130.

Geological Society of America Bulletin, v. 98, p. 615–617, May 1987.

later imbricated with them as the result of post-accretionary deformation. In the Mount Tobin area south of Hoffman Canyon, work by Tomlinson indicates that Early Permian calcareous turbidites are interbedded with argillite having a slaty cleavage oriented at low angles to bedding. Where the cleavage in the argillite is at an appreciable angle to bedding, the bedding-cleavage intersection lineation is found to be parallel to fold axes of locally developed D_1 folds in the bedded argillite, as well as parallel to D_1 fold axes in adjacent more severely disrupted chert packets. This indicates that the Early Permian calcareous turbidite units were involved in the D_1 deformation which affected older chert units. The lack of outcrop scale D_1 folds in the calcareous turbidites may, at least in part, be due to the greater thickness of the limestone beds and thus be a function of the amplitude and wavelength of D_1 folds formed in the units. Instead, the presence of large, tight folds in the calcareous turbidite units is suggested by the frequent reversal of younging directions over small distances.

Transported fusulinids in these Early Permian limestone turbidites have North American miogeoclinal affinities (Calvin H. Stevens, 1986, written commun.) and are derived from the North American shelf. It would be impossible for these shelf-derived turbidites to be deposited in trench-slope basins on the encroaching accretionary wedge of Brueckner and Snyder's model, as they would have to bypass the coeval trench.

4. Brueckner and Snyder's fourth and final point is that units they have recognized as slump deposits contain clasts that have a predepositional structural fabric, indicating erosion from a deformed terrane. They suggested that if that terrane is the developing allochthon, then this would indicate a protracted deformational history. The critical information, however, is the age of deposition of these slump deposits, because such deposits would be expected to occur in both tectonic settings. The age of deposition would place a minimum age on the initiation of deformation in the wedge and thus help to differentiate between the long-lived and short-lived accretionary prism cases. As the age of the particular deposit discussed by Brueckner and Snyder (1985) is unknown, its presence indicates nothing tectonically significant about the deformational history of the allochthon.

Finally, a considerable body of lithostratigraphic, biostratigraphic, and petrographic data from the northern part of the Golconda allochthon in the Independence Mountains, Nevada, does not support Brueckner and Snyder's model. These data have been construed by Miller and others (1984) and Whiteford (1984) as evidence that a thin, relatively undisturbed Upper Devonian through Lower Permian succession existed until the time of post–Early Permian, Sonoma-age, thrusting and that this succession was deposited sufficiently close to North America to receive clastic contributions from the eroding Roberts Mountains allochthon throughout its history. The youngest sediments are present in both structurally highest and structurally lowest thrust plates, contrary to expectations in a long-lived accretionary prism structure. Such conclusions in the Independence Range directly contradict Brueckner and Snyder's general thesis and cannot simply be ignored in a discussion of the paleotectonic setting of the Golconda allochthon.

In summary, we believe that the detailed structural study of Brueckner and Snyder (1985) is excellent in that it provides good documentation of the structural style of deformation in the allochthon, but we think that they have arrived at erroneous conclusions largely because they overemphasized the significance of the structural disruption seen in the allochthon and failed to couple their detailed structural study with the stratigraphic and biostratigraphic studies needed to substantiate their hypothesis.

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Manuscript Received by the Society July 7, 1986
Manuscript Accepted October 17, 1986

Reply

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The points raised by Tomlinson and others about our structural study of the Golconda allochthon (Brueckner and Snyder, 1985a) are stimulating, but we are not persuaded that the accretionary wedge model for the structural evolution of the allochthon should be abandoned in favor of the back-arc thrusting model. The accretionary prism model was developed on the basis of detailed stratigraphic, paleontologic, and lithologic studies (Speed, 1979; see Snyder and Brueckner, 1983a and references therein for most recent review). Our structural study provides additional supportive evidence for the model.

Tomlinson and others contest four of our five lines of evidence (they did not deal with the polyphase nature of the structural fabric). The numbers below refer to those in their discussion.

1. The estimation of lateral shortening in the allochthon is important because the back-arc model requires a relatively narrow basin; hence total shortening should be small compared to that for long-lived subduction. Any firm estimate of total shortening of the allochthon is impossible. The internal shortening recorded in the numerous folded packets, the very large total number of thrusts, and the marked lateral facies and structural changes across these faults decrease the plausibility of small amounts of shortening, however. The more severely telescoped the offscraped sediments are, the easier it is to postulate large amounts of subducted oceanic crust.

2. Our diagenesis-deformation model is based on data and concepts that are far from being simple assumptions (Snyder and Brueckner, 1983; Snyder and others, 1983; Brueckner and Snyder, 1985a, 1985b; Snyder, in press; see especially Brueckner and others, in press). We hope that other deformed-chert sequences will be restudied with the model in mind. The Franciscan complex at the Marin Headlands is a prime example since it has *not* been established that the cherts there have "irrespective of age, . . . deformed in a similar fashion."

Attempts to establish the original thickness of the sedimentary sequences in the Golconda allochthon are so fraught with assumptions that we cannot decide whether the estimates of Miller and others (1984) are minimums or maximums. Pressure solution parallel to bedding has thinned the Havallah sequence (Brueckner and others, in press), whereas thrusting and folding has thickened it (Stewart and others, 1986). Stratigraphic thicknesses (or burial depths) are important only for regions of low heat flow (that is, open-ocean basins) because chert diagenesis rates are primarily functions of temperature (Pisciotto, 1981). Any environment with high heat flow (that is, back-arc basins) should induce rapid diagenesis and consequent brittle behavior in the cherts during deformation.

3. The structural discordance between the highly deformed chert packets and the less deformed calcareous turbidites at Hoffman Canyon is obvious (for example, Stewart and others, 1986; Turner, 1982). These turbidites are not massive. They contain scattered, late, east- and west-verging (D_3 and D_4) folds. We therefore still suggest that, in Hoffman Canyon at least, the chert packets underwent significant folding and faulting prior to juxtaposition with the calcareous turbidites.

The bedding-cleavage intersection lineation of argillites associated with turbidites in areas south of Hoffman Canyon cannot be correlated with the hinges of early folds in cherts on the basis of orientation alone. The hinges of *all* fold generations (D_1, D_2, D_3, and D_4) are subparallel in this part of the Golconda allochthon. It is noteworthy that Tomlinson was not able to detect any mesoscopic folds in the turbidites associated with this cleavage.

The Hoffman Canyon and Independence Mountains calcareous turbidites have *not* yielded fusulinids (Snyder and Brueckner, 1983a) despite a recent intensive search by Stewart and others (1986) in Hoffman Canyon. Where paleogeographic ties have not been established, alternative provenances and depositional settings such as a trench slope basin must be considered (Moore and Karig, 1980).

4. The gravity flow deposits contain debris that could have come only from a westerly source (Snyder and Brueckner, 1983). We agree that the age of these units gives only a minimum date at which such a westerly structural high was developed, that is, that age or *older.* One slump deposit occurs near the top of unit D, which is Mississippian in age (Stewart and others, 1985), but this age cannot be accepted until fossils are extracted from the actual slumped material.

Tomlinson and others end their discussion by stating that studies of the Schoonover sequence, a correlative succession in the Independence Mountains, contradict the accretionary prism model for the entire Golconda allochthon (Miller and others, 1984; Whiteford, 1984). We do not agree. First of all, the recent identification of additional thrust faults, refolded folds, folded thrusts, and folded boudins within the Schoonover sequence (R. J. Johnson, unpub. data) indicates that structural disruption is no less there than it is elsewhere.

Second, even if their interpretation of the Schoonover sequence is valid, the sequence is not representative of the entire allochthon (Stewart and others, 1986). For example, at Bull Run Reservoir, 15 km west of the Independence Mountains, there are Pennsylvanian red-bedded chert, jasperoid, and greenstone, suggesting an open-ocean, spreading-center–type sequence. The Bull Run locality was distant enough from land that it did not receive the terrigenous detritus recorded in units of the same age in the Independence Mountains. Similar facies variations exist for Early Permian (Snyder and Brueckner, 1983). The presence of recycled orogenic debris (Whiteford, 1984; Dickinson and others, 1983) does not conclusively tie any part of the Golconda allochthon to the Roberts Mountains allochthon. The exposed portion of any older orogen, including an accretionary prism, represents an equally viable source. Finally the contention that complete stratigraphic successions occur in all thrust plates of the Independence Range may simply reflect the fact that the accretionary prism collected the Schoonover sequence last, just prior to obduction over North America, as a result of its remote (easternmost) depositional position relative to the advancing subduction zone.

The Golconda allochthon is a severely structurally disrupted association of complex facies relationships. In our view, neither the accretionary prism model nor the back-arc basin model has been proven or disproven. Both models must be retained, therefore, along with other workable hypotheses, until incontrovertible evidence rules out one, or the other, or both.

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Manuscript Received by the Society October 3, 1986
Manuscript Accepted October 17, 1986