# STRATIGRAPHIC RELATIONSHIPS AND DETRITAL COMPOSITION OF THE MEDIAL ORDOVICIAN FLYSCH OF WESTERN NEW ENGLAND: IMPLICATIONS FOR THE TECTONIC EVOLUTION OF THE TACONIC OROGENY: A REPLY TO RODGERS[1]

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The geology of the Taconic Allochthon and surrounding regions of western New England have long been a source of controversy among New England geologists. The relative scarcity of outcrop in this area compounds the problem of interpreting the complex geology present. Zen (1967) aptly summarized this by using the parable of the six blind men and the elephant as a prologue to his now classic paper on this region. Professor Rodgers' discussion is a further illustration of this point. We much appreciate the opportunity provided by his discussion to clarify our views and here emphasize the points of agreement and disagreement from his and other interpretations.

Rodgers' first disagreement with our paper concerns the relationship of the dominant structures observed within the Allochthon to those observed in the structurally underlying parautochthonous flysch and shelf carbonate sequence of the Middlebury Synclinorium. We recognize the three deformations referred to by Rodgers plus one or possibly more late stage deformations producing spaced crenulation cleavages and/or upright kink folds. Previously (Rowley, et al. 1979) we called slaty cleavage and associated folds in the Giddings Brook Slice $D_1$; in this reply, following Rodgers, we term this generation of folds and cleavage $D_2$, based on the subsequent recognition of an earlier set of folds unaccompanied by an axial surface cleavage. We have also been able to recognize three and possibly four different ages of thrust faults within the Allochthon which bear different relationships to the dominant folds and cleavages. The statement that Rodgers quotes from our paper was intended to apply only to the relationship between the predominant slaty cleavage and related folds observed along the western edge of the Allochthon and the slaty cleavage and related folds in the underlying parautochthonous flysch and shelf sequence sediments. Our mapping along the western edge from near West Haven, Vermont to North Granville, New York, as well as mapping by Bosworth (1980) in the Fort Miller and Schuylerville area, indicates that the thrust bounding the western front of the Allochthon (referred to as the frontal thrust) is subhorizontal. It juxtaposes allochthonous rocks containing a well-developed slaty cleavage (our $S_2$) and large-scale folds (our $F_2$) having amplitudes and wave-lengths measured in kilometers, with parautochthonous flysch and carbonates also containing slaty cleavage and related folds that are distinctly differently oriented from those in the Allochthon. Additionally, subhorizontal thrusts mapped by us within the Giddings Brook Slice juxtapose regions in which these structural elements are also differently oriented (Rowley 1980; Bosworth 1980). These observations are contrary to the generally published view that folds with the slaty cleavage as an axial plane foliation maintain a constant orientation from the Allochthon into the parautochthon, as well as within the Allochthon itself. Our observations led us to suggest that the folding and related slaty cleavage development predated final emplacement of the Allochthon. We extended this interpretation to suggest that these structures in the Allochthon in fact pre-date overthrusting of the shelf edge by the Allochthon and were related to the initial thrust stacking of the Allochthon. We stand by our observation that the frontal thrust of

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the Allochthon extending southward from the vicinity of West Haven to at least Schuylerville is a post-slaty cleavage structure. However, recent mapping by one of us (Rowley, summer 1981) has confirmed the mapping of Zen—that at the northern end of the Allochthon, north and west of Halfmoon Lake, a thrust juxtaposing green, gray, and purple slates of the Allochthon with parautochthonous black slates with minor greywackes (Hortonville Fm.), pebbly mudstones (Forbes Hill Conglomerate), and slivers of shelf-derived carbonate, is tightly folded and cross-cut by a well developed slaty cleavage. This relationship is completely different from that observed along the western edge to the south. This folded and cleaved thrust (referred to as the basal thrust) lies structurally below the frontal thrust and appears to have been completely overridden by it in most areas along the western front of the Allochthon, thereby obscuring the actual relationship between slaty cleavage development, folding, and emplacement of the Allochthon. Our more recent observations, confirming those of Zen and Rodgers, now lead us to accept that, at least in some areas, $F_2$ folding and slaty cleavage development occurred after the allochthon had overridden the shelf edge, but prior to the entire allochthon arriving in its present and final position.

However, it is important to note that a main focus of the paper, the fact that the Allochthon was stacked from east to west prior to emplacement on the shelf, is not changed by our revised interpretation of this structural relationship. The later thrusts, which imbricate the original thrust stack, complicate but do not change the critical relationship concerning the initial assembly of the Allochthon during obduction.

The origin and significance of outcrops of shelf-derived carbonate within and adjacent to the Allochthon remain controversial focal points of Taconic geology. We interpret these carbonates as thrust slivers plucked from the carbonate platform during obduction of the Allochthon, whereas Rodgers prefers to interpret them as large olistostromal blocks. As pointed out by Rodgers, we do not disagree that some of the carbonate blocks do indeed have an olistostromal origin, but we prefer this interpretation for only the small size fraction (generally a few meters or less across). Very good examples of such olistoliths are exposed in roadcuts along Route 9J just south of Rensselaer, New York and in the western edges of the Bald Mountain quarries. These olistostromal blocks are always associated with blocks of other lithologies, most commonly flysch-like greywackes and, less commonly, a variety of Taconic lithologies. The point of disagreement relates to the larger masses, for example the one exposed at Bald Mountain. Neither of us have mapped the Bald Mountain locality, but we have both visited the quarries and surrounding areas during fieldtrips, particularly during recent mapping of the area by Bosworth (1980). We have also examined similar examples exposed to the north from the Mettawee River to near West Haven, Vermont. So although we do not have the extensive experiences of Rodgers we do feel some degree of familiarity with these occurrences.

Bosworth's mapping of the Bald Mountain area, referred to by him as the Bald Mountain Terrane, confirms the work of Ruedemann (1914), Platt (1960) and others and suggests that it is a belt approximately 10 km long and up to 600 m wide. The parautochthonous shelf-derived lithologies of the Bald Mountain Terrane include limestones, dolostones, quartz arenites, and carbonate conglomerates all in a dark shale matrix. These occupy a zone with a roughly tabular shape bounded both above and below by essentially flat-lying surfaces which are interpreted to be thrust faults (Bosworth and Vollmer 1981). Below the lower thrust surface there are Forbes Hill-type "conglomerates" containing carbonate blocks in a shale matrix. The carbonate blocks are similar to those observed in the quarry. They are interpreted to be derived from the surficial exposure and erosion of the Bald Mountain carbonate during thrusting, and subsequently overridden by it. Our observations in this area support Bosworth's interpretation.

As an additional point, Bosworth in conjunction with us does not locate any large blocks of Taconic lithologies to the west of the Bald Mountain quarries. Specifically, the large block referred to by Rodgers as Bomoseen we believe to be another sliver of the shelf sequence.

An outcrop that beautifully displays the relationship between carbonates and enclosing shaly matrix is provided by a roadcut on Vermont Route 22A approximately 5.2 km north of its intersection with Route 4 at Fairhaven, VT. The outcrop cuts obliquely across a thrust-repeated sequence consisting of relatively thickly bedded limestone with minor interlayered argillite, followed upward by thinner bedded limestone with interbedded dark calcareous argillite succeeded in turn by dark argillite and thin, pebbly mudstones of the Forbes Hill type. This sequence is repeated several times in the roadcut, but appears conformable between thrusts. We suggest that it is highly improbable that olistostromal blocks containing the relatively high abundance of interbedded argillite observed here would all remain intact and upright during olistostromal sedimentary transport. Furthermore, there are numerous anastamosing mineralized and slickensided surfaces in this outcrop along which the repetition and tectonic excisions occur. More extensive outcrops of shaly melange (Forbes Hill "conglomerate") occur structurally below these carbonates and shales, and the frontal thrust of the Taconic Allochthon occurs immediately to the east of the outcrop (structurally above). In this example we are quite certain that the carbonate blocks, although essentially enclosed within a shaly matrix, are imbricated thrust-related slivers. We feel that most of the large blocks of carbonate observed along the western front of the Allochthon have similar origins and structural style.

If, on the other hand, we were to accept Rodgers' interpretation, we would feel compelled to seek out a source for these large olistoliths. At least in the undisputed boulder size examples, the carbonate blocks are intimately intermixed with greywacke blocks, and blocks of demonstrably Taconic origin, which strongly suggests a generally easterly derivation for the olistostrome as a whole. Therefore somewhere to the east there should be a region characterized by large masses of shelf-derived lithologies intimately associated with Taconic lithologies that could have been simultaneously exposed in order to produce the Bald Mountain Terrane. As the Forbes Hill Conglomerate and associated blocks form a fairly continuous outcrop belt along the western front of the Allochthon, we would expect a similarly extensive source region to the east. To the best of our knowledge no such source terrane does exist in the present geology. We point out that were such a source terrane to exist, its geometry would presumably consist of large thrust slices of shelf-derived carbonates caught along a thrust internal or basal to the Allochthon, from which these large blocks could have spalled and been mixed with Taconic lithologies. This is precisely the geometry that we are advocating, but on a smaller scale, for the Bald Mountain area, where we infer both the source *and* the eroded debris are still preserved. It seems that Rodgers implicitly accepts this mechanism, but wishes to apply it only to areas removed from those presently under discussion along the western front. We feel that this is an unnecessary additional step to take.

A third point of disagreement is contained in Professor Rodgers' statement "I see no reason to abandon the idea that at least what are now the lower Taconic 'slices' were poorly or only partly consolidated when they arrived, and that the final stage of their journey was propelled by gravity down a slope." We find several reasons to abandon these ideas, some of which we discussed in our paper. Rodgers' first concern is the state of the material at the time of emplacement. The mapping that led us to accept a pre-cleavage time of emplacement of at least some areas of the Allochthon also allowed us to examine the basal thrust in some detail. Within the allochthonous slates immediately above the basal thrust we find a zone up to several meters thick characterized by extensive quartz and carbonate veins. These veins are commonly highly deformed and locally completely transposed. At least some of this transposition appears to be deformed by and therefore older than the slaty cleavage. Similar veined zones are also observed along pre-cleavage thrusts within the Allochthon, and along one of these a zone of highly granulated vein quartz constitutes a classical fault gouge. We therefore feel compelled to argue that the rocks now constituting the western Giddings Brook 'slice' were sufficiently lithified to be extensively veined along the basal thrust during emplacement and not just "poorly or only partly consolidated" as Rodgers suggests.

As mentioned in our original paper we find that there is a progressive change in sedimentary facies contained in thrust-bounded packages from west to east across the Giddings Brook slice, such that structurally higher, more easterly packages contain more distal facies. This suggests to us that they display a normal stacking order. Furthermore, within our model of emplacement of the Allochthon (depicted in our figure 4) the rocks now constituting these lowest structural slices (e.g., Sunset Lake, and several thrust packages constituting the traditionally defined (Zen, 1967) Giddings Brook slice) lie in the lowest topographic position within the accretionary prism, because they contain the most proximal facies observed within the Allochthon and therefore were the last material from the continental rise to be accreted. As they lie in the lowest topographic position they should have the lowest gravitational potential of the material within the wedge. We would expect that were gravity sliding to occur, regions of the wedge with higher gravitational potential would fail first, whereas those in lower positions, if they were to fail, would only do so later. This would give rise to a reversely stacked sequence in which structurally lower slices would contain more distal facies, and in slices in higher, more easterly structural positions more proximal facies would be seen, exactly opposite to what is observed. These relationships again compel us to minimize the importance of gravity sliding during the emplacement of the lowest slices of the Allochthon. In the case of partly or wholly gravity-driven thrusting (e.g., gravity "spreading": see Elliott, 1976), normal thrust stacking order will be maintained. Our observations do not allow us to document the influence of gravity "spreading" on the emplacement of the Allochthon. We defer to Rodgers' knowledge of Alpine geology, except to point out that a large part of the complexity observed in the Alps may reflect an originally very complicated paleogeography (Trümpy, 1960, etc.) not, at least at this time, recognized in the paleogeography of the early Paleozoic of western New England.

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