DISCUSSION

REGIONAL IMPLICATIONS OF THE STRATIGRAPHY AND STRUCTURE OF SHOCHARY RIDGE, BERKS AND LEHIGH COUNTIES, PENNSYLVANIA

PETER T. LYTTLE and AVERY ALA DRAKE, JR.

U.S. Geological Survey, Reston, Virginia 22092

In their recent paper, Wright and Stephens (1978) presented a detailed stratigraphic and paleontologic account of the rocks of Shochary Ridge in eastern Pennsylvania (fig. 1). On the basis of our own detailed mapping of Shochary Ridge and surrounding rocks in the Slatedale, New Tripoli, and New Ringgold 7½′ quadrangles, we disagree with several of their findings in detail and, more importantly, with many of their regional implications. Various structural mechanisms, over a long period of geologic time, have produced very significant tectonic shortening in the Shochary Ridge region. Crude lithologic similarities and, in many places, overlapping ages of the various units, as documented by Wright and Stephens, make an understanding of the overall structure vital before the acceptance of a simple model for the environments of deposition, a model that closely ties Shochary Ridge rocks with surrounding rocks. Below, we list the important points of disagreement:

1. Although the relatively simple structure of Shochary Ridge, an overturned asymmetric syncline, has been correctly portrayed by Wright and Stephens, the regional structure and tectonic history of the surrounding Martinsburg Formation and Hamburg klippe rocks are vastly and misleadingly oversimplified. This oversimplification leads to many problems in Wright and Stephens' evaluation of sedimentary facies relations and the timing of klippe emplacement.
2. The nature of the contacts of the Shochary Ridge rocks with all three members of the Martinsburg to the north and east and with rocks of the Hamburg klippe to the south is virtually ignored. In both areas, late (probably late Alleghenian) steeply dipping upthrusts bring these three sequences of clastic rocks into their present positions.
3. Unit 1 of Wright and Stephens' Shochary Ridge sequence crops out on the south side of the Shochary syncline, but it is not present on the north side. The reason is simple. Unit 1 is part of the Hamburg klippe, a possibility envisioned by Wright and Stephens, but for different reasons. Our mapping, as well as that of Wood and MacLachlan (1977), Alterman (ms), and Stose (1946), places the northern limit of the Hamburg klippe just north of the town of Kempton, thus including unit 1 in the klippe. This helps to resolve several structural problems discussed below.

All three of these criticisms point to weaknesses in the structural story presented by Wright and Stephens. The Martinsburg Formation

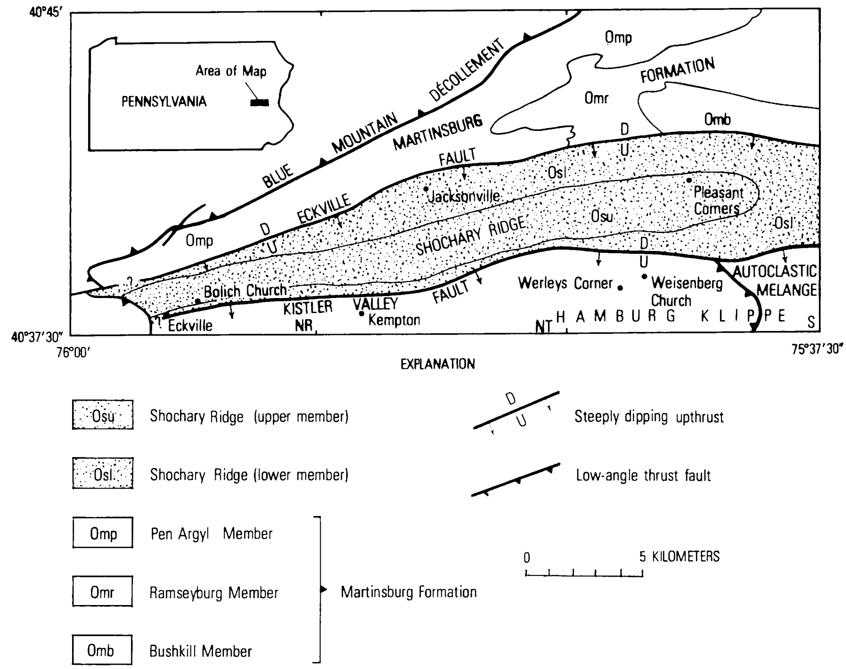

Fig. 1. Generalized geologic map showing Shochary Ridge, the eastern part of the Hamburg klippe, and the parautochthonous Martinsburg Formation. 7 1/2′ quadrangles are indicated in the lower right corners: Slatedale (S), New Tripoli (NT), New Ringgold (NR).

does indeed surround Shochary Ridge rocks to the north and east, but it is part of the overturned limb and brow of the large nappe that has overridden both the rocks of the Hamburg klippe and those of Shochary Ridge (Drake, 1969). In the southeast quarter of the Slatedale quadrangle (fig. 1), both klippe and Shochary Ridge rocks are severely smeared along gently south-dipping cleavage planes and show a pronounced stretching lineation. We interpret this to be a transport lineation produced by the overriding Martinsburg-mantled nappe. In mapping the Slatedale and Cementon quadrangles, very close attention was paid to younging directions, as shown by sedimentary structures, and to the sense of rotation of folds mapped in the Bushkill and Ramseyburg Members of the Martinsburg. This work clearly shows that these rocks are regionally overturned or in the brow of a nappe. In addition, late open folds (roughly east-trending) superimposed on the early nappe-related structures are truncated by a late steeply south-dipping upthrust bringing Shochary Ridge rocks on the south over Martinsburg on the north (see the Eckville fault on fig. 1). Additional evidence for this fault is given below. It is interesting to compare the complex structure and outcrop pattern of the parautochthonous Martinsburg with the relatively simple structure of Shochary Ridge, which has been correctly shown by Wright and Stephens as well as by virtually all previous workers in the area. The structure of Shochary Ridge alone, therefore, is a poor guide to the structure and tectonic history of the surrounding region.

By inference in their text, and as shown in their figure 1, Wright and Stephens have indicated that the klippe rocks are totally surrounded by, and therefore deposited in, a matrix of Martinsburg. The work of Root and MacLachlan (1978) and our own mapping show that this is not the case. Where the Martinsburg is in contact with the klippe rocks, it is part of the envelope of the large nappe system mentioned above which was emplaced after and on top of the klippe. The view of Platt and others (1972) that the allochthonous rocks are best represented as olistostromal plums in a pudding of Martinsburg, and that the resulting assemblage was then involved in hard-rock thrusting, is not sufficient to account for the complex internal structure. It is much more likely that much of the klippe is a mélange as defined by Hsü (1968), involving *tectonic* fragmentation and mixing. Root and MacLachlan (1978) have reported excellent examples of mélanges in the Summerdale allochthon to the west. Many of the mélanges behave, and therefore can be mapped, as rock-stratigraphic units, thereby qualifying as broken formations (Hsü, 1968) or autoclastic mélanges. An understanding of complex structures such as these plays an all-important role in unravelling the tectonic history. Wright and Stephens (1978, p. 1015) stated that "the older the top of the underlying autochthonous limestone becomes, the more rock now judged allochthonous could become part of the autochthonous sequence." They also stated (p. 1014) that a much larger klippe would be "more cumbersome." Both these statements suggest an oversimplified understanding of the Hamburg klippe. If no fossil data were available within the klippe, our understanding of it might be less, but the character and structural complexity of the allochthonous terrane would still be understood in general. Also the mechanisms of formation and emplacement would be operative even if the allochthonous region were 10 times larger.

At the extreme northeast end of the Hamburg klippe (in the southeast corner of the Slatedale quadrangle) a low-angle thrust fault, probably Taconic in age, brings klippe rocks over an autoclastic mélange consisting of clasts of slate and extremely calcareous graywacke in a matrix of medium-dark-gray to light-olive-gray calcareous slate. Extreme deformation makes correlation with nearby units very difficult, but the mélange rocks have many similarities with the rocks near Weisenberg Church several km to the west (fig. 1). The unit in the Weisenberg Church area, much less deformed and recognizably part of the Hamburg klippe, consists of light-olive-gray slate interbedded with rust-speckled grayish-olive graywacke. Classically, the entire northern contact of the klippe with the Shochary Ridge rocks has been interpreted as a low-angle thrust fault. Detailed mapping, however, shows this contact to be a late high-angle upthrust very similar and roughly parallel to the Eckville fault to the north. This high-angle fault, herein called the Kistler Valley fault, cuts the above-mentioned low-angle thrust. Similar relations, namely, steep post-Taconic faults offsetting gently-dipping Taconic thrust faults, are being increasingly recognized by others (Ratcliffe, 1978; MacLachlan, personal commun., 1978). The Shochary Ridge rocks, therefore, are bounded on both the north and south by very late faults that had nothing to do with the mass movement of rocks during the Taconic orogeny, an important point to remember when considering the arguments of Wright and Stephens as to the timing of klippe emplacement. The age of the youngest Shochary beds certainly predates the earliest arrival time of the klippe, but it is very likely that the late faulting postdates those Barnveldian-age beds by as much as 200 m.y. The above is an excellent example of how frustrating the well-dated Shochary Ridge rocks can be to work with; fossils abound, but structural considerations limit some of the potential use of the ages obtained. The existence, nature, and location of both the Eckville fault and the Kistler Valley fault prove, therefore, to be of great import in this discussion. These faults make the measurement of a complete section of Shochary Ridge rocks impossible as the faults truncate the lowest exposed member. Wright and Stephens' estimate of 1500 m represents a *minimum* thickness.

Behre (1933) first noted the Eckville fault and presented an illustration of a slate quarry immediately north of the fault trace where fault movement has folded the slaty cleavage. In this area, the regionally steep, south-dipping slaty cleavage of the Pen Argyl Member of the Martinsburg becomes progressively more gentle as the fault is approached, suggesting that the relative movement on the fault is up on the south (Shochary Ridge) side. Recent detailed mapping by Lash (ms) confirms this movment. Subsidiary faults in several large outcrops along the northernmost edge of the Shochary Ridge rocks just south of Jacksonville and north of Bolich Church (fig. 1) support the steep southerly dip of the Eckville fault and the upward relative movement on the south. The Eckville fault is roughly on strike with a small fault noted by Stephens (ms) and Wright and Stephens (1978) that offsets Silurian clastic rocks on Blue Mountain. Stephens (1969) was unsure of the exact nature of the fault but presented it as a steeply south-dipping reverse fault that may have a stratigraphic displacement of 310 m (up on the south). This structure is consistent with that of the Eckville fault to the east, but talus slopes on Hawk Mountain prevent any direct tracing. The amount of offset on the Eckville fault is impossible to ascertain, but we suggest that it must be more than the 310 m mentioned by Stephens for the Hawk Mountain fault. Near Eckville, the fault places the lowest exposed rocks of the Shochary sequence in contact with the upper member (Pen Argyl) of the Martinsburg. Progressing east along the north side of the fault, one enters the middle (Ramseyburg) and lower (Bushkill) members of the Martinsburg. A reliable estimate of thickness of section encountered is difficult to make because of attenuation of the Martinsburg on the lower limb of the nappe as well as other structural complexities.

The nature of the Kistler Valley fault is a bit more difficult to prove at individual outcrops, but the overall map pattern of a fairly straight fault that cuts across an area of substantial topographic relief (particularly in the area of the Jordan Creek meanders in the southern Slatedale quadrangle) suggests that the fault is very steep or nearly vertical. Hamburg klippe rocks structurally overlie the Shochary Ridge rocks along this fault. At the western end of this fault, near where it disappears under the talus slopes of Blue Mountain, several outcrops of klippe rocks contain small subsidiary faults that dip steeply south. Therefore, the classically held view that the northern structural boundary of the klippe is a low-angle Taconic thrust cannot stand. For the reasons given above, we feel that the Eckville and Kistler Valley faults are similar structurally and probably formed (or were reactivated) at roughly the same time, late in the Alleghenian orogeny.

Near Kempton (fig. 1) we believe that Wright and Stephens have located the northern limit of klippe rocks (or the Kistler Valley fault) incorrectly. All previous mapping that recognized the significance of the Hamburg klippe, as well as own own, places the fault just north of Kempton. The Kempton Community Center water well just north of town penetrated thick fault gouge and was forced to a depth of approx 130 m, much deeper than average wells to the immediate north and south (A. Trexler, personal commun., 1977). Figures 1, 3, and 7 of Wright and Stephens lack quadrangle boundaries or latitude and longitude, which makes specific localities very difficult to find. Locating the fault just north of Kempton, however, forces at least seven of their southern Shochary Ridge localities into the klippe. In their figure 3, all these localities are within their unit 1. Structurally, this makes sense, as by their own admission, unit 1 only appears on the south side of a simple overturned syncline; it also explains the lack of shelly fauna and anomalous current directions in unit 1. In our experience, even the lowest part of the Shochary sequence contains scattered, albeit rare, brachiopod debris. In addition, the rocks at the south edge of Kempton are chert conglomerates that bear no resemblance to any rocks in the Shochary Ridge sequence and are almost certainly part of the klippe. Wright and Stephens show in figure 3 that their unit 2 of the Shochary Ridge sequence extends northward to Blue Mountain. Thus, we assume that they would argue that unit 1 is missing because it is beneath the Blue Mountain décollement. In the New Tripoli quadrangle (fig. 1), they would thus be forced to claim that unit 2 includes three very distinct mappable units, two of which are members of the Martinsburg Formation (Drake and Epstein, 1967). At the base of Blue Mountain, immediately south of the décollement, the rocks of the Pen Argyl Member of the Martinsburg are exposed in a series of slate quarries. In some quarries, beds of excellent slate as much as 6.5 m thick can be found. We would argue, disregarding any age constraints, that this very distinct mappable unit in no way resembles Wright's and Stephens' lithologic description of unit 2. Similarly, a belt of the Ramseyburg Member of the Martinsburg crops out within the northeast limits of unit 2 in figure 3 of Wright and Stephens. Again, this member lithologically defies inclusion in their unit 2. Although Wright and Shephens now have more fossil localities in this area than the two localities shown in their figure 7, we feel that it is a serious mistake to map these lithologically different and structurally separated rock bodies as one unit on the basis of overlapping fossil ages. In doing so, Wright and Stephens have ignored important differences between mappable units and have incorrectly used age as a criterion for rock-stratigraphic definition. At the same time, we welcome the additional fossil data in this extremely complex terrane and remain willing to rethink structural interpretations if the data so demand. At this time, the data remain consistent with the structural story we have presented.

The rocks of Shochary Ridge have deservedly received considerable attention for many years. In an area where Ordovician clastic rocks occupy the low ground, Shochary Ridge provides a rare high between the Precambrian ridges to the southeast and the Silurian rocks of Blue Mountain to the northwest. In addition, because of faunal abundance and diversity, the rocks of Shochary Ridge have been used as a stratigraphic touchstone for a large area of poorly dated clastic rocks. The stratigraphic explanation that best applies to the Shochary Ridge region must take into account abrupt facies changes and the abrupt explosion in fossil abundance across the Eckville fault.

The assumption made by Wright and Stephens and others before them that the Shochary Ridge rocks are continuous with, and part of, the Martinsburg must be looked at very carefully. We have already stated that the Martinsburg to the north and east is part of a large nappe that has overriden both Shochary Ridge and klippe rocks and that Shochary Ridge rocks are fault bounded. This conclusion does not eliminate the possibility, however, that prodeltaic Shochary Ridge units are a shallow lateral equivalent of part of the deep-water flysch deposits of the Martinsburg. Wright and Stephens correctly pointed out several important similarities between the two sequences of clastic rocks. Martinsburg rocks are known to overlie the Jacksonburg Limestone stratigraphically, but it is impossible to know what underlies the Shochary Ridge sequence. The Shochary Ridge sequence has more similarities with the Reedsville Shale (McBridge, 1962; Bretsky, 1969; Thompson, 1970) than with the Martinsburg that surrounds Shochary Ridge. Both the Shochary Ridge and Reedsville rocks have abundant fossil communities dominated by dalmanelled and strophomenid brachipods and crinoid debris in medium-bedded siltstone and sandstone, and bivalve mollusks concentrated in the thinner bedded, fine-grained shale and slate (see Thompson, 1970, p. 42-44; Bretsky, 1969). Both units contain fairly shallow water turbidite deposits; the brachipods have not travelled far from where they originally lived, and there is some evidence of bioturbation. As pointed out by Wright and Stephens in the discussion of units 2, 3, and 4 of Shochary Ridge, the sequence of environments of deposition suggests a northward-prograding delta during Barneveldian time. These events are remarkably similar to the depositional history suggested by Horowitz (1966) and Thompson (1970) for the upper part of the Reedsville. In eastern Pennsylvania in general, and specifically in the region considered by Wright and Stephens, the Shochary Ridge rocks are the only Ordovician clastic rocks included in the omnifarious Martinsburg that were deposited in this nearshore environment. The nearest rocks that have some similarities are 115 km southwest along strike in the New Bloomfield (Dyson, 1967) and Carlisle (Root, 1978) quadrangles. Dyson describes the Martinsburg Formation as containing fine-grained sandstone and siltstone and abundant brachiopod and crinoid debris near Conodoquinet Creek. Much of what he included in the Martinsburg has been reassigned to the Hamburg klippe (Enola allochthon) by Root and MacLachlan (1978); however, the nonklippe Martinsburg is more like the Reedsville facies to the south and west than the Martinsburg in eastern Pennsylvania (Drake and Epstein, 1967). Many geologists (for example, McBride, 1962; Bretsky, 1969) regard southcentral Pennsylvania as the farthest north and east reached by the nearshore deltaic deposits of the Reedsville facies. We would like to suggest instead that the Shochary Ridge rocks are basically autochthonous and represent the northeastern limit of the Reedsville. Furthermore, the Martinsburg Formation north of Shochary Ridge and of the Eckville fault, a thick, deep-water turbidite flysch, was deposited in a deep basin to the southeast and later brought to its present structural position as part of a large nappe. This basin, or elongate northeast-trending trough, became shallower both to the southeast and southwest. Shochary Ridge *might* represent the northernmost lobe of a major delta that partially filled in the southwest end of the deep trough also accepting Martinsburg turbidity currents to the northeast. Current directions in both clastic sequences would be similar (ranging from northwest to northeast), however, sites of deposition would be widely separated. Because of later tectonism, the rocks of the Hamburg klippe were emplaced on top of the Reedsville-like rocks of the Shochary Ridge — Carlisle region and a Martinsburg-mantled nappe rode over both klippe and Shochary Ridge rocks; later still, the Silurian clastic rocks were unconformably deposited on top of all three sequences. Thus, Shochary Ridge is fortuitously preserved today in the major synclinal fold in the Silurian clastic rocks at Hawk Mountain.

References

Alterman, I. B., ms, 1969, Structure and tectonic history of the Taconic allochthon and surrounding authochthon, east-central Pennsylvania: Ph.D. thesis, Columbia Univ., New York, 287 p.

Behre, C. H., Jr., 1933, Slate in Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. M16, 400 p.

Bretsky, P. W., 1969, Central Appalachian Late Ordovician communities: Geol. Soc. America Bull., v. 80, p. 193-212.

Drake, A. A., Jr., 1969, Precambrian and lower Paleozoic geology of the Delaware Valley, New Jersey-Pennsylvania, *in* Subitsky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania, and guidebook of excursions: New Brunswick, Rutgers Univ. Press, p. 51-131.

——— 1978, The Lyon Station-Paulins Kill nappe — the frontal structure of the Musconetcong nappe system in eastern Pennsylvania and New Jersey: U.S. Geol. Survey Prof. Paper 1023, 81 p.

Drake, A. A., Jr. and Epstein, J. B., 1967, The Martinsburg Formation (Middle and Upper Ordovician) in the Delaware Valley, Pennsylvania-New Jersey: U.S. Geol. Survey Bull. 1244-H, 16 p.
Dyson, J. L., 1967, Geology and mineral resources of the southern half of the New Bloomfield quadrangle, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Atlas 137 ed., 86 p.
Horowitz, D. H., 1966, Evidence for deltaic origin of an Upper Ordovician sequence in the central Appalachians, *in* Shirley, M. L., and Ragsdale, J. A., ed., Deltas in their geologic framework: Houston, Texas, Houston Geol. Soc., p. 159-169.
Hsü, K. J., 1968, Principles of mélanges and their bearing on the Franciscan-Knoxville paradox: Geol. Soc. America Bull., v. 79, p. 1063-1074.
Lash, Gary, ms, 1978, The structural geology of the Pen Argyl Member of the Martinsburg Formation in Lehigh and Berks County, Pennsylvania: M.S. thesis, Lehigh Univ., Bethlehem, 213 p.
McBride, E. F., 1962, Flysch and associated beds of the Martinsburg Formation (Ordovician), central Appalachians: Jour. Sed. Petrology, v. 32, p. 39-91.
Platt, L. B., Loring, R. B., Papspyros, Athanasios, and Stephens, G. C., 1972, The Hamburg klippe reconsidered: Am. Jour. Sci., v. 272, p. 305-318.
Ratcliffe, N. M., 1978, Probable Taconic age of the Middlefield thrust zone, eastern margin of the Berkshire Massif, Massachusetts: on the basis of Rb/Sr geochronology of intrusive granitic rocks: Geol. Soc. America Abs. with Programs, v. 10, no. 2, p. 81.
Root, S. I., 1978, Geology and mineral resources of the Carlisle and Mechanicsburg quadrangles, Cumberland County, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Atlas 138ab.
Root, S. I., and MacLachlan, D. B., 1978, Western limit of Taconic allochthons in Pennsylvania: Geol. Soc. America Bull., v. 89, p. 1515-1528.
Stephens, G. C., ms, 1969, Stratigraphy and structure of a portion of the basal Silurian clastics in eastern Pennsylvania: M. S. thesis, George Washington Univ., Washington, D.C., 50 p.
Stose, G. W., 1946, The Taconic sequence in Pennsylvania: Am. Jour. Sci., v. 244, p. 665-696.
Stose, G. W., and Jonas, A. I., 1927, Ordovician shale and associated lava in southeastern Pennsylvania: Geol. Soc. America Bull., v. 38, p. 505-536.
Thompson, A. M., 1970, Sedimentology and origin of Upper Ordovician clastic rocks, central Pennsylvania: Soc. Econ. Paleontologists and Mineralogists, Eastern Sec. Guidebook, 88 p.
Willard, Bradford, 1943, Ordovician clastic sedimentary rocks in Pennsylvania: Geol. Soc. America Bull., v. 54, p. 1067-1122.
Wood, C. R., and MacLachlan, D. B., 1977, Ground-water resources of northern Berks County, Pennsylvania: U.S. Geol. Survey open-file report 77-407, 178 p.
Wright, T. O., and Stephens, G. C., 1978, Regional implications of the stratigraphy and structure of Shochary Ridge, Berks and Lehigh Counties, Pennsylvania: Am. Jour. Sci., v. 278, p. 1000-1017.

REPLY

THOMAS O. WRIGHT* and GEORGE C. STEPHENS**

We thank Peter Lyttle and Avery Drake for their interest in, and comments on, our recent paper (Wright and Stephens, 1978). The regional and local stratigraphy and structure of the Martinsburg Formation in eastern Pennsylvania remain controversial, even after nearly 50 yrs of research by various investigators. Problems still abound that must be resolved before a complete understanding of this complex region can be reached. The nature of Shochary Ridge is certainly one such regional problem. This area containing fossiliferous rocks is located directly north

* Department of Geology, Allegheny College, Meadville, Pennsylvania 16335
** Department of Geology, The George Washington University, Washington, D.C. 20052