

Comment and Reply on "Pine Mountain terrane, a complex window in the Georgia and Alabama Piedmont; evidence from the eastern termination"

COMMENT

K. D. Nelson, *Institute for the Study of the Continents, Cornell University, Ithaca, New York 14850*

In a recent article discussing field relations at the northeast end of the Pine Mountain belt, Hooper and Hatcher (1988, p. 310) concluded that "None of the ductile faults framing the Pine Mountain window are part of the Appalachian detachment." This statement is a response to a suggestion by myself and others that the Appalachian detachment *might* be exposed around the periphery of the Pine Mountain belt (Nelson et al., 1987). In support of their statement Hooper and Hatcher advanced three arguments: (1) The Appalachian detachment, where exposed in the miogeocline to the west, is a brittle decollement, whereas the faults that frame the Pine Mountain window formed in the ductile regime. (2) The Box Ankle and Goat Rock faults are Devonian or older, thereby precluding the possibility that they are segments of the Alleghanian-age Appalachian detachment. (3) The Towaliga fault zone, although likely an Alleghanian feature, is a high-angle ductile formed fault, and therefore unrelated to the low-angle, brittle, Appalachian detachment. These arguments are not compelling.

1. That the Appalachian detachment is a brittle structure beneath the Valley and Ridge province has little relevance to its character in the vicinity of the Pine Mountain belt. Indeed, at this internal position in the orogen one would expect the Appalachian detachment to be a ductile high-strain zone that was deforming, in Alleghanian time, under upper amphibolite or possibly granulite facies conditions. Metamorphic rocks exposed along strike from the Pine Mountain belt, within the Kings Mountain belt and immediately adjacent Inner Piedmont, were cooling through the argon retention temperature for hornblende (~500 °C) synchronously with Alleghanian shortening in the Valley and Ridge province (Dallmeyer et al., 1986; Secor et al., 1986). Using a reasonable geothermal gradient (30 °C/km) to estimate the overburden removed from these rocks, and adding to this value the present depth to the detachment reflectors along the Pine Mountain belt-Kings Mountain belt axis (about 10 km), implies that during the peak of Alleghanian shortening the total depth to the Appalachian detachment in the area was about 25 km, and the temperature at the level of the detachment was about 800 °C. Even if this estimate is considerably in error, it is highly unlikely that the Appalachian detachment at this interior position in the orogen was evolving in pressure-temperature (*P-T*) conditions below lower greenschist facies, which is generally considered to mark the onset of ductile deformation in quartz-rich lithologies. By analogy, the basal decollement in the Norwegian Caledonides, which can be examined in outcrop, is a brittle formed thrust in the foreland and an annealed mylonite zone in upper amphibolite facies rocks in the internides (e.g., Bartley, 1982).

2. The Devonian age designation for the Box Ankle and Goat Rock faults is tenuous at best. It depends critically both on Odom et al.'s (1982) contention that peak metamorphism in the area occurred prior to 365 Ma, and on Hooper and Hatcher's contention that annealing of these faults occurred prior to or during this thermal peak. The isotopic dates forming the basis for Odom et al.'s contention have never been published. Russell's (1976) single Rb/Sr "date" for motion on the Bartletts Ferry fault, which is cited by Hooper and Hatcher as inferential evidence for a Devonian age for faulting in the region, was a suggested interpretation, by Russell, of isotopic data that are clearly disturbed: "The significance of the results

from the Bartletts Ferry mylonite zone is questionable . . ." (Russell, 1985, p. 10).

Even if one allows a Devonian age for peak metamorphism and folding in the region, the time at which the annealing fabrics were superimposed on the faults is entirely unconstrained. Static recrystallization could have occurred at any time subsequent to the thermal peak, so long as the rocks were maintained at a relatively elevated temperature (i.e., within amphibolite facies). There is no reason to suspect that the rocks exposed in the vicinity of the Pine Mountain belt cooled below amphibolite facies conditions prior to late Paleozoic time. Indeed, given the cooling ages reported for rocks along strike in the Piedmont, this seems unlikely.

3. I agree. The Towaliga fault appears to be a major "late" Alleghanian strike-slip fault that offsets Grenville basement, its deformed cover, and the overlying composite Piedmont allochthon. Our only addition to this interpretation is the suggestion that it has a component of dip-slip motion that might well be minuscule compared to the transcurrent component. This dip-slip component, together with any late brittle reactivation, can provide the offset of basement, in cross section, suggested by the COCORP reflection data (Nelson et al., 1987).

I submit that the Appalachian detachment in the innermost region of the orogen is likely to be a composite ductile deformation zone, several kilometres thick, within which basement, cover, and far-traveled Piedmont rocks are complexly interleaved on a large scale. This composite deformation zone will have resulted from multiple episodes of transport at mid- to lower crustal levels. The latest (Alleghanian) throughgoing shear zone might well be preserved at the top of this composite feature, pre-Alleghanian "hanging-wall" mylonites having been transported to the west. It appears to me that the complexly interleaved, ductile deformed basement and Piedmont rocks, bounded above by a throughgoing ductile high-strain zone (Goat Rock fault), that Hooper and Hatcher have mapped at the north end of the Pine Mountain belt is, in aggregate, a good candidate for this structure. Expanding on this comparison, it is perhaps worth noting that the band of reflections associated with the Appalachian detachment on seismic profiles in this part of the orogen is generally about 0.5 s in time thickness, implying that the zone in the crust being imaged is roughly 1 to 2 km thick. This is comparable to the vertical dimension on Hooper and Hatcher's (1988, Fig. 4) cross section through the northern end of the Pine Mountain belt.

REPLY

Robert J. Hooper, *Department of Geology, University of South Florida, Tampa, Florida 33620*

Robert D. Hatcher, Jr., *Department of Geological Sciences, University of Tennessee, Knoxville, Tennessee 37916 and Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831*

Nelson's Comment on our paper (Hooper and Hatcher, 1988) reflects continued interest in the Pine Mountain window, a structure of considerable importance in the tectonic framework of the southern Appalachians. We would like to make it clear that our paper was *not* written in response to the Nelson et al. (1987) paper. We have been conducting detailed geologic studies here since 1980, long before the COCORP Project considered acquiring seismic reflection profiles in the area, and our 1988

paper represents one of several in press (cited in Hooper and Hatcher, 1988).

The most significant contribution of our paper was to document that the Pine Mountain window is framed by three faults of contrasting ages and motion sense, because surface geometry and fault rocks along each yield textural and shear-sense data that provide information showing faults moved both before and after the metamorphic peak, and that it had more than one sense of motion. This evidence led us to conclude that the Pine Mountain is not a simple window.

We stated (Hooper and Hatcher, 1988, p. 309) that age determinations are not forthcoming for any of the faults framing the window and that fault formation could only be related to the relative timing of development of microtextures and metamorphic assemblages. These data, taken in context, provide unequivocal evidence that three faults having separate movement histories—in both space and time—frame the window. Nelson reiterated his contention that the available radiometric dates are questionable because they are published only in abstracts without the supporting data. (Note that none of the reviewers of our paper—including one of the coauthors of the Nelson et al. [1987] paper—objected to our citing these dates.) We believe that these dates are acceptable and constrain the time of metamorphism to be pre-Alleghanian but, regardless of the quality of radiometric age dates, the microtextural and metamorphic assemblage data, along with shear-sense indicators and surface-fault geometry, unequivocally indicate that these cannot be the same faults, or the Alleghanian master detachment.

The oldest boundary fault is the pre-thermal peak, tightly folded Box Ankle fault (Hooper and Hatcher, 1988, Figs. 1 and 5). Mineral assemblages in Box Ankle fault mylonites are in equilibrium with surrounding sillimanite-grade country rocks and contain fabrics typical of prograde, high-grade fault rocks. These rocks are dynamically recrystallized prograde mylonite, comparatively free of unrecovered strain. Nelson incorrectly equated annealing with static recrystallization. Annealing is a process of strain reduction involving migration of defects, and it can occur dynamically or statically at low or elevated temperatures. We can only presume that “static recrystallization” referred to by Nelson, and not by Hooper and Hatcher (1988), is meant to indicate recrystallization under conditions with zero deviatoric stress component. Annealing, however, may or may not involve recrystallization. Subgrain formation, for example, results from annealing and forms low-angle boundaries, but it obviously involves no recrystallization and migration of high-angle grain boundaries. The Box Ankle and Towaliga faults were clearly dynamically recrystallized [annealed] under different *P-T* conditions at different times, as indicated by coeval microtextures and equilibrium mineral assemblages. The Goat Rock fault may have been statically annealed under sillimanite-grade conditions, thus requiring that it formed and was annealed at a different time than the other two faults.

The Goat Rock fault contains sillimanite-grade mylonitic rocks at the eastern end of the Pine Mountain window, but it truncates the Box Ankle fault. This fault must therefore be younger than the Box Ankle fault, having developed synchronously with the thermal peak (or before). Shear-sense indicators also show that the Goat Rock is a dextral fault, contrasting with the dip-slip Box Ankle fault. The Box Ankle fault was overprinted by the dominant foliation, and the Goat Rock fault parallels it. The Towaliga fault truncates the Box Ankle fault and the dominant foliation, and it contains retrograde mylonite (sillimanite retrograded to garnet grade) and dextral shear-sense indicators; it therefore developed after the Box Ankle and Goat Rock faults.

Nelson has made use of entirely unconstrained thermal data to produce an unrealistic value of 800 °C for thermal conditions in an attempt to define *P-T* conditions for faulting at the position of the Pine Mountain window. Nowhere did we state (as indicated by Nelson) that the Appalachian master detachment is a brittle structure at the position of the Pine Mountain window. In fact, evidence from other parts of the orogen suggests

that the detachment is most likely ductile, except along its leading edge. Mylonitic rocks along the Linville Falls fault in the Grandfather Mountain window and faults framing the Sauratown Mountains window are mylonitic—but none of these faults are likely exposures of the Appalachian detachment. Comparisons with other thrust-dominated orogens, as pointed out by Nelson, reveal similar patterns.

The geometries, microtextures, and metamorphic assemblages of the three faults framing the Pine Mountain window clearly indicate that the window is a complex structure whose present geometry is the product of a long history of movement on several currently exposed faults and the Appalachian detachment, which is likely present at depth. In addition, there is no evidence for a normal component of motion on any of these faults, and the COCORP seismic reflection data (Nelson et al., 1987) may be interpreted as in our Figure 5. There are probably additional ways to interpret the seismic reflection data, because they are nonunique. It is unlikely that the moderately dipping Box Ankle fault would produce a significant reflector package comparable to the basal Appalachian detachment, either in amplitude or thickness. Most agree that the reflectors associated with the detachment result from acoustic anisotropy within sedimentary rocks beneath the crystalline sheet, and not acoustic contrasts within it, a conclusion corroborated by seismic reflection surveys in the southern Appalachians that have better resolution in the upper crust than the COCORP surveys (e.g., Çoruh et al., 1987).

The polyphase history of the Pine Mountain window and its complex relations to adjacent terranes indicate that this geology and our paper are easily misunderstood. Whereas we do not claim to have answered all the questions here, we feel our work has resolved the timing relations between faults framing the Pine Mountain window, and their sense of motion, by using a combination of field and microscopic studies. It is clear that the Goat Rock and Towaliga faults are not possible candidates for the Appalachian detachment because of their timing and motion sense. The Box Ankle fault is also not a viable candidate, because of its antiquity relative to the thermal peak. We therefore stand by our original conclusions.

ACKNOWLEDGMENT

We thank Steve Edelman for critically reading this reply.

COMBINED REFERENCES CITED

- Bartley, J.M., 1982, Limited basement involvement in Caledonian deformation, Hinnøy, north Norway, and tectonic implications: *Tectonophysics*, v. 83, p. 185–204.
- Çoruh, Cahit, Costain, J.K., Hatcher, R.D., Jr., Pratt, T.L., Williams, R.T., and Phinney, R.A., 1987, Results from VIBROSEIS profiling: Appalachian ultra-deep core hole site study: *Royal Astronomical Society Geophysical Journal*, v. 89, p. 147–156.
- Dallmeyer, D., Wright, J., Secor, D., and Snoke, A., 1986, Character of the Alleghanian orogeny in the southern Appalachians: Part II. Geochronological constraints on the tectonothermal evolution of the eastern Piedmont in South Carolina: *Geological Society of America Bulletin*, v. 97, p. 1329–1344.
- Hooper, R.J., and Hatcher, R.D., 1988, Pine Mountain terrane, a complex window in the Georgia and Alabama Piedmont; evidence from the eastern termination: *Geology*, v. 16, p. 307–310.
- Nelson, K.D., Arnou, J.A., Giguere, M., and Schamel, S., 1987, Normal-fault boundary of an Appalachian basement massif?: Results of COCORP profiling across the Pine Mountain belt in western Georgia: *Geology*, v. 15, p. 832–836.
- Odom, A.L., Hatcher, R.D., and Hooper, R.J., 1982, A pre-metamorphic tectonic boundary between contrasting Appalachian basements, southern Georgia Piedmont: *Geological Society of America Abstracts with Programs*, v. 14, p. 579.
- Russell, G.S., 1985, Reconnaissance geochronological investigations in the Phenix City gneiss and Bartletts Ferry mylonite zone, in Kish, S., Hanley, T., and Schamel, S., eds., *Geology of the southwestern Piedmont of Georgia* (Geological Society of America annual meeting field trip guidebook): Tallahassee, Florida State University, p. 9–11.
- 1976, Rb-Sr evidence from cataclastic rocks for Devonian faulting in the southern Appalachians: *Geological Society of America Abstracts with Programs*, v. 8, p. 1081.
- Secor, D., Snoke, A., and Dallmeyer, D., 1986, Character of the Alleghanian orogeny in the southern Appalachians: Part III. Regional tectonic relations: *Geological Society of America Bulletin*, v. 97, p. 1345–1353.