The Bull Hill Gneiss: Field, Petrographic and Chemical Characteristics of a Proterozoic Augen Gneiss in Southeastern Vermont

Mark Meagher, Williams College

The Chester and Athens Domes are located in southeastern Vermont, and are part of a belt of domes extending from central Vermont to Connecticut. The Bull Hill Gneiss outcrops along the periphery of the cores of these two domes, as well as along the eastern margin of the Green Mountain Massif, and is distinguished on the Vermont State Geologic Map from similar augen gneisses of the middle Proterozoic Mt. Holly Complex (Doll et al., 1961). The Bull Hill Gneiss has been interpreted as an igneous rock, the tabular shape of its outcrop belts suggesting a series of volcanics or sills, interfingering with the overlying metasedimentary and metavolcanic units (Hepburn et al., 1984). The unit is characterized by distinct augen or flaser gneiss texture, the microcline augen reaching diameters of 5-6 cm; plagioclase, biotite, muscovite, epidote, and locally garnet are secondary components of the rock (Hepburn et al., 1984).

Analysis of zircons in augen gneisses of the Mt. Holly Complex and Bull Hill Gneiss have resulted in U-Pb ages of approximately 1121 Ma (1121+/- 1 and 1119 +/- 3 Ma) and 955 Ma (965 +/- 4, 955 +/- 5, and 944 +/- 7 Ma) respectively, validating the assignment of these into two separate units (Karabinos & Aleinikoff, in press). This Middle Proterozoic age for the Bull Hill presents several interesting questions, such as whether the Bull Hill might be related to the Stamford Granite gneiss in southwestern Vermont, which has been assigned a similar U-Pb age of 960 +/- 6 Ma (Karabinos & Aleinikoff, in press).

The purpose of this study has been to collect field evidence, as well as samples for petrologic and geochemical study, in the hope of elucidating the origin of the Bull Hill Gneiss, and the nature of its protolith. Since very little work has been conducted concerning the Bull Hill Gneiss, it has been my intent in this project to characterize the unit based upon its outcrop patterns, contacts, and petrographic and chemical signature.

<u>Field Data:</u> Ten detailed traverses were conducted through outcrops of Bull Hill Gneiss and adjacent lithologies, at various locations throughout the Chester and Athens Domes; the following tentative conclusions have been reached upon the basis of this field work.

In several of the traverses, there is evidence for increased shear near the contact of the Bull Hill Gneiss and the Mt Holly Complex . Numerous shear zones are found, parallel to the foliation and ~10-50 cm wide. These may contain augen of reduced grain size or zones of biotite concentration; in either case, the composition remains the same as that of the rock adjacent to the shear zone. The mode of deformation is always ductile, as indicated by the significant dynamic recrystallization and lack of brittly-deformed minerals. The density of shear zones in general becomes greater as one approaches the contact of the Mt Holly Complex and the Bull Hill Gneiss, indicating that more intense shear was applied along this contact. This shear was most likely produced by an extensive fault along which the Bull Hill Gneiss was thrust over the Mt Holly Complex; the increased shear along the contact would therefore represent the stress encountered by the rocks near the plane of the fault. The evidence also consistently supports an unconformable contact between the Bull Hill Gneiss and the overlying Hoosac Formation, as interpreted on the State Geologic Map (Doll et al., 1961).

The common occurance of layers containing schist or amphibolite within outcrops of Bull Hill Gneiss pose an interesting question in our interpretation of the augen gneiss: how are we to account for such inconsistencies within an otherwise homogeneous lithologic unit? As well as outcrop-scale inclusions, there are also examples of extensive schist bodies sandwiched between outcrops of augen gneiss; the mineralogy is a quartz-muscovite-chlorite-garnet assemblage. The layers are oriented parallel to the foliation, suggesting that their origin precedes or is contemporaneous with the orogenic event during which the augen gneiss texture was formed. They sometimes have considerable lateral continuity, forming layers up to several meters in length; other layers are lens shaped or ovoid. These have usually very distinct boundaries with the augen gneiss, although at the tails of the lenses they often merge with the surrounding rock.

One possible model for the origin of these inclusions is that of xenoliths of country rock and fractionation products in a plutonic body; such an interpretation is most consistent with the results of this project, though hardly conclusive. The amphibolites are thus early fractionation products along the margins of the pluton; chemical study of the inclusions would probably allow the determination of whether the amphibolite composition was derived from the magma which is now the Bull Hill Gneiss. Unfortunately, the degree of deformation does not permit the use of morphology as a factor in this debate - the outcrops are so deformed that although many inclusions have the shape of a xenolith, the intense folding and shearing preclude the assumption that primary shape has been preserved.

The pegmatites found so abundantly within the Bull Hill Gneiss are of essentially two types: those whose origin appears to predate or accompany tectonism, and those which clearly postdate the formation of the augen texture. Aplite is also found in small dikes, but appears to be a relatively recent addition to the rock, as it cuts through the augen foliation. If one could definitely ascertain that the pegmatites were a feature of the augen gneiss protolith, this would be a strong argument in favor of a plutonic origin. It is a common feature of plutons to have pegmatites along their margins, forming as a partial melt composition of the host rock. These pegmatites are less susceptible to deformation than a less massive granite, and might be expected to maintain a massive texture even through a deformation of the intensity required to form the augen texture (Debat et al, 1978).

The pegmatites of the Bull Hill Gneiss are not, however, consistently of a partial melt composition. The four pegmatite samples stained for k-feldspar contained none, and were presumably composed of quartz and plagioclase. This presents two possibilities: 1) a primary plutonic feldspar has been altered during metamorphism - K^+ has been removed and Na^+ added, perhaps via the circulation of fluids or by diffusion, to form plagioclase and quartz; 2) the plagioclase has been segregated into layers during metamorphism, perhaps not the metamorphism which is responsible for forming the texture. This quandary provides a problem in the interpretation of the pegmatites; further work on their chemistry will be necessary before a definitive conclusion can be reached.

Thin Section Analysis: The dynamic recrystallization of k-feldspar in all the samples of Bull Hill Gneiss indicates primarily ductile deformation. The tension fractures in some feldspar grains suggest that there was a period of brittle deformation either prior to or following the primary ductile event. The plagioclase crystals did not experience significant recrystallization (figure 1a), suggesting that the temperature did not reach the critical point of ~500 degrees C above which plagioclase readily recrystallizes (Voll, 1976).

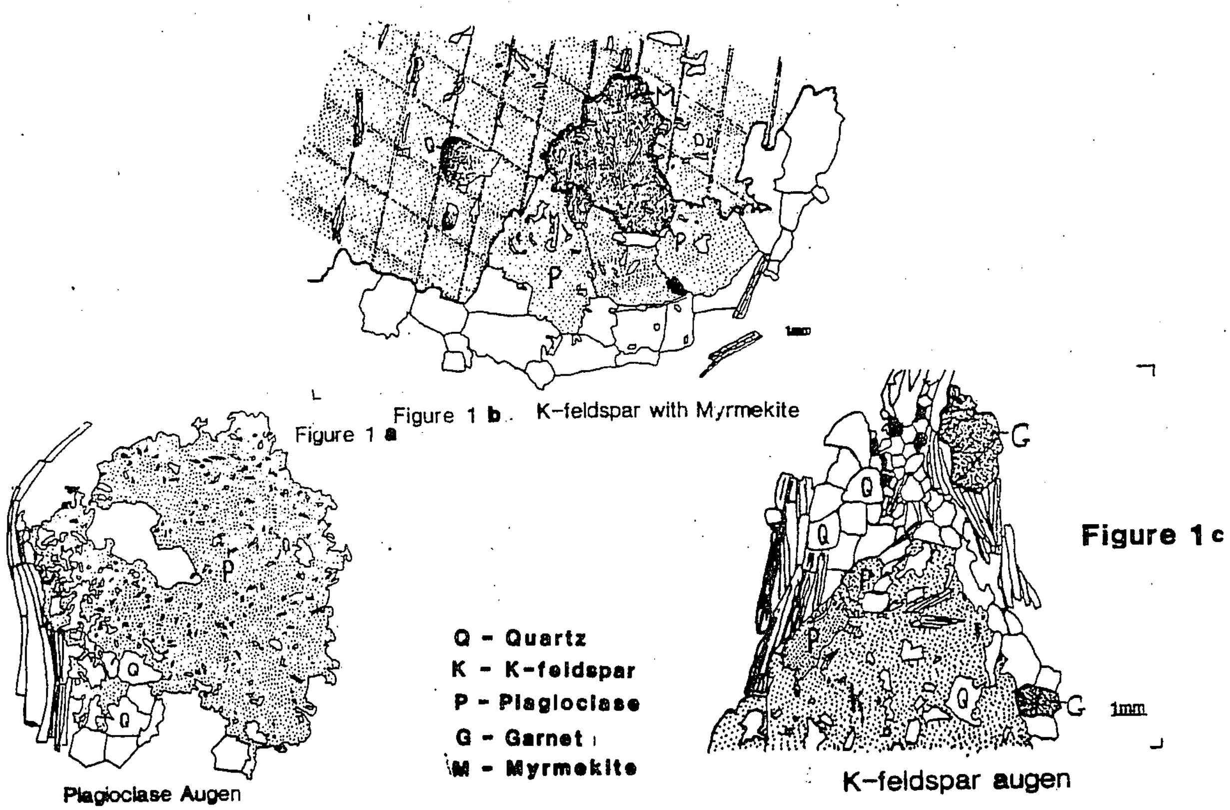

Figure 1: Drawings from photomicrographs. a) plagioclase megacryst; b) k-feldspar megacryst, with myrmekite along its boundary; c) k-feldspar augen, showing recrystallized tail of quartz and k-feldspar.

The k-feldspar and plagioclase megacrysts exhibit undulose extinction and subgrain boundaries, and uneven surfaces. The larger megacrysts are divided into many subgrains, usually with a small subgrain angle. The processes which seem to have been operative are dislocation glide and dislocation creep; recovery of the matrix was achieved by subgrain formation and recrystallization, with straining of new grains. The megacrysts are usually oriented with the 001 direction perpendicular to the foliation, indicating that grains were rotated to this preferred orientation during the early stages of deformation; following this process, they were flattened and elongated, parallel to the foliation. Finally, the recrystallized tails were formed in the recovery of the matrix (figure 1c).The deformation of the pegmatites seems to have occurred contemporaneously with that of the augen gneiss, since the orientation of the stress field is the same for each. Due to the question noted above, however, I do not propose to answer the question here of when the pegmatites were formed, as textural evidence alone is clearly not sufficient.

Comparison of Deformed Stamford Granite Gneiss and Bull Hill Augen Gneiss: The Stamford Granite Gneiss is an igneous rock formation in southwestern Vermont; it has been demonstrated to be of plutonic origin (Jeffries, 1985). As mentioned above, recent U/Pb isotopic dating has indicated that the Stamford and the Bull Hill Gneiss are of approximately the same age; this project has revealed several other similarities between the two lithologies. In thin section it is clear that the two were subjected to quite different conditions of deformation; the megacrysts of the Stamford are fractured and broken, indicating brittle deformation and low temperature metamorphism, whereas the deformation of the Bull Hill is almost entirely ductile (figure 2). Besides this point, however, the two lithologies are extraordinarily similar. They both posess the same mineralogy, although the plagioclase in the Bull Hill Gneiss forms distinct augens and only appears in the groundmass of the deformed Stamford samples (Jeffries, 1985). An abundance of myrmekite surrounding the k-feldspar megacrysts, and a proliferation of garnet in many samples are two common charactersitics of these two very similar lithologies (figure 1b). The Stamford pluton overlaps the boundary of the Biotite-Garnet isograd, whereas the Bull Hill Gneiss of the Chester and Athens Domes falls entirely within the staurolite/kyanite zone (and experienced a higher grade metamorphism during the Taconian), so one would expect to find the noted difference in texture. Major element analysis indicates a nearly indentical chemical signature between the Stamford and Bull Hill Gneiss (figure 3).

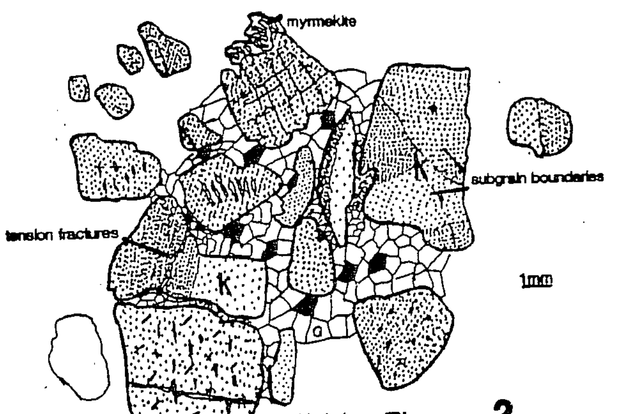

Figure 2

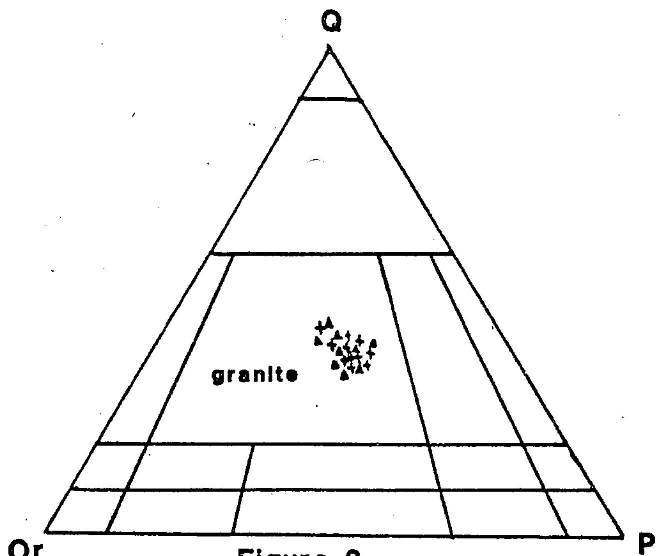

Figure 3.

Figure 2: drawing from photomicrograph of the Stamford Granite Gneiss, showing brittle deformation.
Figure 3: Chemical plot; data kindly provided by Paul Karabinos (Bull Hill Gneiss) and Nicholas Ratcliffe (Stamford Granite Gneiss). Symbols - Bull Hill Gneiss: +; Stamford Granite Gneiss: ▲.

Conclusion: The igneous origin of the Bull Hill Gneiss is well established by the chemical data utilized in this paper. The question thus arises of whether the rock was originally an intrusive or a volcanic rock. Based on the information collected during this study, the following pieces of evidence support the intrusive model over the volcanic, although a definite statement cannot yet be reached. 1) The marked similarity in composition, thin section texture and U-Pb age with the Stamford Granite Gneiss, whose plutonic nature has been demonstrated (Jeffries, 1985), would suggest that the Bull Hill is a pluton resulting from the same tectonic event (the nature of the event is problematic, as discussed below). 2) The large size of the megacrysts would be strong evidence of a plutonic origin if one could be certain that they were primary. Of course, it is possible to extrude a volcanic magma with large phenocrysts, but it is doubtful that 4-6 cm crystals would have survived the eruption process intact. Thus, either the feldspars are primary plutonic or secondary metamorphic minerals - the empirical determination of their origin will mark a turning point in the interpretation of augen gneisses. 3) The abundance of pegmatites which, as I have mentioned above, are only a very tenuous argument for a plutonic origin. 4) The map pattern of the Bull Hill, notably its large outcrop belt, surrounding the Chester & Athens Domes, suggests a sill, which due to its originally horizontal orientation would be expected to have a large outcrop area. Thus, though all evidence concerning this question is circumstantial as of yet, it falls heavily on the side of an intrusive origin.

My field work and thin section analyses indicate intense shear associated with the formation of the augen gneiss, concentrated near the Mt Holly-Bull Hill contact. I would postulate that there exists a thrust fault between the Mt Holly Complex and the Bull Hill Gneiss, along which the Bull Hill Gneiss was thrust westward over the Mt Holly Complex, probably during the Taconian orogeny, which involved a collision along the eastern margin of the North American Plate. During this event, the augen texture was formed. The field evidence also indicates that the Hoosac Formation rests unconformably over the Bull Hill Gneiss, and not in fault contact.

The tectonic context of the Bull Hill Gneiss is extremely puzzling. Throughout the Appalatian orogen, there are numerous examples of rhyolites and granites associated with the opening of the Iapetus Ocean at ~800 Ma, involving the rifting of the Grenville Province (Rankin, 1975). The date of the Bull Hill Gneiss and Stamford Granite Gneiss fall, however, ~150 Ma. before this rifting event and ~100 Ma after the Grenville orogeny (Moore, 1986). Their interpretation within a plate tectonic context is therefore contingent upon the discovery of other igneous rocks with similar ages in other terrains around the world.

In the southern part of East Greenland, augen gneisses dated by the zircon U/Pb method have yielded an age of 950 Ma. (Powell et al., 1988), indicating that there was igneous activity in other parts of the world contemporaneous with the intrusion of the Bull Hill Gneiss and Stamford Granite Gneiss. These augen gneisses contain sillimanite and garnet, and have been folded into a series of large-scale isoclinal recumbent folds (Higgins, 1976). It will be interesting to compare this lithology with the Bull Hill Gneiss, in order to determine the global tectonic context in which both were formed.

References Cited

Debat, P., Soula, J.C., Kubin, L. & Vidal, J.L. (1978): Optical studies of natural deformation miscrostructures in feldspars *Lithos* vol. **11**, pp. 133-146

Doll, C.G., Cady, W.M., Thompson, J.B., & Billings, M.P. (1961): Centennial Geologic Map of Vermont *Vermont Geological Survey*, scale 1:250,000.

Hepburn, J.C., Trask, N.J., Rosenfeld, J.L., and Thompson, J.B. Jr. (1984): Bedrock geology of the Brattleboro quadrangle, Vermont-New Hampshire: *Vermont Geological Survey Bulletin* **32**

Higgins, A.K. (1976): Pre-Caledonian metamorphic complexes within the southern part of the East Greenland Caledonides *Journal of the Geological Society of London*, vol **132**, pp. 289-305.

Jeffries, E.F. (1985): Petrology, geochemistry and structure of the Stamford Granite Gneiss, Southern Green Mountains Undergraduate Thesis, Williams College.

Karabinos & Aleinikoff, J.N. (in press): Two distinct ages of augen gneisses from the Green Mountain Massif and Chester Dome, Vermont

Moore, J.M. (1986): Introduction: the 'Grenville Problem' then and now In Moore, J.M. ed. The Grenville Province *GSC Special Paper* **31**.

Powell, D., Andersen, T.B., Drake, A.A., Jr., Hall, L., & Keppie, J.D. (1988): The age and distribution of basement rocks in the Caledonide orogen of the north Atlantic in Harris, A.L. & Fettes, D.J. (eds.), 1988, The Caledonian-Appalachian Orogen *Geological Society Special Publication* No. **38**, pp. 63-74.

Rankin, D.W., Stern, T.W., Reed, J.C. Jr., & Newell, M.F. (1975): Openings of the Iapetus Ocean: Appalatian salients and recesses as PreCambrian triple junctions *GSA abstracts with programs*, vol. **7**, p 1238.

Voll, G. (1976): Recrystallization of quartz from Variscan granites along a profile through Aar-and-Gotthard Massif (Swiss Alps) *Conference on Fabrics, Microstructures and Microtectonics*, Leiden, March 3-5, 1976 [Abstract].