GEOLOGY 305

DUCTILE DEFORMATION:

FOLDING, CLEAVAGE, AND MAPPING IN THE APPALACHIAN VALLEY AND RIDGE OF NORTHERN VIRGINIA

November 9, 10 and 11, 1995

FIELD TRIP REPORT:

The report for this field trip consists of answering in writing the questions posed in this guidebook, reporting data where instructed, and making drawings and sketches where instructed. The information submitted should be entered in the guidebook in the field, at the location where you collect the data. The completed guidebook is due at the beginning of class on Wednesday, November 15.

Answer all entries indicated by a " - " at the left margin. Answer them in the space provided.

GENERALIZED STRATIGRAPHY OF THE APPALACHIANS IN NORTHERN VIRGINIA

QUATERNARY SYSTEM

alluvium

Varicolored, unconsolidated sand, clay and gravel. Thickness variable, usually 25-50 feet.

terrace deposits

Varicolored, unconsolidated sand, clay and gravel. Thickness variable, usually 25-50 feet.

colluvium

large, angular blocks (generally of Massanutten sandstone) in steeply sloping, dangerously loose talus piles with open interstices, and as low, lobate debris flows on the valley floor. Thickness variable, maximum 15-20 feet.

UNCONFORMITY

DEVONIAN SYSTEM

Marcellus Shale

The Marcellus Shale comprises dark gray to jet black shale, is paper-thin-splitting and fissile. Hard to tell bedding from cleavage. Contains disseminated pyrite. Poorly exposed. Thickness 350-400 feet.

Needmore Formation

The Needmore Formation is characterized by dark greenish-gray to olive-gray mudstone to siltstone. Blocky- to pencil-splitting; thin-splitting, platy, but not fissile. Commonly well-cleaved, and can be used for cleavage-bedding relations. Contains rare, 2-12 inch, rounded calcareous concretions. May contain thin, 1-6 inch fossiliferous limestone beds in upper 50 feet. Fossiliferous, with brachiopods and bryozoans. Thickness 100-250 feet.

Oriskany Formation

The Oriskany Formation is characterized by white to gray, rusty- weathering, coarse, quartz-arenite sandstone and quartz-pebble conglomerate. Pebbles reach 1/2 to 1 inch in long dimension. Base is unconformable on Helderberg. Often contains calcite cement, and reacts with acid. Usually fossiliferous, but no fossils found so far in Strasburg area. Generally poorly exposed. Thickness 10-100 feet, and variable.

Helderberg Formation

The Helderberg Formation contains two distinct lithologies, both thin and rarely exposed. The upper member (New Scotland) is characterized by gray to dark gray-brown, finely crystalline and fossiliferous limestone. Weathers gray-brown. Contains interbedded, lenticular, cryptocrystalline chert beds. Fossiliferous with rare large brachiopods and common fine-grained recrystallized skeletal hash and crinoidal debris. Also contains thin, discontinuous lenticular beds of crinoidal grainstone, of which the New Creek member may merely be one. Thickness 10-40 feet.

The lower member (New Creek) consists of coarse, crinoidal grainstone (coarsely crystalline limestone) with much sand-size crinoidal skeletal debris. Weathers medium gray. Poorly exposed; lenticular, and pinches out locally. Thickness 0-6 or 8 feet, and locally absent.

SILURIAN/DEVONIAN SYSTEMS

Keyser Formation

The Keyser Formation is characterized by limestones of various kinds, both thick- and thin- to medium-bedded, brownish-gray, very-fine-grained (aphanitic) limestone, which is more common in the lower half of the formation. Nodular and cobbly weathering; displays a lumpy aspect, contrasts with the Tonoloway which weathers with a smooth surface. Fossiliferous, with bryozoa, crinoids and brachiopods.

Contains thin, lenticular beds of crinoidal and normal grainstone, which are not visibly fossiliferous. Most common in upper part of formation; they are hard to distinguish from New Creek grainstones.

Contains rare, laminated to very-thin-bedded, microcrystalline (aphanitic) limestones with thinly interbedded buff-weathering dolomite laminae. Resembles Tonoloway lithologies. Sparsely fossiliferous, with body fossils and stromatolitic structures.

Contains many thin beds of argillaceous limestone and calcareous shale; tan weathering, fossiliferous.

Contains rare quartz sandstones. Calcite-cemented, coarse, well sorted. Buff to tan weathering.

Contains rare, lenticular sequences of red shale and red to maroon sandstone, resembling Bloomsburg lithologies. Unfossiliferous. Thickness of formation 100-175 feet.

SILURIAN SYSTEM

Tonoloway Formation

The Tonoloway Formation is characterized by interbedded chalky-white-weathering, very-fine-grained crystalline limestone and buff-weathering, argillaceous dolomite. Laminated to very-thin-bedded, often wavy-bedded and wavy-laminated. Individual laminae usually less than 1/2 inch. Sparsely fossiliferous, with rare ostracoda and skeletal debris and stromatolitic algal structures. Poorly exposed. Thickness less than 50 feet.

Wills Creek Formation

The Wills Creek Formation comprises yellow to light greenish-gray, blocky weathering to pencil-weathering mudstone to silty mudstone. Contains thin calcareous siltstone and fossiliferous limestone beds near middle. Very poorly exposed. Thickness 150 feet.

Bloomsburg Formation

The Bloomsburg Formation is characterized by dark red-gray to maroon sandstones and shales to siltstones. Sandstones are argillaceous and micaceous, cross-bedded in 1- to 2-foot sets, and often contain intraformational shale-clast conglomerate layers. Shales and mudstones are micaceous and blocky weathering. Scale of interbedding ranges from one to ten feet. Occasionally contains drab, greenish gray shales and gray blotches in sandstones. Shales occasionally contain dark flesh-pink, 1- to 2-inch-diameter calcareous concretions. At Edinburg Gap, Bloomsburg contains a 10-to 15-foot thick white, orthoquartzitic sandstone near middle; existence of this sandstone remains to be proven in Strasburg area. Unfossiliferous. Thickness about 400 feet.

McKenzie Formation

The McKenzie Formation is characterized by light greenish-gray to yellow-brown shale, which weathers tan and is pencil- to blocky-splitting. Contains thin layers of wavy-bedded, well-sorted quartz sandstone; in Strasburg area contains a 5- to 10-foot thick white sandstone at top. Fossiliferous, with small brachiopods and other skeletal debris. Thickness 0-75 feet, and variable.

Massanutten Formation

The Massanutten Formation comprises medium to very coarse, light gray to white quartz-arenite sandstone and quartz-pebble conglomerate. Conglomerate contains white quartz and chert pebbles reaching 2 inches in diameter; conglomerates are lenticular, and are most common in the lower 100 feet. Most of the formation is coarse, hard, white quartzite, strongly cross-bedded and channeled, with both planar and trough sets reaching 3-5 feet in thickness. Contains very rare and very thin and discontinuous shale partings, some of which are black, and contain carbonized fragments of vascular plants, perhaps the oldest reported to date in the world. Aside from these and rare *Arthrophycus* trace fossils, the formation is totally unfossiliferous.

Sandstones in the upper 300 feet are commonly irregularly stained red with hematite, and rarely sandy hematitic ironstones (with limonite) are present, interbedded with dark red-black siltstones. These have been locally mined for iron. Thickness of entire formation is 700-800 feet.

UNCONFORMITY

ORDOVICIAN SYSTEM

Martinsburg Formation

The Martinsburg Formation is characterized by interbedded fine-grained sandstones and olive gray mudstones to shales. The lower third of the formation consists predominantly of yellow-brown to olive brown, tan-weathering shale. The upper two thirds contain thinly interbedded dark gray to black, thin- to pencil-splitting shales and siltstones. Both sandstones and shales are micaceous. Scale of the interbedding up to one or two feet, but averages 2-6 inches. Graded bedding is common, in both sandstones and siltstone-shales. Sandstones sparingly fossiliferous, mainly with brachiopods and graptolites. Uppermost part of the formation is predominantly sandy (brown-weathering), sparsely fossiliferous with molluscs and brachiopods. Total thickness about 3000 feet.

Oranda Formation

Calcareous siltstone with interbedded argillaceous limestone and metabentonite; locally fossiliferous. Thickness 40+ feet.

Edinburg Formation

St. Luke member: dove-gray, fine-grained limestone. Liberty Hall member: medium-bedded, dark-gray to black limestone. Lantz Mills member: dark-gray, nodular-weathering limestone. All units fossiliferous. Thickness 425-600 feet.

Lincolnshire Formation

Medium to thick-bedded, dark gray medium-grained limestone with black chert; lenses of light gray, coarse-grained limestone; fossiliferous. Thickness 90-110 feet.

New Market Limestone

Massive, dove-gray sublithographic limestone. In lower parts, thin-bedded, buff limestone and carbonate conglomerate.

UNCONFORMITY

Beekmantown Formation

Massive to thick-bedded, gray to brown dolomite with white chert; minor bluish-gray limestone and dove-gray limestone and dove-gray sublithographic limestone. Thickness 2000-2500 feet.

Stonehenge Formation

Thick-bedded, bluish-gray, fine to medium-grained limestone; sparsely fossiliferous. Thickness 500+ feet.

Some formations, mainly carbonates, are missing here.

CAMBRIAN SYSTEM

Conochocheague Formation

Laminated, bluish-gray limestone; massive, gray, medium-grained dolomite; algal "reefs" locally. Thickness 2500+ feet.

Elbrook Formation

Thick-bedded, nonlaminated, bluish-gray limestone and shaly dolomite. Thickness 500+ feet.

CAMBRIAN(?) SYSTEM

Antietam Formation

White to light gray massive, thick-bedded quartzite and sandstone; upper beds thinner bedded, rusty calcareous and "moth-eaten"; sparingly fossiliferous. Some shaly layers. Locally changed to quartz schist with strong cleavage and hardly recognizable bedding. Thickness 300-800 feet.

PRECAMBRIAN

Harpers Formation

Gray phyllite and slate, banded with quartzite. Always with strong cleavage which tends to obliterate bedding. Thickness 2000 feet.

Weverton Formation

Light gray to dark purple-banded, granular to vitreous quartzite, partly cross-bedded with conglomerate layers. Thick-bedded white quartzite layers. Shaly beds between quartzites. Thickness 200-300 feet.

Loudoun Formation

Highly ferruginous, dark, sandy phyllite and thin-bedded arkosic quartzite; conglomerate layers. Basal beds blue and green slate and conglomerate of unsorted pebbles of quartz and slate in slaty matrix. Thickness 0-200 feet.

Catoctin Greenstone

Metabasalt with amygdular layers and secondary quartz, calcite, and epidote. Closely folded and altered to hornblende-chlorite schist and greenstone. Metarhyolite: gray and purple slate and breccia.

UNCONFORMITY

Pedlar Gneiss

Intermediate to granitic gneisses of widely varying composition. Rock types include granite, granodiorite, syenite, quartz diorite, anorthosite, and unakite. Typically hypersthene-bearing.

A SHORT SUMMARY OF THE GEOLOGY OF NORTHERN VIRGINIA

The geologic setting of the Massanutten area may be best understood in terms of the regional geology of the central and southern Appalachians, as exemplified by the northern Virginia area. The generalized geology of this area is given on the attached map; the geology was taken from the Virginia state geologic map of 1963. It will help to refer to this map during the following discussion. The clear, unpatterned area running southwest down the right side of the map represents the Blue Ridge province. The patterned area west of the Blue Ridge is the Valley and Ridge province, and the patterned areas east of it are the Piedmont and Triassic areas. Color the map units, to help bring out the distribution and structure more clearly.

Virginia is a very long state east-west, and includes portions of all Appalachian geologic provinces in addition to the modern Coastal Plain in the east. The area of north-central Virginia shown on the map contains parts of the Piedmont, Triassic, Blue Ridge and Valley and Ridge physiographic-geologic provinces; the Plateau province commences just west of the west edge of the map and extends west for 200 miles or so.

The Plateaus are underlain by unmetamorphosed, essentially flat-lying Paleozoic sedimentary rocks; the rock section is approximately 10,000 feet thick in eastern West Virginia, and represents the thinned equivalent of the deformed sedimentary rock section in the Valley and Ridge belt to the east.

The Valley and Ridge province, in which Strasburg and the field area are located, is maybe 75 miles wide, and consists of elongate, continuous, parallel ridges supported by sandstones and conglomerates, with intervening valleys eroded into shales and carbonates. The topographic section here is perhaps 20,000 feet thick; it is a stratigrapher's paradise, and has been divided into more than 100 formations, of which maybe 30 are important. The lower third (approximately) of the section is Cambrian and Ordovician carbonates; the remainder contains Silurian and younger clastic rocks, of which the Devonian is probably the thickest. This younger clastic section contains three tough, resistant quartzites and conglomerates which support the major ridges of the Valley and Ridge; these are the (Silurian) Tuscarora Quartzite, the (Mississippian) Pocono Sandstone, and the (Pennsylvanian) Pottsville Conglomerate. Within the clastic sequence is contained the stratigraphic evidence foe the evolution of the Appalachian mountain system.

The Valley and Ridge belt consists structurally of a series of decollement folds and thrust faults which have detached upper parts of the section and slid them west and northwest over older, undisturbed rocks below. Horizontal thrust faults with westward tectonic transport are common in the Valley and Ridge; displacement on each of the 10 to 15 major thrusts is as much as 20 miles. The area of northern Virginia contains more folds than thrust faults; faulting becomes more important farther south, in Tennessee and southwest Virginia. The thrust faults are splays off a master decollement at depth, probably located in the weak Martinsburg shales. The rocks were cold and elastic when decollement occurred, and fold styles are concentric, with much kink-banding and brittle fracturing.

The Valley and Ridge is essentially a synclinorium, with generally younger rocks (albeit folded) appearing westward. The lower Paleozoic carbonates are thus exposed on the eastward and southeastward margins, and form a broad and continuous valley running from Pennsylvania to Tennessee; this is called the Shenandoah Valley in Virginia.

Immediately southeast of the Shenandoah Valley carbonates lies the Blue Ridge province. The Blue Ridge is a structurally high-standing zone of Precambrian metasedimentary and metaigneous rocks. These Precambrian rocks were deformed in the Paleozoic along with the Valley and Ridge rocks, but are of older origin and were not part of the Appalachian depositional story. Two major rock types comprise the Blue Ridge. The oldest is gneisses and schists (Pcm on map) and granites (Pci) of middle Precambrian age, which were highly deformed and metamorphosed in the billion-year-old Grenville orogeny; these rocks make up the continental "basement" on which all later rocks were deposited. They are unconformably overlain by the second major Blue Ridge lithology, 5000-10,000 feet of basaltic lavas and intervening sediments of the Catoctin Greenstone. The Catoctin (Pcc) is largely responsible for the topography and "ridge" aspect of the Blue Ridge. The Catoctin is approximately 800 million years old, younger than Grenville but distinctly pre-Paleozoic. These tholeiitic basalts are thought to represent continental, rift-valley volcanism, and thus to record the initial opening of the Proto-Atlantic Ocean in the latest Precambrian.

Unconformably overlying the Catoctin lies a thick sequence (3000-4000 feet) of barely Paleozoic clastic sedimentary rocks, the Chilhowee Group. These clastics are split into the basal Weverton Quartzite, the Harpers Formation (largely siltstones and shales) and the Antietam Formation (quartzites and shales). The first *Olenellus* trilobite, and therefore the base of the Cambrian System, is found about 500 feet below the top of the Antietam; the underlying Chilhowee is then just barely Precambrian. The Chilhowee Group flanks the Catoctin on the west side of the Blue Ridge, and represents units transitional into Paleozoic sediments of the Valley and Ridge.

The Blue Ridge province contains much deformation and metamorphism, of different ages. The basement complex was deformed and metamorphosed in the Grenville, and the Catoctin plus basement complex were deformed mildly in the latest Precambrian. Both the Precambrian rocks and the overlying (and now eroded away) Paleozoic rocks were deformed in late Paleozoic times in westward-directed, horizontal compressional tectonics; this resulted in overturning of folds to the west, and in decollement and thrust faulting. The Blue Ridge was deformed into a major asymmetric anticline, which becomes progressively more overturned and sheared off farther south. In northern Virginia and in West Virginia and Maryland, the Blue Ridge structure is an overturned anticline with axial plane dipping 15-20° SE, and the west limb nearly completely overturned. Cleavage, parallel to the axial plane, dips more steeply than bedding on the overturned limb. Farther south, in central and southern Virginia, the lower limb has become completely sheared off, and the upper limb transported a large distance (30 miles) westward on the resulting Blue Ridge thrust fault. Thus the Precambrian Blue Ridge rocks are often in thrust contact with the underlying, Paleozoic rocks. Two isolated segments of the Blue Ridge thrust are visible on the map at the west edge of the clear area, indicating tectonic transport to the west.

The Blue Ridge passes imperceptibly eastward into the Piedmont province, probably by increasing metamorphic grade and general younging of rocks. The Piedmont is a low-lying, gently rolling area underlain by essentially Paleozoic metamorphic rocks. The metamorphic grade generally increases eastward from the Blue Ridge, and culminates in amphibolite-grade metamorphism along an axis passing through Baltimore and Washington.

Much of northern Virginia is underlain by phyllite- and schist-grade metasedimentary shales, metabasalts and pyroclastic rocks; quartzose rocks are lacking. Plutonic igneous rocks are abundant throughout the Piedmont. Several types of tectonic rocks are present, such as olistostromes, gravity slide blocks, fault breccias and chaotic tectonic rocks. Deformation of Piedmont rocks was high temperature and led to ductile systems of recumbent, isoclinal folds and nappe systems. In contrast to the Late Paleozoic decollement in the Valley and Ridge, Piedmont deformation was early Paleozoic and involved all rocks, probably including Precambrian basement.

Interspersed in the Piedmont (and maybe Blue Ridge also) are elongate valleys underlain by unmetamorphosed and undeformed Triassic continental sediments and basalts. One of these is visible on the geologic map. Structurally these valleys are asymmetric synclines and/or half-grabens (normally faulted on one side); they indicate a tensional tectonic regime, different from and later than the Paleozoic compressional tectonics which generated the Piedmont, Blue Ridge and Valley and Ridge structures. These Triassic structural basins truncate pre-existing structures, but generally lie sub-parallel to them (as on the map). They probably represent rift-valley faulting, sedimentation and volcanism associated with the early stages of opening of the present Atlantic Oceanic; they are plate tectonic equivalents of the Catoctin Greenstones.

FRIDAY, NOVEMBER 10, 1995

THE MASSANUTTEN SYNCLINORIUM: THE BRUNTON COMPASS

By the end of today you will be able to:

- locate yourself on a topographic map using drainage and topography;
- take a bearing with a Brunton;
- measure strike and dip with a Brunton;
- distinguish limbs from noses of folds;
- distinguish anticlines from synclines based on limited exposure;
- gain a better understanding of the Massanutten fold system.

INTRODUCTION TO MASSANUTTEN MOUNTAIN GEOLOGY:

We will spend two days examining the geology and structure of the Massanutten mountain area. There are questions to answer in the guidebook, and sketches to make. You will collect a lot of strikes and dips from all over the fold, and back in Newark you will plot up a stereonet diagram of your data.

The emphases of the Massanutten Mountain study are doing good field work, keeping yourself oriented and located, locating yourself on a map, entering geologic data on a map, how cleavage is related to folds, and how small folds are geometrically related to large folds.

This morning we will introduce ourselves to the Massanutten fold and the Brunton compass by walking through the hinge of the fold along the creek and the road. The hike is about 2 miles long, and is level. There is **DANGEROUS TRAFFIC**, however

This afternoon we will climb the east ridge on a trail and look at rocks and dips and the east limb of the fold. We will deal with many facets of structural geology, including:

- orienteering, and locating yourself on a map
- reading contours, and locating yourself with respect to contours
- stratification in sedimentary rocks as a primary structure
- the Brunton compass, and using the Brunton compass to determine dip and strike

- primary sedimentary structures, and criteria for facing direction
- dipping rocks, and criteria for up- and down-dip vs. up- and down-section
- form and orientation of folds, relative locations of axial regions of anticlines and synclines
- plunge, and dip and strike of bedding on the noses of folds
- map-scale folds vs. outcrop-scale folds
- cleavage, and its relation to axial regions of folds.

ASPECTS OF THE GEOLOGY:

Massanutten Mountain is the topographic expression of the nose of a large, plunging syncline. The nose of the syncline is in the area around the campground and north of it. The syncline plunges gently about S30W @ 15-20. There are several minor folds associated with the major fold; these also plunge S30W @ 15-20. We will traverse obliquely across the axis of the fold this afternoon, from the SE limb to the axis itself, in the vicinity of the hinge.

The stratigraphy of the Massanutten area ranges from Upper Ordovician to Middle Devonian, and is given on pp. 2-6. The thickest unit in the area is the Martinsburg Formation, at several thousand feet. The most prominent and structurally most interesting formation in the area is the Massanutten Formation, a lower Silurian, nonmarine collection of pure white quartz arenite sandstone and quartz-pebble conglomerate. It shows other, less pure facies, that we probably will not see. It is up to 1200 feet thick and is ultra-competent, and largely controls the shape of the Massanutten syncline. The folding in the Massanutten formation itself is predominantly solution and flexural-flow folding, due to the lack of incompetent beds, and the flow mechanism is pressure solution rather than dislocation creep.

The next most significant formation structurally is the Middle Silurian Bloomsburg Formation. The Bloomsburg comprises about 400 to 500 feet of interbedded red-brown shale and sandstone. With considerable internal competence contrast, deformation in the Bloomsburg is largely by flexural slip rather than flow.

The marginal reaches of the main valley floor, adjacent to the steep walls, are covered with landslide and debris-flow material termed colluvium. The colluvium material is made up of coarse boulders and talus blocks set in a finer-grained, often sandy to clayey matrix. The colluvium is arranged in distinct flows or lobes of debris-flow material, and lobe boundaries are often prominently visible. The courses or creeks often trace out the edges of debris flows, and accentuate the lobe appearance. The creeks often cut down through the colluvium, and bedrock is exposed in the creek beds. So pay attention to what is in the creek beds; that is the most likely place to find outcrop in the valley floor.

TO DO ON THE TRAVERSE:

On the traverses, keep your eyes and your map open, and keep track of your position on the map. Use topography and the Brunton to keep oriented, and where you get in trouble use the dip of the rocks as a guide.

Look closely at the rocks. Look at what **lithology** the rock is: what rock name would you use? How would you describe grain size? sorting? maturity? composition?

Look for primary sedimentary structures; look for bedding and cross-bedding, graded bedding. Look for facing direction; look for truncation, look for concavity of cross-bed foresets, look for evidence indicating which way is up, i.e. toward younger beds. The table below summarizes the traversing relations between stratigraphy (up- or down-section), dip direction (up- or down-dip), and whether stratigraphic sequence is in normal order or is overturned.

The first law of field geology states **THE ROCKS ARE RIGHT**; if you think dips should be in a different direction than what the rocks indicate, check to make sure your data are reliable, and then rethink your prediction, because the rocks are right.

FRIDAY, NOVEMBER 10:

BLUE HOLE:

- Find several places today to take strike and dip measurements on bedding. In fact many places. Record them in the space below:

map location number	stratigraphic unit	strike	dip	plunge

- Locate on your map the position of each measurement you took. Place a strike and dip symbol, about 1/4 inch long, at the place you took the measurement. Make the intersection of the strike line and the dip line lie exactly on the location of the measurement. Write the degrees of strike away from North near the N end of the strike line, and write the dip angle near the end of the dip line. Do these in ink, because pencil tends to rub off.

- Describe the Martinsburg sandstones along the road with respect to bedding, grain size, color, estimated energy level at the time of deposition.

- At the base of the cliff - describe the Massanutten sandstones with respect to bedding, grain, size, color, and estimated energy level at the time of deposition. Which unit is more proximal, Martinsburg or Massanutten?

- Take strike and dip on the Massanutten at the base of the cliff.

- In the high cliff face, note the sets of systematic joints. How are joints expressed?

- How many sets of joints? Characterize each major set by (1) strike and dip, and (2) average spacing between individual joint planes.

- What criteria do joint sets have to meet to be interpreted as conjugate pairs? Do these joints meet those criteria?

- Look for slickenlines on the joint surfaces. Any consistent sense of movement?

- How would you describe the sedimentary facies of the Massanutten?

- Leaving the cliff, proceeding along the road, are you walking parallel to strike or to dip direction?

- As you proceed along the road, notice the gradual change in the abundance of conglomerate, the average pebble size, and the proportion of finer-grained rock types. What changes do you notice?

- Are we getting higher or lower in the Massanutten Formation? What is your reasoning?

- Notice any changes in the type of bedding or cross-bedding in the Massanutten as we come down the road?

PASSAGE CREEK:

- If conditions permit we will descend from the road to the creek level, and will traverse through the McKenzie and Bloomsburg Formations. What is the strike and dip of the rocks down here?

- In what sedimentologic ways does the McKenzie differ from the Massanutten? Would you call them the same facies?

- The Bloomsburg shows excellent examples of rock **CLEAVAGE**. The cleavage is a parallel splitting property wherein the splitting planes are anywhere from 1 mm to 2 or 3 cm apart. Cleavage generally does not follow bedding, and may have any orientation at all; however, in any one rock, all the cleavage planes are parallel. This is a **spaced cleavage**.

In the Bloomsburg, define bedding and cleavage; they are not parallel.

- List the criteria you used to **define bedding:**

- Measure strike and dip of bedding:

- List the criteria you used to **define cleavage:**

- Determine the strike and dip of cleavage:

- Sketch the relations of bedding to cleavage at the top of the outcrop:

- Is cleavage equally well developed in all lithologies? Which lithologies are most strongly cleaved? Why the difference?

- Does the **spacing** of cleavage change between the different rock types? What could cause this?

LOCATING A FAULT:

- Notice how dip abruptly steepens as you go SW. Look end-on, and draw this change in dip.

- Notice the slickenlines on the steepened bedding planes. Which side moved which way? Use steps.

- Look for the next outcrop SW of this one, beyond the gully. What lithology? What possible formation? Measure strike and dip here.

- List four criteria (that you have just established) for the presence of a fault in the gully.

- We will climb back up to the road and examine exposures of Tonoloway and Keyser limestones in road cuts. This is a tricky outcrop. Look hard for bedding here; the most obvious candidates for bedding surfaces are not bedding. Look end-on to the northeast, nearly parallel to the road. Take a strike and dip here if you can. But be sure to state what surface you took strike and dip <u>of</u>.

I suspect there is a lot of pressure solution going on here, and that if we look for them stylolites will jump out at us.

It's Lunchtime. We'll go to the campground.

MASSANUTTEN MOUNTAIN TRAIL:

After lunch, climb the Massanutten Mountain trail that leads east from the picnic grounds. **THE TRAIL SEEMS LONG, AND IT DEFINITELY IS STEEP AND EXHAUSTING; IT TAKES LONGER THAN YOU THINK. TAKE IT EASY, STOP OFTEN, THERE'S NO HURRY, TAKE WATER WITH YOU, TAKE YOUR FLASHLIGHT (don't ask why).** We'll convene at the top. There's not much to see on the way up, but take your time anyway.

- Just as we get started, we come to Needmore Shale outcrops in the trail. Take strike and dip for reference point. Can you find cleavage here? Present, but difficult to identify.

- At the top: what's the formation exposed here? As you came up, were you walking up- or down-section? Which way would you go to find the Martinsburg Formation?

- At the top, find the trail to the left, and walk NE in a steady, slow climb along the nearly flat ridge crest. There's much outcrop of Massanutten in the trail, low, looks like float, but actually outcrop. Take strike and dip, and mark your location.

- At some point I will locate, turn left and walk out to some large nearly flat outcrops overlooking Fort Valley. Beautiful view, especially if the sun's out. Take strike and dip here. Which way relative to the valley axis to these rocks strike? Does that make sense to you?

HILL 2015:

- Just south of Hill 2015 are large outcrops of Massanutten showing excellent small folds, cross-bedding, channel-cutting, ripples, size- grading (?), and other sedimentologic features. Does this look like the same facies as the Massanutten you saw this morning?

- Sketch some of the cross-beds; show tangential nature of the foresets, show concave-up nature, show truncation.

Just barely north of the summit, to the east, is Blue Ridge Lookout; a good place to do some tectonic synthesizing. The Blue Ridge thrust, comes just over your head here (duck). A good look at the incised meanders of the Shenandoah River.

Leaving Hill 2015: As you start downhill, the **TRAIL TURNS SHARPLY LEFT** without much warning; **LOOK FOR A RED ARROW ON A ROCK BESIDE THE TRAIL**. Easy to miss. If you go too far straight down the hill, you've missed it.

- There is much outcrop along the trail on the way to Buzzard Rock. Take several strike and dips as you go.

BUZZARD ROCK:

- Buzzard Rock overlook. Dip and strike, dip slopes, cross-bedding. Take dip and strike.

- Is this trough cross-bedding or planar cross-bedding? What facies? What reasonable depositional environments?

- Descend in elevation to the Martinsburg-Massanutten contact. It's an unconformity, like it was along the road, but you can't see it here either. Damn.

- Retrace route back to trail, down to vans, to camp. Takes an hour at least to get down. Use your flashlight if you have to.

SATURDAY, NOVEMBER 11:

GREEN MOUNTAIN TRAVERSE

FIELD MAPPING TECHNIQUES: ANATOMY OF FOLDS

By the end of today, you will be able to:

- read topographic contour lines and contour patterns;
- recognize stratigraphic contacts when you encounter them in the field;
- locate contact lines on a map with reasonable accuracy;
- predict the locations of anticline and syncline axes;
- recognize when you have passed axes of folds;
- explain the parallelism and the non-parallelism of fold axes;
- plot fold elements on a stereonet and interpret the net;
- keep track of your position on a traverse by reading topography.

This day will comprise a single, long traverse on which we will do actual field mapping. The traverse will climb 1700 feet vertically to the summit, Meneka Peak. It will ascend the ridge up the stream draws and through the bush, and will descend along Signal Knob trail. Total length will be six miles or more. The traverse will cross the western limb of the main Massanutten fold, and will cross the axis of the neighboring subsidiary folds. We will see many small folds, and will examine the relations of the minor folds to the major fold.

TAKE MUCH WATER AND FOOD.

TO DO ON THE TRAVERSE:

On the traverse we will examine the anatomy of folds and the plunge of folds. We will consider the relation of small folds to large folds, and deal with the concepts of flexural vs. passive folds, slip vs. flow mechanisms, and drag folds. We will collect strike and dip data, and will plot them on a stereonet diagram. You will be able to actually see how the attitudes are distributed on the folds; this will help you considerably in visualizing what a stereonet actually represents.

We will start the traverse at 0800 at the parking lot near Draw 16.

- On the valley floor: we will traverse up the stream, and the stratigraphic units will be pointed out to you. The first rocks are Devonian. Where is this place, structurally, relative to where we ended yesterday?

- Take strike and dip of rocks in the creek along the valley floor. Plot them on your map.

- Keep track of your position on the topo map, and locate pencil lines at the contacts as they cross the stream. Use your colored pencils to color areas of the map where different rock units underlie the soil.

- On the valley floor, examine the colluvium, and locate a debris-flow lobe boundary.

- When we enter the steep-walled canyon, keep looking high on the slopes for the first bedrock exposures. What direction of dip? How steep? What unit? Where's the Bloomsburg? What can you say about the relative resistance of the Bloomsburg?

WHERE THE TRAIL CROSSES THE CREEK, FOLLOW THE CREEK UP THE DRAW.

- As we have come from the road thus far, which stratigraphic direction have we been walking (toward younger beds or toward older beds)?

ANALYZE A FOLD:

- Find a small fold in the Massanutten. There are plenty to go around. From the opposite valley wall, or other position where you can get a good look at the fold, draw a careful sketch of the shape of the fold. **DRAW IT CAREFULLY AND ACCURATELY**. Pay attention to the thickening or thinning of beds in the nose, the orientation of the axial surface of the fold, and the possible development of a spaced fracture cleavage in the hinge region (and not on the limbs).

- Measure strike and dip of each limb. Measure strike and dip of bedding on the axis. Use your notebook to approximate the axial surface, and measure its strike and dip. Measure the plunge of the axis.

FORM OF THE FOLD:

- As you go up the canyon, keep track of large-scale, overall changes in the dip and dip direction of the rocks. As you came into the canyon, what was the dip of the rocks? What's the dip here at the upper end? What's going on? Sketch a cross-section showing what you think the large-scale structure here is.

CREATING A MODEL:

- What is the trend of the plunge of the small folds? Measure several.

- What direction do the beds here strike?

- What's the relation between the directions of strike of bedding and trend of plunge? What is that telling us about where were are structurally?

- As you continue to climb, be on the lookout for a change in dip direction. What have we passed? Which way are we walking now (up-section or down-section)? Make a structural model (hypothesis to more normal people) at this point: what is the structure we are approaching? and what stratigraphic unit should we encounter next? How does this sit with the cross-section you just drew?

- Suppose the next unit you encounter isn't the one you expected, i.e. it isn't the next unit in the stratigraphic column. Does this automatically invalidate your model?

TESTING THE MODEL:

- Lo and Behold - were we right or wrong? What is the lithology here? What is this formation? What is its dip direction? Is your model of structural relations supported or refuted?

- If your model is supported, what formation would you expect to find next? What direction would you go to find it? and what would its dip direction be?

- If your model is refuted, how can you alter your model to correctly predict what you now know the relations actually are?

- As we leave this place: What does your model predict should happen ahead of us? What should we expect to see?

Take the left fork out of here, and proceed upstream to the next outcrops (maybe 25-50 m)

- What is the lithology here?

- What formation is this?

- What direction does it dip? Take strike and dip here.

- Good examples of **cleavage** in these rocks, and of **refraction of cleavage**. Refraction is caused by competence contrast. Draw a sketch of the cleavage refraction.

- In which lithology is the cleavage most nearly parallel to the axial plane of the fold?

- What is the orientation of the axial surface of the major fold?

- Using the refraction relations, and remembering that this is a syncline? is the axial surface northwest or southeast of this position?

- Where is our present position on the structure these rocks are showing?

- Leaving this place - as we go up the draw, are we going up- or down-section? What units should you expect to find ahead?

Continue up the draw. **KEEP YOUR MODEL GOING; NURSE AND PROTECT YOUR MODEL. KEEP IT HEALTHY.** In maybe 100-200 m, locate low, ledgy outcrops on the south wall of the draw.

- What formation?

- What strike and dip?

- Facing which way?

- What are the structural implications of this facing direction?

- What have we passed? Where (relative to present position) is the axis? Locate axis on your map).

- How did your model handle these data?

- Sketch a cross-section of what we've actually come through so far. At our present position on the section, draw a heavy vertical line. To the NW of that line draw in what you **predict** we will find as we continue northwest.

The draw gradually turns to the right, more N. The trail is up the left draw wall, to the NW. Find the trail, follow it into flat saddle; it has a yellow (?) blaze.

- Given your last strike and dip, and noting how the trail as turned, which way relative to strike of bedding are we walking as we come in to this saddle?

<u>TAKE</u> <u>THE</u> <u>LEFT</u> <u>FORK</u> where the trail forks in the saddle.

- As you turn left here, what are you walking parallel to now - dip or strike?

- As you climb, think about what you are climbing <u>toward:</u> if we are going down-section as we go up-slope, should we be approaching the axis of an syncline or an anticline? Keep testing your model against the outcrops you come to on the trail. Take strike and dip on the rocks, locate your positions on the map, etc.

- Just below the summit: there is good outcrop just off the trail. Take strike and dip, and determine facing direction, on the rocks on and close to the trail. Test them against your model.

- The top of the ridge. ***LUNCH.*** What formation are we in? What is the direction of dip here? Take strike and dip.

- After lunch, turn NE, and follow the trail (white blaze) along the ridge crest toward the summit. Find outcrop, and measure strike and dip and facing direction.

- What does cross-bedding say about facing direction? Which direction would you go to find the Bloomsburg Formation? the Martinsburg?

- Does dip direction here support or refute what your model predicted would be here? If supported, what does your model predict should happen west of this ridge? If refuted, how must you modify your model to account for what is actually here? And where is the anticline axis?

Keep track of whether the trail is straight or turns slowly NE. Makes a difference to your structural interpretations.

- As we approach Meneka Peak, notice the progressive change in dips. Take strike and dip. Dips are generally too low here to use the Brunton in the usual way, because the compass rides up on the metal ring on the base and does not give a true reading. Take dip and dip direction here, and determine strike by adding or subtracting 90°.

- Back to the change in dips: what's going on here? and why?

MENEKA PEAK. Massanutten summit. Top of the world. 2393 feet. Notice the steepness, the jaggedness of this alpine crag. Where is it? Hard to find. Find the benchmark that is on some piece of solidly attached Massanutten float. A real permanent elevation marker.

- On your map, draw in the anticline axis across the area we traversed in the steep climb. Which beds does it pass through, and which beds does it separate?

- Draw a summary cross-section of the structure we've crossed on the traverse. Show the relations you actually found rather than the ones your model might have predicted.

Leaving Meneka: take the trail NE down off the knob. Take several S and Ds going down.

When the trail levels out, turn due N and crash through the brush to find the Signal Knob trail. Follow it W (left) to Signal Knob.

SIGNAL KNOB:

Shenandoah Valley. Thrust faults, cut-out stratigraphy, decollement. Civil War history.

SIGNAL KNOB TRAIL: THE TRIP DOWN:

The trip down is along Signal Knob trail; follow it all the way to road at bottom. It's a long trail; it winds around many ridges and valleys, and seems to take forever. **DON'T HURRY** or run; the trail is rocky and rough and murder on your feet, and you don't want to twist an ankle or knee. Take short steps, shorten your stride, place less impact stress on your knees. It's a solid hour and a half doing down; get your flashlight out.

Watch how you walk downhill - don't swing your legs out front too far, because it tears hell out of the knees. Keep your knees bent at all times; don't lock your knee straight-out. Trudge, flat-footed in need be, but don't stride like normal walking. Don't let your momentum carry you forward too fast; consciously restrain your rate of walking. Walk with you weight back on your heels. **SHORTEN** your stride; take more but shorter steps. Your knees will thank you.

- There are few good outcrops on the trail, that give important data for the stereonet. **GET SOME STRIKES AN DIPS AND FACINGS GOING DOWN.** Past the Buzzard Rock overlook - look for Massanutten and Bloomsburg dipping steeply SW in the trail. SOUTHWEST? you kidding? What could be going on here?

END OF THE HIKE. DO YOU HAVE ANY FEET LEFT? It's Miller time. We'll go directly to dinner somewhere, then directly home. Arrive Newark about 10.

FOR MONDAY: COMPILE A LIST ON ONE SHEET OF PAPER OF ALL YOUR STRIKES AND DIPS FROM THE TWO DAYS, REGARDLESS OF WHERE THEY ARE ON THE MAJOR FOLD.

BACK IN NEWARK:

- Plot on a stereonet the strike-and-dip data and plunge data you collected on the Massanutten fold. Draw the girdle, find the Pi axis, and compare the Pi axis with your measured fold-axis data.

- From your stereonet data, what is the orientation and plunge of the Massanutten Synclinorium? Write a description of the nature and geometry of the folding in the Massanutten Mountain area.

- Are there any attitude or plunge readings you took that are not explainable by your stereonet girdle and Pi axis? What does this tell you about the relation between large folds and small folds?