SATURDAY, NOVEMBER 7, 1992

STRUCTURE OF THE BLUE RIDGE IN THE HARPERS FERRY AREA

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

- handle a Brunton compass with ease and confidence;
- identify cleavage in various kinds of rocks, and recognize the types of cleavage;
- use cleavage-bedding relationships to identify and interpret structural relations; and
- construct a stereonet analysis of a folded region.

This day will be spent examining the structural geology of the Blue Ridge anticlinorium in the area between Frederick, MD and Harpers Ferry, WV. The day will comprise examination of at least four outcrops.

You will measure strikes and dips of structural elements in the rocks. Back in Newark you will construct a stereonet of the data. and from the stereogram you will interpret the geometry of the Blue Ridge fold. The central outcome of the day will be an increased understanding of the Blue Ridge fold, which you gain by measuring numerical data in the field.

ASPECTS OF THE GEOLOGY:

The Blue Ridge structural province of the Appalachian mountains is an elongate region maybe 50 miles wide by up to 800 miles long, stretching from Harrisburg to Georgia. The main structural element in some places is a strongly asymmetric fold, and in other places a thrust fault. The purpose of today's exercise is to determine the type of structural element in this area, and to understand the form and origin of the structure.

Rocks in the Blue Ridge are Middle to Late Precambrian in age, and grade up into Lower Paleozoic cover rocks. Consult the Stratigraphy section for the appropriate units and formations. The resistant, ridge-formers are the Catoctin metabasalt and the Weverton quartzite (and the Harpers phyllite to a lesser extent); the form of the structure is outlined by the ridges.

STRUCTURAL ELEMENTS:

Your interpretation of the Blue Ridge fold will be based on strike, dip and plunge measurements on **six structures**, listed below:

- poles to bedding, east limb
- poles to bedding, west limb
- poles to cleavage, east limb
- poles to cleavage, west limb
- lineations due to plunge of slickenlines
- lineations due to cleavage-bedding intersections

It is very unlikely that all six, or even as many as four, will be seen in the same outcrop. But by combining data from different outcrops, you can get data for all six. These combined data will allow you to test whether there are differences between east and west limbs, and whether the linear structures (lineations) are related to the planar structures (cleavage, and bedding).

You should develop some symbol nomenclature (triangle, dot, square, diamond, etc.) for each structure, and use that symbol when plotting those data points. This is very important, because it will allow you to differentiate between types and locations of data points when you synthesize and interpret the large-scale picture.

Bring your stereonet on the trip, and we'll plot the data in the field as we collect it.

CLEAVAGE AND BEDDING:

To understand the Blue Ridge fold, you must understand the relation between folding, cleavage and bedding. In the space below draw a sketch of a simple, upright, symmetrical, open anticline-syncline pair. Show several beds being folded. Label one bed "competent" and another "incompetent". Draw in the axial surfaces for the folds. If the folds are upright and symmetrical, what orientation will the axial surfaces have?

Now draw in **axial plane cleavage**. The cleavage will be parallel to the axial surfaces of the folds, and will cut each bed independent of the orientation of bedding. Draw in many cleavage planes, in light pencil. Notice that in this particular drawing the cleavage dips steeper than the bedding, everywhere on the fold. Notice also that the **angle between cleavage and bedding** changes as position on the folds changes; cleavage and bedding are **at right angles at the hinges (on the axes) of the folds**. And are potentially parallel on the limbs, if the fold is isoclinal.

- Now sketch an **overturned anticline-syncline pair**. Overturned folds have one limb that is stratigraphically inverted, that is, older rocks overlie younger rocks in vertical section. Again show several beds, and label one "competent" and one "incompetent". Again, draw cleavage planes parallel to the axial surfaces. In this drawing, the cleavage dips (is not vertical), and because of the overturning **cleavage dips steeper than beds on one limb, and less steeply than beds on the other limb.**

- Figure out the relation between steepness of dip of bedding and of cleavage, and overturning (whether bedding is overturned or right-way-up), and state that relationship as a general rule. It is a consistent and very usable relationship.

We are now ready to examine the Blue Ridge fold. We will work from south to north, and end up at the best exposure.

STOP 1: SOUTH MOUNTAIN, EAST END

The rocks here belong to the Catoctin Formation, and consist of altered basalts and gabbros. The section is reported to consist of stacked basalt flows, with distinct flow bottoms and flow tops, but I haven't seen definite evidence yet to support this. You will see good medium-grained igneous texture, and some whitish, round, maybe 1- to 2-mm grains (feldspars) that could be fillings of gas bubbles (vesicles) in the tops of lava flows.

- Find the cleavage. How many cleavages can you identify here? Which of them are true cleavage, and which are joints? Do you see any cleavage here whose attitude resembles those you have already measured at other outcrops?

- Which rock type will be most likely to contain well-developed cleavage?

- Which dips more steeply, cleavage or bedding?

- Are the rocks right-way-up or overturned?

- What is the strain significance of the large tension gashes?

STOP 2: SOUTH MOUNTAIN, WEST END

The rocks here belong to the Weverton Formation. The light-colored quartzites may be called "Weverton facies", and are typical of the Weverton. The dark-colored sandstones and conglomerates may be called "Harpers facies", and are typical of the Harpers Formation that overlies the Weverton. The interbedding seen in this outcrop reflects an alternation of depositional regimes, and is an original, sedimentary feature of the rock. This outcrop contains excellent examples of many sedimentary and tectonic structures, and we could profitably spend all day here.

- Find <u>bedding</u> here. Look for variations in grain size, or size grading, or compositional changes, or shale beds, to define bedding. Take strike and dip of bedding.

- You will observe and use 4 kinds of information to establish facing direction. List four ways of telling which way is toward stratigraphically younger rocks (i.e., which way's up).

- Look for <u>cross-bedding</u>. It's there, particularly in the western exposures of Weverton facies. Which way is stratigraphically up? Based <u>only on the cross-bedding</u>, are the rocks right-way-up, or are they upside down?

- Find <u>cleavage</u>. It's not widely developed, but it's here. In which rock types is cleavage most strongly developed?

- Take strike and dip of cleavage.

- Which dips steeper, cleavage or bedding? Based only on cleavage-bedding, are the beds normal or overturned?

- Find the conglomerate bed in the Harpers facies rocks. Explain the shape of the bed - it is sedimentary or tectonic?

- Look for grading of pebble sizes in that conglomerate bed. Based only on pebble grading, is the bed right-way-up or upside down?

- Which way does the Weverton dip, toward younger rocks or toward older rocks? Think about the implications of the direction the beds dip: they dip under the rocks in the direction of dip; if right-way-up, beds dip under younger rocks. Is the Weverton here right-way-up, or upside down?

- Look on the east-dipping surfaces in the Harpers-facies rocks, and observe a lineation trending about horizontally across the surface. This is an intersection lineation, in contrast to the transport lineation seen at Stop 5. What might be intersecting to cause this lineation?

- There are small kink folds and crenulation folds in the fine-grained Harpers-facies rocks. These kink folds cut both cleavage and bedding, and show up as very small ridges on phyllite cleavage planes. These are late structures, nearly brittle, and cut across all earlier structures. Measure strike and dip of kink-fold planes.

What is the significance of the tension gashes in these rocks?

STOP 3: ELK RIDGE: US 340, AT "JEFFERSON COUNTY" SIGN

The rocks here are the Weverton Formation. **DO NOT CROSS HIGHWAY**. Do all your examining from the north side of the highway.

SETUP: Cleavage in passive rocks forms essentially parallel to the axial surface of folds.

- Where on a fold can cleavage be parallel to bedding? What adjective can you use for a fold where that is the case?

- Where on a fold can cleavage be normal (or nearly so) to bedding?

- Make a sketch below of a single fold with cleavage parallel to bedding, and cleavage normal to bedding, in the appropriate places.

THE ROCKS:

- Find <u>recumbent folds</u> in the Weverton across the road, about at eye level. Obviously, one set of limbs is upside down; the trick is to determine which one. Walk east along the road, and note the stacking-up of recumbent folds.

- What would you say the general orientation of the Weverton Formation is here, based on what you see?

- If cleavage were developed in these rocks, what orientation would you expect it to have? Draw a sketch showing these relations.

- It turns out that cleavage here is essentially horizontal, and is parallel to the axes of the recumbent folds.

- Here's the tricky part: as we travel west along the road, we encounter Harpers Formation, also with horizontal cleavage. How can this be? What must this mean about the orientations of bedding and of cleavage? What does it say about parallelism of bedding and cleavage? Can bedding be parallel to cleavage? Where must we be on the fold?

- Draw a rough sketch showing your concept of the relations between gross-scale bedding, cleavage, and the recumbent folds in the Weverton. Where must we be on the Blue Ridge fold here?

STOP 4: OLD US 340, JEFFERSON, MD

The rocks here belong to the Weverton Formation. They are quartzites, with minor interbedded schists.

- Find bedding. This may be harder than you think. Make sure it is bedding. What rock type would be best to look in to find bedding? Take strike and dip on bedding.

- Find cleavage. This too may be harder than you think. What rock type would be best to look in to find cleavage? Take strike and dip of cleavage.

- Look for cross-bedding in the quartzites. I'll buy a beer for anyone who finds undoubted cross-bedding. Make sure it is really cross-bedding. Is it right-way-up or upside down? It makes a hell of a difference to your interpretation, so don't merely guess; look at it with your head right-way-up, and with your head upside down.

- Find and list evidence to indicate tectonic transport direction. Make a sketch of what you find.

STOP 5: MD 17, SOUTH OF MIDDLETOWN

The rocks here belong to the Pedlar Gneiss, the Precambrian basement in the core of the Blue Ridge fold. The unaltered rock is a light-colored granitic gneiss, with abundant quartz and feldspar. But here the gneiss is cataclastic, and has been converted to **mylonite** in various stages. Along with the cataclasis has come growth of low-grade-metamorphic, green minerals including chlorite, actinolite and epidote, that give the rock its dark color. What looks like sedimentary layering between coarse and fine dark rocks is actually cataclastic layering, structurally produced by grinding and pulverizing the rock mechanically. Varying degrees of cataclasis may be seen where coarse-grained, whitish gneiss passes gradationally into darker, finer-grained, more closely layered gneiss. Excellent examples of cataclasis exist here, and will be pointed out,

- Sketch the relations shown by a tectonic, cataclastic "fish" and the rock around it. Indicate the variations in gneissic layering in the different parts of your drawing.

- Try to identify cleavage in the outcrop. Be alert to the possibility that cleavage may dip into the hillside, so look in the third dimension if you can. Measure strike and dip of cleavage.

- Find slickensides or slickenlines on various cleavage or fracture surfaces. These slickenlines define a lineation on the cleavage surfaces. Measure the plunge of the lineation of the slickenlines. What sense of movement do they give?

- Important - evaluate how closely the slickenlines parallel the foliation in the gneiss. What could that imply about the origin of the foliation? And why don't all the rocks have that same foliation direction?

STOP 6: **HIGH KNOB,** Gambrill State Park, west of Frederick

The slaty rocks here belong to the Loudoun Formation. The grainy rocks here belong to the basal Weverton Formation. According to the maps, this location is on the nose of a gently N-plunging minor (but still very large), drag fold on the eastern limb of the Blue Ridge fold.

THE VALLEY LOOKOUT:

At the lookout: Introduction to the Blue Ridge structure, and the plan for the day. Topography vs. geology.

- The lookout platform: excellent exposures of the Loudoun Formation here; look at the rocks just to the left (south) of the lookout platform. The most prominent planar feature is cleavage. Look (hard) for bedding in the Loudoun: a beer for any undoubted bedding found. Take strike and dip of cleavage here.

- In those same rocks left of the platform find an excellent <u>small fold</u>, probably a small drag fold. Note that it's asymmetric and overturned. Measure the plunge of the fold axis. Make a sketch of the fold in profile. If it is a drag fold, what does it indicate about the direction of tectonic transport?

- The small fold is itself folded by small <u>kink</u> <u>folds</u>, like those we saw at South Mountain. Draw the kink folds in their present orientation, and indicate the sense of shear that caused them.

- Look hard and closely in the Loudoun for gash vein and/or quartz veins that **show offset along the cleavage**. Sketch these relations if you find them. Which side has been moved which direction?

Walk east toward the stone building. On the way, locate the approximate position of the contact between the Loudoun Formation slates and the Weverton Formation quartzites. Should be easy to find.

THE STONE BUILDING:

- Identify the cleavage in both Weverton and Loudoun lithologies. Measure strike and dip of cleavage.

- Describe the differences in spacing, flatness and planeness of cleavage in quartzite and in phyllite. Cleavage planes that are very close together is called **pervasive** or **penetrative**, while cleavage planes that are farther apart (2-3 mm up to 2-3 cm apart) is called **spaced** cleavage. In which rock is the cleavage "better", or "more strongly", developed (that means more closely spaced, flatter, more planar, more pervasive)? What do you think controls the spacing of

cleavage in rocks?

- Near the parking lot are excellent examples of <u>sedimentary</u> <u>bedding</u> with weak spaced cleavage in grainy, sand-size rocks, and <u>penetrative</u> <u>cleavage</u> with weak bedding in fine-grained rocks. Which dips steeper here, bedding or cleavage? Sketch bedding-cleavage relationships here.

**bedding in the quartzites. Look for cross-bedding, size-
dding, and changes in color that correlate with changes in**
on. etc. **Look closely for bedding in these rocks; it's**
ee sometimes. Look for concavity of cross-bed foresets as
dicators. Holler if you find particularly clear relations.

methods which you have used here to establish whether the
right-way-up or overturned.

the rocks around here for small-scale indicators of direction
ansport: offset veins, drag folds, folded cleavage,
cleavage-bedding intersection lineations, etc. Sketch a few.

- Descend to the large outcrops down the hill south of and below the Visitor House. **<u>WATCH OUT FOR POISON IVY.</u>** On the S-facing face observe good **<u>drag folds</u>** in the quartz veins. What is being dragged here? bedding? or cleavage? and if cleavage, mustn't it be earlier than the folding? Sketch a drag fold.

SYNTHESIS OF THE BLUE RIDGE FOLD:

Stereonet:

At this point your notebook should contain six differently marked types of data: bedding on east limb, bedding on west limb, cleavage on east limb, cleavage on west limb, cleavage/bedding intersection lineations, and slickenline lineations.

- Using different symbols, plot your limbs data (actually, plot poles to limbs) on a stereonet.

- Draw an average Pi girdle (circle) through the poles-to-limbs data points.

- Plot your cleavage-bedding intersection data and your slickenline lineation data. Both of these are **lineation** data. Use appropriate symbols.

- Find the Pi axis for the bedding-data girdle. What other data set is that point near? What geometric element does the point represent? What can you say about the relation of the data set to the fold geometry?

- Draw and label the axial plane on the stereonet.

- Plot (using appropriate symbols) poles to cleavage, from each limb. Determine whether there is a difference in the orientation of cleavage between east and west limbs, or whether cleavage orientation is the same across the entire structure.

- Where does the slickenline lineation data set fall relative to the girdle? What does that tell you about the mechanism of generation of the Blue Ridge fold?

- Locate the average pole to cleavage. Where does it fall relative to the bedding girdle?

- What is the angular relationship between the slickenline-lineation data set and the average pole to cleavage? What does that suggest to you about the nature and origin of the cleavage?

- Use the cross-section sheet to synthesize your observation and measurements into a <u>schematic</u> <u>cross-section</u> of the Blue Ridge fold system. Show eastern limb, western limb, hinge area, cleavage, and (using arrows) direction of tectonic transport.

IF THERE IS TIME:

SATURDAY AFTERNOON, NOVEMBER 7, 1992

SHENANDOAH NATIONAL PARK

This afternoon will be spent in leisurely tourist-type cruising along the Skyline Drive in Shenandoah National Park, looking at the Catoctin metabasalt and the Blue Ridge Thrust Fault. If possible, we will get to Luray and the outstanding recumbent fold at stop 6.

STOP 1. MIDDLE ORDOVICIAN CARBONATES, VALLEY AND RIDGE

This exposure contains a complete section of the Middle Ordovician section, the best in the central Appalachians. Detailed description of section, including Oranda, Edinburg, Lincolnshire, New Market and Rockdale Run Formations, is on next page. Knox unconformity (lower-Middle Ordovician) exposed near base of section. A great variety of limestone types is represented. Bentonite beds are tan, clay-rich zones. Note depositional and deformational effects.

STOP 2. SIGNAL KNOB OVERLOOK: CATOCTIN GREENSTONE

Good view of Valley and Ridge province from east side. Rocks here are late Precambrian Catoctin Greenstone, metamorphosed to greenschist grade and full of epidote. A sequence of thin flows and interbedded clastic sedimentary-volcanic debris. Reddened top of lower flow. Breccias, scoria chunks, etc.

STOP 3. GOONEY CREEK OVERLOOK: BLUE RIDGE THRUST FAULT

View below to north shows trace of Blue Ridge thrust fault, and three resistant hills that occur near the leading edge.

STOP 4. INDIAN RUN OVERLOOK: CATOCTIN GREENSTONE

Here exposed are excellent cooling joints and resulting columns. Layers of sediment(?) between flows, amygdaloidal textures, lineations and slickensides (should be oriented which way?), and abundant epidote. Whence cameth so much epidote?

STOP 5. THORNTON HOLLOW OVERLOOK: CAMBRIAN UNCONFORMITY

Examine Catoctin Greenstone in roadside exposures. Then climb woods above road cut to search for unconformity and basal, arse facies of Weverton Quartzite above it. Should be nglomeratic, This unconformity marks the base of the ntinuous Paleozoic section of the Valley and Ridge province, d has been called basal Cambrian or even earlier ocambrian).

EDINBURG LIMESTONE: EASTERN VALLEY AND RIDGE TECTONICS

posed here is recumbent, westward-verging flexural fold in inburg limestones. Note horizontal axial plane, and rection of tectonic transport. Upper limb and much of lower mb are allochthonous, and have slid over plane exposed in ees. Note fracturing along axial plane.

MARTINSBURG FORMATION: WESTERN VALLEY AND RIDGE TECTONICS

op here is just west of summit of New Market Gap. rtinsburg Formation here displays good turbidite structures, d Bouma cycles, and allows you to determine tops. Cleavage re is vertical, or nearly so.

BROCKS GAP: TACONIC CLASTIC WEDGE

cks exposed here include the upper parts of the Reedsville (western correlative of Martinsburg Formation), Oswego ndstone and Juniata Formation. These two units are not esent on Massanutten Mountain, and represent a considerable ickening of the interval between Martinsburg and Massanutten. p of Reedsville marked by disappearance of fossils. Oswego d Juniata represent clastic debris shed off Taconic mountains late Ordovician. Note cross-bedding, channelling. tcrop is faulted; Tuscarora theoretically not present.

CHIMNEY ROCK. ORISKANY SANDSTONE

esistant coarse fossiliferous orthoquartzites of Oriskany ormation exposed in wall-like form, as surrounding rocks have een weathered away. *Costifspirifer arenosis* abundant in loat.