# Field-based Instruction as Part of a Balanced Geoscience Curriculum at Washington and Lee University

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## ABSTRACT

Traditionally at Washington and Lee University teaching in the field has been the core of our geology curriculum. We emphasize fieldwork at all levels of our instruction from the field-based introductory courses to our senior theses. We are fortunate to be located in a geologically diverse location (in the Valley and Ridge of Virginia and within minutes of the Blue Ridge Mountains). The close proximity of geologic variety allows us to spend nearly every class or laboratory period outside. We view fieldwork, however, as just the beginning of geoscience education. A crucial aspect of field geology is making observations and synthesizing the data collected. It is equally important for students to have well-developed skills in field methods, in analytical techniques, in computation and modeling, and in synthesis and presentation. To emphasize all of these aspects, our coursework is largely focused on emulating the process of research. Because we have had such a strong field emphasis, we are striving to strike a balance in our curriculum. We will present 3 examples of integrated exercises in our geology courses (including introductory geology, sedimentary geology, and geochemistry).

## INTRODUCTION

Washington and Lee University is located in the Valley and Ridge province of Virginia and within minutes of the Blue Ridge Mountains (Figure 1). Our department is situated in the Appalachian fold and thrust belt atop Cabro-Ordivician carbonates. Grenville age igneous and metamorphic complexes are approximately 10 km to the east and Silurian sandstones and Devonian shales 20 km to the west. The close proximity of geologic variety allows us to spend nearly every class or laboratory period outside. We are a 4-faculty department within a small liberal arts college. Our introductory courses have an average of 20 students per class and our upper-level courses an average class size of 8 or 9. For us, fieldwork has traditionally been the core of our geology curriculum. The solid basis for our field-intensive instruction has been founded on years of regional geological experience (Spencer, 1990; www.wlu.edu).

We emphasize fieldwork at all levels of our instruction from the field-based introductory courses to our senior thesis projects. Learning in a hands-on field setting is one of the best ways to reinforce topics learned in the classroom, to integrate academic and experiential learning and to demonstrate the interrelationships of geoscience sub-disciplines (e.g. Lord, 1999; Noll, 2003). Learning to be an effective field scientist, however, is just the beginning of a balanced geoscience education. A crucial aspect of field geology is making observations and synthesizing the data collected. It is equally important for students to have well-developed skills in field methods, in analytical techniques, in computation and modeling, and in synthesis and presentation. To emphasize all of these aspects, our coursework is evolving to focus on emulating the process of research. We are working to fold parts of our own local research into the classroom and to have our students complete projects that begin with field data collection and follow through the analysis and computational phases. We also work heavily with students in our summer research and believe this is one of our most valuable teaching tools. We attempt to make an integrated approach to our teaching. In the following three examples we present a range of activities from our curriculum (introductory geology, sedimentary geology and geochemistry) that emphasize our incorporation of a field component.

## EXAMPLE 1: INTRODUCTORY PHYSICAL GEOLOGY PACE AND COMPASS / GPS / GIS MAPPING

This is the first project of our introductory physical geology class. The course attracts both prospective majors and those satisfying a general education requirement because it has a large field component. The purpose of this lab is to familiarize students with 2 instruments commonly used by field geologists (a compass and a GPS unit), ways of acquiring spatial data, and evaluating the quality of the data collected. In addition, students are exposed to the techniques of GIS mapping that are so commonly employed today by professional geologists. Our exercise is based on previous studies that have incorporated and emphasized the importance of using pace and compass in field instruction (Reichard, 2002), using GPS in introductory classes (Herrstrom, 1999), and using GIS and GPS in field instruction (Onasch and Frizado, 1996; Ludman, 2000; Purk and Pair, 1998). Our exercise extends these examples to give introductory students exposure to field data collection using pace, compass and GPS, and analysis using spreadsheet analysis and GIS.

**Data Collection** - After an introduction to pace and compass surveying, and to a GPS unit, students work in groups of 3 collecting pace, bearing, and GPS waypoints as they conduct a survey loop on campus at survey stations of their choosing. They have a USGS orthorectified aerial photo of campus on which they mark the location of each station. In addition, one GPS unit is left in a fixed location and the entire class contributes to repeat measures of this location.

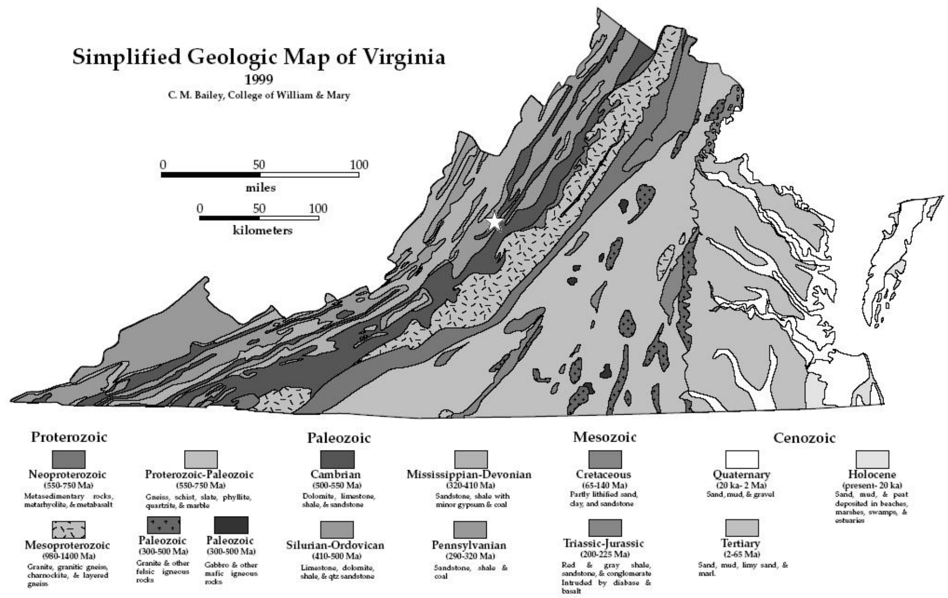


**Figure 1. Simplified Geologic Map of Virginia (Bailey, 1999) showing the location of Washington and Lee University.**

**Data Analysis** - Students input the data into Excel and then reduce the pace and compass data to UTM locations using simple trigonometry (Figure 2). This gives students an appreciation for data reduction as they need to construct simple formulae and input them into Excel.

We next have the students run some simple statistics on the repeat GPS measurements including calculating the 95% confidence of the sample to determine the precision of the GPS measurements. Students generally think the GPS unit is the "correct" measurement of the location because they can see an exact number in the digital read out, and thus they interpret this as the precision of the unit. This analysis shows them that there is indeed uncertainty in the measurements, and gives them an objective measure of this uncertainty that they can use later in their evaluation of the results.

Students next open an ArcMap GIS project to load their data into the GIS. The project has a digital version of the orthorectified aerial photo of campus, and after some data manipulation the students are able to take their data from Excel into ArcMap and display their survey stations on the orthophoto.

**Data Interpretation** - After analysis, students turn in a printout of their orthophoto with survey points plotted and labeled (Figure 3). They also turn in a plot of the GPS uncertainty analysis with 95% confidence displayed as a box around the mean of the sample. With these plots students turn in a discussion detailing the quality of the different location methods. An excerpt from the assignment:

> State in meters how accurate the GPS and pace-and-compass points are relative to locating using the orthophoto. Discuss the possible sources of error for each method of determining location and what you believe is the greatest error with each method (GPS vs. pace-and-compass). Also discuss the nature of these errors. That is, are the errors operator or instrument dependent, are the errors cumulative or dependent on each individual measurement, etc.? Finally, discuss ways in which you could test your hypotheses as to which errors are most significant. Could you set up a method of determining the uncertainty of your pace-and-compass measures as we did for the GPS measurements? Much of your grade is determined by the thoughtfulness of your discussion.

**How well does this exercise work?** - We have found this is an excellent way to expose students to data analysis, reduction, and GIS while learning to use some basic field instruments. It is equally important for us to teach these skills to potential geoscientists and to liberal arts students. Many students feel overwhelmed with the computer work at first, but learn that they are fully capable of doing the work with some assistance. In their analysis students generally overestimate human measurement error with the pace and compass, and miss the fact that local magnetic fields on campus probably play the largest role in inaccuracies of the pace and compass measures. They also overestimate the quality of the GPS measurements. This is one reason we added the repeat measurements section of the exercise. This demonstrates a method for setting up a determination of the measurement uncertainty. Many students use this is as a template for suggesting other ways they could set up to test their hypotheses, for example: conducting repeat measurements of a bearing at a particular location or from varying distances along a line of bearing and then calculating the 95% confidence of this sample.

## EXAMPLE 2: SEDIMENTOLOGY CHEMICAL AND PHYSICAL WEATHERING PROCESSES

The following 2 exercises are integrated as part of our upper-level sedimentology and stratigraphy course. The objectives of these integrated field/lab exercises are to explore weathering processes, to develop and conduct a

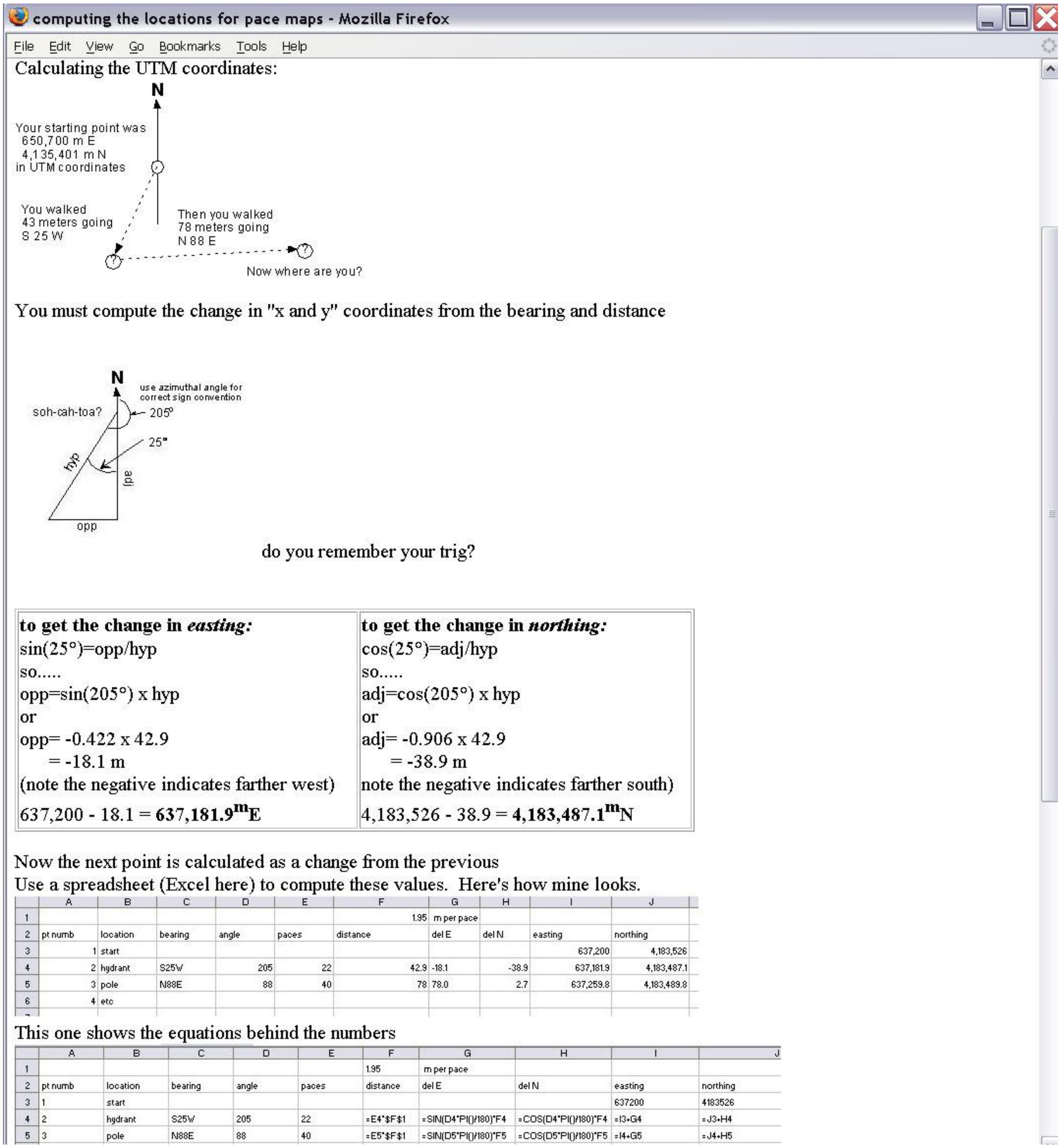


**Figure 3. Plot of GPS locations (boxes) and pace-and-compass (circles) derived locations on top of an orthorectified aerial photo.**

scientific experiment, and to understand science as a collaborative effort. Exercise A is focused on the effects of chemical weathering on various rock types, and Exercise B explores physical weathering processes, differential weathering, and provenance. The students are charged with hypothesis development and testing.

**Data Collection** - The introduction to each experiment begins in the field. The class is taken to a granitic outcrop in the Blue Ridge Mountains to observe, document, and discuss chemical and physical weathering processes. Students collect specimens of fresh and weathered granite, as well as sediments that have accumulated in situ and down slope of the outcrop. For Exercise A, students travel to other sites to collect samples of dolomite, fossiliferous and crystalline limestone, lithic pebble conglomerate and quartz arenite sandstone. For Exercise B, students travel to several streams, creeks and rivers located throughout the region to collect sediments and observe each body of water.

**Experiment Design** - Students are given guidance, rather than instruction, in developing their scientific research. Students work as a group to design the experiment based on very broad questions posed by the instructor. All students must be equally involved in the experimental design and maintenance but may agree to split up tasks once the project is underway. The group


**Figure 3. Web page showing the directions given to introductory geology students for data reduction during the pace and compass / GPS / GIS exercise.**

**Figure 4. W&L students preparing samples in a sedimentary geology laboratory.**

**Figure 5. Smelting iron ore at the Woods Creek Forge, Lexington, VA.**

determines the best way to answer one or all of the questions posed, using the samples they collected.

- Exercise A sample questions: How can you measure the susceptibility of each sample to chemical weathering? How might these samples weather differently? How can you describe the different weathering effects qualitatively in a scientifically meaningful way? How can you quantify the rate of chemical weathering for each sample? Does weathering occur at a linear or non-linear pace? Why or why not?
- Exercise B sample questions: How might the sediments you collected from various river/stream settings differ and why? How does the geologic setting (and bedrock) the stream crosses affect the sediment characteristics of each sample? What role does differential weathering play in determining the sediment characteristics at each site? Will all your hand specimens and sediment samples contain the same ratio of major mineral constituents? Will sediment grains be the same size, shape, etc. at each location? If not, how should your samples differ? Why or why not?

**Hypothesis Development** - Students are provided with the following materials to conduct their experiments: Sieve sets, spatulas, balance, beakers, graduated cylinders, 1% and 10% hydrochloric acid solutions, stereomicroscopes, hand lenses, geologic and topographic maps of the study area, label tape, Petri dishes, permanent markers, rock hammers, weigh paper, access to a low temperature oven, and any other materials practically available (Figure 4). Each group is instructed to formulate several working hypotheses to be explored during data collection and analysis.

This step will vary depending on the experiment design of each group. However, the instructor can pose questions to help guide the students in their experimental work. Sample questions for Exercise A: Are replicates necessary to accurately test weathering of each rock or sediment sample? If so, how many replicates should you test? At what time intervals should you test your samples to get high-resolution data on weathering? If using acid, should the acid be replaced during the experiment?

Each person in the group is responsible for writing a final individual report (less than 5 pages) that consists of: Initial hypotheses, methods, a data table, graphs of results, written results, discussion, conclusion, and what you would do differently next time. Students may all choose to pursue the same hypothesis, different hypotheses, or several hypotheses in their paper.

**How Well Does this Exercise Work?** - After completing Exercise A students enjoyed developing their own experiment protocol and spent more time and effort on the project than expected. They accepted problems with experiment design and adjusted accordingly. They likely would have appreciated a more thorough follow-up after the experiment period. After completing Exercise B students indicated in an informal group discussion that more background information should have been provided before the sample collection and that more direction should have been provided during hypothesis development. They also agreed that the interpretation of results (the paper) should have been more structured. However, students indicated they liked the brainstorming process of developing hypotheses and most students appreciated working with their own samples. In the end of course evaluations in Winter term 2004, 2 of 5 students cited this experiment when asked, 'What did you like the best about this course?'

## EXAMPLE 3: GEOCHEMISTY REDOX PROCESSES: IRON ORE FORMATION AND IRON SMELTING

The following example is taught as part of our geochemistry course for upper-level majors with the purpose of introducing students to oxidation and reduction reactions using a field example of local iron geochemistry. The early economy of our community was founded on the iron industry and the proximity to these (now abandoned) ore deposits. The project includes investigation of the composition of local ore formation as an oxidation process (weathering of charnokite) and smelting of iron (to iron metal) as a reduction process. The series of exercises teaches the concepts of field sample collection, laboratory analysis, and data processing and computation.

The multi-phase exercise includes introductory lectures on oxidation / reduction chemistry, field collection of ore along the western flank of the Blue Ridge, collection of possible source rocks (chosen from student investigation of geologic maps and historical ore mining maps), exploration of nearby 19th century iron furnaces, dissolution (of the whole rock and ores) and analysis of elemental chemistry using ICP and mineralogy using XRD. The students also participate in the smelting of iron ore at the Rockbridge Bloomery (operated by a local blacksmith, Lee Sauder, along with colleagues interested in the history of iron production; for more information about this unique bloomery please visit iron.wlu.edu). Students help to produce a bloom (elemental iron) using ore collected from the field (Figure 5). Here the students learn the direct reduction process firsthand as well as the history of the industry. The students then determine possible ore source and calculate the redox reactions for both the oxidation reactions in ore formation and reduction in the smelting process.

**How Well Does this Exercise Work?** - The skills taught in this exercise include an introduction to local geology and geochemical concepts, field techniques, sample processing and rock dissolution, analytical instrumentation (ICP - including standard preparation and calibration and XRD) and redox reaction calculations and interpretation.

The field sampling and laboratory processing have all gone well. Students enjoy investigating the abandoned iron mines and old furnaces. They like being able to process their own samples and learn analytical instrumentation. Students find the use of ICP and XRD to be instructive except for untimely equipment failures. The interpretation of the data is challenging for the students unless they are given additional background and previous work with which to compare their results (Friedel, 2002). The iron smelting is complicated to setup but the students find the process instructive and awe inspiring.

An alternative laboratory that has worked well for us is in our Chemistry of the Earth class (Knapp, et al., 2003). This laboratory demonstrates reduction reactions with a bronze alloy smelt using an in-house furnace (Dunn, 2003). The "bronze" laboratory is a quantitative study of ore reduction that can work well in any laboratory with a furnace (Dunn, 2003).

## SUMMARY

The Washington & Lee University Geology department has a strong tradition of emphasizing field work. We are striving to balance classroom, field and analytical techniques in our curriculum. We use a skills matrix adapted from Carleton College (Savina, et al., 2001) and a yearly departmental programmatic review to ensure that we are providing the best geologic preparation for our students. We recognize that the skills gained in each of our classes and laboratories are different. Whereas our educational philosophies in the department are similar, our approaches to teaching differ. The multi-phase exercises we use (as demonstrated in these examples) go beyond field observation and emphasize geological skills, field observation and data collection, laboratory and analytical skills, computation and modeling, and scientific writing and presentation. We believe that using field experiences as an overall part of integrative experiences provides the best education for our students.

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