Introducing Field-Based Geologic Research Using Soil Geomorphology

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ABSTRACT

A field-based study of soils and the factors that influence their development is a strong, broad introduction to geologic concepts and research. A course blueprint is detailed where students design and complete a semester-long field-based soil geomorphology project. Students are first taught basic soil concepts and to describe soil, sediment and rock properties using standard description procedures. Then, with minimal geological or field experience, they are led to design and execute a project that examines how soil properties differ as a function of processes, parent material and time. By designing and executing the semester-long project, students gain familiarity with the entire geologic research process including basic field observation, hypothesis development and testing, interpretation and presentation skills. During the course, students learn 1) the basic knowledge necessary to describe geologic materials (soil, rock, sediment) in the field, 2) to make observations and interpret them in the context of geologic hypotheses which they have developed, 3) to develop, and execute a field-based research project, 4) to integrate and draw conclusions about complicated semi-quantitative data sets, 5) to map and survey in the field and 6) to present their research in a public forum. By the end of the semester students are able to make and test hypotheses relating soil properties to the depositional environment, age and/or type of geologic deposits in which they form. The knowledge, skills and research experience gained in this simple, semester-long project serve students well in upper-level courses and beyond. An example project is presented from a 2nd order stream and its adjacent tributary alluvial fans in the Piedmont of North Carolina.

INTRODUCTION

For a geologist or soil scientist, a soil is a naturally occurring body of roughly horizontal layers (horizons) located at the surface of the earth whose morphological, chemical, biological and morphological properties are altered from that of the original sediment or rock from which they have formed (parent material) (e.g. Buol et al., 1997). Soils defined this way are distinct from those defined by an engineer who considers any unconsolidated natural material a 'soil'. A geologist's 'soil' is essentially the weathering rind of the Earth's surface. Thus soil properties are directly related to- and provide insights into- the processes and characteristics of the atmosphere, biosphere, hydrosphere and lithosphere.

Over the past four years, a central component of the lower level undergraduate soil science course at the University of North Carolina at Charlotte (UNC Charlotte) is the development of a soil geomorphology study that examines how soil properties vary in a landscape as a function of the characteristics of local environmental conditions. For the majority of students, this course is one of the first that they have taken beyond introductory geology. Numerous similar soil geomorphology studies exist for the western United States (e.g. Gile et al., 1981, Busacca, 1987; McFadden et al., 1989; Reheis et al., 1992; Bockheim et al., 1996); however, very few have been undertaken in the temperate climates of the eastern seaboard, and fewer still in the Southeast (Levine and Ciolkosz, 1983, Markewich and Pavich, 1991; Lichter, 1998). Thus, the project allows students to collect original data that can contribute to the field of study.

This type of inquiry based learning is a recognized and recommended pedagogy (Barstow and Geary, 2002) that many find difficult to incorporate into lower level undergraduate course work (Apedoe et al., 2006). Nevertheless, numerous workers have demonstrated that such a teaching approach will improve students' overall science-related skills and understanding, including critical thinking and hypothesis development and testing (e.g. National Research Council, 2000; Keller et. al., 2000; Cavello et al., 2004; Garvey, 2002; Gomezdelcampo, 2006). Furthermore, numerous studies have clearly demonstrated the benefits of field-based learning in introductory level geoscience courses (e.g. Elkins and Elkins, 2007; Fuller et al., 2003; Bogner, 1998). Commonly cited difficulties related to such

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Location:	Date:	Time:
Pit Designation:	Described by:	
Geomorphic Surface:	General Notes:	
Parent Material(s):	Vegetation:	

Depth	Horizon	Color Moist / Dry	Structure	Gravel %	Consistence Wet Moist Dry	Pores	Roots	Texture	Clay Films	Bound.	Notes
			m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25 100	lo lo so po vfr so ss ps fr sh s p fi h vs vp vfi vh efi eh	c m f vf	c m f vf	S SICL LS SIL SL SI SCL SIC L C CL SC	v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
			m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25 100	lo lo so po vfr so ss ps fr sh s p fi h vs vp vfi vh efi eh	c m f vf	c m f vf	S SICL LS SIL SL SI SCL SIC L C CL SC	v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
			m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25 100	lo lo so po vfr so ss ps fr sh s p fi h vs vp vfi vh efi eh	c m f vf	c m f vf	S SICL LS SIL SL SI SCL SIC L C CL SC	v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	
			m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25 100	lo lo so po vfr so ss ps fr sh s p fi h vs vp vfi vh efi eh	c m f vf	c m f vf	S SICL LS SIL SL SI SCL SIC L C CL SC	v1 f pf 1 po 2 d br 3 co p cobr	a s c w g i d b	

Figure 1. Soil Description Sheet modified from Birkeland (1999) with permission from David Harbor (previously David Jorgensen). Used in conjunction with 'cookbook' instructions for describing soils (Birkeland 1999, Appendix 1), this sheet includes basic components of a complete field description of a single soil pit in a temperate climate and is consistent with description procedures outlined in Soil Survey Staff (1993).

field-based courses include expense, travel time and student-teacher ratios (e.g. Williams and Griffiths, 1999). Because soils (weathering profiles) are ubiquitous, however, lack of bedrock outcrop does not preclude completing a soil-based study, which can be developed on even the most urban of college campuses. Furthermore, basic soil field data (e.g. Birkeland, 1999; Soil Survey Staff, 1993; Appendix 1) are similar to those of geomorphology and sedimentology, so most geologists have the background knowledge required to develop such a course. Also, the repetitive nature of soil descriptions allows for working with 3-4 students at a time in a 20-30 student class, while other groups are engaged in activities that they are comfortable with. Finally, the skills and concepts learned during such field-based coursework have been demonstrated to be portable to other courses and to be professionally enriching (Kirchner, 1994). Here I describe a blueprint for the UNC Charlotte course that could be employed by almost any geoscience department as a 2nd tier introductory level field-based course.

SOIL GEOMORPHOLOGY CONCEPTS

At UNC Charlotte, concepts of pedogenesis and soil geomorphology are taught to students throughout the semester in separate lectures; however, a separate lecture is not necessary for the field-based component of the course that is described herein. Soil textbooks such as Birkeland (1999), Buol et al., (1997), Schaetzl (2005) and Brady and Weil (1999) are all good references for the following basic soil-geomorphology concepts that should provide a sound starting point for instruction.

A soil profile is described in a similar manner to a rock outcrop. Birkeland (1999; Appendix 1) provides a manual for how to dig a soil pit and describe a soil profile that should be read and reviewed by the instructor and employed by students while in the field. This appendix is a manageable summary of a significant body of widely available soil description literature. In particular Soil Survey Staff, 1993; and Schoeneberger et al., 2002 are both available for free on the web and are excellent resources for the instructor if necessary.

Description of a soil profile incorporates a description of secondary weathering features related to soil development (e.g. horizons, colors, soil structure) as well as any primary features inherent to the parent material such as sedimentary stratigraphy, grain size, or mineralogy. Beginning at the ground surface, soil

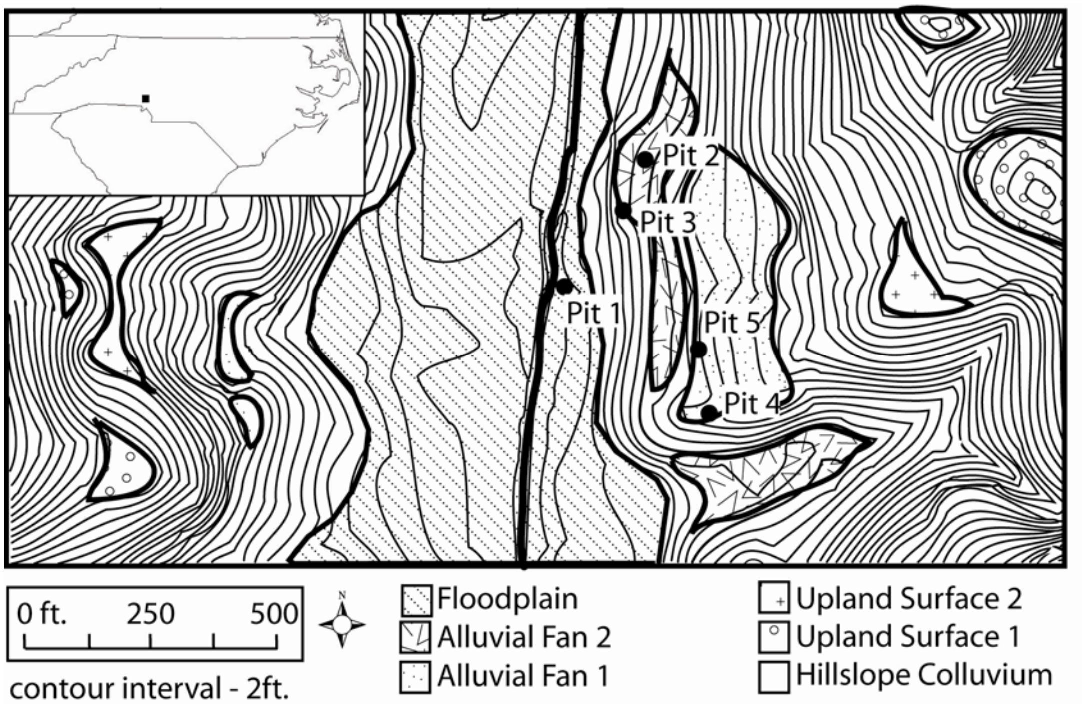

Figure 2. A. Location map of study area in North Carolina. B. Topographic and geomorphologic map (typical of those produced by students for the exercise) of Toby Creek field area. The topographic map is provided to students for an 'office mapping' exercise. Contour Interval is 2 feet.

horizons are typically vertically stratified with notable horizontal boundaries. Horizon boundaries mark changes in weathering characteristics and are located by marking significant changes in observable properties such as color, structure (natural particle arrangement), texture (grain size), induration, root content and/or visible pores. Horizon boundaries may or may not coincide with stratigraphic boundaries that mark different sedimentary or rock units. Once horizons are determined, a standard suite of soil properties is described for each horizon in a profile (Figure 1). Horizons are named according to an accepted nomenclature, A, B, C etc., depending on their properties. In a very general sense, A horizons are zones of leaching and of additions from the ground surface (e.g. dust in arid settings, organic material in humid settings). B horizons are zones of accumulation and in situ alteration (e.g. dominated by secondary salts in arid settings, iron oxides and clay in humid settings). C horizons are relatively non-weathered material in which the primary properties of the parent material dominate the horizon.

Once described, soil profile horizons and properties can be employed to better understand the soil forming environment unique to each soil exposure. Soil development is thought to proceed as a function of soil forming factors: climate, organisms, relief, parent material and time (Jenny, 1941). All five factors influence the suite of chemical and physical weathering processes that serve to create any observed soil profile. Soils forming on toe slopes (an aspect of the 'relief' factor), for example, will often exhibit redoximorphic features such as mottled coloring as a result of developing in a wetter soil climate than their backslope counterparts. Differences in microclimate might then be attributable to differences in the runoff and runon of these two landscape positions.

If four of the five soil forming factors are held constant for a group of soils, then the influence of the remaining factor on soil development can be determined. A soil chronosequence, for example, is a series of soils whose properties vary primarily as a function of the age of the exposure of the surface on which they are forming. Deposits or surfaces of similar age should share similar soil properties if other factors of soil formation are held constant. Young soils, for instance might be characterized by relatively thin horizons, and little evidence of insitu alteration of minerals. Well developed older soils, in contrast, would generally exhibit thicker horizons and profiles with relatively greater mass of secondary, translocated or precipitated minerals accumulated in the profile. A suite of inset fluvial terraces or alluvial fans are examples of settings in which a chronosequence might be developed. In a similar manner, a toposequence, climosequence or biosequence can also be examined. The field of study known as soil geomorphology has stemmed from the development of this soil forming factor concept and has contributed to many geologic studies throughout the world.

Soils are most widely employed by geologists as a tool for mapping and correlating geomorphic surfaces and surficial deposits in a variety of environments (e.g. Birkeland, 1990); however their application extends well beyond a relative age dating tool. Soils developing in deposits with numeric age control can be also be employed to determine a calibrated age for deposits that lack alternative age control (e.g. Switzer et al., 1988, Amoroso, 2006). An examination of soil properties can provide insights into landscape evolution related to climate change or tectonics (e.g. Wells et al., 1987, Tonkin and Basher, 1990, Knuepfer and McFadden, 1990, Eppes et al., 2002, Birkeland, et al., 2003,). Soil variability across a landscape typically can also be directly linked to the spatial variability of surface processes at work there (Harrison et al., 1991, Eppes and Harrison, 1999). Finally, because weathering of geologic materials is so closely linked to moisture availability, soil development can be used to evaluate the hydraulic properties of geomorphic surfaces (Arkley, 1963, Young et al., 2004). Chronosequences, climosequences, toposequences, geosequences and biosequences are thus powerful vehicles for introducing and teaching a variety of geologic concepts and skills to students, for developing and testing hypotheses of varying complexity and for introducing students to field work in a simple, three-hour class throughout the course of a semester .

COURSE DESIGN

Introduction of Concepts and Skill Building

During the first two to three weeks of the UNC Charlotte course, students examine a stream cut bank on campus adjacent to the location of their future project. UNC Charlotte is located in the relatively urban Mecklenburg County in the Piedmont of North Carolina (Figure 2). The field site on the UNC Charlotte campus consists of a typical Piedmont 2nd order stream, Toby Creek, incised into a broad flood plain that includes small (1-2 m wide) levees and a number of level benches and low relief tributary alluvial fans projecting out from adjacent hillslopes. There, as a class, we make qualitative observations about the landscape and the sediments and the soils of the site. For example, I have students map the contact between the floodplain and the adjacent hillslope, using concepts such as changes in gradient, geologic and geomorphic units. Students are encouraged to make the connection and distinction between a landform and the underlying sediments which comprise it. Importantly, I help students to recognize the differences between outcrop attributes that are the result of weathering versus inherent features of the parent material. In my experience, students have some difficulty at first with the concepts of "parent material" and of "soil" as a weathering feature (as opposed to the engineering concept of soil as any unconsolidated material). To have students compare unweathered sediment from the stream with weathered sediment in the cut-bank serves to emphasize the difference between primary and secondary (weathering) characteristics. By the end of this exercise, students can recognize and name basic landforms and geomorphic concepts.

Next, I divide the class into small groups and have each group claim a small (1 m) wide area of the cut bank that we have been examining. Students are asked to make observations about the exposure starting from ground surface. Armed with butter-knives they have brought from home, they draw horizontal lines where major visible or tangible changes occur in the vertical profile. Often students focus on color, but texture and induration are also important properties to address. We regroup, and I explain that they have just determined the 'horizons' of the soil developing in the floodplain deposits of Toby Creek. We go as a group to each section of outcrop and students justify their boundaries to the class. Typically students have difficulty verbalizing what is different about their chosen horizons beyond the property of color. This exercise thus sets the stage for introducing the vocabulary associated with various soil properties such as texture and structure. At the end of this exercise, students can recognize soil horizons, although they cannot yet name them.

One by one, I then demonstrate how the standard suite of soil properties is described. Students are provided with Birkeland (1999, Appendix A) which gives detailed instructions for describing each soil property. Additionally, I provide a modified soil description sheet (Birkeland, 1999; Appendix A; used with permission from David Harbor; Fig 1). These description sheets are invaluable aids for keeping track of what must be described for each horizon. After each demonstration, students return to their own portion of the outcrop and describe the property for each horizon in their soil profile. Thus students repeat the process of description six to seven times. I split my time between different groups and assist as necessary. My emphasis in these first labs is focused on how to make objective, consistent observations about field-derived data. Students are evaluated based on their participation (are they asking and answering questions; 50%) and on their field notebooks and worksheets (50%). Students receive points on the latter for completeness of their descriptions (are all properties described for all horizons), neatness (is everything readable and clear), and sketches (is there a scale, indicator of direction, etc.). At this point, I do not take off points for accuracy of their descriptions. I provide feedback after each lab, so that expectations are clear and improvements can be made for the next lab. After two labs, students are generally familiar with the mechanics of soil descriptions and are capable of making quantitative field observations.

Finally, I introduce students to the concepts of soil forming factors (Jenny, 1941) and soil chronosequences. Students typically find it intuitive that weathering will be affected by variables such as climate and vegetation; however concepts such as local microclimate typically require more attention. Discussing the soil forming factors approach allows review of concepts such as variables and constants and cause and effect in a geological setting. I provide examples of landscapes where chronosequences or toposequences have been examined in the past with a particular emphasis on fluvial terraces because they are a common landform in the Piedmont. The above information provides a segue to explain to the students that they will spend the remainder of the semester designing, and implementing their own soil geomorphology research project. I emphasize that the data that they collect will be unique, and thus will significantly contribute to our knowledge of soil geomorphology in this region.

INTRODUCTION TO THE FIELD SITE

As a single lab exercise, before we go to the specific field site, I supply students with a two-foot-contour interval topographic map of an area of Toby Creek and indicate the field area where they will develop their chronosequence (Figure 2). In this portion of Toby Creek, there are several relatively flat concordant upland surfaces that students map (Figure 2). We review elements of topographic maps, and students convert the scale of the map from feet to meters (an exercise that seemingly cannot be repeated enough at this academic level).

The exercise ultimately requires students to develop a geomorphology map and a topographic profile of a transect across the field area. As a class, we qualitatively note areas of similar morphology (flat, vs. steep vs. very steep) and make hypotheses about origin of the landforms that the map is depicting (floodplain, possible terraces, tributary alluvial fans, and anthropogenically modified areas). I use the concept of 'terrace' and 'alluvial fan' loosely here as the scale is rather small, and I emphasize that by examining the map, we are developing hypotheses of stratigraphy and landform origin that can be tested in the field. I review the concept of a mapping unit and explain how a geomorphologic map differs from a geologic map. Together we define mapping units for the field area (see the 2005 project description below for an example), and students then individually color in their maps using provided possible mapping units and make a key to their units. Students are graded primarily on the accuracy of their topographic profiles and their ability to follow the provided 'rules' of geologic mapping. For example, all polygons must be closed or go off the map, all areas of the map must be assigned a mapping unit, and all maps must be neat with consistent and correct labeling.

Design the Experiment

I next remind the class that the goal of the research project is to gain an understanding of how soil properties change as a function of soil forming factors in the setting of Toby Creek. Armed with this goal, their newly developed geologic maps and their understanding of soil forming factors, students develop hypotheses relating landforms and mapping units to soil properties. The list they develop typically includes the following: 1) if two areas on the map are assigned the same mapping unit (hypothesis), then the soils on those units should be similar (test of the hypothesis). 2) Soils developing on the floodplain should be less-developed than those on a landform mapped as a terrace. 3) If flat areas are terraces, then flat areas of progressively higher elevations should exhibit increasingly developed soils. Students use these hypotheses to choose and mark potential soil pit sites on their maps. Usually these pit locations consist of one to two pits on the floodplain, and three to four pits on two surfaces of different elevations which are office mapped as terraces.

We finally take these maps to the field. I spend a significant amount of time helping students orient themselves with respect to the topography and the units that they have mapped. Together, we find and examine the pre-defined pit locations and mapping units. We discuss map scale and topography as it relates to reality. In Toby Creek, small benches that students have often office mapped as terraces are identified in the field as tributary alluvial fans spilling out into the floodplain from adjacent ephemeral streams. If necessary, we modify their choices of pit locations to allow for an analysis of both temporal and spatial variability of soil development (i.e. more than one pit on individual surfaces). Together we establish a naming scheme for all pits and for any samples collected from the pits.

Project Execution

Until this point, students have been working individually or in instructor-designated groups. I now ask the students to combine themselves into groups of 2-3. Typically there are 5-7 such groups each semester. I emphasize that working on teams is typical of research in any discipline and try to emphasize good teamwork skills. For example, students are told if there are conflicts or disagreements within groups that they be addressed as soon as they arise. To date, I have had very few issues with group work. Soil descriptions such as those executed in this project have been shown to foster good group-working skills (Mooney, 2006).

Each group digs one soil pit from the list that we developed. Typically an entire class period is necessary for this task. If old pits are employed, they must be re-excavated. Pits are dug to about 1-1.5 m depth, taking care to preserve at least one single vertical face with undisturbed ground adjacent. Following procedures outlined in Birkeland (1999) and using the provided description sheet (Figure 1), each group describes the morphology of the pit that they have dug. Over the course of the following weeks each group describes all pits in the project. Typically a single description takes an entire lab period. Initially, each soil description is graded based on completeness of observations. For example, I will not deduct points if a student describes a loam as a silt loam, however I will take off points if texture is missing from their descriptions. In future classes, I become more concerned with consistency of observations and following of instructions. If a student describes the texture of a particular horizon as a loam, but assign it a consistence of very sticky; by the definition provided in the materials that I have given them, these do not co-exist and thus points are subtracted. Each week, my expectations of their descriptions increase as they learn new concepts related to the soils that they are describing.

PRESENTATIONS AND DISCUSSION

Results of the research are presented and discussed at the 'Soil Science Class Research Symposium' held at the end of the semester. This presentation constitutes a significant portion of the final grade for the course and is a substitute for a final exam. I often invite other faculty and students to attend this event. Each group develops and executes a 30 minute GSA-style presentation with each member of the group taking responsibility for different portions of the talk.

Each group presents data from all soil pits. Students are required to incorporate concepts and terminology learned throughout the semester into the presentations. I challenge students to avoid haphazardly presenting all data collected, and to focus their presentations on one or more of the hypotheses that were developed earlier in the class. I encourage them to focus on the portion of the research or the observations that they found most interesting. I urge them to be creative in terms of data presentation so that, visually, the data are clear and unambiguous. As part of their final presentations, students are asked to consolidate their field descriptions into meaningful diagrams or graphs. I encourage students to translate soil description data into numerical semi-quantitative indices so that they can be more easily compared. Students may create their own indices or they may choose to use those available in the literature, such as the classic profile development index of Harden (1991). In the Harden index, for example, soil properties are compared to those of the parent material (in this case unweathered floodplain sediment), and deviations from the parent material are assigned a number. Increasingly higher numbers indicate increasingly more developed soils. Creating and using such indices provides good experience in translating field data into a semi-quantitative record. Presentations must contain the following elements: 1) An introduction and justification of why the research is important 2) A clearly stated hypothesis or goal 3) An explanation of the methods used to test they hypothesis and achieve their goals 4) Results presented in visually clear

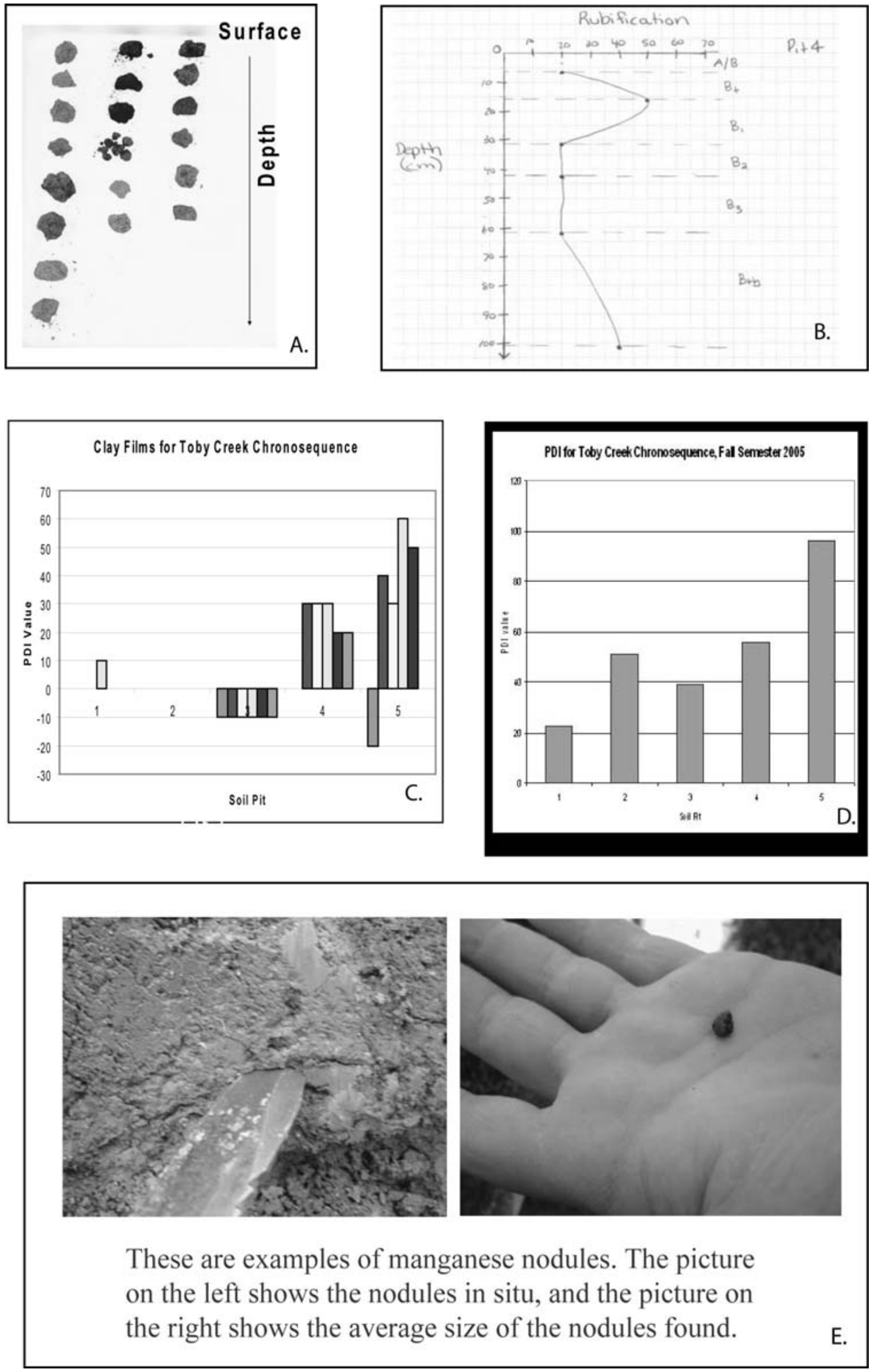

Figure 3. . Examples of soil data presentated by students for the 2005 exercise. See text for explanation. A. Soil samples by horizon from the floodplain soil (Pit 1, far left), the lower alluvial fan surface (Pit 3, middle), and the upper alluvial fan surface (Pit 4, far right). B. Depth profile of soil rubification (after Harden , 1991) for Pit 4. C. Clay film index (after Harden, 1991) for all five soils in the 2005 project. Different bars within a single pit represent different horizons increasing in depth from left to right. Index represents relative development of clay films with respect to a chosen parent material. D. Total Profile Development Indices for all five soils in the 2005 project (after Harden, 1991). E. Illustration of Mn nodules common in many of the soils of Toby Creek with caption provided by a student group.

graphs or diagrams and 5) Interpretation and conclusions in the context of their previously stated hypotheses and goals. Students are provided with a written description of my grading scheme for their final project presentations:

1) Content 33%. Is there a clear problem and/or justification of the topic presented from the beginning? Does the presentation cover the stated topic? Is there originality or creativity in the interpretation or presentation of the data? Do students correctly incorporate concepts and terminology learned in class in their presentations?
2) Organization 33%. Is there a logical flow of thought in the presentation? Does the audience know from the beginning what is going to be discussed?
3) Presentation 33%. Do the speakers speak clearly? Are visuals clear and readable?

As a final portion of the grade for the class, each student in the class is also required to ask one or more questions of another group during the discussion time. After all presentations are complete, we summarize the main similarities and differences between groups and put the overall project back in the context of soil geomorphology research in the Southeastern United States.

2005 PROJECT EXAMPLE

In 2005, students mapped two tributary alluvial fan surfaces and two 'upland surfaces' in their designated field area (Figure 2). Field relationships indicated that one alluvial fan was inset into another so a relative age relationship was established, with Alluvial Fan 1 hypothesized to be older than Alluvial Fan 2. It was hypothesized that the upland surfaces were related to long-term fluvial incision, and thus the higher of the two surfaces (Upland Surface 1) was hypothesized to be older. For logistical reasons, we chose to focus our study on the tributary alluvial fans and the floodplain. Five pits were excavated and described by each group of students. Pit #1 was located on the floodplain. Pits #2 & #3 were located on Alluvial Fan 2, whose surface is approximately two meters above that of the floodplain. Pits #4 & #5 were located on Alluvial Fan 1, whose surface sits approximately 4 meters above the floodplain.

Figure 3 provides five examples of illustrations that students created for the 2005 presentations. These are typical of any year's class in that they range from purely illustrative (Figure 3E) to quantitative (Figure 3D).. The sophistication of the visuals also is variable, but hand-drawn graphs such as that in Figure 3B are accepted and allow less-computer savvy students to feel on equal footing. The following is a combined summary of the results presented by students for the 2005 project. The detail of the results is illustrative of the complexity of the ideas and conclusions that students are able to make using the data that they have collected. With only minimal change in emphasis of data collection and analysis, the same project could have highlighted other geologic disciplines such as geomorphology, sedimentology or mineralogy.

For the 2005 project, there were notable differences between soils on different surfaces and between soils on the same surface (Figure 3). The floodplain deposits expectedly exhibited relatively weak overall soil development (indicated by a low Profile Development Index number (Harden, 1991) in Figure 3D) with A-Bw-C horizonation with a buried soil at depth (visible as a darker horizon in Figure 3A) overlying undisturbed fluvial stratigraphy. Students noted that the surface soil in this pit exhibited slightly redder colors and more structure than the cut-bank exposure they had previously examined. Also, the soil in Pit 1 was lacking the unweathered sand deposit from a 2004 flood which we had also observed in the cut-bank exposure. These observations led students to examine the location of the pit in more detail and to recognize that the area in question was potentially bypassed from flooding due to the presence of a crevasse splay in the nearby levee. I used this and other similar experiences to emphasize to students that we can often learn more when a hypothesis that we propose (in this case, soils developing on a single geomorphic surface should exhibit similar characteristics) is proved false.

The soils exposed by Pits 2 & 3 on the lower alluvial fan exhibited similar characteristics. Both soils are developing in homogeneous, well-sorted grussy-sand that is consistent with a tributary alluvial-fan origin for this surface. The soils exhibited diffuse relatively dark A horizons which extend to approximately 20 cm to 40 cm depth (Figure 3A). These two soils also exhibit approximately 20-40 cm thick oxidized B-horizons with few if any clay films evident. Colors at the bottom of these pits were approaching that of the floodplain sediment (Figure 3A).

Pits 4 and 5 shared both similarities and differences. Pit 4 and the upper horizons of Pit 5 were characterized by similar well-sorted sand as pits 2&3. The A horizons for these pits were much thinner (only 6-10 cm in depth) than those of Pits 2& 3 and were also much more concentrated in organic material as evidenced by darker colors. These A horizons overlie a discrete Bt horizon of 10-15 cm thickness with well-developed clay films developing in the sandy parent materials (Figure 3C). In Pit 4, this Bt horizon graded into a well-oxidized B horizon with occasional clay films present. Underlying a relatively thin Bt horizon in Pit 5, however, was extremely weathered, clay-rich saprolite with extensive mottling, gleying, and clay films. The overall soil development of this portion of Pit 5 was significantly greater than the other four soils examined. This difference in soil development is reflected in a high overall Profile Development Index (Figure 3D).

In the case of the 2005 study, most groups recognized the overall increase in soil development in deposits of increasingly higher elevation. There were notable exceptions to this trend, however, and these were discussed by many groups in their presentations. For example, many students noted the presence of Mn nodules in all pits regardless of age (Figure 3E). Thus, students were able to conclude that the presence of Mn is not a good indicator of soil age. The group that calculated clay film indices noted an unpredicted relative decrease in clay films from the floodplain soil to the soils on the lower alluvial fan (Figure 3C). It was suggested that the decrease was due to the fact that the buried soil in Pit 1 was used as a parent material reference, likely not an appropriate choice for their index. All groups noted that Pit 5 was the only pit prone to filling up with water after a rainfall. Many groups concluded correctly that the high clay content of this pit is contributing to periods of sustained saturation, and thus red-ox conditions, as evidenced by the extensive mottling observed there.

Some groups noted the differences in A horizon morphology between Pits 2&3 and Pits 4&5 and after some prompting were able to draw some conclusions. The relatively high permeability of the sandy matrix in Pits 2&3 permitted dark organic material to be transported to deeper portions of the soil profile, thus resulting in relatively diffuse, thick A horizons. It was suggested that this transportation was not possible in the soils of Pits 4&5 because sufficient clay had accumulated to retard infiltration into these soils. Thus the soil development of the B horizon resulted in a change in the development of the A horizon. A final interesting conclusion from the 2005 project was the recognition that deposition of tributary alluvial fans in the Toby Creek drainage is episodic, as is evidenced by fans with different degrees of soil development. Pit 5 provided evidence that the thickness of these fans is variable and that an older, more weathered landscape is preserved beneath them.

STUDENT RESPONSE

Numerous aspects of the soil geomorphology project have produced positive learning results and experience for students. First, I have found, as have others (e.g. Gomezdelcampo, 2006) that putting the students' work in the context of a topical research problem engages students and encourages care in data collection and critical thinking in a way that a simple assignment does not. Each individual exercise or soil description is given meaning beyond the mechanics of the assignment itself. The fact that students were able to take simple observations, such as noting the presence of Mn nodules, and discuss them in the context of broader hypotheses, demonstrates the success of the project in capturing the students' attention and creativity. The quality and depth of presentations and proceeding discussions demonstrated students newly acquired abilities to synthesize their own field data in the context of new pedologic concepts and their own hypotheses. By the end of the project, students are employing geologic observation skills, vocabulary and concepts with a sometimes surprising fluency.

The teamwork component of the course is an overall positive experience for students. I find that working in teams inspires students to assist one anther, creates a more continuous flow of ideas and helps with the tedium associated with describing sediment and soil properties. I find that group work inspires students to go beyond what is expected of them. For example, students are only required to describe each soil pit in the project. Most groups, however, returned to the field area after class to collect additional data or documentation. For example in 2005, most groups took photographs of the pits and surrounding area, and one group took microphotographs of samples. These types of additional efforts provide further proof that the project has promoted scientific inquiry and made students feel invested in the outcome of their work. The majority of difficulties in group work have come from the preparation of the final presentation. With emphasis on work equality when the assignment is made, however, I can generally reduce scenarios where one person in the group does the majority of the work.

Although digging soil pits is arduous exercise, I find that students feel more 'attached' to their pit once it is excavated than they do if someone else dug it or it was a natural exposure. Such sweat-equity investment unavoidably leads to curiosity and exploration. As students dig, they inevitably note differences in soil properties such as induration and color. These differences seem to pique their curiosity (or perhaps provide an excuse to stop digging) and to generate questions, therefore digging is beneficial and not a waste of class time.

The repetitive nature of the soil descriptions also serves students well. All students make noticeable improvements in the accuracy and precision of their observations over the course of this data collection portion of the exercise. By the last pit, students feel confident in their ability to describe sediment, rock and soil. By the end of the course, students feel comfortable and are successful in presenting results of their data collection during the 'Seminar'. The excitement of the seminar comes, however, when students discuss their interpretations of the data after all presentations have been made. Each student is required to ask 3-4 questions of the different groups as a requirement of the seminar. The groups typically share similar data-sets and are often 'amazed' that that most groups independently made the same observations that they did. Although different groups tend to focus on a variety of differences between soil pits, because all students have collected data from the same sites, they quickly become engaged in the question and answer section and the discussion.

Students' overall feedback regarding their semester long project has been positive. On more than one occasion, students have felt sufficiently invested in their work to present their results at the UNC Charlotte- and/or the North Carolina State- Undergraduate Research Symposium. Students' independent efforts to develop these posters and present them at conferences speak to their enthusiasm about the research that they have completed. Other students have indicated to me that the knowledge and skills that they gained during the soil chronosequence project aided them in gaining employment with geotechnical and environmental consulting firms. In general, the soil geomorphology project in the UNC Charlotte Soil Science course has been a positive component of our geosciences curriculum.

CONCLUSIONS

As other studies have demonstrated, it has been my experience that a field-based research project can provide a good first comprehensive exposure to geological field research. Soil development is closely linked to the properties of the environment in which soils are forming. Thus in a soil-based project, students are required to make sedimentological, geomorphological, hyrological and ecological observations in order to interpret the soil data that they collect. This type of soil analysis far exceeds the coverage of Soil Taxonomy that is included in most introductory geology textbooks. Soils developing in floodplain and adjacent environments in the piedmont of North Carolina are influenced by the local hydraulic and geomorphic conditions of the landscape in which they are forming as well as by the temporal changes in the physical properties of the parent materials. It is an important lesson for students to recognize that soil properties can provide enormous information about the landscape in which they are forming. Concepts related to such a project are universal to field-based research and thus provide a sound first exposure to geological field work and practices.

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