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Integrating student-led research in fluvial geomorphology into traditional field courses: A case study from James Madison University's field course in Ireland

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ABSTRACT

The objective of the environmental science component of the James Madison University field course in Ireland is to provide students with opportunities to conduct original hypothesis-driven research. We use an exercise in fluvial geomorphology as a case example of the way students used field observations and basic principles demonstrated by faculty mentors to develop and test hypotheses about the formation and function of rivers. Specifically, students addressed two fundamental, and currently unresolved, questions: (1) Can the location of large gravel bars be predicted? (2) What controls channel width? Students also gained insight into foundational concepts in fluvial geomorphology by investigating the distribution of deposited sediments, and deciphering how past environmental conditions provide first-order controls on the morphology of a modern-day river channel. In addition to identifying important geomorphic patterns, students gained useful skills in developing and testing scientific questions in a rigorous and data-rich manner.

INTRODUCTION

Geology field courses that include a blending of both traditional and contemporary topics and targeted research projects provide the ideal "capstone experience" for undergraduate geoscience students. Undergraduate students' participation in original research is widely believed to encourage students to pursue advanced degrees and careers in science (Russell et al., 2007). The environmental science component of the James Madison University field course provides students with an opportunity to engage in the process of science by conducting hands-on research projects based on timely and pressing questions that require application of their scientific and geoscience training. This experience is particularly important for undergraduates who do not have the opportunity to conduct senior research projects at their home universities.

Specific objectives of the environmental science component of the field course include: (1) developing a research experience for students that provides hands-on discovery into the scientific method and group problem solving; (2) encouraging field-based formulation and testing of hypotheses that address key uncertainties in fluvial geomorphology; and (3) providing insight into foundational concepts in applied geology and skills in measurement techniques.

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Why an Environmental Science Component in a Field Course Setting?

What is the relevance of a geology field course in the twenty-first century? Some will argue that coursework combined with field trips is sufficient for preparing undergraduates for graduate studies or for the workforce. Others surmise that an undergraduate research experience or an internship is an appropriate substitution for the field course experience. Some cite the unfortunate convergences of rising tuition, increasing travel costs, a general "graying" of field course faculty, and increasing demands on students' time as reasons to omit field course programs from the curriculum. Attending a lengthy field camp in a remote location can also pose significant hardship on nontraditional students, especially young parents and those already in the workforce. However, informal surveys and discussions with students and colleagues who participated in a field course during the past several decades reveal the opposite. The vast majority indicate that the experience was one of the defining moments of their undergraduate training. Some students compare the field course to a medical doctor's residency program, where they synthesize and apply their four years of geoscience training in a 6 wk immersion course, requiring their full commitment and concentration. Several geoscience professional organizations concur with the value of an emersion experience. Both the American Geological Institute (AGI) and the American Institute of Professional Geologists (AIPG) recommend a geology field course as part of undergraduate geoscience curriculum. In summary, it appears that many geoscience professionals agree that the field course ties together much of the undergraduate classroom coursework in an intense, applied setting of the outdoor laboratory.

Traditional field courses often focus on identification, interpretation, and mapping of geologic landforms and structures; however, many programs do not include opportunities for students to conduct original hypothesis-driven research. During a session that focused on the content and curricula development of geology field courses (The Future of Geoscience Field Courses, Denver, Colorado) at the 2007 Geological Society of America (GSA) Annual Meeting, many of the presentations suggested that traditional bedrock mapping was the exclusive focus of their course. While the authors recognize that bedrock mapping is an important and necessary experience for students to develop foundational skills in geology, only a small percentage of students will serve as bedrock mappers as a profession. A study by the American Association of Petroleum Geologists (AAPG) in 2003 showed that over half of all geoscience graduates in the United States and Canada went to work in environmental fields (e.g., the applied geologic fields of hydrology, soils, aqueous geochemistry, engineering, shallow-earth geophysics, and others), and the remainder was split nearly evenly among oil and gas, teaching, and government jobs (Katz, 2004). Given the diversity of professions that geology students enter, a greater diversity in field course curriculum is warranted (De Paor and Whitmeyer, 2009). In addition to increasing the breadth of topics covered during the course, a stronger focus on the important skill sets of synthesis and hypothesis testing is also needed for training young scientists with sharp critical thinking skills.

To meet the changing needs of geology students, James Madison University's (JMU) field course in Ireland has developed a broad curriculum. Traditional bedrock and structural mapping is still a major focus of the course, and it contributes at least 50% of the 6 wk endeavor. Other topics covered in the past 3 yr include digital mapping with global positioning systems (GPS) and geographic information systems (GIS), glacial geomorphology, landslides, coastal processes, and geophysics, where each topic will span from 1 to 5 d, depending on the specialties of faculty present. The final week of the field course is spent on student-led research projects that apply their scientific skills and geoscience training to an applied problem. The exercise is open-ended, experimental, and intended to promote discovery of new knowledge. The specific topic of the environmental science component of the course varies annually, and this article presents one specific study from the 2007 field course.

STRUCTURE OF THE EXERCISE

Student-Led Research and the Role of the Faculty Mentor

Small student groups, of four to six students each, were given a problem statement in environmental science and 5 d to formulate and complete a research project. The role of the faculty mentor was to guide observations and help students focus on developing solid and testable hypotheses. The area of expertise of the faculty mentors was fluvial geomorphology, which explores the form and function of rivers, an area of limited focus in other components of the field course. While students were exploring the field area, the faculty mentor found opportunities to demonstrate and discuss foundational concepts in fluvial geomorphology. More importantly, the mentor reigned in the desire of students to start immediately collecting data before research questions were well developed and the research approach was designed. An important aspect to note in the daily structure of the course (Table 1) is that students spent more time developing research questions based on their field observations, and exploring how geomorphic concepts were evident in the form and function of

TABLE 1. DAILY STRUCTURE OF THE JAMES MADISON UNIVERSITY FIELD COURSE ENVIRONMENTAL SCIENCE RESEARCH PROJECT

Day 1—Overview of field area and introduction to a broad research question.
Day 2—Demonstration of key concepts in fluvial geomorphology by the faculty mentor. Preliminary observations by the students, which they use to refine research questions and develop specific hypotheses.
Day 3—Training in field sampling techniques; demonstration of concepts in geomorphology that complement field observations.
Day 4—Field sampling.
Day 5—Field sampling (morning); data analysis and synthesis (afternoon); presentations and discussion session (evening).

the river network, than in the act of data collection. The instructors believe that this is an important and often underrepresented component of training students to conduct research. Data collection, although a tangible task, is only interesting when set in the context of a unique scientific question that provides insight into geologic principles.

Identifying an Applied Problem

Students were guided through the scientific method, which did not begin with an abstract discussion of the process but rather hands-on discovery through inquiry-based learning. Field courses are an ideal setting for this type of learning because students experience the scientific method as a rich, complex, and unpredictable process, instead of the oversimplified representation that is often taught in classroom settings. We began by identifying a broad question of interest, and as the line of questioning evolved, questions became more specific, and knowledge gaps in the understanding of river systems were identified. To initiate this process, students were guided to field sites that provided opportunities to make observations about a particular topic. In this specific case example, the broad question of interest was identified by a local geoscientist (K.R. Moore, Department of Earth and Ocean Science, National University of Ireland, Galway) and was based on the timely issue that western Ireland is a major target for gold exploration (Moore, 2006). On the first field day, students were taken to a rock outcrop and shown that gold was present in hillslopes, but in low concentrations that were broadly dispersed. Next, students were taken to the Carrownisky River and provided with an opportunity to pan for gold. From their observations, students came to the conclusion that gold was present on hillslopes, but it was concentrated in channels. The question then became, how can the location of preferential deposition be identified?

Preliminary Observations and Developing Hypotheses

On the second field day, students spent a full day with a faculty mentor making preliminary observations that served as a foundation for developing testable hypotheses and designing an observational study. The first question was to determine the location in the river network to search for gold deposits. During the initial visit to rock outcrops and gold panning in the riverbed, students observed that gold was present in predominantly sand-sized particles (<2 mm). The question then became, where were sand deposits most abundant in the riverbed? Students began in the steep headwater streams of the upper river basin and observed that sand deposits were infrequent in small, high-energy streams. There are 772 m of relief in the basin, 92% of which occurs in the upper river basin (Fig. 1, upstream of site 1). Students then deduced that after the river exited the mountains and entered a broad floodplain valley, sand deposits should be more abundant. The group then visited a low-gradient, meandering river in the middle portion of the river channel network (Fig. 1, site 8). The channel had an alternating pool and riffle morphology (Montgomery and Buffington, 1997) and large gravel bars. Students then went searching for areas where sand deposits had formed. To their surprise, and initial disappointment, surficial deposits of sand-sized material were also uncommon in this portion of the channel network. The role of the faculty advisor was then to demonstrate and discuss the process of channel armoring, where finer-grained sediments are trapped, and therefore protected, by a coarse surface layer (Dietrich et al., 1989). This line of inquiry and discovery provided an opportunity to discuss the importance of striving for creative alternatives when preliminary observations do not fit expectations, and it served to illustrate that real learning and discovery involve a constant process of evolving our understanding and questioning of complex environmental systems.

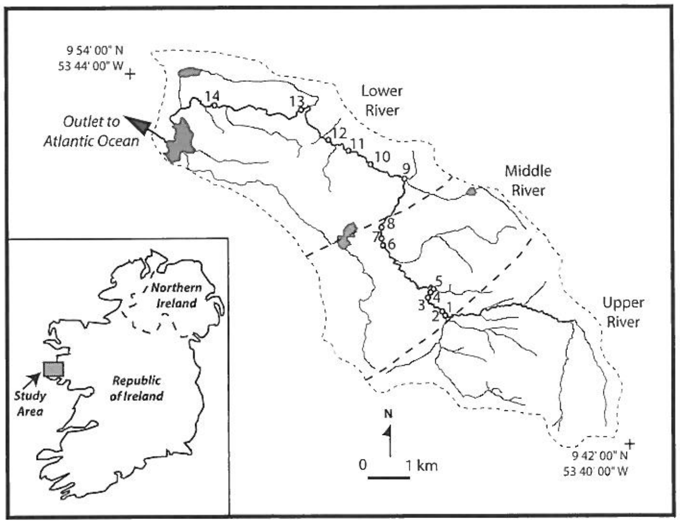

Figure 1. Map of the study area. The midsection of the river, denoted by dashed lines that bisect the basin, contains large gravel bars investigated by student groups 1 and 2. Numbered circles indicate the location of sampling areas for student groups 3 and 4. Inset highlights the location of County Mayo in western Ireland.

From their observations, students deduced that subsurface sediment deposits in large gravel bars would be a rich source of sand, and therefore gold, deposits. Students were then surprised to find that gravel bars were limited to a relatively small portion of the channel network in the midsection of the basin (Fig. 1, sites 1–8). In the upper section of the basin, bar development was limited by channel steepness; downstream bar development appeared to be limited by channel incision into thick layers of cohesive sediment. Cohesive bank materials, caused by roots of streamside vegetation or clay-rich soil, have a direct effect on the processes and rates of bank erosion (Micheli and Kirchner, 2002a, 2002b). In the Carrownisky River, thick clay and organic-rich sediments in the lower floodplain valley have distinct stratigraphic characteristics that suggest the lower river was formerly a wetland (Fig. 1, sites 9–14).

Based on field observations and concepts described and demonstrated by the faculty mentor, specific hypotheses were developed by each of four smaller groups (Table 2). Students

TABLE 2. RESEARCH QUESTIONS, OBSERVATIONS, AND INSIGHTS GAINED FROM FIELD OBSERVATIONS MADE BY EACH STUDENT GROUP

Group number and research question	Observations summarized by the students	Process-based understanding of observations demonstrated by the faculty mentor	Important concepts in fluvial geomorphology demonstrated and discussed	Specific hypothesis tested
1. Where are deposits of sand-sized particles most abundant?	Surficial deposits of sand were uncommon on the surface of the streambed or bars throughout the channel network. The subsurface sediments of gravel bars in the low-gradient floodplain valley contained an abundance of sand-sized particles.	Streambeds are characterized by two distinct layers of the sediment. The surface layer is primarily composed of coarse sediment that is difficult for the river to transport. This coarse surface layer protects the finer-grained subsurface, which more closely approximates the load the river carries.	Selective transport of sediment; channel armoring; and interpretation of imbricated deposits.	**If** the streambed is well armored, **then** deposits of sand-sized material will be more abundant in the subsurface, **because** the coarse surface layer prevents transport of the finer-grained material stored in the subsurface.
2. In reaches of the river where bars form, can the occurrence of large bars be predicted?	Gravel bars of various sizes were present in the midsection of the river. Large bars appeared to be related to the curvature of meander bends.	The size of gravel bars is largely dependent upon the space available to accommodate bar formation. Bar formation is limited in tightly confined river canyons but can be extensive in broad floodplain valleys.	Gravel bar and meander development; mechanisms of bank erosion.	**If** bar size is determined by the radius of curvature in meander bends, **then** small bars should occur where the angle of curvature is low, **because** there is less room for lateral expansion and sediment deposition on the inside of tight meander bends compared to broad, high-angle bends.
3. Where in the channel network do gravel bars form?	The upstream end of the study area was bounded by steep channels, which limited the potential for bar formation. In the midsection of the river, gravel bars of various sizes were very abundant. In the lower river, the channel was narrow, deeply incised, and lacked bar development.	Bar development is limited to channels with less than 2% slope, which is well documented in the literature (e.g., Montgomery and Buffington, 1997). In low-gradient channels, bar development can also be inhibited in narrow channels; however, the controls on channel width are not well understood.	Morphologic channel development; hydraulic geometry; bank erosion and characteristics of cohesive sediments.	**If** channel width inhibits bar development in cohesive sediments, **then** stream banks composed of noncohesive materials will have the greatest abundance of bars, **because** channels can erode floodplains laterally in noncohesive sediment, whereas channels incise vertically into cohesive sediments.
4. How do past environmental conditions affect the modern river channel?	Stratigraphic evidence exposed in the channel banks indicated that landforms in the Carrownisky River valley have varied dramatically through time. Evidence for alternating conditions of gravel-bed river floodplains, deltas, and shallow lakes is present.	Climate change affects river discharge, sediment load, and fluvial landform development.	Stratigraphic evidence for past fluvial features; sediment transport and deposition under varying environmental conditions.	**If** the cohesion of stream-bank materials affects channel development, **then** areas of cohesive and noncohesive stream banks are determined by past environmental conditions, **because** paleolake beds and wetlands contain cohesive sediments, paleochannels produce noncohesive sediments, and deltas have a mixture of cohesive and noncohesive sediments.

were taught a structured form of developing hypothesis statements, in an "if...then...because" format. The "if" portion facilitates recognition of the underlying assumption of the hypothesis, the "then" portion is the actual statement of a testable hypothesis, and the "because" portion provides a causal mechanism for the hypothesis (Smallidge and Everham, 1994). We acknowledge that this is not the classical null and alternative hypothesis format; however, the hypothesis structure we used helps students to identify assumptions and causal mechanisms. This hypothesis structure also helps students to identify two variables and the way they relate to each other. Specifically, if the independent variable is changed, then the dependent variable will change in a predictable way.

Developing an Approach to Test Specific Hypotheses

After each group formulated a specific hypothesis, the approach for testing the hypothesis was developed. Students identified the data needed to answer their specific question. The explicit expectation was that the research projects would be quantitative and data rich, and not merely descriptive. The role of the faculty mentor was to help to identify specific tools and techniques for acquiring the necessary data. Students were then asked to envision the key graphs that could be developed from the data, which led to a plan for the forms of analysis to be used.

Groups 1 and 2 focused their efforts in 2.75 km section of river in the midsection of the basin where large gravel bars were abundant (Fig. 1, sites 1–8). Group 1 measured surface and subsurface grain-size distributions in plot samples on exposed gravel bars using standard methods for pebble counts described in Bunte and Abt (2001). Group 2 measured the surface area and angle of curvature of all gravel bars in this section of the river (Fig. 2). Groups 3 and 4 sampled 14 sites along 12 km of channel in the middle and lower river. Sample sites were spaced such that a broad area was covered with relatively easy access. Group 3 measured hydraulic geometry relations using standard methods described in Leopold and Maddock (1953) and Leopold et al. (1964). This group also identified areas of cohesive, noncohesive, and mixed bank materials. Noncohesive banks were characterized by gravel and sand deposits, cohesive banks were composed primarily of clay and organic-rich deposits, and mixed bank materials were classified as having >25% of the exposed river bank composed of more than one type of bank material. Group 4 interpreted stratigraphic sequences exposed in the channel banks and used this information to infer past environmental conditions. River deposits were identified as clast-supported deposits of imbricated and rounded gravel. Delta deposits were identified by narrow, and often abandoned, river channels composed of fine gravels and coarse sand, interspersed with marsh deposits. Wetland or shallow lake deposits were identified by organic-rich deposits and/or laminated layers of fine sediment.

Figure 2. Illustration of the method students used to measure the angle of curvature of river bends. Tight turns in the river channel had low angles (~90°); broader bends had higher angles. A measure of 180° indicates a straight channel.

Communication of Results through Presentations

At the end of the fifth field day, a student research symposium was held in the evening. Each group gave a 15 min, GSA style, presentation of their results. Students were informed that participation in the presentation, and in question and answer sessions, would be an important component in the overall evaluation of the project. Groups also shared a common theme and study area, so each insight helped to build a broader understanding of the topic, leading to a synthesis discussion. Students were asked to evaluate themselves, their group, and peer groups. Following the presentations, students were expected to turn in well-documented and organized data as part of their project summaries.

GEOLOGIC SETTING

Student research projects were conducted in the Carrownisky River basin, located in the Murrisk Peninsula of southwestern County Mayo, along the western coast of Ireland (Fig. 1). The river originates in the glacial cirques of the Sheefry Hills of the South Mayo region and flows northwest through predominantly flat, boggy terrain prior to reaching the Atlantic coast, south of Clew Bay. The river is underlain by lightly metamorphosed, Ordovician to Silurian sedimentary rocks of the South Mayo Trough, which range from turbidite sequences of the Sheefry Formation through calcareous siltstones, quartzites, and sandstones of the Croagh Patrick succession (Dewey, 1963; Williams and Harper, 1988; Graham et al., 1989; Dewey and Ryan, 1990). The trend of the Carrownisky River generally follows the axial hinge region of a broad, east-west–trending syncline as the river progresses downstream from headwaters among the steeply north-dipping strata of the southern limb of the syncline.

Much of the present-day high-elevation landscape of west-central Ireland is dominated by spectacular cirques, U-shaped

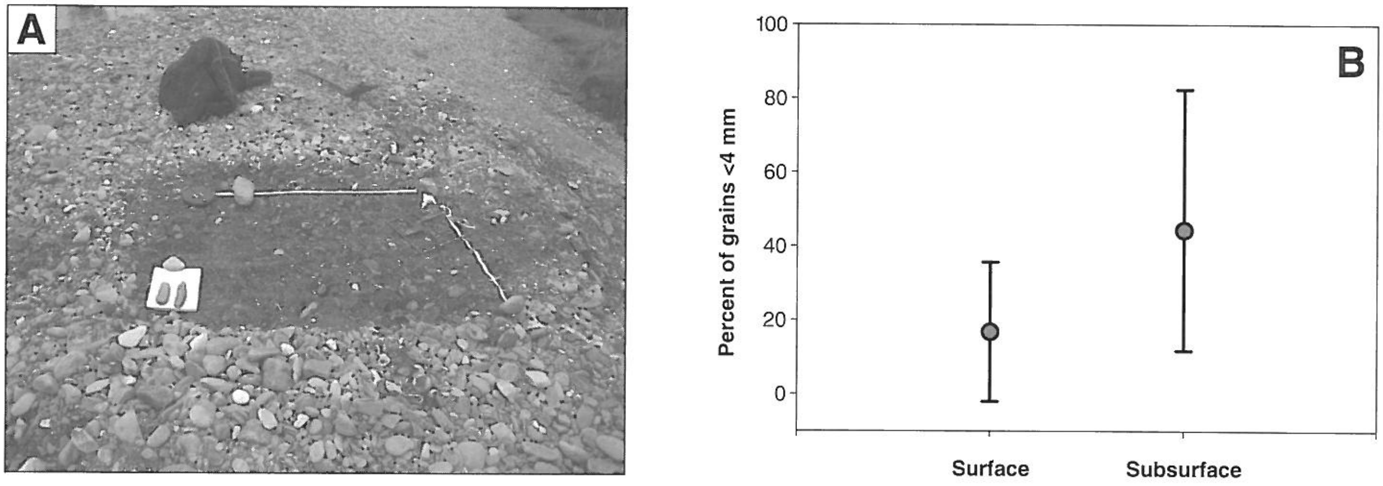

Figure 3. (A) Coarse surface layer of gravel bars underlain by finer subsurface sediments. (B) Distribution of fine sediment (<4 mm) in the surface and subsurface layers throughout the study reach. Error bars indicate one standard deviation around the mean value.

valleys, and fjords carved during the Last Glacial Maximum (Wisconsinian-Devensian glaciation) ca. 19,000–23,000 ka (Mix et al., 2001), during which western Ireland was largely covered by the British and Irish Ice Sheet (Bowen et al., 2002). In the Murrisk Peninsula, retreat and removal of the ice sheet and dramatic warming ca. 10 ka (Walker et al., 1994; Coxon, 2001) were followed by establishment of a pervasive deciduous forest, as evidenced by ancient oak stumps preserved in boggy lowlands (Bradshaw, 2001). Vast expanses of the Carrownisky lowlands are dominated by peat bogs, and these are evidence of a wet and warm period that developed ca. 4500 yr B.P. (Bradshaw, 2001) and persists to the present day. Long-lived human interaction with the local landscape is evidenced by archaeological sites in the Carrownisky River valley that date back to the Neolithic (McNally, 1984; Moore, 2006).

RESULTS AND DISCUSSION

Each student group addressed a specific component of the broader question. The initial question focused on where gold deposits would be most plentiful in a river network; however, interests and observations of the students led to a refinement of the research questions that revealed insights into where and why large bars and sand deposits form in particular sections of a river. Investigations of surface and subsurface grain-size distributions of bars indicated that the channel was extremely well armored. The average for the median grain size (d_{50}) of the surface layer was gravel-sized particles (29 mm), with a much finer subsurface layer composed primarily of sand (3 mm). The proportion of fine sediment in the subsurface was also greater than in the surface layer (Fig. 3), which supported the students' initial hypothesis that sand-sized material would be more abundant in the subsurface. However, it is also important to note that pebble counts underestimate the quantity of fine bed material, so the differences between surface and subsurface grain-size distributions is likely to be greater than reported.

Measurements of channel width revealed a surprising pattern. Hydraulic geometry relations predict that channel width typically increases with drainage area. Data from the Carrownisky River indicate the opposite trend: bankfull width decreased with drainage area (Fig. 4). In this river system, bankfull width was primarily a function of the composition of the stream-bank sediments (Fig. 5). Noncohesive banks were common in the midsection of the river, whereas cohesive banks dominated in the lower river. Cohesive sediments were associated with narrower and deeper channels compared to noncohesive or mixed layered banks (Fig. 6). This supports the students' hypothesis

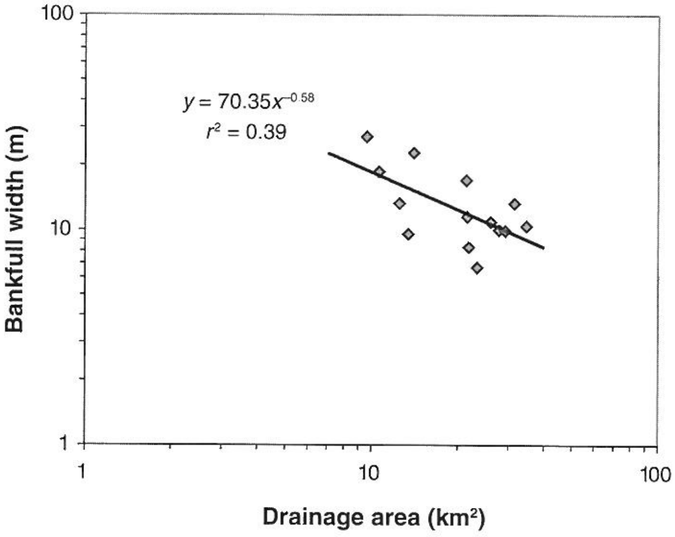

Figure 4. Relation between drainage area and bankfull channel width in Carrownisky River basin.

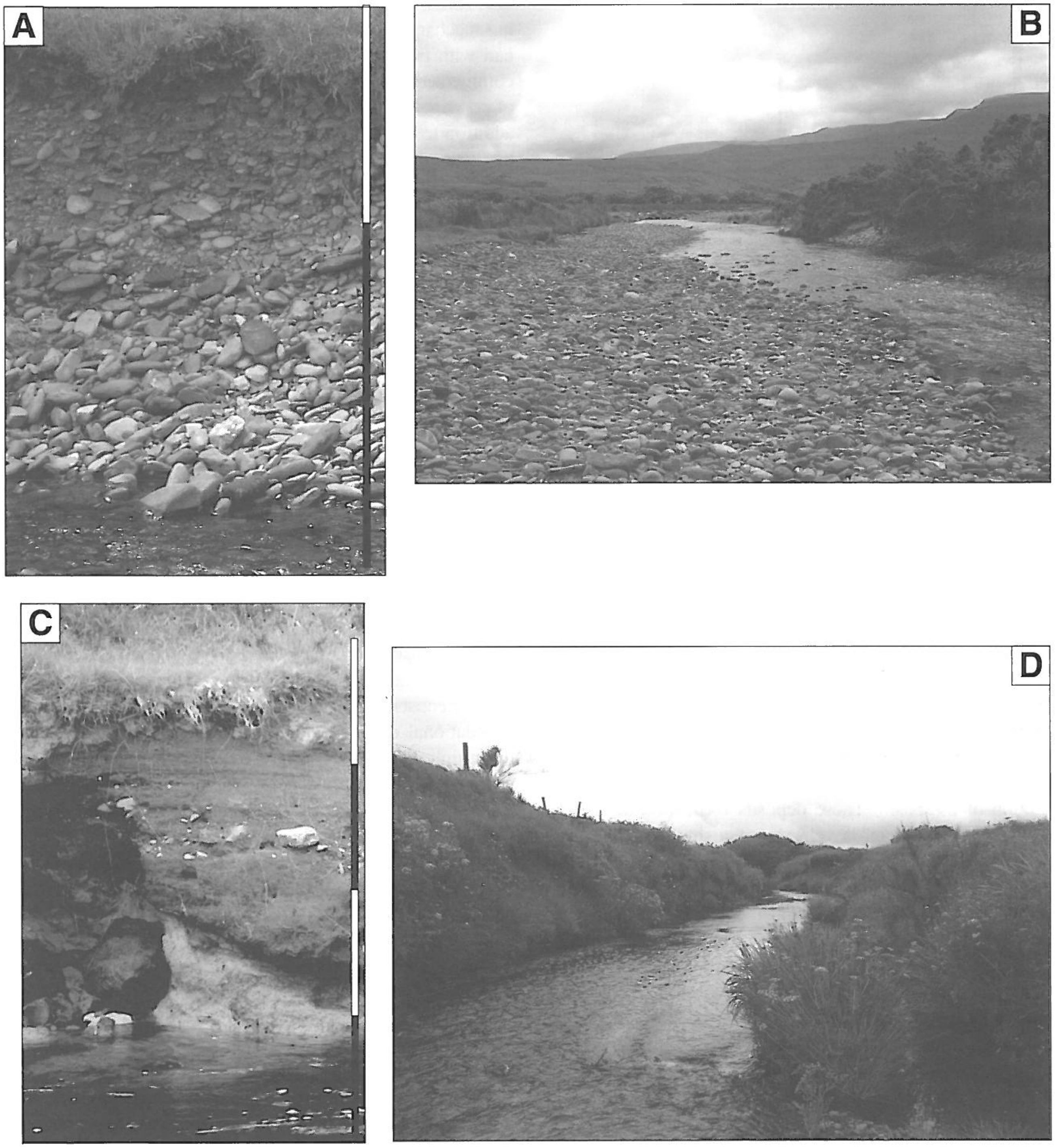

Figure 5. (A) Noncohesive stream banks composed of clast-supported gravels. (B) Broad river channel and gravel bars formed in areas of noncohesive stream banks. (C) Cohesive stream banks formed in clay-rich sediments; organic-rich midlevel layer overtopped by laminated layers of fine sand. (D) Narrow and incised river channel formed in areas of cohesive stream banks. Scale bar denotes 0.5 m increments.

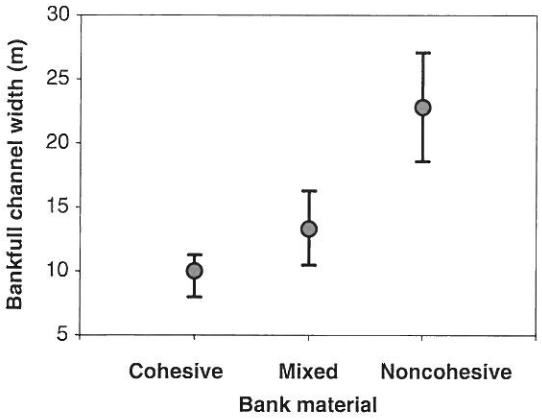

Figure 6. Relationship between bankfull channel width and cohesion of stream-bank sediments.

that cohesive banks can restrict channel width and therefore bar development.

Students were able to predict where bars of varying sizes would occur based on the angle of curvature of meander bends (Fig. 7). High-angle bends were associated with large bars because there was ample room for channel expansion and sediment deposition on the inside of bends. In contrast, low-angle bends were associated with smaller bars because the space to accommodate bar formation was limited in tight river bends.

Emanating from an interest in understanding the pattern of channel development, students also wanted to interpret how past environmental conditions influenced the present-day channel. Stratigraphic evidence revealed that the Carrownisky River valley has undergone dramatic changes in landforms and fluvial features (Fig. 8). Stratigraphic evidence in exposed river banks suggests that a broad, braided river system flowed through the midsection of the basin. These deposits form the noncohesive banks where the modern-day channel is a single-thread meandering channel with abundant gravel bars (Figs. 5A and 5B). In the lower river, stratigraphic evidence suggests that the valley has alternated between a delta and shallow lake or wetland, and a river-floodplain. These deposits form the cohesive sediments where the modern-day channel is narrow and deeply incised into the floodplain (Figs. 5C and 5D). The combined landforms of braided rivers and wetlands are indicative of wetter climate periods, when river discharge increases and sediment supply to rivers is high due to accelerated hillslope erosion. Evidence of widespread climatic cycles, including major flood events and the expansion of wetlands, has been observed in other sedimentary and archaeological records in the region (e.g., Barber et al., 2003; Macklin and Lewin, 2003; Moore, 2006).

Learning Assessment

Students were evaluated on the quality of the data, thoroughness of the analysis, and content of the final presentation. A high level of student learning was evident. During the field component of the exercise, students displayed a sense of curiosity and pride in discovery as their research questions evolved and the data provided answers. Their drive to discover patterns and their underlying mechanisms was acutely evident in the discussions students had with peers and the faculty mentor. Several of the students commented that the exercise provided a "real understanding" of concepts they had learned about in lectures and textbooks. In addition to providing a research experience for undergraduates, the data collected in this endeavor provided insight into timely and pressing questions in fluvial geomorphology over which the students felt ownership. Discovery is particularly important since student experiences are often limited to "canned" exercises, where results are known by the instructor in advance, and the task of the student is to find the "correct" answer. In this exercise, the students took the lead in developing and refining the research questions, and the role of the faculty mentor was to facilitate this student-led exploration. Another critical role of the faculty advisor was to ensure that reliable data were collected. This was accomplished through training, oversight, and quality control at all stages in the process.

CONCLUSIONS

In the environmental science component of the field course, students learned important concepts in fluvial geomorphology (e.g., hydraulic geometry, channel morphologic development, sediment transport, and landform development). These concepts were demonstrated and explored in the student-led research projects and presentations, which provided an opportunity to learn how scientists develop, test, and communicate ideas based on foundational concepts in the geosciences. In addition to gaining insight into the scientific method and foundational concepts, students were able to address two fundamental (and currently unresolved) questions in geomorphology: Can the location of large gravel bars be predicted, and what controls channel width? Importantly, students were able to use simple field methods to develop observational studies that were quantitatively rigorous and data rich. Specific research questions focused on four key topics: (1) identifying where sand deposits would be most abundant in the river network; (2) predicting where large gravel bars were most likely to form within the river network; (3) identifying important controls on channel width and incision; and (4) interpreting how past landforms have influenced the development of the modern-day river channel. These research questions were derived from the initial observations that gold deposits were linked to in-stream deposits of sand, which led to a process-based understanding of how rivers form and function. The specific new knowledge gained from the students' research will form the foundation for future research projects during the field course.

One particularly important aspect of the research project was the emergence of new questions and insights throughout the course of the study. Through their observations of the linkages between sand deposition and gold deposits, and the constraints

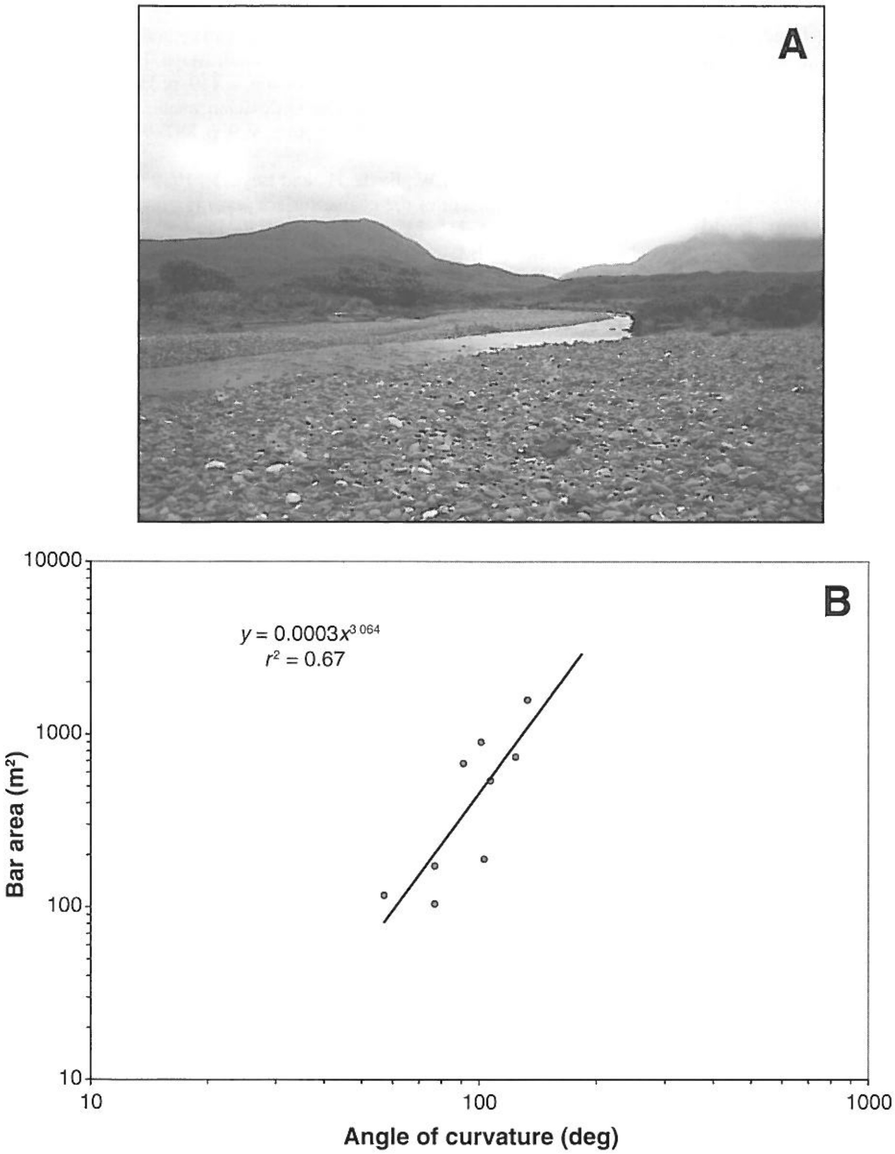

Figure 7. (A) Large gravel bar formed in high-angle bend. (B) Relation between angle of curvature of the river and surface area of gravel bars.

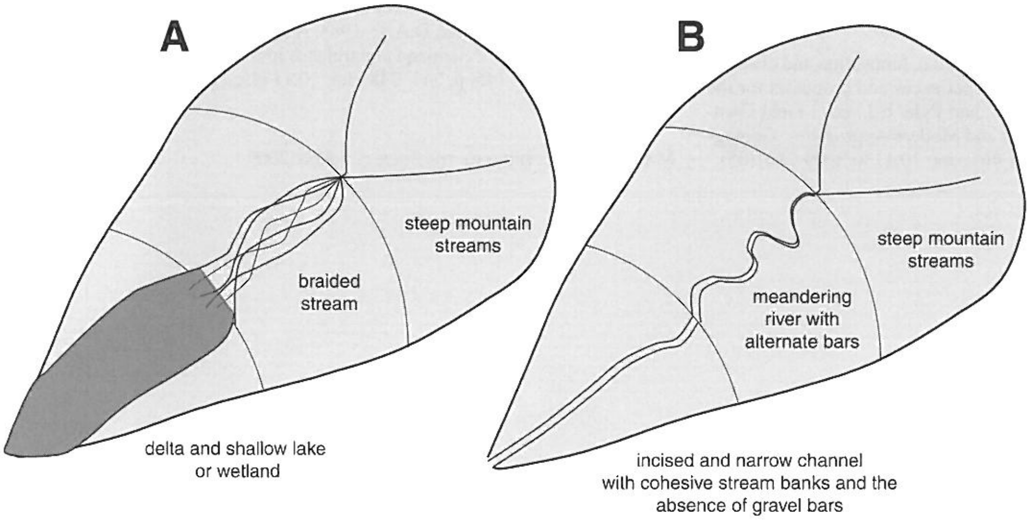

Figure 8. Conceptual model of how (A) past environmental conditions create the template for (B) the modern-day river morphology.

on channel width in the field area that provided a first-order control on bar development and sediment deposition, new research questions emerged. The emergence of new ideas and questions is critical to the way scientific knowledge evolves and progresses. Only through active inquiry can the evolution of learning be demonstrated, and our experience suggests that this is best done through student-led research in a field-based setting. Field courses provide an ideal opportunity for teaching geoscience in a way that mirrors the processes of discovery used by professional researchers, and it moves far beyond many traditional methods of teaching that only present established knowledge.

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