

REU SITE: RATES, PROCESSES, AND IMPLICATIONS OF BIG CHANGES IN THE SHAPE AND STYLE OF THE MISSOURI RIVER

OVERVIEW

Each continent has a limited collection of very large rivers that are highly conspicuous features of the landscape, ecosystem, and economic structure of the nation they pass. These rivers are sensitive to changes in climate and land-use that periodically drive reordering of the morphology and profile of these rivers. Understanding these large responses to change is pivotal to understanding, managing, and restoring these critical natural resources. We intend to address a fundamental research question within the topic of river response to external change. Specifically, we will ask, “If, how, and at what rate, do upstream morphology and profile changes transmit down stream within large river trunks?” We intend to use this research question as a tool for providing a positive environment for learning the processes of scientific research through a diverse field- and lab-based undergraduate research experience. The field study site will be the Lower Missouri River Valley. Some educational objectives are learning basic research skills and knowledge, and include: application of the scientific method at nested large and small scales, benefits and structure of professional collaboration and this sense of “culture” of the scientific community, and gaining of a broad range of experiences related to river research. The science objective is to address the above research question by tracking of two morphological and one profile change through the length of the Lower Missouri River trunk and assessing the manner and rate for any downstream progression of this signal. The students will each have an individual project that entails addressing this question for their discrete area through field-based geologic mapping and lab geochemical, petrographic, and geochronologic techniques. Students will then work collaboratively with other students to determine how each of their findings fit together into the larger puzzle in order to address the larger science objective.

The project will be overseen by the PI (John Holbrook) and Co-PI (Ronald Goble). Both the PI and Co-PI and their host institutions have a strong commitment to undergraduate research and this project in particular. The project proposed here grew from a series of highly successful EDMAP projects in the Lower Missouri Valley downstream of the areas targeted for this research. This research originally defined river changes that are to be examined in more detail in this proposal. These EDMAP projects also provided the base experience from which the educational and science plan proposed here was tested and honed. The PI and the Co-PI have collaborated on each of these six EDMAP projects that have collectively supported 10 undergraduate students. The host institutions of University of Texas at Arlington and University of Nebraska, Lincoln have supported these EDMAP projects well, and will continue their support during this proposed research by continuing to provide all lab and classroom facilities and field and lab equipment needed for successful completion of this project. The PI and Co-PI have also enlisted the support of three guest mentors. These guest mentors will serve to demonstrate the social relevance of the REU research through discussion of their related research, and will discuss career opportunities in their respective fields. These include Dr. Scott Lundstrom (USGS), Dr. Wedge Watkins (USFWS), and Dr. Chris Paola (NSF-NCED facility in St. Anthony Falls, Minnesota). Dr Lundstrom will also serve as an outside evaluator and will aid in the publication of student maps.

We plan to devote an extra effort toward developing the skills of participating students from a state of training and dependence to a state of independent student research. The PI will offer a 3hr course at the beginning of each summer that is intended to constitute basic training. This will include 1.5 weeks of mixed class and field instruction followed by extended field-trip-based instruction (1 week). The students will then undertake field work (4 weeks), which will initiate with close mentoring and end with independent research by the students. The students will complete their project with lab-based

examination of field samples at the University of Nebraska, Lincoln under the instruction and guidance of the Co-PI Ron Goble.

Upon completion of the project, the students will gain a clear picture of the thought processes and opportunities in a field of science. This will be a transferable experience for still broader aspects of science. The students will also gain valuable first-hand experience directly applicable to environmental careers. In addition, the students will gain publications of their independent and group work as well as 3hr of transferable college credit.

NATURE OF THE RESEARCH

The Research Problem. Numerous researchers have long established that fundamental changes in water discharge regime, sediment discharge amount and type, and valley gradient have a first-order control on morphology (channel dimension and pattern) and profile (channel incision vs. aggradation vs. stability) in alluvial rivers (rivers which migrate freely within sedimentary deposits) (see Bridge, 2003 and Schumm, 2005 for reviews). While such morphology and profile changes may occur locally on century to millennial time scales from either valley gradient changes caused by local faulting events (Holbrook, et al., 2006a), major and lasting bank vegetation shifts (Schumm, 2005), or “slugs” of anomalous sediment loads introduced in local reaches (Macklin and Lewin, 1989), such changes in long reaches lacking these local factors may be assumed to record fundamental changes in water and/or sediment input from drainage-basin tributaries (Leopold and Miller, 1954; Schumm, 1965 and 2005; Gregory, 1983). As sediment and water input derived from the drainage basin are controlled ultimately by climate and land use, such morphology and profile changes are commonly ascribed to climate change where major landscape modification through land-use changes can be negated (e.g. Knox, 1983; Veldkamp and Van Dijke, 1998, Vandenberghe and Huisink, 2003; Lang, et al., 2003).

Linking of change in channel morphology and profile to changes in climate and land use depends on an understanding of the lag time or “coupling rate” between the upstream change and the river response. Generally this coupling is assumed to be rapid. This assumption is valid in small drainages and upstream parts of large drainages where the response of rivers to changes in sediment and water input is found to be on the order of decades (Harvey, 1986 and 2002; Kasai, 2004, Liebault, et al., 2005). In lower parts of larger drainages where a climate or land-use response has been propagated for long distances down the trunk of the river system, the coupling relationship is far less understood and the appropriate lag time to impose between the measured response and the basinal change it records is uncertain. Profile changes are better studied, but not completely understood, and are found to take several decades to centuries to propagate several 10’s to a few 100 km downstream through modest-sized river systems (Church and Jones, 1982; Knighton, 1989 and 1999; Harvey, 2002). Lag time required to propagate fundamental changes in stable channel morphology to lower reaches of large rivers, however, is much more poorly understood. Most such work has focused on observations of historic river changes and suggests that translation of major morphology changes to lower trunk drainages could be on the order of several decades (e.g. examples in Schumm, 2005) or many centuries (e.g. Hooke and Harvey, 1983). Historic changes mostly reflect high and sudden degrees of land-use change owing to human industrial-age impacts, however, and are also generally still likely in progress and have not reached the eventual stable form (Harvey, 2002; Schumm, 2005). While changes in river morphology induced by climate and/or modest land-use changes that complete and endure for millennial scales are identified from deposits of Holocene floodplains for modestly large rivers (e.g., Vandenberghe and Huisink, 2003), complications in dating resolution, signal clarity, and river scale have kept an understanding of the downstream propagation history of these past changes elusive. Understanding of the magnitude and rate for propagation of these changes is critical for gaining the century-scale resolution desired for use of channel processes as a paleoclimate proxy, and is important more generally to river researchers and managers

needing to understand predictive river response and response rate to climate- or human-induced formative changes.

The rates and the processes by which fundamental and enduring changes in channel morphology may propagate downstream in large river systems remain particularly enigmatic. Common wisdom is that such fundamental reordering of floodplains will have a tendency to dampen downstream, will require up to centuries to propagate through the lower trunk drainage, and will become increasingly complex as the signal propagates through the lower reaches and interacts with other long-term effects (reviewed in Harvey, 2002). These premises await an opportunity for thorough testing within the trunk system of a clearly large river.

The Missouri River presents a rare opportunity to field test hypotheses regarding the rate and nature of downstream propagation for changes in river morphology and river profile within a large river system. The Missouri River is a very large river that drains roughly one-sixth of the conterminous United States, hosts discharges as high as 676,000 cu. ft/sec, and has pre-modification trunk channels on the order of 600 m wide and 9 m deep. Research efforts by the PI, Co-PI, and 14 students through the USGS EDMAP Program have succeeded in mapping a 50 km alluvial reach of the Missouri River floodplain in the far lower trunk of the Missouri River drainage (Figure 1). Through detailed mapping of channel elements and high-resolution OSL dating, we have been able to identify two fundamental changes in river morphology and one major profile adjustment occurring over the past 5000 years. These include 1) an abrupt change from a very high-sinuosity single-channel river to a low-sinuosity locally braided river somewhat abruptly at 3400 \pm 100 years before present (ybp), 2) a gradual switch from this low-sinuosity and locally island-braided channel to a fully braided system spanning 3000 ybp to 1200 ybp, and 3) a phase of 2 m of incision in association with the second pattern change spanning 3200 ybp to 1700 ybp. While gradient changes related to local faulting can cause similar pattern changes, the length of river affected, the duration of change, the absence of active tectonic features, and the overall consistency of gradient are inconsistent with a tectonic cause (Holbrook, et al., 2006). There is also no evidence of major local sediment input changes or major bank vegetation shifts at these times. These three signals appear to record initiation and completion of fundamental readjustments of the river because of changes in input of water and sediment into the lower river reaches.

We intend on tracing these three observed signals 540 km up dip in the river valley by mapping additional sections of the floodplain extending into the uppermost parts of the lower trunk river (Figure 2). We will determine how and if these signals change along the river profile. We will also determine if propagation of these signals is below our dating resolution, thus on the scale of decades, or above our resolution, and thus the number of kilometers/century. The information gained from this study will be widely applicable for understanding response rates and processes in rivers in general. This information will also be directly applicable to understanding fundamental changes in climate within the northern Western Interior of the U.S. as encompassed by the Missouri River drainage basin. The knowledge of late Holocene climate change within the Missouri River drainage is minimal, and falls to a few local studies (Meyer et al, 1995; Fritz, et al., 2000; Baker, et al., 2000, Miao, et al., 2005). No regional picture of climate change is understood here. The more regional view of the Southwest (e.g., Enzel, 1989) and Midwest (e.g., Knox, 2003) U.S. are better understood. While there is literature that hints at a major shift in climate and/or climate trend around the Missouri drainage near 3600 ybp (Brown, et al., 1999; Knox, 2003; Miao, et al., 2005), this remains inconclusive owing to lack of direct evidence from the Missouri drainage proper. Better understanding of lag times and processes relating climate change and lower-drainage response gained from this study would help determine if these changes are being recorded directly or indirectly by the three observed morphology and profile shifts in the lower trunk system, or if these changes record another unknown cause.

Social Benefits from Alluvial Mapping and Mapping-Based Research within the Missouri Valley.

The Missouri River corridor has been defined as a high-priority USGS focus area, and Quaternary surficial deposit maps have been identified as a critical data need in the draft Missouri River Science Plan (Robb Jacobson, USGS, pers. comm.). Currently the collection of maps developed by the PI, Co-PI, and students for the USGS EDMAP Program, in Figure 1 and also extending upstream 50 km farther to Kansas City, are the only detailed surficial geology maps available for the Missouri River floodplain. There are several avenues where alluvial mapping, and conclusions derived from this mapping, in the Missouri Valley would have tremendous benefits that are directly and indirectly transferable to general public consumption. Each of these benefits will be relayed to REU students through field trips and mentors.

First, knowledge of distribution of surficial materials gained from mapping has very tangible benefits. For instance, numerous towns and urban centers (including Sioux City, Omaha, Kansas City, and St Louis) are built partly to mostly on top of Missouri Valley alluvium. Substrate stability is of tantamount concern for construction (e.g., homes, roads, bridges, etc.) and other development (e.g., parks, landfills, ranches, etc.) in these areas, and is controlled at its first order by distribution and sedimentary characteristics of Quaternary units. These areas are presently undergoing intensive development as populations spread into the previously rural valley floors as part of a national trend of rapid urban sprawl. This ongoing development is currently taking place without the benefit of the most fundamental planning tool, maps of substrate materials. In addition, extraction and protection of water resources for agriculture and valley-area development is also of critical and on-going need. Concerns include quantity and quality of water for public supply, contaminant infiltration sites and migration rates, and connections between surface and groundwater flow (Kelly, 1996). Quaternary alluvium provides the medium for groundwater flow, and distribution of surficial fines dictates potential locations of aquifer recharge vs. confinement. Thus, detailed mapping of the architecture, and by proxy the permeability distribution, of these strata provide the template upon which more robust predictions of groundwater flow and accessibility are to be made.

Fundamental research derived from mapping has benefits related to river restoration, ecosystem management, wetland protection, and hazard management. Maps of Quaternary valley-fill deposits will elucidate the distribution and characteristics of ecosystem deep foundational materials that are currently not available from more near surface (approx. upper two meters) soil maps. Alluvial mapping is allowing workers to explore methods to streamline identification of regions with suitable parent material and landscape position for environmental-based projects, like wetland development, allowing for more focused environmental reclamation efforts and land-acquisition proposals (e.g., Holbrook, et al., 2006). Furthermore, understanding of long-term natural variability in river morphology is an emerging tool for developing reasonable baselines for river restoration projects and developing models for predicting natural channel morphological response to human-imposed discharge conditions (Gregory, 2004; Holbrook, et al., 2006). Better understanding of propagation rates and processes for river-altering events gained during this study will also help in planning efforts for downstream policy response to upstream changes.

Student Research Methods/Research Activities. REU students will be performing allostratigraphic surficial mapping for the field part of their research in order to determine location, dimension, and pattern of segments of older river channels preserved in the Missouri River floodplain deposits. Allostratigraphy defines map units based on recognition and delineation of their bounding discontinuities (e.g., channel scours, valley scours, traceable soil horizons, etc.) (NACSN, 1983). Examples of scour-bound sedimentary bodies that may be mapped as allounits include: ox-bow lake/channel fills, incised valley deposits, deposits of terrace fragments, individual channel belts, etc. (see Figure 1). The first step in the mapping procedure entails observation of topographic maps, aerial photographs, digital elevation models,

satellite imagery, and existing soil maps for recognition of landforms characteristic of likely depositional units. Basic assumptions of depositional style derived from these observations are used in conjunction with established sedimentary architectural models (e.g., Miall, 1996) to assess likely allostratigraphic mapping units within the valley alluvium. Construction of a series of “hypothesis maps” of allunit distribution within the target stratal body follows, and are based on the above models and landform trends. The next step is to test landform-based hypotheses by drilling. Units assessed on hypothesis maps infer characteristic lithofacies. For instance, an arced topographic trough is usually inferred to be an abandoned-channel/ox-bow fill. One would predict that drilling here should thus encounter muddy strata. If drilling confirms this prediction, the abandoned-channel-fill hypothesis is supported. If not, it is falsified and a new hypothesis is required. Continued hypothesis testing eventually results in a unique solution that is prepared as a final map of allunit distribution and lithologic characteristics.

The students will also collect data relevant to age of allunits. Relative age of allunits will be assessed using techniques established for relative dating of alluvium in the lower Mississippi and Missouri valleys. These are generally revealed during normal mapping procedures, and include crosscutting relationships (e.g., Saucier, 1994); loess stratigraphy (e.g., Blum, et al., 2000); and relative soil development (e.g., Aslan and Autin, 1996). Absolute dating of allunits will utilize optically stimulated luminescence (OSL) techniques following sample collection protocols that proved successful for dating studies of Missouri and Mississippi valley alluvium by the PI and Co-PI.

In the lab phase of the research, the students will prepare OSL samples for dating and analyze the geochemical and petrographic data from these samples for provenance information. OSL samples require repeated long runs within optical readers that will be overseen by the Co-PI during the coming months after the summer REU experience. Running of samples also requires considerable preparation before samples can be finally loaded into the optical reader. The students will be responsible for preparation of their samples for loading, will learn the processes and theory of the dating technique, and will receive the results of the reader during the following semester. The students will also be charged with analyzing both geochemical and petrographic data for evidence of changes in the source and characteristics of the river bedload sediments. All OSL dates are derived from sand samples collected from point-bar deposits of the main river channel. These sand samples thus record bed load material carried by the river at the time of sand deposition. A portion of each sample is sent for a 47-element bulk-chemical analysis as part of the OSL dating process. A bank of 30 analyses is currently available from prior dated samples in the area of Figure 1, and new samples will be made available each year. Likewise, sand for each sample will be grain-mounted and point counted for proportion of framework minerals. The students will use this information to search for evidence of changes in bed load material with respect to time and space. This information will be used to determine potential times and/or valley locations where changes in bed load input occurred. This will be a first-cut tool for assessing source tributaries responsible for input changes that may have caused morphology and/or profile shifts.

Upon receipt of OSL dates, the students will be charged with connecting preserved river segments of similar age to reconstruct reasonable patterns and relative incision of the Missouri River over discrete segments in time. This will be done according to procedures outlined in Holbrook et al (2006a) and shown in Figure 1. Evidence for fundamental changes in river morphology and profile will be ascertained from these reconstructions and compared with reconstructions from other parts of the river. In this way students will determine if signals observed within the valley can be traced up stream, and, if so, how they propagate and at what rate. Students will present these results the following year at the Annual Meeting of the Missouri River Natural Resources Committee.

A separate 40-50 km alluvial segment of the Missouri River Valley will be selected each of the three years for the above procedure. Three segments are currently targeted for this approach: one just upstream from Sioux City Iowa, one just down stream from Sioux City Iowa, and one in the vicinity of Omaha,

Nebraska (Figure 2). These three segments reach to the uppermost limit of the lower trunk drainage of the Missouri River and incorporate 540 km of valley up dip of the reach mapped in Figure 1. Farther up stream, the river floodplain disperses into tributaries of the Upper Missouri Valley, and is also mostly submerged by large hydroelectric and recreational dams (Figure 2). The target selections also avoid narrow parts of the valley just up dip of Kansas City, Missouri that may be bedrock controlled and thus prone to a locally derived and non-comparable morphology signal. Tracing of observed Lower-Valley signals through these reaches will also distinguish whether these signals derive from upstream of the limits of study (the Upper Valley), or were integrated from large Lower-Valley tributaries, such as the Platte River. Though no detailed mapping currently exists over these reaches, preliminary small-scale mapping in the Sioux City area by one of the guest mentors (Scott Lundstrom) does reveal evidence for some shift from meandering toward braided patterns in floodplain deposits that is potentially related to similar pattern shifts depicted in Figure 1 (Lundstrom, et al., 2006). These preliminary observations are currently undated and will be examined more closely during the proposed study.

Student Mentoring and Training Strategy. Great discoveries are rarely made as a result of one observation. Indeed, research typically involves one finding that provides a piece of the puzzle, and several of these puzzle pieces cumulate to address a still larger puzzle piece. Through this iterative process, all the pieces are finally provided to cumulatively address a larger question. The proposed research is designed in this same manner, and will teach this aspect of the research process. Each student will be given their own map area, and their own independent lab sample to examine. Each student will thus be charged with addressing distribution of units and identifying evidence for fundamental temporal changes in stream process for their independent area. The size of this area will vary with local conditions and unit complexity, but will generally be on the order of 40 km². The student team members for each summer will need to pool their local findings to determine if any temporal stream changes can be identified that are pervasive through the entire study reach, and thus record a fundamental change in the river system for some point in time. The students from all three summers will then need to pool the findings from each summer group to address the overarching question of this proposal. Namely, if, how, and at what rate, do upstream morphology and profile changes transmit down stream within large river trunks? In consistency with this approach, one student from each field pair will present their findings during each year at the Annual Meeting of the Missouri River Natural Resources Committee, or an equivalent meeting. All students will collectively present their findings at the end of the third year.

Students will also be mentored in the collegial nature of science through practical application. Each student will be responsible for their independent map of their own area. However, students will work in the field in pairs, and will collaborate with each other on ideas regarding their mutual areas. Likewise, they will need to cooperate on best division of resources to finish their respective map areas while working in the field together. In addition, the PI will arrange regular sessions during field work whereby each student presents their progress for critical peer review and questioning by the group at large. In the lab, students will further need to collaborate in order to assess the meaning of their individual part of the larger sample set.

While the joys of discovery are sufficient for some, many students need to see the practical application of their research and tangible career opportunities where their research may be applied in order to become excited. We will thread several opportunities to learn these applications from active practitioners through efforts by the PI and Co-PI directly, and from a collection of guest mentors. Some examples include the following. Students will accompany the PI to several sites in the Dallas/Fort Worth area where he has done consulting work to limit hazards to new construction because of the current state of incision by the Trinity River drainage. They will also accompany the PI to the New Madrid seismic zone of the Lower Mississippi Valley to see how understanding of fault effects on the river has become an important tool in assessing trends for damaging earthquakes and limiting earthquake hazard. The students will also visit a site on the Lower Missouri River floodplain where mapping of floodplain materials is being used as a key

element in the restoration of the floodplain and channel environment. They will be lead here by guest mentor Dr. Wedge Watkins (Biologist, USFWS). They will then get to work with Dr. Scott Lundstrom while conducting their field mapping. Dr. Lundstrom is a Quaternary geologist heading the official mapping project for the Lower Missouri Valley on behalf of the USGS. The students will also gain a strong dose of exposure on geochemistry and petrographic applications from the Co-PI during the final lab part of the project. We also plan a visit to the NCED facility at the University of Minnesota. This is the premier national facility for experimental study of natural river systems, and directly serves research in fundamental river processes and river restoration. In addition, the PI has pursued understanding of job placement for geologists and scientists in general in the workforce (i.e. Holbrook, 1997), and will give an extended lecture on this topic during the research experience. It is also anticipated that showing this strong connection between research and application/career will aid in the retention of students already committed to the sciences.

THE RESEARCH ENVIRONMENT

The research will be mentored primarily by the PI (Holbrook) and the Co-PI (Goble), and will draw upon the diverse pool of guest mentors discussed above and below who will serve to further broaden the research experience at interspersed moments. The mentors and the facilities devoted to enriching the research experience for the REU students are discussed below.

John Holbrook (PI: Ph.D., Indiana University). Dr. Holbrook is in his third year as a Professor at University of Texas Arlington, where he teaches courses in Sedimentology/Stratigraphy, Surficial Processes, Historical Geology, and Field Camp. He advises both undergraduate and graduate students in an active research program focused on modern and ancient sedimentary processes. He has made undergraduate research a priority throughout his professional career and continues to do so at UTA. During the twelve years prior to coming to UTA, at Southeast Missouri State University, he established the first formal program for fostering and mentoring undergraduate research in the College of Science and Math, the ERA program. Structure and early results of this program are published in the *Journal of Geological Education* (Holbrook, et al., 1994). He has sought and received two PRF grants focused on undergraduate research involvement, which funded mentoring for a total of seven students for six-week summer field-research projects. These projects addressed Cretaceous bedrock of Colorado/New Mexico and Holocene floodplain strata of the Mississippi Valley, respectively. Likewise, he has maintained a mapping-based research program in the Mississippi and Missouri river valleys since 1999 that has been funded by six consecutive USGS EDMAP grants. These EDMAP projects are geared toward training and mentoring of equal numbers of graduate and undergraduate students in mapping-based field research, and serve as the experience and research base from which the current proposal is developed. Ten undergraduate students have been mentored to successful completion of their EDMAP projects thus far through this ongoing project, and two more are currently in the field. Eight additional undergraduate students have been supported by internal research grants, including two who are currently engaged in their projects. In total, Dr Holbrook has sought, attained support for, and mentored to completion 23 undergraduate research projects, and currently mentors an additional four undergraduate projects. Each of these students has been regarded as a protégé and received close interaction and individual career concealing. Of the 23 students, seven developed their projects into formal senior theses for “Graduation with Distinction;” ten went on to graduate school in geology, one went to law school, one went on to graduate research in archeology, one went on to graduate school in biology, one made a career of the Navy, seven began environmental consulting careers with their B.S., and two, along with the current students, are still within their undergraduate program. Each of the EDMAP students have published their personal first-authored map, and are co-authors on additional maps, as part of a map series published as Open File Reports by the Missouri Geologic Survey. There are 18 maps in this series thus far with prominent undergraduate authors. In addition, undergraduate students of Dr. Holbrook have presented 24 abstracts at national (11) and regional (13) meetings, published 4 refereed papers, published 3 reports,

have two papers in preparation, and had research for two undergraduates featured on the Discovery Channel.

Ron Goble (Co-PI Ph.D., Queen's University). Dr. Goble is an Associate Professor at the University of Nebraska-Lincoln, where he teaches courses in Introduction to Geology, Physical Geology, Mineralogy and Optical Mineralogy (now Minerals, Rocks and Ores), and Optical Dating. He has directed the Geosciences Luminescence Geochronology Laboratory since its establishment in 1999. He oversees both graduate and undergraduate course work and research in optical dating techniques and applications, and has jointly or solely supervised three Ph.D., three M.S., and two senior undergraduate dissertations/theses which extensively utilized optical dating. The two undergraduate research projects were funded two-year University of Nebraska UCARE research projects; a third undergraduate UCARE project using optical dating is entering its second year. This student research has produced seven published, two in-press, three accepted and in-revision, and two in-review articles, and more than twenty abstracts of papers presented at national and international meetings. Collaborative research has been a major priority, and has included projects involving over thirty-five researchers at seventeen different institutions, and includes current research projects involving students at three universities in addition to UNL.

Guest Mentors. In order to add to the diversity of research experience provided by the PI (Surficial processes and Sedimentology) and the Co-PI (Optical Geochronology, Petrology, and Geochemistry), the project will draw upon a pool of guest mentors. These guest mentors will spend a day to a week with the students and provide them the opportunity to be exposed to diverse applications of their research, and will augment diversity of career and research mentoring provided by the PI and Co-PI. This pool includes Dr. Wedge Watkins, Dr. Scott Lundstrom, and members of the NCED facility lead by Chris Paola. Dr. Watkins is Refuge Biologist for the Big Muddy Wildlife Refuge, which is a growing refuge within the US Fish and Wildlife system. This refuge is mandated for growth to 60,000 acres of floodplain habitat in the lower Missouri River Valley. He is stationed in Columbia, Missouri and is working on techniques to restore and monitor river and floodplain habitat in the lower Missouri Valley. He has collaborated with the PI on undergraduate research in recent years. Dr. Scott Lundstrom is a Quaternary geologist for the USGS National Cooperative Geologic Mapping Program, and is stationed in Denver, Colorado. He has recently performed geologic mapping in support of natural hazards, climate change, and landscape evolution research as part of the Southern California Area Mapping Project, the Las Vegas Area Urban Corridor Project, and regional projects in the Great Lakes and Desert Southwest. He is currently the leader for the Missouri River Geologic Framework Project, where he is mapping the bedrock and surficial deposits in the areas targeted for this proposal on behalf of the USGS. The PI and Co-PI have closely cooperated synergistically with Dr. Lundstrom from the inception of this proposed project. The National Center for Earth Surface Dynamics (NCED) is an NSF National Science and Technology Center located at St Anthony Falls in Minneapolis, Minnesota. This is an experimental facility with purpose "to catalyze development of an integrated, predictive science of the processes shaping the surface of the Earth, in order to transform management of ecosystems, resources, and land use." They sponsor research programs in stream restoration, desktop watersheds, and stratigraphic architecture, and are focused on understanding the interactive coupling of river system processes, sedimentary deposits, and the forcing mechanisms that drive these. The program has 23 research leaders and 11 cooperating institutions and is headed by Director Dr. Chris Paola. Dr. Paola will be guiding student mentoring during the REU visit to the NCED facility.

Research Facilities, Institutional Support, and the Field Research Environment. Both UTA and UNL are well equipped to provide a positive research environment. UTA has classroom facilities for the initial instructional phase for each summer. In addition, the university has computers, printers, scanners, and software (ArcGIS 9.0) sufficient to teach and use GIS systems in both the lab and field environment. These will be available to the project with no additional direct charges to the proposal. Field equipment needed for the project is also available through UTA. This includes all drilling equipment (seven

Eijkelkamp Dutch-auger sets), GPS systems, and Munsell color charts required for field collection and recording of borehole data. In addition, UTA has a field truck which will serve as a field platform for drilling and transportation of personnel. The University of Nebraska-Lincoln (UNL) Geosciences Luminescence Geochronology Laboratory has all facilities and equipment necessary for optically stimulated luminescence (OSL) dating, including a Daybreak Nuclear, and two Riso National Laboratories optical readers, with one of the latter equipped with a single-grain attachment. Sample preparation and data collection and analysis are carried out within the laboratory, but samples are submitted to an external laboratory for geochemical analysis. Students will be given a brief introduction to the theory and practice of optical dating, and each student will prepare one sample for analysis. Because of restrictions associated with the presence of radioactive sources on the readers, students will utilize data files collected from similar samples in their training, rather than directly utilizing the readers; actual reader data collection for student samples will be carried out by Dr. Goble. Petrologic studies will utilize grain mounts prepared in the sedimentology laboratory. MS Excel will be used to look for geochemical trends related to river morphology/time.

The field environment will range across a span of river types. During the training phase, the students will visit a wide range of rivers for in-field observational learning. The highly entrenched urbanized watershed of the Trinity River, the braided sand-rich Red River, and the meandering Brazos River are all in close proximity to UTA and will be visited on day trips during the stay at UTA. Fluvial outcrops, the Mississippi River, and the Big Muddy Refuge of the Missouri River will all be visited in transit to the field research site. The field research site on the Missouri River floodplain is dominantly agricultural. Numerous roads provide public access to areas targeted for drilling. Most of the land is private, but landowners have been consistently supportive of our mapping efforts and have denied access less than 1% of the time over drilling of >1000 boreholes currently collected by the PI and students in the Mississippi and Missouri floodplains. Most all of the drill sites will be adjacent to public roads.