# Surficial Geologic Mapping in the Oneida Narrows Region, Southeast Idaho:
## Addressing the Co-evolution of the Bear River and Lake Bonneville

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### Introduction

The Bonneville Basin record is one of the world's most important archives of continental paleoclimate, and it is one of the birthplaces of modern Geology (e.g. Gilbert, 1890; Currey, 1990). The Bonneville Basin, at the northeastern corner of the Great Basin, formed during late Cenozoic extension when block-faulting disrupted regional drainage patterns and created a set of large closed-lake basins inboard of the North American plate margin. During the Quaternary, a large pluvial lake system occupied the Bonneville Basin, fed by the paleo-Weber, Provo, and Bear Rivers flowing out of the high Wasatch and Uinta Mountains to the east (Fig. 1). Several cycles of lake expansion and evaporation have been documented tracking global climate fluctuations, the largest of which is the most recent, the Bonneville cycle (~28-15 ka, MIS 2). During the late Pleistocene, Great Basin pluvial lakes expanded with increased effective moisture due to cooling and a southward displacement of the jet stream (Benson & Thompson, 1987; COHMAP, 1988; Thompson et al., 1993). Lake Bonneville became the largest pluvial lake in the western U.S. (~51,000 $km^2$) and the only one to overflow its threshold catastrophically. The famous Bonneville flood across the threshold at Zenda/Red Rock Pass linked the basin hydrologically with the Snake River system, and dropped Lake Bonneville ~100 m to its Provo shoreline (Gilbert, 1890; Malde, 1968; O'Connor, 1993).

Expansion of Lake Bonneville to its late Pleistocene highstand appears anomalously large (10-fold increase in surface area) relative to the growth of other Great Basin lakes during that time (Benson et al., 1990). Previous workers have postulated that the lake rose so high partly in response to the arrival of the Bear River (Bright, 1963), which has the largest discharge of any river in the Great Basin. Field and geochemical evidence suggests that Pleistocene basalts in southeastern Idaho diverted the river south from the Snake River, into the southern Thatcher Basin, and then into the Bonneville Basin sometime about 100-50 ka (Fig. 1; Bright, 1963; Bouchard et al., 1998; Link et al., 1999). Based on ostracode zonation, a strong freshening of Lake Bonneville waters is seen in GLAD800 sediment cores between 50 ka and 30 ka (Balch et al., 2005), prior to the lake actually rising to the Bonneville highstand. Though this is generally an episode of transition into glacial climate, the freshening is earlier and stronger than previous Pleistocene pluvial cycles in the record. The potential influence of this geologically-instantaneous riverine addition of ~1/3 of the freshwater input to Lake Bonneville challenges traditional models that the lake's rise to the Bonneville highstand was an incremental, stepwise progression that took ~15 ky (e.g. Gilbert, 1890; Oviatt et al., 1992). The arrival of the river at some point in the late Pleistocene must have had a profound affect on the hydrological balance of the entire regional system, from glaciated headwaters to lake basin, and it remains an uncontrolled variable that inhibits our understanding of this valuable record.

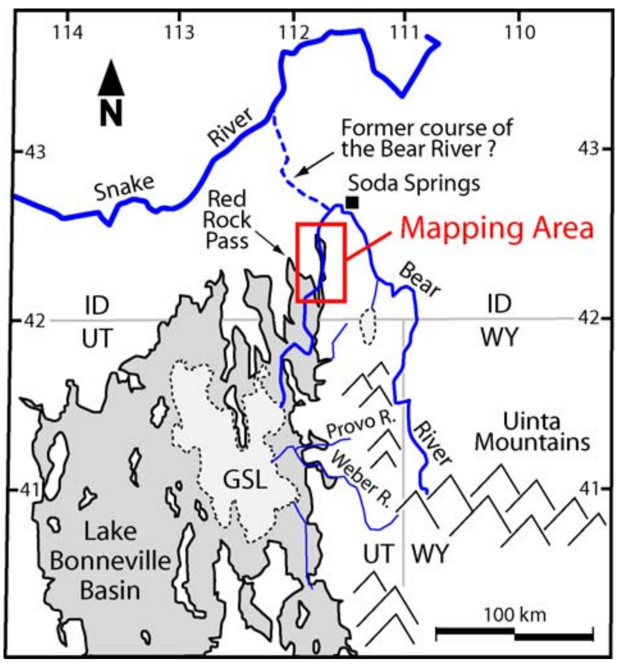


Figure 1. Regional map with study area highlighted red. The Bear River likely flowed to the Snake River prior to being diverted south by volcanism in the late Pleistocene.

**Purpose of this Research**

Despite decades of speculation connecting the river's input to the lake's rise, little effort has been directed towards mapping and dating Bear River deposits in the key region where it enters the basin. *New mapping proposed here will focus on: 1) basin-fill deposits that record the arrival of the river into the southern Thatcher Basin; 2) the river's integration, superposition, and incision through this structural basin and the bedrock canyon of Oneida Narrows; and 3) the mysterious interaction of Lake Bonneville and the post-incision Bear River at the apex of its delta through Oneida Narrows* (Fig. 2). Detailed stratigraphic analysis, geochronologic sampling, and hydrologic modeling that build upon the groundwork of this mapping will shed sorely needed light on the co-evolution of Lake Bonneville and its largest tributary.

**Geologic Background and Setting**

The mapping area is located in northeastern Bonneville Basin 25 km southeast of Red Rock Pass, Idaho (Figs. 1 and 2). The area encompasses parts of two structural basins (Cache Valley and Thatcher Basin) connected by the ~300 m-deep bedrock gorge of Oneida Narrows. Cache Valley lies east of the main Wasatch Fault Zone and is bound on the north and east by the Bannock, Portneuf, and Bear River Ranges. Thatcher Basin is bound to the west by the Portneuf Range, to the east by the Bear River Range, and to the south by a lower upland transition zone between the two ranges, which Oneida Narrows is cut into. The northern Thatcher Basin is filled by a basalt plateau formed by poorly dated mid-late Pleistocene thoeliitic basalts associated with Snake River Plain volcanics and including basalt flows as young as ~30 ka (Armstrong et al., 1975; Fiesinger and Nash, 1980).

The Pleistocene basin-fill record of Thatcher Basin, the Main Canyon Formation, holds critical information. From ~700 to perhaps 50 ka, the internally drained Thatcher Basin received local sediments shed towards a fluctuating axial lake system with shorelines as high as 1660 m (Bright, 1963). The ~200 m of exposed Main Canyon Fm. is roughly divided into an earlier shallow-water phase and a later deep-lake phase based on compiled stratigraphic sections (Hochberg, 1996), and is marked by tephras including the Lava Creek B (~640 ka), Hebgen Narrows (~150 ka), and Mt. St. Helens (~110 ka) (Izett, 1981; Lanphere et al., 2002). Initial work on the Main Canyon Fm. produced radiocarbon samples collected near the top above the Mt. St. Helens ash with uncertain ages between 27-42 ka (Bright, 1963). Bouchard et al. (1998) attempted to identify and date the arrival of Bear River water into the paleo-Lake Thatcher through fingerprinting water sources by $^{87}Sr/^{86}Sr$ ratios. They interpreted an isotopic shift in shell composition corresponding with a facies change interpreted as a strong transgression of the lake at the top of the Main Canyon Fm. as the arrival of the Bear River between ~100-50 ka. Hypothetically, at this time the surge of lake water spilled across a divide at the southern end of the Thatcher Basin and became integrated into the Bonneville Basin.

Much less is known about the local landscape evolution after this integration event. The superimposed Bear River apparently incised Oneida Narrows remarkably quickly, as Bonneville highstand waters at ~20 ka are assumed to have backflooded the entire canyon, already cut to its present depth, up into the Thatcher Basin (Bright, 1963; Oriell and Platt, 1980). The Bonneville and lower Provo shorelines form prominent benches well above the present Bear River downstream of the gorge. Upstream of the gorge, conspicuous gravel deposits flanking the Bear River are capped sharply by finer-grained sediment, which then underlie terraces at about the elevation of the Bonneville highstand. Yet whether key surficial deposits like these along the Bear River corridor are fluvial versus deltaic, and what their long-profile chronostratigraphic correlation and meaning are, is unknown (Fig. 3).

**Proposed Research**

We propose new surficial geologic mapping in a key corridor along the Bear River linking the deeply incised Thatcher Basin to the northeastern to the Bonneville Basin via Oneida Narrows (Fig. 2). The total area covers 57 sections in portions of six USGS 7.5-minute quadrangles (Fig. 2).

Our work will build on early mapping by Bright (1963) and initial stratigraphic investigations by Hochberg (1996) and Bouchard et al. (1998). Mapping areas include extensive sections of the Main

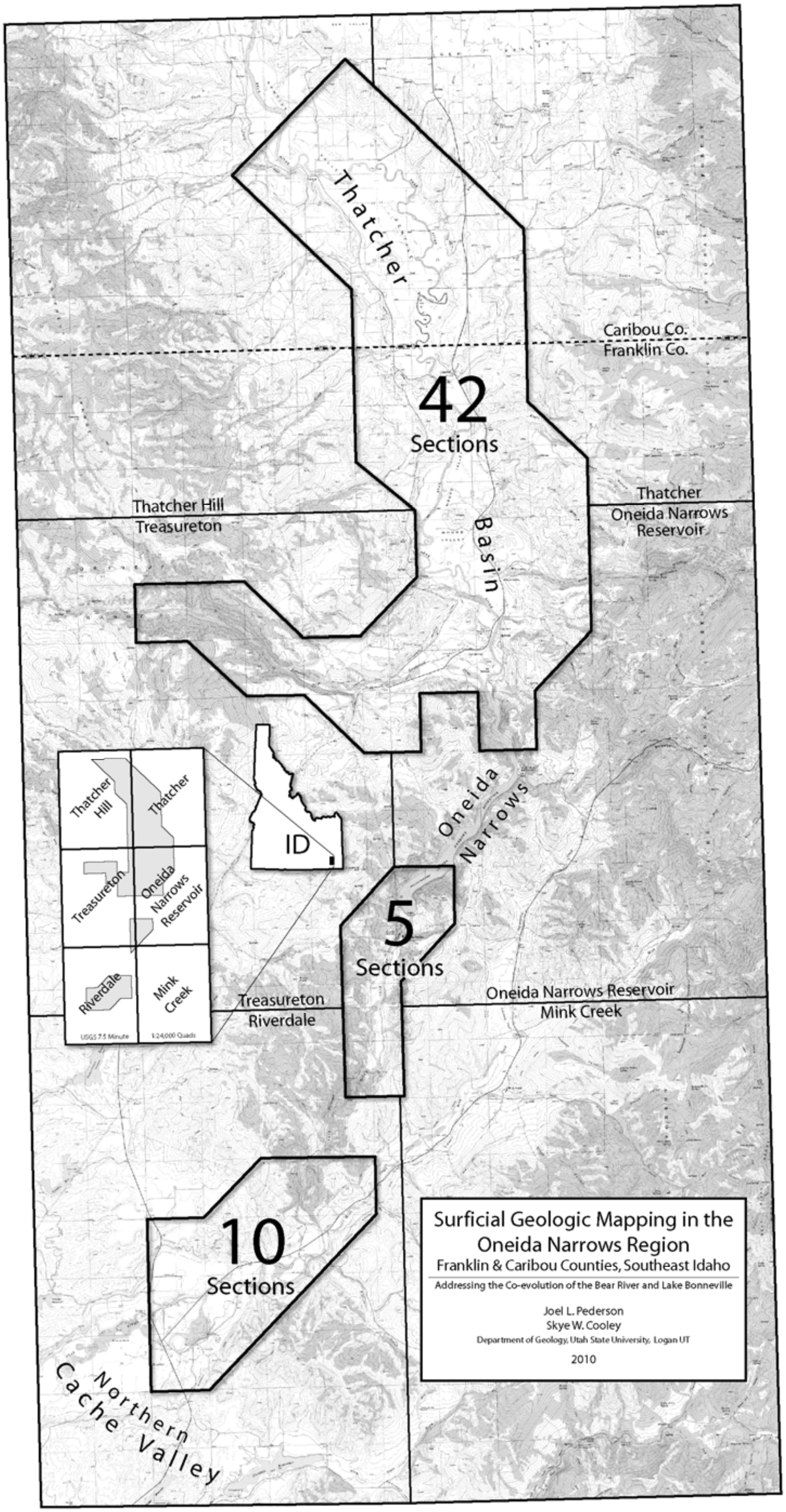


Figure 2. Detail map of northern, central, and southern mapping areas and the topographic quadrangles that include them. 57 total sections or square miles of proposed surficial mapping approximates the size of a regular 7.5 minute quadrangle.

Canyon Fm. Pleistocene basin fill and a series of inset deposits and landforms that record the post-Bear River integration incision history of the region. Numerous natural exposures, a dozen gravel pits, an extensive road system, and a sparsely-developed landscape afford clear views into the local stratigraphy. Prominent in the southern field area at the toe of Oneida Narrows are deposits and landforms representing the shoreline and deltaic features of the Bonneville highstand (~1550 m), younger Provo level (~1450 m), and prominent inset terraces below the Provo level (<1400 m). Key surficial deposits are preserved as fill terraces within a wide reach of central Oneida that is our middle mapping area. A prominent and well exposed sequence of terraces lie in the map area above the canyon along the Bear River valley. Study of these northern deposits and landforms will test the hypothesis that they includes sediment of the Bonneville highstand backflooding through Oneida Narrows (Bright, 1963; Oriell and Platt, 1980; Fig. 2).

**Research Questions**

Mapping and associated sedimentologic and stratigraphic work, as well as pilot geochronologic sampling, will address three primary geologic problems, which are also stated in the "Purpose" section above. In addition, establishing answers to these three research questions will also lay the foundation for a broader scope of work in Cooley's greater dissertation.

*1) Understanding and dating Main Canyon Formation deposits of the northern mapping area that record the diversion and arrival of the Bear River.* What are the depositional environments and trends within the Main Canyon Fm.? What are the stratigraphic and temporal relations between this basin fill and the basalt flows to the north that diverted the river and can Ar/Ar dating of these flows help constrain key events in the landscape evolution? When did the transition from closed-basin to external drainage occur? To our knowledge, detailed stratigraphic sections have never been measured in the Main Canyon Formation, and key locations for this will be identified through this mapping. Basaltic clasts from local eruptions are abundant in the Main Canyon Fm (Bright, 1963), but detailed investigation is still needed and so local pillow basalts and potential interbedding with the Main Canyon Formation will be investigated and sampled for OSL dating and with collaborators from the New Mexico Bureau of Mines and Geology for Ar/Ar dating. The upper Main Canyon Fm. very likely can be dated by OSL, and thus establish an upper age bound on the arrival of the Bear River (Fig. 4A).

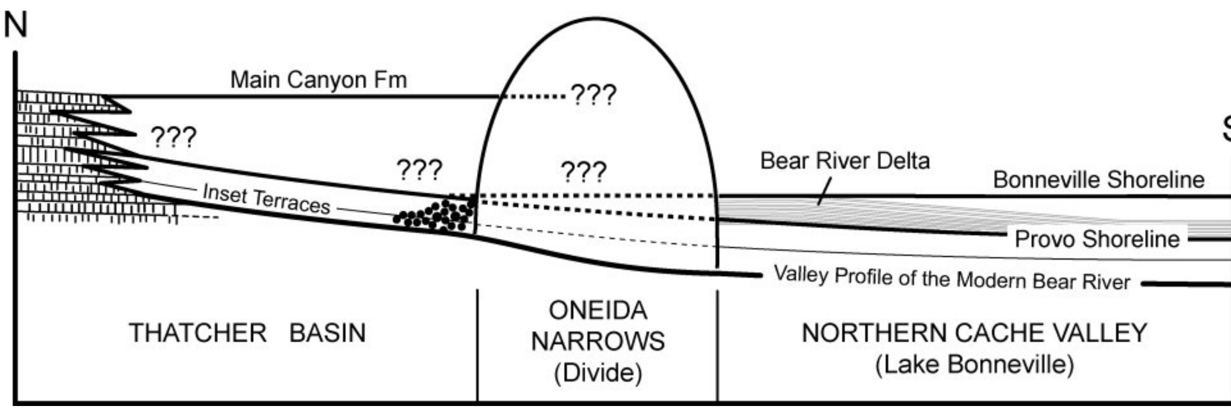


Figure 3. Long-profile illustration through the Oneida Narrows mapping areas of some key unknown geologic relations to be explored to answer research questions.

*2) Constraining the integration of the Bear River and its incision rates of Oneida Narrows.* Field mapping in the uplands surrounding Oneida Narrows should help reconstruct the pre-incision landscape and elucidate the location and mechanism of drainage integration across this highland. This will answer questions about exactly how much incision was accomplished recently by the Bear River versus how much relief already existed in the terrain. With the chronologic framework we will construct, the uppermost Main Canyon Fm. (first Bear River deposits) and the age of younger deposits that are at the valley bottom and project through Oneida Narrows will constrain the timeframe of incision of the ~300 m deep inner canyon. Previous research and hypotheses suggest this incision may have occurred in 30 ky or less, which would make Oneida Narrows, obscure as it is, the location of perhaps the fastest incision rates in North America.

*3) Recording patterns, interpreting depositional environments, and establishing chronostratigraphic correlations between key deposits and landforms at the head, center and toe of Oneida Narrows.* Correlation and origin of fill terraces and potential deltaic deposits through southern Thatcher Basin and Oneida Narrows gorge (Fig. 3). If proximal deltaic deposits of the Bonneville highstand do exist above Oneida Narrows, then they represent a backflooded Bear River upstream of the canyon at ~20 ka. This would be a remarkable feat for Lake Bonneville to transgress so quickly that it backflooded many miles of this narrow canyon and trapped coarse sediment in the Thatcher Basin, especially considering that its competition in doing so is the significant sediment load of its largest tributary river, as evidenced by the expansive size of the sandy delta preserved below the canyon. Alternatively, these may be fluvial terrace deposits sloping and graded to older deposits or to younger Provo-level terraces within and at the mouth of the canyon. In this case, the record represents a Bear River charged with enough sediment supply to keep the apex of its delta below the canyon (Fig. 4B). The key tests of these hypotheses will be absolute-dated stratigraphic correlations and long-profile geometric trends of terraces.

Although we are not requesting funds for geochronology in this mapping proposal, a key to answering all three of these research questions will be OSL geochronology. Two pilot samples were gathered from the key deposits in southern Thatcher Basin at the head of Oneida Narrows by the faculty

Figure 4A (left) Transgressive contact and littoral (?) deposits atop a paleosol in the uppermost Main Canyon Fm. may mark the arrival of the Bear River to Thatcher Basin, but the chronostratigraphic framework is not well established. 4B (right) Basal gravel deposits in lower Thatcher Basin overlain by finer-grained sediment may record backflooding and proximal deltaic sedimentation or may be associated with fluvial deposits graded to lower baselevel beyond Oneida Narrows.

PI a couple years ago. Preliminary data from these samples confirm that fluvial-lacustrine sediments in the study area have a bright, well-bleached response and abundant quartz, and thus are well suited to single-aliquot-regenerative OSL techniques (Aitken, 1998; Murray and Wintle, 2000). Initial samples collected in conjunction with field mapping will be processed by Cooley at the USU Luminescence Lab (www.usu.edu/geo/luminlab), which is directed by PI-Pederson and managed by Dr. Tammy Rittenour. An accurate chronology can test key hypotheses and produce critical ages will also provide a common basis for interdisciplinary research into questions concerning the paleoclimatologic, paleobiologic, and paleohydrologic evolution of late Pleistocene landscape in the Bonneville Basin and beyond. Previous geochronology work in Bonneville Basin is abundant, but mostly focused on indirect dating of littoral or profundal lake deposits by radiocarbon methods (e.g. Oviatt et al., 1992; Godsey et al., 2005), or relatively imprecise amino-acid racemization dating (e.g. Kaufman, 2003). OSL dating can very likely directly and precisely date the deposition of nearly any sandy fluvial or deltaic strata we choose in this setting.

*Foundation for broader work.* At the end of this first phase of mapping research, in the fall-winter of 2009, the NSF proposal that it is leading to will be written and submitted. Cooley's broader dissertation is slated to include detailed chronostratigraphic studies of the massive delta of the Bear River downstream of Oneida Narrows linked to this mapping area, as well as other delta deposits in Cache Valley. In addition, we hope to build a 2-D numerical hydrologic mass-balance model to explore the sensitivity of the overall watershed system to the impact of the Bear River's dynamics as well as other variables. Forward modeling could explore various Pleistocene climatic controls, and interpretations of field findings can parameterize model scenarios. The work will build on previous hydrological and sediment mass-balance investigations on the modern Great Salt Lake (Mohammed, 2006) and Pleistocene Lake Bonneville (Lemons et al., 1996; Balch et al., 2005). Dr. David Tarboton, Professor of Civil & Environmental Engineering and Utah Water Research Laboratory, will partner with Cooley on the project.

**Geologic Mapping Strategy**

Analog aerial-photographic stereo pairs utilized in the laboratory will be essential for initial draft mapping, as well as refining contacts at the end of the mapping processes. 1-m resolution color NAIP digital orthophoto imagery will provide the baselayer for the field map, allowing for higher mapping precision than topographic quadrangles. Field mapping will be conducted at 1:12,000 scale, although final products will be at 1:24,000 scale.

Our investigations into the surficial geology will be guided by published bedrock mapping (Oriell & Platt, 1980; Janeke et al., 2003, Steely et al., 2005). Simplified bedrock units will be mapped as well as surficial units. This is important in order to work from the ground up in a thoughtful manner, and also to understand deposit sources and the buried topography that surficial units mantle. Surficial units will have a thickness threshold of <1 meter before we consider them mappable, surficial units are so ubiquitous below 1 m thickness that mapping becomes difficult to reconcile with bedrock maps. All map units will be three-dimensional deposits, not the two-dimensional surfaces that overlie them. This provides more information, meshes naturally with bedrock mapping, and is especially critical because the Main Canyon basin fill is a thick unit potentially with members to be broken out, and the younger inset fluvial and Lake Bonneville deposits are also valley fills with significant depth.

Part of the greater research that this map forms the basis for includes measured sedimentary sections of characteristic Main Canyon Formation basin fill, and RTK-GPS surveys of several cross-valley profiles to get high-precision stratigraphic and topographic data for cross sections accompanying the completed map. Topographic data for the longitudinal profile analyses central to this project can be extracted from digital terrain models in GIS. Likewise, digital compilation and cartography will be done in ESRI ArcGIS using geology-specific palettes, symbols, and fonts. The map lines and polygons will be directly digitized onscreen into ArcGIS rather than undertaking inefficient scanning procedures.

**Timetable and Mentoring Strategy**

Travel times to the study area are relatively short; about one hour's drive from Logan, UT to Grace, ID in the northern mapping area. The student and faculty PI have already conducted significant reconnaissance of the mapping area as a team, and this will continue through spring of 2009, to the limited extent that weather conditions allow. The spring of 2009 will also be the time to produce the initial aerial-photography based unit contacts, which can guide subsequent field mapping. Fieldwork will then be concentrated in the summer of 2009.

Because of the convenience of this mapping area to our academic home, the faculty PI will be able to join the student in the field repeatedly and frequently throughout the project for mentoring on mapping and unit description. Idaho Geological Survey personnel, Bill Phillips in particular, will join us during the summer field season when possible and collaborate through other correspondence. This state survey involvement will be especially important for assuring that units and unit descriptions match IGS protocols. A complete draft of the map will be the product of the summer field season, and this will be submitted to the IGS and USGS at the end of the field season.

Follow-up aerial photographic work in the fall of 2009 will help refine lines for the final product. Inevitably, further visits to the nearby field area by both the student and faculty PIs will occur at this time to check problem areas in the mapping. Fall may also provide an opportunity to do a more formal field review of the map area with IGS personnel, other research partners, and USU students as class field trips. Fall of 2009 also will be spent by Cooley in corrections, digitizing the map into GIS, and drafting cross-sections and longitudinal-profile diagrams. We anticipate collaboration with IGS personnel to guide the details and format of the digital map product to meet their specifications. Delivery of final paper and digital deliverables will be in the winter of 2009-2010.

**Deliverables**

The final USGS product for this research will be hardcopies of surficial geologic map of the three irregular-shaped mapping areas along the Bear River corridor (Fig. 2). This mapping will also appear as an appendix in Cooley's Dissertation at the original 1:12,000-scale, including an explanation of map units and symbols with unit descriptions and at least one characteristic cross-section illustrating the physical relations of key deposits in the study area. The final product of this map will be within a GIS format,and this will be delivered to the Idaho Geological Survey, specifically at 1:24,000-scale to be amenable to being published at some level in the future.

**Project Personnel** (short vitae are at the end of this proposal)

Cooley is a beginning PhD student at Utah State University. His MS in Geology from U Wyoming was in igneous petrology and remote sensing, and he completed a BS from Whitman College with a Senior Thesis studying Missoula flood deposits. Cooley has years of directly applicable professional experience in surficial geology and geomorphology as well as GIS through employment as a private consultant. Producing a formal surficial geologic map is a skill Cooley can carrying forward to students of his own, considering his goal of a career in academia.

Pederson is a field-oriented process geomorphologist specializing in the landscape evolution of the Interior West and the response of landscapes to climate change. Field mapping and GIS are fundamental to all of his and his student's research. Pederson's first EDMAP experience was, in fact, as a PhD student himself. The USU Luminescence Laboratory was built by Pederson, and Cooley will receive training and access to this lab for his initial sample analyses. Pederson has overseen two successful prior EDMAP grants, funded in 2002 and 2005. These supported graduate students to conduct similar surficial mapping in the Uinta Mountains, which are the headwaters for the Bear River. These successful grants resulted in peer reviewed maps and papers, as well as the student's MS Theses, and those former students are now employed using the mapping skills gained from their EDMAP experience.

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## Short Vitae

### Graduate Student: Skye W. Cooley

Education
MS Geology, University of Wyoming, 2000
BA Geology, Whitman College, 1996 *Distinction*

Pertinent Work History

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| Instructor in Natural Resources, Spokane Community College | 2007-08 |
| Geologist, Cirque Geoscience Consultants | 1997-present |
| Soil Scientist and Geomorphologist | 2002-07 |
| Colville Confederated Tribes - Nespelem WA | |
| GIS Specialist, Metron & Associates, Inc. Land Surveyors - Arlington WA | 2001-02 |
| Geologist Intern - Exxon Mobil | 1999 |

Pertinent Publications
Cooley, SW, 2008, Clastic Dikes: Indicators of climate during late-glacial Missoula flooding? *GSA Annual Meeting Abstracts w/ Programs, 188-11*
Cooley, SW, 2007, Geomorphic Landtype Units: Integrating soils, geology & GIS in the undergraduate classroom, *GSA Cordilleran Section Meeting Abstracts w/ Programs*
Cooley, SW, 2005, Geomorphologic Map of Site 45-FE-497 Through Eight Miles of the Lower Kettle River, Ferry County WA, *Grand Coulee Dam Cultural Resources Project (GCDCRP) Report*
Cooley, SW, 2005, Geomorphic landform units of the Colville Indian Reservation WA: A new GIS approach for managing complex landscapes, *Colville Confederated Tribes Environmental Trust, 1:48,000 scale map set*

## Faculty Advisor: Joel L. Pederson

Education

Ph.D. Earth and Planetary Sciences (Geomorphology and Sedimentology), 1999, Univ. of New Mexico.
M.S. Geology (Quaternary Geology), 1995, Northern Arizona University.
B.A. Geology, 1990, Gustavus Adolphus College.

Previous EDMAP Grants

2002-2003 #02HQAG0075, Geologic mapping of surficial deposits for the Dutch John quad, northeastern Uinta Mountains, Utah; $14,851

2004-2005 #04HQAG0085, Surficial Geologic Mapping in Central Browns Park, Utah and Colorado—Building Upon Previous EDMAP Results; $14,973

Some Recent Publications Relevant to Proposal (drainage evolution, OSL dating of fluvial records)

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