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TITLE OF PROPOSED PROJECT **Collaborative Research: An Absolute Chronology of the Southernmost Advances of the Laurentide Ice Sheet**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
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PI/PD DEPARTMENT Department of Earth and Space Sciences	PI/PD POSTAL ADDRESS Box 351310 Seattle, WA 98195 United States
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Southwest Missouri State University

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TITLE OF PROPOSED PROJECT **An absolute chronology of the southernmost advances of the Laurentide Ice Sheet**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 41,250	24 months	02/01/06	

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PI/PD DEPARTMENT

Department of Geosciences

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COLLABORATIVE RESEARCH: AN ABSOLUTE CHRONOLOGY OF THE SOUTHERNMOST ADVANCES OF THE LAURENTIDE ICE SHEET.

Scientific merit. The regular advance and retreat of continental ice sheets is the defining feature of the last several million years of Earth history. Most of what we know about these glaciations is drawn from marine geochemical and sedimentologic proxies for ice extent, in particular the oxygen isotope composition of seawater. The marine $\delta^{18}O$ reflects only global ice volume, and very few other marine records provide any information on size, configuration, or even the existence of any particular ice sheet. This in turn makes it difficult to answer even very basic questions about the evolution of the Northern Hemisphere ice sheets and their role in major Plio-Pleistocene climate change. The key to better understanding the history of these ice sheets is the direct sedimentary record of their advance and retreat that is preserved on the continents themselves, near the margins of present and former ice sheets; the challenge in extracting the information we need from these sedimentary records, in turn, is that glacial sediment sequences are inherently difficult to date. In the case of the Laurentide Ice Sheet (LIS), the age of glacial deposits too old to be dated with radiocarbon or luminescence techniques can only be bracketed between three dated volcanic ashes and two easily recognizable magnetostratigraphic boundaries. As these time markers are not only widely spaced in time but rarely occur together in the same stratigraphic section, we have only a bare minimum of knowledge about the pre-late Pleistocene history of the LIS.

Our goal in this proposal is to fill this large and important gap in our knowledge of the late Cenozoic ice ages by using newly developed methods of cosmogenic-nuclide geochronology to directly date the sequences of interbedded tills and paleosols that are common in the glacial deposits of the north-central United States. We will begin in east-central Missouri, near the extreme southern limit of LIS advances, where the glacial sediment section is relatively simple, well-exposed, and well-mapped, and where the stratigraphy is inherently well-suited to the dating technique. As the project continues, we will work northward into the increasingly complicated glacial stratigraphy in eastern Nebraska and western Iowa, with the goal of connecting our absolute chronology with the existing relative till chronology in that region. This project will yield entirely new information about the history of North American continental glaciation, providing direct dates for at least five of the southernmost advances of the LIS. This in turn will enable more direct comparison of Plio-Pleistocene ice sheet advances with other climate records, provide information that is needed to evaluate many hypotheses about the role of ice sheets in Plio-Pleistocene climate and environmental change, and provide the first step toward an eventual goal of understanding the full development and evolution of the Laurentide Ice Sheet.

Broader impacts. First, the problem of dating and correlating a large number of discontinuous, lithologically similar tills, which hampers basic research about the history of Northern Hemisphere glaciation, is also the chief problem facing state geological surveys, other government agencies, and consulting geologists that are interested in the geohydrology of the north-central U.S. This project has the potential to yield important practical benefits by making not only our specific results, but cosmogenic-nuclide techniques in general, available to state geological survey personnel who seek to solve regional stratigraphic problems. Second, this project will provide career development benefits by fostering collaboration between two members of the project team: Charles Rovey, a stratigrapher from an undergraduate-focused state university who has received little NSF support in the past, and Greg Balco, a recent Ph.D. who specializes in geological applications of cosmogenic-nuclide geochemistry. By combining Rovey's expertise in regional stratigraphy with Balco's work in developing new geochronology methods, both fields benefit. Third, the results of initial research that we carried out in preparation for this proposal, as well as a separate collaboration between Balco and Rovey on dating recently discovered Pleistocene megafauna in Missouri, generated a surprising amount of public and press attention and resulted in significant positive public exposure to Earth science research. This high level of public interest so far leads us to believe that our proposed work on placing the glacial deposits of Missouri into the context of Plio-Pleistocene global change will continue to capture regional public interest, and provide valuable resources for education at all levels.

Results of prior NSF-funded research: John Stone, University of Washington.

Erosion beneath the Laurentide Ice Sheet and its role in Pleistocene ice age dynamics (NSF EAR 0207844; $ 214,765; 7/02-6/05)

This project was intended to: a) adapt cosmogenic-nuclide dating methods to determine the age of early and middle Pleistocene tills deposited by the Laurentide Ice Sheet (LIS); and b) use the concentration of atmospherically-produced ^{10}Be in these tills to determine whether these tills were formed from deeply eroded bedrock or retransported preglacial regolith, and thus evaluate hypotheses about the role of the preglacial regolith in the evolution of the LIS (e.g., Clark and Pollard 1998).

In the first part of the project, we developed a method for dating till-paleosol sequences that is based on the differential decay of cosmogenic ^{26}Al and ^{10}Be, and applied it to glacial sedimentary sequences throughout the midwestern US. Among other results, we found that the lowermost till in central Missouri records the first, and nearly the largest advance of the LIS, that took place 2.41 ± 0.14 Ma. This provides the first direct evidence that large-scale Northern Hemisphere glaciation did in fact begin during the global cooling and general intensification of glacial activity worldwide, previously inferred from marine sedimentary records, at 2.7-2.4 Ma. This part of the project resulted in Greg Balco's Ph.D. dissertation (Balco, 2004), two GSA theme sessions, and three additional articles by Balco (Balco et al., 2005a,b,c; see Figure 4 for a summary of some of these results). The most important outcome of this project, however, is that we can now use cosmogenic-nuclide techniques to determine the age of Plio-Pleistocene till-paleosol sequences that have previously been difficult, if not impossible, to date. This opens the possibility of closing some of the major gaps in our present knowledge of Northern Hemisphere ice sheet history, and provides the impetus for the present proposal.

In the second part of the project, we found that the stratigraphically lowest tills in the north-central U.S. formed by remobilization of ^{10}Be-enriched regolith that must have predated North American glaciation, and younger tills incorporated little regolith and were largely derived from erosion of fresh bedrock. This validates the idea that early advances of the Laurentide Ice Sheet mined a pre-existing inventory of easily deformable sediment, which may have affected ice dynamics by facilitating fast glacier flow. However, the fact that the entire regolith inventory appears to have been exported from the core area of the LIS by the earliest Pleistocene glacial advances is inconsistent with the hypothesis that a reservoir of deformable subglacial sediment persisted until ca. 1 Ma, and its exhaustion at that time provided a trigger for the middle Pleistocene climate transition (Clark and Pollard, 1998). We have submitted these results for publication.

Retreat history of the West Antarctic Ice Sheet, Marie Byrd Land (Stone; OPP-9989778; $ 119,814, 7/00-12/02), Deglaciation of the Marble Hills, Ellworth Mts, West Antarctica (Stone; OPP-0230198; $ 55,681, 4/03-3/05), and Collaborative Research: Late Quaternary History of Reedy Glacier (Stone, Conway, Hall; OPP-0229314 (UW: $ 370,051 / UofMaine: $ 180,818); 6/03-5/06)

These projects have revealed evidence of steady Holocene deglaciation in three marginal areas of the West Antarctic Ice Sheet (WAIS): Marie Byrd Land, the Ellsworth Mountains and the Transantarctic Mountains. The results complement evidence of mid- to lateHolocene deglaciation in the Ross Sea (Conway et al., 1999). Work on the first of these projects was carried out in the Ford Ranges, where most peaks were overrun by the WAIS during the last glaciation. Exposure ages of erratics from elevation transects on six of these peaks show that they emerged from beneath the ice sheet between 10,400 and 3,500 yr. B.P. Subsequent steady downwasting throughout the Holocene, at rates of 5-10 $cm \cdot yr^{-1}$, removed 300-700 m of ice from the region (Fig. 1; Stone et al., 2003). The deglaciation record from the Marble Hills in the Ellsworth Mts is complicated by prior cosmic ray exposure of many samples. Nevertheless, it shows thinning of at least 380 m in the past 10,300 years, which resulted in deflection of formerly-transverse ice flow around the range. A similar history is emerging from ongoing work at Reedy Glacier, where there is evidence of more than 250 m of thinning since the last glacial maximum, continuing up to 1500 years ago. Rates of deglaciation in these regions through the mid-Holocene were similar to those occurring in the Pine Island / Thwaites Glacier region at the present day. This project has resulted in two publications to date (Stone et al., 2003; Sugden et al. 2005), and others have been submitted.

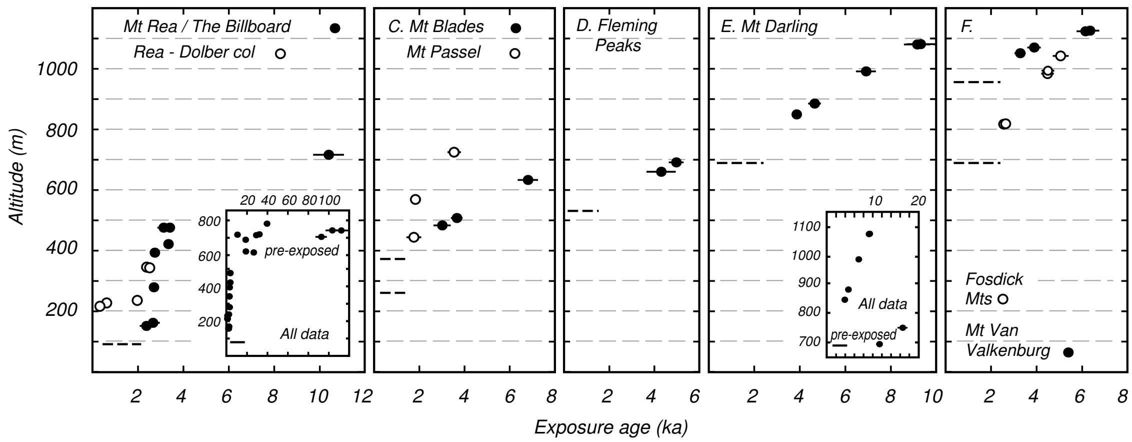

Figure 1: Exposure ages of glacial erratics plotted vs elevation on seven peaks in Marie Byrd Land. Mountains run inland from L-R; dashed black lines indicate present-day glacier height at each site. Summits of these peaks were overrun by the WAIS during the glacial maximum and emerged between 10.4 and 3.5 ka. Linear age vs elevation trends indicate steady thinning of outlet glaciers at 5-10 cm/yr through the Holocene.

Long-term history of the West Antarctic Ice Sheet (NSF OPP 0229915; $ 50,279; 1/0312/04).

In this project we have documented widespread disequilibrium between cosmogenic ^{10}Be, ^{26}Al, and ^{36}Cl concentrations in bedrock surfaces in Marie Byrd Land, indicating histories of intermittent exposure and prolonged protective cover by the West Antarctic Ice Sheet. The data from this study show that: (i) Total cosmic ray exposure times are much greater than the time since recent deglaciation (Stone et al., 2003), and increase with altitude on each mountain, (ii) Minimum cumulative burial times range from tens of thousands to 4.5 Myr, and (iii) Many of these bedrock surfaces have only been ice-free for 1-5 % of Pleistocene time. Some outcrops cannot have been exposed for more than ten thousand years in the last million years. These results indicate that Holocene deglaciation of West Antarctica has exposed outcrops that seldom emerge from beneath the ice sheet; the Holocene therefore appears to be among the most extensive deglaciations of the middle and late Pleistocene. Our results also call into question the ideas that higher sea level during Marine Isotope Stage (MIS) 5e was caused by West Antarctic melting, and that the ice sheet experienced a catastrophic deglaciation during MIS 11 (cf. Scherer et al., 1998).

Collaborative Research: A proposal for the Cosmic-Ray prOduced Nuclide Systematics on Earth (CRONUS-Earth) Project (NSF EAR 0345574 $ 5.7M between 17 PIs at 14 institutions; 4/053/10).

This project commenced in April and most of the research activities therein have just begun. The primary goal of the project is to improve calibration of the production rates of cosmogenic ^{26}Al and ^{10}Be, and it should also resolve existing uncertainties in the half-life of ^{10}Be. Thus, it is an important adjunct to this proposal in that it will very likely result in significant improvements to the dating technique that we are using.

COLLABORATIVE RESEARCH: AN ABSOLUTE CHRONOLOGY OF THE SOUTHERNMOST ADVANCES OF THE LAURENTIDE ICE SHEET.

Project description.

I. Background; importance of the project. The advance and retreat of large continental ice sheets is the defining feature of the last several million years of Earth history. The landscape of the northern continents owes its present form to erosion at the bed of these ice sheets, and the large, cyclical changes that are evident in nearly all records of Plio-Pleistocene climate and environment could not have happened without their periodic growth and decay.

Most of what we know about these Plio-Pleistocene glaciations is drawn from marine sedimentary records, mainly because long and undisturbed sedimentary records are more common in the oceans than on the continents. The primary sources of information about the timing and extent of continental glaciations have, to date, been marine geochemical proxies for ice extent, in particular the oxygen isotopic composition of seawater. Seawater δ^{18}O reflects the total amount of water that has been removed from the oceans and stored in continental ice, and therefore the total continental ice volume (Emiliani, 1955; Shackleton and Opdyke, 1973). The rhythmic variation in seawater δ^{18}O in Plio-Pleistocene marine records is the basis for our present understanding of continental glaciations as being strongly influenced by Earth's orbital variations (summarized in Imbrie and Imbrie, 1979). It has also led directly to key unanswered questions about the long-term evolution of the ice-climate system, in particular the causes of a) the inception of 41,000-yr ice volume periodicity and increase in delivery of ice-rafted debris to many Northern Hemisphere sites near 2.5 Ma, and b) the growth in overall ice volume and onset of 100,000-yr glacial-interglacial cycles near 1 Ma (e.g., Shackleton et al., 1984; Raymo, 1994; DeMenocal, 2004; Ravelo et al., 2004; Haug et al., 2005;). One important limit to our ability to understand the exact chain of events near these major climate transitions, and, more generally, to better understand the overall role of continental ice sheets in the global ice-climate system, is the fact that the marine δ^{18}O record reflects only global ice volume. It tells us little about the location of ice on the continents or about the size or even existence of any particular ice sheet. In some cases, ice-rafted debris in marine sediments (e.g., Shackleton et al., 1984; Krissek et al., 1996; Mangerud et al., 1996) or records of regional surface-water chemistry (Joyce et al., 1993) can provide clues to the location of continental ice, but in general we have very little information about the location and size of late Pliocene through middle Pleistocene ice sheets. For example, the mid-Pleistocene increase in peak global ice volumes is commonly explained by thickening of the Laurentide Ice Sheet (LIS), perhaps due to a change in basal conditions (Clark and Pollard, 1998), but marine sedimentary records from the Arctic Ocean in which ice-rafted debris is only present after 0.8 Ma (Spielhagen et al., 1997) suggest the possibility that the ice volume increase is the result of a major expansion of the Eurasian Ice Sheet instead. We cannot distinguish between these two first-order possibilities, or answer a number of similar and equally basic questions about the evolution of the Northern Hemisphere ice sheets, on the basis of marine records alone.

The key to better understanding the evolution of the Plio-Pleistocene ice sheets is, of course, the direct sedimentary record of ice sheet advance and retreat that is preserved on the continents, near the margins of present and former ice sheets. These sedimentary records are thick, widespread, and record many ice sheet advances. In the case of the Laurentide Ice Sheet, for example, boreholes in southwest Minnesota and adjacent states penetrate up to 250 m of glacial sediment that records a minimum of 12, and possibly as many as 25, distinct ice sheet advances between approximately 2 Ma and the present (Patterson, 1997; Patterson, 1998; Lineburg, 1993; Setterholm, 1995; Balco et al., 2005b). This region may preserve a nearly complete record of Plio-Pleistocene advances of the LIS, but, despite this extensive stratigraphic record (and similar ones elsewhere in North America and Europe), it remains very difficult to relate particular glacial deposits to particular marine oxygen isotope fluctuations. This is because it is very difficult to date and correlate pre-late-Pleistocene tills. Only the very youngest tills, those of the last two glacial-interglacial cycles, can be directly dated by radiocarbon or luminescence techniques. Older tills can only be dated by comparison to three widely distributed volcanic ashes, and two easily recognizable magnetic reversals. These stratigraphic markers are discontinuous and rarely occur together in the same section. Furthermore, many tills share the same provenance, so it is difficult to trace individual tills between dated sections on the basis of lithology. Thus, we have only a bare minimum of knowledge about the pre-late-Pleistocene history of the LIS: in the north-central U.S., we know only that there was at least one ice sheet advance prior to 2 Ma, at least two between 1.2 Ma and 0.8 Ma, and at least three since then, at least one of which postdated 0.6 Ma (see further discussion and citations below).

If we were able to accurately date pre-late-Pleistocene tills, we could make significant progress toward two important goals that we cannot now achieve.

First, as we discuss above, we could begin to answer basic questions about the evolution of the Northern Hemisphere ice sheets: for example, does the mid-Pleistocene transition from short-period, low-amplitude to long-period, high-amplitude variability reflect an change in the size, the shape, or the number of ice sheets? To what extent do major climatic or environmental changes in unglaciated regions (e.g., Zhang et al., 2001; DeMenocal, 2004) reflect changes in ice sheet size? Do sedimentary records of ice-rafted debris delivery to the deep oceans accurately reflect the extent of continental glaciation? When did the first Northern Hemisphere ice sheets become large enough that climate feedbacks that depend on these ice sheets could have contributed to late Pliocene global cooling? These and other questions can only be answered with a better understanding of the glacial sediment sequences on the northern continents, which in turn depends on advancing our ability to date these sequences.

Second, a better chronology for the pre-late-Pleistocene deposits of the north-central U.S. would yield important practical benefits. State and local governments, agriculture, and industry devote significant resources to mapping and correlating these deposits for a variety of purposes, studies of groundwater hydrology in particular. All such efforts face the fundamental problem that the region is underlain by many tills of similar provenance and appearance, glacial sediments are inherently discontinuous and full of unconformities, and thus lithostratigraphy alone is not sufficient for accurate stratigraphic correlation. The ability to directly date glacial sediment sequences would be enormously helpful in these efforts.

In this project, we will work toward these goals by applying new geochronological methods to better understand the sedimentary record of LIS advances into the north-central U.S. The overall problem of understanding the entire pre-late-Pleistocene stratigraphic record between Minnesota and Missouri and from Maine to Montana, of course, is well beyond the scope of any single proposal. Thus, our approach to this problem is to begin in central Missouri, near the southernmost limit of glaciation in North America, where the stratigraphic section is relatively simple and well-understood, the density of outcrops and boreholes is high, and the stratigraphy is well suited to the dating technique that we will use. Tills in this region inherently record the most extensive ice sheet advances. Many ideas about the long-term evolution of the LIS depend on long-term changes in ice sheet size: if the existence of a preglacial regolith in the early Pleistocene (e.g., Clark and Pollard, 1998) encouraged fast ice flow and low ice sheet slopes, we might expect to find the most areally extensive ice sheets in the early Pleistocene; if marine oxygen isotope records accurately reflect the size of the LIS, we might expect them more recently. Dating the largest ice sheet advances is the simplest way to obtain a first-order view of long-term trends, or lack thereof, in ice sheet extent. In the remainder of this proposal, we describe the stratigraphy in our proposed focus area in Missouri, introduce the method of dating till-paleosol sequences by the cosmogenic nuclides ^{26}Al and ^{10}Be and show that the stratigraphy of this region is the best possible match to the dating technique, and thus is likely to provide the most accurate possible information on the timing of major advances of the LIS.

II. Proposed field area in Missouri. The overall arrangement of glacial sediment in the north-central U.S. is as follows: areas closest to the center of the LIS, in northern Minnesota and the upper Great Lakes region, are largely bedrock with only patchy Wisconsinan sediment, reflecting long-term glacial erosion, and the glacial sediment section becomes thicker and more complete to the south (Figure 2). The thickest glacial sediments, which appear to record the largest number of ice sheet advances, are located in southwest Minnesota and adjacent South Dakota. The stratigraphic section here consists mostly of till with few paleosols and little evidence of long interglaciations, suggesting that most if not all Plio-Pleistocene ice sheet advances covered this region and deposited tills. Farther to the south, in Iowa, Nebraska, and Missouri, there are fewer tills, and paleosols and loess become more common, reflecting the fact that fewer ice advances reached this latitude and ice-free periods were longer (Patterson, 1997; Patterson, 1999; Setterholm, 1995; Lineburg, 1993; Hallberg, 1986; Hallberg and Kemmis, 1986; Roy, 2004; Boellstorff,1978a,b,c; Rovey and Kean, 1996; Rovey and Tandarich, 2004; Rovey et al., 2004b).

Of the till sequences near the southern limit of glaciation in North America, our proposed focus area in east-central

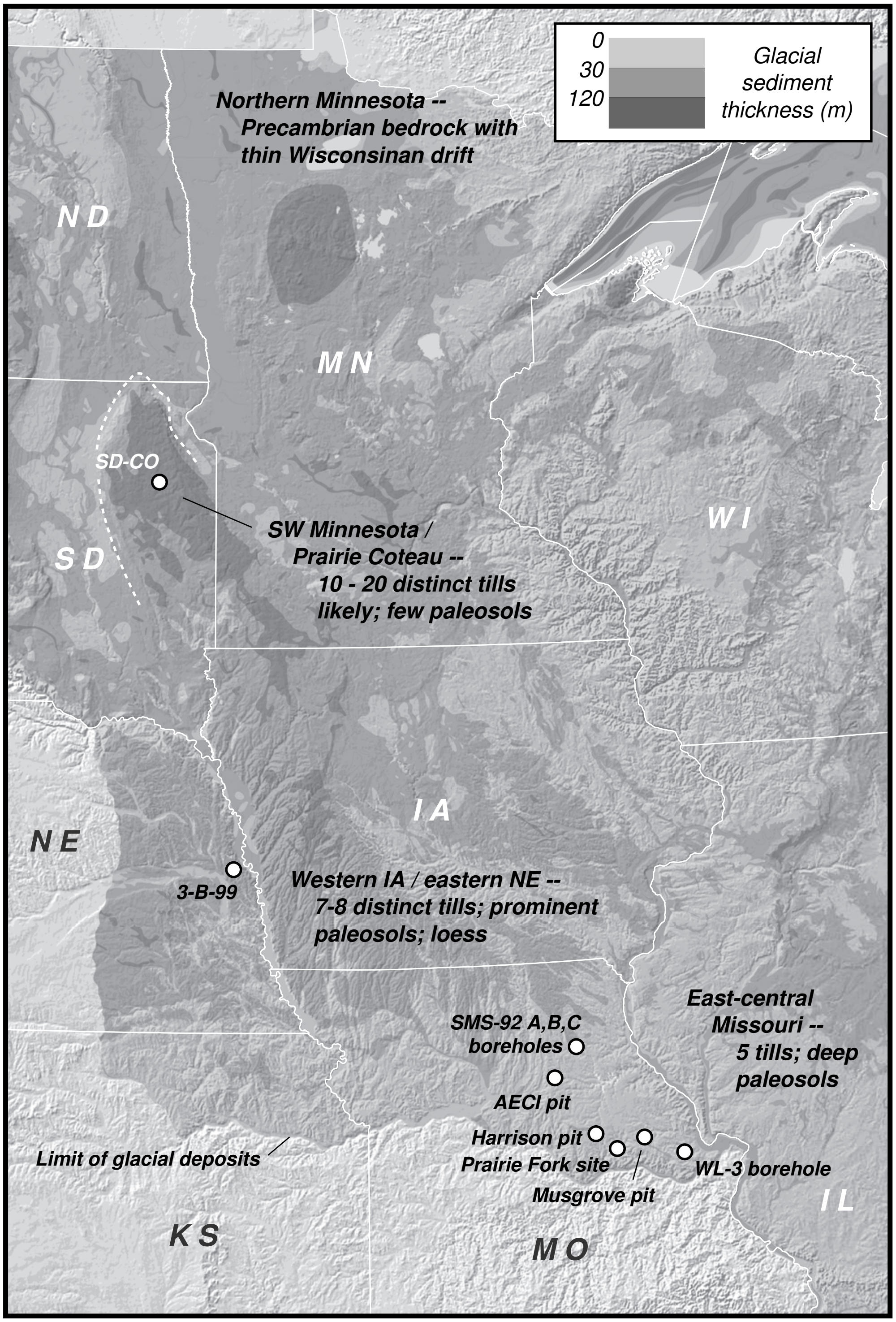

Figure 2: The glaciated area of the north-central United States, showing the extent and thickness of late Pliocene through Wisconsinan glacial sediment, as well as the location of sites and boreholes discussed in the text. The sediment thickness data are taken from Soller (1998), and do not extend into Canada.

Missouri has two key characteristics that are important for our purposes. First, the region is a major clay mining center as well as the subject of detailed mapping and drilling efforts by the Missouri Geological Survey. The unusually high density of pit excavations and boreholes in this region, combined with the extensive previous work by Rovey and his colleagues, means that the till stratigraphy is well established. Thus we can focus on selecting the best sites to date each of the tills, and on obtaining the most accurate dates possible. Second, as we discuss below in our description of the ^{26}Al-^{10}Be dating technique, the stratigraphic situation in which well-developed paleosols are buried by thick tills provides the ideal situation for applying our dating technique.

There are five tills in east-central Missouri, as follows. Rovey and Tandarich (2004) provide a complete description of the stratigraphy, which we condense here and in Figure 3.

Atlanta Formation. The Atlanta Formation is the stratigraphically lowest till in the region, and the oldest known till in North America. It occurs mostly in the subsurface, typically in paleotopographic lows that survive from a Pliocene karst landscape developed on the underlying Missisipian carbonate bedrock. Existing exposures of the Atlanta Fm. are mostly located in active clay mining operations. It overlies deeply weathered regolith and colluvium (informally known as the Whippoorwill formation), composed entirely of locally derived material, that reflects a long period of Pliocene surface stability and slow weathering prior to the onset of Northern Hemisphere glaciation. The Atlanta till is capped by another well-developed weathering profile that suggests another long period of surface exposure prior to deposition of the overlying Moberly till. The Atlanta till is relatively fine-grained, depleted in expandable clay minerals, and enriched in locally derived chert and limestone clasts relative to other tills in the region. It is recognized by its stratigraphic position and this distinctive lithology. The till itself, as well as laminated silt units which are occasionally present both above and below the till, are magnetically reversed. The Atlanta till is the only till in the region whose age is known: in the initial work that led up to this proposal, as we discuss above, we measured ^{26}Al and ^{10}Be in quartz from the underlying Whippoorwill paleosol and found that the till was deposited at 2.41 ± 0.14 Ma (Balco et al., 2005a).

Moberly Formation. The Moberly formation directly overlies the paleosol developed on the Atlanta till. The Moberly till is lithologically distinct from the Atlanta in that it contains many more erratic igneous and metamorphic clasts, and from overlying tills by its clay mineralogy. The till itself as well as laminated silts underlying it are magnetically reversed. At the bottom of the Moberly till, the Atlanta/Moberly contact often preserves an identifiable A horizon in the Atlanta paleosol, as well as flattened wood fragments at the interface of the two tills. At the top of the Moberly till, another paleosol is usually present beneath the overlying Fulton till, although it is less developed than the underlying Atlanta paleosol. We measured ^{26}Al and ^{10}Be concentrations in surface samples from the Atlanta paleosol, which may not reflect the age of emplacement of the Moberly till accurately because we have not yet measured the concentration-depth profile needed to account for the inherited nuclide concentration in the Atlanta till (e.g., Balco et al., 2005c), but do provide a limiting age of ca. 1.8 Ma (Balco et al., 2005a). Thus, the Moberly is younger than 1.8 Ma but presumably older than the Brunhes/Matuyama boundary at 0.78 Ma.

McCredie Formation. The McCredie Formation as formally defined actually consists of three distinct tills, informally known as Fulton, Columbia, and Macon. The Fulton till directly overlies the Moberly paleosol and is in turn overlain by the Columbia and then the Macon tills. These tills can be distinguished from the Moberly till by their higher concentration of expandable clay minerals. The three McCredie tills have subtle compositional differences, but are most reliably distinguished from each other by the presence of paleosols at the top of each till (Figure 2 again). There are several sites where all three tills occur together and are separated by well-preserved paleosols, so for the purposes of this project we will not have to rely on lithologic correlation between sites to identify these three tills. All three tills are normally magnetized and therefore presumably younger than 0.78 Ma.

Relationship of the Missouri till sequence to the Iowa/Nebraska till sequence farther north. The till sequence to the north of our focus area, in eastern Nebraska and adjacent Iowa, has been studied at some length during the past several decades, primarily because of the presence of several volcanic ashes from the Yellowstone volcanic center that have provided the only previous age limits on major LIS advances. Many chronologies have been proposed for these tills, beginning with the classical Nebraskan-Kansan-Illinoian-Wisconsinan classification of all tills into four major glaciations. The present consensus is that there were either one or two ice sheet advances that predate the 2.0 Ma

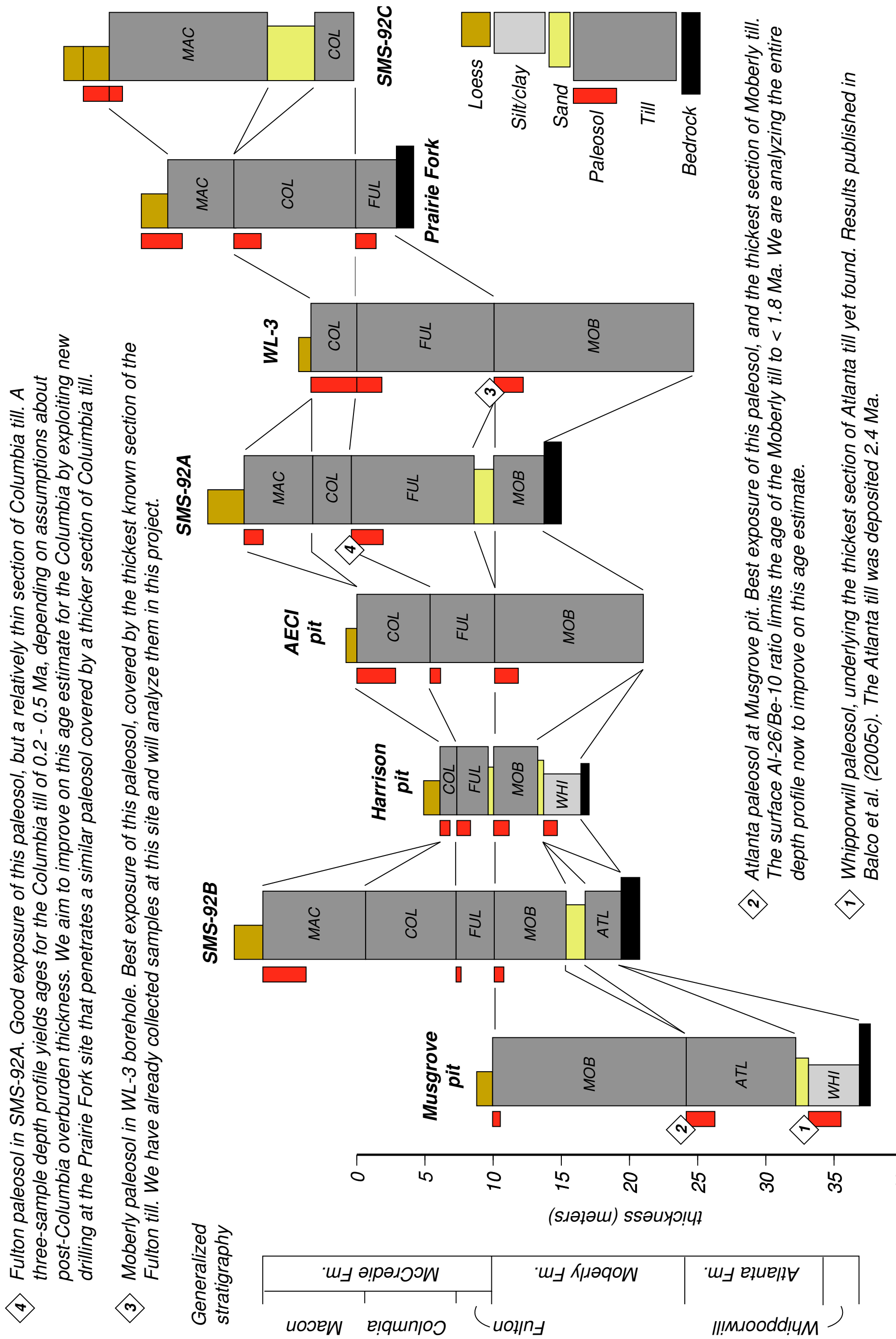

Figure 3: Stratigraphy of glacial deposits in east-central Missouri, showing stratigraphic context of paleosols on which we have already made ^{26}Al - ^{10}Be measurements, as well as paleosols where we have collected samples or begun analyses in preparation for this project. The paleosols at the Musgrove Pit denoted (1) and (2) are described in Balco et al. (2005c). In selecting the best possible sites, we are looking for a thick, well-developed paleosol (red bars on this figure indicate the depth of B horizon development at each site), buried by a thick till.

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Huckleberry Ridge ash (the 'C' tills of Boelstorff, 1978a,b,c and the 'R2' tills of Roy et al., 2004); at least two ice sheet advances that postdate the 1.2 Ma Mesa Falls ash (Boelstorff's 'B' and 'A4' tills; Roy's 'R1' tills); and at least three tills that postdate the 0.78 Ma Brunhes/Matuyama magnetic reversal (Boellstorff's 'A' tills; Roy's 'N' tills), at least one of which is younger than the 0.62 Ma Lava Creek ash.

Despite this existing chronology, we chose to focus our study to the south in Missouri for two reasons. First, our proposed focus area in Missouri has a much higher density of boreholes and pit exposures, allowing us both a better understanding of the stratigraphy and a greater ability to select sites where the stratigraphic situation allows accurate dating (see discussion below). Second, our strategy of starting at the southern margin of the glaciated area of North America, where there are the fewest tills, and working northward into areas of greater stratigraphic complexity is best served by beginning in Missouri.

With regard to the correlation between the Missouri and the Nebraska/Iowa tills, it seems reasonable to correlate the Atlanta till and the C/R2 till(s) on the basis of their similar lithologies and compatible age constraints (Rovey and Tandarich, 2004). There is little direct evidence for any other correlations, except for the general observation that the normally magnetized McCredie Fm. tills and the A/N tills ought to be of broadly similar age. A secondary objective of this proposal will be to work northwards from our focus area into north-central Missouri and adjacent Iowa, with the goal of better establishing this correlation. The stratigraphy in northern Missouri is not yet as well documented as it is in our main focus area, so this part of the project will require more preliminary mapping to locate key sites for dating, but we view it as a critical element of the project in that it will a) help to make the results of the main part of the project more useful over a wider area, and b) continue working toward our long-term goal of developing an overall chronology of major Plio-Pleistocene LIS advances. Finally, working to extend our chronology north into Iowa is of historical interest – many till-paleosol sections in Iowa have been extensively studied for decades and were important in the original construction of the R.F. Flint-era idea of four Pleistocene glaciations and four corresponding interglaciations. Although many questions undreamt of by the first American Quaternary geologists have now been answered, the one that they were most interested in, the age and correlation of Laurentide Ice Sheet tills, is still open. It would be very gratifying to finally make progress on this problem.

III. Dating till-paleosol sequences by cosmogenic ^{26}Al and ^{10}Be– development and uses to date. The basic idea of dating buried sediments using pairs of cosmic-ray-produced nuclides is that these nuclides are produced, by cosmic-ray bombardment of mineral grains exposed at the Earth's surface, at a ratio which is fixed by the chemistry of the target mineral. The most commonly used such nuclides, aluminum-26 and beryllium-10, are produced in quartz at a ratio ^{26}Al: ^{10}Be = 6.1. If quartz grains that are exposed at the surface for a time are then buried, and thus removed from the cosmic ray flux, the nuclide inventories that resulted from the initial exposure decrease by radioactive decay. ^{26}Al decays faster than ^{10}Be, so the ^{26}Al/ ^{10}Be ratio decreases over time and can be used as a burial clock. This idea of 'burial dating' dates to the early development of terrestrial cosmogenic nuclide geochemistry (e.g., Klein, 1988), and since then has been used in a variety of situations, most notably to date river terraces (Granger and Smith, 2000; Wolkowinsky and Granger, 2004) and river sediment deposited in caves (Granger et al., 1997; Granger et al., 2001; Stock et al., 2004).

In a previous NSF-funded project (EAR-0207844), we applied this idea to date till-paleosol sequences, which record soil formation during long periods of landscape stability, punctuated by burial of the soils by till during ice sheet advances. In this case, the ^{26}Al and ^{10}Be concentrations of the buried soil tell us the age of the overlying till. The major added complexity in this situation, relative to previous applications of burial dating, is that soils buried by tills are usually developed on older tills. The detrital quartz in these tills is often recycled from still older surface sediments, that may themselves have had a long history of surface exposure and burial. Thus, in order to determine the burial age of the paleosol by ^{26}Al-^{10}Be dating, we need to account for the inherited ^{26}Al and ^{10}Be concentrations in the quartz at the time the soil parent material was deposited. This is possible because the variation in the concentration of a single cosmogenic nuclide with depth in a soil profile provides information about not only the exposure time and erosion rate of the soil, but also about the inherited nuclide concentrations in the soil parent material (e.g., Anderson, 1996; Wolkowinsky and Granger, 2004). If we measure concentration-depth profiles of two nuclides in a paleosol buried by a till, we can thus extract all the needed information: the shape of the profile tells us about the inherited nuclide concentration and the duration of soil exposure, and the ratio of two nuclides tells us how long the soil has been buried and thus provides the age of the overlying till. We have described this method in detail in Greg Balco's Ph.D. dissertation (Balco, 2004) as well as a series of papers (Balco et al., 2005a, b, c.). In particular, Balco et al. (2005c) provide a detailed analysis of the effect of analytical, geological, and production rate uncertainties on the precision of the method. We will not duplicate the entire description in this proposal, but will focus on the strengths and limitations of the method, and explain why the stratigraphy of our proposed field area in Missouri is particularly well suited to obtaining the best possible age precision using this technique.

III. A. Relationship of soil development, burial depth, and production rate uncertainties to dating precision. There are three major sources of uncertainty that come into play in dating buried paleosols by ^{26}Al and ^{10}Be measurements: A), the analytical uncertainty in the cosmogenic-nuclide measurements themselves; B), the uncertainty in the production rates of the two nuclides, both at the surface by spallation reactions and, more importantly, by muon interactions well below the surface; and C), the uncertainty in how deeply the soil was buried between its initial burial and the present time, that is, how well we understand the geologic history of the site. Both B) and C), the geologic and production rate uncertainties basically affect our ability to estimate subsurface nuclide production rates: not knowing how deeply a sample is buried is equivalent to not knowing exactly what the production rate is at a certain depth.

Analytical uncertainty decreases when higher nuclide concentrations are present, so paleosols that experienced a longer period of exposure before being buried yield more accurate dates.

The uncertainty in subsurface production rates is important because, although ^{26}Al and ^{10}Be production rates drop rapidly with depth below the surface, they do not disappear, and we must be able to account for subsurface ^{26}Al and ^{10}Be production during the time the samples have been buried. These uncertainties are most important in situations where the ^{26}Al and ^{10}Be concentration at the time of burial is relatively small, and the samples are buried at a relatively shallow depth: in this case, subsurface nuclide production during burial accounts for a large proportion of the nuclide concentration that we eventually measure in the samples, and the uncertainty in determining what this proportion is becomes important. In the opposite situation, if a soil is exposed for a relatively long time, has correspondingly high nuclide concentrations when it is buried, and is buried by a thick till, then the total amount of post-burial production is small in comparison to nuclide loss by decay. Even large uncertainties in estimating the nuclide production rates during burial, either because of uncertainties in the production rates themselves or because we do not know the exact depositional history after the emplacement of the first till, are negligible relative to the total nuclide inventory (in this case, the important uncertainty is that in the decay constants for ^{26}Al and ^{10}Be which we discuss below).

To summarize, paleosols that are exposed for a relatively long time and then deeply buried can be dated accurately. Paleosols that were exposed only briefly and buried only shallowly can not.

Figure 4 illustrates this with examples from our previous work in developing the technique. In eastern South Dakota, where potentially the most complete records of LIS advances are preserved in the thick till sections beneath the Prairie Coteau highland, paleosols are rare, generally poorly developed, and often truncated by subsequent ice sheet advances. We measured ^{26}Al and ^{10}Be concentrations in one deeply buried paleosol from this area (upper panel of Figure 4; Balco et al. 2005b), and found that it reflected only a few thousand years of surface exposure. Our analytical uncertainties were large, and, even though the paleosol was buried by a thick till, nuclide production after burial was nearly as large as decay of the initial nuclide inventory, meaning that different assumptions about subsurface nuclide production by muons yielded significantly different ages.

The opposite is true for the late Pliocene Whippoorwill paleosol that underlies the Atlanta till in our proposed field area. This paleosol is the result of perhaps millions of years of surface exposure prior to the onset of Northern Hemisphere glaciation, which means that nuclide concentrations are extraordinarily high, analytical uncertainties are correspondingly low, and the emplacement of the overlying till can be very accurately dated (third panel from the top in Figure 3; Balco et al., 2005a). This paleosol consists only of locally derived regolith, which allows a simpler age calculation and correspondingly greater precision than is possible in the more general situations, but the main reason for the relatively high age precision is that the paleosol was buried with very high ^{26}Al and ^{10}Be concentrations, beneath a relatively thick till.

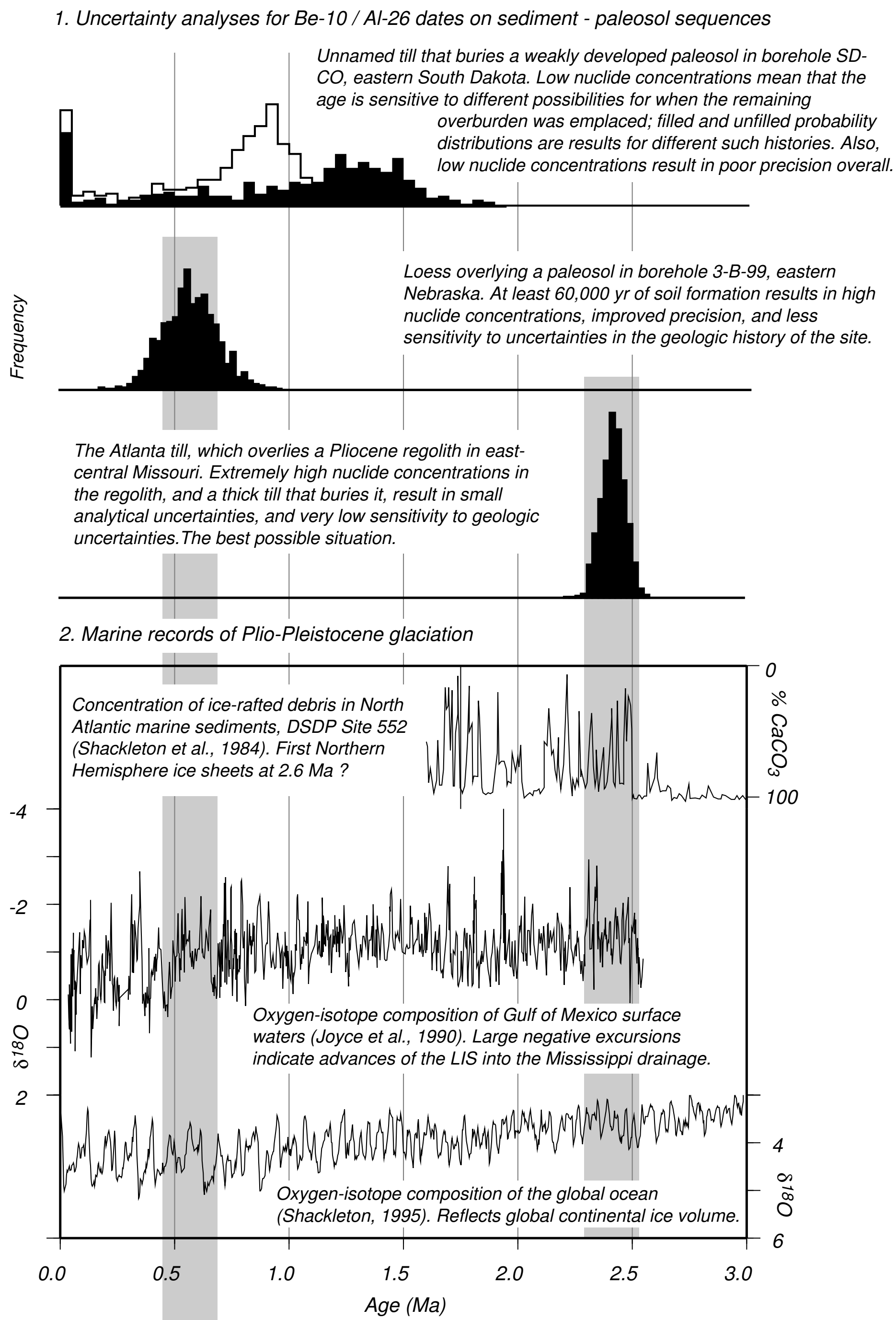

Figure 4: Applications of ^{26}Al - ^{10}Be burial dating to till-paleosol sequences to date, and paleoclimatic context for Northern Hemisphere glaciation. Part 1 of the figure shows probability density functions for the age uncertainty of three ^{26}Al - ^{10}Be dates on tills, generated by Monte Carlo analyses. All three have the same scale. These uncertainty analyses are described in detail in Balco et al., 2005b, 2005c, and 2005a respectively. Part 2 of the figure shows marine paleoclimate records that pertain to continental glaciations. The gray bands show 1-sigma uncertainties for the lower two probability distributions.

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Site selection strategy. The key conclusion to draw from the discussion of dating uncertainties above is that the geologic character of a particular till-paleosol sequence determines how accurately we can date it. Thus, proper site selection is the key to the success of this project. Our strategy in seeking to date each particular till in our field area consists of seeking those sites where, A) paleosols are best developed, reflecting the longest possible periods of exposure, and B), the tills are as thick as possible. This is why our proposed field area in Missouri is so well-suited to the ^{26}Al-^{10}Be dating technique: each till is underlain by a well-developed paleosol, and the large number of available boreholes and outcrops means that we can find the best-preserved example of each paleosol, and thickest possible section of each till.

Likely precision of our results. Finally, as we are interested in comparing the timing of ice sheet advances with other paleoclimate events, here we discuss whether we can obtain sufficient accuracy to achieve this goal. Our past work as well as the few analyses we made in preparation for this project suggests that we can date late Pliocene through middle Pleistocene tills to a precision of 5-8%. Absent any additional information, this is not sufficiently precise to associate individual tills with individual marine oxygen-isotope stages. It is, however, more than adequate to answer the major first-order questions about the evolution of the Laurentide Ice Sheet that motivate this proposal, and, more importantly, would be an enormous step forward from the existing situation in which the age of particular tills can only be bracketed between a few widely spaced chronostratigraphic markers. Also, we do have additional information that we can use to better refine our ages: First, the fact that we will date a series of tills whose stratigraphic order is known provides an additional constraint that serves to improve the statistical precision of our ages. Second, as we correlate tills in our field area with tills farther to the north, we can use limiting ages provided by volcanic ashes to further reduce our uncertainties. Third, the Plio-Pleistocene oxygen-isotope record from the Gulf of Mexico (Joyce et al., 1993) provides additional evidence as to which advances of the LIS entered the Missisippi River drainage, giving us a series of potential tie points between the terrestrial and marine stratigraphy. When we combine our results with this additional evidence, it is likely that we will have strong evidence for correlating at least some of the ice sheet advances represented in our field area with particular events recorded in other paleoclimate records.

Parenthetical remarks on uncertainties in half-lives. At present, one difficulty in using the ^{26}Al-^{10}Be pair for burial dating is that existing measurements of the half-life of ^{10}Be, although individually precise, converge on one of two values that differ by 13%. When propagated through ^{26}Al/^{10}Be age calculations, this results in a systematic difference of approximately 10% between ages calculated with the different half-lives. Experiments designed to decide which of the two possible half-lives is the correct one have recently been carried out (M. Caffee, personal communication), and others are in progress (F. von Blanckenburg, personal communication). Thus, we expect the half-life issue to be resolved by the time we are ready to publish the results of this project.

IV. Research plan.

We envision a two-year research project. In the first year, we will identify the sites and stratigraphic sections that are best suited to accurate dating of each till, and begin to analyze samples from these sites. We have already identified a few such sites, and are already preparing a few samples, as described below. Rovey will take primary responsibility for site identification, and will focus on coordinating with existing drilling programs by Missouri state agencies (see below), checking on active clay pits for possible new exposures, and verifying the identity of each till at our preferred sites via sedimentological, paleomagnetic, and soil-stratigraphic techniques. The first year budget includes funds for local travel for Rovey as well as funds for Balco and Stone to visit important sites and participate in sample collection. We will also begin cosmogenic-nuclide analyses in the first year, both on samples that we have already collected from two sites and on samples to be collected. Balco will take primary responsibility for the analytical portion of the project, and we have also budgeted travel funds for Rovey to visit Seattle to learn about the analytical techniques. In the second year, we will have mostly completed fieldwork and sample collection, and will focus on sample analysis and data interpretation.

Our primary field area will be the region of central Missouri that we describe above. Here we will take advantage of both active clay mining operations and an ongoing Missouri Geological Survey – USGS Surficial Materials Mapping Program project, in which the MGS are drilling nearly 50 boreholes/year in support of surficial mapping efforts. The next two years of this project are focused on the southernmost part of the glaciated area of eastern Missouri, approximately following the I-70 corridor between St. Louis and Columbia, that is, precisely the area of most interest to us. Rovey has been working closely with the MGS on this project for the past two years, and we anticipate that this collaboration will continue in future (see attached letter of support). Thus, we will have access to many new boreholes at previously unexplored sites during the period of this project. We will also have input into planning new boreholes, and therefore will very likely be able to drill additional sites in areas where we suspect there are particularly well-developed paleosols and particularly thick tills.

Our secondary objective will be to begin correlating the central Missouri till sequence with other till/paleosol sections further north, in northern Missouri and adjacent Iowa. At present, as we discuss above, there are some ideas about the correlation of Missouri tills with other prominent tills further north (summarized in Rovey and Tandarich, 2004), but these have not been firmly established either by detailed lithostratigraphy or by direct dating of the tills. We intend to use both methods to work towards this goal, so we have budgeted for additional local travel, sedimentologic/paleomagnetic measurements, and cosmogenic nuclide measurements at at least one or two sites to the north of our primary focus area.

We have budgeted for ^{26}Al and ^{10}Be measurements on 5-sample depth profiles at a total of nine sites, as follows (also see Figure 3):

1. Atlanta paleosol at the Musgrove pit. This paleosol should provide the age of the Moberly till. We have already collected samples at this site and analysed surface samples; analyses of the entire depth profile are in progress.
2. Moberly paleosol in the WL-3 borehole. Should provide the age of the Fulton till. We have already collected samples from this site.
3. Fulton and Columbia paleosols in the Prairie Fork borehole. Should provide ages for the Columbia and Macon tills, respectively. New drilling is in progress at this site at present; we expect to have samples available soon.
4. Three additional sites in the main field area in east-central Missouri. Although the above selection of sites, as well as our previous work on the age of the Atlanta till, is in principle sufficient to establish the age of all five central Missouri tills, we have budgeted for additional sites so that we can a) date at least some of the tills at multiple sites to better evaluate the precision and consistency of our results, and b) take advantage of new sites that will likely be discovered during the project. In particular, although we have found one site (the Prairie Fork borehole) where there is a well-developed paleosol in the Columbia till covered by a sufficiently thick section of the Macon till, we know that the Macon till is thicker elsewhere (for example, in borehole SMS-92C, although no Columbia paleosol is present here). We would like to find an additional, and perhaps better, site to date this till.
5. Two additional sites to the north of our primary field area in northeastern Missouri or southern Iowa. These sites are intended to support our secondary objective of extending the central Missouri till stratigraphy far enough north that it can be correlated more accurately with the till sequence in Iowa.

V. Summary and expected outcomes.

Scientific merit.

This project will yield entirely new information about an important gap in our knowledge of the late Cenozoic ice ages. At present, there are almost no direct dates at all for pre-late-Pleistocene advances of the Laurentide Ice Sheet. This project will yield direct dates for at least five of the southernmost advances of the LIS, which will enable more direct comparison of Plio-Pleistocene ice sheet advances with other climate records, provide information that is needed to evaluate many hypotheses about the role of ice sheets in Plio-Pleistocene climate and environmental change, and provide the first step toward an eventual goal of understanding the full development and evolution of the Laurentide Ice Sheet.

Broader impacts.

First, this project will help to make new cosmogenic-nuclide dating techniques available to state geological surveys, other government agencies, and geohydrologists in the north-central U.S. The correct correlation of numerous lithologically similar Plio-Pleistocene tills is the major stratigraphic problem that faces geologists interested in the stratigraphy and geohydrology of the glaciated region of North America. By working closely with state geological survey personnel we will both be able to provide them with results from this project that may help to solve local stratigraphic problems, and make them familiar with cosmogenic-nuclide dating methods that may be useful to them in future.

Second, this project will play an important career development role for two project participants. Greg Balco is a recent Ph.D., whose graduate research was supported by the previous NSF-funded project in which we developed the dating methods we will use here. This project is intended to apply those methods to broader research problems, which is important in broadening and developing his research career. Chuck Rovey is a teacher and scientist from a university that is primarily focused on undergraduate education. He is comprehensively knowledgeable about the glacial geology and Quaternary stratigraphy of the central U.S., but has received little NSF research support in the past. This project would benefit the research community by allowing him to contribute his knowledge and skills to an important problem in basic Earth science research, and would benefit him, his undergraduate students, and Southwest Missouri State University by providing them access to new developments in cosmogenic-nuclide geochronology.

Third, we anticipate that this project will lead to significant positive public exposure to Earth science research. In the initial work that we did in preparation for this proposal, we unexpectedly discovered that the Atlanta till was the oldest known evidence of North American continental glaciation. This recieved a surprisingly large amount of attention, not only in the scientific literature but in the popular press, including coverage in local Missouri newspapers, the Kansas City Star, and the New York Times. This press interest, presumably the result of Missouri's mining and mineral-industry heritage, the general interest among Missourians in the natural history of their region, and the fact that the idea of when the great ice ages first began is easily accessible and broadly interesting to the general public, resulted in a surprising number of contacts between us (Balco and Rovey) and a variety of interested people, including reporters, private-sector geologists, and teachers at all levels. All of this resulted in positive public exposure for Earth science research.

In an additional recent development, another collaboration (unrelated to this project) between Rovey, Balco, and other Missouri geologists to use cosmogenic-nuclide methods to date the fossil-bearing sediments in a newly discovered cave in southwest Missouri has generated another wave of positive press coverage for cosmogenic-nuclide geochemistry. Public interest in this cave, Riverbluff Cave, was already high because of the array of fossils and animal traces found in the cave, including mammoth bones, peccary trackways, saber-toothed cat claw marks, and the undisturbed dens, claw marks, and dung of the deadly, twelve-foot-tall, short-faced cave bear (more info at the Riverbluff Cave web site – http://www.riverbluffcave.com). Our collaboration established that the cave sediments and the associated fossils are 600,000 - 800,000 yr old, making this one of the oldest Pleistocene fossil assemblages in any North American cave, and resulting in an additional series of reports in regional newspapers. The public appeal of Pleistocene megafauna is well known, making this an exceptional opportunity to bring even something as arcane as cosmogenic-nuclide geochemistry into the public eye. Thus (although this project does not directly involve Pleistocene megafauna) the high level of public interest in our work so far leads us to believe that placing the glacial deposits of Missouri into the context of the global climate and environmental changes of the Plio-Pleistocene ice ages will result in additional positive public exposure for NSF-funded research, as well as providing new resources for regional museums and educators.

References

R.S. Anderson, J.L. Repka, and G.S. Dick. Explicit treatment of inheritance in dating depositional surfaces using in-situ be-10 and 26-al. *Geology*, 24:47–51, 1996.

G. Balco. *The sedimentary record of subglacial erosion beneath the Laurentide Ice Sheet*. Unpublished Ph.D. thesis, University of Washington, 2004.

G. Balco, C. W. Rovey, and J.O.H. Stone. The First Glacial Maximum in North America. *Science*, 307:222, 2005a.

G. Balco, J.O.H. Stone, and C. Jennings. Dating Plio-Pleistocene glacial sediments using the cosmic-ray-produced radionuclides ^{10}Be and ^{26}Al. *American Journal of Science*, 305:1–41, 2005b.

G. Balco, J.O.H. Stone, and J. Mason. Numerical ages for Plio-Pleistocene glacial sediment sequences by ^{26}Al/^{10}Be dating of quartz in buried paleosols. *Earth and Planetary Science Letters*, 232:179–191, 2005c.

J. Boellstorff. Chronology of some late Cenozoic deposits from the central United States and the ice ages. *Transactions of the Nebraska Academy of Sciences*, VI:35–48, 1978a.

J. Boellstorff. A need for redefinition of North American Pleistocene stages. *Transactions of the Gulf Coast Association of Geological Societies*, XXVIII:65–74, 1978b.

J. Boellstorff. North American Pleistocene stages reconsidered in light of probable Pliocene-Pleistocene continental glaciation. *Science*, 202:305, 1978c.

P.U. Clark and D. Pollard. Origin of the middle Pleistocene transition by ice sheet erosion of regolith. *Paleoceanography*, 13:1–9, 1998.

H. Conway, B.L. Hall, G.H. Denton, A.M. Gades, and E.D. Waddington. Past and future grounding line retreat of the West Antarctic Ice Sheet. *Science*, 286:280–283, 1999.

P.B. DeMenocal. African climate change and faunal evolution during the Pliocene-Pleistocene. *Earth and Planetary Science Letters*, 220:3–24, 2004.

C. Emiliani. Pleistocene temperatures. *Journal of Geology*, 63:538–578, 1955.

D. E. Granger, D. Fabel, and A. N. Palmer. Pliocene-Pleistocene incision of the Green River, Kentucky, determined from radioactive decay of cosmogenic ^{26}Al and ^{10}Be in Mammoth Cave sediments. *Geological Society of America Bulletin*, 113(7):825–836, 2001.

D. E. Granger, J. W. Kirchner, and R. C. Finkel. Quaternary downcutting rate of the New River, Virginia, measured from differential decay of cosmogenic ^{26}Al and ^{10}Be in cave-deposited alluvium. *Geology*, 25(2):107–110, 1997.

D. E. Granger and A. L. Smith. Dating buried sediments using radioactive decay and muogenic production of ^{26}Al and ^{10}Be. *Nuclear Instruments and Methods in Physics Research Section B Beam Interactions with Materials and Atoms*, pages 822–826, 2000.

D.E. Granger and P.F. Muzikar. Dating sediment burial with in situ-produced cosmogenic nuclides: theory, techniques, and limitations. *Earth and Planetary Science Letters*, 188(1-2):269–281, 2001.

G.R. Hallberg. Pre-Wisconsinan glacial stratigraphy of the central Plains region in Iowa, Nebraska, Kansas, and Missouri. In V. Sibrava, D.Q. Bowen, and G.M. Richmond, editors, *Quaternary Glaciations of the Northern Hemisphere*, pages 11–15. Pergamon Press, Oxford, 1986.

G.R. Hallberg and T.J. Kemmis. Stratigraphy and correlation of the glacial deposits of the Des Moines and James lobes and adjacent areas in North Dakota, South Dakota, Minnesota, and Iowa. In V. Sibrava, D.Q. Bowen, and G.M. Richmond, editors, *Quaternary Glaciations of the Northern Hemisphere*, pages 65–68. Pergamon Press, Oxford, 1986.

G.H. Haug, A. Ganopolski, D.M. Sigman, A. Rosell-Mele, G.E.A. Swann, R. Tiedemann, S.L. Jaccard, J. Bollman, M. Maslin, M.J. Leng, and Eglinton. G. North Pacific seasonality and the glaciation of North America 2.7 million years ago. *Nature*, 433:821–825, 2005.

J. Imbrie and K.P. Imbrie. *Ice Ages*. Harvard University Press, 1979.

J.E. Joyce, L.R.C. Tjalsma, and J.M. Prutzman. North American glacial meltwater history for the past 2.3 m.y.: oxygen-isotope evidence from the Gulf of Mexico. *Geology*, 21:483–486, 1993.

J. Klein, R. Middleton, R. Giegengack, and P. Sharma. Revealing histories of exposures using in situ produced ^{26}Al and ^{10}Be in Libyan desert glass. *Radiocarbon*, 28:547–555, 1988.

L.A. Krissek and K.E. Kudless. Pleistocene ice-rafting records from the Irminger Basin, SE Greenland margin; preliminary results. *Eos, Transactions, American Geophysical Union*, 77(46 Suppl.):296, 1996.

J.M. Lineburg. *Sedimentology and stratigraphy of pre-Wisconsin drifts, Coteau des Prairies, eastern South Dakota*. M.S. thesis, University of Minnesota, 1993.

J. Mangerud, E. Jansen, and J. Y. Landvik. Late Cenozoic History of the Scandinavian and Barents Sea ice sheets. *Global and Planetary Change*, 12:11–26, 1996.

C.J. Patterson. Surficial geology of southwestern Minnesota. In C.J. Patterson, editor, *Contributions to the Quaternary Geology of Southwestern Minnesota. Minnesota Geological Survey Report of Investigations No. 47*. University of Minnesota, St. Paul, MN, 1997.

C.J. Patterson. Quaternary Geology - Upper Minnesota River basin, Minnesota. Minnesota Geological Survey Regional Hydrologic Assessment RHA-4, 1999.

A.C. Ravelo, D.H. Andreasen, M. Lyle, A.O. Lyle, and M.W. Wara. Regional climate shifts caused by gradual cooling in the Pliocene epoch. *Nature*, pages 263–267, 2004.

M.E. Raymo. The initiation of northern hemisphere glaciation. *Annual Reviews of Earth and Plantary Sciences*, 22: 353–383, 1994.

C.W. Rovey II and W.F. Kean. Pre-Illinoian glacial stratigraphy in east-central Missouri. *Quaternary Research*, 45: 17–29, 1996.

C.W. Rovey II, W.F. Kean, and L. Atkinson. *Paleomagnetism of sediments associated with the Atlanta Formation, north-central Missouri, USA*, pages B1–B14. Kansas Geological Survey, 2005.

C.W. Rovey II and J.P. Tandarich. *Lithostratigraphy of glacigenic sediments in north-central Missouri*, pages A1–A15. Kansas Geological Survey, 2004.

M. Roy, P.U. Clark, R.W. Barendregt, J.R. Glasmann, and R.J. Enkin. Glacial stratigraphy and paleomagnetism of late Cenozoic deposits of the north-central United States. *Geological Society of America Bulletin*, 116(1/2):30–41, 2004.

R.P. Scherer, A. Aldahan, S. Tulaczyk, B. Kamb, H. Engelhardt, and G. Possnert. Pleistocene collapse of the West Antarctic Ice Sheet. *Science*, 281:82–85, 1998.

D.R. Setterholm. Quaternary Geology – Southwestern Minnesota. Minnesota Geological Survey Regional Hydrologic Assessment Series RHA-2, 1995.

N.J. Shackleton, J. Backman, H. Zimmerman, D.V. Kent, M.A. Hall, D.G. Roberts, D. Schnitker, J.G. Baldauf, A. Desprairies, R. Homrighausen, P. Huddlestun, J.B. Keene, A.J. Kaltenback, K.A.O Krumsiek, A.C. Morton, J.W. Murray, and J. Westberg-Smith. Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region. *Nature*, 307:620–623, 1984.

N.J. Shackleton and N.D. Opdyke. Oxygen-isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year scale. *Quaternary Research*, 3:39–55, 1973.

D.R. Soller and P.H. Packard. Digital representation of a map showing the thickness and character of Quaternary sediments in the glaciated United States east of the Rocky Mountains. USGS Digital Data Series DDS-38, 1998.

R.F. Spielhagen, G. Bonani, A. Eisenhauer, M. Frank, T. Friederichs, H. Kassens, P. Kubik, A. Mangini, N. Nørgaard-Pedersen, N.R. Nowaczyk, S. Schäper, R. Stein, J. Thiede, R. Tiedemann, and M. Wahsner. Arctic Ocean evidence for late Quaternary initiation of northern Eurasian ice sheets. *Geology*, 25(9):783–786, 1997.

G. Stock, R.S. Anderson, and R.C. Finkel. Pace of landscape evolution in the Sierra Nevada, California, revealed by cosmogenic dating of cave sediments. *Geology*, 32:193–196, 2004.

J.O.H. Stone, G. Balco, D.E. Sugden, M.W. Caffee, L.C. Sass III, S.G. Cowdery, and C. Siddoway. Holocene deglaciation of Marie Byrd Land, West Antarctica. *Science*, 299:99–102, 2003.

D.E. Sugden, G. Balco, S.G. Cowdery, J.O.H. Stone, and L.C. Sass III. Selective glacial erosion in the Sarnoff and Allegheny Mountains, Marie Byrd Land, Antarctica. *Geomorphology*, 67:317–334, 2005.

A. Wolkowinsky and D. Granger. Early Pleistocene incision of the San Juan River, Utah, dated with ^{26}Al and ^{10}Be. *Geology*, 32:749–752, 2004.

P. Zhang, P. Molnar, and W. Downs. Increased sedimentation rates and grain sizes 2-4 myr ago due to the influence of climate change on erosion rates. *Nature*, 410:891–897, 2001.

BIOGRAPHICAL SKETCH — JOHN O. STONE

PROFESSIONAL PREPARATION

1988-89 Post-doctoral Fellow, Division of Geological and Planetary Sciences, California Institute of Technology. Isotopic anomalies in meteorites.

1986-87 Post-doctoral Research Associate, Enrico Fermi Institute, University of Chicago. Study of the isotopic composition of solar wind nitrogen, as recorded in lunar soils.

1983-86 Ph.D. in Earth Sciences (Geochemistry), University of Cambridge, England.

1979-82 B.Sc. (Hons.) in Geology and Geophysics, University of Sydney, Australia.

EMPLOYMENT HISTORY

1998-05 Assistant/Associate Professor, Quaternary Research Center and Department of Earth and Space Sciences, University of Washington. Research and teaching with emphasis on surface processes, geochemistry and geochronology.

1990-97 Research Fellow, Research School of Earth Sciences, Australian National University. Member of the Environmental Geochemistry group; research involving stable isotopes and geological applications of cosmic-ray-produced ^{36}Cl, ^{10}Be and ^{26}Al.

RELATED PUBLICATIONS

2005 Balco G., Rovey C.W. II, and Stone J.O. The First Glacial Maximum in North America. *Science*, (Brevia section) 307, 222.

Balco G., Stone J.O. and Jennings C. Dating Plio-Pleistocene glacial sediments using the cosmic-ray-produced radionuclides ^{10}Be and ^{26}Al. *Am. J. Sci.* 305, 1-41.

Balco G., Stone J.O. and Mason J.A. Numerical ages for Plio-Pleistocene glacial sediment sequences by $^{26}Al/^{10}Be$ dating of quartz in buried paleosols. *Earth Planet. Sci. Lett.*, 232, 179-191.

Ng F., Hallet B., Sletten R.S. and Stone J.O. Fast-growing till over ancient ice in Beacon Valley, Antarctica. *Geology*, 33, 121-124.

2003 Stone J., Balco G., Sugden D.E., Caffee M.W., Sass L.C. III, Cowdery S.G. & Siddoway C. Holocene deglaciation of Marie Byrd Land, West Antarctica. *Science*, 299, 99-102.

OTHER SIGNIFICANT PUBLICATIONS

2005 Stone J.O. and Ballantyne C.K. Dimensions and deglacial chronology of the Outer Hebrides Ice Cap, NW Scotland: implications of cosmic-ray exposure dating. *J. Quat. Sci.*, in press.

Sugden D.E., Balco G., Cowdery S.G., Stone J.O. and Sass L.C. III, Selective glacial erosion in the Sarnoff and Allegheny Mountains, Marie Byrd Land, Antarctica. *Geomorphology*, 67, 317-334.

2004 Barrows T., Stone J.O., Roberts R.G. and Fifield L.K.; The timing of Late Pleistocene periglacial activity in Australia. *Quat. Sci. Rev.*, 23, 697-708..

2002 Barrows T., Stone J.O., Fifield L.K. and Cresswell R.G. The timing of the Last Glacial Maximum in Australia. *Quat. Sci. Rev.,* 21 (1-3), 159-173.

2000 Stone J.O. Air pressure and cosmogenic isotope production. *J. Geophys. Res.* 105, 23,753-23,759

SYNERGISTIC ACTIVITIES

Development of production systematics, calculation methods and laboratory techniques for use in cosmogenic nuclide studies and distribution of the this information to other scientists in the field (e.g. http://www.depts.washington.edu/cosmolab).

Member, Advisory Committee to the NSF-funded PRIME Lab facility for Accelerator Mass Spectrometry, Purdue University.

Member, NERC (UK) Cosmogenic Isotope Analysis Facility, Steering Committee.

Development of innovative computational teaching materials for University of Washington courses in geochemistry and geochronology. Examples range from simulations of Earth outgassing to exploration of paleo-environmental records preserved in corals.

Talks on Antarctic science to Seattle area Elementary School students.

COLLABORATORS AND CO-AUTHORS (last 4 years):

Ballantyne C.K. (University of St Andrews)
Caffee M. (Purdue University)
Christensen H. (University of Copenhagen)
Conway H. (University of Washington)
Enzel Y. (Hebrew University)
Fifield L.K. (Australian National University)
Finkel R. (Lawrence Livermore NL)
Gillespie A. (University of Washington)
Hall B. (U. Maine)
Hallet B. (University of Washington)
Kent A. (Oregon State University)
Lambeck K. (Australian Nat'l University)
Mann D. (University of Alaska, Fairbanks)
Mason J. (U. Wisconsin)
McCarroll D. (University of Swansea)
Montgomery D. (University of Washington)
Ng, Felix (MIT)
Nunn P. (University of the South Pacific)
Jennings-Patterson C. (Minnesota Geological Survey)
Rovey C. SW Missouri State University)
Sletten R.S. (University of Washington)
Sugden D.E. (University of Edinburgh)
Summerfield M. (University of Edinburgh)
Vasconcelos P. (University of Queensland)
Whipple K. (MIT)

GRADUATE AND POSTDOCTORAL AFFILIATIONS:

R.K. O'Nions (University of Oxford)	graduate advisor 1983-86
R.N. Clayton (University of Chicago)	postdoctoral sponsor 1986-88
S. Epstein / G.J. Wasserburg / I.D. Hutcheon (Caltech)	postdoctoral sponsors 1988-89

STUDENTS SUPERVISED AND POSTDOCTORAL ASSOCIATES (Total 8; past 5 years):

Gendaszek A. (MS student, University of Washington 2003-2005)

Kuharic M. (MS student, University of Washington 2003-2005)

Todd C. (PhD student, University of Washington 2002-2005)

Cowdery S. (MS student, University of Washington 2002-2004)

Balco G. (PhD student, University of Washington 1998-2004 / postdoc 2004-2005)

Smith M. (MS student, University of Washington 2000-2002)

Barrows T. (PhD student, Australian National University 1996-2000)

Evans J.M. (PhD student, Australian National University 1994-2001)

BIOGRAPHICAL SKETCH – GREG BALCO

Professional preparation

University of Washington, Seattle, WA. Ph.D., Earth and Space Sciences, 2004. M.S., Applied Mathematics, 2004. Quaternary and glacial geology, paleoclimate, surface processes, cosmogenic-nuclide geochemistry, quantitative geomorphology, GIS applications in geology.

University of Maine, Orono, ME. M.S., Geological Sciences, 1997. Coastal sedimentology, sea-level change, Quaternary and glacial geology, paleoenvironmental reconstruction.

Williams College, Williamstown, MA. Bachelor of Arts, magna cum laude, 1992.

Employment history

Research Associate, University of Washington. 2004-present.

Carpenter, Otis Burt Construction, West Tisbury, MA. 1998.

Legislative staff, House Committee on Resources, Subcommittee on Fisheries Conservation, Wildlife, and Oceans, Washington, DC. 1987-88.

Staff geologist, JME Companies, Lakewood, CO. 1993-1994.

Related publications

Balco, G., Rovey, C.W., Stone, J.O.H., 2005. The First Glacial Maximum in North America. *Science* 307, p. 222.

Balco, G., Stone, J.O.H., Mason, J., 2005. Numerical ages for Plio-Pleistocene glacial sediment sequences by Al-26/Be-10 dating of quartz in buried paleosols. *Earth and Planetary Science Letters* 232, pp. 179-191.

Balco, G., Stone, J.O.H., Jennings, C., 2005. Dating Plio-Pleistocene glacial sediments using the cosmic-ray-produced radionuclides Be-10 and Al-26. *American Journal of Science* 305, pp. 1-41.

Other significant publications

Balco, G., Stone, J.O.H., 2005 in press. Measuring middle Pleistocene erosion rates with cosmic-ray-produced nuclides in alluvial sediment, Fisher Valley, southeastern Utah. *Earth Surface Processes and Landforms*.

Sugden D., Balco G., Cowdery S., Stone J.O.H., Sass L., 2005. Selective glacial erosion and weathering zones in the coastal mountains of Marie Byrd Land, Antarctica. *Geomorphology* 67, pp. 317-334.

Stone, J.O.H., Balco, G., Sugden, D., Caffee, M., Sass, L.C. III, Cowdery, S., Siddoway, C., 2003. Holocene deglaciation of Marie Byrd Land, West Antarctica. *Science* 299, p. 99.

Balco, G., Stone. J.O.H., Porter, S.C., Caffee, M., 2002. Cosmogenic-nuclide ages for New England coastal moraines, Marthas Vineyard and Cape Cod, Massachusetts, USA. *Quaternary Science Reviews* 21, pp. 2127-2135.

Montgomery, D., Balco, G., Willett, S., 2001. Climate, tectonics, and the morphology of the Andes. *Geology* 29, pp. 579-582.

Synergistic activities

Development of calculation methods and laboratory techniques for cosmogenic-nuclide measurements and interpretation, independently and in the context of the NSF-funded CRONUS-Earth project, including development of online exposure age calculators for ^{10}Be, ^{26}Al, and ^{36}Cl.

Development of the UW Cosmogenic Nuclide Lab web pages (*http://depts.washington.edu/cosmolab*), including chemical and mathematical methods for cosmogenic-nuclide research, distribution of Antarctic maps and images, and access to published and unpublished data.

Collaborators and co-authors

Stone J. (U. of Washington)
Jennings C. (Minnesota Geological Survey)
Rovey C. (Southwest Missouri State University)
Mason J. (U. of Wisconsin)
McCormick K. (South Dakota Geological Survey)
Montgomery D. (U. of Washington)
Willett S. (U. of Washington)
Porter S. (U. of Washington)
Willett S. (U. of Washington)
Sugden D. (U. of Edinburgh)
Schaefer J. (Lamont-Doherty Earth Observatory)
Gehrels R. (U. of Plymouth)
Staudenmayer J. (U. of Massachusetts)
Belknap D. (U. of Maine)
Kelley J.T. (U. of Maine)

Graduate and postdoctoral advisors

John Stone (U. of Washington): Ph.D. advisor and postdoctoral supervisor, 1998-2004
Dan Belknap (U. of Maine): M.S. advisor, 1994-97

BIOGRAPHICAL SKETCH

VITA
CHARLES W. ROVEY II
Associate Professor of Geology
Department of Geography, Geology, and Planning
Southwest Missouri State University, Springfield MO 65804
417/836-6890, email: charlesrovey@smsu.edu

a. Professional Preparation

Augustana College, Rock-Island, IL	**Geology.**	**B.A. 1980**
University of Wisconsin-Milwaukee	**Geosciences**	**M.S. 1983**
University of Wisconsin-Milwauke	**Geosciences.**	**Ph.D. 1990**

b. Appointments

Associate Professor, Southwest Missouri State University, 1996-present.
Assistant Professor, Southwest Missouri State University, 1991-1996

c. Publications
(i) related to project

Balco, G., C.W. Rovey II, and J.O.H. Stone (2005). The first glacial maximum in North America. Science, v. 307, p. 222.

Rovey, C.W. II and J.P. Tandarich, (In Press). Lithostratigraphy of glacigenic sediments in north-central Missouri. Kansas Geological Survey Guidebook Series.

Rovey, C.W. II, W.F. Kean and L. Atkinson, (In Press). Paleomagnetism of sediments associated with the Atlanta Formation, north-central Missouri, USA. Kansas Geological Survey Guidebook Series.

Rovey, C.W. II, and W.F. Kean, 2001. Palaeomagnetism of the Moberly formation, northern Missouri, confirms a regional magnetic datum within the pre-Illinoian glacial sequence of the midcontinental USA. Boreas, v. 30, pp. 53-60.

Rovey, C.W. II and W.F. Kean, 1996. Pre-Illinoian glacial stratigraphy,north-central Missouri. Quaternary Research, v. 45, pp. 17-29.

(ii) other publications

Rovey, C.W. II and W.L. Niemann, 2005. Do conservative solutes migrate at average pore-water velocity? Ground Water, v. 43 (1), pp. 52-62.

BIOGRAPHICAL SKETCH

(This is a continuation page)

Rovey, C.W. II and W.L. Niemann, 2001. Wellskins and slug tests: where?s the bias? Journal of Hydrology, v. 243, pp. 120-132.

Niemann, W.L. and C.W. Rovey II, 2000. Comparison of hydraulic conductivity values obtained from aquifer pumping tests and conservative tracer tests. Ground Water Monitoring and Remediation, v. 20(3), pp. 122-128.

Rovey, C.W. II, 1997. The nature and origin of gleyed polygenetic paleosols in the loess covered glacial drift plain of northern Missouri, USA. Catena, v. 31, pp. 153-172.

Rovey, C.W. II and M.K. Borucki, 1995. Subglacial to proglacial sediment transition in a shallow glacial-lacustrine lake. Boreas, v. 24, pp. 117-127.

d. Synergistic Activities

Teaching graduate-level class in Stratigraphy and Sedimentation, Undergraduate class: Field Geology of the Midcontinent Region.

Supervising drilling and logging of core for numerous projects dating to 1981.

Site instrumentation at the SMSU Bull Shoals Field Station for hydrologic field exercises.

e. Collaborators & Other Affiliations

(i) Collaborators

Bill Kean University of Wisconsin-Milwaukee
Bill Niemann University of Dubuque

(ii) Graduate Advisor

Doug Cherkauer University of Wisconsin-Milwaukee

(iii) Thesis Advisor

Bill Niemann University of Missouri-Rolla (Ph.D)
Charles Meyer Southwest Missouri State University (M.S.)
Paul Hester Southwest Missouri State University (M.S.)
Three additional graduate students advised

SUMMARY PROPOSAL BUDGET   YEAR 1

ORGANIZATION University of Washington			FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR John O Stone			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. John O Stone - Assoc Prof	0.00	0.00	0.25	$ 1,993	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.25	1,993	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES	2.00	0.00	0.00	7,416	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (1) UNDERGRADUATE STUDENTS				600	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				10,009	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,249	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				12,258	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				3,700	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,300	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				552	
5. SUBAWARDS				0	
6. OTHER				15,735	
TOTAL OTHER DIRECT COSTS				18,587	
H. TOTAL DIRECT COSTS (A THROUGH G)				34,545	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 55.5000, Base: 34545)					
TOTAL INDIRECT COSTS (F&A)				19,172	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				53,717	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 53,717	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME John O Stone	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Adelia yee	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Washington

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
John O Stone

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. John O Stone - Assoc Prof	0.00	0.00	0.25	$ 2,073	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.25	2,073	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES	2.00	0.00	0.00	7,713	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (1) UNDERGRADUATE STUDENTS				600	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				10,386	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,337	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				12,723	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				3,300	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,840	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				552	
5. SUBAWARDS				0	
6. OTHER				12,688	
TOTAL OTHER DIRECT COSTS				15,080	
H. TOTAL DIRECT COSTS (A THROUGH G)				31,103	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 55.5000, Base: 31103)					
TOTAL INDIRECT COSTS (F&A)				17,262	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				48,365	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 48,365	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
John O Stone

ORG. REP. NAME*
Adelia yee

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0545518

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: University of Washington

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: John O Stone

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. John O Stone - Assoc Prof	0.00	0.00	0.50	$ 4,066	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.50	4,066	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (2) POST DOCTORAL ASSOCIATES	4.00	0.00	0.00	15,129	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				1,200	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				20,395	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				4,586	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				24,981	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				7,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				4,140	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				1,104	
5. SUBAWARDS				0	
6. OTHER				28,423	
TOTAL OTHER DIRECT COSTS				33,667	
H. TOTAL DIRECT COSTS (A THROUGH G)				65,648	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				36,434	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				102,082	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 102,082	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME: John O Stone

ORG. REP. NAME*: Adelia yee

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0545518

COLLABORATIVE RESEARCH: AN ABSOLUTE CHRONOLOGY OF THE SOUTHERNMOST ADVANCES OF THE LAURENTIDE ICE SHEET

Detailed budget and justification: University of Washington

			Year 1	Year 2	Total
SALARIES			**2/06-1/07**	**2/07-1/08**	**2/06-1/08**
	P.I.	John Stone, Assoc. Professor 0.25 months each year	1,993	2,073	4,066
	Postdoc	Greg Balco 2 months each year	7,416	7,713	15,129
	Undergrads	Undergrad lab assistant (hourly wage)	600	600	1,200
	Total Salaries		**10,009**	**10,385**	**20,394**
	Benefits (faculty & postdocs 23.2%; undergrad 11.1%)		2,249	2,337	4,586
	Total Salaries and Benefits		12,258	12,723	24,981
TRAVEL					
	Seattle-Missouri for field work (Airfares, car rental, per diem; $1450/trip)		2,900	1,450	4,350
	Travel to AMS facility for isotopic analyses (Airfares, per diem; $800/trip)		800	800	1,600
	Conference travel (1 mtg Balco in yr 2)			1,050	1,050
	Total Travel		**3,700**	**3,300**	**7,000**
SUPPLIES					
		Reagents, consumables for Al-26/Be-10 preparation; for 25 samples year 1; 20 samples year 2, at $92/sample	2,300	1,840	4,140
	Total Supplies		**2,300**	**1,840**	**4,140**
OTHER DIRECT COSTS					
		Be-10 analyses: 25 year 1, 20 year 2; PRIME Lab rate	4,375	3,500	7,875
		Al-26 analyses: 25 year 1, 20 year 2; LLNL-CAMS rate	10,000	8,000	18,000
		ICP analyses (10 hrs yr 1, 8 hrs yr 2 @ $61/hr)	610	488	1,098
		Sample shipping	150	100	250
		Departmental computing support fee	552	552	1,104
		Computing costs (software, upgrades, poster printing)	300	300	600
		Communications (long distance calls, postage, Fedex)	300	300	600
	Total Other Direct Costs		**16,287**	**13,240**	**29,527**
TOTAL DIRECT COSTS			34,545	31,103	65,648
	Indirect Costs (UW rate 55.5% of MTDC)		19,172	17,262	36,434
TOTAL			53,717	48,365	102,082

Detailed justification

The project will take two years to complete. Balco will take primary responsibility for organizing and carrying out fieldwork, sample preparation, analysis and data interpretation. Stone will retain fiscal and reporting responsibility and will also participate in all other aspects of the work, from fieldwork and data interpretation through to write-up. Major costs of the project are:

Salaries: In view of his central role in the project we request 2 months per year of postdoctoral salary support for Balco. Stone will play a supporting role in this project, and we therefore request only 0.25 months summer salary per year to cover his participation in field and laboratory work and project administration. Salaries are projected assuming a 4%/year annual increase.

Travel: We request support for two field trips to sampling sites in Missouri in year 1 and one trip in year 2. Also included is the cost of one trip by Balco or Stone to LLNL-CAMS (Lawrence Livermore Center for Accelerator Mass Spectrometry) or PRIME Lab (Purdue University) each year to participate in AMS analyses. Costs for Balco to attend one meeting (GSA/AGU) in year 2 are also included.

Supplies: The budget includes the cost of consumables, labware and reagents for preparation of 25 paired cosmogenic $^{26}Al/^{10}Be$ samples in year 1 and 20 samples in year 2, at $92 per sample.

Other Direct Costs: Accurate, high-precision AMS analyses are central to the success of the project, and represent the largest cost item in this budget. We are proposing to make coupled ^{26}Al and ^{10}Be analyses on 25 samples in year 1 and 20 in year 2. In comparison to conventional exposure dating or erosion-rate studies, we require very precise AMS measurements in order to determine $^{26}Al/^{10}Be$ ratios and burial ages with the highest possible accuracy and precision. Based on our previous work, we anticipate having to make $^{10}Be/^{9}Be$ and $^{26}Al/^{27}Al$ analyses with uncertainties less than ±3% and ±5% respectively at ratios $< 10^{-13}$. Recent upgrades and modifications of the PRIME Lab accelerator should allow us to achieve this level of precision for Be isotopic measurements, which we have budgeted at the NSF-subsidized rate of $175 per analysis. We have budgeted to carry out the more challenging Al isotopic measurements at LLNL-CAMS, at a higher rate of $400 per analysis. We note, however, that PRIME Lab is planning to modify existing ^{26}Al measurement procedures to achieve much higher levels of sensitivity, by injecting molecular AlO^- ions and analyzing ^{26}Al after separation from interferences using a gas-filled magnetic spectrometer. If these plans materialize during the term of this project, we will carry out ^{26}Al analyses at PRIME. Any funds saved by so doing will be used to analyze additional samples, extending the scope of the project.

Minor items are ICP analytical costs for Al and Be analyses of quartz, sample shipping, computer support charges and communications costs (long-distance phone calls and express mail).

Indirect Costs: Indirect costs are calculated at the standard UW rate of 55.5% of MTDC.

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Southwest Missouri State University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Charles W Rovey

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Charles W Rovey - CoPI	0.00	0.00	2.00	$ 10,443	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	10,443	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				10,443	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,193	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				12,636	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,987	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				0	
H. TOTAL DIRECT COSTS (A THROUGH G)				15,623	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Total Salaries, Wages and Fringe (Rate: 42.0000, Base: 12636)					
TOTAL INDIRECT COSTS (F&A)				5,307	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				20,930	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 20,930	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Charles W Rovey

ORG. REP. NAME*
William Alter

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INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0545023

SUMMARY PROPOSAL BUDGET YEAR 2

ORGANIZATION Southwest Missouri State University				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Charles W Rovey				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Charles W Rovey - CoPI	0.00	0.00	2.00	$ 10,652	$	
2.						
3.						
4.						
5.						
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	10,652		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0		
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0		
3. (0) GRADUATE STUDENTS				0		
4. (0) UNDERGRADUATE STUDENTS				0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				10,652		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,237		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				12,889		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				0		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,018		
2. FOREIGN				0		
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				0		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0		
3. CONSULTANT SERVICES				0		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				0		
TOTAL OTHER DIRECT COSTS				0		
H. TOTAL DIRECT COSTS (A THROUGH G)				14,907		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Salaries, Wages and Fringe (Rate: 42.0000, Base: 12889)						
TOTAL INDIRECT COSTS (F&A)				5,413		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				20,320		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 20,320	$	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI/PD NAME Charles W Rovey				FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* William Alter				Date Checked	Date Of Rate Sheet	Initials - ORG

2 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET — Cumulative

ORGANIZATION: Southwest Missouri State University				**FOR NSF USE ONLY** — PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Charles W Rovey				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Charles W Rovey - CoPI	0.00	0.00	4.00	$ 21,095	$	
2.						
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	4.00	21,095		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0		
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0		
3. (0) GRADUATE STUDENTS				0		
4. (0) UNDERGRADUATE STUDENTS				0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				21,095		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				4,430		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				25,525		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				0		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,005		
2. FOREIGN				0		
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS $ 0						
2. TRAVEL 0						
3. SUBSISTENCE 0						
4. OTHER 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				0		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0		
3. CONSULTANT SERVICES				0		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				0		
TOTAL OTHER DIRECT COSTS				0		
H. TOTAL DIRECT COSTS (A THROUGH G)				30,530		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)						
TOTAL INDIRECT COSTS (F&A)				10,720		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				41,250		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 41,250	$	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					

PI/PD NAME: Charles W Rovey	**FOR NSF USE ONLY** — INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*: William Alter	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Year 1

Personnel ($10,4434):

Two months of summer salary are requested for the following tasks: 1)Scouting drilling locations (along with personnel of the Missouri State Geological Survey), as well as new surface exposures, 2)Measuring and sampling sections in new exposures, 3)Logging, collecting and sampling core from drilling sites, and 4)laboratory preparation and analysis of the collected samples. Approximately 5-6 days of work are generally needed to complete the laboratory analyses for each suite of samples. During this year six suites of such samples are anticipated from cores and surface exposures. Thus, the salary request reflects (approximately) two weeks of field work and 6-7 weeks of lab work.

Fringe Benefits ($2193):

Fringe benefits are estimated at 21% of salary.

Travel ($2987):

Field Work:

8 round trips to field area (430 miles/trip)for a total of 3440 miles @ $0.345/mile: $1187.00

Lodging and meals (10 overnights) @ $75.00/day: $ 750.00

Meetings:

GSA meeting (airfare/mileage, registration,lodging & meals) $1050.00

Travel Total: $2987.00

Indirect Costs ($5307):
The university's federal negotiated rate is %42 of salary, wages, & fringe.

Year 2

Personnel ($10,652):

Two months of summer salary are requested (see tasks for Year 1, above) assuming a %2 increase in base salary. For year 2 it is anticipated that field work will require slightly less time, while lab time will be proportionately greater. Fewer drilling sites will need to be selected during this year, and some of the cores can be logged and sampled at the Missouri State Geological Survey's warehouse. However, there should be more deep core to analyze as the survey continues to move its mapping and drilling program eastward to where thick tills are generally preserved.

Fringe Benefits ($2237):

Estimated at %21 of salary.

Travel ($2024):

Field Work:

4 round trips to field area (430 miles/trip) for a total of 1720 miles @$0.345/mile: $593.00

Lodging and meals (5 overnights) @ $75.00/day: $375.00

Meeting:

One GSA meeting: $1050.00

Travel Total: $2018.00

Indirect Costs ($5413)

The university's federally negotiated rate is %42 of of salary, wages, and fringe.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **John Stone**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: Late Quaternary history of Reedy Glacier**

Source of Support: **NSF Office of Polar Programs**

Total Award Amount: $ **371,853** Total Award Period Covered: **06/01/03 - 05/31/06**

Location of Project: **Antarctica, Seattle**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **1.68** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: A proposal for the Cosmic Ray prOduced NUclide Systematics on Earth (CRONUS-EARTH) project**

Source of Support: **NSF Geomorphology and Land Use Dynamics**

Total Award Amount: $ **5,700,000** Total Award Period Covered: **04/01/05 - 03/31/10**

Location of Project: **Seattle, Antarctica**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.18** Sumr: **0.50**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: Chronology of Ice Fluctuations in the South Shetland Islands Since the Last Glacial Maximum**

Source of Support: **NSF Office of Polar Programs**

Total Award Amount: $ **83,863** Total Award Period Covered: **06/01/04 - 05/31/06**

Location of Project: **Seattle**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.09** Sumr: **0.50**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: Grounding-line Retreat In the Southern Ross Sea - Constraints from Scott Glacier**

Source of Support: **NSF Office of Polar Programs**

Total Award Amount: $ **365,044** Total Award Period Covered: **07/01/06 - 06/30/09**

Location of Project: **Antarctica, Seattle**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **1.09** Sumr: **0.50**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: The Last Millennium of Eruptive Activity on Mauna Loa, Hawaii**

Source of Support: **NSF Petrology and Geochemistry**

Total Award Amount: $ **45,127** Total Award Period Covered: **01/01/06 - 12/31/07**

Location of Project: **Seattle, Hawaii**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.18** Summ: **0.50**

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **John Stone**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Collaborative Research: An Absolute Chronology for the Southernmost Advances of the Laurentide Ice Sheet (this proposal)**
Source of Support: **NSF Geomorphology and Land Use Dynamics**
Total Award Amount: $ **99,332** Total Award Period Covered: **02/01/06 - 01/31/08**
Location of Project: **Missouri, Seattle**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.09** Sumr: **0.25**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Greg Balco**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Postdoctoral Research: Cosmogenic-Nuclide Geochronology of Glaciated Surfaces in the Upper Dry Valleys**

Source of Support: **NSF Office of Polar Programs**
Total Award Amount: $ **108,840** Total Award Period Covered: **07/15/05 - 06/30/07**
Location of Project: **Antarctica, Seattle**
Person-Months Per Year Committed to the Project. Cal: **8.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Charles Rovey**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Riverbluff Cave - Connecting Research with Education**

Source of Support: **NSF**

Total Award Amount: $ **2,699,811** Total Award Period Covered: **01/01/06 - 01/01/11**

Location of Project: **Greene County, Missouri**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.90** Sumr: **1.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Weaubleau Impact Structure**

Source of Support: **NSF**

Total Award Amount: $ **5,274** Total Award Period Covered: **01/01/06 - 12/31/07**

Location of Project: **St. Clair Co., Missouri**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.25**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Facilities, Equipment and Other Resources

1. Laboratory:

1.1 Samples for cosmogenic nuclide analysis will be prepared in dedicated chemistry labs at The University of Washington. The labs provide all necessary equipment and facilities for sample preparation, from leaching and dissolution of quartz through to loading of accelerator cathodes. Blank Be problems encountered during 2002-03 were traced to Be-10 contamination of Al metal cathodes, most likely due to the presence of meteoric ^{10}Be in bauxite ores from which the Al was refined (Middleton et al., 1990). Since replacing Al cathodes with stainless steel, all procedural blanks run with UW beryl carrier have given ^{10}Be/^{9}Be ratios $< 10^{-15}$ ($< 2 \times 10^{4}$ atom ^{10}Be).

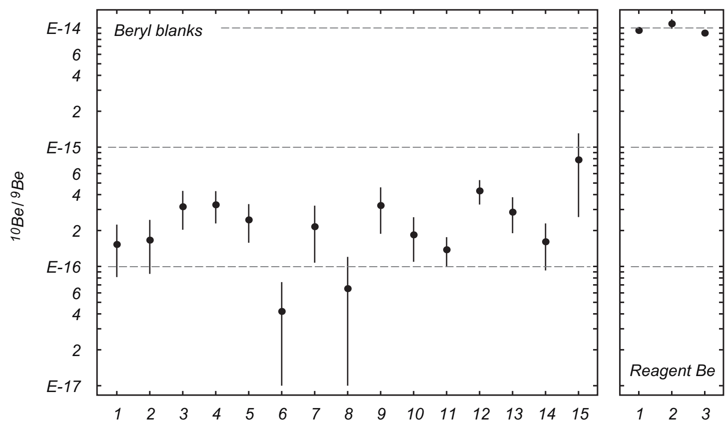

Fig. H1: UW Cosmogenic Nuclide Lab ^{10}Be procedural blanks, 2004-05

2. Computer facilities:

2.1 Cosmogenic isotope data reduction and interpretation will be carried out using programs written at UW in Mathematica and MATLAB. Results of this study will be made available via the UW Cosmogenic Isotope Lab web site (http://depts.washington.edu/cosmolab/data.html).

3. Major Equipment:

3.1 FN tandem accelerators at PRIME Lab and LLNL-CAMS, for ^{26}Al and ^{10}Be analyses, as described above.

4. Other Resources:

4.1 UW Quaternary Research Center, Glaciology research group and Program on Climate Change. UW supports cross-disciplinary programs dedicated to the study of Earth-surface systems, history and processes. These bring together a large number of researchers with interests and expertise in glaciology, glacial geology, ice-core research, atmospheric and oceanic climate-change research, remote sensing and related fields. This project will be carried out in an active, multi-disciplinary environment.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory: **Lithologic analysis of the glacial tills will be completed at the Southwest Missouri State University Sediment Analysis Laboratory. Standard analyses for texture, sand-fraction lithology, and clay mineralogy uniquely identify each till in northern Missouri. Therefore, these**

Clinical:

Animal:

Computer:

Office:

Other:

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

Scintag X-ray diffraction unit: This unit is housed in the Sediment Analysis Laboratory at Southwest Missouri State University. This unit will be used to measure the clay-mineral compositions of the tills at each location.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

Molspin GS-1 magnetometer and associated a.f. and thermal demagnetization equipment: This equipment is housed at paleomagnetic laboratory, University of Wisconsin-Milwaukee, under the direction of Dr. W.F. Kean. This lab has provided magnetic measurements of glacial sediment to the P.I. for the past 12 years (contract basis). Dr. Kean has affirmed his willingness to continue this support.

LABORATORY FACILITIES (continued):

lithologic analyses will be completed to confirm assignments to respective lithostratigraphic units and to help assess the development/preservation of paleosols developed atop each till.

The analyses for texture and sand-fraction lithology can be completed with just basic lab equipment (e.g. sieves, hydrometer jars, binocular microscopes)and materials already stocked in the Sediment Analysis Laboratory. The clay mineral analyses will be completed with a Scintag X-ray diffraction unit, also housed in the same laboratory.

July 12, 2005

Mr. Greg Balco
Quaternary Research Center
University of Washington – Box 351310
Seattle, WA 98195–1301

Dear Mr. Balco:

The Geological Survey and Resource Assessment Division (GSRAD) of the Missouri Department of Natural Resources (MDNR) has been the principal investigator of the state's geology for more than 150 years. The agency welcomes and encourages the geologic research performed by interested faculty of the state's universities.

GSRAD is currently mapping surficial materials and bedrock deposits in the glaciated regions north of the Missouri River with support from the United States Geological Survey's STATEMAP component of the National Cooperative Mapping Program. The Missouri Department of Transportation, and the MDNR Soil and Water Conservation Program are also partners in this work. The surficial materials mapping portion of the project includes a boring program that has produced a sizeable collection of cores. Half of the core is consumed in analyses of the physical characteristics of the surficial material, and the unused portion is available for use by the research community. Over the last several years we have appreciated Dr. Rovey's participation in this project and look forward to his continued involvement.

The timing of glaciation in the midcontinent has been a subject of some controversy for many years. Cosmogenic-Isotope dating is a technique that has proved useful in dating the time at which sediments are buried below the depth penetrated by cosmogenic rays. Dr. Rovey intends to use this technique to date the age of burial of paleosols encountered in one of our drill core from central Missouri. Results of Dr. Rovey's research will further our understanding of the state's glacial history and complement our mapping in this region of the state.

As such, GSRAD recommends that the National Science Foundation approve and support Dr. Rovey's request for funding to utilize cosmogenic-isotope dating in his research.

Sincerely,

GEOLOGICAL SURVEY & RESOURCE ASSESSMENT DIVISION

Mimi R. Garstang, RG
Director and State Geologist
Director's Office - Administration Program
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