AMQUA 2014

American Quaternary Association

23rd Biennial Meeting, 2014

Program and Abstracts

People and Processes in Quaternary Pacific Northwest

Hosted by the Quaternary Research Center,
University of Washington

UW Husky Union Building (HUB),
Seattle, Washington
August 7-10, 2014

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AMQUA 2014, 23rd Biennial Meeting

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Field Trips

<u>Pre-meeting field trip 1</u>: Glacial history of Whidbey Island and the Ledgewood Beach landslide site
Leader: Terry Swanson, University of Washington

<u>Post-meeting field trip 1</u>: Mt. St. Helens and Mima Mounds Tour
Leader: Ronald Sletten, University of Washington

<u>Post-meeting field trip 2</u>: Hazardous Seattle
Co-leaders: Brian Atwater, US Geological Survey
Kathy Troost, GeoMapNW; University of Washington

Program
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People and Processes in Quaternary Pacific Northwest

Thursday, August 7

7:00a – 5:00p **Pre-meeting Field Trip 1** **Whidbey Island**
Leader: Terry Swanson
Meet at the Johnson Circle, a traffic circle besides the Johnson Hall and Gerberding Hall, University of Washington campus.

5:00 – 8:00p **Registration / Opening Mixer at the University of Washington Club**

Friday, August 8

8:30 – 9:00a **Welcome and Opening Remarks** *HUB, South Ballroom*

9:00 – 10:30a **Plenary Session 1: Ice Sheets, Sea Level, and Landscape Change**
John Clague, The misuse of radiocarbon ages in late Quaternary chronologies.
Nancy Bigelow, Late glacial and Holocene landscape change in eastern Beringia--what people encountered.

Pop ups for Poster Session 1 (30 minutes)

10:30 – 11:00a **Poster Session 1 / Coffee** *HUB, South Ballroom*

11:00a – 12:00p **Plenary Session 2: Sedimentary Records in Coastal Waters**
Karl Wegmann et al., How important is seismically induced erosion above the Cascadia subduction zone? Insights from the stratigraphy of large lakes on the Olympic Peninsula, Washington State.
Audrey Dallimore, Tales from Effingham; What we know about the Pacific Northwest coastal ocean, climate, tectonics and ecosystems from the past decades of work in Effingham Inlet, B.C., Canada.

12:00 – 1:30p **Lunch**

Friday, August 8

12:15 – 1:30p **AMQUA Council Meeting** *Johnson Hall, Room 170*

12:00 – 1:30p **USNC / INQUA Business Meeting** *Johnson Hall, Room 377A*

1:30 – 3:00p **Plenary Session 3: Tsunamis and Floods** *HUB, South Ballroom*

Lisa Ely et al., Geological and historical records of tsunamis: Examples from south-central Chile.

Jim O'Connor, Does the river give a dam? — Quaternary outburst floods, causes, and consequences in the U.S. Pacific Northwest.

Pop ups for Poster Session 2 (30 minutes)

3:00 – 3:30p **Poster Session 2 / Coffee** *HUB, South Ballroom*

3:30 – 4:30p **Plenary Session 4: Volcanoes** *HUB, South Ballroom*

Richard Waitt, Witnesses tell of Mount St. Helens' 1980 eruption.

Britanny Brand, Pyroclastic density currents from the May 18th, 1980 eruption of Mount St. Helens – The story retold.

4:30 – 5:30p **Posters** *HUB, South Ballroom*

6:00 – 9:00p **Reception at the Burke Museum**

Saturday, August 9

8:30 – 9:00a **Welcome Coffee** *HUB, South Ballroom*

9:00 – 10:30a **Plenary Session 5: Earliest Peoples of Western North Amercia**

Dennis Jenkins, Archaeological science at the Paisley Caves in south central Oregon.

Charlotte Beck and Tom Jones, What they did after they got there: Life during the terminal Pleistocene in the intermountain west.

Pop ups for Poster Session 3 (30 minutes)

10:30 – 11:00a **Poster Session 3 / Coffee** *HUB, South Ballroom*

11:00a – 12:00p **Plenary Session 6: Quaternary Vertebrates**

Michael Wilson, Pacific Northwest North American fossil vertebrates, paleoenvironments, and opportunities for human migration with last glacial advance and retreat.

Duane Froese et al., Bison dispersal from Beringia into North America via the ice-free corridor.

12:00 – 3:00p **Lunch**

Saturday, August 9

12:30 – 2:00p	**Mentoring Event for Early Career Scientists**	*Johnson Hall, Room 170*
2:00 – 3:00p	**AMQUA Awards & Business Meeting**	*HUB, South Ballroom; Johnson Hall, Room 377A*
3:00 – 4:30p	**Plenary Session 7: Paleoecology and Ancient DNA** David Meltzer and Eske Willerslev, Genetics, archaeology and the Pleistocene peopling of North America. Elizabeth Alter, Using ancient DNA to infer population responses of Arctic whales to climatic changes in the Holocene. *Pop ups for Poster Session 4 (30 minutes)*	
4:30 – 5:30p	**Poster Session 4**	*HUB, South Ballroom*
6:00 – 9:00p	**Closing Banquet at the Hotel Deca**	*Grand Ballroom*

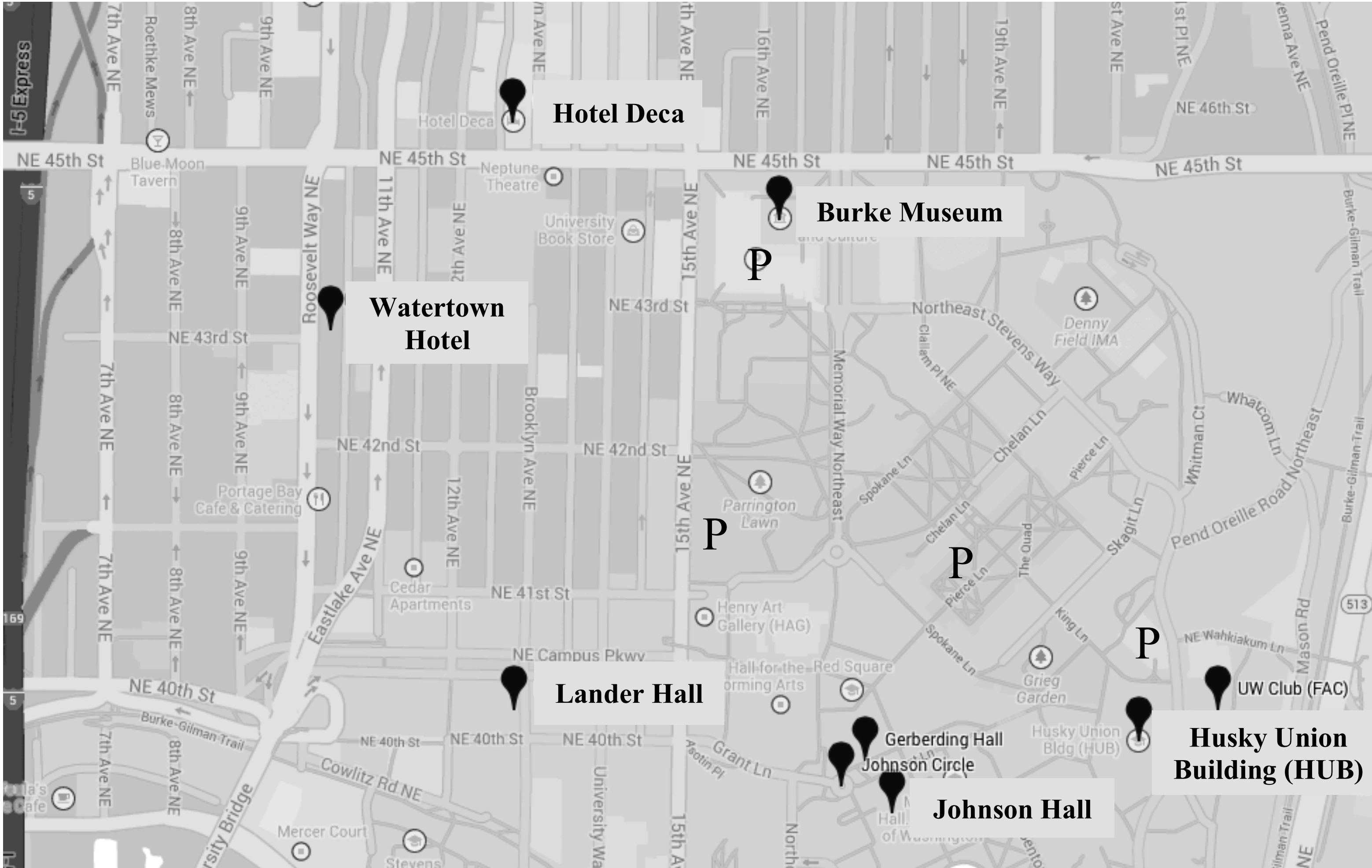
Sunday, August 10

7:00a – 6:30p	**Post-meeting Field Trip 1** Leader: Ron Sletten Meet at the Johnson Circle, outside of the Johnson Hall, University of Washington Seattle campus.	**Mt. St. Helens / Mima Mounds**
8:00a – 5:00p	**Post-meeting Field Trip 2** Co-leaders: Brian Atwater and Kathy Troost Meet at the Johnson Circle, outside of the Johnson Hall, University of Washington Seattle campus.	**Hazardous Seattle**

Parking and Bus

Getting around the town and UW campus is not hard. Bus routes run through the campus, for example #67, and a map is available at http://metro.kingcounty.gov/schedules/066/map.html

Parking may be available at your hotel. Please inquire with your hotel about on-site parking. Daily parking permits can be purchased at the campus gates for $15 (6am-5pm, Monday-Friday), and Night permits for $5. Central Parking Garage charges a non-refundable $10 event rate, but other parking lots near Burke Museum or HUB don't charge that fee. Please find details at http://www.washington.edu/facilities/transportation/commuterservices/parking


Hotel Deca
Burke Museum
Watertown Hotel
Lander Hall
Gerberding Hall
Johnson Circle
Johnson Hall
UW Club (FAC)
Husky Union Building (HUB)
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Eastlake Ave NE
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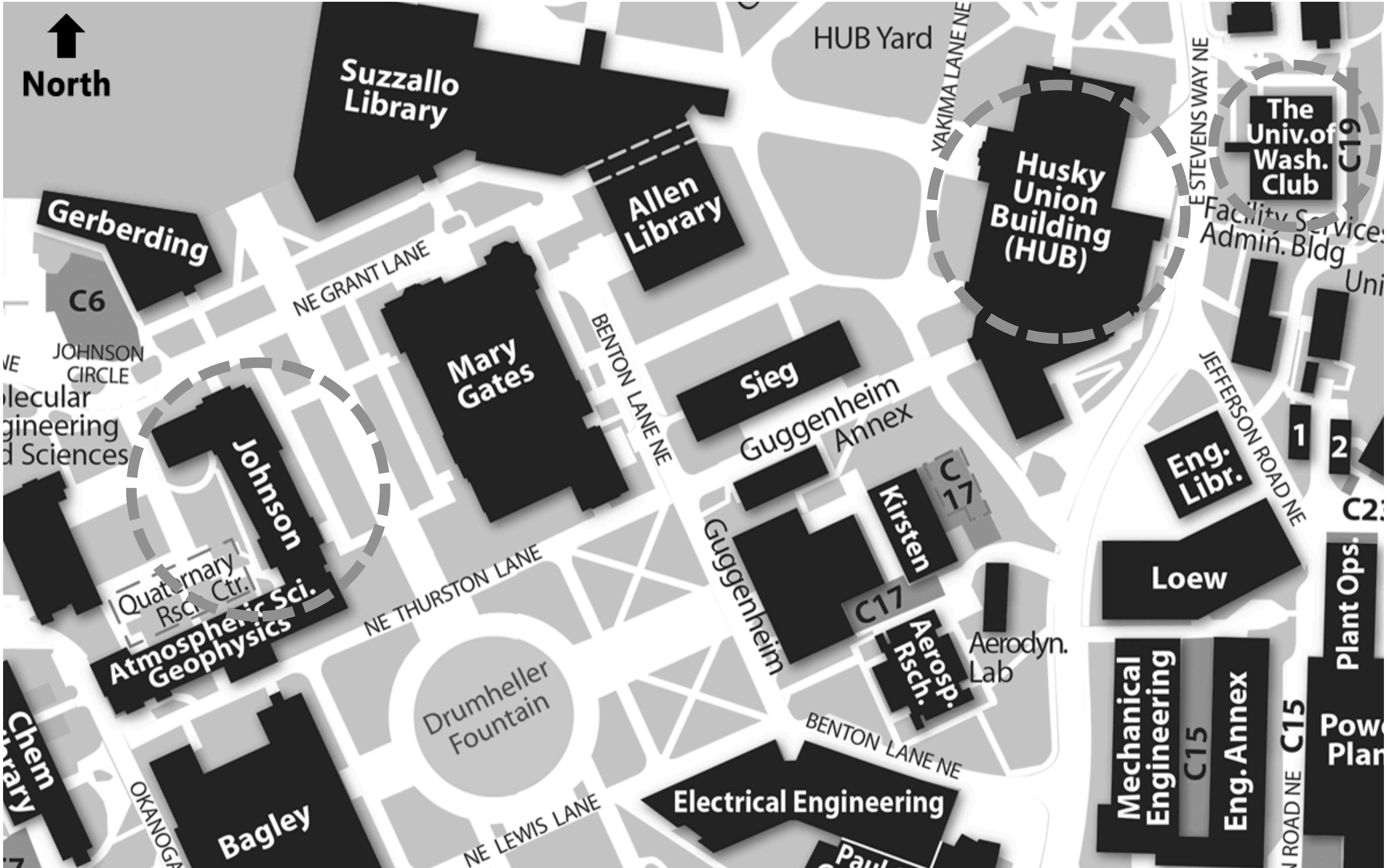
Brooklyn Ave NE
15th Ave NE
7th Ave NE
8th Ave NE
9th Ave NE
16th Ave NE
19th Ave NE
Memorial Way Northeast
Northeast Stevens Way
Pend Oreille Road Northeast
Mason Rd
Burke-Gilman Trail
Cowlitz Rd NE
I-5 Express
Red Square
The Quad
Parrington Lawn
Henry Art Gallery (HAG)
University Book Store
Neptune Theatre
Blue Moon Tavern
Portage Bay Cafe & Catering
Cedar Apartments
Mercer Court
Denny Field IMA
Grieg Garden
Husky Union Bldg (HUB)



North
Suzzallo Library
Allen Library
HUB Yard
YAKIMA LANE NE
Husky Union Building (HUB)
E STEVENS WAY NE
The Univ.of Wash. Club
C19
Admin. Bldg
Gerberding
C6
JOHNSON CIRCLE
NE GRANT LANE
Mary Gates
BENTON LANE NE
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Guggenheim Annex
Johnson
Quaternary Rsch. Ctr.
Atmospheric Sci. Geophysics
NE THURSTON LANE
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Aerodyn. Lab
Eng. Libr.
JEFFERSON ROAD NE
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Loew
Plant Ops.
Drumheller Fountain
BENTON LANE NE
Electrical Engineering
NE LEWIS LANE
Bagley
Mechanical Engineering
C15
Eng. Annex
C15

Abstracts of Invited Plenary Presentations

USING ANCIENT DNA TO INFER POPULATION RESPONSES OF ARCTIC WHALES TO CLIMATIC CHANGES IN THE HOLOCENE

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Changes in sea ice and sea level over the Holocene dramatically impacted both habitat and dispersal routes for many species of marine mammals. We examined ancient DNA from gray whales and bowhead whales, two species of baleen whale that utilize Arctic and sub-Arctic habitats. The Atlantic gray whale represents the only known recent extinction of a great whale species or population from an ocean basin, but very little is known about its demographic history or its relationship to the extant Pacific populations. Our results show that the Pleistocene population in the Atlantic persisted through the last glacial maximum to the Holocene. Migrations between the Pacific and the Atlantic Ocean were climate-dependent, and occurred both during the Pleistocene prior to the last glacial period, and during the early Holocene immediately following the opening of the Bering Strait. We observe a decline in genetic diversity in the Atlantic gray whale population over an extended interval beginning in the mid-Holocene, perhaps precipitated by climatic or ecological causes. These results contrast with findings for bowhead whales, which show a high level of gene flow between Atlantic and Pacific stocks in the recent past. Unexpectedly, samples from the central Canadian Arctic show a much closer genetic relationship with modern Pacific stocks than with modern Atlantic stocks, supporting high gene flow between the central Canadian Arctic and the Beaufort Sea over the past millennium despite extremely heavy ice cover over much of this period. These results indicate that gray and bowhead whales responded differently to climatic changes in the Holocene, highlighting how complex ecologies in these species shape their response to climate.

WHAT THEY DID AFTER THEY GOT THERE: LIFE DURING THE TERMINAL PLEISTOCENE IN THE INTERMOUNTAIN WEST

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Hamilton College, 198 College Hill Road, Clinton, NY 13323

In spite of the fact that the colonization of the Americas has been debated for over 100 years, it is only recently that the complexities of this process are being realized. While in the mid-1980s most accepted the Ice Free Corridor as the route of entry, today there are suggestions of multiple routes and, possibly, multiple migrations. For instance, there is strong circumstantial evidence of human migration along the Pacific coast and then expansion into the interior along major river corridors. One such corridor—the Columbia River Basin—likely provided entry into the Columbia Plateau, Snake River Plain, and Great Basin, referred to here as the Intermountain Region (Fig. 1). There is also some suggestion of early colonization along the Gulf coast. And of course there is a modest amount of support for an Atlantic crossing and entry along the east coast of North America. These multiple possibilities together with an increasing number of credible pre-Clovis sites has prompted a revision of the Clovis-first hypothesis from 'Clovis was the first on the continent' to Clovis was the "first to colonize large swaths of the continent" (Waguespack 2007:72). Even this revised hypothesis, however, may be in jeopardy.

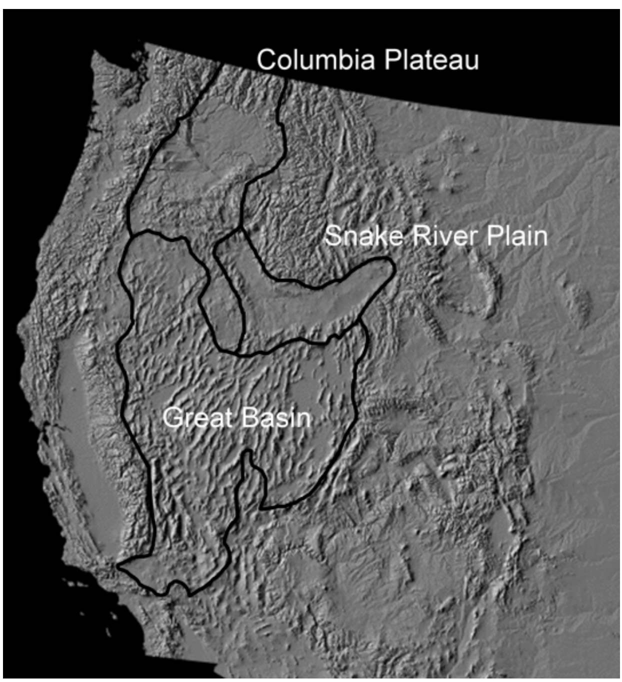

Figure 1. The intermountain region (from Beck and Jones 2013).

A few years ago we revisited a hypothesis first proposed by Alan Bryan in the late 1970s (Bryan 1979, 1980) that the region west of the Rocky Mountains was colonized by people migrating down the Pacific coast who utilized a technology ancestral to the earliest technology of that region, known as the Western Stemmed Tradition (WST) (Fig. 2). In fact, we argued that when Clovis migrants entered the Intermountain West, people utilizing this technology were already there, and thus Clovis and WST were at least contemporaneous (Beck and Jones 2010). But as dates from the Paisley Caves in Oregon indicate, there was a human presence there by ca. 12,000 yr BP (Gilbert et al. 2008), likely the ancestors of those interior folks of the WST.

We have argued that Clovis migrants crossed the mountains from the northern Plains onto the Snake River Plain and primarily migrated northwestward as evidenced by the Fenn, Simon, and East Wenatchee Clovis caches (Beck and Jones 2010, 2013). Although there certainly is evidence of Clovis to the south, most Clovis sites discovered to date lie to the north. Clovis, when viewed from a continental perspective, is argued by some to have been fairly broad in spectrum (e.g., Cannon and Meltzer 2004, 2008), but on the Plains big game appears to have played a more significant role, and thus it may have been in pursuing bison that Clovis migrants crossed the mountains onto the Snake River Plain. WST populations, on the other hand, were not big game hunters, but primarily 'little game hunters'. Their focus was largely on wetlands where they relied on birds, small mammals, and plants, although there was a component of large game – deer, antelope – in their diet. Even though their subsistence strategies were quite different, Clovis and WST populations visited the same places, evidenced by the occurrence of both technologies at many localities.

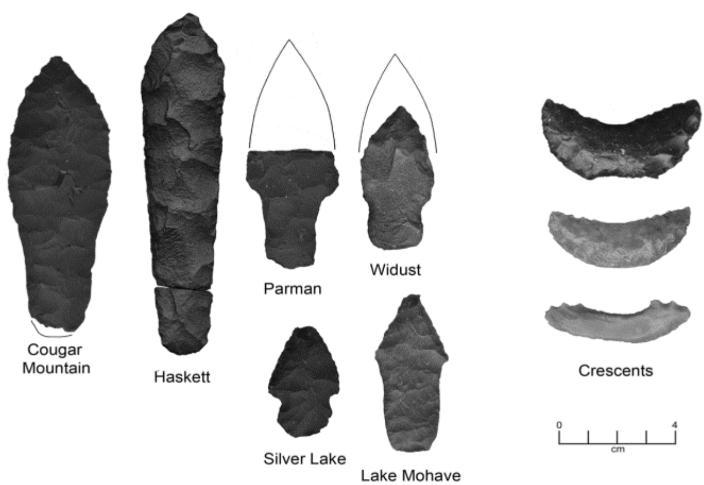

Figure 2. Projectile points and crescents of the western stemmed tradition.

The nature of the interaction between these two populations, however, is not easily investigated because the archaeological record of this region, especially the Great Basin, is on the surface, preserving only stone artifacts. Therefore, after an initial discussion outlining the background concerning Clovis and WST, we spend much of our discussion on the latter, for which there are several lines of evidence of people adjusting to Younger Dryas landscapes. Among these are land use patterns, the components of technology, as well as the meager subsistence record from a small number of excavated deposits. An important component of WST land use patterns, for example, is the association of WST artifacts and pluvial landforms left by the recession of terminal Pleisocene lakes, which has been noted repeatedly across the Great Basin. This association was first observed during the 1930s in the Mojave Desert by a team of geologists and archaeologists (Campbell et al. 1937)—geologists studying the physical features of extinct pluvial lakes, archaeologists recording the artifacts associated with those features. To the north in the Snake River Plain and Columbia Plateau the association is more often between artifacts and riverine environments, which also occurs to the south.

It is not only the location of these sites near wetlands, but their nature that give insight into Younger Dryas society in this region. If these people were operating in small groups and quite mobile in their pursuit of subsistence resources, we should expect to find many small sites situated on late Pleistocene landforms near valley bottoms. As in the case of the Mojave Desert record, this is precisely what we find in valleys that sustained Younger Dryas-age lakes or wetlands. Moreover, as we learn more about the distribution of geologic sources of stone tool materials, we see that items in WST toolkits were transported over great distances, often hundreds of kilometers. Although archaeologists are not satisfied that they can isolate the precise mechanisms of material conveyance and just how much of these exotic materials are products of exchanges between neighboring groups, the evidence points to substantial distances traversed by these groups.

But the record is not exclusively that seemingly created by small, mobile groups. In fact, there are Younger Dryas-age sites of extraordinary size, covering several-to-hundreds of hectares. Certainly the sizes of these sites imply complex use histories—repeated visits over centuries. They tend to lie where an amenity—usually a perennial stream—persisted for a very long time. The sizable assemblages of artifacts at these sites typically contain the most diverse set of tools, among which are a small number of formal tools made from rare and distant sources of toolstone. Such sites may represent aggregation sites where groups from neighboring economic/social territories gathered for activities we can only guess about, but which surely included social activities that sustained the viability of the small biological units.

Here we discuss this pattern of site-environmental feature association in detail, an association that ended quite soon after the Younger Dryas in many Great Basin valleys and soon after the first millennium of the early Holocene as lowland wetlands desiccated. Its disappearance was accompanied by changes in the nature and scale of mobility as well as changes in technology and, presumably, subsistence strategies.

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LATE GLACIAL AND HOLOCENE LANDSCAPE CHANGE IN EASTERN BERINGIA--WHAT PEOPLE ENCOUNTERED

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Recent DNA analyses of both living humans and skeletal remains have sparked renewed interest in the timing and location of human migration into the new world (c.f. Tamm et al. 2007; Raff and Bolnick 2014; Hoffecker et al. 2014. This paper focuses on three aspects of the DNA results: a) If people paused on the Bering Land Bridge (BLB) prior to travelling further into North America, what sort of landscape would they have encountered? b) How viable is the coastal migration hypothesis? c) What did people encounter in interior Alaska and how soon could they have migrated through Canada using the interior route?

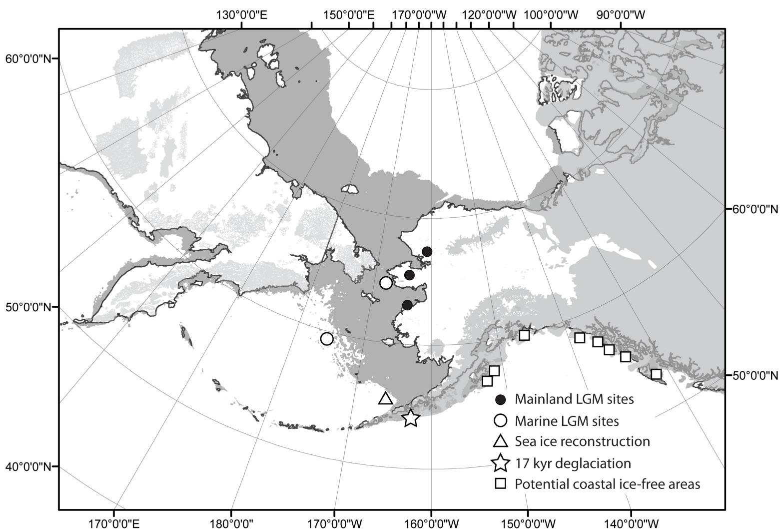

Figure 1. Map of Beringia showing the 100 m bathymetric contour (dark shading), LGM ice extent (light shading) and sites mentioned in the text

The Beringian stand-still hypothesis suggests that people paused on the BLB for several thousand years before travelling further into North America (Tamm et al. 2007). During the Last Glacial Maximum (LGM), when sea level was lowered by about 120 m, the BLB was a continental-sized landmass stretching between about 55°N and 75°N (Figure 1). Paleoecological data present somewhat contradictory landscape reconstructions, but they are interpretable if site location is taken into account. Pollen and macrofossil records from what is coastal Alaska today (Seward Peninsula, St. Michael's Island, lower Kobuk River valley) indicate a herbaceous tundra with a few willow shrubs in the protected areas. During the LGM, these sites would have been 800 to 1000 km from the ocean and in some cases more than 400 m above sea level. In contrast, analyses on terrestrial sediments preserved in marine cores from the BLB suggests the vegetation was a good deal more mesic and shrubbier than implied in the records from the Alaska mainland. In addition, pollen analyses on marine sediments from just south of the BLB suggest the continued presence of shrubs (and possibly trees) during the LGM. Circumstantial data indicate that woody taxa may have been reproducing vegetatively during the LGM and leaving only a small trace in the pollen records. Taken together, these data suggest that during the LGM, the BLB was more mesic with a woodier vegetation than the adjacent Alaska mainland. However, there is also evidence that the Bering Sea south of the BLB may have been ice covered for much of the year. If this is the case, then it is possible that the southern margin of the BLB may have been somewhat inhospitable, though inland areas could have been warmer (at least in summer time), similar to the climate patterns seen on Ellesmere Island today.

The coastal migration hypothesis has been around for decades, but it wasn't until more accurate glacial reconstructions (as well as the likelihood that the southern Alaska Peninsula could have been deglaciated by about 17,000 cal yr BP [Figure 1]) and the discovery of LGM and early postglacial-aged paleontological remains from southeastern Alaska that the idea gained credence. Aerial reconstructions of ice front limits, combined with a lowered sea level, revealed large ice-free areas along southeast Alaska and the Queen Charlotte Islands (Figure 1). Excavations in caves in the Alexander Archipelago revealed the presence of bears, foxes, caribou and ringed seal during the LGM and early postglacial. Pollen records indicate the rapid expansion of pine trees about 14,000 cal yr BP, implying that pines were probably already present, but not producing pollen. This, together with extensive DNA data suggesting the isolation of numerous taxa in the region, indicates the presence of cryptic refugia that would have had suitable resources for people to exploit. While coastal migration is still hypothetical, the data do suggest that it was indeed a possible migration route.

In interior Alaska, LGM climate was harsh and arid. Vegetation reconstructions indicate a sparse herbaceous tundra with only scattered woody vegetation. Most lakes in interior Alaska were dry during the LGM, only the deepest survived. Amelioration (marked by more abundant vegetation and shrub expansion) and increasing moisture (marked by lake level rise) began somewhat before 14,000 cal yr BP, which, coincidentally or not, is about the same age as the oldest archaeological sites. Current research suggests that a narrow and proglacial lake-choked ice-free corridor was present by about 14,000 cal yr BP (Dyke 2004). It is unlikely that people would have used the corridor at this early date because resources would have been limited and this would have been at the time of ameliorating climate in the interior.

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PYROCLASTIC DENSITY CURRENTS FROM THE MAY 18TH, 1980 ERUPTION OF MOUNT ST. HELENS – THE STORY RETOLD

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Pyroclastic density currents (PDCs) are one of the most dangerous phenomenon associated with explosive volcanism. However, processes such as density segregation, the effect of channelization and interaction with topography, and the controls and consequences of substrate erosion remain poorly understood. The May 18th, 1980 eruption of Mount St Helens (MSH) is one of the best studied explosive volcanic eruptions within the past 100 years. Visual observations and estimates of mass flux, detailed measurements of recently exposed strata, and multiphase numerical modeling are combined to better constrain the dynamics of the voluminous PDCs produced through the afternoon of the May 18th eruption. Four primary flow units are identified along the extensive drainage system north of the volcano. The PDCs associated with Units I and II likely occurred during the pre-climactic, waxing phase of the eruption. These currents flowed around and filled in the hummocky topography left behind by the earlier debris avalanche, leaving the massive to diffusely stratified deposits of Units I and II. The deposits of both Units I and II are generally massive in low lying areas and stratified in areas of high surface roughness, suggesting that surface roughness enhanced basal shear stress within the flow boundary. Units III and IV are associated with the climactic phase of the eruption, which produced the most voluminous and wide-spread PDCs. Both flow units are characteristically massive and enriched in vent-derived lithic blocks. However, an increase in the proportion and size of lithic blocks is found (1) downstream of debris avalanche hummocks, suggesting the PDCs flowed over and around debris avalanche hummocks and were energetic enough to locally entrain accidental lithics from the hummocks and transport them tens of meters downstream, and (2) within large channels cut by later PDCs into earlier PDC deposits, suggesting self-channelization of the flows increased the carrying capacity of the subsequent channelized currents. Increasing the bulk density of a PDC due to substrate erosion and flow channelization could significantly increase runout distance. These findings are being tested with experiments and will ultimately be incorporated into numerical models. The results of this work will advance our knowledge and ability to assess the hazards related to PDCs in similarly explosive eruptions elsewhere, including the primary controls on runout distance, effects of topographic obstacles, and quantification of fine ash produced during lateral transport, which has significant relevance aviation hazard assessment and potential climactic effects.

THE MISUSE OF RADIOCARBON AGES IN LATE QUATERNARY CHRONOLOGIES

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Radiocarbon age dating is the most widely used method for establishing chronologies of Earth events ranging in age from the prehistoric period back to about 40,000 years ago. Important stages in the development of the technique, following its introduction to the archeological and earth science communities by Willard Libby in 1949, include recognition of differences in the $^{14}C/^{12}C$ ratio in different parts of the carbon exchange reservoir; calibration of radiocarbon ages using tree rings and corals; and the introduction of the accelerator mass spectrometry (AMS) technique, allowing dating of carbon-bearing samples as small as 10 μg. However, the scientific literature continues to be burdened with radiocarbon ages that do not accurately reflect the age of reported events, slowing progress in geology, geography, and archeology. This problem has many dimensions; here I report ten sources of possible error. First, researchers might incorrectly interpret depositional environments of sediments. Second, samples might be contaminated with younger carbon that is not easily removed through pretreatment, and the contamination may not be obvious. Third, some organisms, notably aquatic mosses and mollusks, incorporate carbon that in not in equilibrium with the atmosphere while alive, resulting in ages that are too old. Fourth, scientists commonly assume that dated fossils record the age of the sediment from which they were collected. Radiocarbon ages on fossils that are not in growth position should only be considered maxima for the age of the sediment in which they lie, due to the possibility of reworking and re-deposition. Fifth, and related to the preceding point, wood or bark fragments sourced from a tree that lived for hundreds of years, may have been dead and undergoing isotopic decay long before the tree itself died. Sixth, age inferences in the literature are commonly based on only a few, in extreme cases only one, radiocarbon age. Due to the above-mentioned issues, such inferences should be viewed with skepticism; chronologies should preferably be based on a large number of ages. Seventh, a researcher may calculate calibrated ages based on 1-sigma radiocarbon age ranges (the standard reported by laboratories), and with only 1-sigma calibration age ranges. There is approximately a 50 percent chance that the true age of these samples is outside the reported calibrated age range. Eighth, the range of a calibrated age must be reported, not simply the median or mean of the range. Calibrated age distributions are non-Gaussian, thus means and medians are statistically invalid. Ninth, radiocarbon ages, and their calibrated counterparts, are commonly reported in the literature with false precision. And tenth, finite ages older than about 35,000 years should be viewed with caution. The amount of ratio of ^{14}C to ^{12}C in samples that are 35,000 years old is about 1%, approaching laboratory background values. A very small amount of modern carbon contamination, especially for samples of milligram size, can make a sample that is, for the sake of argument, millions of years old appear to be 35,000 years old. Multiple ages are required for dating strata that are a few tens of thousands of years old.

TALES FROM EFFINGHAM: WHAT WE KNOW ABOUT THE PACIFIC NORTHWEST COASTAL OCEAN, CLIMATE, TECTONICS AND ECOSYSTEMS FROM THE PAST DECADES OF WORK IN EFFINGHAM INLET, B.C., CANADA

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The annually laminated sediments preserved in anoxic, glacially carved fjords of the British Columbia coastline (locally known as inlets) have proved to be valuable high resolution records of the local paleoenvironmental history of the Holocene and Late Pleistocene (Dallimore and Jmieff 2010). Two international drill ship expeditions investigated British Columbia anoxic inlets: Saanich Inlet near Victoria B.C. (Fig. 1) in 1996, ODP Leg 169S (Bornhold et al. 1998), and then anoxic Effingham Inlet, B.C. in the 2002 Marges Ouest Nord Américaines (MONA) campaign (Beaufort 2002). The high number of radiocarbon dates measured from these cores spanning the Holocene and Late Pleistocene, combined with the annually laminated sediments and the presence of the Mazama Ash which are preserved in both Saanich and Effingham Inlets, have enabled the calibration of high resolution age models, which can then be applied to paleoseismic event chronology in the seismically active B.C. coast area (Enkin et al., 2013).

These comprehensive expeditions have produced well-dated, highly detailed paleoenvironmental records for the south coast of British Columbia of the nature of sedimentary deposition in anoxic inlets (see Marine Geology Special Issue 174 for complete results of ODP Leg 169S in Saanich Inlet, BC) Blais-Stevens et al. 2001; Dallimore et al. 2005); deglacial history (Cowan 2001; Mosher and Moran 2001, Dallimore et al. 2008, Ivanochko et al. 2008a), paleoproductivity (Dean et al. 2001; McQuoid and Hobson 1997, 2001; Patterson et al. 2000; Hay et al. 2003; Chang et al. 2003, 2013); paleo-fish populations (Tunnicliffe et al. 2001; O'Connell and Tunnicliffe 2001; Wright et al. 2005) ; paleoclimate (Pellat et al. 2001; Chang and Patterson 2005; Dallimore et al. 2005; Hay et al. 2007, 2009; Ivanochko 2008b) and paleoseismic events (Blais-Stevens et al. 1997, 2009; Dallimore et al. 2008; Thomson et al. 2013).

In Effingham Inlet, modern analogue climatic, oceanographic and sedimentary data (Patterson et al. 2000; Hay et al. 2003; Dallimore et al. 2005; Chang et al. 2013) have been compared to down-core multi-proxy data, leading to a robust interpretation of the method of deposition of the lithofacies found in Effingham Inlet sediments. These studies show that the variability in preservation and deposition of biogenic laminae and biogenic re-mixed sediments which we term homogenties (Dallimore et al. 2005; Hay et al. 2007, 2009) archive the abrupt crossing of depositional thresholds that are related to climate and oceanographic changes (Chang and Patterson 2005; Change et al. 2013; Hay et al. 2009; Dallimore et al. 2005; Ivanochko et al. 2008a, b), as well as de-glacial processes and sea level changes in the inlet (Dallimore et al. 2008, Ivanochko et al. 2008a).

In addition, non-biogenic unlaminated lithofacies are also found in Effingham sediments, which we term seismites and we infer that these are deposited as the result of mass wasting events, many of which are probably initiated by seismic shaking. Modern sediment trap studies in Effingham compared to weather records have shown that homogenites, in contrast to seismite candidates, represent the suspension, re-mixing and re-deposition of laminated sediments in the inlet by incoming density currents, and are therefore indicators of changes in oceanographic and climatic conditions and are not indicative of seismic shaking (Dallimore et al. 2005). Thus, the only other mechanism for deposition of unlaminated non-homogenite units found in Effingham are mass wasting events from the thin soil cover of the inlet bedrock walls, and/or failures of small deltas from several ephemeral streams and the small Effingham River at the head of the inner basin (Dallimore et al. 2005, 2008).

This presentation will summarize the paleoenvironmental research form Effingham, and look to future applications to maximize the research to date. The large team of researchers who have worked in Effingham over the past two decades, look forward to the use Effingham as a Holocene chronological "tie-point" for other paleoenvironmental studies of the northeastern Pacific, use of the now 18 year long oceanographic water properties time series in Effingham (longest on the Canadian Pacific coastline), as a backdrop to future global climate change impacts along the BC coast , and high-resolution comparison to the now published Holocene atmospheric paleo-environmental record from the Mount Logan and Eclipse Icefield Holocene ice core records.

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GEOLOGICAL AND HISTORICAL RECORDS OF TSUNAMIS: EXAMPLES FROM SOUTH-CENTRAL CHILE

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Geological records, written historical documents and archaeological evidence from coastal areas ringing the Pacific Ocean provide complementary information for reconstructing the recurrence, relative magnitude, and geomorphic effects of past earthquakes and tsunamis (Atwater et al., 2005). The relatively frequent, well-documented subduction-zone earthquakes and tsunamis in Chile provide examples of how all of these sources can be utilized together, and thus potentially employed in similar regions of subduction zone earthquakes. Integrated earthquake and tsunami histories such as this can elucidate aspects of subduction-zone behavior during great earthquakes and ultimately improve forecasts of future similar events. Chile holds one of the longest historical records of earthquakes and tsunamis on the Pacific Coast of the Americas, extending back to AD 1570. However, meager and fragmentary records from sparse historical settlements introduce uncertainty into estimates of the relative magnitudes and rupture areas of even the largest past events. Geological investigations of tsunami deposits and seismic land-level changes conducted at several locations in south-central and southern Chile augment the historical record and vice versa.

The rich historical record of earthquakes and tsunamis in south-central Chile (36.5-38.5˚S Lat.) served as a guide in the search for surviving geological evidence of these events at different locations. The historical accounts include those of Charles Darwin and Captain Robert Fitz-Roy during their voyage on the Beagle (Darwin, 1839; Fitz-Roy, 1839). They described the impacts of the severe earthquake and tsunami of February 20, 1835 that devastated the cities of Concepción and Talcahuano, Chile. Their recorded observations comprise one of the earliest scientific studies of co-seismic land-level changes and the geological effects of tsunamis: descriptions of 3 waves up to 23 ft (7 m) high, measurements of up to 9 ft (2.7 m) of land uplift on Santa Maria Island and other sites near Concepción Bay, and descriptions of damage to human settlements. We initially focused field investigations of potential tsunami deposits and earthquake-induced liquefaction on sites described by Darwin and Fitz-Roy in the wake of the 1835 tsunami.

Although the severe effects of the 1835 tsunami are historically well documented, sedimentary deposits at these sites indicate that other tsunamis in the last 500 years were as large and probably even greater. For example, of the nine historically recorded tsunamis in this region, only four were large enough to leave a detectable deposit 1.5 km up the river at our main study site near at Tirúa (38.3° S), most likely in 1575, 1751, 1960 and 2010. The four sand layers display similar thickness, lithology, and lateral extent along the river. This area is strategically located within the region of overlap between the ruptures of two recent great subduction-zone earthquakes in 1960 (M_w 9.5) to the south and 2010 (M_w 8.8) to the north, and is thus positioned to selectively preserve deposits by large tsunamis from both northern and southern sources. The sands deposited by the tsunamis in 1960 and 2010 were among the subset preserved in the 500-year geological record at this intersection of great subduction zone earthquakes, thus substantiating their importance. The sand layer interpreted as the AD 1575 tsunami deposit conformably drapes over at least 20 buried furrows oriented perpendicular to the river. The uniform amplitude (20-30 cm) and spacing (~1.7 m) of the furrows suggest that they are agricultural features created by indigenous farmers. Similar features have been described and dated as early as AD 1200 in this part of Chile (Dillehay et al., 2007).

Changes in the channel morphology, geometry of sand spits and dune ridges at embayments, and coseismic uplift could all affect the accumulation and preservation of the tsunami deposits, in addition to the magnitude and source of the rupture. Our experience in Chile, where geological, historical and archaeological data are available for comparison, points out the value that each type of information contributes to a more complete understanding of subduction zone ruptures and the resulting earthquakes and tsunamis.

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BISON DISPERSAL FROM BERINGIA INTO NORTH AMERICA VIA THE ICE-FREE CORRIDOR

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The concept of an ‘ice free’ or ‘deglacial’ corridor has figured prominently in models of biogeographic exchange between Beringia and continental North America for much of the last century. Geological research during the last two decades has clarified that the Laurentide and Cordilleran ice sheets coalesced during the height of the last glaciation, closing a longstanding pathway between Beringia and interior North America. Despite a greater clarity concerning coalescence, the timing and nature of deglaciation of the Corridor, as well as its biotic habitability, have remained in doubt, limiting a more refined understanding of faunal and human dispersals in terminal Pleistocene North America. Here we make use of one of the more readily available data sources from within the deglaciating Corridor region with a direct bearing on its biotic status: Quaternary vertebrate fossils. Bison are a well-represented species in Pleistocene and early Holocene assemblages in western North America, and previous research has revealed that genetically distinct northern or Beringian as opposed to southern bison clades can be identified through mitochondrial DNA (mtDNA) analyses of the fossils (Shapiro et al., 2004). Radiocarbon dates and mtDNA from more than 40 bison from central Alberta provide a new record of the dynamics of the Late Pleistocene-early Holocene dispersal of bison through the corridor. Vertebrate dates suggest that horse and bison from the south first occupied the corridor, but northerly bison quickly met these populations just prior to 13,000 cal yr BP. In the Edmonton area, within the central Corridor, of 20 bison dating between 11,500 and 13,200 cal yr BP, the ratio of northerly to southerly bison is roughly even suggesting a well-established connection between Beringia and continental North America at this time. And in contrast to models of a bleak, unproductive post-glacial landscape, these bison were part of a diverse grazing community of herbivores and their predators that occupied the area during the early stages of deglaciation.

The direction of bison traversing the Corridor is largely north to south during the Late Pleistocene, and only a single latest Pleistocene bison of southern origin in northern Canada, dating to ca. 12,200 cal yr BP, has been recovered. This early northern dispersal likely took place prior to the development of significant ecological barriers, such as the boreal forest which may have limited subsequent dispersal of bison into Beringia. Our findings have significant implications for terminal Pleistocene faunal dispersals, including pathways for ancestral indigenous populations. Movement in both

directions between eastern Beringia and regions south of the continental ice masses was feasible during the Clovis era (cf. Waters and Stafford, 2007), and likely a few centuries before. This time frame is not sufficiently early, however, to support the Corridor region as the prime route for initial human settlement of the Americas. Instead, the Corridor likely played an important role for secondary movements of human populations from south of the ice masses; it may also have provided the pathway for the cultural diffusion of fluted point technology through western Canada toward pre-existing eastern Beringian human populations.

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ARCHAEOLOGICAL SCIENCE AT THE PAISLEY CAVES IN SOUTH CENTRAL OREGON

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Archaeological investigations were initiated by Luther S. Cressman at the Paisley 5 Mile Point Caves site (35LK3400) in the Chewaucan Basin of south-central Oregon in the summer of 1938. Excavations continued during the summers of 1939 and 1940, revealing the apparent presence of extinct Pleistocene animal remains (camel, horse, bison) and obsidian artifacts on and around a small house floor in Cave #3. Cressman (Cressman 1940, 1966; Cressman and Williams 1940) reported his evidence for Pleistocene human presence in the caves. However, doubts about the veracity of these claims continued to plague him to his death in 1994, primarily because he could not illustrate the precise locations and stratigraphic association of the Pleistocene materials (Heizer and Baumhoff 1970; Krieger 1944). Review of field notes at the Museum of Natural and Cultural History reveals Cressman was not on the site when the best deposits were excavated by his crew. The excavations were hastily conducted with little attention to *in situ* recovery and recording of artifacts and paleontological remains.

The UO archaeological field school conducted new excavations at the site in 2002, 2003, 2007, and 2009-2011 with the express intention of testing the hypothesis that if Cressman was correct in his assessment that humans occupied the Paisley Caves during the Pleistocene then artifacts and paleontological specimens identified to species would be recovered in verifiable stratigraphic context and their radiocarbon ages would overlap. If not, then radiocarbon dates on cultural and paleontological remains would not overlap.

UO excavations revealed that there is generally little lithic debitage at any chronologic period in the Paisley Caves, a reflection of short-term occupations at a site that was not a destination location. However, the site does contain a highly unusual record of perishable industries (cordage, sandals, basketry, threads, skins, bone, wood) and coprolites of which ~1800 have now been recovered. A number of these coprolites are 13,000-14,620 calibrated years old (11,000-12,400 ^{14}C yr BP) and have been shown to contain ancient human DNA of haplogroups A2 and B2 common in Pleistocene Siberia and east Asia (Gilbert et al. 2008a, b; Gilbert et al. 2009; Rasmussen et al. 2009). Radiocarbon dating of single elements (n=>225) identified to species reveals that humans occupied the Paisley Caves when Rancho Labrean megafauna inhabited the plains below the caves overlapping them chronologically between 13,200 (early or pre-Clovis era) and 14,620 calibrated years BP (Jenkins 2007; Jenkins et al. 2012; Jenkins et al. 2013). This presentation reports the results of the most up-to-date multidisciplinary research conducted at the site and in the laboratory. Exhaustive analyses establish the reliability of both the stratigraphic contexts and ancient DNA results.

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GENETICS, ARCHAEOLOGY AND THE PLEISTOCENE PEOPLING OF NORTH AMERICA

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In the last two decades DNA has figured prominently in discussions of the origins and antiquity of the first Americans, the number and timing of migrations to the Americas, and the route(s) taken to this continent. Up until a few years ago that evidence was primarily derived from studies of maternally-inherited mitochondrial DNA (mtDNA) and paternally-inherited DNA from the non-recombining portion of the Y chromosome (NRY) (cf. Reich et al. 2012), with all samples obtained from living individuals. A number of inferences have been drawn from this evidence not all of which are congruent. Among them: that ancestral Native Americans diverged from an ancestral Asian population from a single geographic origin perhaps immediately after the Last Glacial Maximum, that they experienced a population bottleneck in the process, came to the Americas in a limited number of migratory pulses (~1-3), perhaps spent a long period of isolation in Beringia, moved south of the ice sheets via the Pacific coast, and then once in the Americas spread rapidly resulting in geographic structure. Some of these inferences are more compelling than others; few can be directly reconciled with current archaeological evidence (Meltzer 2009).

Moreover, there are limits to what one can securely infer from *modern* DNA about *ancient* patterns and processes of migration and colonization, particularly from the relatively small corners of the human genome represented by mtDNA and NRY. This is so for several reasons, not least the presence significant sampling biases, limited chronological control, the confounding effects of gender-influenced cultural (e.g. marriage and residence, mobility) and biological (e.g. fecundity and mortality) patterns on the genetic signal, and especially complications resulting from evolutionary processes of isolation and genetic drift (including lineage loss) that have occurred in the more than 12,500 years people have been in the Americas (and particularly in the last several centuries as a result of Native American demographic collapse in the wake of European colonization). There has long been reason to suspect that genetic lineages that once existed in the Americas have since vanished and would never be detected in modern populations, even if those populations were adequately sampled (as they are not).

Accordingly, efforts began in the last decade to extract ancient DNA (*a*DNA) including mtDNA, NRY and whole genome DNA from Pleistocene human remains. There are considerable challenges to doing so, chief among them problems with preservation and contamination. As a result of these challenges and a dearth of samples, relatively few *a*DNA studies bearing directly on the peopling of the Americas have thus far been completed.

Nonetheless, those studies that have been done have been of great value, revealing for example the occurrence of a mtDNA founding lineage that is no longer present in modern populations indicating “that significant undocumented genetic structure still exists in the Americas” (Mahli et al. 2007); documenting a pre-Clovis presence in North America (Gilbert et al. 2008, Jenkins this meeting); and effectively putting to rest claims for a European origin of Pleistocene Americans by showing the whole-genome similarity of a Clovis-age skeleton to Pleistocene Siberians as well as modern Native Americans (Raghavan et al. 2013; Rasmussen et al. 2014). Investigations of *a*DNA are ongoing of additional human remains from a number of important early sites in the Americas which, if completed in time for the AMQUA meetings, will be discussed.

Ultimately, *a*DNA has the potential to revolutionize our understanding of the peopling of the Americas, for with it we will be able to test inferences about population history drawn from modern DNA as well as from other kinds of evidence such as morphological variation in skeletal remains, track changes in Native American genetic diversity over time and the response of populations to environmental events, and better link genetic data with actual archaeological evidence of the peopling process.

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DOES THE RIVER GIVE A DAM? — QUATERNARY OUTBURST FLOODS, CAUSES, AND CONSEQUENCES IN THE U.S. PACIFIC NORTHWEST

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Outburst floods from impounded water bodies are universal phenomena, producing large and geomorphically significant floods affecting the Earth, Mars, and possibly other planetary surfaces. Peak discharges from outburst floods on Earth have ranged up to 10^7 m^3/s, exceeding the largest known meteorological floods by a factor of 100 (Figure 1). Even larger floods, as great as 10^9 m^3/s, may have channeled the Martian surface. Floods from natural dam failures are geomorphically important because their deep and fast flows produce shear stresses and stream powers orders of magnitude greater than meteorological floods. Such flows can exceed critical thresholds for eroding bedrock, can carve valleys, and transport clasts with diameters of many meters, thus forming spectacular landscapes. Additionally, rapid releases of immense volumes of freshwater to oceans during large outburst floods are strongly linked to Quaternary climate fluctuations.

Outburst floods are an integral aspect of the U.S. Pacific Northwest where the dynamic tectonic environment has combined with climatic setting and history to establish conditions triggering all kinds of outburst floods, ranging from the colossal Missoula floods of the last ice age to the much smaller but nevertheless geomorphically effective and hazardous floods from landslide dams, moraine dams, and even constructed dams. As we have learned more about such floods, new (and old) questions have emerged regarding the role of outsized floods in shaping landscapes.

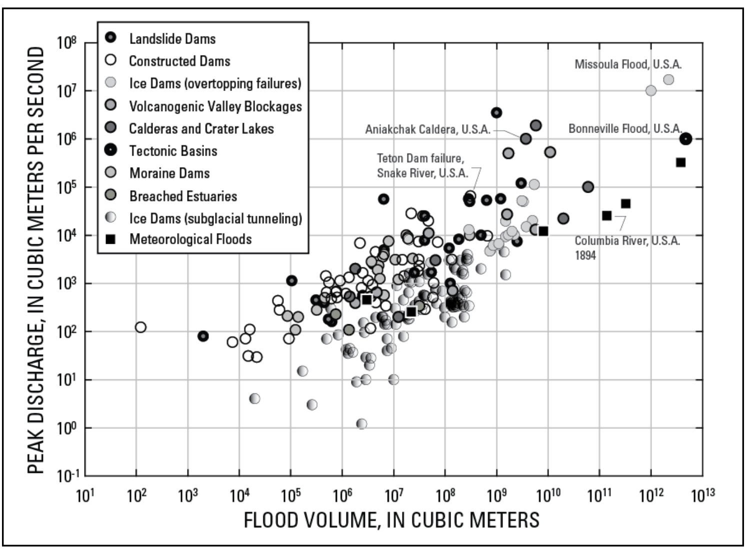

Figure 1. Outburst floods and selected meteorological floods for which flood volume and peak discharge are known. Largest floods of each type are labeled. Data from Walder and Costa (1996), O'Connor et al. (2002), and O'Connor and Beebee (2009). Modified from O'Connor et al., 2013.

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WITNESSES TELL OF MOUNT ST. HELENS' 1980 ERUPTION

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"It's a beautiful day, everything quiet . . . Oh wait!"
"Earthquake shakin', there's a whole . . ."
"Holy Shit!"
"The cloud booked downvalley toward us."
"The speedometer pegged at 80, I rounded curves tipped onto two wheels."
"The mountain! The mountain!" He was incoherent. "The mountain!"
"The cloud front poured down with such force it bubbled back up."
"It got hot right away, scorching hot, and impossible to breathe."
"Many dirt clods thumped on the ground. My hands began burning."
"All the trees were down, everything drab gray covered in ash, a wholly different world."
(Excerpted from Waitt, 2014).

No matter how good you are as a geologist or how much time you spend in the field, you cannot discover some things about a volcanic eruption except through people who were in it or nearly so. Here we shall hear about Mount St. Helens' 18 May 1980 eruption as only survivors and other close witnesses can tell.

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HOW IMPORTANT IS SEISMICALLY INDUCED EROSION ABOVE THE CASCADIA SUBDUCTION ZONE? INSIGHTS FROM THE STRATIGRAPHY OF LARGE LAKES ON THE OLYMPIC PENINSULA, WASHINGTON STATE

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Large earthquakes often trigger landslides in mountainous regions (Keefer, 2002). The largest earthquakes occur on subduction plate boundaries. The importance of these subduction zone megathrust events to terrestrial sediment flux from coastal mountain ranges is not well known, due in part to their infrequent recurrence. In contrast, upper plate earthquakes such as the 1999 Chi-Chi, Taiwan and 2008 Sichuan, China events each resulted in thousands of landslides that will continue to impact fluvial systems for decades (e.g., Parker et al., 2011; Yanites et al., 2010).

Along the Cascadia margin, abundant paleoseismic evidence exists for the occurrence of both great subduction megathrust events (M > 8.6) as well as large (M 6 – 7.5) shallow crustal ruptures within the Puget Landwards (e.g., Atwater & Hemphill-Haley, 1997; Nelson et al., 2006; Goldfinger et al., 2012; Enkin et al., 2013; and Sherrod and gomberg, 2014). However, very little is known about the ***upland terrestrial*** response in Cascadia to earthquakes from either of these source regions. By comparison to other locals with significant topographic relief, such as exists within the Olympic and Cascade Mountains, the total number of earthquake-triggered landslides and volume of hillslope sediment transport may be substantial during and following future earthquakes. Furthermore, the surface process response to seismogenic landsliding may have decadal-scale impacts on sediment supply to fluvial networks and coastal margins (e.g., Hovius et al., 2011), with implications for both fresh and salt-water ecosystems. Over millennial time scales, mass wasting associated with large earthquakes may play an important role in modulating the flux of terrigenous sediments to the marine environment and perhaps to the overall evolution of topography above Cascadia and other subaerial forearc subduction margins.

Within this framework, we present preliminary seismic and sediment coring results from Lake Quinault, located at the western front of the Olympic Mountains about 30 km inland from the Pacific coast (Fig. 1). Our working hypothesis is that this lake records the sedimentologic and geochemical signatures of seismogenic mass wasting in its catchment. The lake is impounded behind a late Pleistocene (29 – 20 ka) terminal moraine of the Quinault valley glacier. The lake, with a maximum water depth of 70 m is about 60 m above sea level. Lake side slopes are steep and the upper Quinault River is building a delta at the eastern end of the lake. In 2013 we recovered several ~ 6 m long cores from the distal (western), central, and delta-proximal (eastern) sides of the lake using a Kullenberg piston coring system. Initial radiocarbon results indicate that we've recovered ca. 4500 year sediment record from the distal end, 700 years from the lake-center and about 500 years from the delta toe-slope at 50 m water depth. Mean accumulation rates are ~1 cm/yr from the delta toe and lake center locations, where sediment is a mix of sand and silt. The rate decreases to 0.1 cm/yr at the distal coring sites, where the median grain size is silty clay.

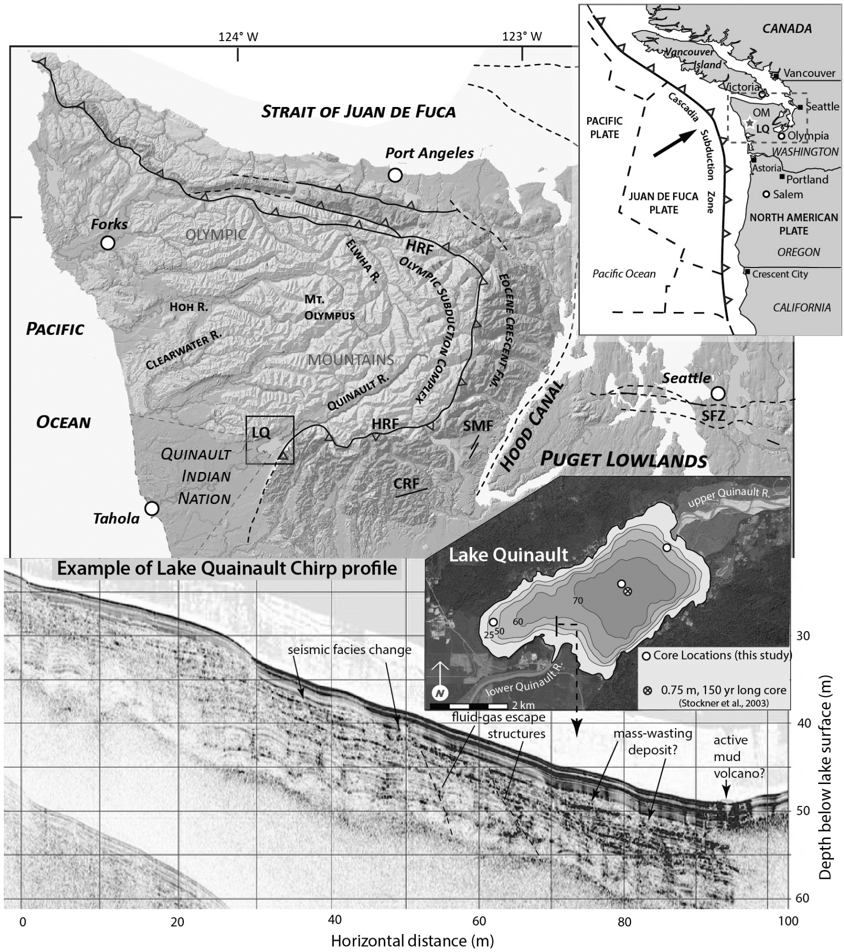

Figure 1. Location of Lake Quinault with respect to Cascadia margin and Olympic Peninsula (top); Bathymetry, core locations, and example of seismic stratigraphy (bottom).

We investigated the seismic stratigraphy of Lake Quinault using an Edgetech 3200 series SB-216 Chirp sub-bottom profiler in the 2-16 kHz range. Across most of the lake, sediments below ~1 m of the bottom surface are obscured from observation by pervasive gas blanketing; due in large part to the influx of organic material, rapid burial rates, and the subsequent generation of methane gas in this system. However, quasi-brittle lateral spreading (creep) of lake-margin sediments in places around the distal end of the lake allows for improved seismic penetration that reveals up to 25 m of stratified sediments. This indicates that a much longer sediment archive exists in this lake than we were able to core, likely extending well into the late Pleistocene. From the gas-free zones, we observe a major seismic facies change at ~2.5 to 3 m beneath the lake bed. Beneath this interval, fluid-gas expulsion structures are common and regularly spaced, the majority of which are truncated and draped by undeformed sediments that in turn are cut by relatively few fluid escape pipes. This 2.5 to 3 m deep change in seismic facies corresponds to a marked increase in core density and magnetic susceptibility that we attribute to fluid-gas expulsion and sediment compaction below the discontinuity versus in the sediments above it. In open cores, we observe soft sediment deformation; including small-scale folding and fracturing in a ~30 cm zone from this same depth interval that likely represents an in-lake mass movement deposit that we believe was triggered by an earthquake.

Our preliminary ^{14}C age model suggests that this seismic-core discontinuity is about 1300 ^{14}C yr BP. We are working to refine this estimate. In addition to the in-lake evidence for a seismic event layer, the distal cores record color and grain size changes immediately above that we hypothesize resulted from stepped progradation of the delta front in response to an increase in sediment delivery to the lake by the upper Quinault River. Superimposed on this one major seismic and sedimentary facies change, we see evidence for smaller-scale events related to decadal-scale and river floods into the lake. In addition, the deep water cores from the center of the lake preserve a distinct turbidite (delta front failure) that is also associated with small-scale soft sediment deformation at a correlative level on the distal side of the lake. Based upon our age model this latter event happened around 300 ^{14}C yr BP, or about the time of the well-documented AD 1700 Cascadia subduction zone (CSZ) megathrust event. Although it is premature to ascribe a seismic source to the major discontinuity in the distal cores at ~1300 ^{14}C yr BP, our working hypothesis is that this event was caused by an upper crustal fault, perhaps on the margins of the southern or eastern Olympic Mountains rather than a CSZ megathrust earthquake. If true, this would indicate that the seismic erosion (mass wasting) within mountainous topography may be more pronounced during local crustal events likely sourced along the western periphery of the Puget Lowlands (e.g. Schuster et al., 1992) than in response to great CSZ thrust events.

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PACIFIC NORTHWEST NORTH AMERICAN FOSSIL VERTEBRATES, PALEOENVIRONMENTS, AND OPPORTUNITIES FOR HUMAN MIGRATION WITH LAST GLACIAL ADVANCE AND RETREAT

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The Pacific Northwest of North America is a key area for study of biotic responses to environmental changes. The area marked the western and southern margins of the Last Glacial Cordilleran ice sheet, providing biotic evidence reflecting its advance, maximum, and retreat. In complementary fashion the area marked the northwestern extreme of the midcontinental biota and the southern extreme of the Beringian biota. Given other evidence for mixing of northern and southern biotas, it is important to investigate the possibilities for coastal biotic dispersal between ca. 25,000 and 10,000 cal yr BP. In terms of the overall coastal route for possible human migrations, this is not simply a matter of "before or after" glaciation. Glacial chronologies from southeast Alaska, through British Columbia, to Washington indicate that LG ice-lobe advances, maxima, and retreats were latitudinally time-transgressive, such that glaciers were in retreat in the north while still advancing in the south. This provides the possibility that shortly before the southern LG maximum (which was between ~19,000 and 15,000 cal yr BP) there was a window of opportunity for human groups to move southward along the coast, particularly if umiak-style craft were used. Relative sea-level curves are greatly variable from region to region, not only in the chronology of land depression and emergence but also in the presence and extent of forebulge development, reflecting regional differences in tectonic settings. Times of low RSL provided emergent platforms and hence opportunities for dispersal to and between islands; dispersal was also facilitated by transient development of sandur plains in advance of ice lobes (e.g., Quadra sands). Hence megafauna such as mammoth, muskox, bison, and horse were able in pre-LG times to colonize Vancouver Island, which for a time was functionally an extension of the British Columbia mainland. Sandur deposits were subsequently eroded by advancing ice and further scoured by subglacial meltwater flow; after ice retreat they were vulnerable to lateral cutting by wave action. Hence, even for RSL values that were similar before and after the LG maximum, the dispersal dynamics would have differed. For example, a depauperate island biota suggests filter bridges after the LGM for Vancouver Island. For sea mammals and birds, discontinuous chains of islands and emergent platform areas would have provided stopping points for north-south migration through the LGM, and seamounts were also emergent beyond the continental margin. The terrestrial megafauna as yet provides little evidence for southward coastal movements even in pre-LGM times, with species more likely linked to populations to the south and east; however, this does not preclude southward human movements. The post-LGM fauna from Vancouver Island and the San Juan Islands provides evidence for northward dispersal of megafauna from reservoir populations to the south. Apparent absence of post-LGM mammoths from the Puget Lowland and these islands could reflect species differences in dispersal ability and rate, coupled with the timing of megafaunal extinctions in the midcontinent. Marine invertebrate faunas and some vertebrates (fish, birds, and sea lions) allow integration of information from coeval marine and terrestrial faunas, both pre- and post-LGM.

Marine environments close to ice fronts were strongly estuarine with reduced salinity and possibly stratification of the water column. On land, the fauna, including megafaunal carnivores and herbivores, played roles in importation of plant propagules as well as exerting a trophic influence upon vegetation succession. The disappearance of megafauna likely had a significant impact upon succession, though it has been portrayed as a possible result of such changes. Human groups were hunting megafauna (mastodon, bison) in the Salish Sea region by ~12,000 ^{14}C yr BP (~14,000 cal yr BP); therefore it is important not to stereotype coastal human populations as maritime-adapted. Challenges remain in comparison of marine and terrestrial radiocarbon chronologies and are incompletely met by use of generalized marine reservoir correction values. Application of one MRC value (e.g., -950 yr) for dates older than 10,000 ^{14}C yr BP and another (e.g., -720 yr) for younger dates creates a dating "artifact" at 10,000 ^{14}C yr BP, close to the end of the Younger Dryas climatic episode. In addition, the history of rapid submergence and emergence of landscapes, as RSL changed, led to large-scale infusions of decomposing terrestrial organic matter in the marine environment, then infusions of decomposing marine organic matter into terrestrial ecosystems, with consequences for isotopic values. Despite this, it is possible to produce reconstructions that integrate landscape, marine biota, and terrestrial biota to provide a context for the understanding of early human migrations.

Abstracts of Contributed Poster Presentations

LATE PLEISTOCENE AND HOLOCENE ALPINE GLACIATION IN THE KLAMATH-SISKIYOU MOUNTAINS OF NORTHWESTERN CALIFORNIA

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The geomorphic signature left by the fluctuation of alpine glaciers offers unique evidence of paleoclimate (Davis et al., 2009). The glacial history of the Klamath-Siskiyous Bioregion is particularly interesting due to the low elevation, proximity to the Pacific Ocean, and the dominant east-west trend of the mountain range. The glaciated landscapes in the Klamath-Siskiyous are particularly constrained by topographic controls (Lopez-Moreno et al., 2006) in comparison to the glaciated landscapes in the higher elevations of the Cascades and Sierra Nevada Ranges to the East. Prior mapping by Sharp (1960) in the Trinity Alps, and Harms (1983) in the Marble Mountains focused on glaciations within single mountain ranges. This present study is an effort to systematically map the glaciated landscapes of the Syskiyous, Graybacks, Trinity Alps, Red Buttes, Russian, Marble Mountains, and the Yolla Bolly of Northwestern California using several automated morphometric techniques in conjunction with supervised classification. The primary objective is to identify the maximum latest Pleistocene glacial advances and to recognize potentially unidentified sites of Holocene glacial advances. Specifically we have adapted a minimum curvature criteria method (Prasicek et al., 2014) as well as manual morphometric mapping using digital elevation models and remote sensing (Federici and Spagnolo, 2004).

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THE TIMING AND SPATIAL EXTENT OF LATE-HOLOCENE FIRE-INFERRED DROUGHT CONDITIONS IN THE WESTERN GREAT LAKES REGION

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Long-term fire histories, used in this study as a proxy for drought conditions, from a transect of six lakes in eastern Wisconsin and the Upper Peninsula of Michigan were compared to determine the spatial extent of drought periods over the last 2000 years. The sites represent a north/south transect which spans the ‘tension zone’, a climate boundary that divides the Upper Great Lakes area into cool/dry and warm/wet regions. Synchronous fire events at several sites centered on 1100 cal yr BP and 600 cal yr BP indicate regional drought conditions. Regional atmospheric conditions that produced these drought conditions likely consisted of a persistent upper level ridge that deflected storm systems away from the region. This project adds to our understanding of the resilience of the tension zone climate boundary, and provides new information on the extent and timing of drought conditions in the past.

POLLEN-FIRE INDEX (PFI): A NEW METHOD OF DETERMINING COMMUNITY SHIFTS RELATED TO CHANGES IN FIRE REGIMES

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The importance of fire regimes in shaping vegetation communities is widely acknowledged. The influence of fire on vegetation composition extends to the functional characteristics of the communities, through the expression of different plant traits. By reconstructing the variation in these traits of the past using pollen data, it may be possible to provide information on changes in past fire regime that are both independent of and complimentary to charcoal records. This requires an interpretive framework that identifies fire-related traits and links these to pollen types, that we term the Pollen-Fire Index (PFI). Here we present a preliminary study based on ecosystem traits associated with changes in fire-sensitivity related to ecosystem mortality and survivorship. The results allow us to reconstruct changes in fire sensitivity and mortality as fire frequency and intensity varies, highlighting fire-vegetation relationships that are not evident in non-transformed pollen data.

Using a dataset of forest compositional change around a subalpine lake in the Oregon Cascades, Breitenbush Lake, PFI shows plant community fire trait evolution that is unique to the overall vegetation history. Over the past 15 ka this vegetation history indicates pine forest dominance established 12.5 ka with later increases in mesic taxa like fir and mountain hemlock. Modern forest composition of mountain hemlock-fir-spruce formed 5.5 ka. Over the total record, the sensitivity of the forest to mortality by medium and high intensity fires has increased. This sensitivity has evolved in the plant community independent of major vegetation changes indicated by pollen zone boundaries.

BRINE SHRIMP CYST CONCENTRATIONS IN SHORT CORES FROM MONO AND BIG SODA LAKES CORRELATE WELL WITH CHANGES IN LAKE LEVEL AND SALINITY

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In this study we explore the potential of brine shrimp (*Artemia* spp.) cysts as a paleoclimate proxy. Brine shrimp are commonly found in saline lakes around the world. They produce chitinous cysts that can remain dormant from months to years and hatch when favorable conditions arise. The cysts may be present in sediment cores in very high concentrations, i.e., thousands per cc. Their average size is ca. 250 micrometers and they can be easily extracted by sieving. There has been extensive research into the brine shrimp life cycle and numerous experimental studies have made connections between brine shrimp populations and variables such as temperature, nutrients, salinity, and dissolved oxygen. In contrast, relatively few studies have focused on cysts in lake sediments. Exceptions include: Neilson and Bowen (2010); Kelts and Shahrabi, 1986); and Last and Schweyen (1985).

This study is based on short cores from Mono Lake, California and Big Soda Lake, Nevada. The Mono Lake core was recovered by LacCore in 2007 and the Big Soda core in 2010 by the USGS and UC Berkeley. Both cores are laminated and the seasonal couplets are assumed to be varves. The age model for the Big Soda Lake core is based on ^{210}Pb age estimates, the first appearance of non-native pollen, and other stratigraphic evidence of human activity, such as a peak in heavy metals, which we assume reflects mining activity in the Carson City area. The chronology for the lower part of the core is based on varve counts. The chronology for the Mono Lake core is based on varve counts and a tephra at the bottom of the core that dates to ca. A.D. 1700 (Stine, 1990).

Both lakes have been intensively studied and lake level records are available that extend back to the nineteenth century. Mono Lake has a surface area of 180 km^2 and formed in a tectonic depression (Stine, 1990). Big Soda Lake has surface area of 1.5 km^2 and occupies a maar crater (Kharaka et al., 1984). Both Mono and Big Soda lakes are saline and alkaline. They differ somewhat in their degree of stratification. Mono Lake has been periodically meromictic during the twentieth century because of freshwater influx while Big Soda Lake has been consistently meromictic since 1920 (Kharaka et al., 1984). The lakes differ dramatically in terms of their twentieth century lake level histories. Mono Lake reached its historic high stand in 1919 and then dropped to its low stand in 1982 because of water diversion via the Los Angeles Aqueduct (Stine, 1990). Conversely, at Big Soda Lake lake levels were low in the late nineteenth century and then rose rapidly between 1907 and 1930 due to irrigation (Kharaka et al., 1984). They have remained high throughout the second half of the twentieth century. The primary research question in this study is whether brine shrimp cysts in the two lakes reflect the differences in lake level history.

We isolated the cysts by sieving constant volume sediment samples with 300 and 180 μm sieves. Sub-samples of the concentrated cysts were then digitally imaged with a Nikon 7000 camera and the images produced analyzed with ImageJ using a macro written especially for the project. The data obtained included total number of cysts, cyst diameter, and cyst area. Each sample was analyzed twice to test the reliability of the methods.

Our results show the expected opposite trend in cyst concentrations at the two lakes. In the latter part of the twentieth century, the number of cysts at Mono Lake increased while the lake level dropped, whereas at Big Soda Lake the number decreased as the lake level rose. The cysts made up a significant fraction of the core material at most levels and showed significant variation in concentrations at both sites. For example, at Mono Lake, counts ranged from a low of approximately 3 cysts per cc in 1710 to a high of 650 cysts per cc in the 1970s. The changes in cyst size at the two lakes are more difficult to interpret than the changes in concentration. For example, they show opposite trends at the two lakes in the nineteenth century i.e. before significant human impact. We are currently investigating possible reasons for this.

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ALTERNATING STABLE STATES IN SPATIALLY PATTERNED SUBAPLINE FORESTS IN NORTHERN COLORADO DURING THE PAST TWO MILLENIA

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Ribbon forests are a type of subalpine parkland found in the Rocky Mountains. They consist of alternating strips of forest and meadow that form because bands of *Picea* and *Abies* trees act as snow fences with large snowdrifts forming on their lee sides. These drifts provide moisture for trees adjacent to the snow during the summer, but increase seedling mortality close to the drifts. Given the feedbacks between the forest pattern and snow accumulation, ribbon forest fit within the framework of patterned ecosystems thought to experience rapid regime shifts when the feedbacks breakdown. The paleoecological record of ribbon forests allows us to investigate the hypothesized potential for rapid state transitions.

Our fossil pollen data from Summit Lake, located on the Continental Divide in the Park Range, northern Colorado, indicate that a closed forest transitioned to a ribbon forest state in the past millennium. The transition is marked by increased *Artemisia* pollen (from ~20% to ~35%) and decreased *Picea* and *Abies* pollen (from ~25% to ~15%). A decrease in charcoal influx (decreased from ~0.6 pieces/cm^2/yr to ~0.4 pieces/cm^2/yr) and fire frequency (decreased from ~4.5 fires/ka to ~1.5 fires/ka) coincides with the pollen assemblage changes, and is consistent with decreased landscape biomass and fuel connectivity. Independent climate reconstructions support the hypothesis that snow drifting develops and maintains ribbon forests as pollen assemblages similar to modern are found only when the climate is wet and dominated by winter precipitation. Further analyses will examine the rate of change and effect on nitrogen availability.

COMPARING PUGET SOUND AND STRAIT OF JUAN DE FUCA INTERTIDAL MARSHES – RELATIVE SEA LEVEL AND TSUNAMI INUNDATION HISTORIES

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Two Washington intertidal marshes: one at the head of Hood Canal—Lynch Cove; the other in Discovery Bay, off the Strait of Juan de Fuca, are positioned a similar distance from the Cascadia subduction zone deformation front, and are both about 45 km above the subducting Juan de Fuca plate. Because of their similar positions, these sites should experience similar amounts of land-level change—if any—during subduction zone earthquakes, but are likely to preserve tsunami deposits differently due to their geographical differences. Discovery Bay, closer to the outer coast, is more likely to preserve tsunami deposits from both local and far-traveled tsunamis, while Lynch Cove's more remote position at the head of Hood Canal suggests that it would preserve very large, or locally-generated tsunamis only. The marsh at Discovery Bay contains nine tsunami deposits, while the marsh at Lynch Cove has two candidate tsunami deposits.

A comparison of modern intertidal marsh diatom distributions with fossil diatoms preserved in marsh sediments allows a relative sea level history to be constructed for each site. Transfer function analysis provides a quantitative technique for characterizing modern diatom assemblage elevations in the intertidal zone and relating them to fossil diatoms preserved in the marsh sediments. The Lynch Cove marsh contains a record of 2+ m of uplift during the A.D. 900-930 Seattle fault earthquake. Tide flats were raised out of the intertidal zone and later became forested. The forested areas have since been submerged back into the intertidal zone by either sea-level rise, tectonic subsidence, or a combination of the two. In one part of the marsh, the submergence is dated between A.D. 1670-1780. In another yet-undated part of the marsh, there is a 2 cm thick gray sandy mud layer interpreted as a possible tsunami deposit between the upland and intertidal marsh deposits. The presence of a potential tsunami deposit, and environmental change around the time of the A.D. 1700 Cascadia earthquake is intriguing. Estimates of total vertical deformation will provide useful constraints for models of the tectonic setting, and local sea-level rise.

HIGH-RESOLUTION POLLEN AS AN INDICATOR FOR FIRE SEVERITY DURING THE POPULUS PERIOD, 2000-4000 CAL YR BP

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Paleoecological proxies, such as charcoal and pollen, are valuable tools for reconstructing previous fire regimes and vegetation change. However, fire severity, or the ecological response to fire events, is one variable of fire reconstructions that is currently not extractable from sediment core data. This study attempts to analyze fire severity using lake sediments from southeastern Wyoming, during a unique period of time coined the '*Populus* period' (Carter et al., 2013). The '*Populus* period' (3,100-4,000 cal yr BP) was a time when vegetation composition and fire regimes changed from a lodgepole pine dominant system to a quaking aspen system. This study investigates 12 fire events from 2000-4000 cal yr BP to determine the ecological response associated with fire events and to identify driver(s) associated with vegetation change and fire regimes. In order to determine fire severity, this study compares high-resolution charcoal and pollen data to peak magnitude data from CharAnalysis (a statistical treatment program). Linear discriminant analysis (LDA) is used to set a threshold by which pollen taxa are associated with low or high severity fires. Preliminary LDA results suggest that low severity fires have a peak magnitude lower than 200 particles/cm^2/episode and high severity fires have a peak magnitude higher than 200 particles/cm^2/episode. Superposed epoch analysis (SEA) will be used to model pollen behavior through fire sample intervals to determine the ecology response associated with each of the 12 fires events. Statistical analysis using LDA and SEA can potentially be used in combination to determine fire severity. Long-term reconstructions of fire severity can be beneficial for informing land managers in the 21^{st} century.

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INTERPRETING THE SEASONALITY OF PRECIPITATION IN NORTHERN BAJA CALIFORNIA FOR THE LAST ~45,000 CAL YR BP

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The Sierra de Juarez of Northern Baja California lies in a region that is heavily influenced by the El Niño Southern Oscillation (ENSO), which brings winter precipitation and the North American Monsoon (NAM), which brings summer precipitation to the region. Little is known about the impacts that the seasonality of precipitation have had on fire and vegetation throughout the region, especially extending into the early Holocene and Pleistocene. Fire regimes and ciénega processes, as indicate by loss on ignition, magnetic susceptibility, and charcoal data, appear to be controlled by the amount of precipitation to the region and groundwater levels. Preliminary pollen analysis shows an inversely proportional relationship between summer-wet and winter-wet taxa throughout the record. Based on existing ENSO and NAM data, we know that the influences of both phenomena have changed in their intensities and spatial boundaries throughout time. Our study sites (Ciénega Chimeneas, 32^{o} 14’ N and 116 ^{o} 06’ W, and Ciénega San Faustino, 32°12’30.4”N and 116°09’55”W, spanning the last ~45,000 cal yr BP) are located in a region that can help define when and where changes in the seasonality of precipitation have occurred since the late Pleistocene. Additional dating and pollen analysis will allow us to further validate the relationships between ENSO and NAM like activity and ecosystem processes for this site.

ASSESSING THE ABILITY OF TREE-RING ISOTOPES TO IMPROVE OUR UNDERSTANDING OF THE CLIMATIC DRIVERS OF STREAMFLOW IN THE UPPER COLORADO RIVER BASIN.

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With recent declines in snowpack, a major water reservoir, in the mountains of Colorado, there is a need to develop paleoclimate data sets to investigate the climatic drivers behind snowpack declines and its associated impact on streamflow in the Colorado River. Recent work indicates that spring temperatures are increasingly becoming an important driver of snowpack declines in the Southern Rockies. At present tree-ring records from the western US and Upper Colorado River have been used to provide records of summer temperature, winter precipitation and streamflow. However the ability to provide annually resolved reconstructions of cool season temperatures and summer precipitation has eluded dendrochronologists.

Here we have investigated $\delta^{18}O$ records derived from tree-rings of Douglas-fir and piñon pine in western Colorado to assess whether isotopic records derived from tree rings can be used as a proxy for cool-season temperatures. We sampled trees at 6 sites in western Colorado, at low, high and mid elevations. All trees were moistures sensitive and our sites were chosen to have paired sites at each elevation of Douglas-fir and piñon pine.

Results show significant correlations between Douglas-fir $\delta^{18}O$ and March-May temperatures ($r = 0.54$; $p<0.01$). piñon pine $\delta^{18}O$, however, correlates most strongly with prior September ($r = 0.48$; $p<0.05$) and May-July precipitation ($r = -0.43$; $p<0.05$). Our results indicate that $\delta^{18}O$ records obtained from Douglas -fir in western Colorado could be a good proxy of spring temperatures. We also assessed whether there was a difference in isotopic value between earlywood and latewood and found no difference in isotopic value between the two. Our results also indicate that by using isotopic records of $\delta^{18}O$ in conjunction with ring widths it could be possible to develop improved paleoclimate reconstructions incorporating temperature and precipitation from both winter and summer from the same region. This would provide a valuable tool to disentangle the climatic influences on snowpack and streamflow in western North America, in both the past and the present.

HUMAN PALEODEMOGRAPHY AND ECODYNAMICS IN THE SUBARCTIC NORTH PACIFIC: TELECONNECTIONS IN LARGE TIME AND SPACE SCALES?

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Archaeological research has improved our understanding of the evolution of human maritime adaptations in the subarctic North Pacific. Paleoclimatological and paleoceanographic studies have clarified aspects of long-term coupled atmospheric and oceanic processes over large spatial scales. In this poster, we present newly synthesized evidence of human demographic change from archaeological locations around the North Pacific Rim and explore possible environmental and social causes for the evident trends. In particular we focus on an inversely correlated population growth record between the east and west sides of the North Pacific in the past millennium.

Radiocarbon-based paleodemographic proxy models are presented for the Kuril Islands (Fitzhugh 2012; Fitzhugh et al. in prep), Aleutian Islands (unpublished), Sanak Island (Maschner et al. 2009) and the Kodiak Archipelago (Brown in prep; Fitzhugh 2003). Each model shows overall growth from the mid to late Holocene and variability at century to millennial scales. While some models are based on limited sample sizes (the Aleutian and Sanak databases, in particular), some trends are robust and replicated. In the last millennium, the strongest and most consistent pattern is of population increase in all Northeast Pacific data sets from ca. 1300-1700 CE. At the same interval, the Northwest Pacific (Kuril) data shows a dramatic decline sufficient to suggest a near abandonment of the Kuril islands for several centuries. The populations of the two regions were culturally unrelated and the inverted demographic patterns may be coincident. On the other hand, people in both regions depended for their subsistence on marine resources and may have been vulnerable to spatio-temporal asymmetries in ecosystem productivity. We examine proxy evidence for climate and ocean conditions to evaluate a model linking these two regions to a centennial-scale North Pacific oscillation affecting marine productivity, human food security, and demographic consequences for large maritime communities prior to the advance of state-sponsored colonialism into these regions.

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RADIOCARBON AGE-OFFSETS IN AN ARCTIC LAKE DESCRIBE THE RESPONSE OF A PERMAFROST WATERSHED TO CLIMATE CHANGE

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Many older late Quaternary studies mistakenly rely on the ^{14}C ages of bulk samples of lake sediment to supply their dating control. Unfortunately for the resulting chronologies, a date on bulk sediment is usually older than the true age of that sedimentary horizon as determined by AMS dating a terrestrial plant macrofossil. Age offsets between bulk samples and macrofossil samples from the same horizon can result from hard water effects (ancient dissolved inorganic carbon derived from of carbonate rock or soil respiration), and/or from the input into a lake of aged organic carbon (OC) previously stored in soil, peat, and/or permafrost (Abbott and Stafford, 1996).

Although age offsets in lake sediment have confused dating of events like the Younger Dryas and the Holocene Thermal Maximum in the Arctic, they have a valuable use in describing the long-term rates of soil organic matter erosion from watersheds into lakes (Vonk et al., 2012). Periods of enhanced soil- and permafrost-carbon release are associated with increases in the age offsets between bulk sediment ages and the ages of terrestrial macrofossils from the same sedimentary layer. By comparing a time series of ^{14}C age offsets with known periods of climate change in the past, we can gauge the sensitivity of carbon release from high latitude soils and permafrost, and provide a long-term proxy for permafrost thaw responding to past climate change.

Here we present a time series of ^{14}C age offsets from a lake on the northern flank of the Brooks Range in Arctic Alaska. The record encompasses prehistoric periods of both warming and cooling from the latest Pleistocene (beginning 14.5 cal ka BP) through much of the Holocene (last 11.7 cal ka BP). To interpret this age-offset record, we assess the possible sources of aged OC entering the main study lake and surrounding lakes by ^{14}C dating the particulate organic carbon (suspended organic matter) entering, exiting, and being deposited in surface sediments. In addition, we measure the ^{14}C content of submerged aquatic plants growing in our main study lake to serve as the samplers for C sources to algae in the lake system. We also assess the effect that wave-base depth has on age offsets today and determine past lake-levels by sedimentological inferences. We combine these observations to interpret both modern and prehistoric age offsets in lake sediment, and add further detail to this record by using ramped-temperature ^{14}C techniques to estimate OC quality and the ages of discreet OC sources reworked into the lake under different climate regimes in the past. Our results provide an estimate of the age and amount of soil and permafrost OC released from the watershed during episodes of climate change and landscape evolution over the past 14.5 ka.

Today, age offsets in a typical permafrost watershed in arctic Alaska are ~2.0 cal ka BP, which is indicative of slow-cycling OC pools whose dynamics are controlled by decay-resistant vegetation, shallow active layers (the topmost layer of permafrost that thaws every summer), and the underlying permafrost. Earlier in postglacial times when summer air temperatures were ~2–3^{o}C warmer than today, age offsets were 3–5 cal ka. During these previous relatively warm periods, the Bølling-Allerød interstadial (14.5–12.9 cal ka BP) and the Holocene Thermal Maximum (11.7–8.0 cal ka BP), rates of ancient OC release from the watershed were up to ten times greater than today. In contrast, during the relatively cold Younger Dryas (12.9–11.7 cal ka BP), age offsets and both total and ancient OC transfers from the watershed to the lake were similar to today. The similarity of age offsets between the Younger Dryas and today is probably the result of the peat and surface soil organic layers that have progressively spread and accumulated in the Arctic Foothills beginning in the early Holocene. The insulating effects of this organic cover has probably reduced near-surface temperatures in the ground significantly over the course of the Holocene and tempered active layer depths and permafrost thaw. Exceptions to this trend occur when isolated mass movements disrupt the insulating cover, trigger the thaw of permafrost containing organic matter, and so generate pulses of ancient OC into the lake. Because of the temperature-buffering effects of surface organic layers, the air-temperature threshold above which widespread thawing of permafrost can occur in Arctic Alaska is now higher than it has been at any time in the past 14.5 ka. Although climate is warming rapidly in the Arctic, this warming has yet to mobilize the vast stores off ancient OC stored in active layers and permafrost in the Arctic Foothills of Alaska.

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PLEISTOCENE ELA DEPRESSION ALONG THE PACIFIC COAST OF NORTH AMERICA

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Mountain glaciers grow in response to lowered summer temperatures, T_s, and increased snowfall. T_s may exert more control in maritime climates at temperate latitudes, but winter precipitation, ppt_w, becomes increasingly important in cold, arid continental interiors. On the Pacific Coast south of the Cordilleran Ice Sheet, the average glacial climate relative to modern climate was colder by an estimated ≥8°C (*1*) and drier in the NW but wetter in the SW (*2*). The COHMAP (*4*) paleoclimate simulation for 18 ka also suggests that the west coast was cooler and drier north of middle California to the Cordilleran ice Sheet, and moister south of this boundary, although lacustrine records show that the peak hydrologic balance followed the LGM deglaciation (*3*). The boundary in ppt_w may have coincided with the southern branch of a split jet stream similar to but south of the one we see today when tropical moisture is directed to the west coast (*2*). In contrast, on the Pacific Coast today, T_s is highly correlated on decadal to multidecadal time scales (*5*).

Ppt_w is spatially more variable than T_s due to orographic effects such as rain shadows. Ppt_w is delivered by storm systems ~10^3 km across, such that in any single event part of the coast is receiving precipitation while the rest is not. Furthermore, there are two main types of storms, one delivering larger amounts of rain or snow from tropical latitudes near Hawaii, and the other delivering moisture from the North Pacific. Both types can make landfall anywhere on the coast as the jet stream moves north or south. The balance of the two sources varies over time.

Since ELAs respond to climate, the gradient of glacier ELAs along the Pacific Coast may have been discordant relative to modern snowline, with a possible steep section in N California, and it is an open question whether paleo ELA patterns on the Pacific Coast reflect those of the continental interior or not. Experience in Central Asia suggests that Pleistocene climate and paleo ELAs may have differed regionally from glaciation to glaciation (*6–8*).

It is not clear what the patterns of spatial complexity in climate along the Pacific Coast actually were in the Pleistocene. When T_s (ablation) dominates glacier mass balance, ELAs will rise inland from the Pacific Coast and with decreasing latitude. However, mass-balance modeling (*1*) suggests that ppt_w must have exerted an important constraint of glaciation in the Sierra Nevada. Thus, we expect ELAs to also rise inland as ppt_w decreases, but possibly to exhibit a more complex pattern with latitude.

In this study we aggregate ELA measurements from previous studies, adding to them measurements made from Google Earth images and topography (SRTM) as necessary. Based on field studies and dating, ELAs in some drainages can be assigned to different glaciations; in nearby drainages assignments to glaciations were made by photo interpretation. We sought to answer several questions about glaciations and paleoclimate on the Pacific Coast.

1) *Do the ELAs for the ~18 ka LGM reveal spatial patterns that can be associated with patterns in ppt_w or T_s? What was the gradient of ~E–W ELA transects? Did the ELAs rise linearly with decreasing latitude, or reveal gradient changes that might be related to the average position of the jet stream?*
   - At 47°N, MIS-2 ELAs rose from ~900 to 1850 m amsl from W to E across the Cascades (*9*)
   - At 41°N they rose from ~1650 (*10*) to 2400 m amsl across the Sierra Nevada.
   - Between 36 and 38°N the ELAs lowered 3.1±0.2 m/km (*11*), but north of Mt Lassen the lowering was <1 m/km.
2) *Do the ELA transects for different glaciations indicate similar paleoclimates?*
   - In the Sierra, pre-MIS-2 ELAs were depressed ~100 (MIS 4–6) to 200 (~0.8 ka) m relative to the LGM, similar to values for the Cascades, suggesting that although the early climates were more 'glacial' their spatial heterogenities were similar to the LGM.
3) *What was the duration of the LGM in the Sierra?*
   - We dated LGM glacial erratics in Convict Canyon from the terminal moraines (16.3±0.3 ^{10}Be ka) to the cirques (14.9±0.4 ka) to obtain a time estimate of ~1.4 ka for the entire retreat, consistent with *(12, 13, 14)* who argued that ice was largely gone from the cirques by 15 ka.s
4) *Are there Younger Dryas (YD) moraines in the Sierra?*
   - No YD moraines have been found in the Sierra Nevada. Recess Peak moraines, C-14 dated to 13.1±0.1 cal ka BP (13), may precede the YD by a few hundred years. At Convict Creek we identified a candidate YD moraine between a late Holocene (neoglacial or LIA) rock glacier (3.7±0.1 ka, n=5) and Recess Peak (RP) moraines. However, the ^{10}Be ages for the candidate YD and the RP moraines were indistinguishable (14.2±0.2 ka, n=7). The reason for the regional absence of YD in the Sierra Nevada is unknown, but it appears that the late Holocene glaciers likely overrode moraines formed during the YD. Despite cooling during the YD, mass balance may have decreased because of reduced snowfall.

Our findings suggest that the paleo ELAs for MIS-2 glaciers did lower monotonically with latitude in the Sierra Nevada, but the gradient was less in the Northwest, consistent with existing ppt_w estimates. The end of the MIS-2 LGM was abrupt, lasting perhaps 2 ka, and was over before the rapid increase in pluvial lake height to the east. The Recess Peak advance occurred during or following the high stands, and was distinct from the YD advances, which have not been found in California. The study of glacier ELA patterns does appear to add useful detail to paleoclimate models.

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ICE-AGE MEGAFAUNA IN ARCTIC ALASKA: PATTERNS OF CHANGE

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The first people arriving on the North Slope of Alaska encountered a much different mammal fauna than what exists there today. The megafauna (mammals >44 kg was more diverse, and megafaunal biomass at certain times during the last ice age (40-10 cal ka BP) was significantly greater. Horse was the dominant species in terms of numbers of individuals, while mammoth comprised almost 50% of the biomass, in contrast to the today when caribou dominate both in numbers and biomass. Lions, short-faced bears, wolves, and possibly grizzly bears comprised the predator/scavenger guild. Bone-isotope measurements on hundreds of radiocarbon dated bones (Mann et al, 2013) suggest megafaunal niches were segregated along a moisture gradient, with the surviving species (muskox and caribou) utilizing the warmer and moister portions of the vegetation mosaic. As the ice age ended, the moisture gradient shifted and eliminated habitats utilized by the dryland, grazing species (bison, horse, mammoth). The proximate cause for this change was regional paludification, the spread of organic soil horizons and peat. The spread of shrubs, as the environment changed, allowed both humans and moose, two wood-dependent species to invade the region. The youngest mammoth so far recovered lived 13,800 years ago, while horses and bison persisted on the North Slope until at least 12,500 years ago during the Younger Dryas. The first people arrived on the North Slope ca. 13,500 years ago and so co-existed in the region with horse and bison for >1000 years. Hunting seems unlikely as the cause of these extinctions, but it cannot be ruled out as the final blow to megafaunal populations that were already functionally extinct by the time humans arrived in the region. End-Pleistocene extinctions in arctic Alaska represent local, not global extinctions since the megafaunal species lost there persisted to later times elsewhere.

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AN 18,200-YEAR DIATOM RECORD FROM A GLACIAL LAKE IN COSTA RICA

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Glaciers are absent from modern Costa Rica, but the Chirripó massif in the southeastern part of the country is high enough (elevation 3819 m) to have supported glaciers as recently as 10,000 to 12,000 years ago, during the Chirripó I glacial stage (Orvis and Horn, 2000). The retreat of these glaciers left behind dozens of small basins now occupied by lakes, including some excavated in bedrock and other lakes dammed wholly or in part by glacial till (Lachniet and Seltzer, 2002; Horn et al., 2005). Almost all of these basins were scoured by ice during the last advance, and thus do not contain sediments older than the Holocene. One exception is Lago de las Morrenas 3A (9.4969N, 83.4914W, 3494 m), which is perched above the most recent lateral moraine and was not scoured during the Chirripó I advance.

We cored Lake Morrenas 3A and examined diatoms to extend our knowledge of environmental changes beyond the Chirripó I deglaciation. The chronology of the core is provided by six radiocarbon dates, the deepest of which was obtained on organic sediment overlying mineral flour; this indicates a minimum age of 18,200 cal yr for the lake, and thus also for the Chirripó II glacial advance that created it.

The diatom assemblages in the core, at virtually all levels, were dominated by an undescribed species of *Aulacoseira* related to *A. alpigena*. The remaining diatoms were benthic species, reaching a total maximum relative abundance of 21-87% in Zone C (~ 14,800 - 11,800 cal yr BP); this suggests relatively shallow waters, and the presence of *Frustulia saxonica* (up to 27% of all diatoms), *Pinnularia braunii* (up to 25%), and *Eunotia* spp. (up to 6%) suggest that the lake may also have been slightly more acidic at this time. The most recent zone in the sediment core, Zone A, began approximately 10,900 years ago.

Pollen assemblages in the core indicate continual presence of páramo vegetation (dominated by a dwarf bamboo); in Zone C, *Isoëtes* (a quillwort, Division Lycophyta) was abundant. Microscopic charcoal was noted at 12,500 cal yr BP and peaked at 10,400 cal yr BP. Stable carbon isotope signatures suggest increases in C_4 grasses and/or aridity during deglaciation.

A similar history has been inferred for a nearby lake, Lago de las Morrenas 1 (elev 3480 m) (Haberyan and Horn, 1999). It, too, has been dominated by this *Aulacoseira* species throughout its history, but the record in Morrenas 1 begins only 11,800 calibrated years ago. Thus the record from Lago de las Morrenas 3A adds some 6000 years to the known history of the region.

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CLIMATE AND VEGETATION SINCE THE LAST INTERGLACIAL (MIS 5E) IN A PUTATIVE GLACIAL REFUGIUM, NORTHERN IDAHO, USA

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There are very few terrestrial sediment records in North America that contain a nearly continuous pollen record that span from the last interglacial period (120 ka) to the present. We present stratigraphic records of pollen and several other proxies from a *Carex*-dominated wetland located 140 km south of the maximum extent of the Cordilleran ice sheet and near the current southern extent of interior mesic forests in northern Idaho. Many species in this region are disjunct by 160 km of arid steppe and dry forest from their more extensive distribution along the Pacific Northwest coast and may have survived in an interior refugium. The chronology for the upper 251 cm was determined by six radiocarbon dates and one tephra deposit, and the remainder of the core (251-809 cm) was determined by correlation with SPECMAP $\delta^{18}O$. Fluctuating water levels were inferred from alternating peat, biogenic silica, and aquatic pollen types. During MIS 5e the region was warmer and drier than today and was dominated by *Pinus* (likely *P. contorta*) mixed conifer forest surrounding a *Carex* meadow. A warm-moist climate (MIS 5b-5d) soon developed, and the site was inundated with deep water. Pollen indicated bog vegetation (*Betula glandulosa,* Typhaceae, and *Salix*) developed around a lake with a *Pseudotsuga/Larix* and *Picea* forest on the surrounding slopes. During MIS 5a, a slightly warmer climate supported a *Pseudotsuga/Larix, Abies,* and *Picea* forest on the surrounding hillsides and a *Carex*-dominated environment within a dry meadow. From MIS 4 to MIS 3, a cool and wet *Pinus* and *Picea* forest predominated. Water levels rose, enabling *Nuphar* to persist within a perennial lake while a sedge fen established along the lake margin. As climate transitioned into MIS 2, a cooler and drier climate supported a *Pinus* and *Picea* subalpine parkland, though water levels remained high enough to support *Nuphar*. During the Last Glacial Maximum the sediment was mainly silt and clay with high *Artemisia* and very poor pollen preservation. Glaciers descended to 500 m elevation above Star Meadows in adjacent drainages suggesting a periglacial environment occurred at Star Meadows. Lake level decreased through the Pleistocene-Holocene transition (ca. 11.7 ka) and the site returned to a sedge peatland surrounded by an open *Pinus* forest. The most striking vegetation change occurred in the middle to late Holocene with the first occurrence and then later dominance of Cupressaceae pollen, most likely *Thuja plicata*, which is a dominant species in modern interior mesic forests. The late Holocene vegetation was uniquely mesic in the context of the last 120,000 years, casting doubt on this region serving as a glacial refugium.

APPLICATION OF GEOMORPHOLOGY AND QUATERNARY VERTEBRATE PALEONTOLOGY TO INFER LONG-TERM PATTERNS OF LANDSCAPE DYNAMICS AND BIODIVERSITY

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The sequence, frequency, time-span and magnitude of change in landscapes can help explain patterns of biodiversity (Watson et al., 2014). Quaternary climate change and human land-use have influenced long-term patterns of biodiversity, as inferred from changes in faunal communities over time (Swetnam, 1999; Louys, 2012). For example, processes contributing to the evolution of ecosystems in the northern Rocky Mountains are related to patterns of global change. These include the introduction and extinction of vertebrate species, land-use activities by humans, and conservation policies. Evidence of late Quaternary ecological changes before and after the presence of humans can be used in attempts to 1) distinguish natural environmental variability from human (anthropogenic) impacts, and 2) test models of the ways human activities are directly or indirectly linked to changes in the environment (Dietl and Flessa, 2011). This study examines long-term patterns of biodiversity connected with landscape change and human activity in mountain ecosystems using an integrative paleoescience-geohistorical approach (Willis et al., 2010; Dearing et al., 2011). It relies on data sets from paleontology, geoarchaeology, and landscape ecology. Methods include the collection of Quaternary fossils (mostly vertebrate remains) and artifacts from stratigraphic sequences, geomorphic field studies, and the use of historical and survey records.

Changes in landscape settings and biotic communities during the late Quaternary are inferred from these datasets. This is illustrated by deposits containing vertebrate faunal assemblages radiocarbon dated to before 10,000 years ago (the Younger Dryas or earlier) from Centennial Valley, Blacktail Cave, Indian Creek, MacHaffie, Sun River, and Sheep Rock Springs in the northern Rocky Mountains. These archives contain a mixture of extinct and extant fauna (Hill, 2006). For example, vertebrate assemblages from these localities contain extinct forms of genera such as *Mammuthus*, *Miracinonyx*, *Homotherum*, *Equus*, *Camelops*, *Bootherium/Symbos* as well as extant species such as *Canis latrans*, *C. lupus*, and *Castor canadensis*. While demonstrating the long-term presence of some faunal elements, there is also evidence for the restructuring of biotic communities after the Younger Dryas. The vertebrate assemblages from these stratigraphic localities appear to support the contention that, during the late Pleistocene and for most of the Holocene, the temporal and spatial distribution of biotic communities was strongly influenced by climate change.

Long-term patterns of human resource use and landscape evolution, as reflected in the geoarchaeological and geomorphic records, appear to have been initially connected with hunting and gathering. For instance, faunal assemblages from Lydle Gulch (Sappington, 1981) and Dry Creek Rockshelter (Webster, 1978), within Idaho's Boise River watershed help to characterize patterns of Holocene biodiversity and resource use. Vertebrate remains dating from about 3,500 to 800 BP include Artiodactyla (*Odocoileus*, *Antilicapra*, *Ovis*, and *Cervus*), Carnovoria (*Canis*, *Taxidea*, *Martes*) as well as Rodentia and Lagomorpha. The intensity of human influence on the physical environment and biodiversity increased during the late Holocene. Prior to the 1800s, human activities included the use of fire, and a reliance on terrestrial vertebrates and riparian resources.

During the 1800s long-term changes in landform processes and biodiversity resulted from activities such as beaver trapping, mining, logging, grazing and agriculture, and changing settlement patterns. For instance, in the Boise River watershed (Chaffee, 1931), extensive trapping of *C. canadensis* starting in 1811 led to its near or apparent extirpation by about 1834. Mining within the watershed began in 1863 and was associated with extensive logging. Grazing and agricultural practices along with a combination of other human activities contributed to the extirpation of large herbivores (the wapiti or North American elk, *Cervus elaphus*) and carnivores (wolf, *Canis lupus*). Management strategies initiated since the early 1900s, such as the reintroduction of extirpated ungulates (eg. wapiti) and carnivores (wolf), have affected biodiversity. In the time-span of the late Holocene a sequence of changes of different magnitudes--ranging from relatively low intensity use of riparian habitats and modifications associated with fires, human adaptations associated with the reintroduction of the horse, extirpation of beaver associated with trapping and the fur trade, landscape modifications associated with mining and deforestation, agriculture and grazing, irrigation and dams, abandonment and resource management, and the regrowth of secondary forests--have transformed northern Rocky Mountain ecosystems. The region presently contains wildland-urban interface areas where human activities are influenced by the geoecologic setting and intensification of human land-use has contributed to environmental change. Thus, climate change and human-induced environmental change appear to have influenced patterns of biodiversity and long-term landscape dynamics within the northern Rocky Mountain ecosystem.

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MULTI-SCALAR GEOLOGICAL AND PALEOENVIRONMENTAL ANALYSIS OF THE LINDSAY MAMMOTH, YELLOWSTONE BASIN, MONTANA

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Multiple scales of geologic analysis, ranging from isotope measurements to petrographic descriptions of rock fragments to regional landscape studies, have been applied to the investigation of a mammoth discovered near Lindsay, Montana. The skeleton was discovered in 1966 with subsequent excavations by L.B. Davis in 1967 (Davis and Wilson, 1985) and later geologic studies of the immediate locality and region (Hill and Davis, 1998). Here we provide a summary of some of the geologic studies that have been undertaken which include sedimentological and stratigraphic studies, identification of lithic raw materials, and regional-scale geomorphic studies. The stratigraphic and geomorphic investigations related to the Lindsay mammoth provide information on local and regional paleoenvironments, the chronology of geomorphic events, as well as taphonomic processes at the mammoth locality.

In eastern Montana, within the drainage basin of the Yellowstone River, a nearly complete skeleton of a mammoth (cf. *Mammuthus columbi*) was recovered about 12.4 km northwest of Glendive. The mammoth was found in an upland divide between the drainages of the South Fork of Deer Creek and Spring Creek (Deer Creek Church USGS 7.5 minute quadrangle). The Tertiary bedrock in this upland area north of the Yellowstone River is overlain by silt deposits (fine-grained clastics) containing buried paleosols. The mammoth remains were found embedded in these silts (see figure 1). Within the Lindsay locality stratigraphic sequence, a set of eight rock fragments composed of quartzite were found in association with the mammoth bones and imbedded in the silt. In some places, the sedimentary matrix enclosing the top of the mammoth bones contains higher levels of secondary pedogenic carbonates and is overlain by a buried soil A-horizon. Locally, gravels interpreted as remnants of older alluvial terraces also overlie Tertiary bedrock.

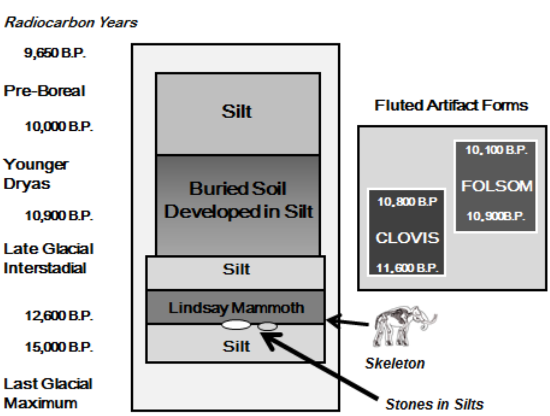

Figure 1. Schematic geology of the Lindsay Mammoth site.

A set of direct radiocarbon measurements of the mammoth bones as well as correlations with other regional geomorphic and stratigraphic localities, leads to the conclusion that the mammoth is older than 12,000 ^{14}C yr BP. Between 1973 and 2012, sixteen radiocarbon dates were obtained on materials from the mammoth bones. The youngest date is 9,490 +/-135 ^{14}C yr BP (I-7028) and the oldest date is 12,495 +/-88 ^{14}C yr BP (AA98617-1), while the measurements with the lowest standard deviations range from 12,220 +/-35 (SR-8254) to 12,300 +/-35 ^{14}C yr BP (SR-8253). The buried paleosol within the stratigraphic sequence at the Lindsay locality may correlate with buried soils exposed during stratigraphic studies of Oscar T. Lewis (OTL) Ridge, situated in the uplands south of the Yellowstone River. Radiocarbon measurements of the OTL Ridge buried soils suggest that they range in age from about 11,415-9,330 ^{14}C yr BP (Hill, 2006). If the radiocarbon measurements on the bones that are older than 12,000 ^{14}C yr BP provide the most reasonable age estimates, then the conclusion would be that the Lindsay mammoth is older than both the Younger Dryas (which has an age range from about 10,900-9,800 ^{14}C yr BP), and also older than Clovis artifact assemblages (which have been proposed to range from either about 11,600-10,900 or 11,050-10,800 ^{14}C yr BP. See Fig. 1).

Although the Lindsay locality is situated in an unglaciated region of the northern Plains, glacial lakes extended into the valleys of Redwater River and the Yellowstone River. These lakes were the result of the drainages being blocked by lobes of the Laurentide Ice Sheet. Glacial ice advanced to the vicinity of Glendive, where mammoth remains dated to around 20,500 ^{14}C yr BP have been recovered in alluvial gravels overlain by silts (Hill, 2006). Gravels at Wibaux contain tusk dated to about 26,000 ^{14}C yr BP (Hill 2006). These data suggest that a regional-scale series of alluvial deposits may be related to events associated with the Last Glacial Maximum. Deposition of the alluvium was followed by incision which resulted in the formation of the terraces. In this scenario, the silts containing the Lindsay mammoth remains are interpreted as loess that began to accumulate in upland areas prior to 12,000 ^{14}C yr BP. Deposition of wind-blown sediments continued throughout the late Pleistocene and early Holocene interrupted by several intervals of landscape stability perhaps correlated with the Younger Dryas and reflected by the buried soils observed within the stratigraphic sequences at the Lindsay mammoth locality and at OTL Ridge.

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GEOARCHAEOLOGY OF THE BEAR CREEK PALEOINDIAN SITE, KING COUNTY, WASHINGTON: PRELIMINARY STRATIGRAPHIC FRAMEWORK

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The Bear Creek Site (45-KL-839) remains the only archaeologically excavated site in the Western Washington segment of the Puget Lowland yielding Paleoindian artifacts in a dated (cal yr BP 12,700-12,596) and well-stratified context (Figure 1). The site was initially discovered in 2008 during a routine cultural resource assessment carried out in conjunction with a salmon restoration project in the City of Redmond, east of Seattle. Testing and data recovery excavations, the latter completed in 2013, have produced archaeological, geoarchaeological and paleoecological data relevant to understanding the human presence in the Puget Lowland landscape during the Late Pleistocene-Holocene transition. Even though analyses are ongoing, we take this opportunity to present the overall stratigraphic framework of the site and to propose our preliminary model of environmental shifts during this critical period of human entry into the New World.

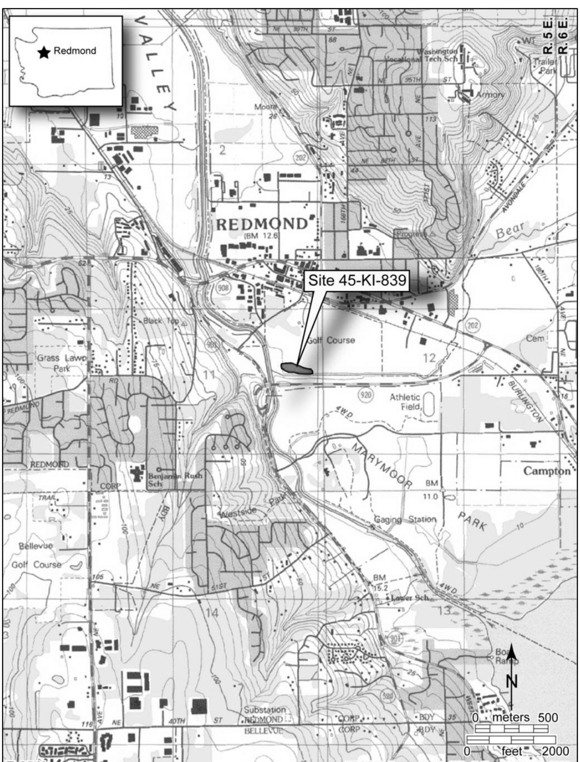

Figure 1. Bear Creek location.

The observations and analyses of the site deposits were organized using lithofacies types as the fundamental unit of observation. These were then grouped into larger units approximating depositional systems, here called *strata*, defined on the basis of bounding discontinuities separating groups of genetically related lithofacies (Table 1). Discontinuities include unconformities, soils, or facies transitions into unrelated depositional systems indicated by rapid changes in texture or style of bedding. The resulting stratigraphic framework is a reconstruction of site-specific depositional events and event sequences that form the basis for characterizing the chronostratigraphy and formation history of 45-KI-839, and for reconstructing the local landform history. The onsite depositional sequence, however, is related to broader-scaled events in the Sammamish Basin, and so offsite geological investigations are currently underway to erect a regional context to explain the shifts in depositional systems represented in the site stratigraphic record.

Table 1. Summary of Stratigraphy at 45-KI-839

Stratum	Facies Associations	Inferred Depositional Environment
I		Deposits associated with historical and modern land use.
II		A six-foot-thick sequence of diatom-rich silts (diatomaceous earth) interpreted as later Holocene Sammamish River slackwater alluvium which underlies the 19th century floodplain.
III	a, b	Ancestral Bear Creek alluvium represented by amalgamated braided channel deposits including ripple-laminated, horizontally laminated and trough-bedded sand, with numerous scour-and-fill structures and mud drapes. The basal unconformable contact to Strata V and VI passes to a conformable upper bounding contact with the overlying Stratum II. Stratum IIIa appears to be the western leading edge of a much later channel which is mostly east of the site.
IV		Sand beds and laminated sand-silt couplets along with discontinuous soil bodies preserved in topographic lows in the southwest portion of the site intercalated with Stratum II diatomaceous earth. This stratum is well-expressed west of the site and is considered to have been deposited by the ancestral Sammamish River.
V	a	Well-laminated clay, silt and organic matter representing the transition from the wetlands complex of Stratum Vb to the slackwater depositional system of Stratum II. Mazama tephra occurs at the upper contact of this facies association.
	b	Wetland complex consisting of a thick sequence of interbedded fibrous peat and sedimentary peat at the east end of the site laterally transitioning westward to thin fibrous and soil-affected peat at the west end of site; represents relative rise in water level.
	c	Thin artifact-bearing upland nearshore depositional system characterized by lateral facies shifts from predominantly silty sediments at the east end of the site to very fine sandy sediments at the west end of the site. Represents a period of relatively lower water level. Conformably overlain by the Stratum Vb wetlands facies association.
VI		Well-bedded cobble-gravel glacial outwash at depth veneered in places with poorly-sorted and fabric-supported reworked glacial sediments inferred to be ice melt-out.

The stratigraphy exhibits an overall well-defined tabular geometry in which the vertical shifts represent widespread shifts in depositional systems (Table 1 and Figure 2) and subdivisions within a stratum, particularly Stratum V, represent lateral facies shifts. The Paleoindian component (Vc), which was the major focus of excavations, rests directly on glacial sediments (Stratum VI) and is overlain by peaty wetland deposits (Stratum Vb). Other archaeological materials were found within diatomaceous earth (Stratum II) and in sandy stream channel deposits (Stratum III) associated with a fluvial erosional event that scoured obliquely through the central portion of the site. At the west end of the site, ancestral Sammamish River flood sediments (Stratum IV) are intercalated with Stratum II. During data recovery fieldwork, a 13-foot-deep channel excavated just outside the western site boundary showed the upper contact of the Stratum VI glacial gravels dipping westward from the site, and buried by a complex set of stream flood, wetland, and fan-delta depositional systems included in Stratum IV. Other nearby offsite exposures indicate the archaeological site occupied a well-defined, though subdued, topographic high.

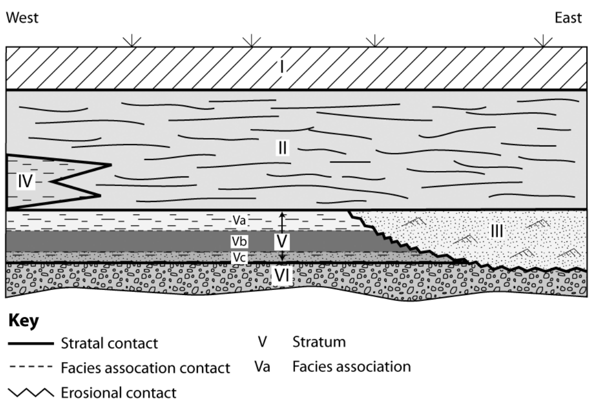

Figure 2. Schematic of major stratigraphic relationships

In addition to the mesoscale stratigraphic documentation described above, a column sample was collected from the west end of the site for micromorphological analysis to provide a more detailed examination of the bounding contacts between and within the strata bounding the Paleoindian-bearing facies association. The gradational contact between the diatomaceous earth of Stratum II and the peat of Stratum Vb, represented by Stratum Va, consisted of interlaminated diatomaceous silt, silty peat, and wholly decayed organic matter representing a gradual shift from a wetland to an alluvial slackwater or seasonal palustrine setting. The top of the peat is bioturbated, but otherwise lacks evidence for significant soil horizon differentiation. Within the peat, however, there is preferential bioturbation of certain lamina suggesting brief hiatuses and subaerial exposure during accumulation of the peat. Charcoal is present throughout the column and is especially prevalent towards the base of the peat; however, laterally extensive burned layers were not identified. At this sampling location, the silty fine sand facies of Stratum Vc exhibited incipient soil formation. Field observations suggest soil development in Stratum Vc exhibits a westward developmental trend and additional micromorphology samples are currently being analyzed to characterize and confirm this trend.

GEOCHEMISTRY AND MINERALOGY OF LOESS IN WISCONSIN INDICATES GREAT PLAINS SOURCE AREA

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Loess associated with transport and accumulation during the last glaciation occurs in several landscape regions in Wisconsin. Historically loess was recognized in the unglaciated Driftless Area and was believed to be sourced from the Mississippi River valley train. Increasingly, loess deposits have been recognized on land surfaces glaciated during MIS 2 and separated from thicker deposits close to the Mississippi River by broad sandy plains. Jacobs et al. (2011) proposed that loess on the southern Green Bay Lobe land surface was sourced in the Upper Mississippi Valley region and was delivered to the deglaciated land surface by repeated entrainment across an eolian sand landscape that acted as a surface of transport. The loess eventually accumulated on topographically high landscapes above the migrating sand. Jacobs et al. demonstrated that the mineralogy of 8-63 μm silt was not useful for determining the provenance of the loess, because all possible source units had statistically similar concentration of major minerals. However, because silt and clay travel together in loess sedimentary systems, they concluded that the smectitic clay mineralogy distinctly indicated a western source for the loess. Schaetzl (2012) questioned these conclusions and instead proposed, on the basis of grain size trends similar to those presented by Jacobs et al., that the loess was sourced from local glaciogenic deposits. In response to this, we have further analyzed the geochemistry of the silt minerals data set used in Jacobs et al.

Lab methods include an HF digestion of the 8-63 μm silt fraction samples, followed by analysis by ICP-OES for trace elements and a mix of light and heavy rare earth elements detectable by ICP-OES. Elements near the detection limit or with overlapping spectra were typically excluded from analysis, but the resulting data set includes 24 elements, including 9 trace elements, 8 LREE, and 7HRE elements. Analysis of the data includes comparison of elemental ratios, ternary plots, and normalized plots of elemental abundance in different lithologic units that could be sources of silt minerals. The original data set included samples of loess from the Green Bay Lobe land surface and the Driftless Area, glaciogenic sediments (till and outwash) of the Green Bay Lobe, and lake sediments from both Glacial Lake Wisconsin and Glacial Lake Oshkosh. New to this study is the addition of 10 samples from scattered loess and Cretaceous and younger bedrock units from the Great Plains, specifically from Iowa, Nebraska, and South and North Dakota.

Results tend to clearly group the loess from the Green Bay Lobe, the Driftless Area, and the various Western source units together in nearly all plots. The glaciogenic Glacial Lake Oshkosh sediments often plot together and are commonly separated from the cluster of points for the loess and Western source units. The silt from Glacial Lake Wisconsin often groups with the loess, but in some plots is intermediate between the clusters described above. Some notable differences include greater normalized concentrations of REEs in the loess and Western units, with the exception of a spike in the heavy REE Gd in the glaciogenic and Glacial Lake Oshkosh sediments, which likely is due to magmatic source rocks the Green Bay Lobe eroded (Figure 1).

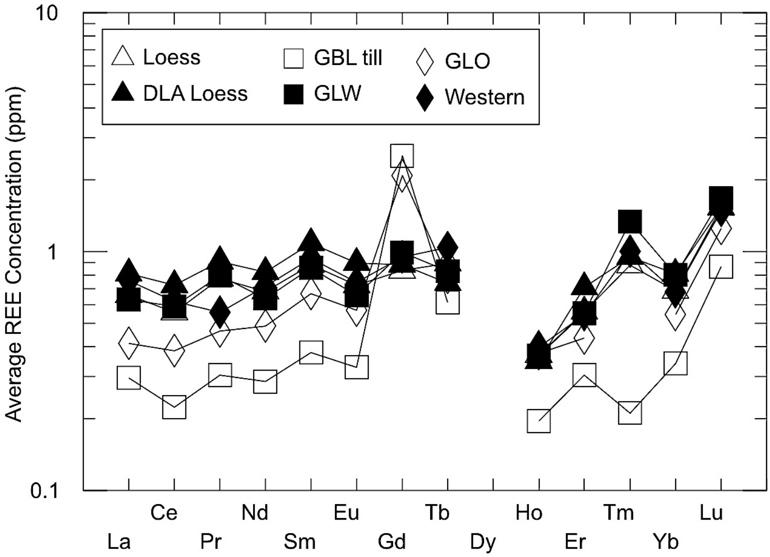

Figure 1. Average REE concentrations of sediment units normalized to upper continental crustal values (Taylor and McLennan, 1985). Note values for loess units and possible western source units are typically clustered and 2x in concentration. Symbols: Loess: Green Bay Lobe loess; DLA: Driftless Area; GBL till: Green Bay Lobe; GLW: Glacial Lake Wisconsin; GLO: Glacial Lake Oshkosh.

Trace element ratios and ternary diagrams also clearly cluster and discriminate the loess units in Wisconsin and the Western source units from the glaciogenic and lacustrine sediments (e.g., Figure 2). Our results support the contention of Jacobs et al. that loess mantling the Green Bay Lobe land surface is similar to loess in the Upper Mississippi Valley region. Furthermore, we hypothesize that Upper Mississippi Valley loess deposits have a strong provenance signal from rocks in the Great Plains, in part because both Late Wisconsin and Pre-Illinoian ice sheet lobes carried eroded material from the eastern Great Plains into the Upper Mississippi basin, but also possibly because of far-traveled dust transport from the Plains.

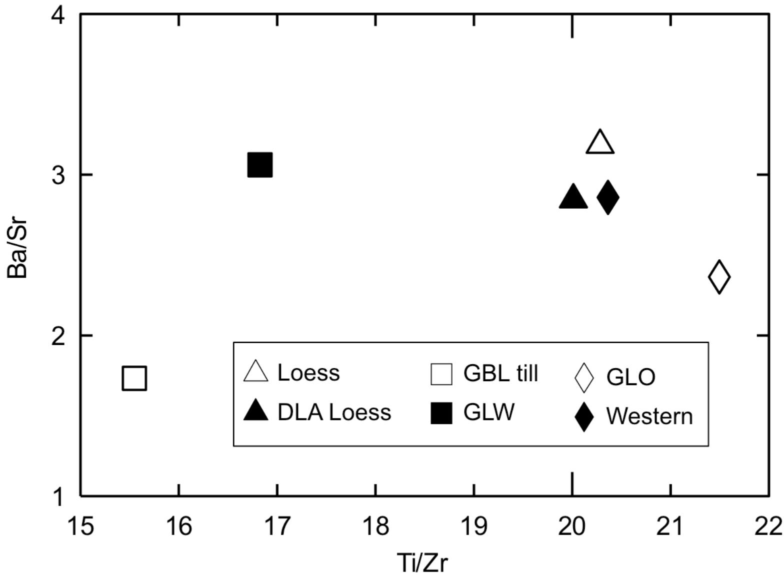

Figure 2. Scatterplot of average elemental ratio values for the lithologic units. Note the cluster of values for loess units and possible western source units. Symbols same as Figure 1.

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ENHANCED PRODUCTION IN LAKES UNDER WARMER CONDITION DURING THE MID-HOLOCENE PERIOD IN NORTHWEST ONTARIO

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Increases in anthropogenic emissions of greenhouse gases over the coming decades is expected to result in unprecedented climate change in boreal ecosystems, especially those located near ecotonal boundaries (Frelich and Reich, 2010). Climate warming will likely have adverse effect on boreal lakes in terms of both water availability and water quality. Increasing temperature could result in increases in primary production in lakes. Projections from General Circulation Models (GCMs), based on a range of future emission scenarios, suggest that annual air temperatures in northwest Ontario, Canada, will increase by ~2°C by 2020, and by > 3°C by 2050 (Chiotti and Lavender, 2008). In boreal lakes, our hypothesis is that overall lake production could increase drastically under warmer conditions. An objective of the current study is to assess if warmer conditions in the past resulted in changes in lake-water production in the past during by examining changes in algal and bacterial pigments and changes in diatom assemblages in well dated sediment cores during the Hypisthermal period in northwest Ontario.

The Hypisthermal period in North America is well known for enhanced aridity, in comparison to modern conditions. Pollen records spanning the Holocene from near the Manitoba/Ontario border to lakes up to ~300-km east of the prairie-forest ecotone, indicate a warmer and possibly wetter mid-Holocene period across northwest Ontario from ~8000 to 4500 cal yr BP. Near-shore sediment core (for detail Laird et al. 2011) were used to show that lake levels were substantially lower than today from 8.5 to ~4 K in three lakes studied in northwest Ontario (Laird and Cumming 2008, Karmakar et al. submitted). Evidence from a deep-water core (30 m) taken from Lake 239, showed that during the warmer mid-Holocene period, the diatom flora switched from a nutrient-poor diatom assemblage to a vastly more productive mesotrophic assemblage (Moos et al. 2009). Here we examined changes in the fossil pigment and the diatom assemblages from two other lakes (including Lake 239) from this region to understand lake production during mid-Holocene period when summer temperature was 1-4°C higher (Moos and Cumming, 2011). Fossil pigment analysis indicates enhanced production during mid-Holocene period. Chl a, β-carotene, cyanobacterial pigments increased in all three lakes. Additionally diatom assemblages and inferences of diatom-inferred TP showed change in trophic status with increasing higher nutrient diatom taxa. Fossil pigment and inferences from diatom assemblages indicate that enhanced lake-water production was common in the mid-Holocene period, and that similar changes might not be unexpected in the future.

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PALEOECOLOGICAL RECONSTRUCTION OF A MODERN WHITEBARK PINE (*PINUS ALBICAULIS*) POPULATION IN GRAND TETON NATIONAL PARK, WY

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Whitebark pine (*Pinus albicaulis)* is a critically threatened North American conifer. In modern times, it has experienced a significant decline in population due to pine beetle infestations, blister rust infections, fire suppression, and climate change. While climate, fire, and vegetation are strongly linked on regional and global scales, the relative roles of these three factors are not well-documented during the Holocene in high elevation mountain sites of North America. Recent anthropogenic changes in climate and fire management practices are underway, but the potential responses of subalpine vegetation to these environmental changes remain relatively unknown. Here, we documented the paleoecology of a watershed surrounding an unnamed, high-altitude pond containing a large number of whitebark pine trees located at 2805m elevation in Grand Teton National Park, U.S.A. Using a 1.5 meter lacustrine sediment core collected in 2010, we generated a Holocene-scale fire and vegetation record using fossil pollen, charcoal, and macrofossils preserved within the core. We also conducted a dendrochronological study of the current stand of whitebark pine in the watershed to determine both approximate dates of establishment and responses to past climate change of this modern stand.

Sedimentary charcoal data indicate significant variability in both fire frequency and fire intensity during the Holocene. The fire regime observed in the past 1000 years is seemingly unprecedented at this site, with lower fire frequency and higher fire intensity than any other time during the Holocene. Sedimentary pollen data suggest the study site has been primarily dominated by whitebark pine until the last 1000 years, with brief periods of vegetation dominated by non-arboreal taxa that indicate the presence of either successional dynamics or shifts in treeline location. Ages of individual living whitebark pine trees average 365 years, and dendrochronology data suggest that ring widths of the current stand have been declining since 1991. Statistical analyses of PRISM climate data with ring width data suggest that this decrease in annual growth is likely the result of decreased growing season temperature ranges driven by a warming climate. While this stand of whitebark pine is threatened by both warming climate and fire suppression, there is the potential for low-intensity prescribed burns to play a role in conservation and restoration management plans for this threatened conifer.

EXPANDED TEPHROCHRONOLOGY FOR THE 220,000-YEAR RECORD FROM CARP LAKE, WASHINGTON, USA

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Two cores from Carp Lake, Washington, reaching 23 m depth (bottom of sediment not reached), provide a 220,000 year paleoenvironmental and tephra record. The tephra beds both constrain the chronology of the cores and contribute information about regional volcanic activity, especially eruptions of Mt. Saint Helens (MSH). Previous work described 15 tephra layers (Whitlock et al., 2000).

Re-examination of the two cores yielded 55 samples of tephras and possible tephra-bearing sediments ranging in thickness from about 1 mm to 40 cm and with grain sizes range from fine ash to coarse sandy ash. Analysis of tephra glasses on the ARL-SEMQ electron microprobe at Concord University resulted in the identification of 37 tephra beds with well-defined geochemistries. In total, the cores have yielded 29 tephras containing rhyolitic glass, 5 with andesitic-dacitic glass, and 3 with basaltic glass. MSH sets Y, S, M, and C but apparently not J are represented by 8 beds. Also present are 10 older tephras with MSH set C-like, Y-like, and S-like chemistries. Together, these samples provide the best-known record of the early pyroclastic eruptive history of MSH. The lowermost tephra bed in the sequence has geochemistry that closely matches (Fig. 1) the ~215 ka Antelope Well tuff from Medicine Lake volcano which is also at Summer Lake, Oregon as bed KK (Kuehn et al., 2010). Together, the deposits at Carp Lake and Summer Lake document a NNE distribution of tephra from this eruption. The lower Carp Lake record also contains a tephra, which is compositionally similar to Summer Lake bed JJ. That the two corresponding deposits both occur several cm above the Antelope Well/KK bed adds further support for this correlation.

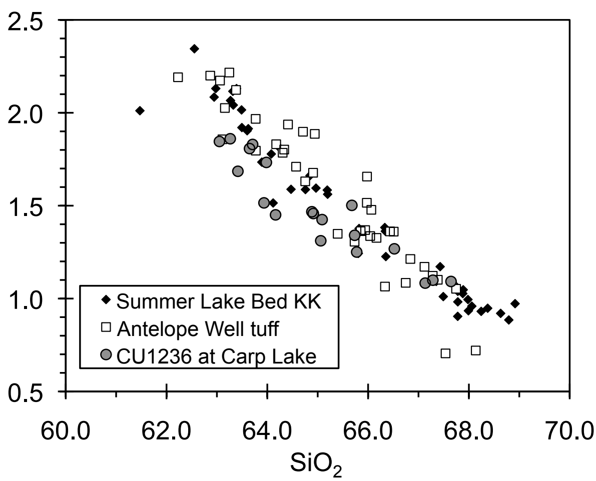

Figure 1. Comparison of glass geochemistry illustrating the excellent match between the lowermost bed in the Carp Lake cores (CU1236) and the Antelope Well tuff from Medicine Lake volcano in northern California and its equivalent at Summer Lake, Oregon.

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USE OF LATE PLEISTOCENE STRANDLINES AS INDICATORS OF LANDSCAPE STABILITY ALONG THE EMERGENT COASTLINE, MALIBU, CALIFORNIA, USA

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Quaternary stratigraphy and geomorphic analyses are routinely applied in California to assess landscape stability for the purpose of engineering mitigation and compliance with regional coastal planning guidelines. These studies are required by local government permitting agencies to assess geomorphic response of coastal terrain, predict future response and prescribe siting constraints. These studies typically rely on detailed mapping, subsurface exploration and geomorphic analyses that make use of historic photographic and topographic resources to assess terrain stability.

As a consequence of continued uplift and Late Pleistocene glacio-eustatic sea-level variation, a vertical sequence of at least three successive emergent marine terraces has formed at the base of the Santa Monica Mountains along the Malibu coastline (Davis, 1933). The strandlines typically consist of erosional and depositional elements. The erosional features are a planar marine-abrasion platform slightly inclined seaward that intersects a steep coastal bluff at the shoreline angle point.

A typical sedimentary sequence overlies the erosional features and commonly conceals the shoreline angle point. Beach deposits, consist predominantly of well-sorted sand that coarsens with depth, resting on a marine-abrasion platform. Gravel, where present, is generally found at the base of the deposits. The clasts, most of which are pebble size and are subrounded to rounded. Some beach deposits are unoxidized, or only slightly oxidized, and are not indurated, whereas other deposits are reddish brown (Munsell Hue $\leq$ 7.5 YR) and are moderately indurated; there are no consistent trends with age.

A wedge of colluvium occurs at the foot of most elevated coastal bluffs, commonly resting on the beach deposits. Thicknesses generally increase toward the base of the bluff thereby masking the shoreline angle except where exposed by erosion. Characteristic features include poor sorting of both matrix and gravel sizes, crude layering parallel to fan surfaces, the common occurrence of clay-rich layers, and only slight rounding of gravel clasts.

The accepted model of coastal development assigns a numeric age to each member of the terrace sequence (McGill, 1989, Heron and Shaller, 1997) that may be used to assess relative age of related features such as fault rupture and landslides. The Late Pleistocene strandlines also provide well-defined, laterally extensive marker units that may be used as a datum over the period subsequent to the shoreline regression. Where the shoreline angle is concealed observations of the lowest bluff exposure can be combined with the highest marine-abrasion platform exposure to sufficiently reduce uncertainty using the method of Birkeland (1972). A sufficient number of recorded observations now exist in public record archives to allow this use of Late Pleistocene shoreline angles despite apparent broad uplift and seaward tilting.

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QUATERNARY EROSION OF THE TSANGPO GORGE BY MEGAFLOODS, EASTERN HIMALAYA

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Where the Yarlung River crosses through the easternmost Himalaya to join the Brahmaputra River in India, it drops >2 km over a spectacular ~100 km knickzone: the Yarlung-Tsangpo Gorge. Presently, erosion rates within the gorge are extremely rapid (~7-10 mm/yr) and focused over an active crustal scale antiform, the Namche Barwa Massif. Quaternary and Neogene sedimentary units near the Brahmaputra confluence record similarly rapid exhumation rates (~5-10 km/Myr) sustained since the Late Miocene, suggesting the potential for a self-perpetuating relationship between focused erosion and rock uplift in this ~1200 km^2 region. However, striking evidence for widespread glacial ice and debris damming of the headwaters to the gorge suggest that river discharge may have been restricted during the Quaternary, limiting the erosional capacity of the river. We interpret Quaternary deposits ~100 km downstream of the gorge, remaining along valley walls at multiple elevations up to 150 m off the modern channel, as slackwater deposition from large-magnitude flood events following breaching of upstream dams. Using petrographic analysis and LA-ICPMS U-Pb dating of detrital zircons from five slackwater deposits and four analogous flood deposits from a lower magnitude flood in 2000, we demonstrate that these deposits originated in Tibet and are consistent with high-magnitude flood events that preferentially excavated material from the Yarlung-Tsangpo Gorge. Himalayan and Tibetan zircons are differentiable by U-Pb age, Himalayan zircons are >300 Ma whereas zircons sourced upstream of the gorge are dominated typically <100 Ma, derived from from Trans-Himalayan plutons and Tethyan sediments. While the modern zircon population downstream of the gorge reflects a ~30-50% bedload enrichment of gorge-derived Himalayan zircons already, flood sediments from high-magnitude events are twice as enriched. Interestingly, samples from the lower magnitude 2000 flood are not similarly more enriched, suggesting a threshold flood magnitude necessary for gorge excavation that may relate to coupling between flood scouring and shallow landsliding. With a simple illustrative model, we speculate that such megafloods may have been an important agent of erosion, contributing to the high long-term rates of rock exhumation during the Quaternary Period and potentially related to capture of the northern Yigong-Parlung River. Our results compliment a growing collection of detrital data from within the Yarlung-Brahmaputra network and contribute to the broader discussion of the influence of high-magnitude, low-frequency events on long-term landscape evolution and how that evolution may be preserved in the sedimentary record.

MAMMUTHUS FINDS IN FORMER LAKE LEWIS OF SOUTHEASTERN WASHINGTON

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The number, frequency, and relative size of Ice Age floods in southeastern Washington State have been the subject of much discussion. Studies on the distribution, geologic context and age of mammoth (*Mammuthus*) finds in areas inundated by temporary Lake Lewis document the impact of these floods on mammoth and by inference other Pleistocene animals.

Repeated cataclysmic floods that crossed southeastern Washington State encountered a hydraulic constriction at Wallula Gap, causing the floodwaters to backup over 275 m deep forming temporary Lake Lewis. Erosional trim lines and spillover channels in Wallula Gap indicate the largest of these temporary lakes reached an elevation of about 380 m in the Pasco Basin (Bjornstad 2006). These floodwaters carried with them a tremendous amount of debris including icebergs, erratics, vegetation, and animal carcasses.

It is not hard to imagine the impact of these cataclysmic floods on Pleistocene animals occupying low-lying areas in the path of the floods, nor how their remains may have been concentrated in quiet, backflooded areas of temporary Lake Lewis. Efforts to catalog the distribution of mammoth finds in southeastern Washington State have identified over 100 locations where mammoth skeletal elements have been found. Forty-five of these locations are located within the area inundated by temporary Lake Lewis. Although paleontologic and geologic context information and age controls are severely lacking for most of these sites, we have identified at least 24 sites as most likely located in Ice Age flood deposits. Eleven of these sites had multiple skeletal elements that were in most cases partially articulated suggesting that the mammoths died coincident with Ice Age flooding.

Four sites located in flood deposits have been assigned relative age dates greater than that of the Mount St. Helens set “S” tephra (estimated at about 16,000 years old [Clynne et al. 2008]). However, numerical (radiocarbon) age dates are available for only two of these sites, the Moxee City Mammoth Site (dated at 17,420 to 18,008 cal yr BP) and the Coyote Canyon Mammoth Site (dated at 17,146 to 17,795 cal yr BP) (Lillquist et al. 2005; Barton et al. 2012). The Moxee City mammoth date comes from an isolated tusk that was interpreted to have been relocated by floodwaters from its original location (Lillquist et al. 2005). Thus, the age of the flood deposits containing the tusk are somewhat younger than the tusk itself.

Four of the six sites for which there are some age data constraints (all >16,000 years old), are located at elevations below 235 m (180 m average), well below the maximum flood elevation of 380 m for temporary Lake Lewis. However, at elevations near 320 m both of the Moxee City and Coyote Canyon Mammoth sites are located much nearer the maximum flood elevation.

Waitt (1980), Last and Bjornstad (2009) and others have suggested that fewer flood events and shorter water columns have left fewer slackwater deposits at these higher elevations. Lillquist et al. (2005) identified evidence for three Ice Age floods at the Moxee City Mammoth Site, with an isolated tusk found in the last of these flood units. Guettinger et al. (2010) found evidence for six to seven floods, with at least four of these flood units potentially overlying the bone bed at the Coyote Canyon Mammoth Site. Subsequent excavation of the Coyote Canyon Mammoth Site has since shown that the mammoth bones are spread over a vertical interval of at least 50 cm. Last and Krogstad (2014) demonstrated that the youngest of the Ice Age flood deposits extends to about 15 cm overlying the mammoth bones. Graded beds (rhythmites) exposed in nearby measured section #1 at the site range from about 28 to 46 cm, suggesting that at least two different flood events were necessary to fully bury the mammoth remains. This is supported by work by Wahl and Barton (2013), who found that a number of bones from the Coyote Canyon Mammoth site show signs of scavenging by rodents and lagomorphs. This suggests that some period of subaerial exposure occurred after the mammoth carcass was initially deposited, and that subsequent floods then more fully buried the mammoth remains.

Mammoth remains in the Lake Lewis area and available paleontologic, geologic, and age constraining data, suggest that some mammoths (and by inference other Pleistocene animals) were likely swept to their deaths by the Ice Age floods coming to rest on the temporary shorelines of Lake Lewis, where their carcasses were scavenged, weathered, and partially scattered between flood events. This evidence also supports the hypothesis that early (>17,000 year old) Ice Age floods from the last glacial cycle were large enough to inundate areas above an elevation of about 320 m, while subsequent floods were restricted to lower elevations. It is also interesting to note that, within this area at least, mammoth remains have not been associated with Ice Age flood deposits younger than about 16,000 years old.

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LATE QUATERNARY STRATIGRAPHY AND PALEOENVIRONMENTAL CHANGE IN THE CIMARRON RIVER VALLEY, SOUTHWESTERN KANSAS

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Stratigraphic and paleoenvironmental investigations were conducted on late-Quaternary alluvial and eolian sediments preserved in the Cimarron River Valley, southwestern Kansas. The stratigraphy of two distinct alluvial fills (T-1 and T-2), as well as the Ogallala Formation into which the fills are inset, was studied in a series of sand pits in the Cimarron River valley.

The T-2 terrace fill consists of 3.5+ m of alluvium in which three buried soils are developed. The lowest buried soil has a prominent, 50 cm-thick A horizon. Soil organic matter (SOM) from the upper 10 cm of this cumulic soil yielded a radiocarbon age of 23,330 ^{14}C yr BP (Early Marine Oxygen Isotope Stage 2 [MIS 2]). A radiocarbon age from a similar buried soil exposed upstream in a gravel quarry (Porter, 1997) suggests that this soil began forming before ~33,000 ^{14}C yr BP (Late Marine Isotope Oxygen Stage 3 [MIS 3]). Based on these ages, the deepest buried soil is coeval with the loess-derived pedo-complex comprising the Gilman Canyon Formation on the uplands.

The T-1 terrace fill is 4.3+ m thick and contains four buried soils. Slow aggradation accompanied by soil development resulted in the formation of a prominent cumulic soil with a 40 cm-thick A horizon. Radiocarbon ages determined on SOM (10,490-10,890 ^{14}C yr BP) indicate that this soil formed during the Younger Dryas chronozone. Given the difference in elevation between the T-1 and T-2 surfaces, over 15 m of incision occurred sometime between ~23,000 and 11,000 ^{14}C yr BP. Pending OSL ages will help better constrain the timing of incision and aggradation in the study area.

Stable carbon isotope data (δ^{13}C) indicate major shifts in vegetation communities associated with climatic changes throughout the late-Quaternary. The δ^{13}C values for the Younger Dryas and MIS 2/3 soils show an increase in the contribution of organic matter from C_4 plants going from the bottom to the top of the soils. Also, δ^{13}C data reveal a dramatic shift after ~23,000 ^{14}C yr BP, from C_4-dominated (-14.6‰) plant communities to completely C_3-dominated (-23.52‰) communities. Analysis of the δ^{13}C data for paleoclimatic reconstruction is ongoing.

In addition to studying exposures of valley fills, a 50 m-long core was drilled on the High Plains surface, which captures a 20 m-thick eolian succession that buries the Ogallala Formation. The eolian succession consists of silty and sandy facies and eight buried soils. The buried soils are typically 1-3 m thick, with Bk-Btk-BC-C horizonation, and have stage II to III carbonate morphologies. Preliminary correlations indicate that the Gilman Canyon pedocomplex, the Sangamon Soil and a potential pre-Illinoian soil are preserved in the core. The δ^{13}C values indicate a predominantly C_3 signal throughout the sequence with shifts to a mixed C_3/C_4 plant communities during periods of soil formation.

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CHRONOLOGY AND CLIMATE OF THE LAST GLACIATION AND DEGLACIATION IN THE SANGRE DE CRISTO RANGE, COLORADO

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New ^{10}Be surface-exposure ages on moraine boulders and glacially polished bedrock surfaces yield information on the timing of the local last glacial maximum (LLGM) and the pacing of latest Pleistocene deglaciation in the Sangre de Cristo Range of Colorado. A total of eleven boulders have been dated from moraines in the Willow Creek, South Crestone Creek, and South Colony Creek drainages and along with eleven polished-bedrock samples from along the length of the Willow Creek drainage upvalley from the moraines.

Dating of moraine boulders indicates that the glaciers reached the LLGM maximum positions by about 20 ka and remained at or near this position until about 15.6±0.7 ka. The subsequent recession of 6.5 km-long Willow Creek Glacier was rapid. By 13.2±0.5 ka, ice had essentially disappeared from the valley, with bedrock exposed for more than 90% of the distance upvalley from the LLGM moraines to the valley-head cirque backwall. This LLGM and deglacial chronology closely parallels that of the Sawatch Range of Colorado, about 125 km to the northwest and, more broadly, is consistent with the pattern of Western U.S. deglaciation proposed by Young et al. (2011).

Application of a coupled distributed energy/mass balance and flow model (Plummer and Phillips, 2003) to the paleoglaciers in the Willow and South Colony Creek drainages provides information on temperature changes that would have been necessary to drive the dated glacial sequence. On an initial assumption that precipitation amount and seasonality have not changed, our modeling indicates that temperatures during the LLGM would need to have been 5.0-5.6°C colder than present (1970-2000 AD), to have sustained the LLGM glaciers in mass balance equilibrium. We are currently using the model to assess magnitudes and rates of climate change during the rapid deglaciation of the Willow Creek valley between about 15.6 and 13.2 ka.

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THE IMPACT OF MT. MAZAMA TEPHRA DEPOSITION ON FOREST VEGETATION IN THE CENTRAL CASCADES, OREGON

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The eruption of Mt. Mazama, ca. 7630 years before present, was the largest North American volcanic event during the Holocene. High-resolution pollen and charcoal analyses were used to examine the impact of Mt. Mazama tephra on forest vegetation and possible synergistic interactions with fire activity in the Central Oregon Cascade Range. We selected four small watersheds on a longitudinal transect north of Mt. Mazama and recovered lake sediment that spanned the period of tephra deposition. Our sediment records had between 17 and 35 cm of tephra deposited and we analyzed the sediment at centimeter resolution before and after the deposition horizon in each sediment record. Our analysis shows that non-arboreal pollen percentages and accumulation rates were depressed after Mazama tephra deposition. Recovery to pre-tephra deposition rates occurred after approximately 50-100 years. Arboreal pollen percentage and accumulation rates were less severely impacted suggesting that the Mazama tephra deposition disrupted understory communities more significantly than overstory species, and that forest communities returned to their pre-tephra-deposition conditions after approximately 50-100 years. Fire events in conjunction with the Mazama tephra occurred in two of the four sites suggesting that tephra deposition did not create conditions that precipitated a fire event in a consistent way. This research reinforces the notion that disturbance events may have cumulative effects on forest vegetation but that the impacts of disturbance events need to be felt by similar constituents of the forest ecosystem to be truly additive.

RECONSTRUCTING VEGETATION DISTRIBUTION PATTERNS THROUGH THE LATE QUATERNARY: INCORPORATING SPECIES ASSOCIATIONS THROUGH COMMUNITY LEVEL MODELS

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Understanding species response to climate change is imperative given the projected future. Traditional species distribution models (SDMs) predict species responses by utilizing species-environment relationships. However, biotic interactions also affect species responses and they are rarely included in SDMs. New community level models (CLMs) use multivariate approaches to infer and examine species co-occurrence patterns as well as climate in order to determine community structure and composition. With the inclusion of species co-occurrences, CLMs may achieve more accurate predictions of species distributions and community structure in response to climate change. Here we compare the predictive performance of a series of SDMs and CLMs on a robust database of fossil pollen occurrences from the Last Glacial Maximum to the present. By testing model performance on fossil occurrence datasets, we analyze the predictive ability of these models on novel climatic and environmental landscapes.

We used a variety of SDMs and CLMs to construct models for 500-year time slices from 21,000 yr BP to 1950 AD. Climate data for the models were based on downscaled CCSM3 paleoclimate simulations and pollen data were drawn from the Neotoma database. Models were then projected onto targeted time periods (e.g. the Younger Dryas). Model performance was analyzed with macroecological and species-level metrics.

Preliminary results indicate SDMs may predict species distributions and community composition better than CLMs even though they do not include species co-occurrences. The predictive accuracy of models varied between algorithms. For SDM-CLM model pairs, the SDM model performed better. The general linear models (GLM) and general additive models (GAM), both SDMs, perform best overall according to macroecological analyses (e.g. Jaccard Similarity) and test statistics (e.g. AUC). The artificial neural network models (ANN) had the least predictive accuracy. Overall, model performance decreased with increasing climatic dissimilarity. The inclusion of species co-occurrences and CLMs may not increase the predictive performance of species and communities in response to climatic changes, however the variation in predictive performance between models suggests inclusion of biotic interactions is influencing algorithms. Continued evaluation of CLMs will shed light on these differences and how CLMs can supplement traditional SDMs.

A 15,500 YEAR RECORD OF LANDSCAPE RESPONSE TO CLIMATE CHANGE PRESERVED IN ALLUVIAL FANS IN MIDCONTINENTAL NORTH AMERICA

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Alluvial fans along a steep bio-climatic gradient that extends from the dry-subhumid and semi-arid shortgrass prairie of the west-central High Plains to the moist-subhumid forest-prairie border of the Central Lowlands harbor well-preserved records of sedimentation and soil formation produced by landscape response to bioclimatic change. Alluvial fan development was time-transgressive across the region. On the High Plains of western Kansas and Nebraska, slow sedimentation began to form fans about 13,500 ^{14}C yr BP and was punctuated by multiple episodes of soil development between ca. 13,000 and 9,000 ^{14}C yr BP. Organic-rich cumulic soils dating to the Younger Dryas (11,000-10,000 ^{14}C yr BP) are especially common and are mantled by thick early- through middle-Holocene fan deposits; late-Holocene fan deposits generally are absent. In the Central Lowlands, on the other hand, alluvial fan sedimentation began between 9500 and 8500 ^{14}C yr BP and ended by ca. 2000 ^{14}C yr BP. Most fans in the Central Lowlands exhibit three major aggradation episodes; one from about 8500-6500 ^{14}C yr BP, a second from 6000 to ca. 4000 ^{14}C yr BP, and a final episode from 3000 to 2000 ^{14}C yr BP. This sedimentation pattern has produced a related soil stratigraphic pattern in those fans; buried soils dating to about 10,000, 8500, 6500, 4100, and 2500 ^{14}C yr BP are common. The two fan aggradation episodes associated with the greatest sedimentation rates, and by inference the most delivery of sediment from tributary basins, began about 8500 and 6000 ^{14}C yr BP respectively.

We postulate that regional climate change forced time-transgressive geomorphic response of small drainage basins that is reflected in alluvial fan sedimentation patterns across the region. Fan sedimentation cycles were driven by interactions among climate-related changes in vegetation communities that altered ground cover, and changes in the magnitude, frequency, and seasonal distribution of precipitation. These bioclimatic changes altered erosion, runoff and sediment delivery relationships in the basins feeding alluvial fans.

TIMING OF THE NORTHWEST COAST ICE GATES: GLACIER EXTENT AND RELATIVE SEA LEVEL ON THE GULF OF ALASKA MARGIN

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People may have first entered lower latitude North America by traversing the Pacific coast between Beringia and western Washington. Although this is an old idea, we still know very little about the feasibility of the Northwest Coast Route at various times in the past. Here we review what is known about glaciation and relative sea level (RSL) along the Pacific coast between the Alaska Peninsula and Southeast Alaska during the late Pleistocene (20-10 cal ka BP).

Glaciers advanced down Shelikof Strait to reach Low Cape on southwest Kodiak Island sometime after 26.4 cal ka BP. An area of several hundred km^2 remained ice free on Kodiak Island during the last glacial maximum (LGM), though it was largely filled by proglacial lakes (Mann and Peteet, 1994). Glacier modelling suggests ice probably reached the outer edge of the continental shelf south of Kodiak Island during the LGM. Deglaciation occurred at Low Cape (100 km inboard of outer edge of continental shelf) sometime before 17.6-18.2 cal ka BP (Mann and Peteet, 1994). On Sanak Island, 600 km west of Kodiak near the tip of the Alaska Peninsula and 40 km from the outer shelf edge, deglaciation occurred before 15.9-16.5 cal ka BP (Misarti et al., 2012).

A glacial readvance is recorded at Low Cape on Kodiak Island during a 500-year period beginning ca. 16 cal ka BP (Mann and Peteet, 1994). This advance seems to have terminated on the inner continental shelf. There is no evidence for glacial ice reaching Sanak Island again after ca. 16 cal ka BP (Misarti et al., 2012).

RSL records from the northwestern Gulf of Alaska are fragmentary and are complicated by tectonism along the Aleutian Trench. Jordan et al. (2001) found a postglacial marine limit of ~25 m in the inner fjord zone of the western Alaska Peninsula. Ice thickness during the LGM may have been 500-600 m in this area (Mann and Peteet, 1994), though Misarti et al. (2012) argue for significantly thinner ice based on purported trimlines on Sanak Island. The absence of raised marine deposits on southwest Kodiak suggests sea level has never been higher than today, implying minimal isostatic depression and therefore relatively thin ice cover on the continental shelf during the LGM. In turn, minimal isostatic depression suggests that sizable expanses of subaerial terrain existed on the outer shelf early in postglacial times.

A 1500-km gap in our understanding of glacial and RSL history exists in the northern Gulf of Alaska between southwestern Kodiak and the northern end of the Alexander Archipelago. Although there are classic examples of cross-shelf, glacial troughs along this coastline (Molnia, 1986), glacier timing is poorly constrained, and it remains uncertain whether these troughs were occupied by glaciers during the LGM.

In Cross Sound at the northern edge of the Alexander Archipelago, glacial trimlines onshore suggest an outlet glacier terminated at the outer shelf edge during the LGM (Mann, 1986). To the south, LGM ice overran Yakobi Island at high levels and terminated on the continental shelf. To the north along the outer coast of what is now Glacier Bay National Park, glaciers had a more restricted extent and terminated near the present coastline during the LGM. Ice had retreated out of the middle-fjord zone of Icy Strait by 14 cal ka BP (Mann and Streveler, 2008).

Further south, LGM glaciers probably reached the outer shelf edge at the mouths of major fjords in the Alexander Archipelago, but ice may not have covered intervening areas (Carrara et al., 2007). Unfortunately, the timing of LGM ice on the continental shelf is poorly constrained. The middle fjord zone of the Alexander Archipelago was deglaciated by 13.8 cal ka BP (Prince of Wales Island; Ager et al., 2007), and the inner fjords were deglaciated before 12.9 cal ka BP (Heceta Island; Ager et al., 2010).

RSL history in Southeast Alaska is spatially and temporally complex. On the outer coast north of Cross Sound, ongoing tectonism along the Fairweather-Queen Charlotte Fault greatly complicates interpretation of RSL. South of Cross Sound on the outer coast of Yakobi Island, the post-glacial marine limit seems to be only several meters above present high tide. In Icy Strait 130 km east of the outer shelf edge, RSL was 55 m above its present level at the time of deglaciation ca. 14 cal ka BP (Mann and Streveler, 2008) but then fell rapidly and passed below present sea level before 13.5 cal ka BP. Further south in the Alexander Archipelago, RSL more closely resembled the pattern at Haida Gwaii in northern British Columbia, where an isostatic crustal forebulge raised the land relative to the sea. In Sitka Sound on the west coast of Baranof Island, RSL was below -122 m prior to about 12.5 cal ka BP, while in the Gulf of Esquibel offshore of Prince of Wales Island, a transgression reached the present shoreline around 10.5 cal ka BP, and a highstand of about 16 m between 9.5 and 7.6 cal ka BP (Baichtal and Carlson, 2010).

In summary, at the southern exit from Beringia to the west of Kodiak Island, much of the continental shelf was probably ice-free and emergent by 17,000 cal yr BP. A similar situation appears likely to have existed along the outer coast of Southeast Alaska. This is good news for the opening of a feasible coastal route early in postglacial times; however, the intervening 1500 km of coastline in the northern Gulf of Alaska remains *terra incognita* regarding glacial and sea level history during the late Pleistocene.

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ABRUPT CLIMATE CHANGE IN THE NORTHERN MID-LATITUDES AT CA. 5KA: POLLEN-INFERRED EVIDENCE FOR SUB-CONTINENTAL-SCALE CLIMATE CHANGE

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Temperatures in North America have increased by ~0.91°C since 1880 AD. Future temperature changes are expected to exceed those of recent millennia, making rapid ecosystem and species changes likely. The past 11.5 ka (ka = 1000s of years before 1950 AD) of Earth history provide numerous examples of abrupt change in a system with boundary conditions similar to those of today, however, the physical processes driving these changes are not well understood. One technique used to examine past changes in ecological communities is the modern analog technique (MAT). This research employs the MAT across highly resolved sites in the northern mid-latitudes from the Great Plains to the east coast. Here, we interpret the MAT results not as a measure of absolute temperature change, but as an index of plant community temperature preference. The primary question of interest is whether these sites show evidence of abrupt change during the past 11.5 ka, and if so, what might be driving these changes.

Preliminary results indicate that most sites (n=14) show an abrupt change at ca. 5 ka, however, the direction of change is not always the same. Instead, coherent regions of cooling and warming are apparent. At 4 sites from North Dakota to Ontario, vegetation temperature preferences declined, while 9 sites from Iowa to Massachusetts indicate a preference for warmer conditions. One coastal Massachusetts site, however, indicates a dramatic shift to cool tolerant communities. These changes do not differ significantly in time across sites and with oxygen and carbon isotopic changes at multiple sites. The isotope data support the interpretation that climatic changes played a role in the ecologic community changes. Some studies suggest a northward shift in the jet stream around this time, as well as a negative phase of the North Atlantic Oscillation, which may have altered atmospheric circulation across this region, and thus, temperatures and storm tracks. The spatially heterogeneous nature of the MAT results suggest that future climate changes may not produce the same changes on sub-continental scales, abrupt changes are likely and need to be validated by climate models to fully understand the processes driving the changes.

HOLOCENE SEA RISE AND HUMAN LAND USE IN THE SAN FRANCISCO BAY AREA: A NEW RADIOCARBON-DATED SEA-LEVEL CURVE

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The first well-dated sea-level curve proposed for the San Francisco Bay Area was developed more than 37 years ago by Atwater et al. (1977), based mainly on the uncalibrated age and elevation of 13 radiocarbon-dated samples. Since then, numerous geologic, archaeological, and paleoenvironmental studies have been conducted throughout the Bay Area, which have generated literally hundreds of additional radiocarbon assays and stratigraphic data relevant for understanding the timing and extent of regional sea-level rise. As such, this study represents an exhaustive compilation and rigorous examination of 333 radiocarbon dates from the San Francisco Bay and Delta estuary system, and presents the results of a revised Holocene sea-level curve based on 250 radiocarbon dates from samples associated with marsh deposits that were formed near or above sea level. The rest (n=83, 24.9%) are samples of marine shells or organic sediments that were deposited in open waters or along beaches or shores at a wide variety of elevations that do not accurately monitor sea-level rise.

To estimate the rate of sea-level rise, we plotted the age and depth of all 250 marsh samples and fitted the models to this dataset using both Excel and a lesser known program known as "R." The latter is a programmable language for statistical computing and graphics developed by the Statistics Department of the University of Auckland that is available from the internet at no cost (www.r-project.org). In this case, R was selected because of its capabilities to perform a wide array of statistical techniques, such as linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, and clustering, in a more robust fashion than can be achieved in Excel.

The first model is a local polynomial regression that was created by using the "loess" package in R, with the span set to 0.3 and the polynomial degree set to 2. This span was selected because it was the smallest one that produced a reasonable amount of smoothing to the data. The resulting curve is plotted graphically against the raw data, along with a confidence interval of ±2-sigma error, the terms of which are extracted from the model using the "predict" package (Figure 1). This one is also called the "Punctuated Model" because the fitted data do not form a continuous curve, but are instead "stepped" through the middle part of the sequence.

The second model is a 3rd-degree polynomial regression (y~B0 +Age^3+Age^2+Age+err) using the robust linear regression package in R (rlm). Due to the substantial heteroschedasticity of the data, a robust regression was chosen rather than the standard regression package. That is, instead of being the same throughout, the error terms are more widely distributed across the older part of the sequence than they are at the younger end. Again, the predicted model is graphed against the raw data, along with a standard ±2-sigma error bar (Figure 1), extracted using the same analysis used for the Punctuated Model. This one is also known as the "Curve Model" because the fitted data form a relatively continuous curve over the entire sequence.

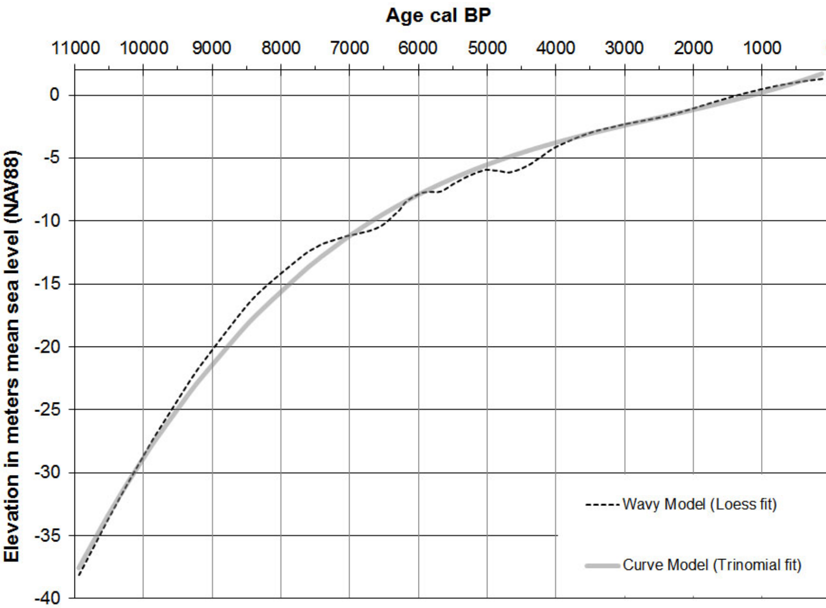

Figure 1. New Holocene sea-level curve for San Francisco Bay

When the two models are plotted against one another, the results are very similar, with any differences of one being within 2-sigma error range of the other. Here again, the only notable difference between these models occurs in the Middle Holocene, where some flattening of the curve is suggested by Loess analysis. This model identifies three "flat" periods, the first extending roughly from 7400 to 6600 cal yr BP, the second from about 6000 to 5600 cal yr BP, and the third between 5400 and 4600 cal yr BP (Figure 1), which may represent significant decreases in the overall rate of sea-level rise, or possibly, "still stands" or "near still stands" of the sea during the Middle Holocene. It is not known if these variations represent actual fluctuations in sea-level rise or whether they resulted from processes unrelated to sea-level rise (e.g., subsidence, tectonic movement) or reflect sampling bias or other undefined errors in the dataset.

Regardless, the earliest evidence of human use of estuary or tidal resources in the Bay Area first appears between about 6300 and 4600 cal yr BP, at sites such as CA-ALA-307 (West Berkeley), CA-MRN-17 (DeSilva Island), CA-SCL-484 (Warburton), CA-SCL-613 and CA-SCL-623 (San Francisquito Creek), SMA-40 (San Bruno), SMA-150 (Belmont), CA-SFR-28 (BART Skeleton), and possibly the Transit Center Skeleton. The appearance of these sites around the Bay is a strong indication that a substantial decrease in the rate of sea-level rise did occur during the Middle Holocene, and that it may or may not have included one or more still stands or slow-stands of the sea, as suggested by the Punctuated Model.

Based on the new sea level curve, a large part of the landscape once available for prehistoric human populations is now buried or submerged due to Holocene sea-level rise in the San Francisco Bay and estuary system. The discovery in early 2014 of an intact human skeleton at an elevation of 12.6 meters (41 feet) below sea level in downtown San Francisco is the fourth such example found below sea level in the San Francisco Bay over the past 45 years (Table 1). These discoveries underscore the need for accurate Holocene sea-level reconstructions to predict where buried or submerged prehistoric archaeological resources are likely located, and to evaluate long-term relationships between land, sea, and human occupation in the San Francisco Bay Area.

Table 1. Age and Elevation of Prehistoric Human Skeletons Found Below Sea Level in the San Francisco Bay-Delta Area.

Trinomial Site No. and Name	Area	cal BP (med. prob.)	Elevation meters (MSL)
CA-SJO-225, Potato Slough Skeleton	Delta	>4463	-2.60
CA-SMA-273, Coyote Point Marina Skeleton	Bay	4273	-3.65
CA-SFR-028, BART Skeleton	Bay	5630	-7.92
CA-SFR-xxx, Transit Center Skeleton	Bay	~7000	-12.65

Notes: cal BP is calculated median probability (med. prob.); Date from SJO-225 of 4463 cal BP on non-cultural peat above burial is the minimum age of burial; age of Transit Center skeleton based on new sea-level curve.

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CORRELATION OF FAULT-OFFSET FLUVIAL TERRACE SURFACES USING WEATHERING RINDS OF PERIDOTITE BOULDERS IN WILSON VALLEY, LAKE COUNTY, CALIFORNIA

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For over a decade, students from Humboldt State University and College of the Redwoods have been mapping and dating terraces along Cache Creek, located east of Clear Lake in northern California, within the federally designated Cache Creek Natural Area. This previous work has focused on identifying many of the terraces as well as recording the relative ages of subsets of terrace treads and risers by examining soil development. The goal of this study is to evaluate the age differences and possible correlation of two fluvial terraces, each with a vertical offset by suspected faulting. The study area is in an area of a tensional right-step between the lower Bartlett Spring and upper Berryessa fault systems. This was accomplished by examining the weathering rinds of peridotite boulders found on either side of the offset terrains. Because of the relatively fast rate of weathering of ultramafics, it is hypothesized that surface peridotite boulders on either side of the presumed faulting on the two terraces will have similar age characteristics, indicated by similar weathering rind thicknesses. Boulders on each side of suspected faulting have the same rind thicknesses and suggest the difference in elevation between the two surfaces is the result of offset by faulting, and not fluvial incision. Furthermore, age variation between the two stream terraces shows up as a significant variation between weathering rind thicknesses. A total of 480 boulders were randomly sampled. Rind thicknesses were measured to the nearest mm, perpendicular to boulder surface. Statistical analysis was performed using R studio. Sample size was determined using a 95% Power test after an initial pilot study of 60 boulders on the lower terrace (30 each side of suspected fault). A students T test and a Welches T test were used to determine if the populations across the faulted terraces are the same. Results yielded a 2-sided p-value of 0.314 across the older upper terrace and 0.428 across the younger lower terrace, indicating a failure to reject H_0 in each case. Using these two statistical tests, the populations across each fault were determined to be on the same surfaces, thus supporting the faulting of the terraces and differentiation of the two terraces.

ECOLOGICAL AND ANTHROPOGENIC DISTURBANCE REGIMES IN THE BRITISH VIRGIN ISLANDS

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Global climate change poses significant threats to the Caribbean islands. Increased global temperatures are predicted to change causing global sea level rise, and changing the frequency and intensity of storm events. Little is known about the long-term disturbance regimes in these island ecosystems. This research investigates the past 1000 years of natural and anthropogenic disturbances through the analysis of a latitudinal transect of sediment records from coastal salt ponds in the British Virgin Islands. There are two primary research aims in this study: (1) to determine long-term patterns of tropical cyclone frequency and intensity, (2) to explore anthropogenic landscape modification pre- and post-European settlement. This research employs a multiproxy paleoecological approach including (eg: pollen, charcoal, grain size and isotope analysis) combined with high-resolution chronologies to provide a window into past frequency of cyclone activity in the Caribbean. These data will be used to evaluate the ecological response to changes in cyclone activity. The extent of anthropogenic landscape modification, including the introduction of grazing, agriculture and invasive plant species, will also be investigated through high-resolution pollen and charcoal analysis. Preliminary grain size analysis from two sediment records from Thatch Island and Belmont Ponds identify three major storm surge events over the last 800 years. Significant storm surges, e.g. hurricanes, are identified by bands of sand within the predominantly fine organic-rich sediments of these coastal salt ponds. Charcoal data indicate a significant increase in fire activity following large storm events. This research represents a significant contribution to a largely underrepresented database of paleotempestology. This network of data can then be compared to modern hurricane records to better understand the evolving mechanisms responsible for changing hurricane risk.

FORESTS, FIELDS, AND FLOODS: A LATE HOLOCENE ENVIRONMENTAL HISTORY OF CAHOKIA AND THE CENTRAL MISSISSIPPI RIVER VALLEY

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Cahokia emerged as a major Mississippian population center in the central Mississippi River valley at 1050 CE, but the entire region was almost completely abandoned by 1350 CE (Milner, 1998). Environmental changes, namely resource depletion, flooding, and/or drought, have previously been invoked as important factors in Cahokia's emergence and decline (Woods, 2004; Benson *et al.*, 2009), although few paleoenvironmental records exist from this region to test these hypotheses. Here, we present multi-proxy paleoenvironmental records (pollen, charcoal, $\delta^{13}C_{org}$, particle-size) from three oxbow lakes along the central Mississippi River valley that provide an ecological and hydro-climatic history for Cahokia and its surrounding region.

At Horseshoe Lake in Madison Co., IL, situated adjacent to the Cahokia site itself, pollen assemblages track the abrupt removal of floodplain and upland trees and the expansion of indigenous seed crop production beginning at A.D. 450, during the Late Woodland period, followed by the gradual intensification of maize agriculture through the Mississippian period to the abandonment of Cahokia at A.D. 1350. At Horseshoe Lake in Alexander Co., IL, situated 200 km downstream near the confluence of the Mississippi River with the Ohio River, the abrupt replacement of trees with stands of indigenous seed crops also occurs during the Woodland period, although there is little agricultural activity during the ensuing Mississippian period. Together, these records demonstrate that early forms of agricultural land use based primarily on indigenous seed crops constituted an important driver of vegetation communities at broad spatial scales along occupied sections of floodplain and adjacent uplands. Our data also demonstrate that humanized landscapes emerged in the central Mississippi River valley centuries before the emergence of Cahokia and other large settlements.

At all sites, flood waters from the Mississippi River deposited layers of distinct fine-grained sediment during high magnitude flood events. In Horseshoe Lake (Madison Co., IL), adjacent to Cahokia, the most pronounced flood deposit consists of 19 cm of well-sorted fine silt dated to A.D. 1200 ± 80, corresponding with the onset of Cahokia's decline. At least three additional flood events are recorded over the following centuries, with the most recent event corresponding with the historic A.D. 1844 flood, reported to have inundated much of the floodplain around Cahokia. Several of these large flood events are also observed in the sedimentary record from Grassy Lake (Union Co., IL), situated 170 km downstream from Cahokia.

The timing of these large flood events implies that a shift in flood regime towards more frequent high magnitude events may be linked to the abandonment of Cahokia and its surrounding region during the Late Prehistoric period (e.g., Cobb & Butler, 2002).

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ACCELERATION IN SEA-CLIFF EROSION?

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Retreat-rate estimates presently provide the primary measurable for studying sea-cliff erosion and for monitoring the response of this ongoing ubiquitous process to environmental changes such as sea-level rise, changes in stormicity and precipitation patterns, near-shore ocean dynamics and anthropogenic influences [e.g., 1, 2]. Where available, retreat-rate measurements of sea-cliff erosion are frequently as high as several m/yr for annual observation windows, are typically < ~1 m/yr over decadal-scale time windows and are < 0.1 m/yr for centennial-millennial time-scales [e.g., 3]. Here, we examine the physical significance of such apparent time-scale dependency in sea-cliff retreat-rates and assess our ability to effectively measure recent changes in sea-cliff erosion with such measurements.

We focus on Israel's actively retreating Mediterranean eolianite sea-cliff and use airborne LiDAR data, near-shore underwater surveys, luminescence dating and archeology to examine the process and rates of sea-cliff retreat since the mid Holocene. Our results indicate 'background' millennial-centennial inland retreat rates < 0.06 m/yr that compare with decadal and annual-scale rates of up to ~1 and 10 m/yr, respectively, previously determined for this sea cliff [4-6]. We find a cliff-parallel retreat pattern since the mid-Holocene driven by localized retreat events of 15±5 m per ~0.5-1 kyr. Plotted as a function of duration of their observation time-window the maximum retreat-rate estimates for the examined sea-cliff plot along a simple reciprocal function of observation time-scale. It thus appears that the apparent acceleration in modern retreat rates likely results from a sampling bias of a natural geomorphic process characterized by episodic activity with a characteristic time-scale that is longer than sampling time intervals.

In addition to the local implications on sea-cliff retreat in the eastern Mediterranean our results highlight the due caution in interpreting measurements of modern sea-cliff retreat rates in other actively eroding 'soft rock' sea-cliff environments, e.g., other Mediterranean coasts, the US west coast, Europe's northern coast and Japan. We propose that 3D measurements of volumetric changes in sea-cliff morphologies provide a new and more efficient approach for monitoring sea-cliff erosion and detecting changes in erosion rates with short-duration (annual-decadal) observations.

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ICE RETREAT TIMING AND BEDROCK EROSION OF THE PUGET LOBE OF THE CORDILLERAN ICE SHEET

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During the Frasier glaciation, ice from the Cordilleran ice sheet flowed south from Canada across the San Juan Islands and into the Puget Lowland. This ice lobe, known as the Puget Lobe, reached its maximum extent in the Puget Lowland ~16.95 cal. ka ago (Porter and Swanson, 1998), and soon after began to retreat. We collected and measured cosmic ray-produced ^{10}Be in glacial erratics and glacially eroded bedrock samples from around the Puget Lowland and San Juan Islands in Washington State. Measured ^{10}Be concentrations in these rocks can be used to calculate their exposure ages, and in the case of bedrock samples, infer the extent of erosion by glacial ice. We compare the ^{10}Be chronology to existing ^{14}C dates from the Puget Lowland (Porter and Swanson, 1998). Where dates diverge significantly from existing ^{14}C chronology we can identify instances of limited erosion, resulting in anomalously high concentrations and apparent exposure ages, and shielding due to soil, sediment or tree cover, which diminishes the ^{10}Be and apparent exposure age.

Bedrock samples from Goose Rock, located on the north end of Whidbey Island, yielded apparent exposure ages older than downstream radiocarbon dates, which would require limited glacial erosion of the landform during the last glaciation. Two overprinted sets of glacial striations preserved at Goose Rock may be related to a brief readvance of the retreating ice when it became grounded at Penn Cove, central Whidbey Island, following calving retreat. Further exposure dating of erratic boulders or radiocarbon dates from Penn Cove are needed to test this hypothesis. Bedrock samples collected further north, on Mt. Constitution, eastern Orcas Island, showed no prior exposure in a 5-sample north-south transect across the mountain and are consistent with radiocarbon ages located upstream and downstream of that location. Exposure ages are consistent with an ice-free Mt. Constitution by ~14.5 ka. Samples collected from large glacial erratic boulders in the southern Puget Lowland, near the terminus, greatly underestimate the true exposure age, possibly due to heavy shielding from cosmic radiation in thick forest (Bretz 1913). With independent age constraints, cosmogenic isotope measurements from these samples could be used to estimate forest canopy biomass following deglaciation (Plug 2007).

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DEGLACIAL CLIMATE VARIABILITY IN THE GULF OF ALASKA

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Resolving the deglacial climate history of the North Pacific is not only relevant for our understanding of northern hemisphere climate dynamics, but also for understanding the climatic context of human adaptation and migration into the Americas across the Bering land bridge. So far, high-resolution records with precise chronologies from this region have been sparse, and paleoclimate models and proxy reconstructions have been in disagreement about the deglacial climate changes that are predicted/observed to have occurred. Marine sediment records from the Gulf of Alaska (GOA) have exceptionally high resolution (~1 cm/yr) with excellent age controls (28 radiocarbon dates), and span the last deglacial transition (18 – 10 ka), providing the most detailed climate reconstructions to date from the high latitude North Pacific. These new climate records include multi-decadal scale planktonic oxygen isotopes and alkenone temperature estimates, as well as a regional record of ice-rafting and deglacial volcanic activity sourced from the Mt. Edgecumbe volcanic field.

Gradual warming from glacial conditions was initiated at ~16 ka, but an abrupt warming of ~4-5°C occurred at 14.7 ka, coincident with the onset of the Bolling-Allerod warm period (BA). Climate fluctuations in the GOA closely mirror those observed in the Greenland ice cores throughout the Bolling to Holocene climate sequence, in contrast to studies that suggest the North Pacific should experience opposite climate patterns to those in the North Atlantic. The sediments record high input of ice-rafted debris (IRD) during the late glacial period (18 - 14.7 ka), indicating that marine-terminating glaciers persisted in the GOA until the rapid warming at the onset of the Bolling, making a coastal route for the first Americans seem challenging prior to this warm event and the pull-back of glaciers. An interval of peak volcanic activity from Mt. Edgecumbe occurred from 14.9 – 13.1 ka, which was concurrent with the transition to BA warmth, the disappearance of IRD, and a period of rapid vertical land motion associated with modeled isostatic adjustment in response to glacial retreat, consistent with the idea that regional deglaciation can trigger volcanic activity. The timing of intense volcanic activity also coincided with a period of high climatic variance in the foraminiferal oxygen isotopes and alkenone temperature records, suggesting a possible feedback between climate and volcanism, in which isostatically induced volcanism may enhance climate variability during the deglaciation. These climate records point to a highly dynamic environment during the presumed period of first human migration into the Americas.

HOLOCENE TEPHROSTRATIGRAPHY IN HIGH-LATITUDE PEATLANDS OF THE SOUTHERN HEMISPHERE: A LINK THROUGH TIME?

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We present preliminary tephrostratigraphic data from south Patagonian peatlands and moss-banks from the Antarctic Peninsula that provide greater chronological constraint to Holocene palaeoclimatic records and increase the potential for inter-regional correlation.

Relative to the Northern Hemisphere, there is a paucity of high-resolution, robustly dated Holocene palaeoclimate records in the Southern Hemisphere. This paucity must be addressed in order to validate climate models and improve our understanding of the global climate system. The southern westerlies represent an important component of the climate system in the region and, in turn, variation in their position and intensity play a key role in determining whether the Southern Ocean functions as a sink or source of atmospheric carbon dioxide. Variability in the southern westerlies is strongly influenced by the Southern Annular Mode, an atmospheric pressure gradient between the high and mid-latitudes of the Southern Hemisphere. However, as regional instrumental records are limited to the latter half of the twentieth century, relatively little is known about the long-term variability of the southern westerlies and their subsequent effects.

Southern Patagonia is directly situated in the core path of the southern westerlies during the austral summer making it ideally suited for studies of past westerly variability. Abundant *Sphagnum magellanicum* dominated peatlands can record long-term atmospheric circulation changes, as wind intensity and westerly latitudinal position affects precipitation and temperature, two key drivers of water-table dynamics in ombrotrophic peatlands. Similarly, moss banks provide a unique terrestrial palaeoenvironmental archive from the Antarctic Peninsula. Records of past ecological change are rare on the Peninsula and provide vital context for the recent, rapid biotic change recorded since the mid-20th century. We have developed regional networks of multi-proxy palaeohydrological reconstructions (testate amoebae, plant macrofossils, $\delta^{13}C$, $\delta^{18}O$ and δD) for both regions from archives that are currently underexploited in terms of palaeoclimate reconstruction.

Robust chronologies are imperative for the accurate examination of spatial and temporal patterns in Holocene climate variation. Tephrostratigraphy provides valuable marker horizons that can be geochemically identified across sites in a region. Previous research has demonstrated that discrete tephra horizons are preserved well in south Patagonian peatlands but the presence of distal, cryptotephras are not widely confirmed and are thus underemployed as a geochronological tool. Initial results confirm the presence of cryptotephra layers in Antarctic Peninsula moss bank cores.

The chronological potential of both regions is considerable, given their high and largely continuous accumulation rates and abundance of *in situ* organic material suitable for ^{14}C dating. This presents opportunities to refine the ages of major Holocene eruptions using high-resolution ^{14}C and short-lived radioisotope chronologies.

Crucially, the confirmed presence of tephra horizons of Patagonian origin in Antarctic ice-core records demonstrates that atmospheric distribution of tephra shards via tropospheric pathways may provide a potential method of linking palaeoclimatic records from south Patagonian peatlands and moss-banks from the Antarctic Peninsula. Here, we present initial tephrostratigraphic results from both regions and explore the links between them.

POLLEN ANALYSIS FROM THE PAISLEY CAVES & APPLICATION TOWARDS A LARGER PALEOECOLOGICAL CONTEXT

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Pollen from Paisley Caves in south central Oregon recovered from stratigraphic context represent a 6,000 year time span from 7,600–13,600 cal yr BP. Initial pollen analysis from Cave units 2/6B and 2/4C have yielded a high resolution record of climate-driven ecological changes within the Summer Lake sub-basin, and show the impacts of the Younger Dryas cooling period and the Pleistocene to Holocene warming trend. These climate shifts were light in the Paisley region but distinct and help shed light on the paleoenvironmental context of early human occupants at Paisley Caves. The results from Paisley Caves will be discussed as a model of approach towards questions of a larger, region-wide paleoenvironmental context.

LATE-QUATERNARY FLUVIAL STRATH TERRACE EVOLUTION, RELATIVE DATING, AND MINERALOGY ALONG THE NORTH FORK OF CACHE CREEK NATURAL AREA, LAKE COUNTY, CALIFORNIA

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Many river systems have retained a geologic record of long-term incision rates through the development of fluvial strath terraces. These geomorphic features may reflect paleo-climatic event signatures, tectonic events, or both. In northwestern California, there have been many strath terraces identified, mapped, and studied along multiple watersheds within the region of the Mendocino Triple Junction (MTJ). The MTJ is the region where the North American, Gorda, and Pacific plates meet. Cache Creek Natural Area (CCNA) is a watershed that has been influenced by the northward migration of the MTJ, and is located within the northeastern portion of the large strike slip boundary (San Andreas fault system) formed between the North American and Pacific plates. The CCNA is located east of Clear Lake, Lake County, CA., approximately 220 km south-southeast of the MTJ, bordered by right lateral strike slip faults, the Bartlett Springs to the NW and the Berryessa fault system to the south.

Investigation of soil development on terrace surfaces have provided a general soil chronosequence, relative dating, and clay mineralogy variations. This portion of our research was conducted primarily to provide further insight into the timing of landscape evolution and the history of early human occupation within the CCNA. A major goal of our studies is to investigate the relation between times of occupation and geologic events. The active tectonic setting of the CCNA has made correlation of terrace remnants difficult. However, the relative ages and spacing of the terrace flights are providing valuable insight into the style and age of the tectonics.

CONSTRAINING THE CLIMATE AND DYNAMICS OF THE LAST ICE LOBE TO COVER THE PUGET SOUND IN WESTERN WASHINGTON

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The climate and dynamics of the Puget Lobe of the former Cordilleran ice sheet during the last glacial maximum (LGM) advance are investigated using a mass budget study and a two-dimensional ice flow model. The Puget Lobe is an ideal candidate for this modeling investigation because its extent, surface profile, chronology, and bed topography have been well-studied, providing many constraints. A range of steady-state climate functions is generated, and then used in a shallow ice approximation and Weertman sliding ice flow model to determine which best reproduces the reconstructed profile of the lobe and the lobe's sensitivity to climate. Non-steady-state climates and ice flow that could build and sustain a lobe for the time period of actual occupation are also modeled; the lobe is determined to be near steady-state. Best-fit lobe paleo-climates are relatively dry (0.5 to 1 m/a ice equivalent accumulation) and 7 to 8°C cooler than today. Modeled sliding speeds in the center of the lobe vary from 350 to 550 m/a dependent on the climate of the lobe. As the lobe encountered the Olympic Mountains it banked up against the range; the modeled super-elevation locally enhanced both ice and basal water flow and probably contributed to the incision of Hood Canal of the Puget Sound.

POST-GLACIAL SEA LEVELS IN PACIFIC NORTH AMERICA – HINGE ZONES AND HUMAN OCCUPATION

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Post-glacial relative sea level (RSL) histories vary with distance from ice loading and associated factors such as time-transgressive ice retreat, diverse tectonic settings, and differential crustal responses. At the last glacial maximum (LGM), the Cordilleran Ice Sheet depressed the crust over which it formed and created a raised forebulge along peripheral areas offshore. We synthesize the state of knowledge regarding post-glacial sea-level changes on the Pacific coast of North America based on approximately 2,200 previously published radiocarbon dates from northern California to Cook Inlet, Alaska. We then describe a 1000-km long hinge zone, separating the isostatically depressed inner coast from the forebulged outer coast, and discuss the implications for human occupation, based on 100 new radiocarbon dates from the central coast of British Columbia.

On the Oregon and much of the Washington State coasts, which were unglaciated, RSL history was governed primarily by eustatic sea level rise, overprinted by seismically induced RSL changes due to subduction earthquakes. In British Columbia and southeast Alaska, which were heavily glaciated at the LGM, early-postglacial marine highstands range from 150 m above present mean sea level (masl) around the Lower Mainland (greater Vancouver area), to 200 masl at Kitimat on the north British Columbia coast (Clague, 1981), and 230 masl at Juneau in southeast Alaska (Mann, 1986), due to isostatic depression. At these fjord head locations, RSL rapidly dropped with isostatic rebound. In the Lower Mainland and near Victoria on Vancouver Island, RSL dropped below present datum in the early Holocene, prior to reaching present levels (James et al., 2009). At Kitimat and Juneau, no data below the present shoreline, and very few Holocene-age data are available. Offshore on Haida Gwaii, Hecate Strait and Queen Charlotte Sound, sea levels were up to -150 masl lower than present due to a crustal forebulge raising the land relative to the sea (e.g. Fedje and Josenhans, 2000). As the forebulge collapsed, the sea transgressed the present shoreline at the beginning of the Holocene, reaching a highstand of about 16 masl on Graham Island (Wolfe et al., 2008), before dropping slowly to the present level. The forebulge extended into southeast Alaska, raising parts of the Alexander Archipelago and resulting in RSL at least -122 masl and possibly as much as -165 masl in the late Pleistocene (Baichtal and Carlson, 2010). Data to constrain post-glacial RSL in south-central Alaska are scant, but a number of sites (e.g. Reger and Pinney, 1995) record a relatively low marine limit, ranging from 10 to 36 masl in Cook Inlet for example, followed by regression during much of the Holocene.

The post-glacial RSL history for several locations on the northwest coast of North America can be described as relatively stable, where isostatic effects kept equal pace with eustatic sea level rise. These include (from south to north) the Broughton Archipelago and the northern tip of Vancouver Island, the Bella Bella/Calvert Island region on the central coast of British Columbia, the Dundas Islands Archipelago near Prince Rupert, and the area east of Prince of Wales and Baranof islands in the Alexander Archipelago. These regions form a hinge zone, demarcating the isostatically depressed inner coast, from the forebulged outer coast. The stable shorelines along this hinge zone represented a reasonably hospitable landscape for human occupation and as a result, some of these regions have proven to contain rich archaeological records. On the central coast of British Columbia, we record evidence of persistent human occupation for at least 10,000 years, which represents some of the longest continuous records of occupation on the northwest coast.

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A NORTHERN BERING LAND BRIDGE ENVIRONMENTAL RECORD FROM THE CHUKCHI SEA: OSTRACODE AND POLLEN EVIDENCE FOR RAPID CLIMATE AND VEGETATION CHANGE PRIOR TO THE MARINE TRANSGRESSION

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A 270 cm-long sediment core collected from the northeastern Chukchi Sea (USGS Core 70-92; 69.95° N, 165.367° W, 42 m depth) penetrates 130 cm of marine sediments, then 140 cm of terrestrial Bering land bridge sediments dating to the final two millennia before the core site was inundated in the marine transgression during deglaciation. Three AMS radiocarbon ages on fine plant detritus (processed to remove coal particles) provide the chronology for the core. Analyses of ostracode and pollen assemblages preserved in the terrestrial sediments provide a basis for reconstructing a rapid sequence of environmental changes between ~14,900 cal yr BP and ~12,900 cal yr BP when the site was flooded by rising seas. Ostracode assemblages can be assigned to four zones that reflect faunal changes that responded to environmental and climatic changes during those 2000 years. Zone 1, the oldest (270-258 cm core depth; ~14,900 cal yr BP) contains a cold climate assemblage that includes ostracode taxa that are now found only in the high arctic. Zone 1 taxa include *Pteroloxa cumuloidea* and *Candona rectangulata*. *P. cumuloidea* is tolerant of salt spray and estuarine conditions in the Arctic today, suggesting some slight exposure to nearby ocean water or spray at this time. Zone 2 (257-250 cm; ~14,640 cal yr BP) ostracode assemblages suggest an ephemeral freshwater pond environment under a much warmer climate, with summer temperatures similar to those found today in subarctic to mid-latitude regions. Taxa include *Fabaeformiscandona rawsoni* and *Limnocythere inopinata*. The abrupt shift in climate from arctic to subarctic or warmer temperatures between Zone 1 and 2 coincides with the onset of the Bölling-Alleröd warming event that began ~14,700 cal yr BP. The overlying Zone 3 (247-245 cm; estimated 14, 400 to ~14,200 cal yr BP) faunal assemblage includes *Cytherissa lacustris*, and suggests a more permanent freshwater pond environment, with temperatures similar to that in Zone 2. Pollen evidence from the lower part of the core (equivalent to ostracode faunal zones 1-3) indicates that the vegetation in the area of the core site was graminoid-willow-herb tundra associated with an arid climate. This is the first evidence yet reported for full-glacial graminoid-herb vegetation type from sea floor sites on the former land bridge north of Bering Strait. Ostracode zone 4 (242-180 cm; est. 14,200 to ~13,600 yr BP) assemblages indicate a shift from the permanent pond environment of Zone 3 to a peaty wetland. Zone 4 taxa include *Cypria ophtalmica*, *Cyclocypris cf. ampla*, and *Limnocythere inopinata*. Core sediments above 170 cm core depth (Zone 5) contain no ostracodes, but chironomids and seeds persist until the time of marine transgression at 130 cm core depth, although Charophytes extend from Zone 4 to Zone 5 up to only ~150 cm core depth. Pollen, spores and *Pediastrum* green algae fossils are present throughout the terrestrial sediments in the core.

Pollen assemblages from core depths 230-190 cm show a gradual shift from full-glacial graminoid-herb tundra vegetation to a more mesic climate graminoid-herb tundra with some dwarf birch. In the upper part of the core's terrestrial sediment deposits (core depths 190-130 cm) the pollen assemblages indicate that a mesic dwarf birch shrub tundra with Ericales (heaths), graminoids, herbs, and sphagnum moss existed at the site from ~13,700 cal yr BP until the marine transgression ~12,900 cal yr BP.

This core's fossil record shows that the ostracode faunas responded rapidly to the sudden climatic change from cold arctic conditions to the Bölling-Alleröd warming event that began ~14,700 cal yr BP. In contrast, the pollen evidence indicates that the vegetation response to rapid climatic warming at this land bridge site was delayed for centuries. This delay may have resulted from a lack of local seed sources for mesic shrub tundra plants on the windswept lowlands at the northern end of the Bering land bridge. Nearly all of the previous paleoecological and paleoclimatological investigations of late Pleistocene deposits in eastern Siberia/Chukotka and northern and western Alaska indicate that regional climates during Marine Oxygen Isotope Stage 2 were characterized by aridity, widespread eolian deposition of sand and loess, continuous permafrost, general absence of peaty soils, and graminoid-herb-willow tundra vegetation. There is no evidence at present time for the existence of mesic shrub tundra on the land bridge north of Bering Strait until late glacial time, after 14,700 cal yr BP.

BERGMANN'S RESPONSE, MORPHOLOGICAL VARIABILITY AND PALEOENVIRONMENTAL IMPLICATIONS FOR NORTH AMERICAN BLACK BEARS (*URSUS AMERICANUS*) THROUGHOUT THE QUATERNARY

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The genus *Ursus* evolved in the Old World during the early Pliocene and dispersed into the New World shortly thereafter (Kurtén and Anderson 1980). Today, there are three different species of *Ursus* – *U. arctos* (brown or grizzly bear), *U. maritimus* (polar bear), and *U. americanus* (black bear) in North America. *Ursus arctos* and *U. maritimus* arrived in the New World during the Racholabrean Land Mammal Age. The black bear and its many related fossil species are Blancan (Pliocene) immigrants. The first black bears were small and increased in body size over time as reflected in measurements of their dentitions, although Van Valkenburg (1990) has shown that dental measurements for bears only correlate with body size 80% of the time.

Today, modern black bears have been interpreted to show a negative Bergmann's response based upon populations from Florida, Virginia and Alaska (Harlow 1962). In other words, body size of black bears decreases towards the north with the largest black bears inhabiting Florida today. If this assumption is correct, then fossil black bears and their size would be useful in paleotemperature reconstructions. To test this hypothesis, dentitions of modern black bears were measured for various populations throughout North America.

We have analyzed measurements of modern and fossil bears of the genus *Ursus* with particular attention to *U. americanus* and sister taxa throughout the Quaternary. To this end, we ran a Principal Components Analysis (PCA) on two *U. americanus* datasets: one containing only modern specimens and one containing only Pleistocene specimens. The dimensions of the upper second molar (M2) and the lower first molar (m1) were standardized relative to the largest specimen in each dataset to reduce the bias of abnormally large or small taxa, and these data were then reduced to their principal components. By performing this multivariate analysis, we were able to consider the breadth and length of molars together in an ordination. The first principal component axis was then plotted versus latitude to determine whether there exists a cline in molar size with latitude for either the modern or Pleistocene *U. americanus* populations. To asses overall variability amongst ursine taxa, we then plotted the first and second principal component axes versus one another to determine whether distinct species might cluster together in ordination space.

Our results falsify the hypothesis of a negative Bergmann's response, and they do not fit with a positive response either. Instead, the dental size of populations is to some degree "randomly" distributed across the landscape, although there appears to be a strong relationship between dental parameters and vegetation quality. Larger bears live in environments with vegetation that provides higher quality forage for the bears; whereas, the smaller dentitions are associated with lower quality. Thus, black bear dental size may not reflect prehistoric temperatures, but they can be useful in characterizing quality of vegetation in areas at different times.

During the late Pleistocene, the skulls and dentitions of fossil black bears were much larger than those of modern forms (Graham 1991). However, as mentioned earlier, bear dentitions may not be the best proxy for body size. Instead, skull measurements (skull length, breadth across the orbits, etc.) are better predictors of body size. However, like other mammals (e.g., Hadly 1997) skull parameters may be phenotypic and quite plastic. On the other hand, dental parameters provide a better evolutionary (phylogenetic) history of bears. Analysis of our data is consistent with the general increase in black bear size through time with periodic fluctuations throughout the Quaternary (Graham 1991). It also documents that some fossil bears originally assigned to grizzlies because of their large crania are actually black bears and that many of the fossil subspecies of black bears based upon dental size are probably part of the normal geographic and temporal variation in black bear populations (Graham 1991).

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GLACIAL HISTORY OF THE WEDDELL SECTOR, WEST ANTARCTICA

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During the last ice age, the Antarctic Ice Sheet advanced across the continental shelf, filling low-lying embayments, and thickening up to ~1000 m in some areas near the margins. Substantial thickening of the ice sheet interior was prevented by reduced accumulation, resulting in a larger and lower-gradient ice sheet than at present. Previous ice ages were probably broadly similar to the most recent; however, most of the evidence for these events has been erased by subsequent ice cover. Many of the constraints on past ice thickness come from the Ross Embayment, where ice-free areas in the Transantarctic Mountains and seasonally sea-ice-free waters have facilitated extensive terrestrial and marine research. Less attention has been paid to other sectors of Antarctica, and, in these areas, past ice thicknesses tend to be poorly known. We present new ice-thickness constraints from the Pirrit Hills, a small, far-flung group of nunataks located in the Weddell Sector of Antarctica.

On the eastern side of the Pirrit Hills, fresh glacial erratics are evidence of thicker ice during the last ice age and indicate that ice levels were at least ~350 m, but less than ~450 m, above the present level. The highest elevation erratics have preliminary ^{10}Be exposure ages of ~16 ka, confirming that they were deposited during the last ice age. The exposure ages of the erratics generally decrease with decreasing elevation, recording the thinning of ice in the region.

Despite recent thicker ice, bedrock extending down to the present ice level is weathered and exhibits delicate cavernous forms in places, evidence of prolonged subaerial weathering prior to the last ice age. The preservation of these features, along with the lack of evidence for wet-based glacial erosion, indicates that former ice cover was cold-based and protected the underlying bedrock. Over the elevation range in which we found glacial erratics, bedrock ^{10}Be, ^{26}Al, and ^{21}Ne concentrations are consistent with modest ice cover, and have exposure ages ranging from ~0.3-1.5 Myr.

Around 450 m above the present ice level, higher than where glacial erratics were found, bedrock ^{10}Be, ^{26}Al, and ^{21}Ne concentrations increase by a factor of ~4-5 and no longer display evidence for past ice cover. This height coincides with a break in the otherwise steep slopes of the Pirrit Hills, and the bedrock above shows evidence for more prolonged subaerial weathering than the bedrock below. This transition evidently marks the elevation above which ice cover, if it has occurred in the past few million years, has been extremely rare, short-lived, and cold-based. This feature may be related to the trimline imprinted on ridges throughout the Ellsworth Mountains (Denton et al., 1992). In both cases, an alpine landscape appears to have been preserved by a cold polar climate and subsequent glacial highstands that only rise partway up the mountain flanks.

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HOLOCENE GLACIER HISTORY OF THE BOWSER RIVER WATERSHED, NORTHERN COAST MOUNTAINS, BRITISH COLUMBIA

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Accelerated glacial recession and downwasting of glaciers in the Bowser River watershed of the northern British Columbia Coast Mountains has exposed subfossil wood remains and laterally contiguous wood mat layers. These wood remains represent periods of Holocene glacier advance, where glaciers expanded and overwhelmed downvalley forests. To develop an understanding on Holocene glacial fluctuations in this region, field investigations were undertaken in 2005, 2006 and 2013 at Frank Mackie, Charlie, Salmon and Canoe glaciers. Dendroglaciology and radiocarbon analyses revealed five intervals of glacial expansion: (1) an unnamed mid-Holocene advance at 5.7-5.1 cal ka BP; (2) an Early Tiedemann advance at 3.6-3.4 cal ka BP; a Late Tiedemann advance at 2.7-2.4 cal ka BP; (4) a First Millennial advance at 1.8-1.6 cal ka BP; and, (5) two advances corresponding to the Little Ice Age at 0.9-0.7 and 0.5 cal ka BP. These results provide new evidence for mid-Holocene glacier activity for northern British Columbia, as well as supporting previous research that Holocene glacier advances were episodic and regionally synchronous.

EVIDENCE OF EXTENSIVE MOUNTAIN GLACIATION DURING MIS 4/3 IN THE NORTHWESTERN AND WESTERN INTERIOR UNITED STATES

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Much is known about glacial extent during the Last Glacial Maximum (LGM), but often overlooked are more extensive advances that occurred earlier in the last glacial cycle, during marine oxygen isotope stage (MIS) 4 and 3. These advances are expressed in mountain glacier geomorphic and stratigraphic sequences.

A handful of studies have produced radiometric ages for pre-LGM ice limits. In the Olympic Mountains, Washington, multiple advances during MIS 4 and 3 extended more than 20 km beyond the LGM ice limit (Thackray, 2001; Marshall, 2013; Wyshnytzky, 2013). ^{36}Cl exposure dating reveals multiple MIS 5-3 moraines in the northeastern Washington Cascade Range (Porter and Swanson, 2008) and radiocarbon dates reveal late-MIS 3 mountain ice advances in the NW Washington Cascades (Riedel *et al.*, 2010).

In the Teton Range, Wyoming, LiDAR data illuminate a remarkable moraine-fault interaction, which was used to estimate moraine ages in an effort to expand understanding of regional glacial sequences (Thackray and Staley, 2014). The Teton fault crosses east-facing moraines and other deglacial surfaces, displaying different landform offsets. Using the offset rates, moraine age estimates correspond to MIS 4/3. Our interpretation of the Teton moraine age pattern suggests that larger MIS 4/3 moraines may exist elsewhere in the northwest United States, but are yet to be demonstrated.

Other interior mountain glacial sequences are limited to relative dating techniques, but those studies reveal possible MIS 4/3 moraines. These sequences provide a platform for more detailed analysis. In the Wallowa, Sawtooth, western Salmon River, Lost River, and Pioneer Mountains, moraines downvalley of dated or inferred LGM moraines display characteristics suggestive of MIS 4 and 3 ages. Equilibrium line altitudes of inferred MIS 4 and/or 3 moraines across the region reveal climatic influences on these important earlier events.

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MAPPING AND MEASURING LAKE AGASSIZ STRANDLINES IN NORTH DAKOTA AND MANITOBA USING LIDAR DEM: REVISING CORRELATIONS AND INTERPRETING ANOMALOUS ISOSTATIC REBOUND GRADIENTS

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Beaches and erosional strandlines of glacial Lake Agassiz form a discontinuous sedimentary and morphological record of lake levels around the southern part of the basin. Higher elevation strandlines reflect older levels of the lake and have steeper isostatic rebound gradients. Using LiDAR DEM data at 1 m spatial resolution, with ~0.15 m vertical accuracy, Lake Agassiz strandlines in northeastern North Dakota and southern Manitoba were mapped and their elevations determined. Two different techniques for determining elevations from LiDAR imagery were compared. One used the approach of Yang and Teller (2012) and measured crest elevations of constructional beaches. The other used the technique of Breckenridge (2013), which measured the elevation of the LiDAR shadow reflecting either the steep slope lakeward of the beach or a wave-eroded notch. Isostatic rebound gradients calculated by both techniques resulted in similar values. For the Campbell strandline—the most prominent and extensive in the Lake Agassiz basin—we combined the two LiDAR techniques, using beach crest elevations in the south and shadow elevations of the wave-cut scarp in the north where the beach was poorly developed; both resulted in a similar gradient across the region.

Our LiDAR reconstructions of strandlines formed after the Moorhead low-water stage of Lake Agassiz indicate that correlations around the Pembina delta in North Dakota by Upham (1895) in his classic U.S.G.S Monograph (which have been used by all researchers since then) are incorrect. Specifically, the Emerado, Ojata, and Gladstone strandlines south of the delta lie ~10 m *above* the elevation of the same named strandlines to the north of the delta; this is the case using both LiDAR techniques. Thus, we have re-correlated Upham's Emerado strandline south of the delta with Upham's Hillsboro to the north, the Ojata south of the delta to the Emerado to the north, and the Gladstone in the south to Upham's Ojata in the north.

Although calculated gradients for the Tintah, Campbell, McCauleyville, and Blanchard strandlines are consistent across the region, elevations around the Pembina delta for the younger Emerado and Ojata strandlines are anomalous, with nearly flat elevations across >20 km, rather than the normal rise in elevation from south to north due to differential isostatic rebound. And, to the north of the delta, elevations on those strandlines are much steeper than to the south of the delta. We suggest that compaction of fine-grained, high-moisture content sediment of the Pembina River delta sequence that underlies these strandlines, which reaches thicknesses of >50 m in places, may have been responsible, offsetting the rise in elevation due to differential isostatic rebound in that area compared to the surrounding thinner or coarser lacustrine sequence.

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EXTENSIVE MOUNTAIN GLACIATION DURING MIS 5-3 ON THE WESTERN OLYMPIC PENINSULA, WASHINGTON, DOCUMENTED THROUGH LIDAR TOPOGRAPHIC ANALYSIS AND LUMINESCENCE DATING OF GLACIAL SEDIMENTS

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A new luminescence chronology for glacial sediments in the Hoh and Queets valleys extends a previous radiocarbon chronology in time and space, and new LiDAR topographic datasets reveal ice-marginal landforms within several km of the coastline. These findings demonstrate that mountain ice was very extensive during MIS 5-3, and confirm that MIS 2 ice margins lay 20-40 km upvalley.

The spatial and temporal patterns of glaciation are best expressed in the Hoh valley. LiDAR topographic datasets reveal two previously unrecognized ice margins in the Hoh valley, and also demonstrate the preservation of fine morphologic features of ice-marginal landscapes (Marshall, 2013). The two newly identified ice margins, Lyman Rapids A and B lie ca. 5 and 15 km upvalley of the coastline and represent the maximum extent of Late Pleistocene ice. The maximum Late Pleistocene moraine defined by Thackray (2001), designated Lyman Rapids C, lies ca. 4 km further upvalley, and the younger Hoh Oxbow B and C moraines lie 8 and 13 km further upvalley. Thus, five sequences of ice-marginal landforms lie within 28 km of the coastline. The LiDAR topographic images reveal that the ice marginal sequences consist of broad and thick accumulations of sediment, with push moraines and fluted moraines superimposed upon the broader landforms. These findings demonstrate the notable improvements of bare-Earth LiDAR data compared with the previous limitations of topographic maps and aerial photographs, particularly in this heavily vegetated landscape.

The new luminescence chronology extends the radiocarbon chronology of Thackray (2001), providing age constraint for older ice advances and for previously undatable sediments that contain no organic matter. Provisional OSL ages suggest that the Lyman Rapids A and B advances occurred ca. 90 ka and 65 ka respectively, i.e., during MIS 5 and 4 (Marshall, 2013). The Hoh Oxbow B and C sequences yielded provisional ages of ca. 34 ka and 39 ka, respectively. Thackray (2001) dated the Hoh Oxbow B sequence to 34-30 cal ka BP using radiocarbon, and these OSL ages confirm and extend that general age interpretation.

Notably, glacial landforms and sediments dating to the Last Glacial Maximum (MIS 2) lie far upvalley of the MIS 5-3 margins. Wyshnytzky (2013) delineated three ice marginal landform-sediment sequences in the South Fork Hoh Valley (20 km upvalley of the Hoh Oxbow C ice limit) and concluded that the South Fork glacier fluctuated rapidly within 5-km of valley length between 19 and <17 ka.

Together, these findings confirm and extend previous results. It remains clear that the Hoh valley glacier was far more extensive during MIS 5-3 than during MIS 2. The new ice margins identified in the lower Hoh valley and in the South Fork Hoh valley reveal the marked fluctuations of these large valley glaciers and permit further evaluation of the climatic influences on their mass balance and sedimentary and geomorphic processes.

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QUATERNARY MEGAFLOOD CHRONOLOGY FROM LUMINESCENCE AND RADIOCARBON DATING OF FLOOD SANDS, EASTERN HIMALAYA

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Sedimentary evidence suggests that high-magnitude glacial outburst floods have occurred repeatedly throughout the Quaternary on the Yarlung-Siang-Brahmaputra River in the eastern Himalaya. Estimates of stream power calculated for these events and recent detrital analyses performed on slackwater flood deposits observed in the river valley indicate that these megafloods are highly erosive, but there is debate over the relative importance of these extreme floods in long-term river incision. Although several slackwater deposits have been identified and analyzed, no deposits have been dated and correlated to ages of upstream glacial lake terraces. Here we present field observations and ages from 18 new slackwater megaflood deposits identified in the Siang River valley during fieldwork performed in 2013. Radiocarbon dating of charcoal within several deposits has produced ages that range from 1200-1600 yr BP, which correlate well with glacial lake terraces dated to the Holocene. Infrared luminescence dating (IRSL) of feldspar grains in other deposits has produced ages that range from 15 – 34 ka, similar to older glacial lake terraces dated to the late Pleistocene. Further dating of downstream deposits will help constrain the timing of megaflooding in the region, which is essential to understanding the long-term frequency and erosional impact of these events.

TREE-RING RECONSTRUCTION OF THE KLAMATH RIVER

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In 2001, severe drought conditions in the upper Klamath Basin brought to a head conflicts between the competing water needs of farmers, Native Americans, and the environment. While a dry year, 2001 is not among the 10% driest of years recorded in the USGS gage record of the Klamath River at Keno, Oregon. Although sequences of even drier years occurred in the 1990s and in the 1930s, water demands and uses have changed, and as a consequence, impacts of drought have become greater in recent years. A question that arises is: how common are the dry years of the 20th and 21st centuries? And have there been more severe droughts in the past? Extended records of streamflow reconstructed from tree rings have been found useful for water resource planning in a number of major river basins in the western US. These records can be used to evaluate modern periods of droughts and characterize flow variability in a long term context. The focus of this study is the reconstruction of upper Klamath River flow, but a major challenge in this reconstruction concerns the lack of a high quality streamflow record for reconstruction model calibration. A long history of diversions for irrigation, along with the complex wetland hydrology of this basin, has made the accurate estimation of natural flows difficult, and even contentious. Given these uncertainties as well as those inherent in reconstruction models, the most robust information comes from the sequences of flow, and duration and frequency of wet and dry intervals.

In the Klamath flow reconstruction, AD 1493-2010, analyses of frequency and distribution of extreme low flow years, runs of consecutive years of low flows, and the probability of transitions between wet and dry years (Prairie et al. 2008) all document long-term natural hydrologic variability. This reconstruction suggests the driest years (lowest 10%) are not evenly distributed over time, but occurred with higher frequency prior to the early 17th century. Sequences of years in the driest tercile show the persistent drought of the 1930s was matched or exceeded by drought conditions in the 1650s. Analysis of transitional probabilities indicates that in the Klamath River system, persistence of wet or dry conditions for two consecutive years is much more the norm than year-to-year variability in flows, and that is consistent over the full reconstruction period. Recent extremes in flow have challenged water management, but the reconstruction of Klamath River flow places these extremes in a long term context, indicating the range of flow variability over which the impacts of climate change will be imposed. Future work will include ways to better deal with uncertainty in the estimated natural flows, which have not been widely accepted by stakeholders or scientists.

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DID THE INDIAN SUMMER MONSOON PENETRATE INTO IRAN DURING THE EARLY HOLOCENE?

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The early to mid-Holocene is known for having warmer than modern temperatures, which may have resulted in intensification in weather systems (Stephens and Hu, 2010), such as monsoons. The Indian summer monsoon (ISM) in particular may have been intensified due to these warmer temperatures and a northward shift of the ITCZ (Schubert and Ferreira, 1997) (Fig. 1), leading to wetter conditions in Oman and the Arabian Peninsula (Burns et al., 2001; Parker et al., 2006, Fleitmann et al., 2007). However, we still do not know how far north the ISM penetrated. Although studies in northern Iran show no evidence of wetter conditions in the early-to-mid Holocene due to the ISM (Stevens et al., 2006, Stevens et al., 2001), it is possible that the ISM did extend as far north as southwestern Iran.

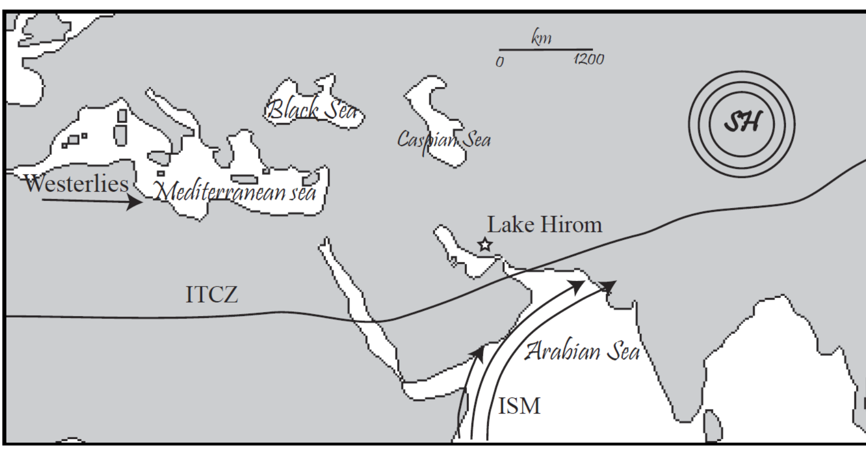

Figure 1. Storm tracks and position of the summer ITCZ, the Indian Summer Monsoon (ISM), and the Siberian High (SH). Study location is denoted by star.

To examine this possibility, a sediment core from Lake Hirom (27º 57’N, 53º52’E) was collected in 2010. The lake is located in an intermontane basin, with significant ground water seepage at the base of the mountains. The edge of the lake is dominated by wetland reeds, and open water exists during the winter of wet years. A sediment core, 7-m in length, was collected in shallow water near the northern edge of the basin. The sediment is comprised of alternating marl and peat and extends back to 9.6 ka BP. Paucity of macrofossils results in a poorly constrained chronology with 3 dates on peat. ^{210}Pb dates were impossible due to high amounts of Radium in the sediment.

In general, sedimentology matches the speleothem records of Oman (Fleitmann et al., 2007) and the lake records of the Arabian peninsula (Parker et al., 2006). The notable exception is the peat (9.6-9.3 ka BP), which is interpreted as a dry climate with only modest ground water recharge. This is inconsistent with the wetter than modern climate proposed by Oman speleothems (Fleitmann et al., 2007). Precipitation of marl and gypsum between 9.3 to ~6.3 ka BP suggests intermittent flooding (standing water) and generally wetter conditions than the peat--although the flooding was likely seasonal. Wetter conditions at Hirom are consistent with paleolakes in the Rub' al-Khali that are linked to ISM moisture (Parker et al., 2004). Above this early Holocene marl is a second peat interval dated from 6.3-1.9 ka BP. The dryer conditions inferred from the peat are consistent with the drying of the Arabian lakes and the hiatus in the Oman speleothems. That is, the peat records a regional drying event—although the onset is earlier than Oman and the duration longer. A return to marl precipitation with abundant ostracodes in the last 2000 years is also consistent with a return to wetter conditions in Oman. To better constrain paleoenvironmental conditions, mineralogy, stable isotopic values of ostracodes, and pollen are used to infer general climate for the early Holocene.

The lowermost section of the early Holocene marl contains abundant amounts of liverwort pollen (*Riella)*, which suggests that Hirom experienced significant water fluctuations with repeated seasonal inundation by brackish to saline waters. A peak in the halophytic aquatic plant, *Salicornia*, occurs above the *Riella* zone, indicating a transition to saline plains. This zone is followed by one with few aquatic plants that is difficult to interpret. In all of these pollen sections, there is a lack of macrofauna, which may indicate extremely dry conditions or a lack of substrate necessary for their survival and preservation. The unstable hydrology is coincident with wet conditions in both Saudi Arabia and Oman.

At approximately 7.2 ka BP, there is a transition to abundant aquatic pollen that may signal a small, permanent water body over the coring site. Not coincidentally, this zone marks the appearance of ostracodes (*Cyprideis torosa* and an unidentified Candona) as well as gastropods and foraminifera. The macrofossils allow for a geochemical record to be established.

TOC values for the early Holocene marl interval have small and frequent variations between 0–2% (Fig. 2). TIC values show large fluctuations in the earliest Holocene (9- 8 ka BP) with values ranging from 1-8%. The lack of coherent changes between the TIC and TOC suggests that evaporites (gypsum and halite) are more common in this interval, which may help to explain the absence of ostracodes. Sr/Ca ratios of *C. torosa* are initially similar to those of the late Holocene, albeit slightly higher. However, between 6.9-6.3 ka BP a large increase indicates a shift to drier conditions prior to the middle Holocene peat layer. The lack of an increase in the Mg/Ca ratios suggests a more complicated temperature signal. The fact that early Holocene Sr/Ca values are consistently higher than those of the last 2000 years suggests drier overall conditions during this period. Unfortunately, the paucity of ostracodes in the early Holocene prevents long-term elemental and isotopic records.

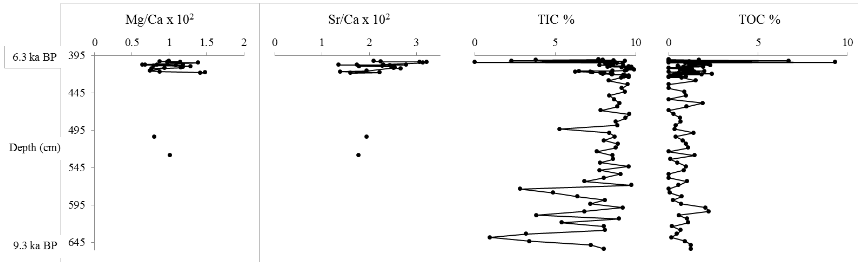

Figure 2. Lower marl interval bounded by peat layers dated at 9.3 ka BP and 6.3 ka BP. Trace element ratios of *Cyprideis torosa* (female) valves, percent total organic carbon (TOC) and total inorganic carbon (TIC).

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ASSESSING THE POTENTIAL ROLE OF VEGETATION AND FIRE DRIVERS OF WOLLY MAMMOTH EXTINCTION ON ST. PAUL ISLAND, A HOLOCENE REFUGIUM

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In North America, more than 50% of all mammal species heavier than 32kg and all species heavier than 1000kg were extirpated during the last deglaciation, with the latest mammoths on the North American mainland dating to about 12,291 years before present (Haile et al., 2009). Hypothesized extinction drivers include climate change, vegetation changes, human hunting, or combinations among the three. However, woolly mammoth (*Mammuthus primigenius*) survived into the middle and late Holocene on two known island refugia: Wrangel Island and St. Paul Island, AK. On St. Paul, an isolated remnant of the Bering Land Bridge, fossils of woolly mammoth date to 6,480 years before present (Veltre *et al.*, 2008). The mechanisms enabling survival and eventual extinction of woolly mammoth on St. Paul are enigmatic because the environmental history of the island is poorly known. A pollen record collected by Paul Colinvaux in 1981 indicates a vegetation transition from a herb tundra without trees or shrubs to a forest community dominated by *Picea*, *Alnus* and *Betula* and finally to the modern herb tundra since the last glaciation, but requires redating. There is no evidence of human presence on St. Paul Island prior to Russian arrival in the 1780s.

This project aims to explore the possible drivers of megafauna extinction in Arctic islands by reconstructing vegetation and fire history from pollen and charcoal records from Lake Hill, St. Paul, AK. Spore from *Sporormiella*, a coprophilous fungus known to be associated with woolly mammoth, is used to document megafauna population changes on the island. Other paleoenvironmental proxies and sea-level models will also be used to analyze the influence of climate and environment changes on megafauna extinction on St. Paul.

A 13.5 meters composite core was retrieved from Lake Hill in March, 2013. Sediments were relatively more organic rich for the top 5 m and more silts and sands below. Initial radiocarbon dates indicate that the core at 7.2 m date to 11,390 years before present and there is lithological transition around 5,500 years BP. Initial counts of *Sporormiella* indicate that it is consistently present in low abundances (2%, around 700 grains/cm2/yr) in the lower record until it decreases at 558 cm (ca. 6,788 yr BP). The timing of the *Sporormiella* decline at Lake Hill generally matches well to the youngest mammoth bone date on St. Paul. Major pollen types include *Apiaceae*, *Poaceae*, *Cyperaceae*, *Artemisia*, and *Salix*, with lower abundances of *Betula*, *Alnus*, *Asteraceae* undif., and *Ericaceae*, consistent with herbaceous tundra with some shrubs. Declines in *Apiaceae* and *Poaceae* and increases in Artemisia and Salix between 606 and 590 cm (8014 to 7605 yr BP) suggest an increased prevalence of shrub tundra, preceding the *Sporormiella* decline. *Picea* pollen is found at 782 cm, deeper and older than the current age model limits, and about 6,000 years older than *Picea* appearance in the prior reports from Colinvaux (1981).

There is also a sharp decrease of total pollen concentration at 750 cm in the deeper core. Sedimentary charcoal is extremely rare in initial surveys, suggesting that fires are rare to absent. More pollen and charcoal samples will be counted in the next several months, and the vegetation, megafauna population and fire history since deglaciation will be reconstructed and compared.

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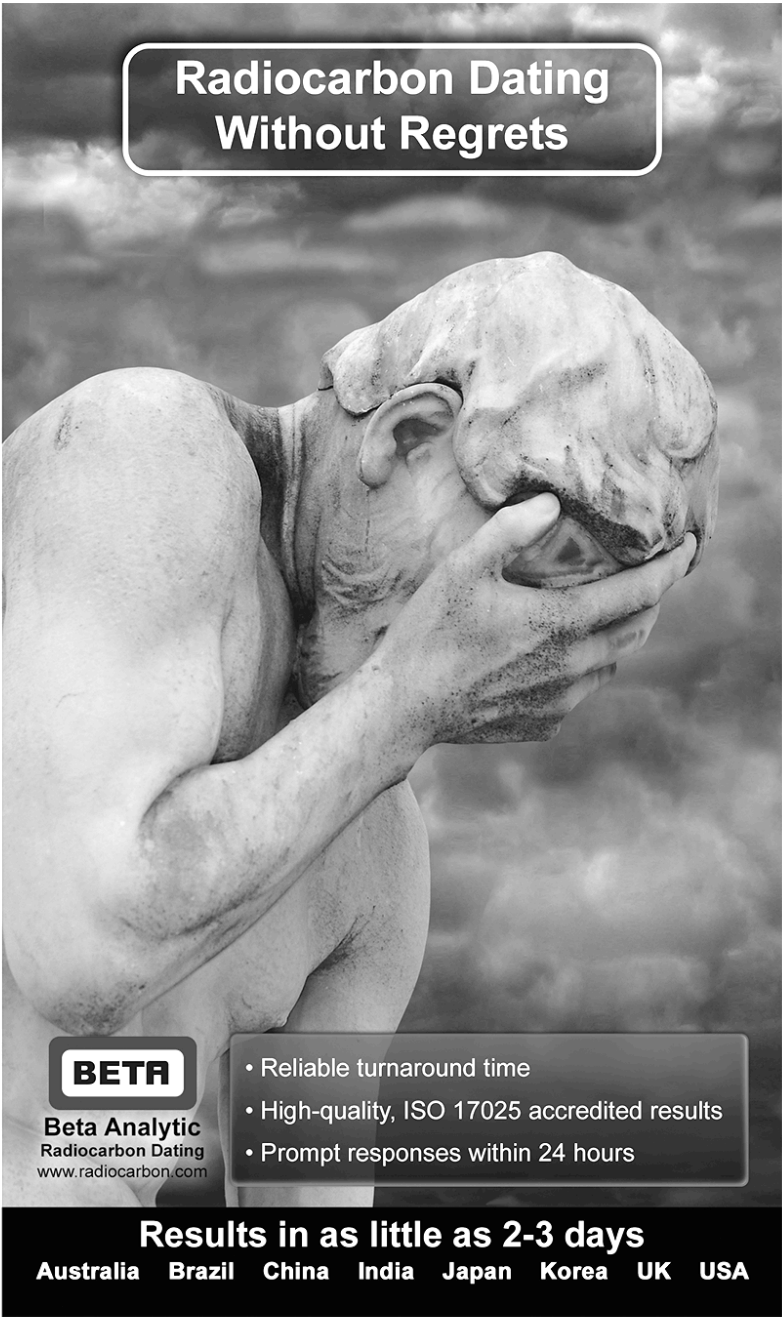
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