

KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-FOURTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Holli Frey
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Union College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Diane Kadyk
Symposium Proceedings Layout & Design
Department of Earth & Environment
Franklin & Marshall College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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Editor and Keck Director
Pomona College

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Diane Kadyk
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Franklin & Marshall College

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2010-2011 PROJECTS

FORMATION OF BASEMENT-INVOLVED FORELAND ARCHES: INTEGRATED STRUCTURAL AND SEISMOLOGICAL RESEARCH IN THE BIGHORN MOUNTAINS, WYOMING

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EXPLORING THE PROTEROZOIC BIG SKY OROGENY IN SOUTHWEST MONTANA

Faculty: *TEKLA A. HARMS*, *JOHN T. CHENEY*, Amherst College, *JOHN BRADY*, Smith College

Students: *JESSE DAVENPORT*, College of Wooster, *KRISTINA DOYLE*, Amherst College, *B. PARKER HAYNES*, University of North Carolina - Chapel Hill, *DANIELLE LERNER*, Mount Holyoke College, *CALEB O. LUCY*, Williams College, *ALIANORA WALKER*, Smith College.

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Faculty: *DAVID P. DETHIER*, Williams College, *WILL OUIMET*, University of Connecticut

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Faculty: *SUZANNE O'CONNELL*, Wesleyan University

Students: *LYNN M. GEIGER*, Wellesley College, *KARA JACOBACCI*, University of Massachusetts (Amherst), *GABRIEL ROMERO*, Pomona College.

GEOMORPHIC AND PALEOENVIRONMENTAL CHANGE IN GLACIER NATIONAL PARK, MONTANA, U.S.A.

Faculty: *KELLY MACGREGOR*, Macalester College, *CATHERINE RIIHIMAKI*, Drew University, *AMY MYRBO*, LacCore Lab, University of Minnesota, *KRISTINA BRADY*, LacCore Lab, University of Minnesota

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GEOLOGIC, GEOMORPHIC, AND ENVIRONMENTAL CHANGE AT THE NORTHERN TERMINATION OF THE LAKE HÖVSGÖL RIFT, MONGOLIA

Faculty: *KARL W. WEGMANN*, North Carolina State University, *TSALMAN AMGAA*, Mongolian University of Science and Technology, *KURT L. FRANKEL*, Georgia Institute of Technology, *ANDREW P. deWET*, Franklin & Marshall College, *AMGALAN BAYASAGALN*, Mongolian University of Science and Technology.

Students: *BRIANA BERKOWITZ*, Beloit College, *DAENA CHARLES*, Union College, *MELLISSA CROSS*, Colgate University, *JOHN MICHAELS*, North Carolina State University, *ERDENEBAYAR TSAGAANNARAN*, Mongolian University of Science and Technology, *BATTOGTOH DAMDINSUREN*, Mongolian University of Science and Technology, *DANIEL ROTHBERG*, Colorado College, *ESUGEI GANBOLD*, *ARANZAL ERDENE*, Mongolian University of Science and Technology, *AFSHAN SHAIKH*, Georgia Institute of Technology, *KRISTIN TADDEI*, Franklin and Marshall College, *GABRIELLE VANCE*, Whitman College, *ANDREW ZUZA*, Cornell University.

LATE PLEISTOCENE EDIFICE FAILURE AND SECTOR COLLAPSE OF VOLCÁN BARÚ, PANAMA

Faculty: *THOMAS GARDNER*, Trinity University, *KRISTIN MORELL*, Penn State University

Students: *SHANNON BRADY*, Union College. *LOGAN SCHUMACHER*, Pomona College, *HANNAH ZELLNER*, Trinity University.

KECK SIERRA: MAGMA-WALLROCK INTERACTIONS IN THE SEQUOIA REGION

Faculty: *JADE STAR LACKEY*, Pomona College, *STACIL LOEWY*, California State University-Bakersfield

Students: *MARY BADAME*, Oberlin College, *MEGAN D'ERRICO*, Trinity University, *STANLEY HENSLEY*, California State University, Bakersfield, *JULIA HOLLAND*, Trinity University, *JESSLYN STARNES*, Denison University, *JULIANNE M. WALLAN*, Colgate University.

EOCENE TECTONIC EVOLUTION OF THE TETONS-ABSAROKA RANGES, WYOMING

Faculty: *JOHN CRADDOCK*, Macalester College, *DAVE MALONE*, Illinois State University

Students: *JESSE GEARY*, Macalester College, *KATHERINE KRAVITZ*, Smith College, *RAY MCGAUGHEY*, Carleton College.

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Keck Geology Consortium: Projects 2010-2011 Short Contributions— Hövsgöl Rift, Mongolia

GEOLOGIC, GEOMORPHIC, AND ENVIRONMENTAL CHANGE AT THE NORTHERN TERMINATION OF THE LAKE HÖVSGÖL RIFT, MONGOLIA

Project Faculty: KARL W. WEGMANN: North Carolina State University, TSALMAN AMGAA: Mongolian University of Science and Technology, KURT L. FRANKEL: Georgia Institute of Technology, ANDREW P. deWET: Franklin & Marshall College, AMGALAN BAYASAGALN: Mongolian University of Science and Technology

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Research Advisor: Susan Swanson

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MELLISSA CROSS, Colgate University
Research Advisor: Bruce Selleck

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JOHN MICHAELS, North Carolina State University
ERDENE BAYAR TSAGAANNARAN, Mongolian University of Science and Technology
BATTOGTOH DAMDINSUREN, Mongolian University of Science and Technology
Research Advisor: Karl Wegmann

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Mongolian Participants: Esugei Ganbold, Aranzal Erdene
Research Advisor: Eric Leonard

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Research Advisor: Dr. Andy deWet

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GABRIELLE VANCE, Whitman College
ESUGEI GANBOLD, Mongolia University of Science and Technology
Research Advisors: Bob Carson and Nick Bader

LATE-CENOZOIC VOLCANISM IN THE HÖVSGÖL RIFT BASIN: SOURCE, GENESIS, AND EVOLUTION OF INTRAPLATE VOLCANISM IN MONGOLIA

ANDREW ZUZA, Cornell University

ARANZAL BAT-ERDENE, Mongolian University of Science and Technology

Research Advisor: Christopher Andronicos

Keck Geology Consortium
Pomona College
185 E. 6th St., Claremont, CA 91711
Keckgeology.org

A MULTI-PROXY STUDY OF HOLOCENE PALEOCLIMATE AND DEPOSITIONAL ENVIRONMENT, HOVSGOL, MONGOLIA

MELLISSA CROSS, Colgate University
Research Advisor: Bruce Selleck

INTRODUCTION

As the reality of climate change continues to sink in, it is becoming increasingly clear that information about short term Holocene climate variability is vital to understanding the consequences of global warming. Recent studies in Mongolia demonstrate the vulnerability of this nation's population, economy, and traditional nomadic culture to climate change and to extreme events (Nandintsetseg, Greene, & Goulden, 2007).

The Lake Hovsgol area (Fig. 1, Wegmann et al., this issue), where this study was conducted, is strongly influenced by three climate systems: the Siberian High, the North Atlantic Oscillation, and to varying extent the East Asian Summer Monsoon; and as such paleoclimate records from this region often carry global signatures (An Chengbang, 2008; Wang et al., 2011). Lake Hovsgol also has a relatively small watershed, making the region ideal for investigations concerning humidity (Prokopenko, 2007). In the last decade, the sedimentology, ecology, and geomorphology of Lake Hovsgol and neighboring Mongolian and Siberian watersheds (An Chengbang, 2008; Peck et al., 2002; Prokopenko, 2007; Shichi et al., 2009; Wang et al., 2011, etc) have been characterized to understand regional climate change. This study investigates the mineralogy, organic and carbonate content, shell calcite isotopes, diatom abundance, and grain size and sorting of the sedimentary profiles of two radiocarbon-dated late Holocene terrestrial sites.

METHODS

Site Description and Sampling

Trenches were excavated at two locations approximately 750 m west and 2.5 km northwest from Lake Hovsgol (Fig. 2, Wegmann et al., this issue). Two sections, PLT2 and PLCB1, are located at this latter site, a hill and steep bank overlooking a small lake.

PLT2 was excavated in benches (Fig. 5, Wegmann et al., this issue) down the western hill slope towards the lake, yielding a fine, cm-scale layered profile of ~3 m in thickness. PLCB1 refers to the more massive section revealed in the short cliff directly above the current lake level, which is 2-3 m below cliff top. PLT2 and PLCB1 are ~13 m apart, separated by a relatively flat area of coarse cross-bedded sands, thickness unknown. HS3 was excavated in a short sandy slope eroded into an otherwise flat area, 2.75 km east of PLT2 and PLCB1. Sections were measured and described with attention to grain size, Munsell color, macrofossils and plant fragments, clarity and internal structure of layers, and other outstanding characteristics. From each layer, 100-500g of loose material was collected and air-dried for several hours in the field. Additionally, samples from PLT2's deepest stratum, a thick carbonate- and organic-rich layer, were removed in cohesive blocks.

ANALYSES

Radiocarbon Dating, Sedimentation Rates

AMS 14C dating was performed at the Earth System Science Department of UC Irvine. Plant materials and charcoal were analyzed, yielding five dates for PLT2 and two each for HS3 and PLCB1.

Mineralogy, Diatoms, SEM Imaging

A quantitative analysis of mineralogy was performed at Colgate University using X-ray diffraction data and the RockJock11 program, version 2/9/11. Twelve samples were chosen to represent a variety of depths and sedimentary type; distribution can be seen in Figures 1-3. These were treated with 30% H₂O₂ to remove organics and were prepared with an internal corundum standard and mounted according to the method in Eberl's USGS report (2009). Diffraction peaks were identified using the XRD program's identification tool; the results were used to customize the list of minerals to analyze in

RockJock. Mineral abundances output by RockJock were normalized to include organics.

Diatom abundances- amounts of amorphous silica- were included in mineralogical analysis, and assemblages are currently being assessed through SEM imaging. Stub mounts of twelve raw samples were imaged uncoated under low vacuum (40Pa). Diatoms were identified by consulting online sources (M. B. Edlund, Stoermer, Jamsran, Soninkhishig, & Williams, ; Spaulding, Lubinski, & Potapova, 2010). During SEM imaging, electron dispersive spectrometry was used to identify trace minerals that were not detected or tested for during XRD and RockJock analysis.

Organic Material and Carbonate Content

Dried, powdered samples were treated with pH 5 NaOAc buffer and washed with distilled water. When samples still effervesced with 1N HCl after the removal procedure NaOAc buffer was applied until fizzing no longer occurred (Grossman & Millet,

1961). Carbonate content was determined by weight difference. LOIs to ascertain organic content were performed at 950°C on portions of the carbonate-free samples. A more typical LOI procedure at 550°C and 1000°C (Dean, 1974) was contraindicated by planned organic carbon isotope analysis.

Grain Size and Sorting

Whole samples dried overnight in a ~110°C convection oven were weighed and sieved. The fine (<1 mm) fraction was run through a Malvern Mastersizer laser diffraction grain size analyzer, and the results were normalized with coarse fraction weight. Computation using Gradistat yielded mean grain size, sorting, and other statistics.

Shell Calcite Isotopes

Gastropod and bivalve shell fragments were removed from raw samples during inspection under the binocular microscope. From PLT2, five layers yielded enough shell material; PLCB1 returned one sample.

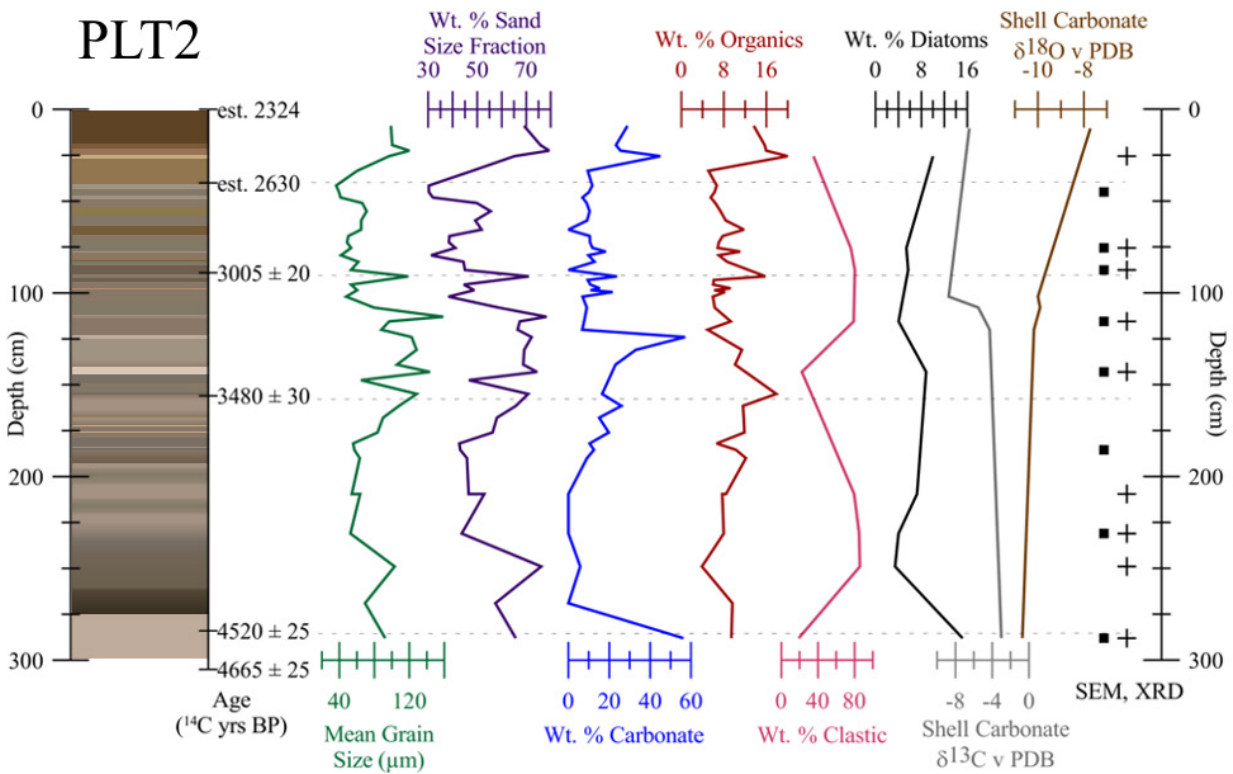


Figure 1. Stratigraphy of PLT2 with observed Munsell color. Pale layers are typically carbonate-rich; dark layers are silty-sandy. Locations of SEM images are indicated by squares, XRD analyses by crosses. Organics, diatom abundance, carbonate generally vary together.

Isotopes were analyzed at New York State University at Albany following standard procedures.

RESULTS

Dates and Sedimentation Rates

AMS ¹⁴C dating indicates that PLT2 (Fig. 1) is the oldest trench, representing an estimated 2300 years beginning at 4665 ¹⁴C years BP. Of the five samples dated, one at 40 cm depth returned an anomalously old age. Ages above 90 cm are extrapolated from the calculated mean sedimentation rate, 1.3 mm/yr. All ages are in ¹⁴C years.

The dates for the 65-70 year PLCB1 (Fig. 2) record are based on material removed from a similar exposure a few meters away. At a sedimentation rate of 10.9 mm/year, this assumption seems safe.

HS3 (Fig. 3) is a 1900 year record that is not synchronous with the PLT2/PLCB1 record. The younger HS3 site and the older PL sites together provide nearly

continuous data on climate from 4665 ¹⁴C years BP to 330 BP (Fig. 4). The sedimentation rate for HS3 was 0.6 mm/yr.

Composition

Quantitative mineralogical analysis reveals that the trenches share similar mineral assemblages. Major clastic constituents are sodic-intermediate plagioclase (4-26%), quartz (2-23%), and iron-rich amphiboles (2-17%). Potassium feldspar is minor (1-11%), as are micas- no more than a few wt. percent each. Chlorite is the most abundant phyllosilicate (2-10%), and other clays together are less than 4%. The major clastic minerals are present in roughly the same ratios everywhere. Sample distribution among and within trenches is shown in Figures 1-3.

The most significant variation in these profiles arises from comparisons of total clastic (plot includes clays), organic, carbonate and diatom content. Clastic minerals constitute 19-85 wt. % of analyzed layers in PLT2, 74% in PLCB1, and 83 and 94% in HS3. Organic

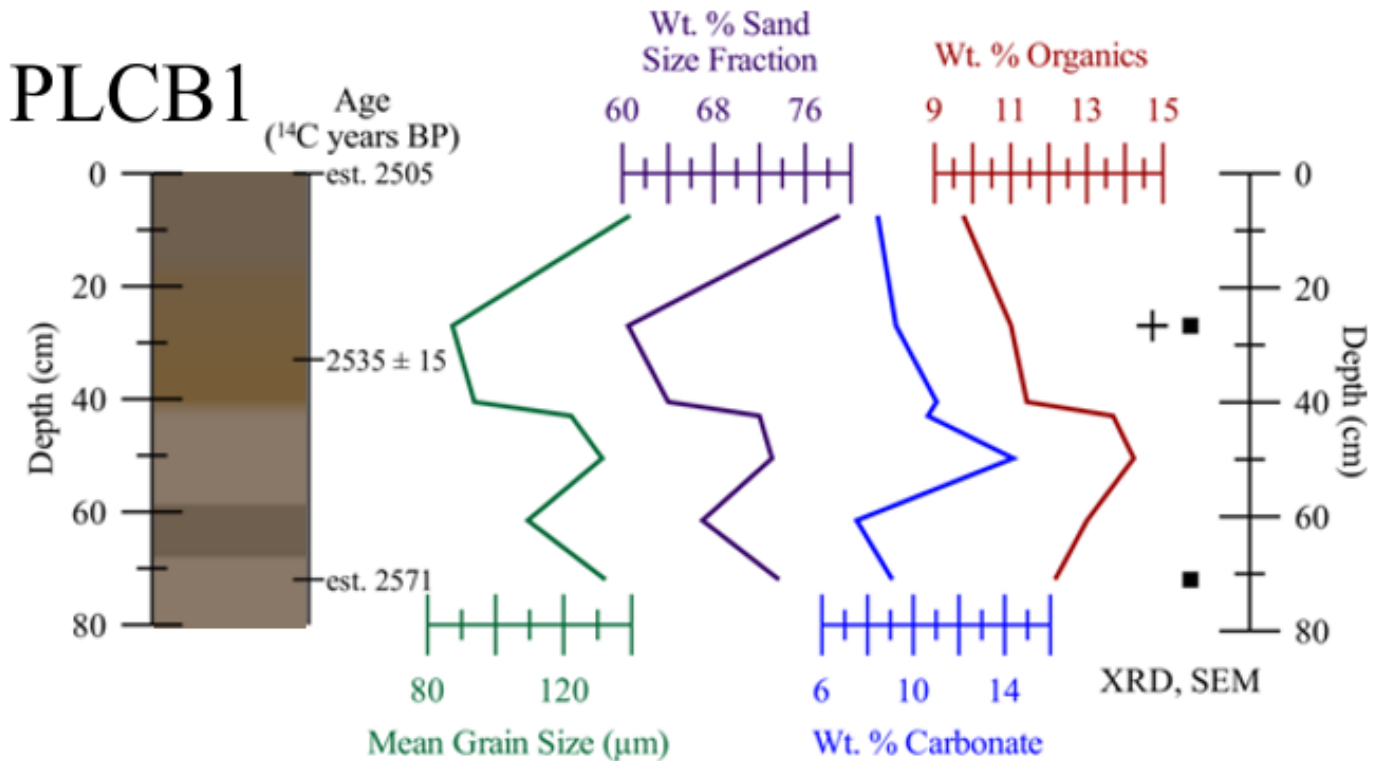


Figure 2. Stratigraphy of PLCB1 with observed Munsell color. Paler layers are more carbonate-rich. Locations of SEM images and XRD samples given by squares and crosses, respectively.

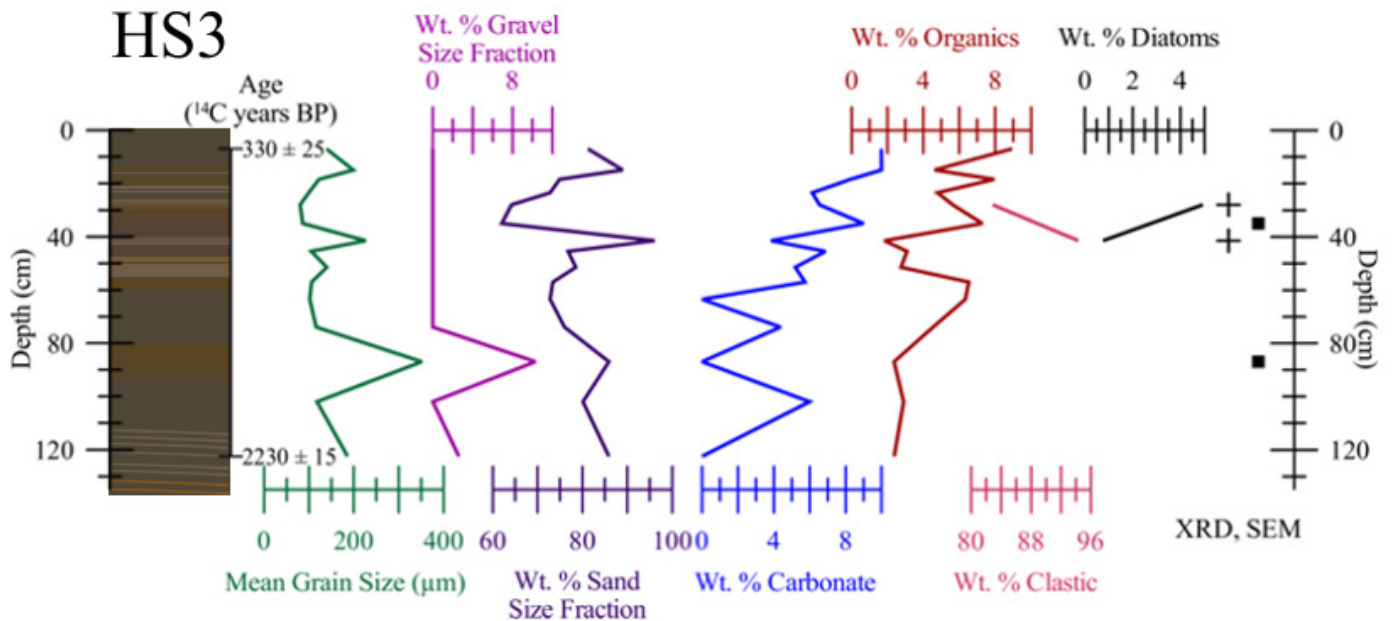


Figure 3. Stratigraphy of HS3 with observed Munsell color. 110 cm to end contains cross bedded laminae and iron oxide staining. Productivity proxies increase synchronously in a sawtooth pattern.

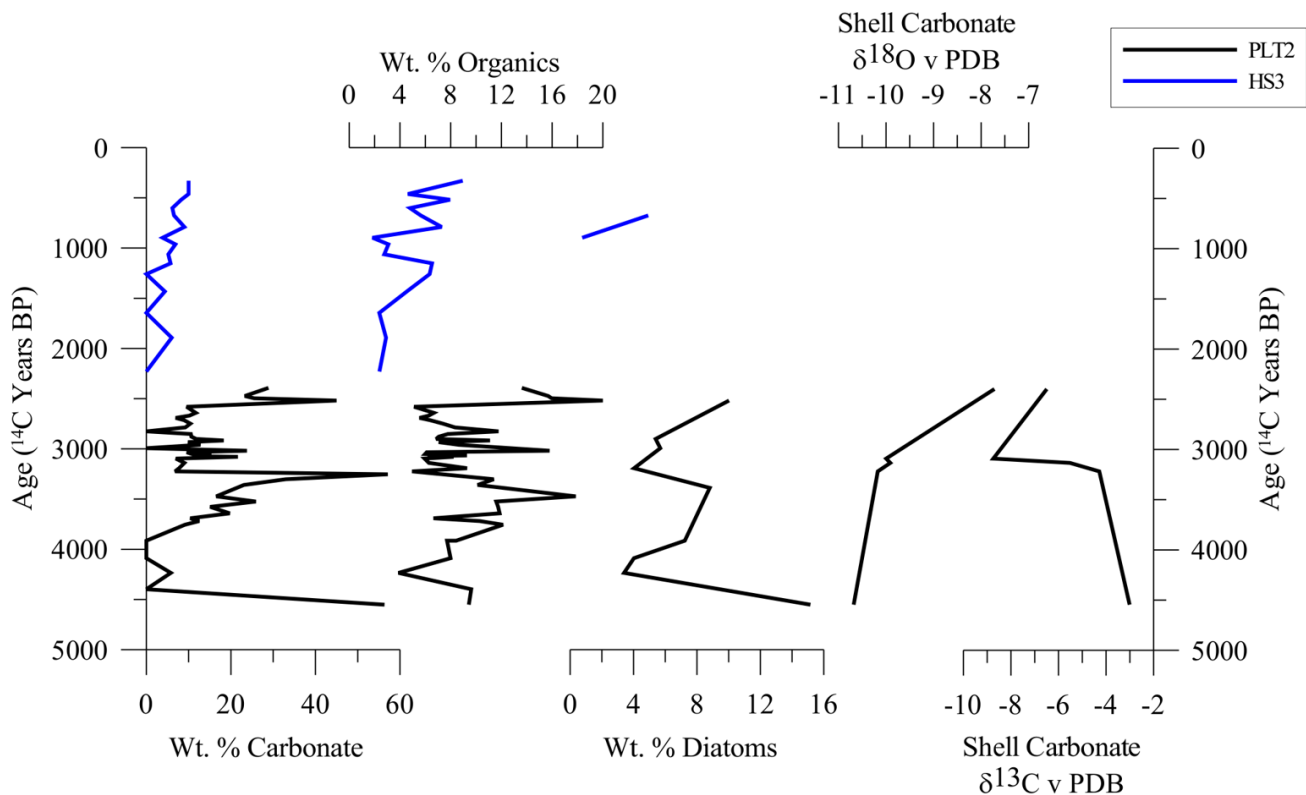


Figure 4. HS3 and PLT2 productivity proxies plotted against time. PLCB1 was left out, as it represents <100 years and plots on the PLT2 lines.

and carbonate contents were determined for almost all layers. PLT2 has 5-20% organics and ~0-57% carbonate, while PLCB1 and HS3 exhibit organic contents of 10-14% and 2-9% and 7-14% and ~0-10 wt. % carbonate. Diatom abundance was assessed as a part of mineralogy; biogenic silica content is an acceptable measure of siliceous microfossil abundance (Conley, 1988). Although the bottom of PLT2 contained some sponge spicules, and no diatoms were observed in the upper HS3 sample, the RockJock output seems reliable. PLT2 diatom abundances varied from 3-15 wt. %; the one PLCB1 value is ~5.5%. Abundances in HS3 are <1% to 5%.

Figures 1-3 illustrate the relationships of clastic, organic, carbonate, and diatom components. Generally, clastic content is negatively correlated to the other three variables. In Figure 4, major transitions from carbonate-rich to carbonate-poor sediments can be seen at about 4500 BP, 3250 BP, and 2500 BP. Shifts in diatom abundance and organic content are approximately contemporary.

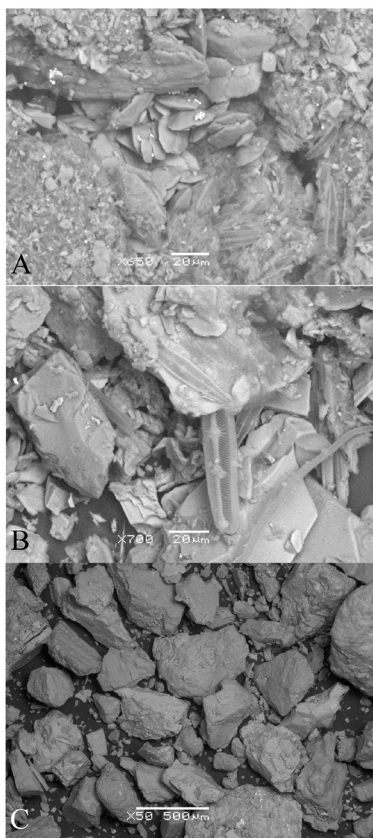


Figure 5. A. Micrite, gypsum, framboidal pyrite, diatoms; from PLT2 at 276 cm. B. *Navicula* with angular, inequant clasts; from PLT2 at 85 cm. C. Relatively rounded clasts; from HS3 at 84 cm.

Diatom Assemblages

Since diatom studies began in this region, most effort has been concentrated on the abundant planktonic diatoms of Lake Hovsgol (M. B. Edlund, Williams, & Soninkhishig, 2003). In PLT2, however, the identified diatoms are benthic and epiphytic. *Navicula* (Fig. 5B) and *Cymbella* are abundant throughout; *Amphora*, *Coconeis*, *Gyrosigma*, *Fragilaria*, *Epithemia*, and other pennates are also present. Carbonate-rich layers have the highest diversity and species richness, especially of fragile, smaller (<30 μm long) forms. A few robust *Didymosphenia* and *Cymatopleura* were observed in clastic-dominated samples.

Grain Size Statistics; Other SEM Imaging and Electron Dispersive Spectroscopy

Grain size and SEM/EDS analyses were undertaken to characterize the sediment. All three trenches exhibit very poor sorting, though HS3 is better sorted. Typically, in PLT2 and PLCB1 higher carbonate content is associated with worse sorting and higher wt. % sand size (Fig. 1, 2). SEM investigations show this is probably due to carbonate particles and aggregates with micritic and dendritic textures (Fig. 5A). Imaging also reveals that clasts in PLT2 and PLCB1 are typically more angular and less equant than in HS3 (Fig. 5B,C).

Gypsum (one interval), framboidal pyrite, (Fig. 5A) and barite were identified via electronic dispersive spectroscopy in PLT2 and PLCB1. Field observations of iron oxide in HS3 were confirmed.

Shell Isotopes

Oxygen isotope ratios become heavier towards the top of PLT2, with $\delta^{18}\text{O}$ increasing from -10.7‰ to -7.7‰. The sample cluster at and immediately after the 3250 BP carbonate spike shows a decrease in $\delta^{13}\text{C}$ of 4.4‰ over a 127-year period.

DISCUSSION

Depositional Environment

The current spatial relationship of PLT2 and PLCB1 suggest that these profiles are related; dating and many environmental proxies (Fig.4) support the idea that these sections are indeed genetically similar. Deposition took place in a bog/shallow lake setting, with clastic materials possibly entering by short range

eolian transport. The presence of framboidal pyrite and organic-associated barite throughout implies a stagnant, low-oxygen environment (Paytan et al., 2004). PLT2 carbonate textures indicate in situ formation. Diatom assemblages are currently not well enough constrained to indicate salinity or pH. The better sorting, iron oxides, and particle rounding of HS3 support the hypothesis that this is a fluvial deposit.

Climate Shifts

Data from the northern Mongolian Plateau indicates humid conditions prevailed from ~4500-2500 BP (Feng et al., 2005), essentially throughout PLT2/PLCB1. However, other sources also indicate that this interval was extremely variable. Low productivity (low carbonates/organics/diatoms) in PLT2 beginning at 4500 and at 3250 14C yr BP correlate fairly well with reported lowstands and dry conditions at Lake Hovsgol (3910 ± 60) and nearby Lake Gun (3300 ± 80) (Prokopenko, 2007). Wang et al. (2011) link higher productivity at Lake Gun from 5600-4100 BP to cooler and wetter conditions, correlating with the carbonate-rich productive interval at the bottom of PLT2 and agreeing with the more negative oxygen isotope data. Also reported is an abrupt climate shift at 2800 BP, which could correspond to the shift recorded in PLT2 at ~2500 BP. These shifts are linked to IRD events in the Atlantic (Bond et al., 1997; Wang et al., 2011). A later IRD event that Lake Gun registered at 1750 BP may correlate with a gravelly layer in HS3 at 1650 BP as a stormy interval (Wang et al., 2011).

Peak Holocene temperatures in this region reportedly lasted from 6000 to 3000 BP, though the limited oxygen isotope data here seems to indicate that peak temperatures lasted at least for 500 years later (Prokopenko, 2007).

Overall, these findings reinforce the idea of a highly variable late Holocene, as well as provide further evidence for the timing of and degree of aridity peaks in the Hovsgol basin.

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