

**KECK GEOLOGY CONSORTIUM  
PROCEEDINGS OF THE TWENTY-THIRD  
ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY  
ISSN# 1528-7491**

**April 2010**

---

Andrew P. de Wet  
Editor & Keck Director  
Franklin & Marshall College

Keck Geology Consortium  
Franklin & Marshall College  
PO Box 3003, Lanc. Pa, 17604

Lara Heister  
Symposium Convenor  
ExxonMobil Corp.

**Keck Geology Consortium Member Institutions:**

Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster, The Colorado College  
Franklin & Marshall College, Macalester College, Mt Holyoke College, Oberlin College, Pomona College, Smith College, Trinity University  
Union College, Washington & Lee University, Wesleyan University, Whitman College, Williams College

---

**2009-2010 PROJECTS**

**SE ALASKA - EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTHEAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FM.**

*Faculty: Cameron Davidson (Carleton College), Karl Wirth (Macalester College), Tim White (Penn State University)*

*Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen*

**COLORADO – INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO.**

*Faculty: David Dethier (Williams)      Students: Elizabeth Dengler, Evan Riddle, James Trotta*

**WISCONSIN - THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN.**

*Faculty: Sue Swanson (Beloit) and Maureen Muldoon (UW-Oshkosh)*

*Students: Hannah Doherty, Elizabeth Forbes, Ashley Krutko, Mary Liang, Ethan Mamer, Miles Reed*

**OREGON - SOURCE TO SINK – WEATHERING OF VOLCANIC ROCKS AND THEIR INFLUENCE ON SOIL AND WATER CHEMISTRY IN CENTRAL OREGON.**

*Faculty: Holli Frey (Union) and Kathryn Szramek (Drake U. )*

*Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien*

**MONGOLIA - PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-ALTAI TERRANE, MONGOLIA.**

*Faculty: Connie Soja (Colgate), Paul Myrow (Colorado College), Jeff Over (SUNY-Geneseo), Chuluun Minjin (Mongolian University of Science and Technology)*

*Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtseren, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropulos*

**KENAI - THE GEOMORPHOLOGY AND DATING OF HOLOCENE HIGH-WATER LEVELS ON THE KENAI PENINSULA, ALASKA**

*Faculty: Greg Wiles (The College of Wooster), Tom Lowell, (U. Cincinnati), Ed Berg (Kenai National Wildlife Refuge, Soldotna AK)*

*Students: Alena Giesche, Jessa Moser, Terry Workman*

**SVALBARD - HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY.**

*Faculty: Al Werner (Mount Holyoke College), Steve Roof (Hampshire College), Mike Retelle (Bates College)*

*Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt*

**UNALASKA - LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND, AK.**

*Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)*

*Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin*

**Funding Provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)  
and ExxonMobil**

**Keck Geology Consortium: Projects 2009-2010  
Short Contributions – MONGOLIA**

**PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-  
ALTAI TERRANE, MONGOLIA**

Project Directors: **CONSTANCE M. SOJA**: Colgate University  
**CHULUUN MINJIN**: Mongolian University of Science and Technology  
Project Faculty: **PAUL MYROW**: The Colorado College  
**D. JEFFREY OVER**: State University of New York at Geneseo

**CHEMOSTRATIGRAPHY OF THE LOWER SILURIAN SCHARCHULUUT  
FORMATION, YAMAAN-US, SHINE JINST REGION, GOBI-ALTAI TERRANE,  
MONGOLIA**

**UYANGA BOLD**: Mongolian University of Science and Technology  
Research Advisor: Chuluun Minjin

**GEOLOGIC MAP AND PALEOECOLOGY OF THE LOWER SILURIAN  
SCHARCHULUUT FORMATION AT “WENLOCK HILL”, SHINE JINST  
REGION, GOBI-ALTAI TERRANE, MONGOLIA**

**BILGUUN DALAIBAATAR**: Mongolian University of Science and Technology  
Research Advisor: Chuluun Minjin

**SEDIMENTOLOGY, DEPOSITIONAL HISTORY AND DETRITAL ZIRCON  
GEOCHRONOLOGY OF THE LOWER DEVONIAN TSAKHIR FORMATION,  
SHINE JINST REGION, MONGOLIA**

**TIMOTHY M. GIBSON**: Colorado College  
Research Advisor: Paul Myrow

**BRACHIOPODS FROM THE LOWER SILURIAN SCHARCHULUUT  
FORMATION, YAMAAN-US, SHINE JINST REGION, GOBI-ALTAI TERRANE,  
MONGOLIA**

**BADRAL KHURELBAATAR**: Mongolian University of Science and Technology  
Research Advisor: Chuluun Minjin

**CHEMOSTRATIGRAPHY AND MAGNETIC STRATIGRAPHY OF THE UPPER ORDOVICIAN DARAVGAI AND GASHUUNOVOO FORMATIONS, GOBI-ALTAI TERRANE, SHINE JINST AREA, SOUTHERN MONGOLIA**

*MADelyn METTE*: Macalester College  
Research Advisor: Ray Rogers

**SEQUENCE STRATIGRAPHY AND PALEONTOLOGY OF THE UPPER ORDOVICIAN DARAVGAI AND GASHUUNOVOO FORMATIONS, GOBI-ALTAI TERRANE, SHINE JINST, MONGOLIA**

*SARA E. OSER*: University of Cincinnati  
Research Advisor: Carlton E. Brett

**PALEOECOLOGY OF LOWER DEVONIAN (EMSIAN) SHELF DEPOSITS IN THE CHULUUN FORMATION, GOBI-ALTAI TERRANE, MONGOLIA**

*ADAM FRANCIS ANTONIO PELLEGRINI*: Colgate University  
Research Advisor: Constance M. Soja

**TRILOBITE PALEOECOLOGY OF THE MIDDLE DEVONIAN TSAGAANKHAALGA FORMATION NEAR TSAKHIR WELL, SHINE JINST, MONGOLIA**

*JENNIFER A. PETEYA*: Mount Union College  
Research Advisor: Lee Gray

**GEOLOGIC MAP SHOWING EAST-TO-WEST FACIES TRANSITIONS IN THE LOWER SILURIAN SCHARCHULUUT FORMATION, SCHARCHULUUT, SHINE JINST REGION, GOBI-ALTAI TERRANE, MONGOLIA**

*MUNKH-OD PUREVTSEREN*: Mongolian University of Science and Technology  
Research Advisor: Chuluun Minjin

**PALEOECOLOGY AND CHEMOSTRATIGRAPHY OF THE AMANSAIR AND TSAGAANBULAG FORMATIONS, GOBI-ALTAI TERRANE, MONGOLIA**

*NADINE G. REITMAN*: Vassar College  
Research Advisor: David P. Gillikin

**THE EIFELIAN GIVETIAN BOUNDARY (MIDDLE DEVONIAN) AT TSAKHIR,  
GOVI ALTAI REGION, SOUTHERN MONGOLIA**

***NICHOLAS SULLIVAN:*** State University of New York at Geneseo  
Faculty Advisor: D. Jeffrey Over

**PALEOENVIRONMENTS AND DEPOSITIONAL HISTORY OF UPPER  
SILURIAN-LOWER DEVONIAN LIMESTONE IN THE AMANSAIR AND  
TSAGAANBULAG FORMATIONS AT ULAANSHAND AND TSAKHIR, GOBI-  
ALTAI TERRANE, MONGOLIA**

***ZOE VULGAROPULOS:*** Oberlin College  
Research Advisor: Dennis Hubbard

**Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)**

Keck Geology Consortium  
Franklin & Marshall College  
PO Box 3003, Lancaster Pa, 17603  
[Keckgeology.org](http://Keckgeology.org)

# SEQUENCE STRATIGRAPHY AND PALEONTOLOGY OF THE UPPER ORDOVICIAN DARAVGAI AND GASHUUNOVOO FORMATIONS, GOBI-ALTAI TERRANE, SHINE JINST, MONGOLIA

SARA E. OSER

University of Cincinnati

Research Advisor: Carlton E. Brett

## INTRODUCTION

A key agenda for sedimentary geology is the documentation and interpretation of sedimentary cyclicity on various scales. Cyclic patterns may be generated by local tectonics or global eustatic fluctuations, the latter commonly linked to widespread faunal patterns. Late Ordovician (Caradoc-Ashgill Stages) strata of eastern North America contain some of the best-documented Paleozoic cycles (Holland, 1993, 1998; Holland and Patzkowsky, 2007, 2009). Yet, to date, there has been little effort to test whether these cycles have counterparts in other regions. It is critical to determine if the boundaries and stacking patterns of third-order depositional sequences identified by Holland (1993, 1998) can be identified in other depositional basins. The objective of this study is to determine if these putatively global, allocyclic effects can be recognized in a distant, oceanic island arc platform in the Gobi-Altai terrane in southern Mongolia. The Upper Ordovician of the Gobi Altai terrane of southern Mongolia, like the Cincinnati, is composed of mixed carbonates and siliciclastics formed on a platform adjacent to developing tectonic source.

The present study presents an analysis of the sequence stratigraphy and paleoenvironments of upper Caradocian to lower Ashgillian strata of a well-exposed section in the Shine Jinst region of Mongolia to reconstruct patterns of relative sea level change (within a tectonic context) and examine how the biota responded to the resulting environmental modifications. A comparison was then made between this section and concurrent sections in Cincinnati, Ohio, in order to distinguish the re-

gional versus global signatures recorded and test for possible eustatic patterns.

## GEOLOGIC AND TECTONIC SETTING

Mongolia is composed of numerous terranes agglomerated during a long and complex tectonic history. The Shine Jinst region is located in southern Mongolia in the Gobi-Altai terrane (Fig. 1). The strata in the Shine Jinst region have been faulted and subjected to varying degrees of folding. As such, much of the sedimentological record has been significantly modified and made discontinuous, presenting a challenge for paleoenvironmental reconstruction. The study area at Shar Chuluut has undergone moderate deformation and fracturing, such that the strata are tilted and folded, yet traceable to some extent (Fig 2) (Badach et al., 2002; Windley et al., 2007; and Lamb et al., 2007).

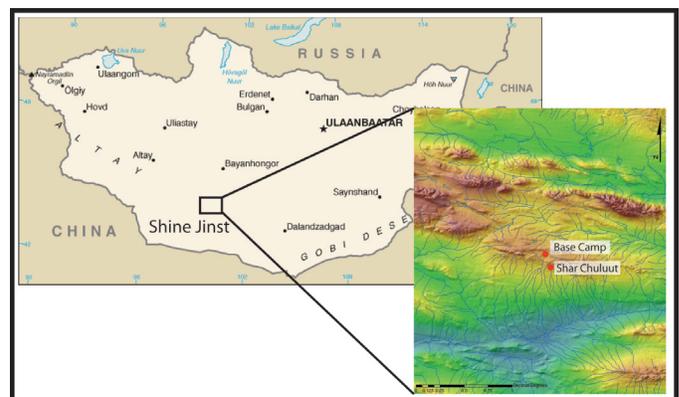


Figure 1: Map indicating the Shine Jinst region of southern Mongolia. Inset shows detail of the study area. Data courtesy of the Seamless server and Geocommunity online.

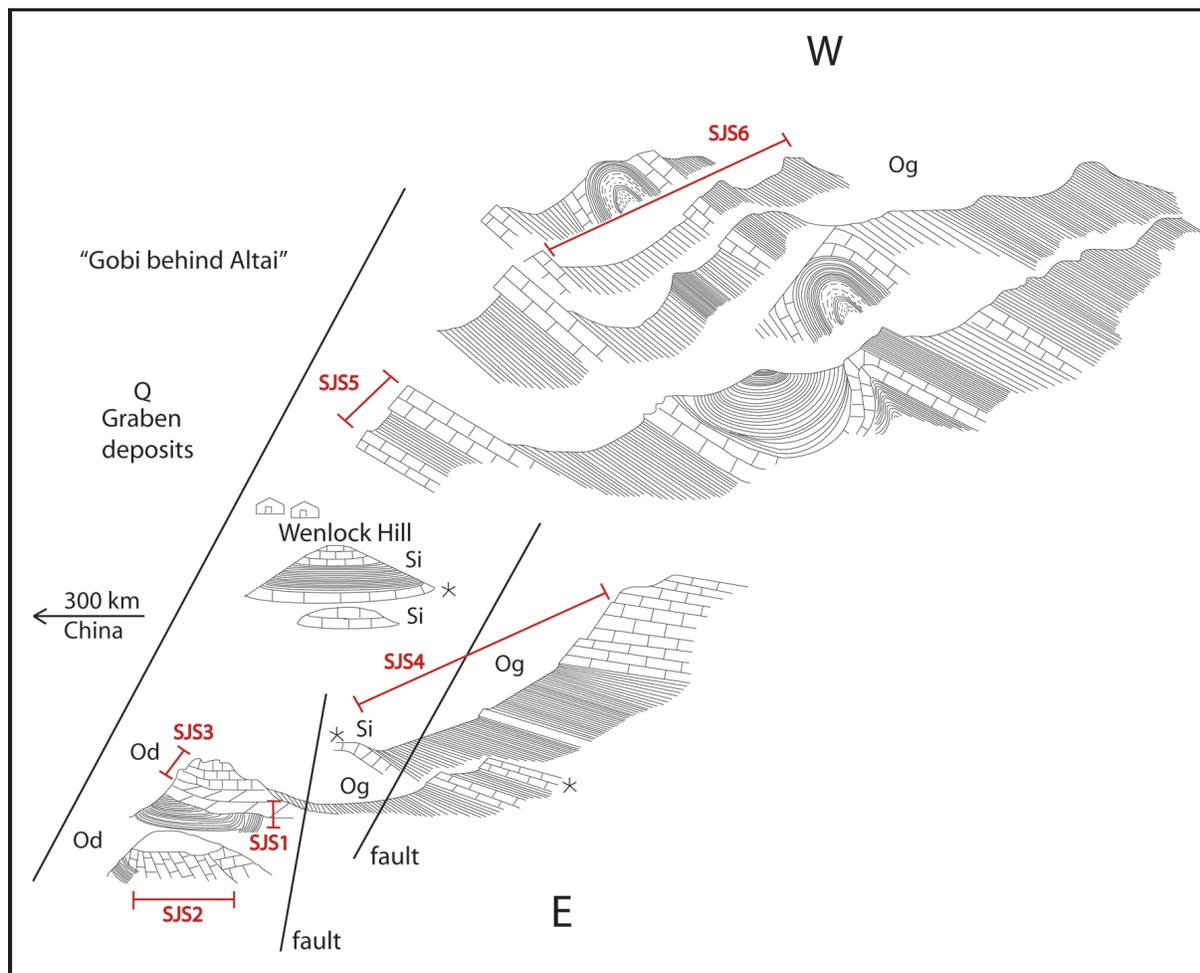


Figure 2: Structural diagram showing the ridge profiles of the sections measured in the Shar Chuluut region.

During the Paleozoic, Central Asia was formed during a complex series of collisional episodes, resulting in the agglomeration of many terranes onto the Siberian and Baltica cratons. Mongolia is a collection of terranes between the Siberian and Chinese cratons formed by the closure of a series of small ocean basins between incoming arcs (Badarch et al. 2002). The northern part of Mongolia, formed from a series of accreting microcontinents during the Precambrian, had stabilized into a coherent block by the Ordovician (Windley et al 2007). The Main Mongolian Lineament formed the southern border, onto which the Gobi-Altai terrane had accreted and was for a time a passive margin (Badarch et al., 2001). During the Silurian, Devonian, and Carboniferous, multiple island arcs accreted via northward subduction, forming the rest of southern Mongolia and culminating in the collision with the North China block in the Permian (Lamb, et al. 2007). The

Permian marks the beginning of the transition to intracontinental deformation of the region, which occurred throughout the Mesozoic and continues to some extent today.

The passive margin along the southern edge of the Gobi-Altai terrane described by Badarch et al. (2001) provided the depositional environment necessary to form the sequence of strata measured in this study. Paleomagnetic studies have placed the region near the equator, within the subtropical zone of reef formation between 30° N and 30° S.

Previous work on the paleontology and stratigraphy of the region was initially conducted by Mongolian and Soviet researchers during the 1970s. Recent detailed work has been conducted by Ch. Minjin (1993; 1997; 2009).



and carbonate before grading into thicker bedded carbonates of generally increasing grain size. SJS3 starts at an abrupt shift into a thin interval of packstones that grade into coarser partially dolomitized carbonate with tabulate corals throughout. The top of this section is distinguished by a paleo-karst surface displaying up to 1 meter of relief, filled by in-situ shale deposits, and a dissolution hole, infilled with lithified debris composed of angular limestone cobbles. SJS3 is capped by the basal shale of SJS4; however, the presence of a fault indicates the possibility of missing strata and an unknown interval of unrecorded time.

SJS4 marks the base of the Gashuunovoo Formation (and the approximate base of the Ashgill stage) and is composed of a 60-meter shale interval, followed by a 70-meter carbonate interval. The carbonate interval is characterized by a coarsening-upward sequence with carbonate mudstone and wackestone that grades into coarser packstone and grainstone. Some dolomitization is common throughout. The upper part is characterized by limestones with an abundance of halysitid corals that grade upward into a rugosan/brachiopod hash facies. SJS5 continues the carbonate interval, but is characterized by more

massive beds with some dolomitization and with rugose corals and stromatoporoids. SJS6 marks a brief return to more shaly facies, grading upward into coarser and more thickly bedded carbonates, including a 2 meter bed of crinoidal grainstone, before abruptly shifting to a predominantly siliciclastic regime through an interval of rhythmically interbedded limestone and/or clastics (rhythmites). The rhythmites occur in a series of three, 1-2 m packages punctuated by one meter shaly intervals and consisting of alternating 2-10 cm beds of muddy siltstone and fine sandstone. These rhythmites terminate at a bed of crossbedded sandstone. Thirty meters higher in the section there is another 4 meter series of rhythmites composed of four, 1-0.5 meter packages of alternating 3-5 cm beds of grainstone and fine sandstone.

### THIN SECTION ANALYSES

Petrographic samples were collected throughout the carbonate intervals and processed into thin sections. SJS2 and SJS6 were analyzed using the methods outlined above, and abundance curves for the abundance of various taxa and for carbonate grain size were generated (Fig. 4). The grain size curves

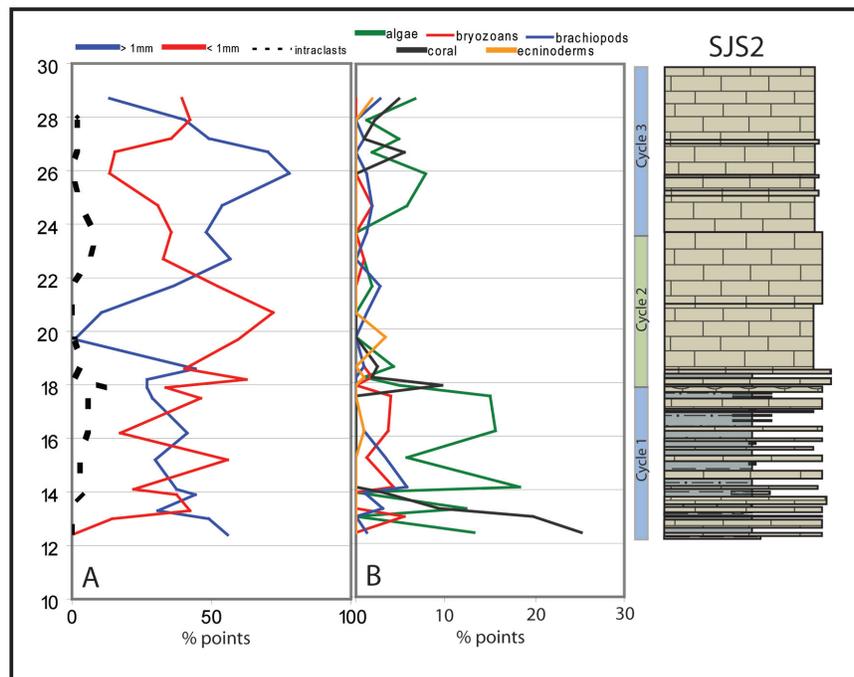


Figure 4: Example grain size (A) and taxon (B) abundance curves for SJS2.

for SJS2 reveal numerous six meter-scale cycles, that alternate between predominantly fine grain size (<1mm) to medium sand size (>1mm) and vice versa. Concurrently a similar 6 meter-scale cyclicality is clearly shown in the faunal abundances, with a strong algal abundance from 12 to 18 meters, which drops off abruptly at 18m before picking back up at 24 to 29 m. The high algal abundance coincides with a larger grain size in this section.

The thin sections for SJS6 reveal that siliciclastics, represented by quartz grains appeared intermittently within the carbonate 90 meters below the major transition to siltstone and sandstone noted in the field. The quartz grain abundance varies within 30-meter scale, 4th order cycles. The coral and bryozoan abundance inversely traces the quartz abundance at the same scale.

## IMPLICATIONS AND COMPARISON

Numerous carbonate - shale cycles can be distinguished in the section (see Fig 5). In particular, a major, karstic unconformity occurs at the Carodocian-Ashgillian boundary as established by Minjin (2008). Using the Carodocian-Ashgillian boundary as a point of correlation, the cyclic changes recorded in the Daravgai and Gashuunovoo Formations are likely correlative to 4<sup>th</sup>, 5<sup>th</sup>, and 6<sup>th</sup> order eustatic sea level changes recorded in Cincinnati strata.

## SEQUENCE INTERPRETATION AT SHAR CHULUUT

The general coarsening upward trend in the carbonates accompanied by the presence of algae, corals,

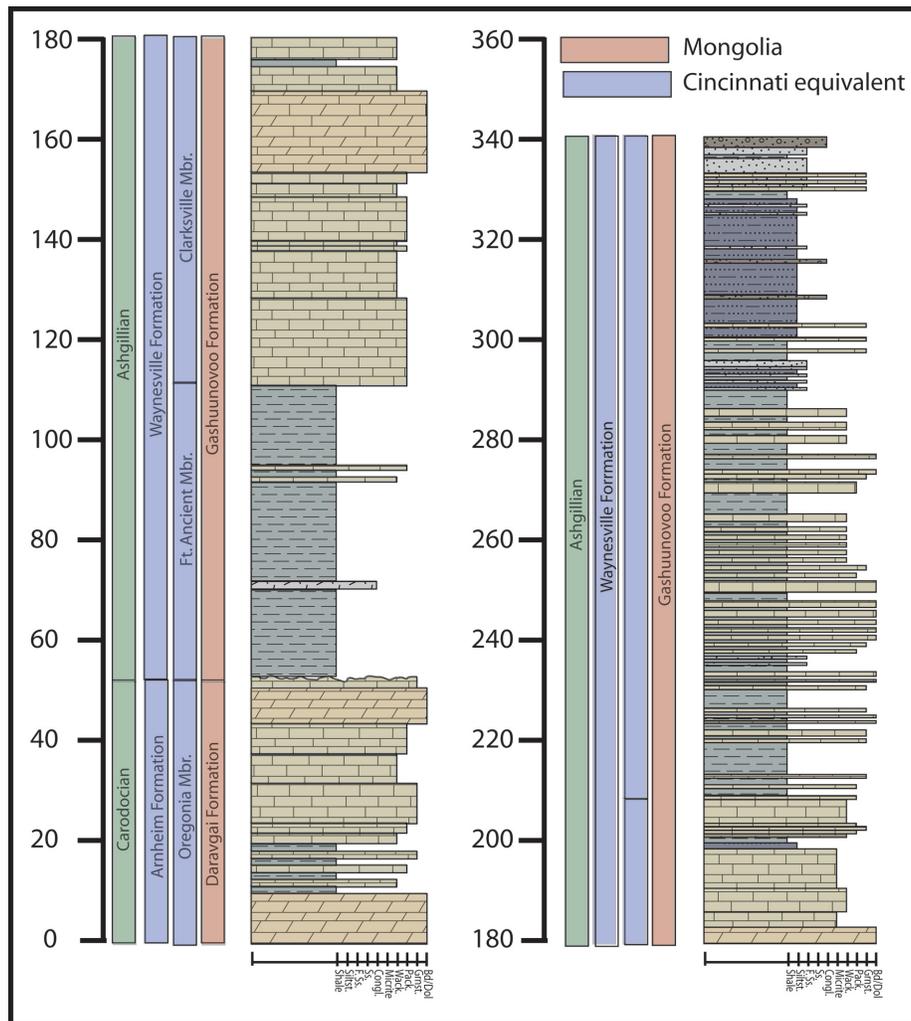


Figure 5: Generalized composite stratigraphic column of the study interval with the analogous Cincinnati units identified. Units are in meters.

and other shallow water taxa suggest that SJS2-SJS3 represents a shallowing-upward interval culminating in subaerial exposure and dissolution, and is interpreted as a major sequence boundary. The paleokarst surface capping SJS3 and marking the Carodocian-Ashgillian boundary suggests that there was very little erosion associated with ravinement at the sequence boundary. The surface is overlain by a thick shale interval indicative of a rapid sea level rise, possibly exaggerated by tectonics. The presence of volcanics in the Gashuunovoo immediately above the measured interval suggests that there was indeed active volcanism at this time. The sparsely fossiliferous shale records an offshore, probably dysoxic environment deposited during a highstand interval.

The shale (SJS3-23.0) is followed by an equally abrupt transition back into muddy carbonate, probably recording a second fourth order sequence boundary. The succession grades from carbonate mudstone to packstone with abundant halysitid corals and intraclasts preceding the return of interbedded limestone and shale. This interval defines a transgression from shallow subtidal facies into deeper subtidal facies (SJS6: transgressive sequence tract).

The interbedded limestone and shale records several small-scale sequences, which are each characterized by an upward-increasing number and thickness of carbonate beds. As observed in the thin sections, this interval is also characterized by an influx of angular quartz grains (approx 0.2 mm) within the carbonate beds. Centered at the 250 meter position is a 50 meter interval with a series of 1-meter packages of bryozoan colonies smothered by minor pulses of siliciclastics. The increasing siliciclastic content of this interval suggests the upper portion of a shallowing upward or regressive succession.

This regression (or falling stage) is followed by a brief return to quartz-free carbonates with intraclasts, then pure crinoidal grainstone. This interval is interpreted as another transgressive systems tract and its rather abrupt base as another sequence boundary. At 290 meters the major siliciclastic influx becomes predominant, introduced by cross-

bedded sandstone and the last crinoidal grainstones. The heavily winnowed crinoidal grainstones and cross-bedded sands indicate a very shallow, possibly tidally influenced environment. These strata are overlain by coarse siltstones, sandstones and pebble-conglomerates that indicate highstand conditions as well as a tectonic influence as the primary driving force of shallowing in comparison to eustatic changes. Regional uplift inland would dramatically increase erosion rates and the shallowing seas would be the prime receiver of this new influx of sediment.

## SEQUENCE STRATIGRAPHY OF THE CINCINNATIAN OF NORTH AMERICA

The Cincinnati Series of North America is an interval which corresponds to a time 450 to 443.7 million years ago ( $\pm 1.5$ ma) (Webby et al., 2004) and consists of the Upper Carodocian and Lower Ashgillian Stages. During the Late Ordovician the Laurentian craton was submerged beneath a shallow intracontinental sea. The eastern continental margin was periodically an active subduction zone with a series of island arcs accreting, building the nascent Appalachian Mountains during the Taconic Orogeny.

The Cincinnati has been subdivided into a series of 3rd-order cycles by (Holland, 1993) and those have now been traced widely in eastern North America. This succession represents the upper Caradoc-lower Ashgill and is thus age equivalent to the Daravgai and Gashuunovoo Formations. Within the Cincinnati, the Caradoc-Ashgill boundary coincides with a major sequence-bounding discontinuity identified as the C4 and C5 boundary within the Richmondian Stage (Holland 1993, 1998). The top of the C4 sequence is the Arnheim Formation and the base of the C5 is the Waynesville Formation. The uppermost member of the Arnheim Formation is the Oregonia and is predominantly limestone. This is overlain by the Ft. Ancient Member of the Waynesville Formation, which is predominantly shale and records a major transgression throughout central North America (Maquoketa transgression). The Clarksville and Blanchester members follow, with increasing limestone abundance (Davis,

1998). Additional sequence boundaries (informally identified as C5b through C5d by Brett et al., 2009) are now recognized at the bases of the Clarksville, Liberty, and Lower Whitewater Formations. The latter shows extremely strong shallowing (Brett et al., 2009).

## COMPARISON

The timing and magnitude of depositional sequences recognized near the Upper Ordovician Caradoc-Ashgill stage boundary in the Cincinnati are mirrored to some degree by those of the Shar Chuluut section. In particular, the major karstic unconformity at the Daravgai and Gashuunovoo Formation contact records a lowstand at the Caradoc-Ashgill boundary that may correlate with the C4-C5 boundary in the Cincinnati. The shallowing succession of SJS1-SJS3 is approximately coeval with the falling stage (regression) of C4, the Oregonia Member in the Cincinnati. The subsequent thick shale interval of the basal Gashuunovoo Formation may thus correspond to the widespread major C5a highstand, seen in the Ft. Ancient Shale member and lower Maquoketa Shale of midwestern North America.

The return of subtidal carbonates observed in the second half of SJS4 through the very base of SJS6 is mirrored by sequence C5b. The shallowing and strong influx of coarse siliciclastics above this level may correspond to the very strong shallowing seen in sequence C5d of the Saluda peritidal dolostones of the Cincinnati region. Above this level, the strong influx of siliciclastics in the Mongolian succession may reflect local tectonic control.

## CONCLUSIONS

Third, Fourth, and perhaps higher order sequences in the section are recognizable from the stratigraphic column and are reinforced by variations in grain size and taxonomic abundances. Combined with general similarities with sequence stratigraphy of the North American Cincinnati, it is plausible that the cyclicity observed at Shar Chuluut is predominantly the result of global eustatic sea level change. The abrupt introduction of coarse siliciclastics at the

top of the section, however, suggests tectonic overprinting.

The 'Richmondian Invasion' is observed in this interval within the type Cincinnati (Holland, 1997; Holland and Patzkowsky, 2007). Future work should focus on obtaining higher resolution paleoecological data through the SJS4-SJS5 interval at Mongolian localities with better preservation. Identifying a dramatic faunal turnover in this interval would be another strong correlation to the Cincinnati "Richmondian invasion" (Holland and Patzkowsky, 2007) and could better constrain the age of the strata.

## ACKNOWLEDGMENTS

This research was funded by the KECK Geology Consortium and ExxonMobil. Logistical support provided by Dr. Connie Soja, Dr. Warren Huff, and Dr. Attila Kilinc. Special thanks to Aaron House and Dr. Arnie Miller for demystifying certain statistical analyses. Thanks also to Dr. Carl Brett and Dr. Connie Soja for their infinite patience and wisdom, to Dr. Jeff Over for expert editing, and to Dr. Paul Myrow for refining our field tactics. Extra special thanks to Ch. Minjin, not only for introducing us to the geology of Mongolia but also for generously engaging us in the culture as well. Last but not least, thanks goes out to my co-conspirator, Maddie Mette.

## REFERENCES

- Badarch, G., W.D. Cunningham, and B.F. Windley, 2002, A new terrane subdivision for Mongolia: implications for the Phanerozoic crustal growth of Central Asia: *Journal of Asian Earth Sciences*, v. 21, p. 87-110.
- Badarch, G. and O. Tomurtogoo, 2001, Tectonostratigraphic Terranes of Mongolia: *Gondwana Research*, v. 4, no. 2, p. 143-144.
- Brett, C.E., P.I. McLaughlin, and M. DeSantis, 2009, Middle Paleozoic sequence stratigraphy and paleontology of the western flank of the Cincinnati Arch. *North American Paleontological*

- Convention, Guidebook 7, University of Cincinnati, Cincinnati, Ohio.
- Davis, R.A., editor, 1998, Cincinnati Fossils: An elementary guide to the rocks and fossils of the Cincinnati region: Cincinnati Museum Center.
- Holland, S. M., 1993, Sequence stratigraphy of a carbonate-clastic ramp: The Cincinnati Series (Upper Ordovician) in its type area: Geological Society of America Bulletin, v. 105, p. 306-322.
- Holland, S. M. 1998, Sequence stratigraphy of the Cincinnati Series (Upper Ordovician, Cincinnati, Ohio region). in Davis, R.A., and Cuffey, R.J., eds., Sampling the Layer Cake That Isn't: Ohio Department of Natural Resources, Columbus, p. 135-151.
- Holland, S. M., 2008, The Type Cincinnati Series: An overview, Stratigraphic Renaissance in the Cincinnati Arch, Ed. P. McLaughlin, C. Brett, S. Holland, and G. Storrs: Cincinnati Museum Center Scientific Contributions, No 2. p. 174-184.
- Holland, S. M., and M.E. Patzkowsky, 2007, Gradient ecology of a biotic invasion: biofacies of the type Cincinnati Series (Upper Ordovician), Cincinnati, Ohio region, USA. *Palaios* 22: p. 392-407.
- Holland, S. M., and M.E. Patzkowsky, 2009, The Richmondian Invasion: Understanding the faunal response to climate change through stratigraphic paleobiology. Ninth North American Paleontological Convention, Guidebook 5, p. 66, University of Cincinnati, Cincinnati, Ohio.
- Lamb, Melissa A., G. Badarch, T. Navratil, and R. Poier, 2008, Structural and geochronologic data from the Shin Jinst area, eastern Gobi Altai, Mongolia: Implications for Phanerozoic intracontinental deformation in Asia: *Tectonophysics*, v. 451, p. 312-330.
- Minjin, Ch., G. Badarch, and F. Tungalag, 1993, Stratigraphy of the Shine-Jinst Paleozoic deposits; Mongolian Tech. University Sci.Trans., v. 3/18, p. 3-19.
- Minjin Ch. and M. Bolortsetseg, 1997, New data on stratigraphy of Ordovician of southern Mongolia; in Problems of geology and mineralogy of Mongolia, 11th international science conference, v. 2, p., 18-21.
- Minjin, Ch. and C.M. Soja, 2009, Geology of the Shine Jinst area of South Mongolia: Mongolian University of Science and Technology, Guidebook.
- Webby, B.D., F. Paris, M.L. Droser, I.G. Percival, eds., 2004. The Great Ordovician Biodiversification Event. Critical Moments and Perspectives in Earth History and Paleobiology. Columbia University Press. New York, p 483.
- Windley, Brian F., D. Alexeiev, Wenjiao Xiao, A. Kroner, and G. Badarch, 2007, Tectonic models for accretion of the Central Asian Orogenic Belt: *Journal of the Geological Society, London*, v. 164, p. 31-47.