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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.

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

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

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

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Students: Alena Giesche, Jessa Moser, Terry Workman

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

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

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

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

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

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

UYANGA BOLD: Mongolian University of Science and Technology
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**PALEOENVIRONMENTS AND DEPOSITIONAL HISTORY OF UPPER
SILURIAN-LOWER DEVONIAN LIMESTONE IN THE AMANSAIR AND
TSAGAANBULAG FORMATIONS AT ULAANSHAND AND TSAKHIR, GOBI-
ALTAI TERRANE, MONGOLIA**

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

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INTRODUCTION

Magnetic susceptibility and stable carbon isotope ratios are useful for understanding paleoclimate, as well as correlation of sections for which precise ages are poorly constrained due to limited fossil preservation, diagenetic and metamorphic modifications, and structural complications (Glumac and Mutti, 2007; Ellwood et al., 2007). These methods are applied to a sequence of carbonate and clastic strata, from the Gobi-Altai terrane in southern Mongolia. Herein geochemical records for the Late Ordovician section are presented and regional correlations proposed. These data also suggest climate fluctuations, sea level change, and depositional environments. Magnetic susceptibility measurements allow interpretation of the significance of terrestrial sediment input to the system and serve as a proxy for sea level. Carbon isotopes are used here primarily for correlation, with the goal of further refinement of the age of the section which is currently constrained by limited biostratigraphy (Minjin, personal communication, 2009).

FIELD SETTING

The field site is located in southern Mongolia near the town of Shine Jinst where Upper Ordovician strata of the Daravgai and Gashuunovoo formations are exposed near the well "Shar-Chuluut." This hilly region of intensely folded and faulted Paleozoic rocks lies adjacent to the expansive steppe-like terrain of the Gobi Desert. The stratigraphic intervals were measured - SJS1 through SJS6 (SJS=Shine Jinst, Shar-Chuluut) - across a series of hill sides where the top of each section is marked by a fault or un-

conformity (Fig. 1). Fossils are abundant throughout, and include brachiopods, bryozoans, crinoids, stromatoporoids, and rugose/favositid/halysitid corals.

METHODS

The 344 meter section was measured with a steel tape and described in detail. Small samples (~30 cm³ each) were collected from carbonate facies at 0.5 meter intervals throughout the section (total of 477 samples). Samples were cut to approximately 2.5 cm cubes. Magnetic susceptibility was analyzed using the KLY-2 Kappa Bridge magnetic susceptibility meter at the Institute for Rock Magnetism at the University of Minnesota. Values were normalized to mass. Sample powders were sent to the Colorado Plateau Stable Isotope Laboratory at Northern Arizona University for carbon and oxygen isotope analysis. A total of 94 samples from SJS1, SJS2, SJS3, and SJS4 were analyzed with a sampling interval of ~1.0 m. The results are reported relative to Pee Dee Belemnite standard.

MAGNETIC SUSCEPTIBILITY

Magnetic susceptibility (MS) in sediments is a measurement that indicates iron-bearing mineral, ferromagnesian, or clay mineral concentration. The calculated value is a function of the composition and concentration of iron-bearing minerals within the rock. Magnetic susceptibility can vary in different directions of measurement due to anisotropy of ferromagnetic mineral alignment, though it has been observed that in carbonates this variance is minimal

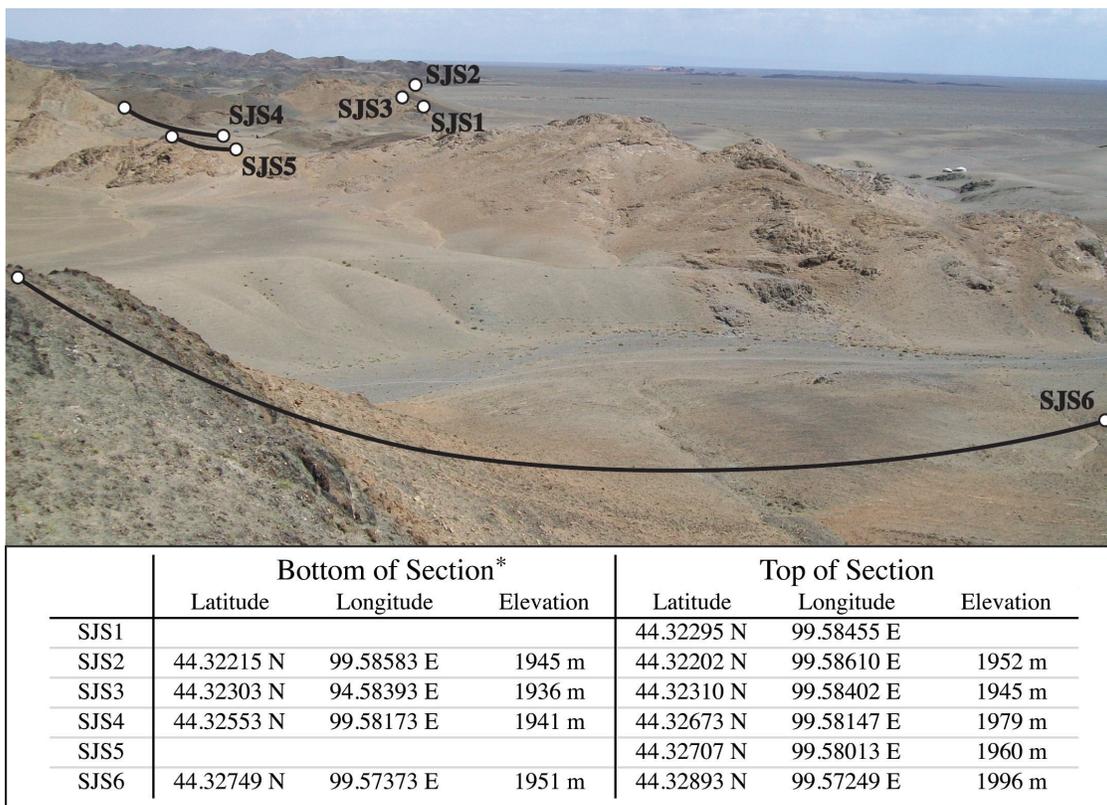


Figure 1. Shar-Chuluut locality diagram showing locations of each section. View is from the top of SJS6 to the southeast. (* latitude/longitude/elevation data contingent on satellite availability).

(Tarling and Hrouda, 1993). A sample containing calcite and/or quartz will reduce the observed MS value because these usually acquire a slightly negative MS when placed in inducing magnetic fields, however, a small amount of ferromagnesian minerals is enough to dominate the MS signal regardless of volumetric abundance (Ellwood et al., 2007).

Change in the amount of iron-bearing minerals in the sediment is the primary cause of MS variations. Because the primary source of iron-bearing minerals in pelagic environments is from terrigenous input, weathering, erosion rates, deposition rates, and biological productivity are the primary factors that influence MS. Magnetic susceptibility can also be affected by post-depositional processes such as pedogenesis, diagenesis, and within-sediment redox effects driven by sulfate reducing bacteria. These processes usually result in a decrease in MS due to the conversion of ferrimagnetic grains to paramagnetic grains. For lithified sediments, MS can be used as a proxy for physical processes responsible for delivering the detrital/eolian component to

sedimentary basins. Magnetic susceptibility is used to track the delivery of detritus to the basin which is influenced by climate, volcanism, tectonism, sea-level changes, and eustasy. Magnetic susceptibility variability curves can show cyclicities which correlate with transgressive/regressive cycles (Ellwood et al., 2007).

Studies addressing magnetic susceptibility for use in correlation and paleoclimate reconstruction typically use sampling intervals of 10 cm or less. Since the data presented here are for a section sampled at intervals of ~50 cm, only large-scale patterns can be addressed.

STABLE CARBON ISOTOPES

Changes in carbon isotope ratios provide a record of overall rates of carbon burial. Burial of organic carbon decreases greenhouse gases in the atmosphere (notably CO₂), which causes cooling. Since organic compounds preferentially incorporate ¹²C, periods of enhanced rates of carbon burial are indicated by

increased values of $\delta^{13}\text{C}$. Therefore, an extended period of enriched ^{13}C in the rock record may indicate global cooling, and perhaps glaciation.

Carbon isotope curves can be used for regional correlation because physiochemical precipitation of marine carbonates occurs in isotopic equilibrium with seawater (Glumac and Mutti, 2007). There is essentially no temperature effect on carbon isotope fractionation in near-surface temperature waters. Thus, $\delta^{13}\text{C}$ values in marine carbonates and the seawater from which they precipitated are closely paralleled. Studies of the post-depositional affects of diagenesis and metamorphism have shown that the primary isotope signal is usually only minimally affected because diagenetic and metamorphic fluids contain small concentrations of carbon (Glumac and Mutti, 2007; Derry et al., 1992). Significant resetting of the carbon isotopic signal can be accomplished if the rocks have experienced extensive flow of carbon-rich fluids through open-system exchange (Banner and Hanson, 1990). Decarbonation reactions during metamorphism can also alter the signal due to isotopic fractionation that accompanies the formation of carbon dioxide that is expelled from the rock (Glumac and Mutti, 2007). Studies have shown that even in extensively altered rocks, carbon isotope excursions are readily preserved (Glumac and Walker, 1998). Dolomitized carbonate sequences are also expected to retain primary isotopic signatures because early diagenesis occurs under conditions similar to those during deposition. Lack of systematic correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ is also commonly cited as evidence that the carbon signal is not strongly influenced by diagenetic processes, which are typically identified by more highly negative $\delta^{18}\text{O}$ values than predicted (Glumac and Mutti, 2007).

RESULTS

LITHOLOGY

The Daravgai Formation is 53 meters thick, consisting of mixed carbonate and fine-grained clastics in sections SJS1, SJS2, and SJS3 (Fig. 2). SJS1 is an 11 meter section composed of wackestone to packstone. The top 8 meters of SJS1 is partially dolomi-

tized and contains few fossils. SJS2 is an 18.5 meter section located 40 meters east of SJS1 and contains wackestone to grainstone interbedded with silty shale. SJS3 overlies SJS1 and is a 23 meter section containing limestone exhibiting karst features, which increase towards the top of the section. The top of SJS3 has been interpreted to represent the end of the Caradocian stage based on corals and brachiopods (Minjin, pers. comm., 2009).

The Gashuunovoo Formation is represented by a thick succession of carbonate, clastics, and basalt in sections SJS4, SJS5, and SJS6 (Fig. 2) where 291 meters were measured. SJS4 is a 51 meter section of carbonate and shale located 150 meters north of SJS1 and SJS3. A 0.75 meter interval of amygdoloidal basalt occurs at 72 meters. SJS5 is a 10 meter section located 50 meters northwest of SJS4. The upper unit of SJS5 is massive limestone containing no fossils. SJS6 is a 144 meter section located 200 meters northwest of SJS5 and is characterized by interbedded shale and carbonate, as well as minor siltstone and sandstone. Some limestone beds are primarily composed of crinoids or bryozoans. No fossils are seen above 305 meters. Shale beds are clayey/silty for the lower 104 meters of sections SJS4 and SJS5 grading to silt-rich for the next 30 meters. The top 10 meters of SJS6 is fine-grained sandstone.

$\delta^{13}\text{C}$ AND MAGNETIC SUSCEPTIBILITY

Data between sections in the Daravgai Formation show obvious discontinuities. Magnetic susceptibility in SJS1 exhibits a slight negative excursion extending to $3.5 \times 10^{-8} \text{ m}^3/\text{kg}$ with one point measuring $1.33 \times 10^{-8} \text{ m}^3/\text{kg}$ (Fig. 2). This section exhibits the lowest values for $\delta^{13}\text{C}$ and the highest values of $\delta^{18}\text{O}$ and MS than in any other section. SJS2 and SJS3 each show a decreasing MS trend and increasing $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ trend (Fig. 2).

The Gashuunovoo Formation measured sections are more continuous. The MS show several positive excursions from a base level hovering around $1.0 \times 10^{-8} \text{ m}^3/\text{kg}$. Major excursions deviating approximately 5 standard deviations ($9.28 \times 10^{-8} \text{ m}^3/\text{kg}$) away from the mean occur at the 140 meter and 250 meter marks.

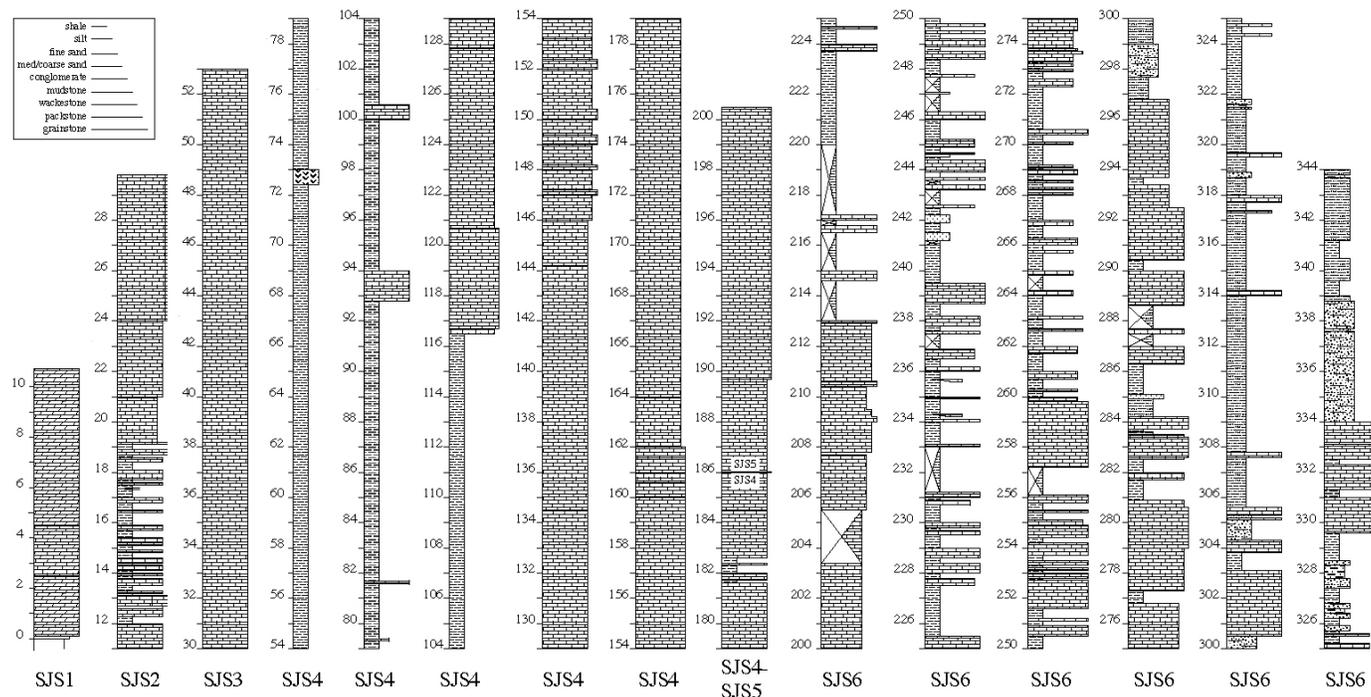


Figure 2. Detailed stratigraphy measured at the Shar-Chuluut locality. Sections are capped by major faults.

$\delta^{13}\text{C}$ data for SJS4 show a narrow range and a positive trend is apparent. $\delta^{13}\text{O}$ data in this section are relatively scattered and exhibit the lowest values measured.

DISCUSSION

LOCAL AND REGIONAL INTERPRETATION

The major shifts in the data between SJS1, SJS2, and SJS3 are certainly a consequence of the major faults separating each section. Several causes can explain data jumps. First, it could represent a hiatus in deposition. Once deposition resumed, perhaps the primary detrital input came from a new source, carrying with it a distinct magnetic signature. Another potential cause of the data jump would be a major geologic event in the region resulting in erosion of a new or different source of detrital material into the basin. The most likely reason is gaps between the sections. Intense tectonic activity could have easily resulted in the displacement of certain sections. SJS1 and SJS2 are capped by faults and so do not necessarily represent the end of a depositional sequence.

The MS data from the Gashuunovoo Formation shows several meter-scale oscillatory trends that likely represent minor transgressive/regressive cycles (Fig. 3). Transgressions are usually characterized by decreasing MS values because detrital sediments become trapped near shore (Ellwood et al., 2007). However, MS peaks can indicate maximum flooding surfaces (MFS) or sudden influxes of detrital material due to turbidity currents or other clastic sediment input. The most pronounced excursions occur in the Gashuunovoo at 140 meters, 222 meters, 248 meters, and 268 meters separated by periods of low value that are relatively stable, hovering around $1.0 \times 10^{-8} \%$. An extended excursion beginning at 312 meters continues to the top of the section. The lithologic properties of the formation exhibit a trend from carbonate to interbedded shale and carbonate to interbedded siltstone and carbonate to interbedded fine-grained sandstone and carbonate which is interpreted as a shallowing upward sequence. The excursion is likely as shallow, near shore depositional environments typically receive more clastic input.

Magnetic susceptibility trends in the Daravgai Formation (Fig. 3) show a large range of values from $-4.84 \times 10^{-9} \text{ m}^3/\text{kg}$ to $6.31 \times 10^{-8} \text{ m}^3/\text{kg}$. An apparent

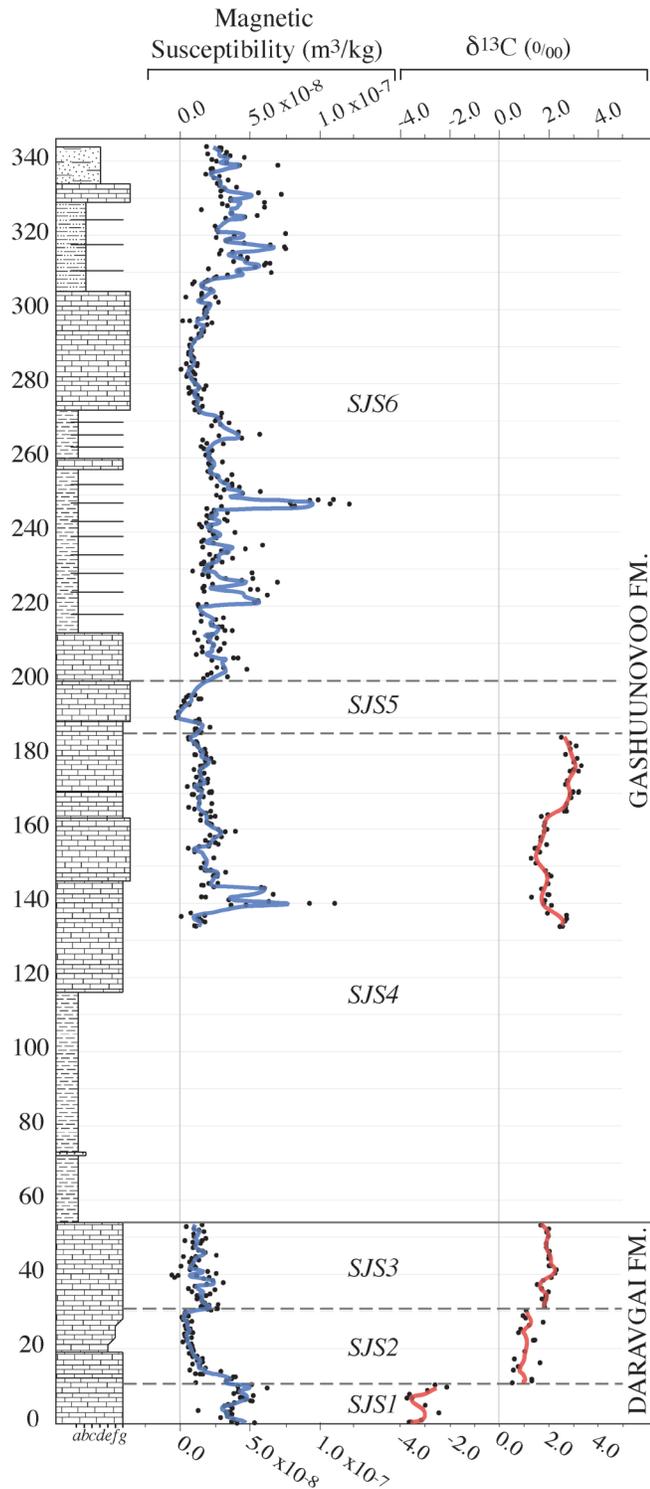


Figure 3. Generalized stratigraphy, magnetic susceptibility, and $\delta^{13}\text{C}$ values for sections measured at Shar-Chuluut. Dashed lines represent major faults and section boundaries. Curves are drawn using 3-point averages. Generalized stratigraphy key: a=shale, b=fine sandstone, c=medium/coarse sandstone, d=wackestone, f=packstone, g=grainstone. Portion of section drawn with thin carbonate beds (i.e. 215 m to 255 m) is generalized and does not depict actual spacing of intercalated carbonate beds. See text for details.

positive excursion in SJS1 is followed by lower more stable values in SJS2 and SJS3, which could be indicative of a deepening trend. Throughout the sequence, $\delta^{18}\text{O}$ values are much lower than the expected range for the Upper Ordovician, an indication of significant alteration of the original seawater values. The data show little correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ and a tightly constrained carbon isotope curve with no significant scatter. These are commonly cited as evidence that the carbon isotopic signal is not strongly influenced by diagenetic modifications (Glumac and Mutti, 2007). The interval with the lowest values of $\delta^{18}\text{O}$, ranging between -13.86 ‰ and -19.39 ‰, would indicate the highest degree of alteration but show the greatest scatter in the correlation plot.

The carbon isotopic trend in SJS4 of the Gashuunovoo Formation shows one major excursion beginning at 164 meters and ending with the top of the section at 185 meters, averaging 2.90 ‰. This could represent an increased rate of carbon burial which may have contributed to climate cooling during this time interval.

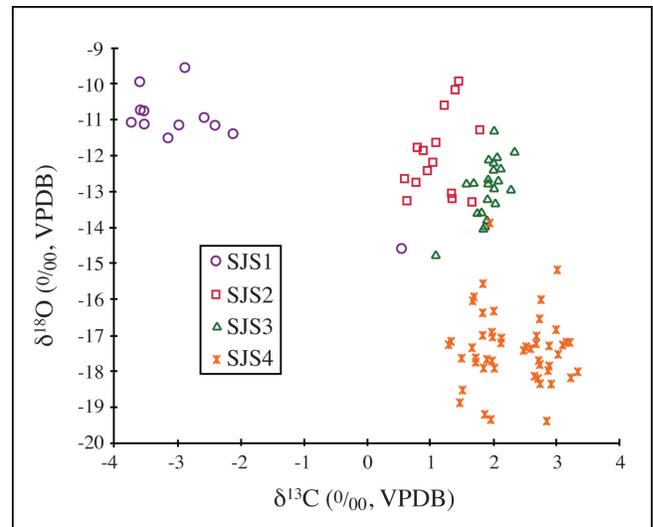


Figure 4. Correlation of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$. All sections show significant scatter, an indication that diagenetic alteration has had little effect on the carbon signal.

Carbon isotopes in the Daravgai Formation also show a large range of values from -14.75 ‰ to -9.53 ‰. SJS1 exhibits unusually low $\delta^{13}\text{C}$ values compared with the rest of the sequence and with the

Upper Ordovician. Highly variable and negative values of $\delta^{13}\text{C}$ coupled with a relatively narrow range of $\delta^{18}\text{O}$ values (in this case standard deviation = 0.573) are typical of diagenetic modification in the presence of decaying organic material (Glumac and Mutti, 2007). However, assuming diagenetic alteration is not a major factor, the overall trend in the Daravgai Formation would indicate increasing carbon burial which could be linked to a cooling trend.

GLOBAL IMPLICATIONS

Five pre-Hirnatian major positive carbon excursions have been globally identified in the Caradoc and Ashgill stages (Kaljo et al., 2002), but it is impossible to determine where these excursions correspond in the Shar-Chuluut sections. A major positive excursion has been globally identified in the Hirnatian substage (late Ashgill stage), thought to be the result of a major glacial event, and is tentatively recognized in the shallowing upward and MS trends in the upper Gashuunovoo Formation.

The Daravgai MS and carbon ratio curves are difficult to use for correlative purposes because they do not show any complete excursion cycle. $\delta^{13}\text{C}$ values for SJS1 are slightly more negative than expected anywhere in the Ordovician (Fig. 5). The lowest carbon isotope values are seen in upper portion

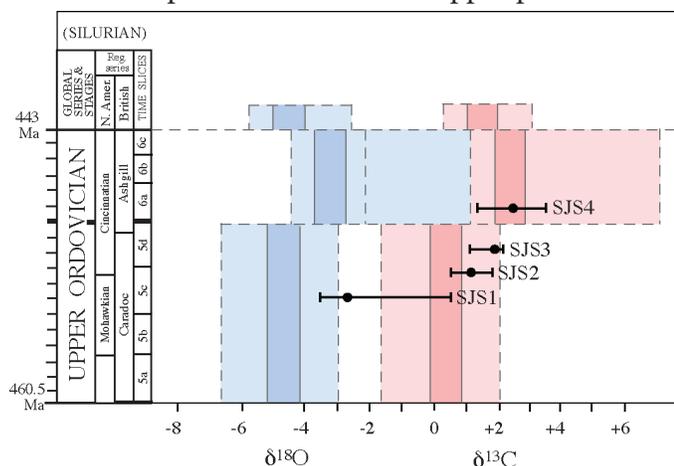


Figure 5. Carbon and oxygen isotopic trends during the Ordovician incorporating all biostratigraphically constrainable brachiopod, conodont, and carbonate component data (modified from Webby and Droser, 2004). Black bars represent ranges and dots represent averages of carbon isotope values measured at Shar-Chuluut for each section.

of the lower Ordovician, well out of range for the presumed age of these rocks. The range of values measured, however, does mostly overlap with the range expected in the Caradoc substage. SJS2 values lie completely within, and SJS3 values lie mostly within, the range of expected values. The top of SJS3 has been previously interpreted to represent the end of the Caradocian stage (Minjin, pers. comm., 2009). This is supported by the presence of karst features which is consistent with an end-Caradocian global sea-level fall. The Gashuunovoo $\delta^{13}\text{C}$ values correspond well with expected values of Ashgillian sequences.

CONCLUSIONS AND FUTURE WORK

The Daravgai and Gashuunovoo formations at the Shar-Chuluut locality near Shine Jinst, Mongolia are typical carbonate shelf deposits of the Upper Ordovician Caradoc and Ashgill stages. Magnetic susceptibility patterns exhibit meter-scale oscillations that likely correspond with sea level fluctuation, which is a major control of detrital input to the marine system.

The Daravgai Formation shows a decreasing MS trend indicating an overall transgressive interval while carbon isotopes may be linked to a cooling climate. These interpretations are generalized and limited due to strata missing in the sequence as evidenced by major faults.

The Gashuunovoo Formation exhibits five significant MS positive excursions that are indicative of influxes of detrital material to the system. They likely identify maximum flooding surfaces, turbidity currents, or other clastic sediment input. The top of the Gashuunovoo Formation shallows upward, an indication of a drop in relative sea level. The carbon isotopic signature in the lower part of the Gashuunovoo Formation likely correlates with one of the four globally identified excursions for this time period. A more complete carbon isotopic dataset is needed for further interpretation.

Biostratigraphic constraints are needed to correlate these sections with global records. Future work

should also include studies of parallel sections at Shar-Chuluut to investigate lateral changes in MS and $\delta^{13}\text{C}$ signals and further establish the timing of major excursions.

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