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Andrew P. de Wet	Keck Geology Consortium	Lara Heister
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Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen

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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

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

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

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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

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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

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

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

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

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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

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Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603
Keckgeology.org

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

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

INTRODUCTION

The goal of this project is to study the sedimentology, depositional history, and detrital zircon geochronology of the Lower Devonian (Lochovian-Pragian) Tsakhir Formation in the Shine Jinst region of southern Mongolia in order to elucidate the tectonic history of the Gobi-Altai terrane (Badarch et al., 2002; Wang et al., 2005). In part, I aim to evaluate the hypothesis that the Gobi-Altai terrane is an exotic crustal fragment that formed as a back-arc basin in the Early Devonian and subsequently amalgamated in the late Paleozoic to early Mesozoic (Badarch et al., 2002; Lamb and Badarch, 1997). I interpret the sedimentology and detrital zircon age-spectra to better understand the Early Devonian geological history of the Gobi-Altai terrane.

MATERIALS AND METHODS

I have described, logged and photographed 630 m of measured section of the Tsakhir Formation in the Shine Jinst region. The base of the formation is in fault contact with the Upper Silurian-Lower Devonian Amansair Formation (Wang et al., 2005). This fault likely developed along a lithological contrast between underlying carbonate strata and the basal conglomerate of the Tsakhir Formation. The formation is generally characterized by tombstone topography across a wide valley, with beds dipping ~80° to slightly overturned. The top of the measured section is at an ~100 m covered interval below the Middle Devonian Chuluun Formation (Wang et al., 2005). I have interpreted the paleoenvironments represented by the various lithofacies and reconstructed the depositional history of this formation. Facies interpretations are based on lithologies, suites of sedimentary structures, petrographic analysis of 34 thin sections, and a point count of 93 clasts within a thick conglomerate unit.

Sandstone samples were collected from the Upper Ordovician Upper Gashuunovoo Formation and the Lower Devonian Tsakhir and Chuluun formations for detrital zircon geochronology analysis using laser-ablation multicollector inductively coupled-plasma mass spectrometry (LA-MC-ICPMS) at the Arizona LaserChron Center. Seven samples were analyzed with 100 grain analyses per sample. Zircon grains were isolated from bulk rock samples by physical separation, gravity table separation, magnetic separation, and heavy liquid separation. Zircon mounts were prepared according to standard procedures at the Arizona LazerChron laboratory prior to analysis.

GEOLOGIC SETTING OF THE GOBI-ALTAI TERRANE

The Central Asian Orogenic Belt is a mosaic of continental blocks and arc fragments separated by accretionary complexes within Asia's cratonic core (Heubeck, 2001). Previous studies have interpreted Paleozoic rocks in southern Mongolia to represent amalgamated microcontinents and island arc terranes that developed in the Paleoasian Ocean from the late Proterozoic to early Mesozoic (~1000-250 Ma) (Badarch et al., 2002; Lamb and Badarch, 1997; Heubeck, 2001; Wang et al., 2005; Windley et al., 2007; Zorin et al., 1993). Specifically, the Gobi-Altai terrane is hypothesized to have formed as a back-arc basin in the Uralian Seaway between Baltica and Siberia in the Paleozoic and collided with Siberia in the Middle Devonian (Lamb and Badarch, 1997; Zorin et al., 1993).

Silurian, Devonian and Carboniferous strata dominate exotic arc terranes in this region (Windley et al., 2007). The Gobi-Altai terrane contains Orodovician to Permian strata that record predominantly marine conditions. Ordovician strata that constitute the oldest rocks of the Gobi-Altai terrane are interpreted by Zorin et al. (1993) to have been deposited in a shelf setting. This terrane is bounded to the north by an island arc terrane and passive continental margin, and to the south by an island arc terrane (Lamb and Badarch, 1997). Basement of the terrane comprises previously rifted lower Paleozoic serpentinized ultrabasic rocks and heterogeneous Precambrian felsic metamorphic rocks with interspersed ocean crust (Windley et al., 2007; Zorin et al., 1993).

The Tsakhir Formation uncomformably overlies the Silurian–Devonian Ammansair Formation, which is a thick carbonate (Reitman, this volume; Vulgaropulos, this volume; Wang et al., 2005). The Lower Devonian (Emsian) Chuluun Formation conformably overlies the Tsakhir Formation and consists of two members, a thick carbonate member (Pellegrini, this volume) and a volcanic member (Wang et al., 2005). Wang et al. (2005) recovered three conodonts from the Tsakhir Formation, which in conjunction with those found in strata above and below it, indicate a Lower Devonian (Lochkovian-Pragian) age. Exposures at Shine Jinst contain a full age-range of Paleozoic rocks that represent marine to marginal marine settings. Associated volcanic flow deposits indicate proximity to sporadically active volcanic centers (Lamb and Badarch, 1997).

SEDIMENTOLOGICAL OBSERVATIONS

The Tsakhir section at Shine Jinst is affected by faults with associated calcite veins that result in apparent displacements up to 10 m. Marker beds were used to correlate across these faults in nearly all cases. Bedding largely strikes ~210°, with the up direction to the north. Bryozoa and rugose coral fossils were discovered in a grainstone bed at 115 m, and a stromatoporoid bed is present at 382 m. Geopetal structures exist in multiple beds, all demonstrating consistent up direction. The formation records general upward fining from cobble/pebble conglomerate to finer grained siliciclastic and carbonate lithologies. Detailed stratigraphic columns for the Tsakhir Formation are presented in Figures 1-3.

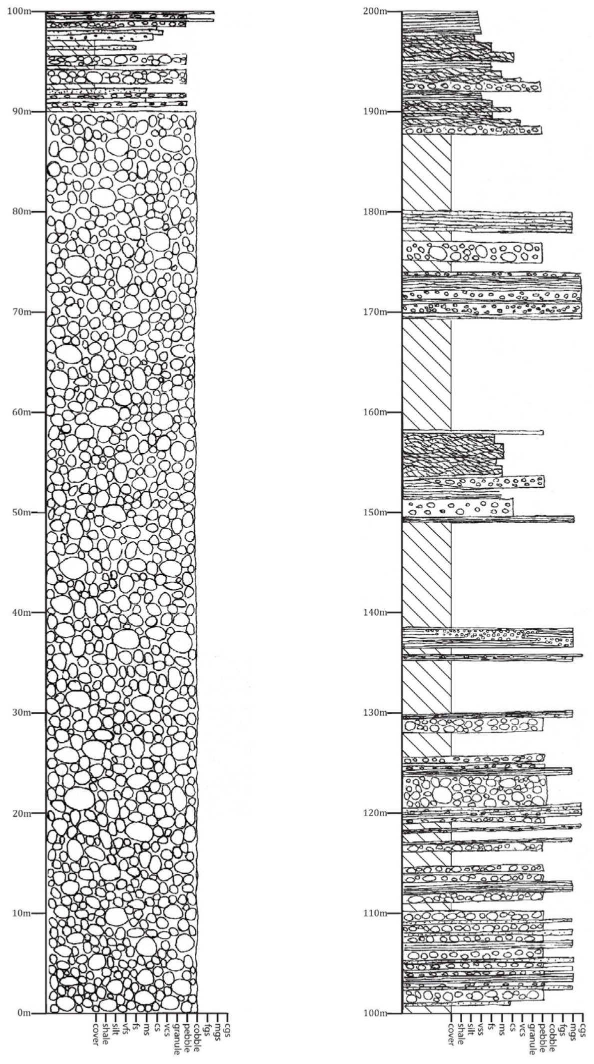

Figure 1. Detailed stratigraphic column 0-200m.

Massive and bedded, very poorly-sorted, rounded to sub-rounded, clast-supported, lithic, conglomerate beds are interbedded with sandstone throughout the formation. Clast lithologies are dominantly grainstone, wackestone, skeletal wackestone, greywacke, silty skeletal wackestone, micrite, dolomite, and bioclasts of tabulate coral and stromatoporoids. Beds of the pebble conglomerate average 50 cm thick and cobble conglomerate beds are massive, with no ap-

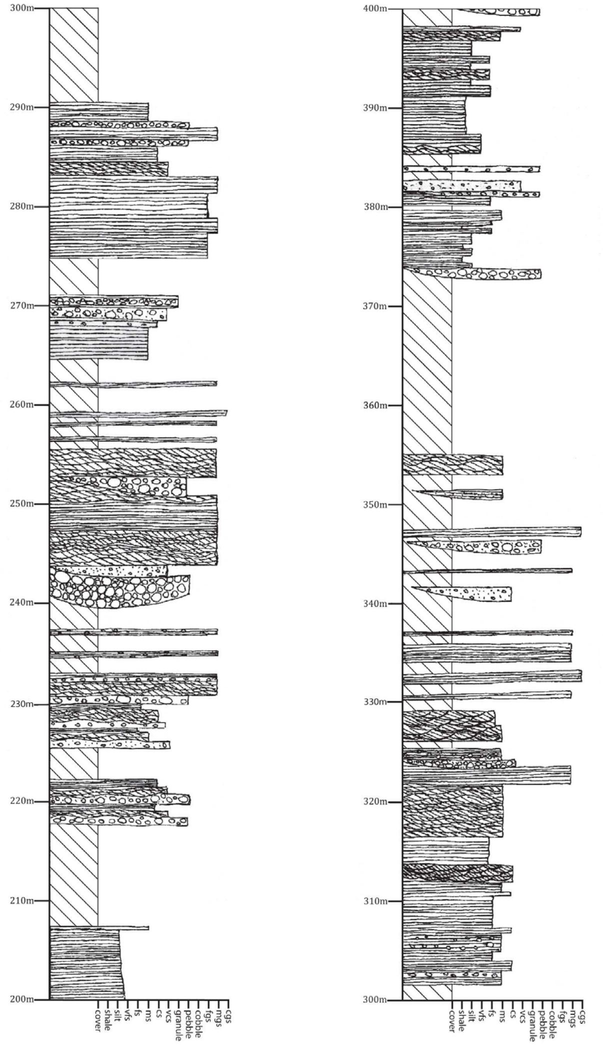

Figure 2. Detailed stratigraphic column 200-400m.

parent difference in grain size between the top and bottom of beds. The matrix is calcareous sandstone that exhibits jagged weathering. It is composed of 40 to 80% quartz grains that range from coarse sand to granule in size. Many beds of this facies have erosional bases and in places exhibit lenticular geometries like those of channel-fill deposits. A massive cobble conglomerate with many boulders constitutes the basal 90 m of the formation. Above this, conglomerate beds greater than 4 m thick with significant cobble- and boulder-sized clasts are absent in the formation until just below the first occurrence of volcanic material at 403 m. Pebble-sized conglomerate beds are present throughout the section, but generally decrease in bed thickness and extent up section. Clasts in cobble conglomerate beds reach a maximum of 33 cm in diameter, and in pebble conglomerate beds they average 2 cm in diameter and reach 30 cm.

Grey, well-sorted, sub-angular to sub-rounded, thinly bedded, medium- to coarse-grained sublitharenite with calcareous cement facies is present throughout much of the formation. Grains range from 0.02 to 0.1 mm in diameter and average 0.75 mm based on thin section analysis. Beds range from 5 cm to 4 m in thickness. Quartz grains make up 70% of grains, and minor lithic fragments, calcite grains and clasts composed of dark grey micrite up to 2 cm in diameter are also present.

Poorly sorted, well- to sub-rounded, fine- to very coarse-grained, sandy grainstone is present throughout much of the formation. Bed thickness averages 5 cm and ranges from 5 cm to 3 m. Pebble-rich beds with sandstone and micrite clasts up to 9 cm in diameter exist within certain horizons. Quartz content ranges from 5 to 40% and lithic fragment content is less than 5%.

The sublitharenite and fine- to very coarse-grained grainstone have similar field appearances and grade into one another. Fining upwards cycles, hummocky cross-stratification, trough cross-stratification, centimeter-scale pebbly horizons and starved ripples are present in these facies. Units of these facies are abundant lower in the section and become less prevalent and more thinly bedded above 400 m.

A very fine-grained, blue-green grainstone facies with 15 to 25% quartz grains and calcite cement is abundant throughout the entire formation. Beds range from 3 cm to 3 m thick, and 1 to 4 mm fissile breaks result in a paper-thin weathering. Minor floating medium to coarse quartz grains and sparse pebbles exist within some beds. Thin section analysis demonstrates that grains average 0.06 mm in diameter and range from 0.03 to 0.2 mm. Burrows along bedding planes are concentrated in this facies from 370-400 m. This facies is abundant lower in the formation and becomes less abundant, more thinly bedded and finer grained above 400 m.

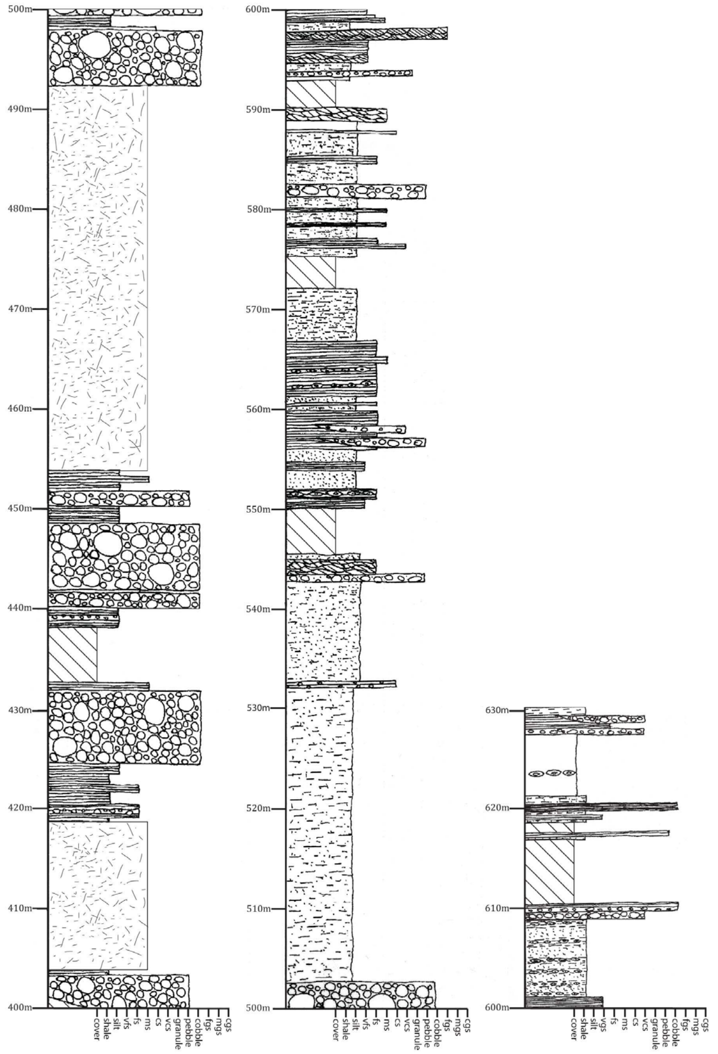

Figure 3. Detailed stratigraphic column 400-630m.

A red, calcareous siltstone facies with lenses of marly, carbonate concretions is present above 500 m in the formation. Grains range from clay to silt-sized particles. Many dark, clay-lined burrows which average 70 mm in diameter, exist along bedding planes. Beds tend to be highly cleaved and laterally discontinuous and range from 10s of cm to 10s of m in thickness.

Massive, green, rhyolitic tuff beds that grade from fine- to coarse-grained volcaniclastic sandstone to volcanic flows to pure tuff beds are present above ~400 m in the formation. The pure tuff beds are green and glassy in texture. The flows are generally porphyritic-aphanitic. Much of the rock has been recrystallized and minimal original texture is preserved. Phenocrysts include resorbed quartz and plagioclase, and the groundmass is fine-grained and felted. Minor apatite, zircon and muscovite (sericite) are included. Bed thicknesses vary from 5 to 35 m.

The Tsakhir Formation contains many 10 cm- to 3 meter thick fining upward cycles. These units fine from either pebble conglomerate, coarse grainstone or sandstone to very fine grainstone. Successions that begin with pebble conglomerate tend to exhibit channel geometry. In many cases, the sand-sized horizons contain hummocky cross-stratification.

SEDIMENTOLOGICAL INTERPRETATIONS

This formation represents the first middle Paleozoic strata in the Gobi-Altai terrane to be dominated by siliciclastic sedimentary rocks and to contain massive conglomerate. Thus, deposition of this formation likely coincided with an increase in siliciclastic input in the Early Devonian that was almost certainly due to a significant tectonic event that exposed quartz-bearing basement.

Deposition of the basal conglomerate is interpreted as a result of an abrupt transition in topography and exposed lithologies. Large clast sizes and a similarity in age and composition of clasts to the underlying Ordovician and Silurian carbonate units suggest that uplift and exposure of these strata provided a local source for the conglomerate (Lamb and Badarch, 1997). Furthermore, quartz-filled fractures within clasts that do not extend into the matrix suggest structural deformation of the source material before deposition. The thickness (90 m) of the basal conglomerate at the base reflects deposition on steep slopes and short transport distances. The channel geometries and lack of bedding suggest that mass movement events, most likely debris flows, deposited this facies. The lack of interbedded finer-grained facies makes it difficult to determine the precise depositional environment, but a proximal subaerial setting, like a fan delta is likely.

Lithologies between 90-400 m are predominantly interbedded pebble conglomerate, medium- to coarse-grained sublitharenite, fine- to very coarse-grained grainstone, and very fine-grained grainstone. The presence of HCS and highly variable grain-sizes between contiguous beds suggest that these facies represent sediment that was deposited in a standing water body as a result of variable fluvial energy levels. The fine-grained sediment was likely deposited from settling of suspended load, in part from sediment plumes. The coarser, sand-sized sediment would have been deposited as turbidity currents or hyperpycnal flows. Transport of pebbles, granules, and coarse sand in standing water requires steep slopes directly adjacent to the depositional basin, such as a coastal alluvial fan. The coarse grain size and channel geometry of many of the conglomerate beds suggest relatively high-energy, flood-stage input from a river mouth. Abrupt changes in grain size in this formation are interpreted as variable erosion on the fan due to short-term climate patterns, such as seasons and storms. Variation in quartz content versus carbonate content between these facies is interpreted as a result of changes in exposed source rock or irregular erosion on the fan (Boggs, 2006; Brown et al., 1989).

Hummocky cross-stratification (HCS) in sand-sized sediment within fining upward cycles provides evidence for storm influence. Deceleration of poorly sorted sediment entering standing water likely resulted in these fining upward cycles. Thus, successions are interpreted as hyperpycnal flows that originated on land as storm-activated floods capable of carrying gravel and mud into a standing body of water. The HCS likely records the wave climate of the water body adjacent to the flooded landscape during the same events.

The succession of massive conglomerate and rhyolitic tuffs beginning at 400 m represents the first recurrence of cobble conglomerate above the basal unit. Seismicity and faulting related to volcanism that produced the volcanic tuff may have triggered debris flows that deposited the conglomerate. Above this, the section is generally finer and dominated by red siltstone beds with many burrows. The emergence of a finer-grained facies shortly after an interpreted tectonic event suggests that the event caused a transformation of the basin. Changes in primary transport direction off the fan could have led to a decrease in coarse sediment influx, while changes in the degree of overturn in the water body may account for the increased oxidization and bioturbation of this facies.

The presence of bioturbation, bryozoa, rugosa, stromatoporoids, and HCS in the Tsakhir Formation almost certainly require a shallow marine depositional environment. Because much of the section contains fine-grained deposits interbedded with coarse-grained, possible hyperpycnal flow deposits, deposition occurred in a tectonically active basin directly adjacent to a steep catchment basin (Boggs, 2006; Lamb et al., 2008).

I interpret the depositional setting of the Tsakhir Formation in the Shine Jinst region to have been a fan delta entering a storm-influenced shelf that experienced large, episodic depositional events from a local source. The general fining-upward trend of the formation is interpreted as a response to tectonic subsidence, given the tectonic setting, although some component of eustatic trasgression cannot be ruled out. In either case, the creation of accommodation space outpaced the rate of progradation of the fan delta.

DETRITAL ZIRCON RESULTS

Samples in this study yield detrital U-Pb zircon ages that range from Archean (~3300 Ma) to Late Devonian. Six of the seven samples contain Archean grains. All samples contain a prominent early to middle Paleozoic peak (513-392 Ma). Except for sample TSA-450, all contain late Proterozic age populations between 796 and 754 Ma and Paleoproterozoic populations between 2063 and 1997 Ma. All four of the Devonian samples contain a major peak of Devonian grains (406-392 Ma) and all Ordovoican samples contain a Neoproterozoic peak (947-768 Ma). Some Paleozoic to Neoproterozoic age populations are anomalously low in U content. Detrital zircon ages are presented in relative age-probability diagrams, which show a curve constructed from the sum of ages for each sample (Fig. 4).

DETRITAL ZIRCON INTERPRETATIONS

Six out of seven samples from strata that range from Upper Ordovician to Middle Devonian contain at least 2.5 billion year old zircon grains. Archean and Proterozoic age sediment in middle Paleozoic strata requires a continental source. Therefore, from the Late Ordovician to Middle Devonian, a continental source must have fed the basin represented by the Gobi-Altai terrane. If the Gobi-Altai terrane did form as a back-arc basin, it could not have formed as an isolated arc within the Uralian Seaway. Assuming that a local source provided the majority of sediment, given the depositional framework outlined above, the detrital zircons were not transported long distances, so the terrane either contained continental basement or it formed directly adjacent to a continental source during much of the early and middle Paleozoic.

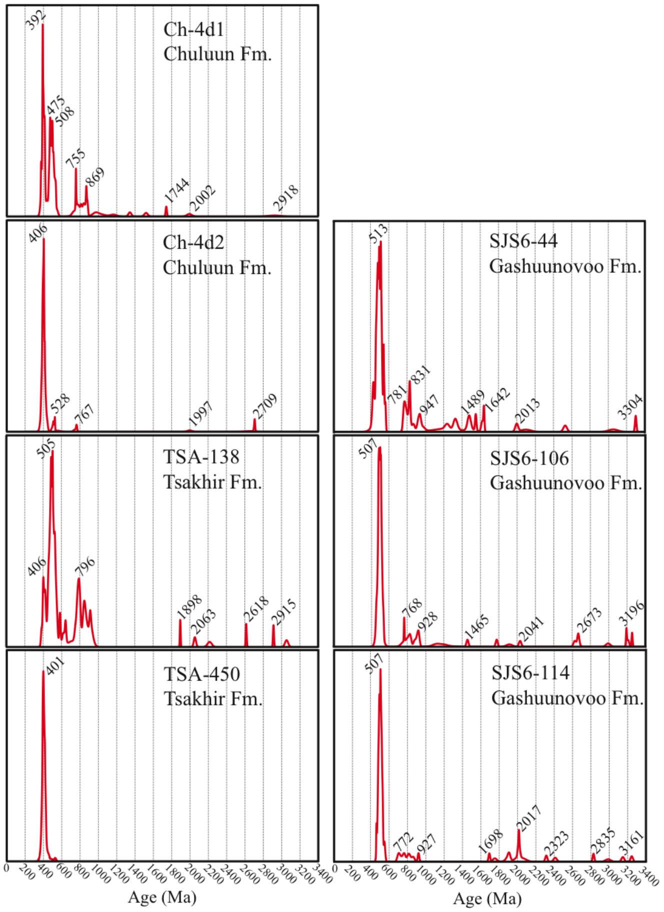

Figure 4. Detrital zircon age probability diagrams for samples from Shine Jinst. Note that relative age probability diagrams show ages and uncertainty (plotted as a normal distribution about the age).

CONCLUSIONS

This study shows that the Tsakhir Formation formed from the uplift of local carbonate strata and underlying basement rocks. The formation represents an alluvial fan-fan delta complex that may have ranged from initial subaerial deposits to a subsiding basin adjacent to a high-relief tectonically active hinterland. The zircons from strata in the Gobi-Altai could have been derived from exposed basement in the Gobi-Altai terrane. Alternative sources for the detrital zircons include Siberia, Baltica, North China, South China, Kazakhstan or the Tuva-Mongolia microcontinent, based on geographic reconstructions of the Paleoasian Ocean in the Devonian.

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