Explorers Club Flag Report

Looking for mass extinctions in all the wrong places: Gobi Altai, Mongolia

Explorers Club Flag # 112
Field Leader Report: Dr. Sarah K Carmichael FN'16 and Dr. Johnny A Waters FN '04
Expedition Dates: July 25, 2018 - August 11, 2018
Location: Khovd Province, Mongolia (base camp at 45.278410°N, 90.963015°E)
Funding Sources: National Geographic (grant #CP113R-17 to SK Carmichael and JA Waters), the Explorers Club (student grants to OC Paschall and AD Dombrowski), and Appalachian State University (University Research Council grant to SK Carmichael, Office of Student Research grants to OC Paschall and AD Dombrowski)

Expedition Team Flag Photo. Flag held by Mongolian team leaders Dr. Sersmaa Gonchigdorj (left) and Dr. Ariunchimeg Yarinpil (right). Photo by Felix Kunze.

1. Project Overview

The Late Devonian (375-350 million years ago) was a time of massive climate instability and is characterized by pulses of mass extinction events, including some of the most severe mass extinctions in Earth's history. Unlike the other "Big 5" mass extinction events, where the causal mechanism is generally well-established (i.e. the asteroid/volcanism combination that killed the dinosaurs, the catastrophic volcanism that caused the end-Permian "great dying" where 96% of the world's species went extinct), the mechanisms for the pulsed extinctions in the Late Devonian that decimated coral reefs 372 million years ago (at the Frasnian-Famennian boundary) and forever changed the evolutionary trajectory of fishes 359 million years ago (at the Devonian-Carboniferous boundary) are still poorly understood.

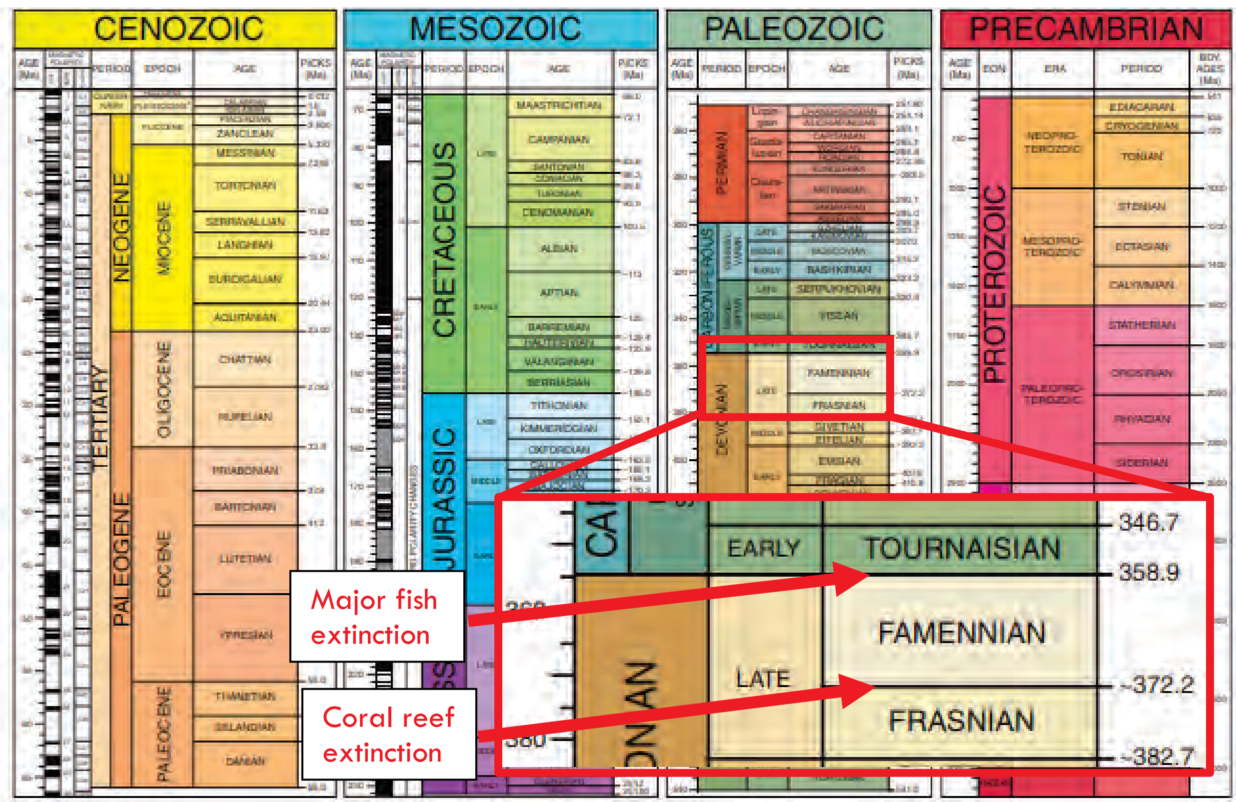

Figure 1. Geologic time scale (from the Geological Society of America), with special attention to the Late Devonian Frasnian-Famennian extinction at ~372 Ma (which devastated coral reefs) and end-Devonian extinction at 359 Ma (which forever changed the evolution of fish).

Both of these extinction events are associated with ocean anoxia events, which are analogous to the dead zones in our oceans that are occurring today in the Gulf of Mexico and the North Sea. The Frasnian-Famennian extinction is associated with the Kellwasser anoxia event, and the end-Devonian extinction is associated with the Hangenberg anoxia event. Our knowledge of this particular set of extinction/anoxia events is limited by considerable sampling bias (as shown in Figure 2), and the way we define and recognize these events is shaped by this bias. Nearly all studies on the Late Devonian are from semi-restricted continental basins, which were not representative of global oceanic conditions at that time. Furthermore, they are mostly from present-day North America and Europe, which were part of the same continental block during the Late Devonian and experiencing considerable sediment input and unusual climatic conditions due to the rising equatorial Appalachian mountain chain (which was the size of the Himalayas during the Late Devonian). Isolated island systems such as those within the Central Asian Orogenic Belt

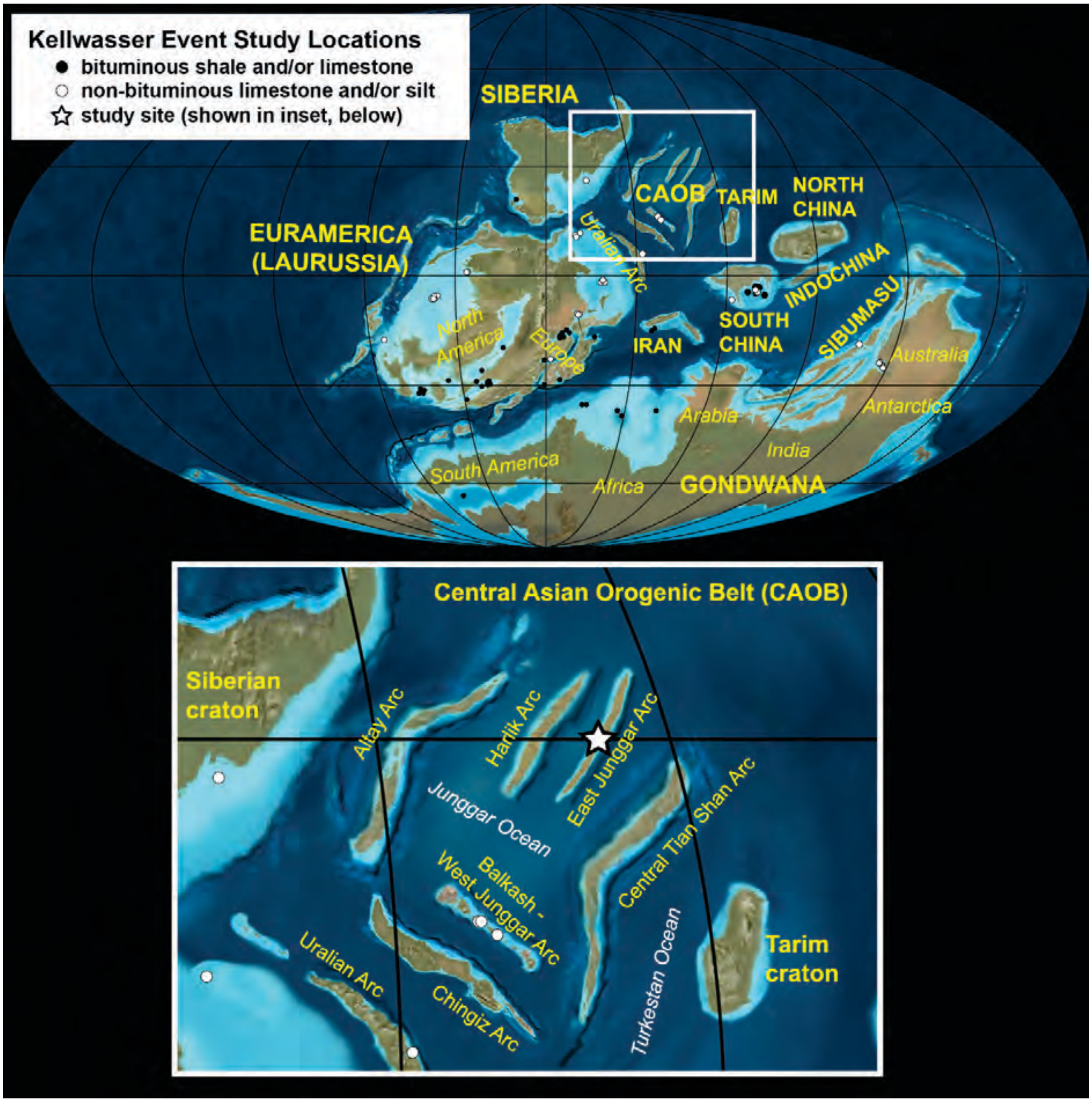

Figure 2. Approximate palaeogeographic locations of 136 studies[1] of the Late Devonian Kellwasser Anoxia Event (374 million years ago) and the associated Frasnian-Famennian extinction event that decimated coral reefs. There are 95 studies in Euramerica alone, with 19 studies in Gondwana (Australia, Africa, India, the Middle East, and South America), 2 studies in Iran, 2 studies in Siberia, 11 studies in South China, 1 study from the Sibumasu Block (Thailand), and 5 studies from the Central Asian Orogenic Belt, or CAOB (Mongolia, Kazakhstan, and northwest China). The unique open ocean, island arc location of the CAOB (see inset) is vital to understanding global oceanic patterns of extinction, anoxia, and origination in the aftermath of extinction events. Base map by Deep Time Maps[2] with some modified continent positions[3-5].

(Figure 2 inset) and are therefore better suited to studying the global effects of these extinction and anoxia events, as their sediments preserve open ocean conditions.

Although landlocked today, our study site in southwestern Mongolia (Figure 3) was part of the East Junggar Arc in the Late Devonian (Figure 2 inset, shown with ★). This makes it an ideal location to study these extinction and anoxia events in a vitally important yet deeply understudied paleoenvironment.

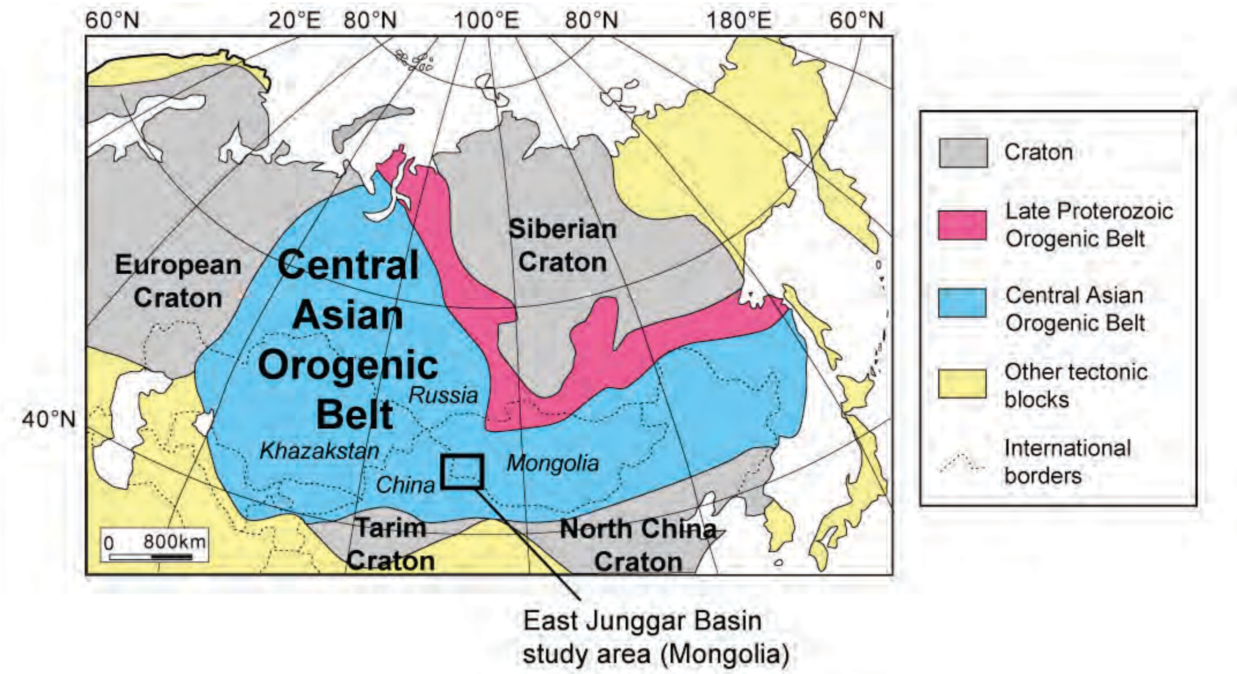

Figure 3. Current location of the study area in southwestern Mongolia (map adapted from the PIs previous work in China[6]).

2. Background and Preparatory Work

The study site for this flag expedition, called Hoshoot Shiveetiin Gol, was discovered literally by accident in 2012 by a team of paleontologists from the International Geoscience Programme Project 596 (IGCP 596) when their van flipped over while trying to navigate a steep incline (Figure 4). IGCP 596 is a UNESCO-funded initiative to partner geoscientists from developing countries with geoscientists from industrialized countries in order to form new paleontological collaborations, provide laboratory infrastructure to scientists from developing countries, and explore field sites that span the globe. The 2012 IGCP 596 reconnaissance team (Dr. Johnny Waters, Dr. Thomas Suttner, Dr. Erika Kido, Dr. Sersmaa Gonchigdorj, Dr. Ariunchimeg Yarinpil, Dr. Gary Webster, and Will Atwood) were working as part of a reconnaissance field workshop funded by the National Science Foundation to describe the Late Devonian fossils and sediments of southwestern Mongolia in the Samnuuruul Formation and analogous geologic units[7]. After the van was pushed right-side-up (through strength fueled by sheer adrenaline) the science team explored the surrounding exposed rock units while the drivers repaired the major damage to the van. They identified the fossils as Late Devonian and tagged the location for a future visit in 2014 for a second, more detailed field workshop with a larger team of scientists.

In August 2014, an expanded IGCP 596 science team (20+ scientists from 9 countries) returned to southwestern Mongolia to sample the sections discovered in 2012 and to further explore and sample the Hoshoot Shiveetiin Gol site. While the paleontology team sampled a section of rock containing numerous marine fossil beds for conodont microfossil biostratigraphy to better refine the age of the Hoshoot Shiveetiin Gol (Figure 5), we (Carmichael/Waters) explored the area with our student (2014 Explorers Club Youth Activity Fund winner Cameron Batchelor) to look for volcanic deposits that could be used to radiometrically age date the rocks if conodont dating proved untenable due to rock alteration.

Figure 4. Discovery of the Hoshoot Shiveetiin Gol flag expedition site in southwestern Mongolia (45°16'18.6"N, 91°04'06.6"E) in 2012, due to an overturned van. Photo by Johnny Waters.

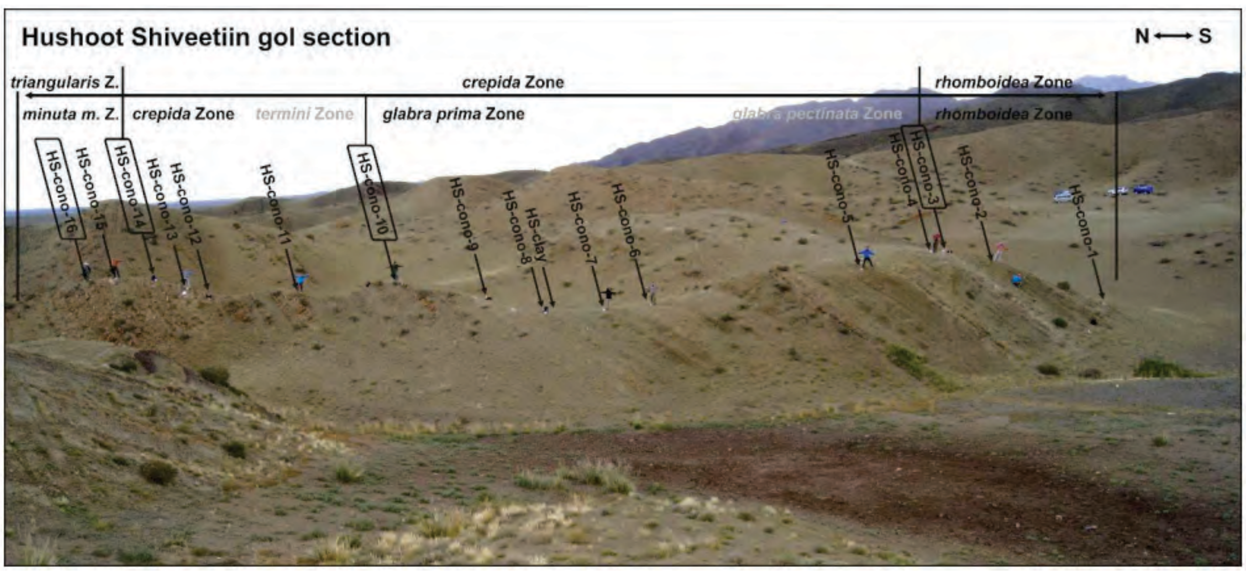

Figure 5. Section at the Hoshoot Shiveetiin Gol sampled for conodont (prehistorical eel tooth) biostratigraphy in 2014. Conodont identification was completed in late 2017, indicating the section is Famennian in age.[8]

We found a lava flow within beach sediments approximately 200 m to the south of the section (Figure 6), but were uncertain about the structural relationship between the lava flow and the measured section (i.e. was it continuous and therefore related, or was it displaced by faulting, and therefore unrelated?). The existing maps of the area[9] were not helpful in answering this question, as they were at a 1:250000 scale (Figure 7) and therefore were not detailed enough to provide information about local structural relationships. We decided it was not prudent to spend significant time and money to age date the lava flow using U/Pb geochronology (via thermal ionization mass spectrometry at the University of North Carolina at Chapel Hill) without knowing if it was structurally related to the rest of the site.

Figure 6. Andesitic lava flow preserved in beach sediments at the Hoshoot Shiveetiin Gol, found by 2014 research team. Photo by Johnny Waters.

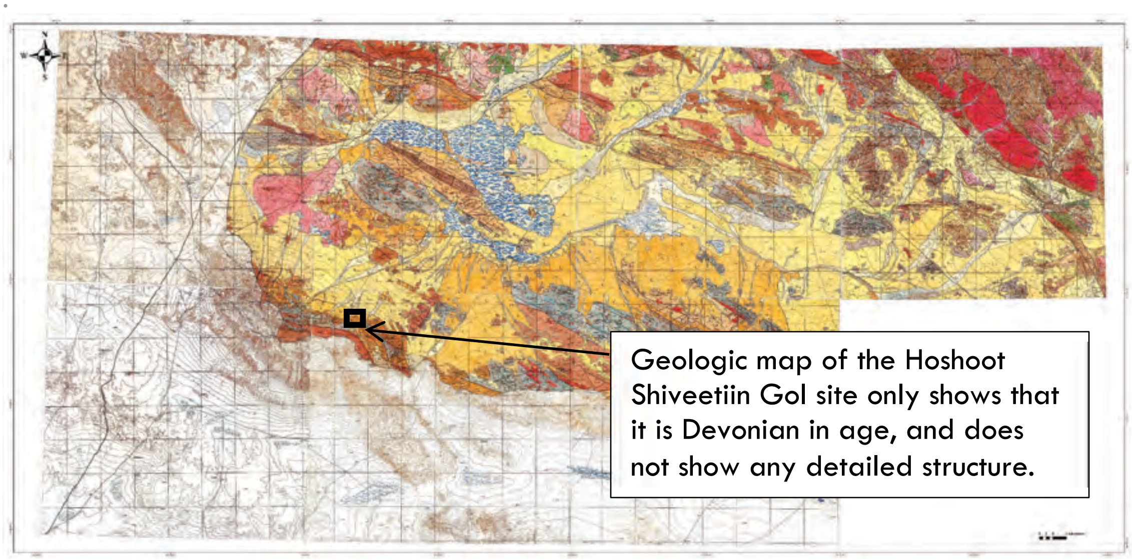

Figure 7. Existing maps of Mongolian geology for the Hoshoot Shiveetiin Gol region are mapped at a 1:250,000 scale[9] and are not detailed enough to indicate continuity between our measured section and the lava flow sampled in 2014.

Subsequent geochemical analysis of the lava flow, the sediments surrounding the lava flow, and the sediments from the measured section indicated that the measured section sediments were not derived from the lava flow[10]. This meant that the lava flow was therefore potentially younger than the marine sediments in the section, or was completely unrelated to anything that we were trying to study and was only near the section due to faulting. Meanwhile, our colleagues had determined via conodont (prehistoric eel) biostratigraphy that the sediments in the measured section were Famennian in age, but that the section did not extend far enough in either direction to cross the Frasnian-Famennian extinction horizon (with the Kellwasser anoxia event) or the end-Devonian extinction (with the Hangenberg anoxia event). Clearly, we needed to return to the site for additional sampling and mapping in order to answer these questions.

3. Specific Objectives and Overarching Goals

Specific Objectives 1-4:

To address the unanswered questions identified in our 2012 and 2014 field seasons, we returned to the Hoshoot Shiveetiin Gol site in 2018 as part of a National Geographic and Explorers Club flag expedition in order to ***1) fully describe the section at the cm scale for microfacies (paleoenvironment) analysis, 2) perform more detailed sampling across the section to better refine the ages***, and ***3) expand the section to include both mass extinction horizons, if possible***. We also needed to ***4) make a detailed map of the entire site at the meter to kilometer scale*** so that we could make a final determination of whether or not to use the lava flow samples collected in 2014 for radiometric age dating. If the section was continuous with the lava flow, determining the radiometric ages preserved in the lava flow would be worthwhile. If the region between the section and the lava flow was faulted or otherwise disjointed, we would not attempt to date the lava flows, as the age dates would not be relevant to the section.

Specific Objective 5:

An additional objective (if possible) was to ***5) correlate the Hoshoot Shiveetiin Gol geology with existing datasets from previous field excursions***[7], from sites 6-50 km away as well as the reference section for the Samnuuruul Formation. The IGCP 596 group had collected significant fossil data in 2014 (both marine fossils and plant fossils)[11-13] and had U/Pb dated zircons in immature sediments at these nearby sites[14], but had been unsuccessful at conodont biostratigraphy at the other sites due to substantial hydrothermal alteration damage to the rocks[15]. We wanted to tie in the extensive work we had done at these other sites to the geology at the Hoshoot Shiveetiin Gol section, and update the existing geologic map of the region with our fossil and zircon age dates.

Overarching Goals:

The overarching goal in sampling across both extinction horizons (if they were indeed present in the expanded section) would be to search for shallow water anoxia signals preserved in the sediments. This assessment cannot be done in the field, unless the section has visible black shale or bituminous black limestone layers. Instead, a combined approach using scanning electron microscopy in conjunction with trace element geochemistry must be employed once the rocks have been returned to the lab. We have used this process in similar sections in China and Vietnam[6,16,17] in sections that do contain extinction/anoxia horizons but don't exhibit the organic-rich, thick black shale layers that are defined as the "standard" indicators of ocean anoxia in the Late Devonian basins of Europe and North America. If our hypothesis that anoxia was present in shallow water, open ocean island systems is correct, it indicates that ocean oxygen loss was much more severe and widespread than is currently thought by many researchers. More importantly, it means that the standard indicators for the Kellwasser and Hangenberg Events (visible black shales) only mark the paleoenvironments that experienced the most severe ocean anoxia, and that scientists have missed countless instances of anoxic conditions because they weren't looking for them.

This concept - that we look for "invisible" mass extinctions and anoxia in understudied places where most researchers wouldn't expect to find them - is the basis for our expedition title: *Looking for mass extinctions [and anoxia] in all the wrong places.*

4. Team Members and Responsibilities

Name	Nationality and Affiliation	Role
Dr. Sarah Carmichael	USA - Appalachian State University	Principal Investigator, local (m-scale) mapping of site, geochemical and mineralogical analysis
Dr. Johnny Waters	USA - Appalachian State University	Co-Principal Investigator, paleontology of section
Dr. Sersmaa Gonchigdorj	Mongolia - Mongolian University of Science and Technology	Expedition coordinator; stratigraphy, cm-scale section description
Dr. Ariunchimeg Yarinpil	Mongolia - Mongolian Palaeontological Centre	Regional mapping coordinator; bryozoan paleontology, regional fossil exploration and assessment
Otgonbaatar Dorjsuren	Mongolia - Gurvantalst Geologic Mapping , LLC	Regional mapping
Tumurchudor Choimbol	Mongolia - Gurvantalst Geologic Mapping, LLC	Regional mapping
Ganbayar Guunchinbat	Mongolia - Gurvantalst Geologic Mapping, LLC	Regional mapping
Otgonbayar Nerkhjav	Mongolia - Gurvantalst Geologic Mapping, LLC	Regional mapping
Dr. Peter Königshof	Germany - Senckenberg Natural History Museum (Frankfurt)	Stratigraphy, cm-scale section description, microfacies analysis, conodont biostratigraphy
Will Waters	USA - ExxonMobil	Site fossil assessment
Olivia Paschall	USA - Appalachian State University (student)	Local (m-scale) mapping of site, GMT topo map development, digital mapping
Allison Dombrowski	USA - Appalachian State University (student)	cm-scale section description (assistant to Königshof and Gonchigdorj)
Felix Kunze	USA/Germany - Felix Kunze Photography	Lead photographer
Ryan Fernandez	USA - Ryan Mikail Photography	Assistant photographer
Molomjamts Munkhjargal	Mongolia - HUNNU Resources	Assistant geologist, driver
Radnaasid Damdinsuren	Mongolia	Driver
Sukhbaatar Lkhamsuren	Mongolia	Driver
Purevbaatar Munkhbat	Mongolia	Driver & field assistant
Jargalsaikan Gonchigdorj	Mongolia	Cook
Damdinjamts Gonchigdorj	Mongolia	Driver & food prep assistant
Baasansuren Gonchigdorj	Mongolia	Cook

5. Methods

We employed traditional, simple geologic field methods while in the field: hammers for sampling, long tape measures for measuring the section, Brunton compasses for mapping the geologic structures (i.e. orientations of rock units), and GPS devices. Due to the lack of topographic maps on a scale that would allow us to map whether or not the 2104 section was continuous with the sampled lava flow, our student Olivia Paschall created our own topographic maps (Figure 8) prior to the trip. These were produced in Matlab using the GMT/MATLAB® API (Generic Mapping Tools toolbox) with satellite data. As there is little vegetation in the area, no vegetation filtering/corrections were needed. GPS elevation data in the field was consistent with all printed contour lines. In addition to these topo maps, the Mongolian mapping team had regional scale printouts of satellite maps, which showed km-scale geologic structures.

More sophisticated laboratory methodologies will be employed upon receipt of the samples (electron microscopy, X-ray diffraction, whole rock geochemistry, radiometric age dating, conodont extraction, etc.). Dr. Peter Königshof will process the 180 m of stratigraphic column data so it is available for cyclostratigraphy analysis and time series modeling, and the conodont extraction will be completed by Dr. Ariunchimeg Yarinpil, Dr. Peter Königshof and Dr. Thomas Suttner. Macrofossil analysis will be completed by Dr. Johnny Waters, Dr. Bernard Mottequin, Dr. Ariunchimeg Yarinpil, Ms. Ariuntogos Munkjargal, and Dr. Erika Kido. Geochemical analysis will be done by Dr. Sarah Carmichael and her students at Appalachian State University.

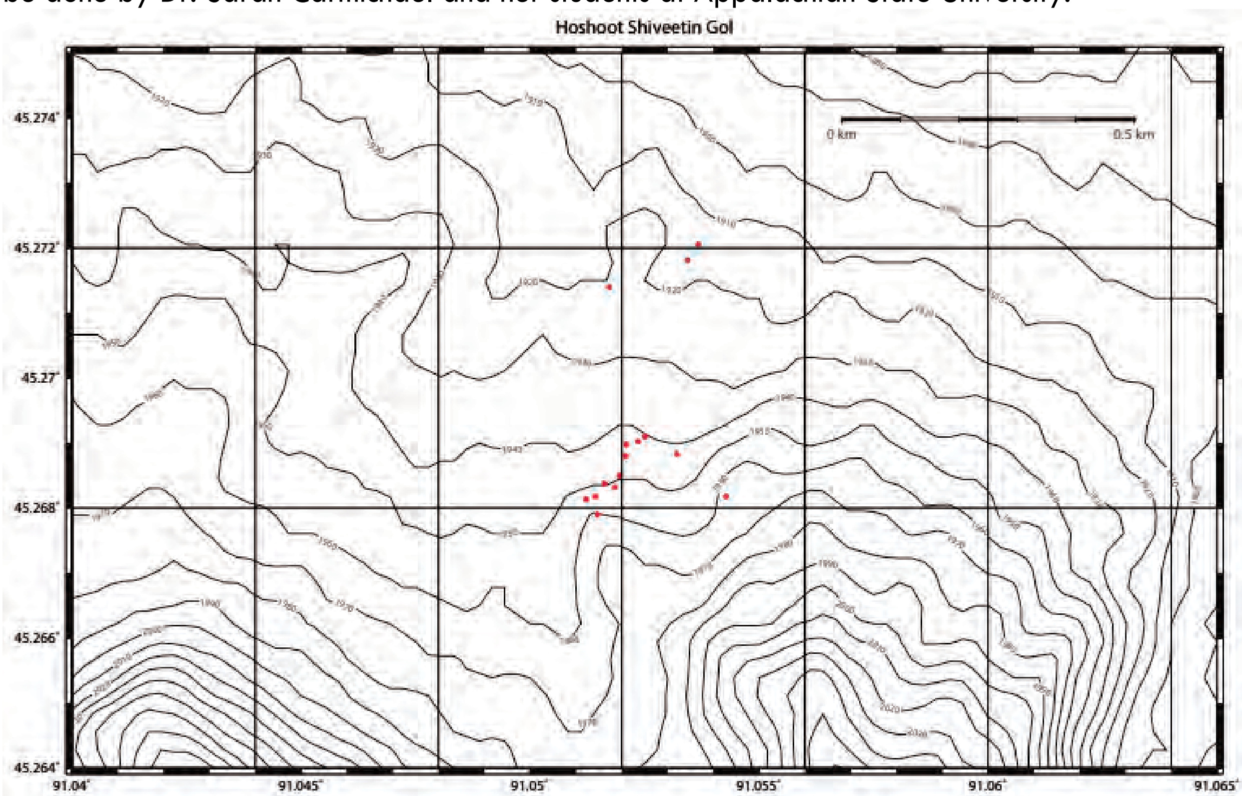

Figure 8. Example of one of the new topographic maps of the site made by student Olivia Paschall using Generic Mapping Tools with satellite digital elevation data. Red dots are sample sites from 2014.

6. Results

The results of our field expedition ***far*** exceeded our expectations. We not only achieved our stated objectives, but were able to begin work on a number of other related projects and tie in our laboratory work from previous field seasons. Related objectives/results are grouped together for clarity.

Objective 1: to fully describe the section at the cm scale for microfacies (paleoenvironment) analysis, Objective 2: to perform more detailed sampling across the section to better refine the ages, and Objective 3: to expand the section to include both mass extinction horizons, if possible.

Dr. Peter Konigshof, Dr. Sersmaa Gonchigdorj, and student Allison Dombrowski were responsible for describing, sampling, and expanding the section (Objectives 1, 2, and 3). The team described nearly 180 meters of section, centimeter by centimeter. They sampled 20 additional limestone beds for conodont fossils to better constrain the biostratigraphy (Figure 9). Field observations indicate that the expanded section crosses both the Frasnian-Famenninan and Devonian-Carboniferous boundaries (see Objective 4 for justification). This expanded section is - to our knowledge - one of the few known sections that crosses both mass extinction horizons, and *the only section in the world* that crosses both extinctions in a shallow water environment. This section is therefore vital for testing our hypothesis that anoxia was global, severe, and "top down" (i.e. that it was present in shallow water environments).

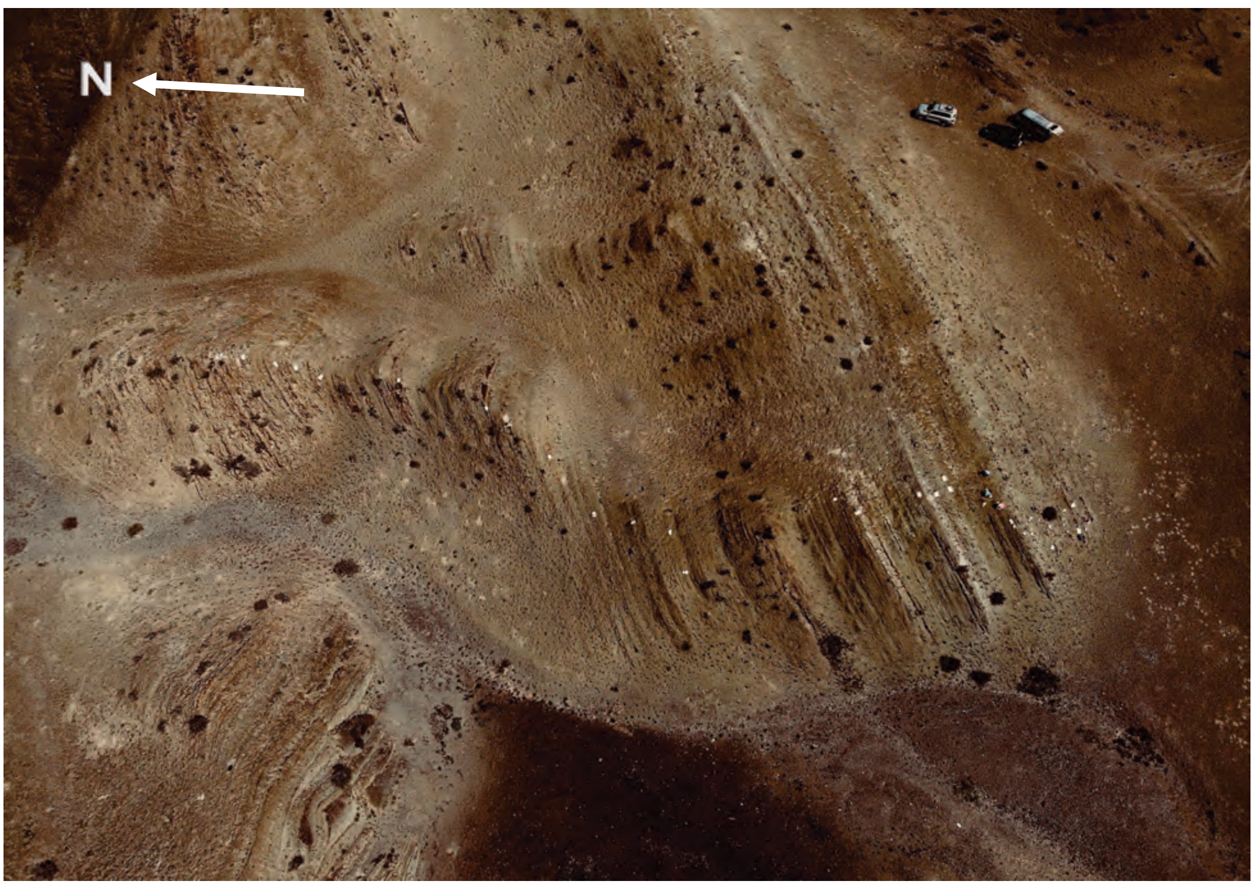

Figure 9. Drone footage of the eastern section of the Hoshoot Shiveetiin Gol prior to expansion, with white bags on limestone beds used for additional conodont biostratigraphy. The western section is approximately 350 m to the west (along strike) where exposure is better. Photo by Felix Kunze.

The section was broken into two parts, as exposure of the late Famennian sediments was better 350 m to the west, while exposure of the early Famennian and Frasnian sediments was best at the original location in the eastern part of the site (Figure 9). The sections were deliberately overlapped and mapped in detail so that there would be no question that they were continuous (see Objective 4 for the scientific justification for separating the sections).

An exciting development of the microfacies analysis was that the sedimentology team identified distinctive and repetitive layering of limestones and shales. These layering patterns represent orbital forcing signals (i.e. the climate changes that can be predicted based on the orientation of the Earth and Sun through time, based on Earth's wobble and orbit). The detailed microfacies measurements the team did in the field will allow for cyclostratigraphy time-series analysis (essentially a signal processing technique) at the University of Bremen by Dr. David De Vleeschouwer, one of the 2014 field workshop participants and an expert on Devonian orbital signals. The cyclostratigraphy data can be calibrated to the conodont data to determine if climate change alone, or in tandem with another event, could have triggered the F-F and D-C anoxia and extinction events.

One of the most exciting discoveries of the trip were the 70+ volcanic ash units that were found interbedded with the limestone and shale sequences in the measured section at the Hoshoot Shiveetiin Gol site, with additional ash and rock units in the reference section 30 km to the east (Figure 10). Volcanic ash beds typically contain zircons and can be used to radiometrically date the rocks. These ash beds provide an unparalleled opportunity to a) fine-tune conodont biostratigraphy ages and b) calibrate Late Devonian orbital forcing models with numerical dates. This is - to our knowledge - the only section in the world where this level of detailed, integrated age dating is possible. We collected 40+ samples of volcanic ash and volcanic rock for zircon analysis.


Figure 10. Otgonbaatar Dorjsuren and Olivia Paschall sample volcanic rocks interbedded with Frasnian sediments for radiometric (U/Pb) age dating using zircons. Photo by Sarah Carmichael.

For the paleontologists (Dr. Johnny Waters and Will Waters), the new fossil discoveries were the most compelling part of the trip (Figure 11). The upper part of the section and additional areas in the reference section contained a number of intact crinoids (filter-feeding echinoderms that look like small palm trees). Several of these crinoids were species that have never been found in Asia, and/or were thought to have gone extinct millions of years earlier. The presence of these crinoids in Late Devonian sediments of western Mongolia is a hugely important discovery for echinoderm paleontologists.

Figure 11. Intact echinoderm (crinoid and blastoid) fossils, some of which have never been found in Asia prior to this expedition. Photo by Felix Kunze.

Objective 4: to make a detailed map of the entire site at the meter to kilometer scale, and Objective 5: to correlate the Hoshoot Shiveetiin Gol geology with existing datasets from previous field excursions

Our mapping objectives were also successful. Dr. Sarah Carmichael and Olivia Paschall mapped the Hoshoot Shiveetiin Gol site at the meter scale (Figure 12), which indicates the Samnuuruul Formation forms a plunging syncline, where the north limb is structurally continuous from east to west, and sedimentation across the north limb is continuous with no visible unconformities or faults. Sedimentation is therefore continuous from the estimated Frasnian units (dark green color on field map) up through the Carboniferous units (pink, brown, and red on the field map). This map allowed the stratigraphy and sampling team the freedom to move along strike to the west to continue sampling at a better outcrop with more exposure, saving at least two days of fieldwork that would have otherwise been spent digging trenches through alluvial deposits to get to the bedrock.

The regional mapping team (Otgonbaatar Dorjsuren, Tumurchudor Choimbol, Ganbayar Guunchinbat, and Otgonbayar Nerkhjav) were able to correlate the mapped units at the Hoshoot Shiveetiin Gol site with the mapped units at the reference section, the War Monument Locality (sampled in 2012 and 2014), and the Border Locality (sampled in 2014). The mapping teams have now formally characterized the Samnuuruul Formation from the m to km scale (Figure 13), and the 2012 and 2014 data from the additional locations can now be used to age date the formation, using both biostratigraphy[12,13,15] and zircon geochronology[18], and fix the original stratigraphic section[7], which was mapped upside down due to existing map[9] which had characterized the plant fossils in the region as Carboniferous instead of Devonian (later work by 2014 ICGP 596 team member Charlotte Stephenson had determined the plants were Devonian[13]). We will be submitting these results for publication within the next year.

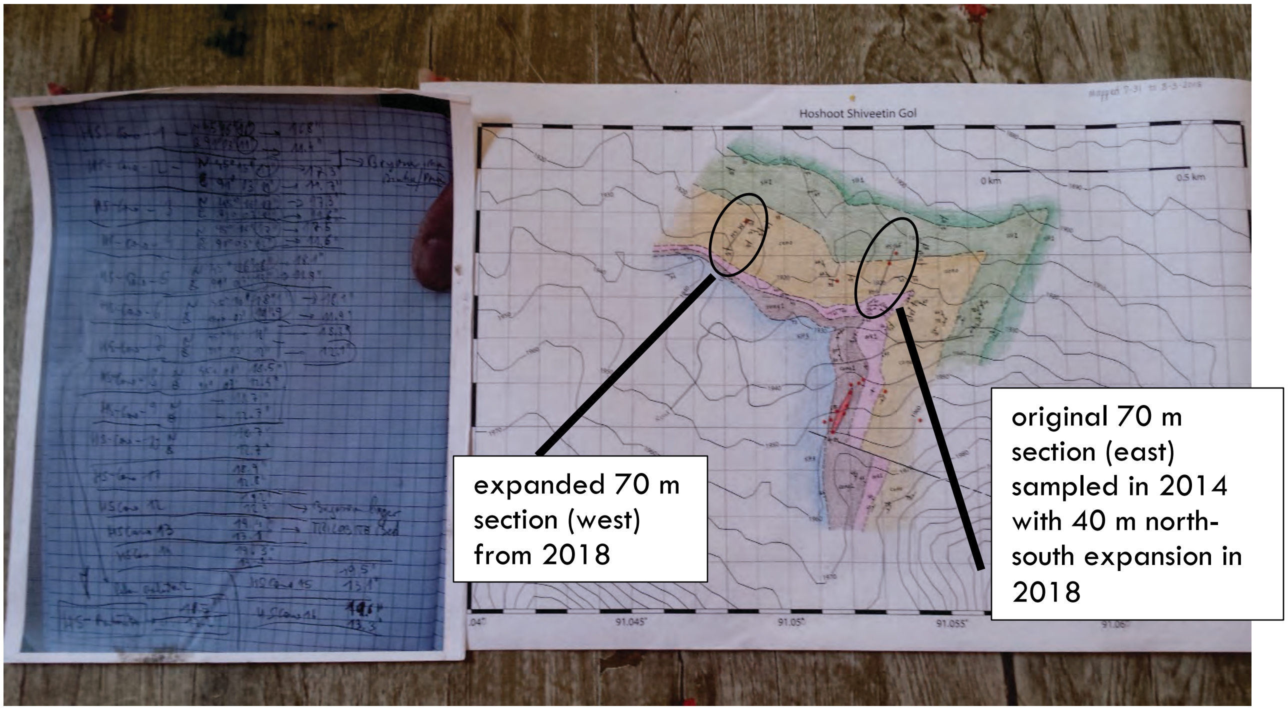

Figure 12. Comparison of early field data from the original section from the 2014 season[8] (left) with new field data and map from the 2018 season (right). The limited data from 2014 included GPS locations with minor observations about dominant fossil groups and mineralogy. The data from 2018 includes microfacies analysis across 180 m of section (both east and west sections), and 80+ strike/dip and GPS measurements to make a meter scale geologic map. The map shows a northeast plunging synclinal fold with continuous sedimentation and no major faulting on the north side of the fold axis, justifying the correlation between the east and west sections.

Figure 13. From left to right: Sersmaa Gonchigdorj, Tumumchudor Choimbol, Otgonbaatar Dorjsuren, and Sarah Carmichael discuss the general stratigraphy and subdivisions of the Samnuuruul Formation. Photo by Olivia Paschall.

7. Implications

The discoveries we have made on this field expedition are profound and multi-faceted. From our field observations we are confident that this section crosses two mass extinctions (the Frasnian-Famennian and Devonian-Carboniferous) and by definition must also cross their associated anoxia horizons (the Kellwasser and Hangenberg Events) in a shallow water, isolated, open ocean environment. This will allow us to test our hypothesis[6,16] that anoxia was global in scope, climate-driven, relatively rapid, and the mechanism was "top down" (via surface eutrophication, i.e. algal blooms) vs. "bottom up" (i.e. due to coastal upwelling or sea level rise through the oxygen minimum zone). The more we know about extinction and anoxia events in the past, the more prepared we can be for similar tipping point scenarios where climate becomes extremely unstable and dead zones in the ocean can expand catastrophically.

From a paleontology perspective, our team will be able to determine not only the faunas that were affected by these extinction events, but also the faunas the benefited from the opening of ecological niches in the aftermath of the extinctions. The faunas that survived can be compared to similar assemblages across the Late Devonian, and we can now start to model the role that paleogeography plays in determining who survives a mass extinction and who does not. In addition, these new fossil discoveries will change the way that paleontologists look at origination and speciation in echinoderm communities.

We are now able to formally describe the reference section of the Samnuuruul Formation for the first time in the scientific literature, and the rock descriptions and eventual geochemical analysis of the volcanic ash beds will help tell the story of magma evolution across a maturing island arc environment.

Our most unexpected discovery perhaps will be the most far-reaching and important of them all: the numerous volcanic ash layers we sampled from the Hoshoot Shiveetiin Gol section offer an unparalleled opportunity for calibrating the calculations used for orbital forcing models that are currently used to model climate changes throughout the middle Paleozoic.

When we proposed this project, we really had no idea if this section would yield any useful results. We thought we were looking for mass extinctions in all the wrong places, but much to our surprise we found that we were looking in exactly the right places. We are delighted to be proven so wrong about our flag expedition title.

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