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

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Geology Honors Thesis

State University of New York at Geneseo

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ABSTRACT

The Middle Devonian Eifelian-Givetian stage boundary records a time of major faunal turnover and climate change that occurred during and after the Kaĉák-*otomari* Event, a globally recognized transgressive episode. The Eifelian-Givetian stage boundary is defined by the first appearance of the conodont *Polygnathus hemiansatus*, though the dacryoconarid *Nowakia otomari* and the goniatite *Maenoceras undulatum* have been used to approximate the boundary.

A 103.0-meter section of the Tentaculite Member of the Govi-Altai Formation near the town of Shine Jinst in the Gobi-Altai terrane was studied with a zero mark established at the level at which a pinkish grey siltstone transitions into a greenish-grey shale with carbonate interbeds. Samples of the carbonate beds were processed for microfossils and magnetic susceptibility was measured at 0.5 meter intervals. Analysis of microfossils constrains the carbonate bed at 68.8 meters to the Lower Givetian *timorensis* Zone. Two volcaniclastic beds were also identified in the section, which is consistent with previous studies that have concluded the region represents a backarc basin that formed behind a volcanic island chain that was active during the Early and Middle Devonian.

Three major positive shifts in magnetic susceptibility were observed. The two positive anomalies, at the 47.5-65.5 meter and 80.5-82.5 meter intervals, correspond to the volcaniclastic beds. The stage boundary is most likely above the positive shift in magnetic susceptibility located between -0.5 m and 3.5 m, but below the 68.8 m carbonate bed.

INTRODUCTION

The Devonian System (418.1 ±3.0 to 365.7 ±2.7 Ma) is subdivided into three series, Lower, Middle, and Upper, which are further subdivided into seven stages. The Middle Devonian is subdivided into the Eifelian (391.9 ±3.4 to 388.1 ±2.6 Ma) and the Givetian (388.1 ±2.6 - 383.7 ±3.1 Ma; Kaufmann, 2006). The boundary between these stages is defined by the first appearance of the conodont *Polygnathus hemiansatus* at the Eifelian-Givetian Stage Global Stratotype Section and Point (GSSP), which is a section at Jebel Mech Irdane in the Tifilalt of Morocco (Walliser et al., 1995). At some sections, the appearance of the goniatite *Maenioceras undulatum* has been used as a proxy for the boundary (Kutcher and Schmidt, 1958).

The Eifelian-Givetian stage boundary occurs just above the Kaĉák Event, a globally recognized hypoxic, transgressive episode associated with the appearance of strata representing deep-water, anoxic facies (House, 1995). Due to its association with the appearance of the Dacryoconarid *Nowakia otomari*, the Kaĉák Event is also referred to as the *otomari* Event (Walliser et al., 1995). Crick and others (2000) described an interval of low magnetic susceptibility values associated with the Kaĉák-*otomari* Event, reflecting a lower detrital iron concentration within the sedimentary record. Lower concentrations of detrital iron are interpreted as the result of transgressive episodes and the resulting migration of clastic input landward (Crick et al., 2000). The end of the Kaĉák-*otomari* Event coincides with a sharp rise in magnetic susceptibility levels roughly concurrent with the Eifelian-Givetian boundary (Crick et al., 2000). Travis and others (2009) have used this positive magnetic susceptibility shift to approximate the Eifelian-Givetian boundary in eastern North America.

The purpose of this study is to analyze and approximate the Eifelian-Givetian stage boundary at the Tsakhir Section, which is located near Shine Jinst (Шинэжинст) in the Govi Altai Region of southern Mongolia. The level of the boundary was determined through a synthesis of biostratigraphic data, magnetic susceptibility, and lithologic data.

GEOLOGIC SETTING

Badarch et al. (2002) argued that Mongolia consists of numerous terranes that were accreted onto small Precambrian cratonic blocks in the Hangay Region of central Mongolia during the Paleozoic and Mesozoic. The focus of this investigation are strata in a region recognized as part of one of these accretionary wedges, which is referred to as the Gobi Altai Terrane (Figure 1; Badarch et al., 2002; Minjin and Soja 2009a). Badarch et al., (2002) interpreted the Gobi Altai Terrane to be a backarc basin, as indicated by abundant volcaniclastic sedimentary rocks. The volcanics within the Gobi Altai Terrane are believed to be derived from an island arc represented by the Mandalovoo Terrane, which was active throughout the Early and Middle Devonian (Badarch et al., 2002).

The study area near Shine Jinst (Fig. 2) represents a series of relatively continuous and mildly deformed strata, ranging from the Ordovician to the Carboniferous (Minjin and Soja, 2009b). Wang and others (2005) argued that the Eifelian-Givetian boundary lies either near the

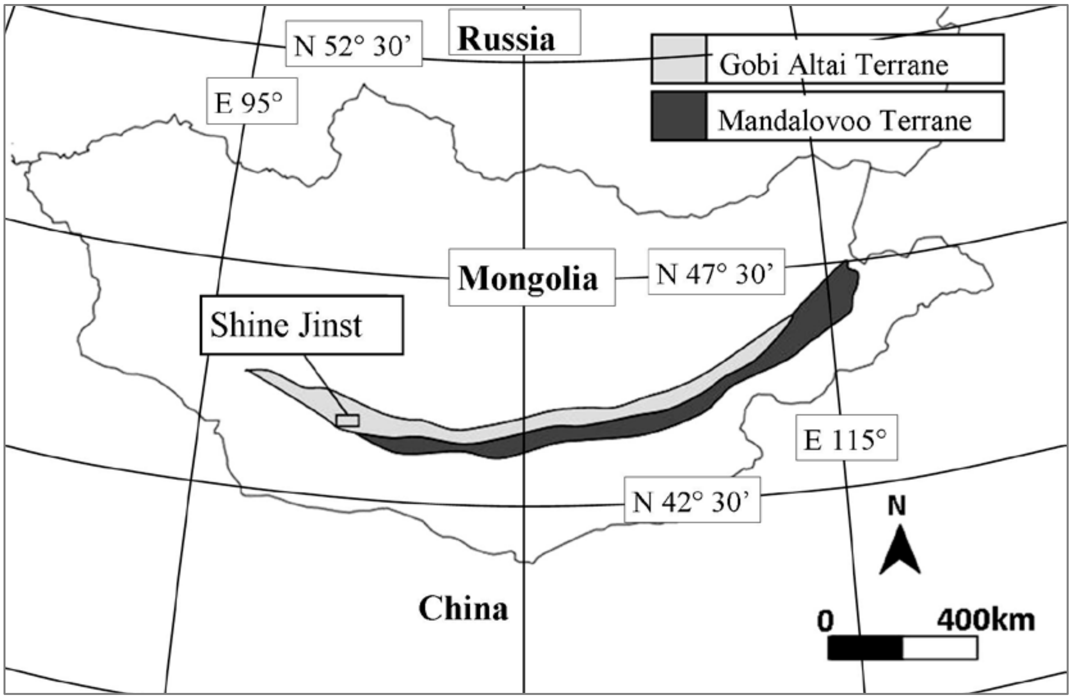


Figure 1 – Simplified tectonostratigraphic terrane map of Mongolia with the Gobi Altai and Mandalovoo terranes highlighted (modified from Badarch et al., 2002).

top of the Tsagaankhaalga Formation, or near the base of the overlying Govialtai Formation, suggesting the possibility of a gap in the stratigraphic record that includes the stage boundary.

Alekseeva (1993) described the Tsagaankhaalga Formation as predominantly massive, bedded limestones and associated conglomerates and sandstone layers. Wang and others (2005) reported the conodonts *Caudicriodus angustus cauda*, *Caudicriodus stelcki*, and *Caudicriodus unwoschmidti*, within the Tsagaankhaalga Formation, constraining the age to the Eifelian.

Alekseeva (1993) subdivided the Govialtai Formation into two members. The Lower or Tentaculite Member is characterized by black siltstones and claystones with occasional sandstone and sandy limestone layers. The Upper or Khar Member is characterized by volcaniclastic sediments with occasional interbedded basalts. Conodonts of the Upper *ensensis* Zone were reported by Alekseeva (1993) in the Tentaculite Member, thereby constraining the age to the lower Givetian.

The Eifelian-Givetian Stage boundary is believed to fall within the upper Tsagaankhalga or lower Govialtai (Alekseeva, 1993; Wang et al., 2005). Alekseeva (1993) suggested that the Tsakhir section is incomplete and that the two formations are unconformable, a sentiment shared by Wang and others (2005).

LOCATION AND LITHOLOGY OF THE TSAKHIR SECTION

The section at Tsakhir was measured and sampled during July and August 2009 as part of an expedition sponsored by the Keck Geology Consortium. The outcrop lies on a ridge that trends roughly northwest-southeast between two drainage channels that are occasionally used as dirt roads (Fig. 2). The crest of the ridge consists of massively bedded, fossiliferous carbonates. A small sample of these carbonate beds, believed to correspond to the base of Unit 18 as described by Alekseeva (1993), was collected for microfossils and thin section analysis.

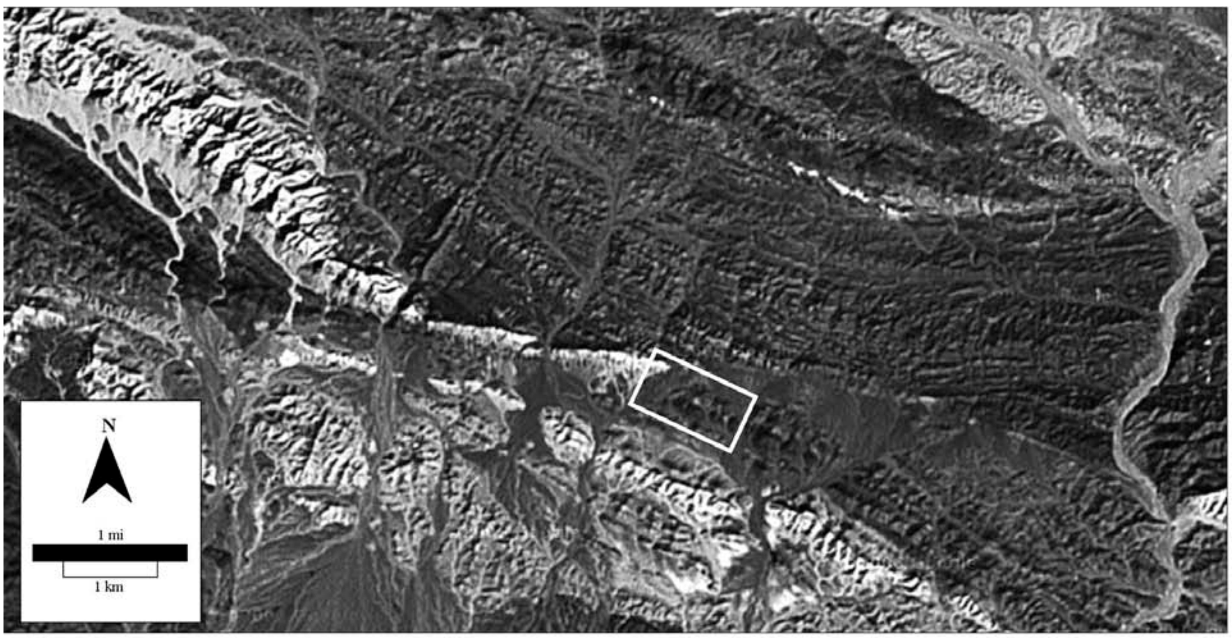


Figure 2 – Satellite photograph of the study area in Shine Jinst, Mongolia. Tsakhir section is outlined in white (modified from Google Earth, © 2010). Location is at approximately 44º 22' 46" N and 99º 27' 20" E.

The primary focus of this study was an outcrop located on the third hill east of the drainage divide that crosses the ridge to the west at approximately 44º 22' 46" N and 99º 27' 20" E (Fig. 3). The strata were found to have a strike of 058° from north with a dip of 50° to the south. In situ fossils and sedimentary structures below the measured section indicate the strata are overturned.

The stratigraphic section consists primarily of fine grained siliciclastics; mostly dark blue to dark gray silty shales (Fig. 4A, 4B). Also present are greenish gray tuffaceous conglomerates and medium green to gray feldspathic rhyolite siliceous beds. Within the fine grained siliciclastic

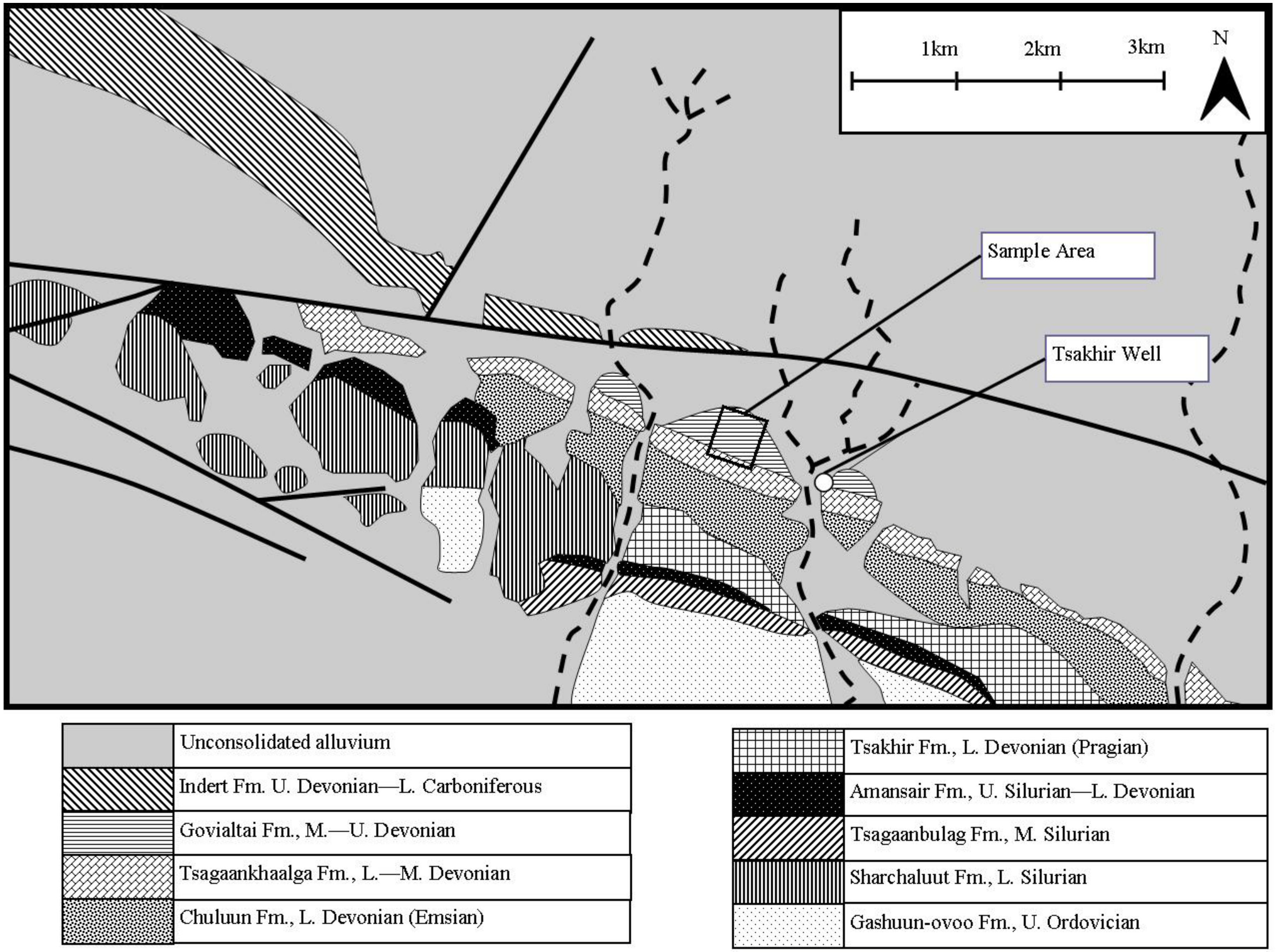


Figure 3 – Location of the Tsakhir section (outlined in the black box) on a simplified geologic map of the study area. Faults are indicated by solid black lines. Drainage channels are indicated by dotted black lines. The Tsakhir Well is represented by the white dot. Geologic units are labeled (Modified from Wang et al., 2005; and Minjin and Soja, 2009). Location of study area is at approximately 44º 22’ 46” N and 99º 27’ 20” E.

strata are interbedded, massive carbonates (Fig. 4C) with a layer of carbonate concretions observed at 71.5 meters (Fig. 4D).

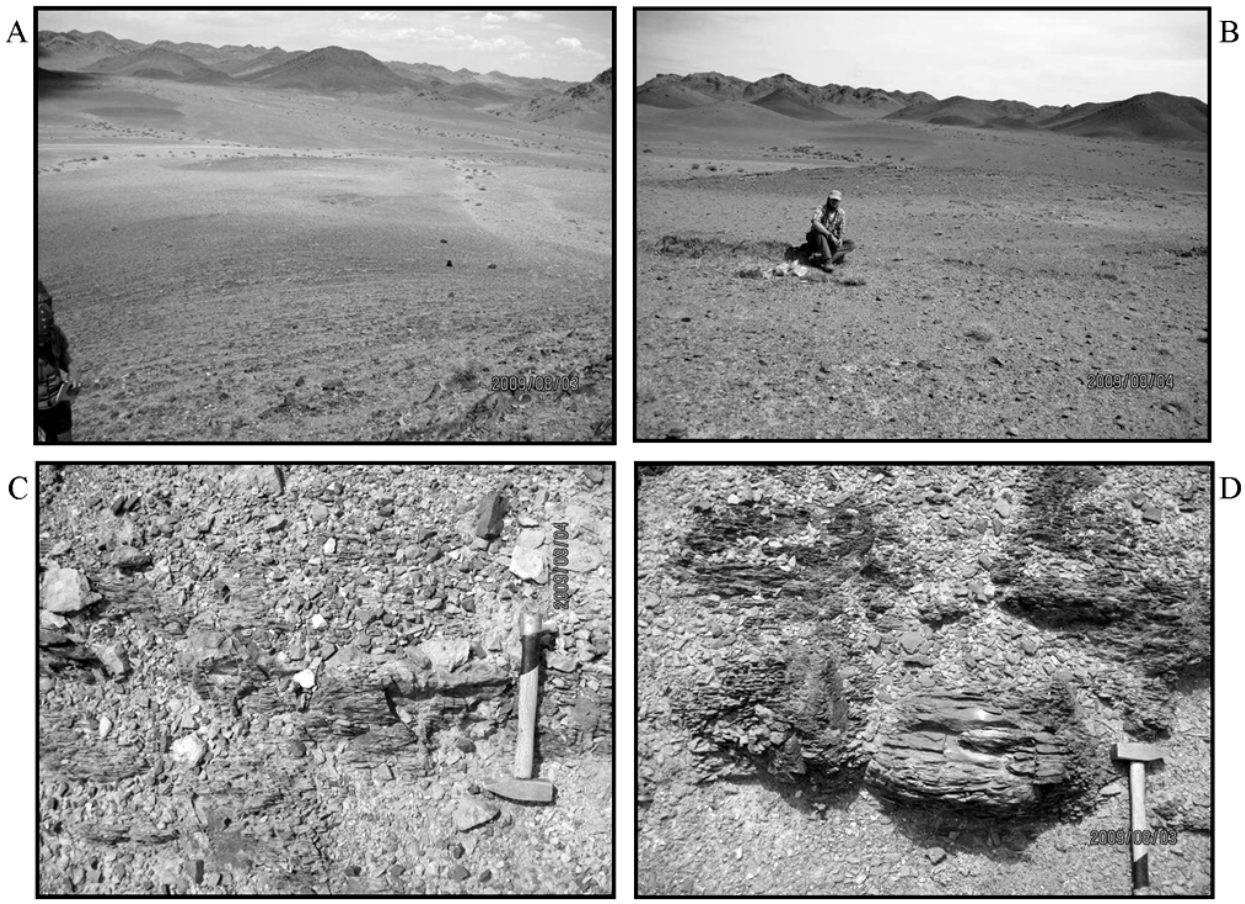
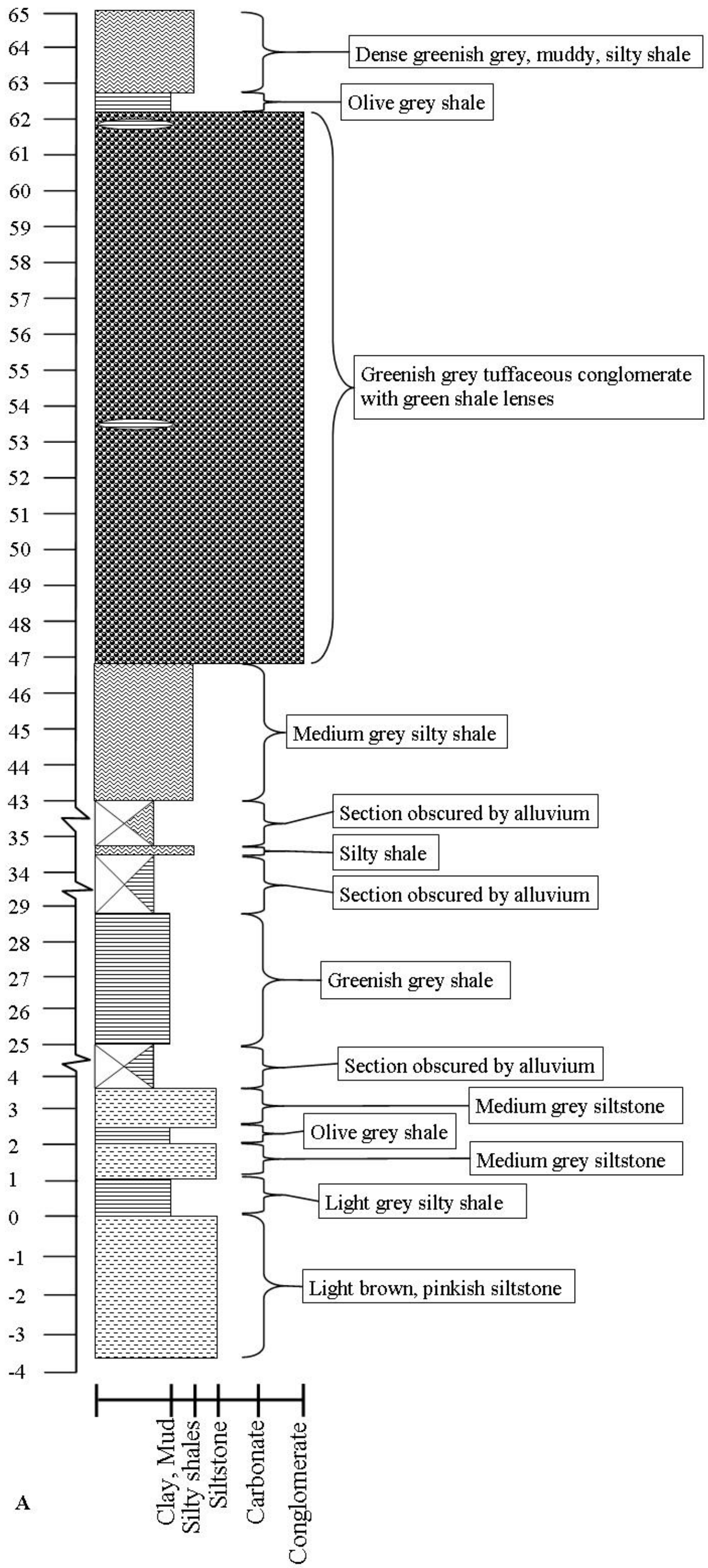


Figure 4 – Photographs of the Tsakhir Section. **A.** Photograph taken from 0.0 mark, looking upsection to the northeast. **B.** Photograph of section taken at 85.0 meters above zero, looking upsection. **C.** Photograph of carbonate bed located at 65.5 meters, rock hammer is 45 cm in length. **D.** Concretion bed located at 71.5 meters above zero, rock hammer is 45 cm in length.

A 103.0 meter section of strata was measured and described, where the base (zero) was established at the horizon where a light pinkish gray siltstone is overlain by a light gray silty shale (Fig. 5). The 3.6 m–25.0 m, 28.8 m-43.0 m, and 49.0 m–53.0 m section intervals were obscured by alluvium and therefore were not described or collected. Magnetic susceptibility samples were collected at half meter intervals through the section. Five bulk samples were collected for production of thin sections and microfossil analysis from the carbonate beds at 65.2 m, 68.8 m, 76.5-77.0 m, 87.0 m and 96.0-97.0 m (Fig. 5).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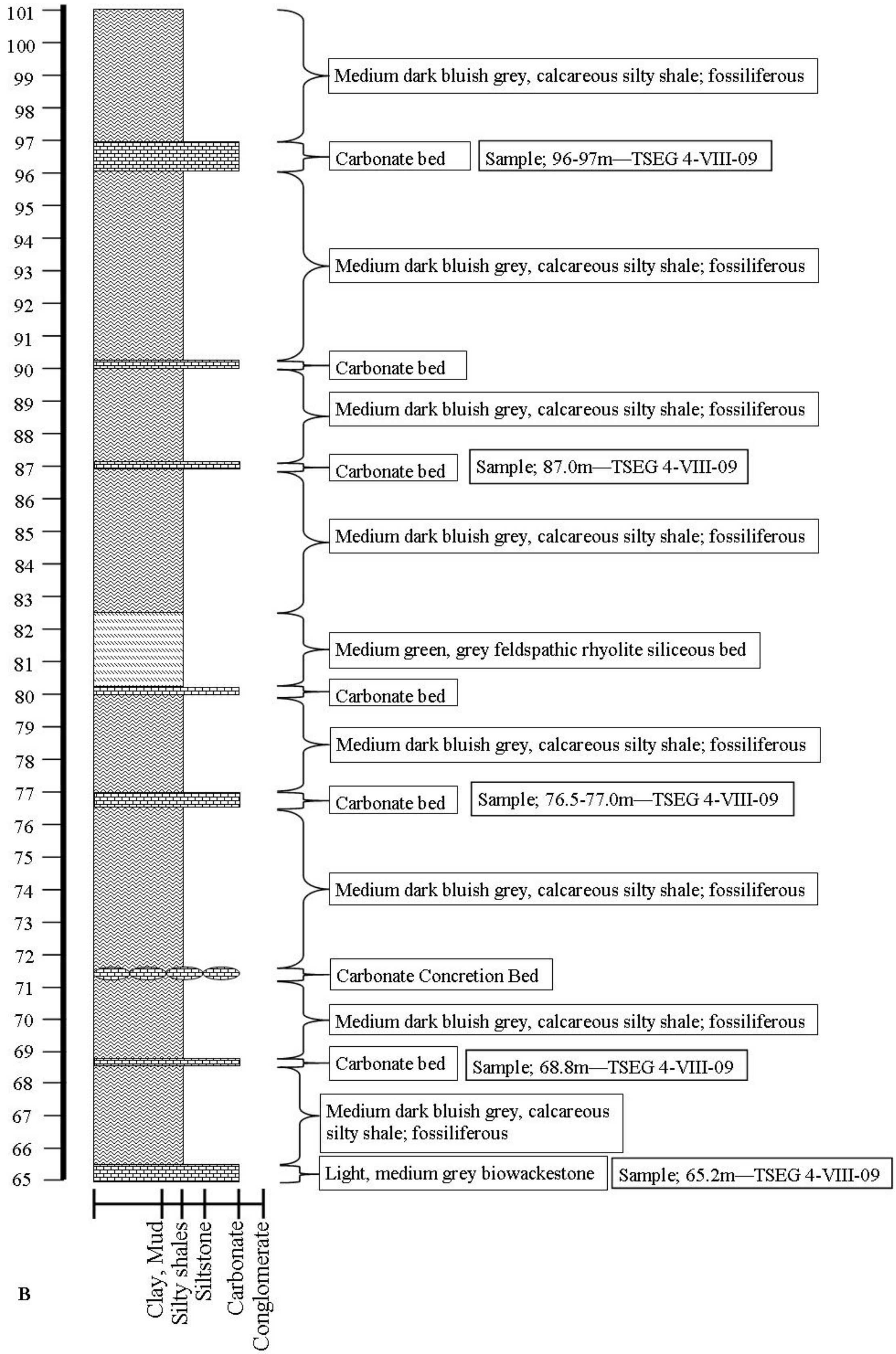
Dense greenish grey, muddy, silty shale
Olive grey shale
Greenish grey tuffaceous conglomerate with green shale lenses
Medium grey silty shale
Section obscured by alluvium
Silty shale
Section obscured by alluvium
Greenish grey shale
Section obscured by alluvium
Medium grey siltstone
Olive grey shale
Medium grey siltstone
Light grey silty shale
Light brown, pinkish siltstone
Clay, Mud
Silty shales
Siltstone
Carbonate
Conglomerate
A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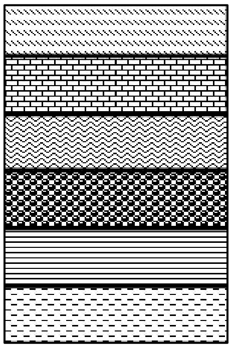
Medium dark bluish grey, calcareous silty shale; fossiliferous
Carbonate bed
Sample; 96-97m—TSEG 4-VIII-09
Medium dark bluish grey, calcareous silty shale; fossiliferous
Carbonate bed
Medium dark bluish grey, calcareous silty shale; fossiliferous
Carbonate bed
Sample; 87.0m—TSEG 4-VIII-09
Medium dark bluish grey, calcareous silty shale; fossiliferous
Medium green, grey feldspathic rhyolite siliceous bed
Carbonate bed
Medium dark bluish grey, calcareous silty shale; fossiliferous
Carbonate bed
Sample; 76.5-77.0m—TSEG 4-VIII-09
Medium dark bluish grey, calcareous silty shale; fossiliferous
Carbonate Concretion Bed
Medium dark bluish grey, calcareous silty shale; fossiliferous
Carbonate bed
Sample; 68.8m—TSEG 4-VIII-09
Medium dark bluish grey, calcareous silty shale; fossiliferous
Light, medium grey biowackestone
Sample; 65.2m—TSEG 4-VIII-09
Clay, Mud
Silty shales
Siltstone
Carbonate
Conglomerate
B

Key to general lithologies



Feldspathic rhyolite siliceous beds

Carbonate beds

Silty shale

Tuffaceous conglomerates

Light to greenish grey shales

Light pinkish brown siltstone

Figure 5 – Stratigraphic column compiled from data collected from the Tsakhir Section (on previous two pages). **A**. -2.0 – 68.0 meters above zero, and **B.** 68.0 meters to 101.0 meters above zero.

MICROFOSSIL DATA

The carbonate beds at 68.8 m, 76.5-77.0 m, 87.0 m, and 96.0-97.0 m were sampled for microfossil analysis. Samples were processed for conodonts using a 10 % solution of buffered formic acid. Conodonts were recovered from the 68.8 m interval and imaged using a scanning electron microscope (Fig. 6). Several of the 68.8 meter conodonts were identified and used for biostratigraphy.

Conodonts were also recovered from the 87.0 m carbonate bed as well. However, these specimens consisted entirely of single cone elements of unknown affinity. Tentaculitids and trilobite fragments were also found in the carbonate interbeds. However, these specimens were poorly preserved and not readily identifiable.

CONODONTS FROM 68.8 METER CARBONATE BED

Icriodus sp.

The P_1 element of *Icriodus* is characterized by three longitudinal rows of nodes with some forms including transverse ridges (Clark et al., 1981). In this specimen, the nodes of the central row are connected by a longitudinal ridge. Transverse ridges are present, running between lateral and central nodes (Fig. 6.1).

Polygnathus linguiformis linguiformis

Polyanthus linguiformis linguiformis is defined by an elongate carminiplanate P_1 element where the posterior platform forms a tongue-like projection which is ornamented with transverse ridges. The anterior portion of the platform is characterized by adcarinal troughs on both sides of the blade (Hinde, 1879; Fig. 6.2).

This taxon is known to have a stratigraphic range from the *kockelianus* Zone of the upper Eifelian to the *timorensis* / Lower *varcus*-Subzone of the lower Givetian at sections in Morocco (Bultynck, 1989).

Polygnathus sp.

The genus *Polygnathus* is defined by carminiplanate P_1 elements. The specimens are two fragments of the same conodont. The straight outer margins of the blade and distinct adcarinal troughs are reminiscent of *P. linguiformis* (Figs. 6.3, 6.4). However, the specimens lack the lateral ridges and tongue-like posterior projections. Relatively flat but discrete protrusions on the platform are also visible. The specimen bears resemblance to specimens identified as *Polygnathus pseudofoliatus* by Walliser (1995, Fig. 4A, 4B) from Morocco.

Polygnathus ensensis

Polyanthus ensensis (*P. xylus ensensis*) is defined by distinctly serrated platform margins just posterior to the geniculation point (Zeigler et al., 1976; Fig. 6.5, 6.6). *Polygnathus ensensis* first appears in the *ensensis* Zone of the upper Eifelian and extends into the *timorensis* / Lower *varcus*-Subzone of the lower Givetian at sections observed in Morocco (Bultynck, 1989).

Polygnathus xylus xylus

P. xylus xylus is characterized by an elongated blade as well as an unserrated anterior platform margin just posterior to the geniculation point (Fig. 6.7). The taxon appears in the Lower *varcus*-Subzone of the lower Givetian extending into the Upper *varcus*-Subzone at sections in Morocco (Bultynck, 1987).

The known stratigraphic ranges of identified taxa were recorded from various sources in the literature (Clark et al., 1981, Bultynck, 1987 and 1989, and Walliser, 1996). The identified taxa have a concurrent range zone that is confined to the *timorensis* Zone, a conodont zone of the lower Givetian (Fig. 7).

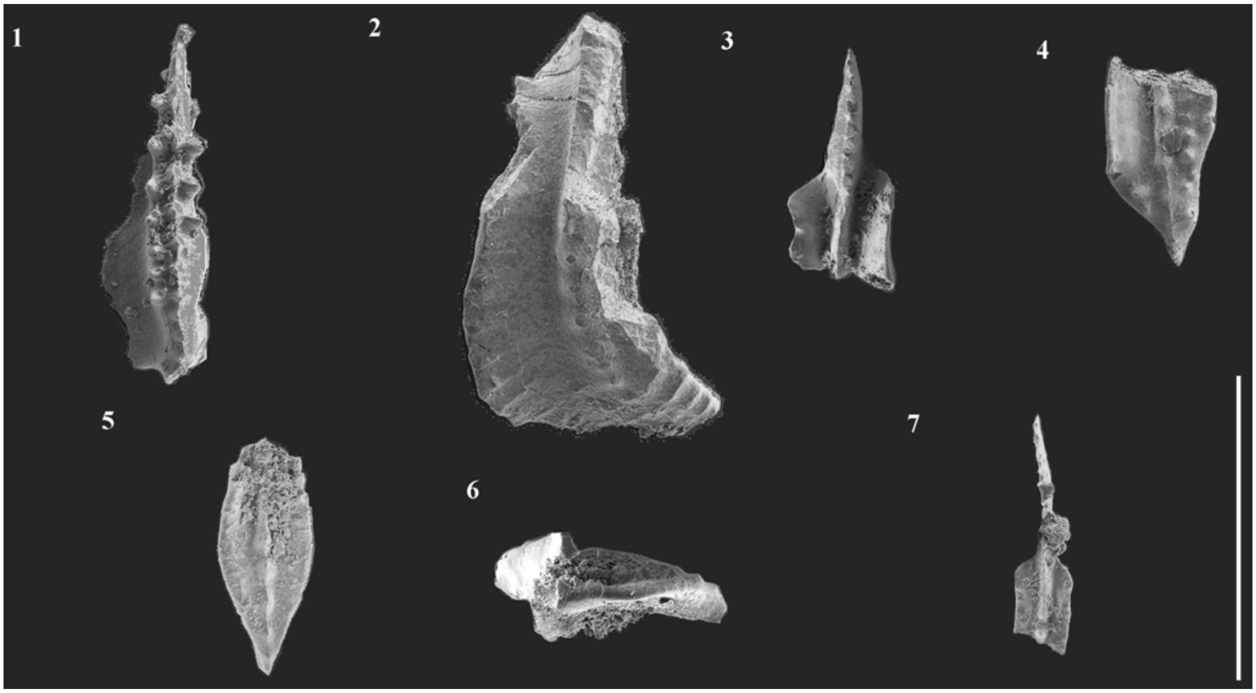


Figure 6 – Scanning electron microscope digital images of conodonts from the 68.8 m carbonate bed. White bar represents two millimeters.
6.1; *Icriodus sp.*; upper view of TSEG 01726, (long axis; 1.19 mm),
6.2; *Polygnathus linguiformis linguiformis*; upper view of TSEG 01734 (long axis; 1.45 mm)
6.3; *Polygnathus sp.*; upper view of TSEG 01730 (long axis 0.84 mm)
6.4; *Polygnathus sp.*; upper view of TSEG 01736 (long axis 0.72 mm), most likely the posterior end of sample TSEG 01730
6.5; *Polygnathus ensensis ;* upper view of TSEG 01736 (long axis 0.77 mm)
6.6; *Polygnathus ensensis ;* oblique view of TSEG 01731 (long axis 0.77 mm)
6.7; *Polygnathus xylus xylus;* upper view of TSEG 01735 (long axis .78 mm)

MAGNETIC SUSCEPTIBILITY DATA

Magnetic susceptibility is a measure of the total magnetism produced by minerals in a sample and as such, it is seen as a rough proxy for the fraction of detrital iron-bearing material in marine sediment (Crick et al., 2000). A sharp rise in magnetic susceptibility has been observed at sections in North America and Africa just below the Eifelian-Givetian boundary (Crick et al., 2000; Travis et al., 2008). This shift is believed to correspond to the deposition of clastic input seaward, reflecting a drop in sea level that occurred at the end of the globally recognized Kaĉák Event transgressive episode (Crick et al., 2000)

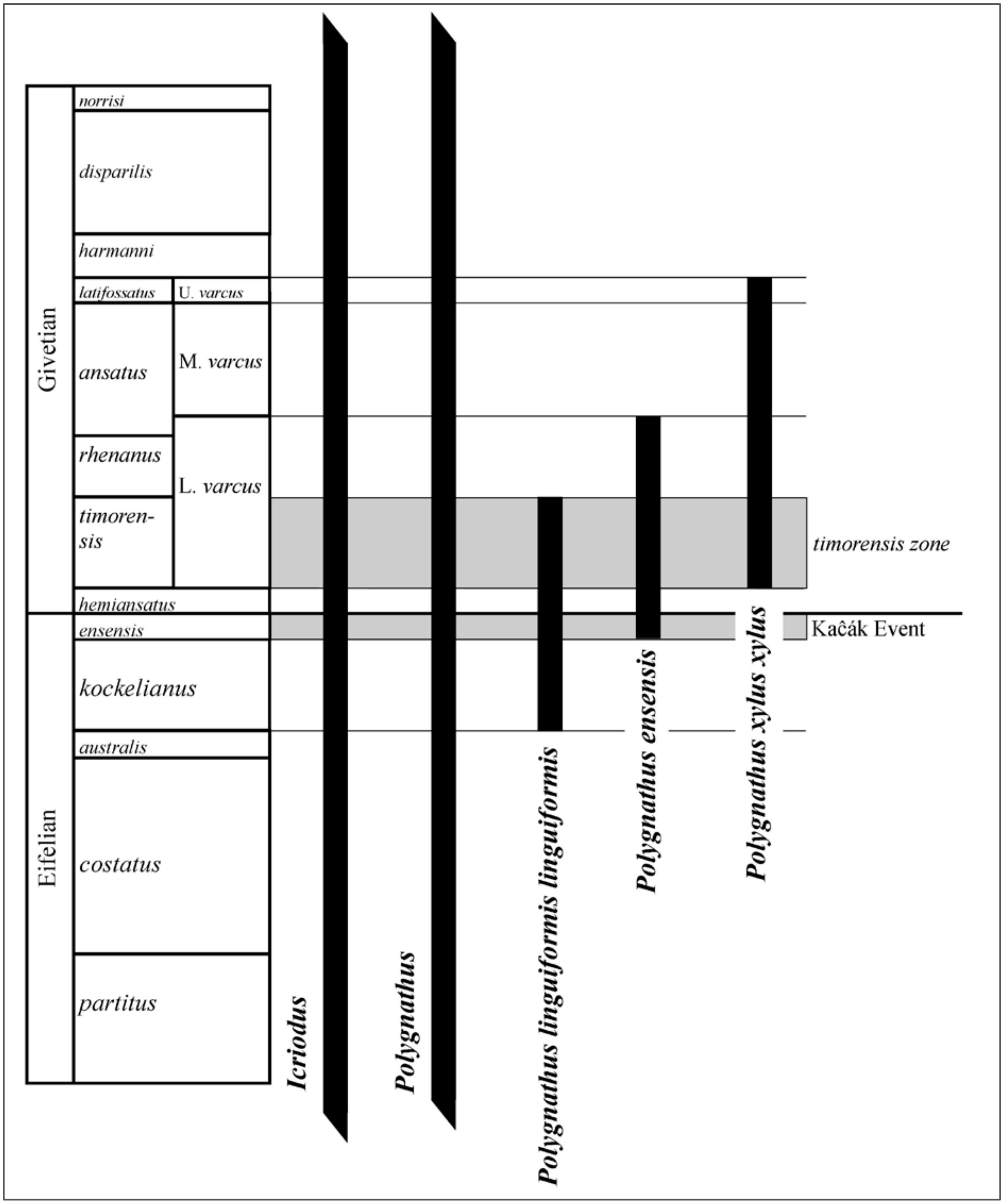


Figure 7 - Stratigraphic range of identified taxa collected from the 68.8 m carbonate bed. Stratigraphic ranges that extend below the Eifelian or above the Givetian are denoted by angular ends. Conodont zonations and stage intervals are from Kauffman, 2006. Stratigraphic ranges are from Clark and others, 1981, Bultynck, 1987 and 1989, and Walliser, 1996.

Magnetic susceptibility was measured using an AGICO MFK1 Kappabridge housed in the SUNY Geneseo Department of Geology. Magnetic susceptibility of each sample was measured at least three times. The average magnetic susceptibility value of each sample was then plotted against stratigraphic thickness in meters (Fig. 8). Magnetic susceptibility was measured against internal standards, uncertainty of measured values is $0.8 * 10^{-8}$ m^3/kg variance from mean measured values. A running average of eight samples is plotted to show the overall trend in magnetic susceptibility.

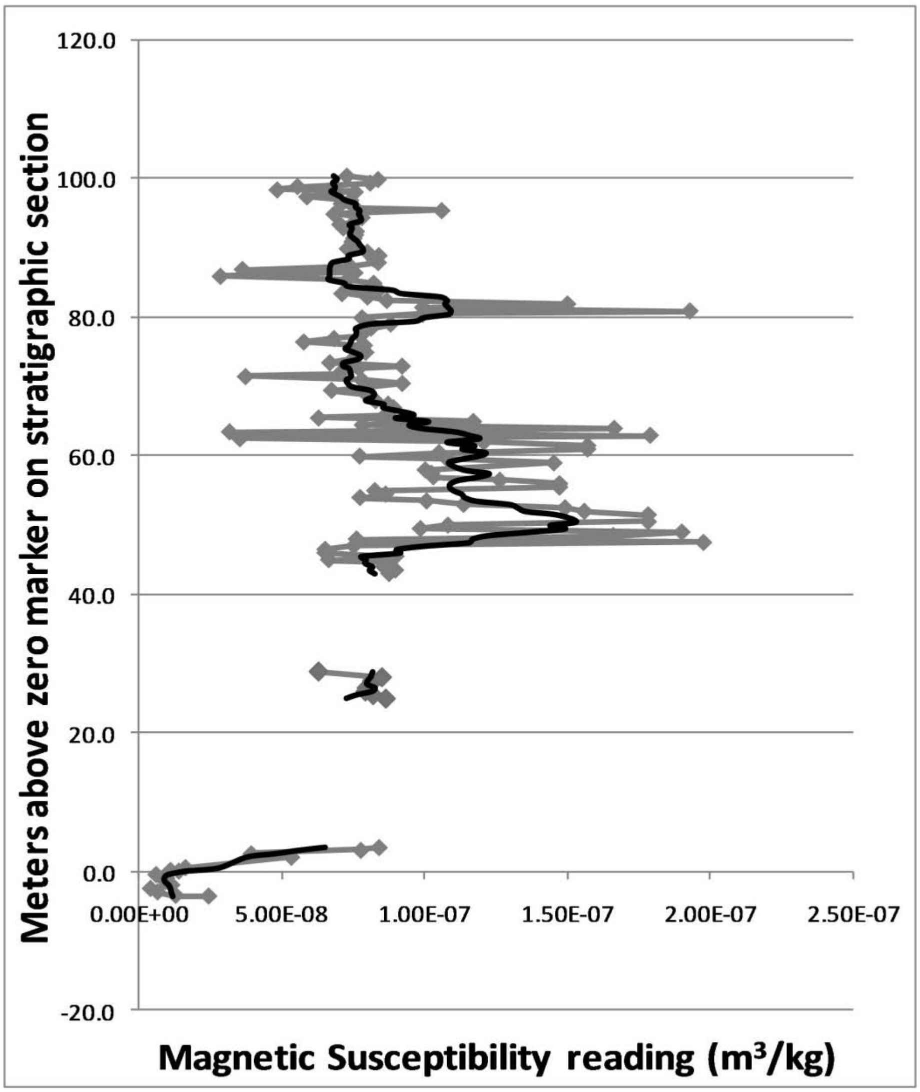


Figure 8 – Magnetic susceptibility (m^3/kg) of samples collected at Tsakhir Section plotted against stratigraphic thickness in meters. Light, thin, grey lines represent magnetic susceptibility of individual samples. Diamonds indicate magnetic susceptibility of sample at given stratigraphic height. The black, curved line represents a running average for sets of eight samples.

DISCUSSION

The massive carbonates of the Tsagaankhaalga Formation, overlain by the more finely bedded siliciclastic shales of the Govialtai Formation, are similar to outcrops of similar age in eastern North America where carbonates of the Onondaga Formation are overlain by the Marcellus and Skaneateles shales. The volcaniclastic units present throughout the section are consistent with the conclusions of Badarch and others (2002) who placed the Shine Jinst area within an accretionary terrane representing a backarc basin that formed behind a volcanic island arc that was active during the Devonian.

The conodonts *Polygnathus linguiformis linguiformis* (Fig. 6.2), *Polygnathus ensensis* (Fig. 6.5, 6.6) and *Polygnathus xylus xylus* (Fig. 6.7) share a concurrent range zone within the *timorensis* Zone, indicating that the carbonate bed at 65.8 m is lower Givetian in age (Fig. 7). The specimens of *Icriodus sp.* (Fig. 6.1) and *Polygnathus sp.* (Fig. 6.3, 6.4) are believed to represent taxa that have not been previously described in the literature.

Magnetic susceptibility data show an overall positive trend moving up the section. Three major positive shifts in magnetic susceptibility were measured at the -0.5 to 3.5 m, 47.0 to 65.5 m, and 80.5 to 82.5 m intervals. The positive magnetic susceptibility anomalies at the 47.5 - 65.5 m and 80.5 - 82.5 m are concurrent with two intervals of volcanogenic sediment.

The Eifelian-Givetian boundary is tentatively placed above the positive magnetic susceptibility shift observed between -0.5 m and 3.5 m, where the measurements stabilize at a level between $6.00*10^{-8}$ m^3/kg and $9.00*10^{-8}$ m^3/kg. A tentative correlation was made to the Eifelian-Givetian type section in western Morocco and strata from the Genesee River Valley in western New York (Fig. 9). However, biostratigraphic control is not sufficient to constrain the boundary interval and thick intervals of the section are obscured by alluvium, thus limiting the resolution of magnetic susceptibility trends.

CONCLUSION AND FUTURE CONSIDERATIONS

The strata of the Tsakhir section show similarities to Middle Devonian strata found elsewhere in the world. The massive carbonates of the Tsagaankhaalga Formation, overlain by the interbedded shales and of the Govi-Altai Formation are similar to Middle Devonian outcrops in central New York where the Onondaga Formation is overlain by the Marcellus and

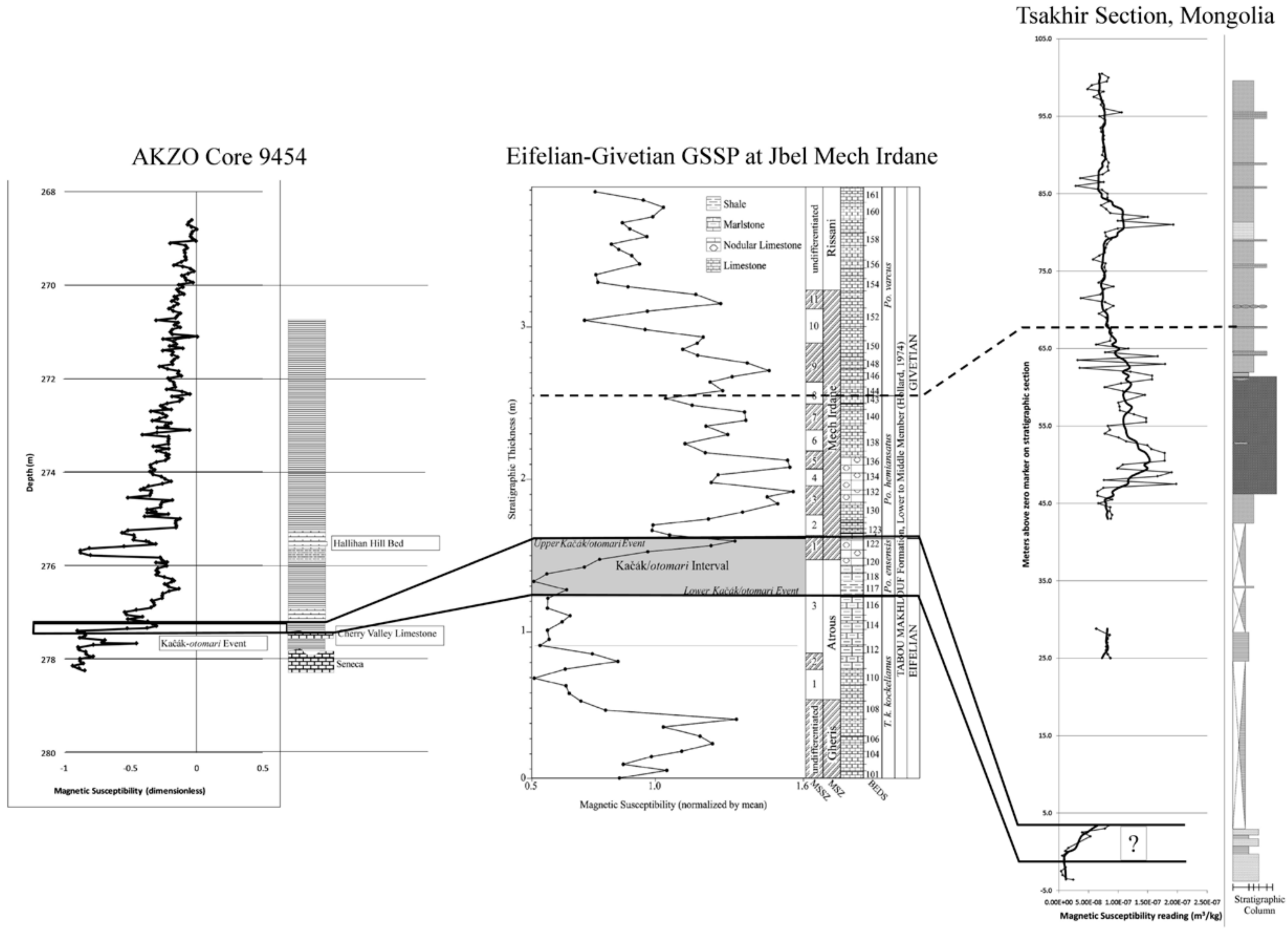


Figure 9 –Inferred correlation of three Eifelian-Givetian Sections; AKZO Well Core from the Genesee River Valley of western New York (Travis et al., 2009), Eifelian-Givetian GSSP from Jbel Mech Irdane in Morocco (Crick et al., 2000), and Tsakhir Section near Tsakhir Well (combined into a single stratigraphic column), Shine Jinst, Govi Altai Region, central Mongolia.

Skaneateles formations. The volcaniclastic beds interbedded with fine clastics and carbonates indicate that the region represents a backarc basin that formed behind a volcanic island arc.

Conodonts observed in the 68.8 meter carbonate bed constrain the age of the strata to the *timorensis* Zone of the lower Givetian. The Eifelian-Givetian boundary is placed above a positive shift in the magnetic susceptibility observed between -0.5 m and 3.5 m but below the 68.8 m carbonate bed. It is recommended that future studies examine sections that include the boundary between the Tsagaankhaalga and Govi-Altai Formations. It is also recommended that future studies sample the volcanic beds for purposes of radiometric dating.

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