PENNSYLVANIAN CONODONT BIOSTRATIGRAPHY OF THE SNAKY CANYON FORMATION, EAST-CENTRAL IDAHO

A Dissertation
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by
Jason M. Abplanalp

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Major Professor: Peter E. Isaacson, Ph.D.

Authorization to Submit Dissertation

This dissertation of Jason M. Abplanalp, submitted for the degree of Doctor of Philosophy with a major in Geology and titled "Pennsylvanian Conodont Biostratigraphy of the Snaky Canyon Formation, East-Central Idaho" has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ____________________________ Date: _______
Peter E. Isaacson, Ph.D.

Committee
Members: ____________________________ Date: _______
George W. Grader, Ph.D.

____________________________ Date: _______
Thomas J. Williams, Ph.D.

____________________________ Date: _______
William C. Rember, Ph.D.

Department
Administrator: ____________________________ Date: _______
Mickey Gunter, Ph.D.

Dean, College
of Science: ____________________________ Date: _______
Paul Joyce, Ph.D.

Final Approval and Acceptance

Dean of the College
of Graduate Studies: ____________________________ Date: _______
Jie Chen, Ph.D.

Abstract

Early (Morrowan) to Late (Missourian) Pennsylvanian conodonts from the Snaky Canyon Formation in east-central Idaho establish biostratigraphic dating of more-or-less continuously deposited foreland basin sequences. Within a siliciclastically influenced carbonate dominated succession, fifteen consecutive conodont biozones are defined and traceable along a 90 km. east to west transect in Idaho's Basin and Range Province. These biozones were deposited along a eustatically and tectonically influenced continental platform recording deep subtidal to nearshore, peritidal eolian, siliciclastic influenced deposition. Conodont faunas within the biostratigraphic interval are dominated by species of *Adetognathus, Rhachistognathus, Declinognathodus, Idiognathodus, Idiognathoides, Neognathodus,* and *Streptognathodus* which comprise over 95% of all conodonts recovered. The fifteen Morrowan to Missourian conodont biozones are the 1) *Rhachistognathus primus* biozone – lowermost Morrowan, 2) *Declinognathodus noduliferous* biozone – lower Morrowan, 3) *Idiognathoides sinuatus* biozone – middle Morrowan, 4) *Idiognathodus sinuosus* biozone – middle to upper Morrowan, 5) *Steptognathodus suberectus* biozone – upper Morrowan, 6) *Declinognathodus marginodosus/Idiognathoides sulcatus parvus* biozone – lower Atokan, 7) *Neognathodus atokaensis* biozone – lower Atokan, 8) *Idiognathodus incurvus* biozone – middle Atokan, 9) *Neognathodus bothrops (columbiensis)* biozone – upper Atokan to lowermost Desmoinesian, 10) *Neognathodus asymmetricus* biozone – lower Desmoinesian, 11) *Idiognathodus obliquus* biozone – lower to middle Desmoinesian, 12) *Idiognathodus expansus* biozone –

upper Desmoinesian, 13) *Idiognathodus magnificus* biozone – uppermost Desmoinesian to lowermost Missourian, 14) *Idiognathodus* sp. *"X"* biozone – lower Missourian, and 15) *Swadelina nodocarinata* biozone – lower Missourian.

These defined biozones redefine stratigraphic positioning of rock units and provide a framework for correlation. The Bloom Member of the Snaky Canyon Formation was deposited from the basal Morrowan to the earliest Missourian and the Gallagher Peak Sandstone Member was time transgressive from west (Desmoinesian) to east (Missourian). Conodonts from the lower Juniper Gulch Member at the type locality indicate a Morrowan to Atokan age, making the member correlative with the Bloom Member. *Palaeoaplysina* buildups initially occur in the middle Desmoinesian. Tectonic and eustatic controls greatly influenced deposition during the early Atokan (eustatic), late Atokan (tectonic), and middle Desmoinesian (mixed). Cyclicity is of 4th order (parasequence) scale that comprises at least three 3rd order sequences.

Acknowledgments

I wish to recognize and thank the following people for encouragement and/or assistance in the completion of this work: Dr. Peter E. Isaacson, major advisor; Dr. Michael C. Pope, former advisor; Dr. William Rember, advisor; Dr. Thomas Williams, advisor; Dr. George Grader, advisor; Dr. Liselle Batt, fellow researcher; and my parents, Donald and Brenda Abplanalp.

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Chapter 1: Introduction

This report documents the occurrence and stratigraphic distribution of conodont specimens from a mostly continuously deposited succession of upper Carboniferous Snaky Canyon Formation strata ranging from the Upper Mississippian (Meramecian) to the Upper Pennsylvanian (Missourian) exposed in the Basin and Range province of east-central Idaho. The recovered biostratigraphic data are utilized to interpret the depositional framework, depositional facies, timing, and tectonic setting of the Snaky Canyon Formation.

Upper Carboniferous Snaky Canyon sediments record equatorial, nearshore marine deposition along the western margin of Laurentia. These complex sediments contain evidence of glacially induced eustatic changes and tectonically controlled depositional changes (Skipp et al., 1979a; Tremblay, 1996; Archuleta, 2004; Archuleta et al., 2006). To date, only limited reports have documented biostratigraphically useful biota identified from the rock unit (Shannon, 1961; Skipp et al., 1979a; Groves, 1984; Verville et al., 1990). In order to fully understand the stratigraphic placement, timing, and formation of the carbonate dominated succession a high-resolution biostratigraphic framework is necessary.

Purpose and Problem

The following report reviews a conodont biostratigraphic analysis of the Pennsylvanian Snaky Canyon Formation of east-central Idaho. Previous studies in the region (Stamm, 1985; Abplanalp, 2006; Abplanalp et al., 2009) have defined and established a conodont biostratigraphic framework for the Mississippian of east-central Idaho. To date, only limited investigations have reported on recovered conodont (Archuleta, 2004) and foraminifera (Shannon, 1961; Breuninger, 1971; Skipp et al., 1979a; Groves, 1984; Verville, 1990) assemblages from the Snaky Canyon Formation. The fusulinid dominated specimens recovered by these studies were generally used for broad (Stage-scale) stratigraphic positioning (Figure 13).

To date, no high-resolution biostratigraphic data have been presented from the Snaky Canyon Formation of east-central Idaho. In order to determine the stratigraphic positioning, duration, tectonic setting, and correlative stratigraphic units for the Snaky Canyon Formation, a high-resolution biostratigraphic framework is necessary. This framework contributes to the overall understanding of the glacio-eustatic influence on an equatorial carbonate succession of strata. A majority of biostratigraphically investigated upper Carboniferous deposits record high frequency and high amplitude eustatic changes likely due to extensive Gondwanaland glaciation (Heckel, 1986; 1994; Batt, 2006; Isaacson et al., 2008; Grader et al., 2009; Batt el at., 2008). As a result of these large eustatic changes, most of the Pennsylvanian stratigraphic record is marked by significant hiatuses representing non-deposition as a result of sediment starvation or emergence (Lane and Straka, 1974; Al-Tawil et al., 1999). A high-resolution conodont based biostratigraphic investigation of the Snaky Canyon Formation provides a rare opportunity to document a complete and relatively continuous record of Pennsylvanian conodont occurrences and stratigraphic ranges from a more-or-less continuously deposited succession of open-marine strata.

Objectives

This report develops a high-resolution (meter-scale) biostratigraphic framework based on conodont occurrences for the Pennsylvanian Snaky Canyon Formation of east-central Idaho. The framework established by this study aids in the age determination and stratigraphic placement of the Snaky Canyon Formation and provides a regional correlation of a relatively continuous deposited nearshore peritidal to deep subtidal carbonate dominated succession. Prior to this report, very limited biostratigraphic information was available for the Pennsylvanian of Idaho (Shannon, 1961; Skipp et al., 1979a; Groves, 1984; Verville et al., 1990). This detailed conodont-based biostratigraphic study provides vital information about the age, duration, and depositional rates of the formation and also provides a means for the evaluation of facies relationships, sequence stratigraphic framework, and the paleogeographic setting for the region during the upper Carboniferous.

The primary objectives of this project are:

1) To develop an upper Carboniferous conodont biozonation framework for the northern Rocky Mountains that is reproducible and able to be applied to all seven of the Snaky Canyon Formation measured sections (Figure 39). This framework will have the potential to be utilized and referenced by future workers conducting studies on upper Carboniferous near-shore carbonate successions.

2) To report on the correlation of seven Pennsylvanian

Snaky Canyon Formation measured sections across east-central Idaho using the conodont biozonation framework.

3) To expand and refine limited pre-existing conodont biozonation schemes for the Carboniferous of the western United States (Figure 14). The Snaky Canyon Formation biostratigraphic succession also greatly contributes to the biozonation identified from the U.S. midcontinent where hiatuses in the rock record may have limited the initial appearance and stratigraphic duration of certain species present in the northern Rocky Mountain strata (Figure 14).

4) To provide systematic and refined biostratigraphic control for the mid- to upper Carboniferous stratigraphy of the region. This allows for a greater understanding of the relationships between Pennsylvanian strata in the region and provides refined stratigraphic placement for each member of the Snaky Canyon Formation (Figure 5).

5) To determine the relationship of the Bloom, Gallagher Peak Sandstone, and Juniper Gulch members at the type sections located in the Beaverhead Range of eastern Idaho (Figure 5).

6) To provide a conodont biozonation framework based on shallow to intermediate depth assemblages from a relatively continuously deposited succession of strata. This offers an alternative to the numerous deep-water and starved basin deposits that represent

the bulk majority of the conodont- based studies conducted during this stratigraphic interval.

7) To define the facies and facies architecture of the Bloom Member of the Snaky Canyon Formation.

8) To further aid in and contribute to the development of a highly detailed sequence and chemostratigraphic framework for upper Carboniferous rocks of the Northern Rocky Mountains region.

9) To aid in the comparison of accommodation rates, basin development, and sedimentation shifts by pinpointing conodont biozonation boundaries and durations in each of the measured sections.

10) To utilize conodont biostratigraphic data to determine the timing, duration, and placement of eustatic and tectonic influences on the basin.

11) To provide a proxy and biostratigraphic foundation for the interpretation of the timing and influence of the waxing and waning of large-scale continental glaciation on a near-shore equatorial carbonate stack.

12) To use conodont biostratigraphic data to determine the duration and timing of individual 4th-order parasequences and identified 3rd-order sequences.

13) To determine and define conodont biofacies for this interval and report on the parameters controlling

individual conodont biofacies.

14) To refine and contribute to the continually developing concepts of upper Carboniferous conodont lineages and phylogeny.

15) To describe the multi-element conodont assemblages (systematic paleontological descriptions) recovered from the aforementioned strata. Also, to photographically illustrate these assemblages for use in future studies.

16) To investigate the concept of conodont sequence biostratigraphy (Ritter et al., 2002) and determine the practical utility of this concept when correlating the parasequences of the Snaky Canyon Formation.

17) To provide a refined understanding of the age of enigmatic upper Carboniferous *Palaeoaplysina* buildups by reporting on conodont based age constraints.

18) To produce a synopsis of Carboniferous conodont based biozonation frameworks delineated by members of the University of Idaho's Carboniferous Research Group.

Chapter 2: Background

A History of Conodont Paleontology

Conodonts were first described in 1859 from claystones and mudstones outside of St. Petersburg, Russia by the paleontologist C.H. Pander (Sweet, 1988). Over the next century, a limited number of investigators determined that the enigmatic and notably diverse conodont fossils could be found throughout marine shales of the Paleozoic and into the lower Mesozoic (Cambrian to Upper Triassic). These early workers extracted the conodont elements by finely sieving shales after soaking in water and by investigating the bedding surfaces of black shales while in the field (Ulrich and Bassler, 1926; Huddle, 1934). Some of these workers attempted to establish a biostratigraphic framework for the Paleozoic, although the results were limited due to meager recoveries and minimal occurrences of other fauna for comparison. These early students of the conodont did recognize that different morphological elements occurred together as natural assemblages and most likely belonged to the same animal (Clark,1987; Barrick, 2012).

The full utility of the conodont assemblage as a stratigraphic indicator was not completely recognized until the 1930s when paleontologists from the United States discovered that conodonts could be recovered from the insoluble residues remaining after digesting carbonate rocks in a solution of weak organic acids (acetic or formic acids). Ellison (1941) published the first paper describing this technique and the Carboniferous conodonts recovered from the process. Future workers continually refined this process, such as that published by Collinson (1961) and continues to be referenced by modern workers (see the conodont processing techniques section).

The discovery and application of the acid digestion process revolutionized the study of conodonts. Large quantities of rocks could now be digested, which resulted in the identification of hundreds to thousands of new conodont species. From the high volume of conodonts identified, systematic studies could be performed on carbonate successions that led to the development of a biostratigraphic framework that became the standard for correlating Paleozoic rocks not only continent wide, but also globally. By the middle of the end of the 20th century, a majority of all Paleozoic boundaries were defined by the conodont fossil record (Clark et al., 1981; Barrick, 2012).

Recent researchers have utilized conodonts as not only a means for time datum and correlation, but also biofacies analysis, isotope analysis, oil and natural gas maturation indicators, and absolute dating. Conodont assemblages have been shown to have been controlled by sea level depth, water energy, and paleogeography, making them ideal for biofacies analysis (Chamberlain and Clark, 1973). As isotopic indicators, conodonts are composed of layered apatite. Apatite remains much more stable over time (as compared to calcite or aragonite) and apatite has been shown to record the oxygen and strontium geochemical signal from the marine waters in which the organism developed (Wheeley et al., 2012). As oil and natural gas maturation indicators, the conodont color alteration index was developed and defines the thermal history of the strata from which the conodont elements were recovered (Epstein et al., 1977; Clark, 1987). Most recently conodonts have been recognized as recorders of minute amounts of uranium, making them candidates for near future absolute dating analysis (Martin, 2010).

What are Conodonts?

From the discovery of conodonts in 1859 until the mid-1980s, the conodont element-bearing organism remained enigmatic and unknown. For decades paleontologists speculated the tooth-like remains were of fish, hagfish, algal, worm, arthropod, chaetognath, and/or mollusc affinities. The function of the conodont assemblages were frequently debated, with schools of thought supporting feeding apparati function from voracious carnivores to delicate planktonic filters (Clark, 1987). It was not until a 1983 discovery in a Scottish museum that the debate remained unsettled.

In the early 1980s, researchers discovered the soft body impression of a conodont bearing organism in cataloged rocks from the Granton Shrimp Bed in the United Kingdom (Briggs et al., 1983). Contributed work by Aldridge in Scotland confirmed it was indeed a preserved original conodont bearing organism and by the close of the 20th century, over 20 soft body impression remains were recovered from across the globe (Barrick, 2012).

The discoveries of conodont-bearing organisms' soft body impressions revealed much about the zoological affinity and morphology of the previously enigmatic creature. The organism lacks all skeletal or hard parts, aside from the conodont elements that seem to be located near the anterior, or mouth region. Remains also indicate the possibility of eyes, the presence of a chevron muscular pattern, and a caudal fin or flap. When classifying the organism into the Linnean system, a dilemma has plagued modern workers. Fossil remains suggest a dorsal notochord running the length of the body of the conodont bearing organism. This would classify the animal as a chordate, but not a vertebrate due to the lack of a hard structure surrounding the centralized nervous system. The ongoing debate is now focused on determining the affinity of the conodont bearing organism and how it relates to the advent, evolution, and development of the modern vertebrate (Clark, 1987; Barrick, 2012).

Pennsylvanian Stages

The North American stage and series names for the Pennsylvanian were established from stratigraphic successions located in the United States midcontinent. In decreasing age, the Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian stages were all defined from regional type midcontinental localities (Figure 1). The Morrowan represents the Early Pennsylvanian; the Atokan and Desmoinesian refers to the Middle Pennsylvanian; and the Missourian and Virgilian are considered Late Pennsylvanian (Heckel, 1999)(Figure 1).

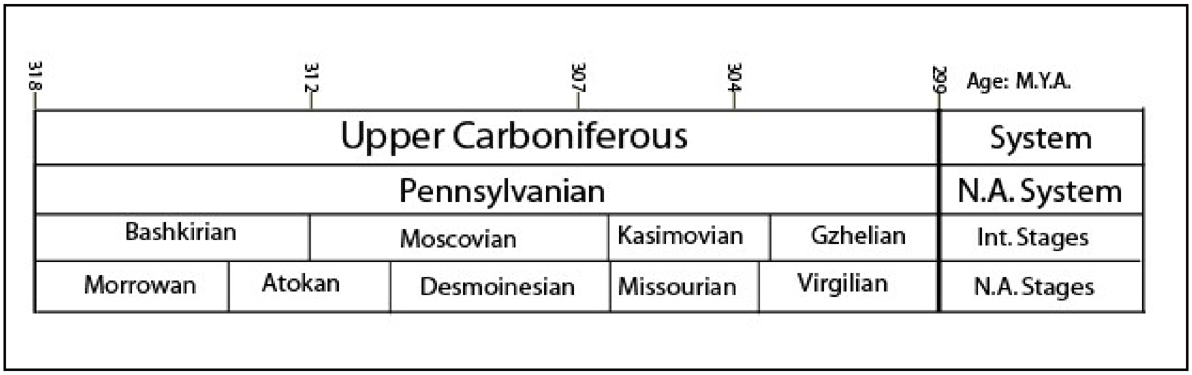


Figure 1: International and North American upper Carboniferous (Pennsylvanian) Stages

Initial workers first considered the Atokan to Missourian subdivision to be of series order. Later work by the Kansas Geological Survey during the 1960s established the greater order designation of stages for these subdivisions of the Carboniferous. Recently (1999, 2001, 2004), proposals by members of the Commission of Carboniferous Stratigraphy have lobbied for the recognition of these stages due to the practicality and utility of the North American stage succession when correlating strata globally. Recently, several workers (i.e., Groves et al., 1999; Gradstein and Ogg, 2004) are correlating the North American Stage divisions to the international stage framework in order to achieve global stage boundary definition and correlation (Figure 1).

The Morrowan Stage

The Morrowan Stage is the stratigraphically oldest North American Stage and it represents the basal upper Carboniferous (Pennsylvanian)(Figure 1). This stage coined its name from the Morrow Formation and a town in northwestern Arkansas (Adams and Ulrich, 1904). Initially regarded as a series during the 1930's and 1940's, the Morrowan was briefly renamed during this time as the Ardian Series (Moore and Thompson, 1949). Most recently, the Morrowan has been determined to be correlative to the lower three quarters of the Bashkirian International Stage division (Groves et al., 1999; Gradstein et al., 2004)(Figure 1).

The type locality for the Morrowan is located in northeastern Oklahoma and is comprised of over 100 meters of fossiliferous shale and limestone with sandstone interbeds. To the north, the Morrowan stratigraphic succession is marked with thin coal measures that occur within or near the sandstones and shales. The base of the Morrowan is marked by a widespread unconformity across the U.S. midcontinent (Heckel, 1999). Recent studies conducted within the western United States (Batt et al., 2007; Abplanalp et al., 2009) determined that the boundary between the Morrowan and underlying Upper Mississippian strata occurs within a continuously deposited succession of carbonate-dominated rock. Due to the record of continuous deposition along the western margin of Laurentia at this time, it was determined by the ICS and IUGS to use the Lower Pennsylvanian Arrow Canyon stratigraphic succession in Nevada to define the Morrowan basal boundary (also the mid-Carboniferous boundary) based on the first initial occurrence of the conodont *Declinognathodus noduliferous* (Lane et al., 1999).

The Atokan Stage

Like the Morrowan, the Atokan North American Stage was originally defined as a series from a stratigraphic succession of the United States midcontinent (Moore, 1948). This stage was named after the town of Atoka and the Atoka Formation in southeastern Oklahoma by Taff and Adams (1900). The regional series names Bendian, Lampasan, and Derryan were also proposed to represent this time frame from strata located in the American southwest and Texas (Moore and Thompson, 1949). Recent workers have correlated the Atokan to the Global Stages of the upper Carboniferous. These workers have determined that the Atokan is likely concurrent with the upper quarter of the Bashkirian and lower half of the Moscovian stages (Gradstein et al., 2004)(Figure 1).

The Atokan Stage marks the lower limit of the Middle Pennsylvanian and is best represented in a six kilometer thick succession of siliciclastic and biochemical strata located in the Arkoma Basin of Oklahoma's Ouachita Mountains. The lower limit of the Atokan is defined by the first appearance of the fusulinids *Profusulinella* and *Eoschubertella* and the upper limit is defined by the first appearance of Desmoinesian Stage fauna (Sutherland and Manger, 1983). These divisions are currently being scrutinized and there are currently ongoing debates above further defining and refining the upper and lower boundaries of the Atokan North American Stage (Heckel, 1999).

The Desmoinesian Stage

As with the Morrowan and Atokan, the upper-Middle Pennsylvanian Desmoinesian Stage was initially regarded as a series level stratigraphic time division for midcontinental strata. The stage was named after the Des Moines Formation located along the Des Moines River Valley of central Iowa (Moore and Thompson, 1949). Recent workers have determined that the Desmoinesian is correlatable to the upper half of the Moscovian and lower third of the Kasimovian International Stages of the upper Carboniferous (Gradstein et al., 2004) (Figure 1).

The type locality for the Desmoinesian records a disconformity to the underlying Atokan strata at the type section (Lambert and Heckel, 1990; Boardman et al., 1991). During this time, dramatic swings in sea level due to large-scale continental glaciation in the southern hemisphere are recorded in the cyclic deposition of marine carbonates capped by terrigenous deposits in the midcontinental foreland basin. These alternating shales, limestones, coals, and sandstones are often divided by significant hiatuses, although stratigraphic sections in the western U.S. and central Oklahoma likely record continuous deposition from the Atokan through the Desmoinesian (Boardman, 1997).

The Missourian Stage

The Upper Pennsylvanian Missourian North American Stage was originally defined from Missouri Formation outcrops in the Missouri River Valley of Iowa and Missouri (Keyes, 1893). This stage was originally defined as a series and the base identified by a pervasive disconformity in the type region of the Missouri River Valley (Moore and Thompson, 1949). Midcontinental workers have also identified a regional extinction event that occurs in the lower boundary of the Missourian in North America and may be correlated with the disconformity (Boardman et al., 1991; Heckel et al., 2002). Recent global workers have determined that the condensed interval of geologic time represented by the Missourian is correlatable with the upper two-thirds of the Kasimovian and lower sixth of Gzhelian International Upper Carboniferous Stage (Gradstein et al., 2004)(Figure 1).

Recent studies by Heckel et al. (2002) determined that the base of the Missourian could be defined by the first appearance of the conodont *Idiognathodus eccentricus* within a regional black shale bed. The lower Missourian is within the lowest fusulinid *Triticites* biozone and is most notably marked by a distinct decline in distinct Desmoinesian microfaunal assemblages (Keairnes, 2002).

The Virgilian Stage

Moore (1932) coined the name Virgilian for disconformity bound strata above the Missourian of east-central Kansas. This disconformity is not laterally persistent and later workers placed the boundary within the lower part of a widely traceable U.S. midcontinent cyclothem (Heckel, 1999). Recent studies conducted in Eastern Europe have determined that the Virgilian North American Stage is likely correlatable with the upper five sixths of the Gzhelian International Stage (Gradstein et al., 2004)(Figure 1).

The Virgilian is the uppermost North American Stage of the Carboniferous (Figure 1). Although the Missourian is considered to be similar in fauna to that of the lower Virgilian Stage, it has been determined that the first occurrence of the conodont *Streptognathodus zethus* likely marks the Missourian/Virgilian stage boundary (Heckel, 1999).

Chapter 3: Geologic Setting

The Pennsylvanian to Lower Permian Snaky Canyon Formation is exposed in the White Knob, Lost River, Lemhi, and Beaverhead ranges of east-central Idaho (Skipp et al., 1979a) (Figure 2). This formation was deposited along the western cratonic margin of Laurentia around 10° to 20° north latitude from around 318 mya. to around 285 mya. (Skipp et al., 1979; Batt et al., 2008). During this time the southern hemisphere was dominated by a massive continental ice sheets that greatly influenced Carboniferous marine depositional patterns (Heckel, 1986; Soreghan, 1994; Isbell, 2003; Fielding et al., 2006; Rygel et al., 2007a, 2007b; Grader et al., 2008; Batt et al., 2008).

Prior to the Pennsylvanian, the north to south trending asymmetrical Copper foreland basin formed to the west of the Laurentian continental margin during the Late Devonian Antler Orogeny and this tectonically driven basin prevented siliciclastic input from the highlands to the west from influencing the outer cratonic carbonate bank (Skipp et al, 1979b; Poole and Sandberg, 1991; Link et al., 2002; Isaacson et al., 2007). During the Mississippian, the carbonate bank prograded westward into the foreland basin and by the termination of the Mississippian, flysch deposition had likely ceased (Poole, 1974; Skipp et al., 1979b; Skipp and Hall, 1980; Link et al., 2002; Isaacson et al., 2007; Batt et al., 2008)(Figure 3).

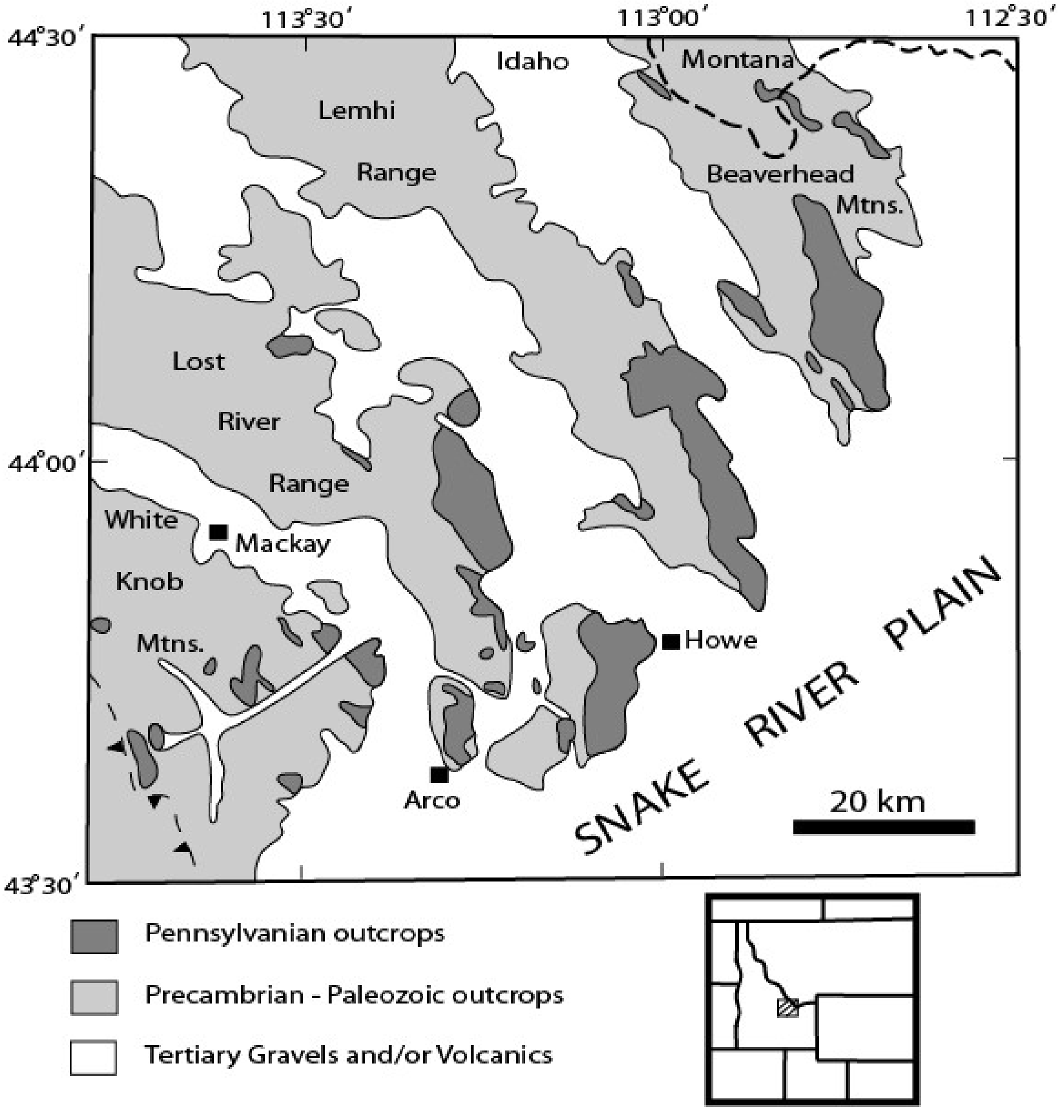


Figure 2: Exposed outcrops of upper Carboniferous (Pennsylvanian) strata in the southern Basin and Range Province of east-central Idaho

During the Morrowan to Atokan (Early Pennsylvanian), the paleotectonic setting of east-central Idaho was very similar to that of the Upper Mississippian and is characterized by siliciclastically influenced carbonate deposition within a near equatorial epeiric sea. The Lower Pennsylvanian Bloom Member of the lower Snaky Canyon Formation records deposition on a shallow, relatively open marine carbonate ramp located to the east of the former Mississippian foreland basin (Skipp et al., 1979a; 1979b; Skipp and Hall, 1980). This carbonate dominated member records a overall deepening and westward progradation of carbonate deposition from the underlying mixed carbonate and siliciclastic Bluebird Mountain Formation (Skipp et al., 1979a)(Figures 3 and 4). Correlative Bloom Member rock units from the region include the lower Wood River Formation, the upper Manning Canyon Shale, the lower Oquirrh Formation, the upper Amsden Formation, and lower Wells Formation, and the lower Quadrant Formation (Figure 5).

The geologic setting of the equatorial western margin of Laurentia greatly changed during the Middle Pennsylvanian. During the Desmoinesian, the Copper Basin Highlands formed at or near the site of the former Antler Highlands (Figure 5). This uplift caused an increase in siliciclastic sediment influence to the east, forming a thick succession of coarse to fine siliciclastics that accumulated in the Oquirrh-Wood River Basin (Poole, 1974; Skipp et al., 1979b; Skipp and Hall, 1980; Mahoney, 1991; Link et al., 2002)(Figure 4). Carbonate deposition remained dominant along the cratonic margin, although the sediments of the Gallagher Peak and Juniper Gulch members indicate deposition within a relatively restricted marine carbonate ramp that periodically became emergent (Skipp; 1979a; Canter and Isaacson, 1991; Archuleta et al., 2006). These Upper Pennsylvanian sediments also record an increase in fine-grained siliciclastics from the Quadrant eolian sand sea from the Laurentian craton to the east (Canter and Isaacson, 1991; Archuleta, 2004)(Figure 4). Correlative Gallagher Peak Sandstone and Juniper Gulch Member rock units from the region include the upper Wood River Formation, the upper Oquirrh Formation, the upper Wells Formation, and the upper Quadrant Quartzite Formation (Figure 5)

The depositional framework characterizing the Upper Pennsylvanian continued into the Early Permian. The lack of Permian age strata to the west of the study area may indicate that a renewed period of uplift may have occurred during this time at the location of the Copper Basin Highlands (Skipp and Hall, 1980; Link et al., 2002). By the Middle Permian, the remnant highlands created a large epicratonic and highly restricted basin in eastern Idaho (Figure 12). This basin accumulated large amounts of organic and phosphatic sediments of the Permian Phosphoria Formation (Link et al., 2002).

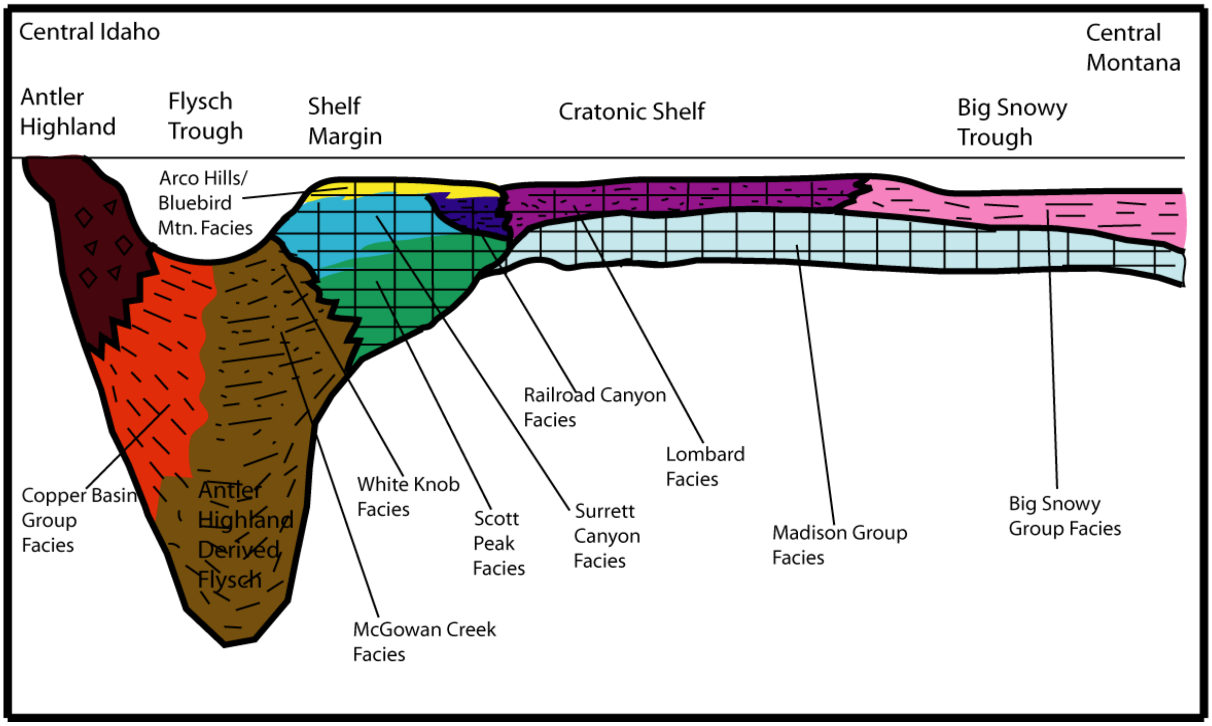


Figure 3: Reconstruction of Chesterian (Upper Mississippian) deposition from the Antler Highlands (likely completely eroded during this time interval) to the western edge of the Williston Basin (modified and created from Rose, 1976; Sando, 1976; and Skipp et al. 1979b).

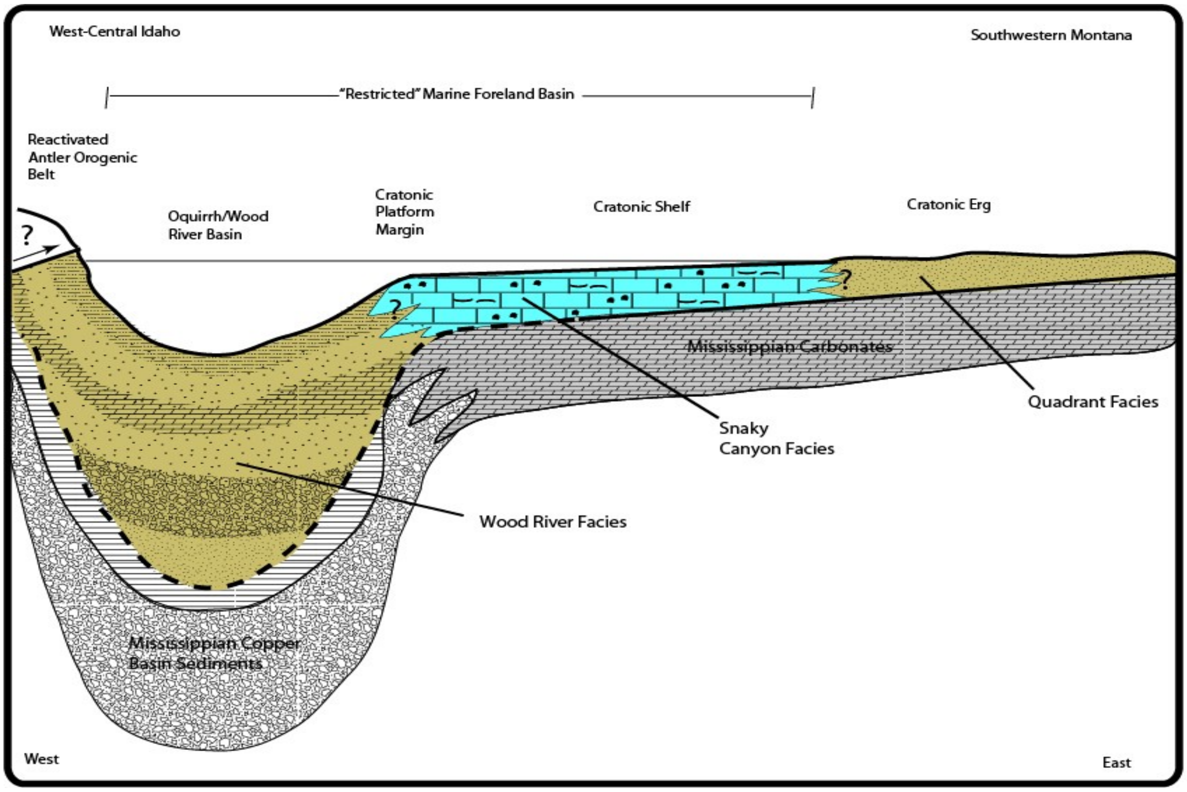


Figure 4: Reconstruction of Middle Pennsylvanian (Desmoinesian) deposition and depositional facies from the reactivated ancestral Antler Highlands (likely emergent during this time) to the western edge of the Quadrant sand sea (modified and created from Rose, 1976; Sando, 1976; Skipp et al., 1979b; Saperstone and Ethridge, 1985; and Link et al., 1996, 2002).

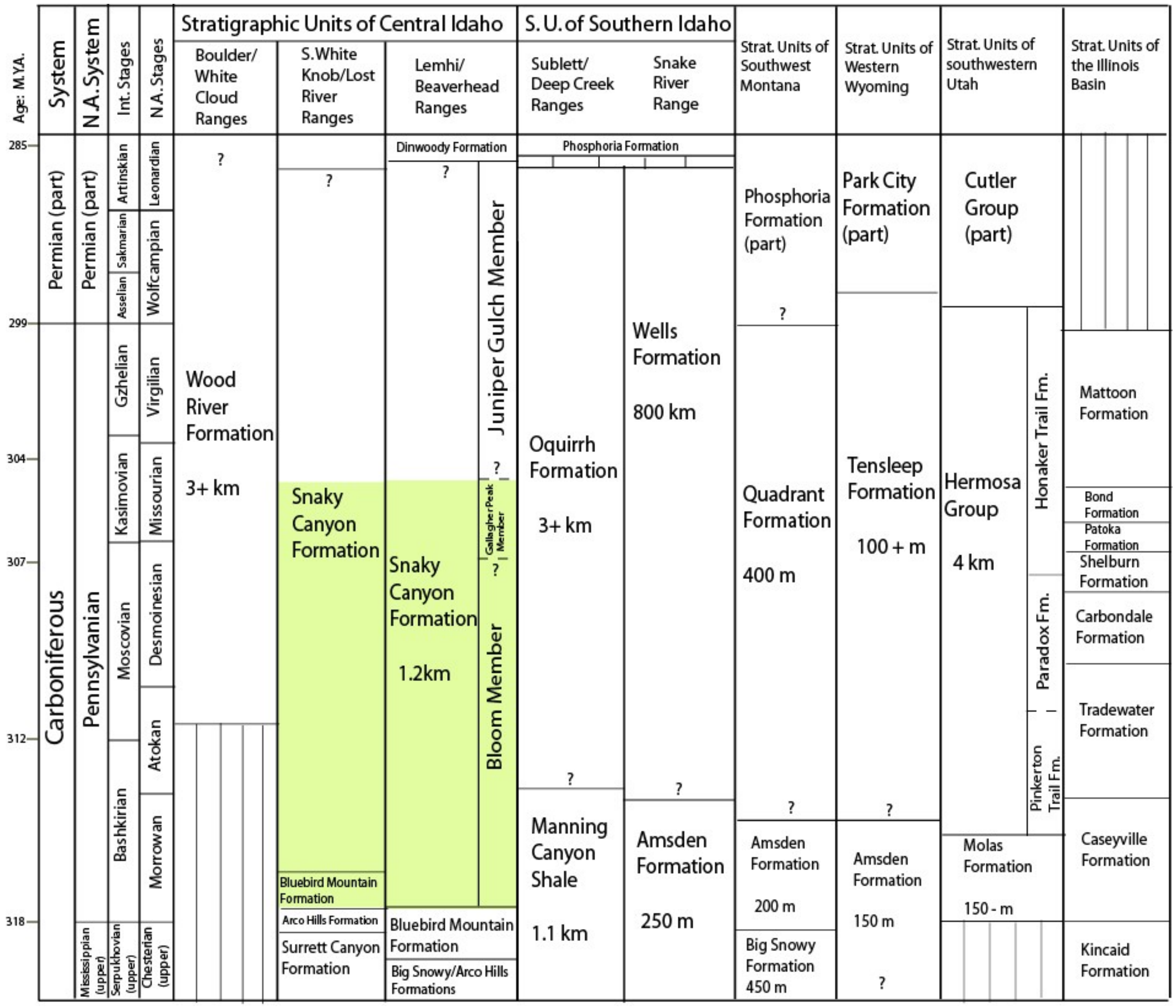


Figure 5: Upper Carboniferous regional and midcontinental Snaky Canyon Formation correlative stratigraphic rock units (from Bostwick, 1955; Scholten et al., 1955; Verville, 1957; Pierce, 1978; Skipp and Hall, 1980; Jacobson et al., 1985; Ritter et al., 2002; and Abplanalp et al., 2009). Stratigraphic positioning of the Snaky Canyon Formation based on limited biostratigraphic data by Skipp et al., 1979a, Groves, 1984; and Verville et al., 1990.

Paleotectonics and Structure

Late Devonian to Early Mississippian Antler Orogeny: Disruption of the Passive Margin

During the Middle to Late Devonian and into the Early Mississippian, the Antler Orogeny disrupted the passive margin of the western Cordillera in the United States. During this transition into a convergent (or transpressional) margin in the Late Devonian, Devonian and older Paleozoic strata were deformed along the continental margin and obducted eastward onto the continental craton (Poole and Sandberg, 1991; Isaacson et al., 2007). These allochthonous strata are referred to as the Roberts Mountains Allochthon and offer evidence of the area to the west of the continental margin. The timing of the transition from passive to active margin is clearly recorded by the stratigraphy, although a definitive thrust system (such as the Roberts Mountains Allochthon of Nevada) has not been clearly demonstrated in Idaho (Dover 1982; Isaacson et al., 2007).

The initiation of the Antler Orogeny is postulated from Nevada stratigraphic successions as a result of the partial closure of a deep marine marginal basin in response to plate subduction to the west of the basin (Burchfiel et al., 1992; Miller et al., 1992). Subduction may have developed an extensional or transtensional setting to the west of the continental margin that may have then spurred the orogenic event and generated a shift from passive to active margin (Miller et al., 1992; Poole and Sandberg, 1977; Isaacson et al., 2007). During this extensional period, it is interpreted that a marginal basin underwent partial closure and strata from within the basin was obducted onto the continental crust (Miller et al., 1992). This convergent deformation event initiated very little metamorphism or volcanic activity along the margin. Previous interpretations invoked a collision with an island arc complex (Poole and Sandberg, 1977; Speed and Sleep, 1982), but significant lack of volcanic debris and sediments within the obducted strata indicate basinal affinity (Burchfiel et al., 1992).

The obducted Devonian and older basinal, continental slope, and continental rise sediments of the Roberts Mountains Allochthon generated a highland and caused minor thrust faulting during the latest Devonian (Speed and Sleep, 1982; Burchfiel et al., 1992). This highland spread from Nevada to southern Idaho (now truncated by the Idaho Batholith) and emplacement of the allocthon upon the continental shelf and slope caused thrust loading and subsequent flexural downwarping (Speed and Sleep, 1982; Burchfiel et al., 1992; Link et al., 1996). This resultant downwarping formed a large foreland basin on the eastern side of the Antler Mountains that ran from southern Nevada to Idaho (Speed and Sleep, 1984; Miller et al., 1992; Burchfiel et al., 1992)(Figure 3). A deep, large and elongate trough formed in the western foreland basin adjacent to the highlands and received sediments shed from the adjacent Antler Mountains throughout the Carboniferous (Figures 3, 4, and 6). During the Early Mississippian, this flysch trough underwent further episodes of localized subsidence and to the east of the trough, starved basin facies are recorded (Poole, 1974). To the west of the highland and trough, continued extension aided in the creation of the deep water, forearc Havallah Basin (Burchfiel et al., 1992).

The Ancestral Rocky Mountains and Late Carboniferous Cratonic Margin

During the Pennsylvanian, the primarily east-vergent thrusting of the former Antler tectonic belt reactivated and resulted in the development of a Late Pennsylvanian foreland basin (Link et al., 2002)(Figures 4 and 6). This crustal loading was initiated at the same time as the creation of the Ancestral Rockies inboard of the western Laurentian cratonic margin and the development of Andean style subduction in what is now the southwestern United States (Geslin, 1998).

The subsidence of the Oquirrh/Wood River Basin was likely produced and amplified by the crustal loading that resulted from the reactivation of the Antler orogenic belt (Link et al., 2002)(Figures 4 and 6). Very limited biostratigraphic information indicates subsidence of the Wood River Basin greatly increased during the Desmoinesian and Virgilian (Mahoney, 1991). Evidence that supports this interpretation of reactivation during the creation of the Ancestral Rockies includes a succession of Middle to Upper Pennsylvanian coarsening upwards sequences that exceed a thickness of 3000+ meters in the Oquirrh/Wood River basins (Figure 4). During this time, the entire western margin of Laurentia was partitioned into restricted and regional basins that record successions of increased tectonic activity into the Pennsylvanian/Permian boundary (Geslin, 1998)(Figure 6). Beyond this time, the Antler orogenic highlands may have been controlled and reactivated by the encroachment of the Sonomian island arc (Dickinson, 2000).

Structure

Much of the Paleozoic strata in east-central Idaho has been transported eastward and northeastward as part of the Medicine Lodge thrust complex (Ruppel et al., 1978). Movement along this decollement surface shifted thick sequences of Paleozoic rocks as much as 160 km. eastward to their present locations juxtaposed against autochonous carbonates of southwestern Montana (Madison Group) (Skipp and Hall, 1980; Ruppel, 1978). This thrust faulting is postulated to have occurred between the Early Cretaceous and early Eocene, with resulting evidence in the form of imbricate thrust faulting and folding (asymmetrical and overturned) (Ruppel, 1978; Ruppel and Lopez, 1981).

During the middle Cenozoic, basin and range extensional tectonics modified the imbricate thrust sheets and created the current physiogeography of the region. This represents the northernmost extent of the Basin and Range associated extension and is responsible for the block style uplifts that mark the Lost River, Lemhi, and Beaverhead ranges of east-central Idaho (Cross, 1986; Miller et al., 1992). Several workers have noted that the change from tensional to extensional regime most likely caused the relaxation of the Cretaceous to Eocence thrust complexes as detachment faults (see Appendix IV: geologic map of the area). It has been postulated that this normal movement along preexisting thrust fault planes may have restored allocthonous Paleozoic strata to its general area of original deposition (Levy and Christie-Blick, 1989; Isaacson, pers. comm.).

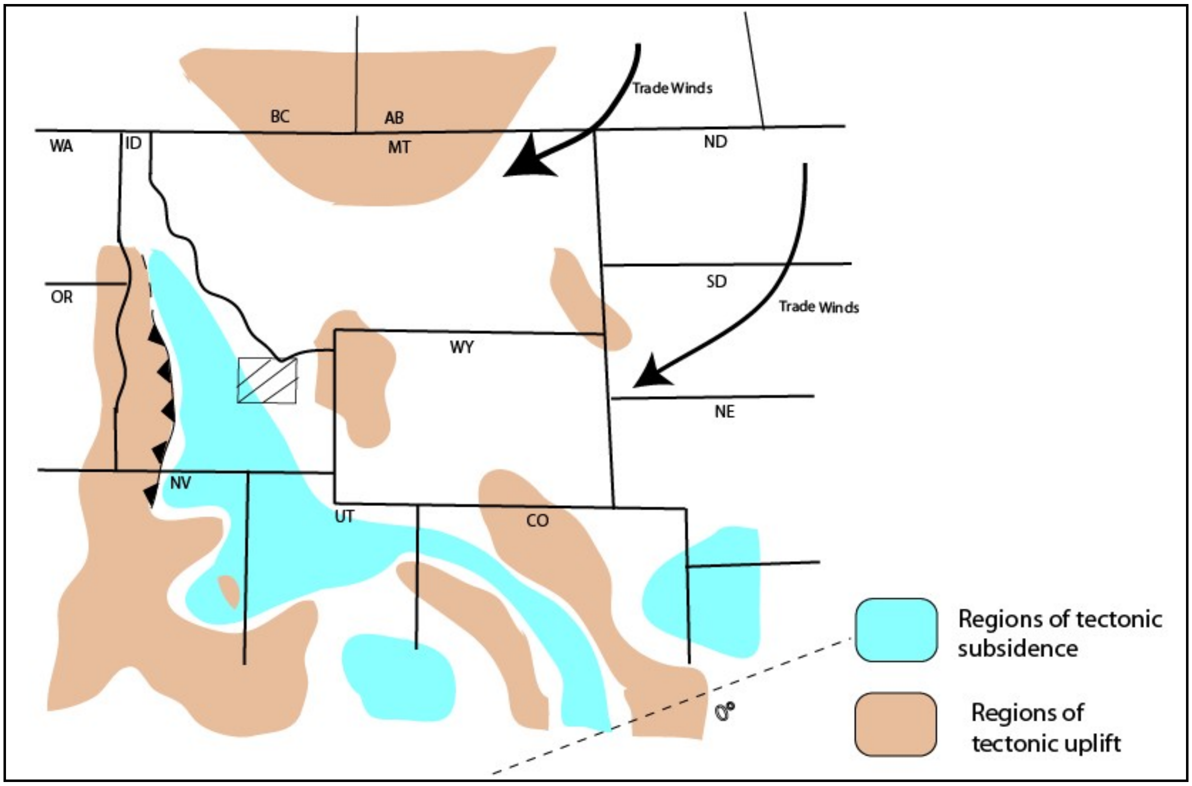


Figure 6: Middle Pennsylvanian (Desmoinesian) paleotectonic map of the inland northwestern United States. Note: Contemporaneous Ouachita-Marathon thrust belt to the southeast and active margin (Andean style or transpressional) to the southwest (From Geslin, 1998; Snyder et al., 1991; Kluth, 1998).

Chapter 4: Paleogeography: East-Central Idaho

Cambrian to Middle Devonian Paleogeography

The Early Paleozoic passive margin of the western United States first developed during the Late Pre-Cambrian. Around 850 million years ago, rifting to the west of the continental craton created and reshaped a new continental margin along western North America (Stewart, 1972). A second stage of rifting between 650 and 600 million years ago is postulated (from subsidence curves) to be the main rifting event that finalized the creation of the passive margin. This event is very similar to the formation of the eastern North American continental margin in the Mesozoic (Poole et al., 1992). Similar events are recorded along the northern margin of western North America, where a similar passive continental margin was created as a result of Late Proterozoic rifting (Fritz et al., 1992).

From the Cambrian to the Devonian, much of the passive margin of the western United States was covered by shallow marine seas. In the Cambrian, a broad shallow water shelf was confined along the western margin of the continental craton. To the east of the shelf, terrestrial land of the craton rose above sea-level and to the west of the shelf deep basinal facies are sparsely recorded (Stewart and Suczek, 1977). During this time, as with much of the Early Paleozoic, terrigenous deposits from the eastward cratonic land mass were trapped by the continental margin and reworked extensively (Poole and Sandberg, 1991).

From the Ordovician to the Early Devonian, the passive margin changed very little. During the Ordovician, a sea level rise (likely due to Taconic tectonic activity in the north-east part of the continent) inundated the shelf margin (Sheehan and Boucot, 1991). At the onset of the Middle to Late Devonian, the passive margin was beginning to transition into an active margin that greatly controlled Late Paleozoic paleogeography (Speed and Sleep, 1982; Poole and Sandberg, 1991; Isaacson et al., 2007).

Early Carboniferous (Mississippian) Paleogeography

The Early Mississippian is marked by (from west to east) the emplacement of the Antler Highlands, the formation of a foreland basin, and the development of a carbonate bank complex (Burchfiel et al., 1992; Link et al., 1996; Poole and Sandberg, 1977; Isaacson et al, 2007)(Figures 3, 7, and 8). The formation of the Antler Highlands and foreland basin is outlined in the preceding section and the carbonate bank complex is defined as a linear shelf margin (or reef) that developed along the western cratonic platfom throughout the Early Mississippian (Rose, 1976). During the Early Mississippian, this aggrading and prograding depositional complex of the cratonic platform and the foreland basin underwent periods of rapid episodic subsidence in response to vertical loading upon the elastic and unbroken continental plate (Dorobek, 1995; Link et al., 1996).

By the mid-Mississippian, tectonic activity had ceased along the continental margin of the Western United States. This return to a passive margin is possibly due to the termination of subduction westward of the craton (Speed and Sleep, 1982). The final result of the Antler orogenic event formed a deep trough and starved basin to the east of the area of uplift and further east, a carbonate platform developed in the Late Mississippian on a possible flexural forebulge (Poole and Sandberg, 1977)(Figures 3 and 7). During the Late Mississippian, thrust faulting is interpreted to have ended and the former Antler Highlands were completely eroded with sediment transport east into the flysch trough (Poole and Sandberg, 1977; Miller et al., 1992)(Figure 3).

Mississippian deposition within the foreland basin and carbonate bank can be divided into two distinct complexes (Rose, 1976). The first complex records deposition from the Kinderhookian to the early Meramecian. During this time subsidence within the flysch trough outpaced sedimentation, trapping Antler Highland derived sediments and creating a starved basin to the east (Link et al., 1996). At the same time, the marginal carbonate bank developed as a widespread and linear reef complex (Rose, 1976).

The second of Rose’s (1976) depositional complexes records deposition from the middle Meramecian to the Chesterian (Figure 3). At this time, sedimentation in the flysch trough outpaced subsidence. As a result, the trough quickly filled and sediments from the highland were transported further east into the former starved basin (Link et al., 1996). The upper depositional complex of the restricted to shallow marine carbonate bank records rapid growth and termination by siliciclastic influx at the close of the Mississippian. This upper buildup complex is interpreted to have prograded out and over the lower carbonate bank as eustatic sea level fell during the latest Chesterian.(Rose, 1976; Skip and Hall, 1980; Isaacson et al., 2007; Batt et al., 2008)(Figure 3).

To the southeast of the study area, strata in Idaho records carbonate bank deposition adjacent a proximal starved basin (Link et al., 1996). Little evidence of the Mississippian flysch trough and Antler Highlands is recorded in southeast Idaho, possibly due to truncation by the Snake

River Plain (Link et al., 1996; Skipp et al., 1979b). The early depositional complex of (Rose, 1976) is recorded by the restricted, mixed siliciclastic and carbonate facies of the Humbug and Deep Creek formations. The sediments of these units are interpreted to have originated from the craton, as the deep foreland trough would have likely trapped sediments from the west (Skipp et al., 1979b). By the upper complex of Rose (1976), siliciclastic deposition was replaced by carbonate bank facies of the Great Blue and Monroe Canyon limestones. These carbonate build-ups are regionally correlative with the upper build-up facies of the Chesterian strata of east-central Idaho (Skipp et al., 1979a; Poole and Sandberg, 1991; Link et al., 1996).

For a more detailed description of lower Carboniferous paleogeography of east-central Idaho, see Batt et al. (2008), Batt (2006), and figure 8.

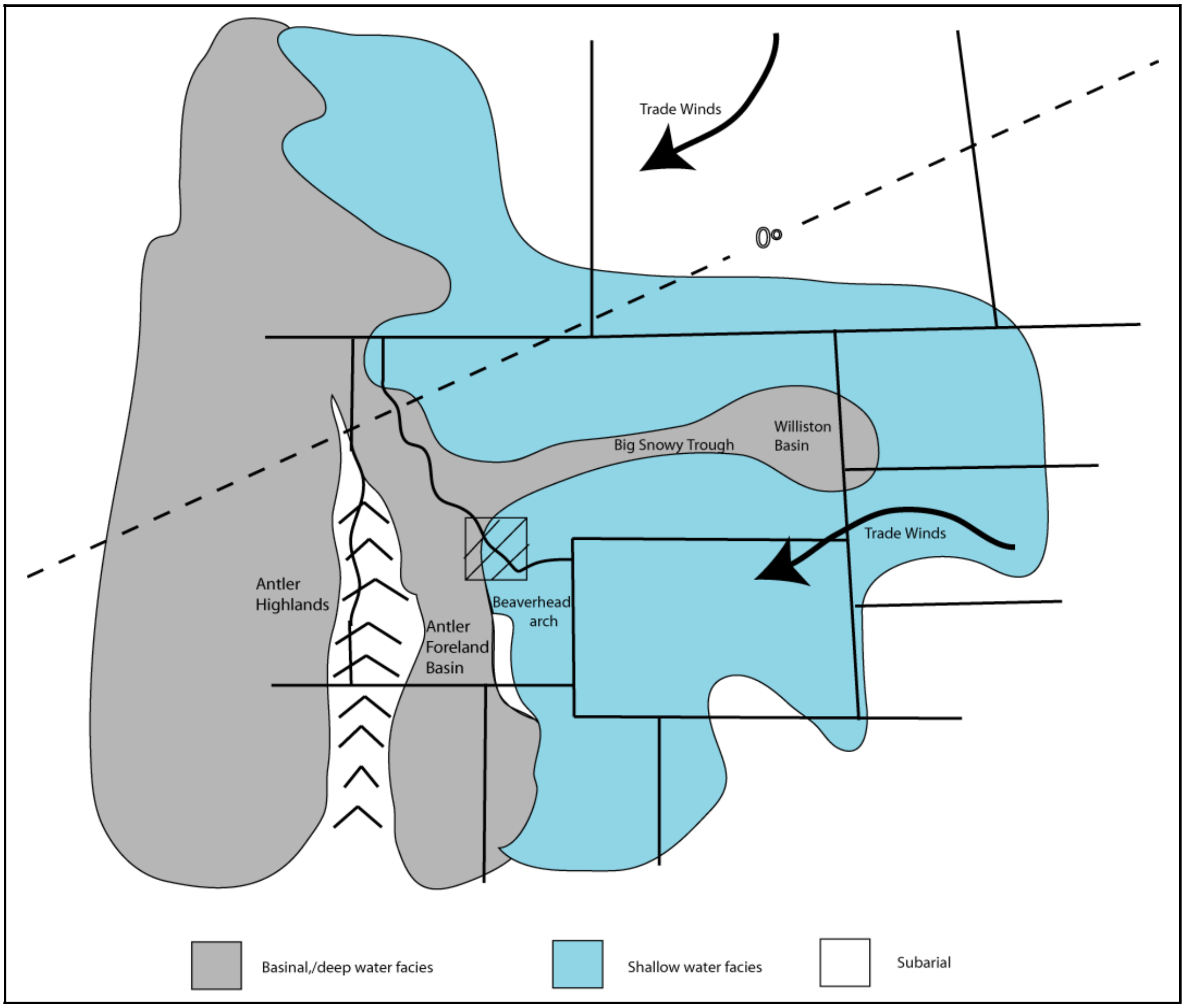


Figure 7: Structural features and paleogeography of the Antler foreland basin during the Chesterian (Late Mississippian) (From Brandley and Krause, 1997; Ross, 1991; and Butts, 2003).

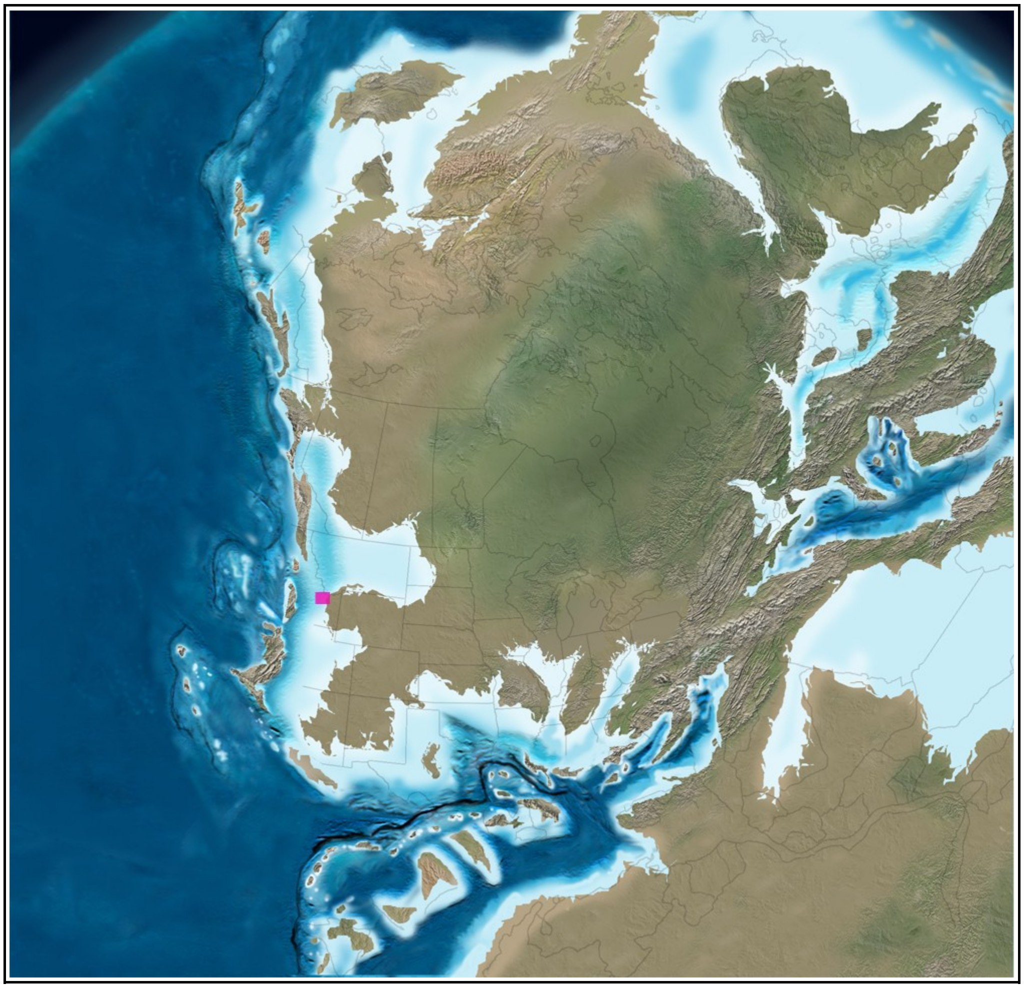


Figure 8: Late Mississippian global paleogeography. Purple box indicates region of study (From Blakey, 2011).

Late Carboniferous (Pennsylvanian) Paleogeography

Early Pennsylvanian (Morrowan to Atokan)

During the Pennsylvanian, the study area located in east-central Idaho was positioned on the western continental margin of Laurentia between 10° and 20° north latitude (Scotese et al., 2002; McKerrow and Scotese, 1990)(Figures 6,9, and 10). During this time, large-scale continental glaciation inundated the southern hemisphere and covered a large proportion of the

Gondwanaland supercontinent (Heckel, 1986; Isbell et al., 2003; Rygel et al., 2007a, 2007b; Grader et al., 2008; Batt et al, 2009).

The Early Pennsylvanian of east-central Idaho is characterized from west to east by the continued infilling of the Wood River Basin of terrigenous siliciclastics from the ancestral Antler Highlands and the continuous carbonate bank buildup along the shallow ramp cratonic margin of dominantly eustatically driven cyclic mixed carbonates and siliclastics (Skipp et al, 1979a; 1979b; Link et al., 2002). The Pennsylvanian strata of east-central Idaho have been grouped into two distinct depositional frameworks by previous workers. The Morrowan and Atokan (Early to early Middle Pennsylvanian) record paleotectonic conditions very similar to the end of the Mississippian (Chesterian). Within the area of study, deposition was dominated by sandy carbonates along the shallow marine epeiric outer cratonic margin (Skipp and Hall, 1980) (Figure 9). Conditions were generally open marine with minimal to moderate siliciclastic influence from the former Missippian flysch trough to the west to the cratonic margin just west of the present Idaho/Montana border. Areas to the east of the cratonic margin were flooded during this time and carbonate and mixed terrigenous sediments accumulated in restricted marine and lagoonal environments (Skipp and Hall, 1980; Sando, Gordon, and Dutro, 1975)(Figure 9).

The Early Pennsylvanian of southeast Idaho is recorded in the mixed siliciclastic and carbonate upper Amsden Formation and the lower part of the carbonate dominated Wells Formation (Figure 5). To the west of the carbonate bank, the upper Manning Canyon Shale and and lower part of the Oquirrh Formation record fine siliciclastic deposition proximinal to a shallow carbonate bank (Figure 5). Like coeval strata in east-central Idaho, deposition south of the Snake River plain during the Morrowan and Atokan reflects the paleotectonic setting inherited from the Upper Mississippian (Skipp and Hall, 1980; Link et al., 2002).

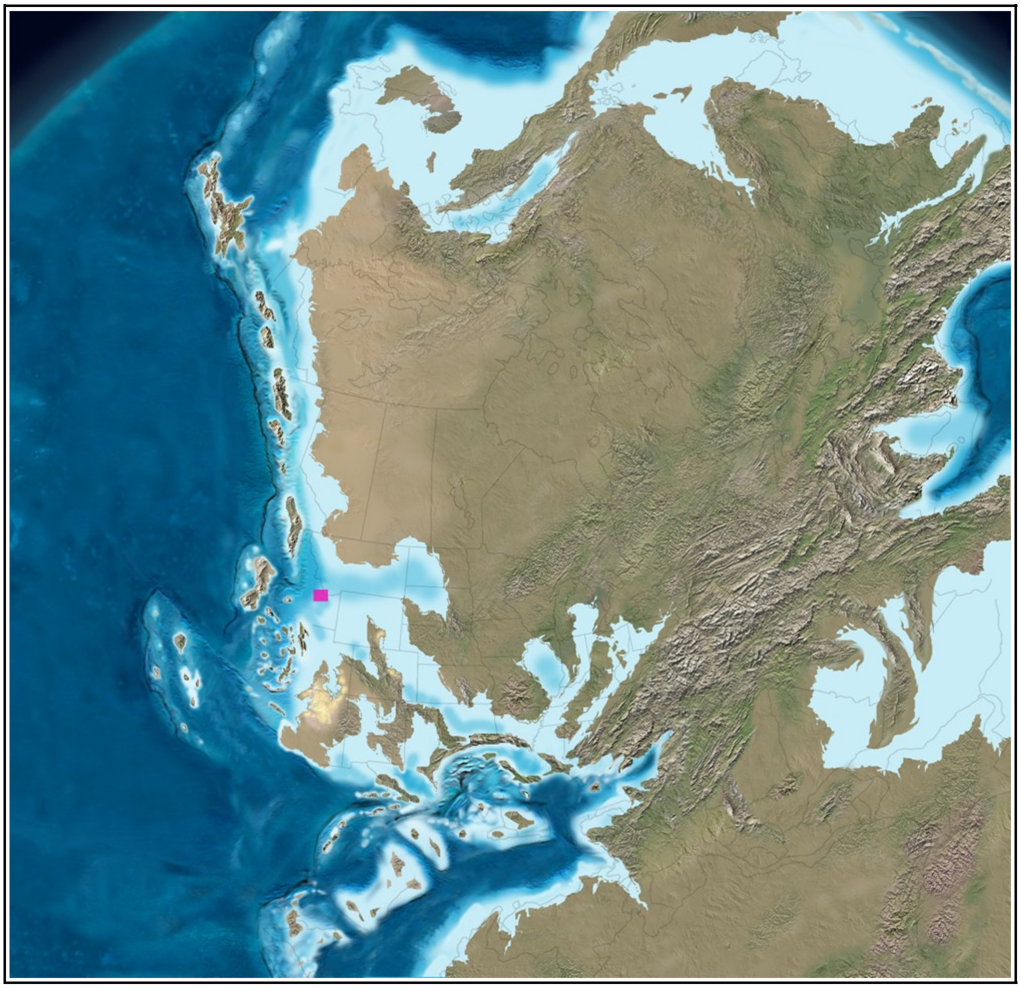


Figure 9: Early Pennsylvanian global paleogeography. Purple box indicates region of study (From Blakey, 2011).

Middle to Late Pennsylvanian (Desmoinesian to Virgilian)

During the Middle Pennsylvanian, it is postulated that the Copper Basin Highland arose to the west of the study area

(Figures 4, 6, and 11). This feature separated the former Antler Highland from the cratonic margin Snaky Canyon carbonate bank to the east (Skipp et al., 1979b; Skipp and Hall, 1980; Mahoney, 1991; Link et al., 2002)(Figure 10). Similar orogenic highs are also interpreted to have developed concurrently along the cratonic margin in Nevada (Humboldt Orogeny) and these also may have flanked the previous Antler Highlands (Ketner, 1977; Poole and Wardlaw, 1978)(Figure 11).

At the Atokan to Desmoinesian boundary, the tectonic setting that had characterized the area from the Middle Mississippian shifted. The former Antler Highlands were completely eroded and became submerged, causing Wood River sediments to become deposited above the former location of the highlands (Poole and Sandberg, 1990; Mahoney, 1991; Link et al., 2002). Block faulting and/or renewed thrusting within the former Mississippian flysch trough caused the formation of the Copper Basin Highlands to the west of the study area. This area of uplift provided coarse chert, quartz, and conglomeratic sediments to the areas immediately surrounding the highland and also protected the carbonate bank to the east from open ocean currents and circulation (Figures 6 and 10). Large amounts of medium to fine-grained quartz sand were also shed and can be traced south of the Snake River Plain (Skipp and Hall, 1980; Skipp et al., 1979a, 1979b; Mahoney, 1991; Link et al., 2002). Notable amounts of sand were deposited within the inner cratonic platform, although it is believed that these siliciclastics are believed to be of cratonic origin and originated from the Quadrant sand sea to the southeast, east, and northeast of the study area (Bissell, 1974; Hall et al., 1974; Canter and Isaacson, 1991; Saperstone and Ethridge, 1984)(Figures 10 and 11).

By the Late Pennsylvanian, high-amplitude glacially controlled eustatic fluctuations (see “Cyclothems” section in the proceeding text) dominated and subsequently controlled the depositional patterns along the western cratonic margin. These fluctuations caused intermittent emergence of the carbonate succession and resulted in the deposition of fine, aeolian sands (Skipp and Hall, 1980; Saperstone and Ethridge, 1984; Canter and Isaacson, 1991). Also during this time, massive carbonate buildups composed of hydrozoans and algae (*Palaeoaplysina*) formed in possibly restricted marine conditions within the units of study (Breuninger, 1971; 1976; Breuninger et al., 1989). By the close of the Carboniferous, the Copper Basin Highland continued to occupy the region between the restricted marine outer cratonic shelf to the east and the Wood River Basin to the west (Skipp and Hall, 1980; Link et al., 2002)(Figures 4, 6, and 10).

To the south of the Snake River Plain the thick Wells Formation, consisting of mixed siliciclastic and carbonate deposits, formed along the cratonic margin. To the west of the shelf, deposition of fine-grained calcareous and noncalcareous Oquirrh Formation sandstones occurred in the rapidly subsiding Sublett Basin (Figure 5). Intervals of coarse pebble conglomerates within the Oquirrh were likely shed into the Sublett Basin from the reactivated Copper Basin Highlands to the north (Skipp and Hall, 1980; Mahoney, 1991).

Paleogeographic elements of the Snaky Canyon carbonate bank are unknown to the north of east-central Idaho due to the lack of exposed Pennsylvanian age strata. To the south, the relation between the Snaky Canyon Formation and correlative upper Carboniferous units is obscured by the massive sequence of Tertiary Snake River Plain volcanics.

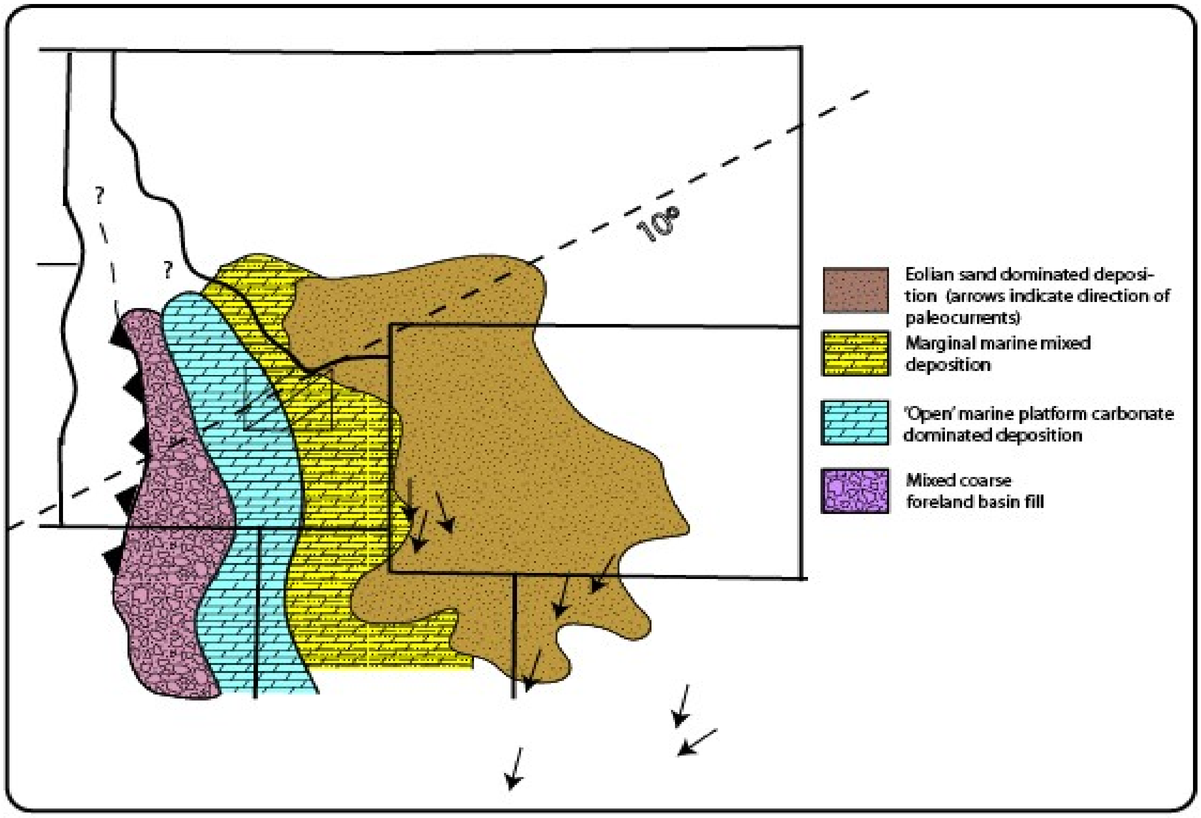


Figure 10: Middle Pennsylvanian (Desmoinesian) depositional facies (From Sando et al., 1975; Sappington and Ethridge, 1984; and Geslin, 1998).

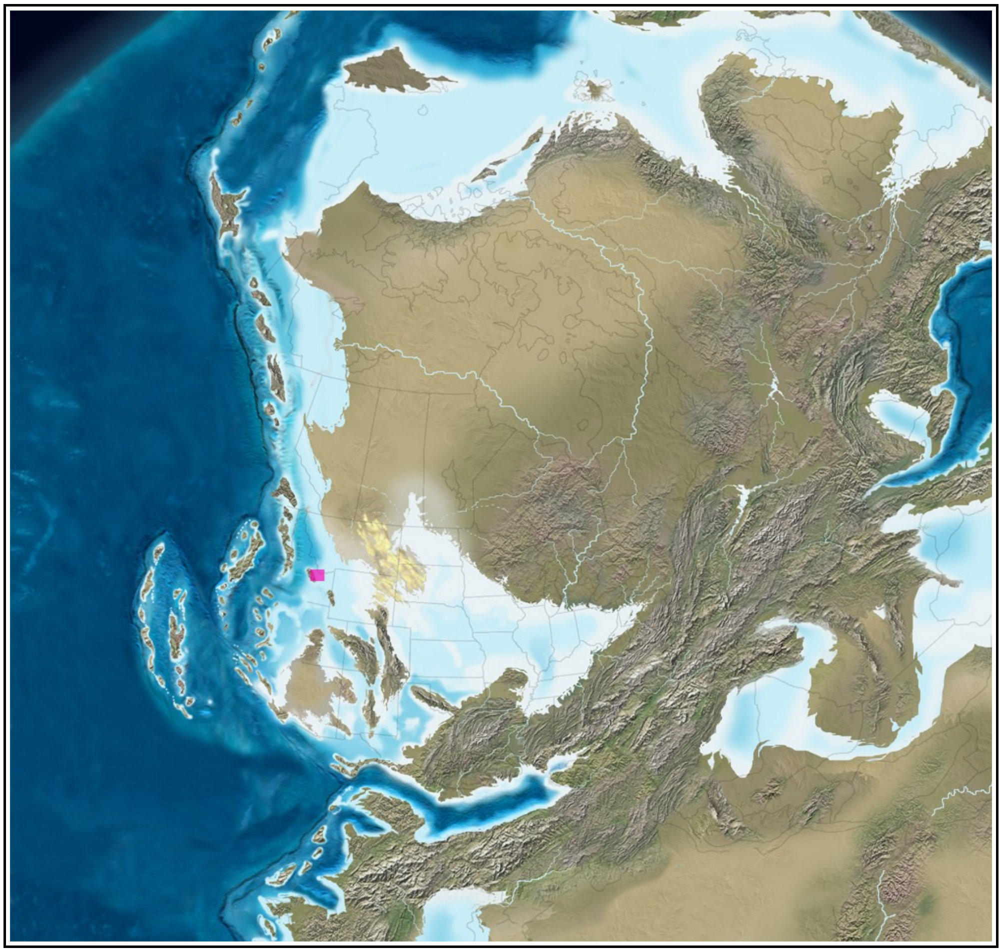


Figure 11: Late Pennsylvanian global paleogeography. Purple box indicates region of study (From Blakey, 2011).

Early Permian (Wolfcampian) Paleogeography

Within the area of study, Permian rocks gradationally overlie the cratonic margin sediments of the Pennsylvanian system. Near the location of the ancestral Copper Basin Highland, no Permian age rocks are present and to the east of the study area, Permian Phosphoria Formation sediments unconformably overlie Pennsylvanian Quadrant Formation sediments (Skipp and Hall, 1980). Very little of the Permian rock record exists within or near the study area. What is recorded is interpreted from float along the eastern

Beaverhead Mountains and likely represents the lowermost transitional Dinwoody Formation at the basal Permian(Skipp, 1979a; Abplanalp et al., 2008).

Previous workers (Skipp et al., 1979a; Canter and Isaacson, 1991) have placed the Pennsylvanian/Permian boundary within the upper limits of the Juniper Gulch Member, although very limited biostratigraphic data exists to support this interpretation (see the discussion on previous biostratigraphic studies located in the following text). It is believed that a mixed marine carbonate/siliciclastic system continued into the Early Permian along the eastern cratonic shelf. To the west of the shallow marine shelf, the outer cratonic shelf/basin margin Copper Basin Highland may have expanded and most likely kept supplying sediments into the restricted western marine basin (Wood River Basin) (Skipp and Hall, 1980; Link et al., 2002)(Figure 12).

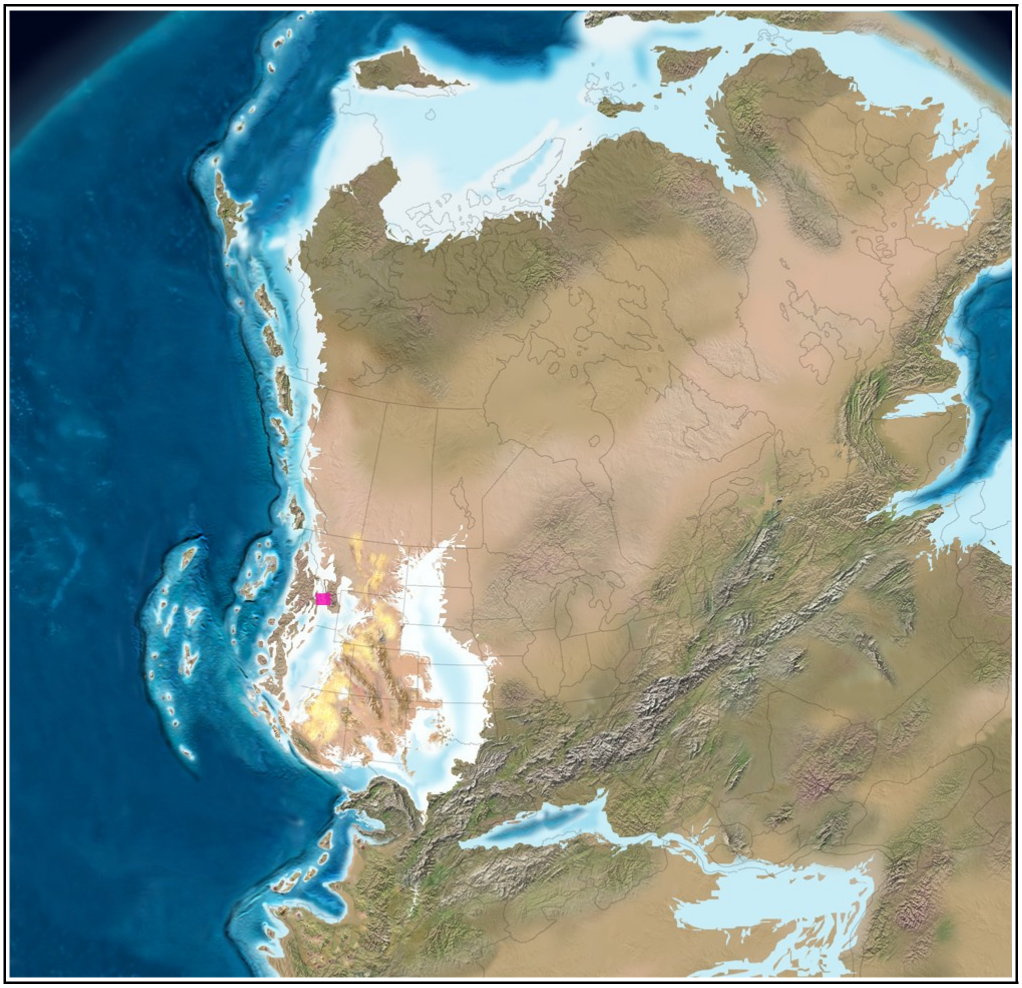


Figure 12: Early Permian global paleogeography. Purple box indicates region of study (From Blakey, 2011).

Chapter 5: Previous Work

Previous Work: Snaky Canyon Formation

The Snaky Canyon Formation has been mapped, interpreted, and described in east-central Idaho by several prominent workers. Most notable of these investigators is Betty Skipp, who along with R.D. Hoggan, D.L Schleicher, and R.C. Douglass first named, subdivided, and described the rock units in their 1979(a) publication that reported on the Carboniferous carbonate bank of the Basin and Range province of east-central Idaho. Further publications (Skipp, Sando, and Hall, 1979b; Skipp and Hall, 1980; Tremblay, 1996; Archuleta, 2004; Archuleta et al., 2006; Batt, 2006; Batt et al., 2008) reconstructed Idaho Carboniferous paleogeography and identified mechanisms controlling deposition.

Succeeding workers have measured numerous sections and attempted to correlate the Snaky Canyon across the Lost River, Lemhi, and Beaverhead ranges of east-central Idaho (Figure 2). Canter (1984) and Canter and Isaacson (1991) investigated the Juniper Gulch Member and identified five dominant carbonate facies. These works established a paleogeographic setting for the Juniper Gulch Member and recognized the depositional cyclicity of the unit. Tremblay (1996) used six closely spaced measured sections in the southern Lemhi range to correlate individual sequences and define reoccurring depositional facies of the Juniper Gulch Member. Archuleta (2004) measured and described four measured sections of the Juniper Gulch Member from the Lost River, Lemhi, and Beaverhead ranges. Her work focused on defining systems tracts facies and correlating the 2nd order to cyclothem scale sequences of the rock unit. Rankey (1996, 1997) also briefly defined and interpreted the Upper Pennsylvanian cyclothems of the Snaky Canyon Formation and compared them to those of the U.S. midcontinent in order to determine the effect of provincial and regional processes on the global eustatic stratigraphic record.

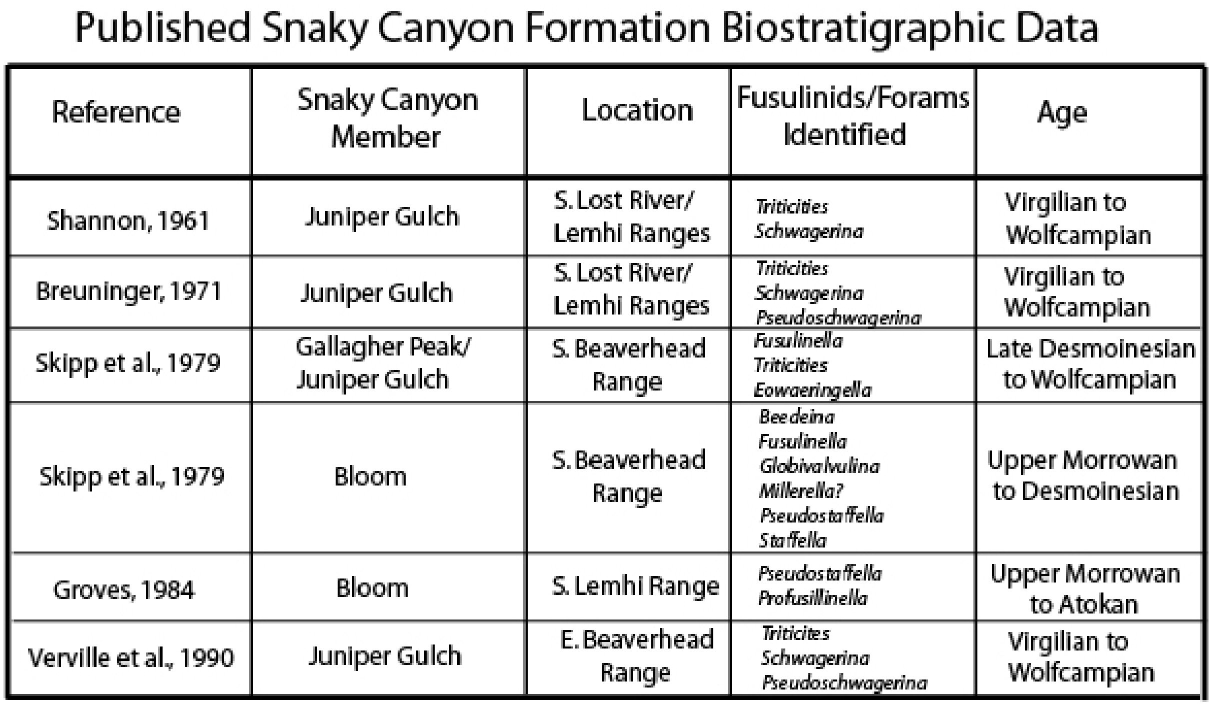
The reef-forming biota of the upper Juniper Gulch Member in the Lost River and Lemhi ranges were first described by R.H. Breuninger (1971, 1976; Breuninger et al., 1989). These works identified the geometry and occurrences of the enigmatic *Palaeoaplysina* and phylloid algal buildups. Later workers (Canter, 1984; Canter and Isaacson, 1991) described and identified similar buildup sequences from a section of the Juniper Gulch Member near Howe, Idaho along the eastern flanks of the Lemhi Range.

Other than the initial investigation of the Snaky Canyon Formation by Skipp et al., (1979a), very little work has been conducted on the Bloom Member or the Gallagher Peak Member. Skipp et al.'s (1979a) and Groves' (1984) preliminary fusulinid biostratigraphy represents the only attempt at dating the Bloom and Gallagher Peak members of the Snaky Canyon Formation.

Pennsylvanian Snaky Canyon Biostratigraphy

There have been no published high-resolution studies reporting on the occurrence of conodonts from the Snaky Canyon Formation of east-central Idaho. In her thesis, B. Archuleta (2004) reported that preliminary conodonts recovered from selected intervals of the four measured sections of the Juniper Gulch Member investigated may indicate a Morrowan to Desmoinesian age. This study was preliminary and in order to be conclusive, increased investigation was stated to be necessary (Archuleta, 2004; Webster, pers. comm.). No other investigations have recovered conodonts from the Snaky Canyon Formation.

Several workers have established a limited biostratigraphic framework for the Snaky Canyon Formation based on foraminifera. Shannon (1961) and Breuninger (1971) first described Virgilian to Wolfcampian (Upper Pennsylvanian to Lower Permian) fusulinids from the upper Juniper Gulch Member in the southern Lost River and Lemhi ranges. In 1984(a) and 1986, J.R. Groves reported on foraminifera from the lower Bloom Member. His studies determined that the Bloom Member of the southern Lemhi Range extended above the Morrow/Atokan stage boundary. In the Beaverhead Range, Skipp (1979a) reported on foraminifera of late Desmoinesian to Missourian age from the Gallagher Peak and lower Juniper Gulch Members. Verville et al. (1990) added to Skipp's initial report and identified Upper Pennsylvanian fusulinids from the Juniper Gulch Member near the Morrison Lake area in the Beaverhead Range at the Montana/Idaho border. See Figure 13 for a complete description of these studies, including location and age indicative fauna identified.



Published Snaky Canyon Formation Biostratigraphic Data

Reference	Snaky Canyon Member	Location	Fusulinids/Forams Identified	Age
Shannon, 1961	Juniper Gulch	S. Lost River/ Lemhi Ranges	*Triticities* *Schwagerina*	Virgilian to Wolfcampian
Breuninger, 1971	Juniper Gulch	S. Lost River/ Lemhi Ranges	*Triticities* *Schwagerina* *Pseudoschwagerina*	Virgilian to Wolfcampian
Skipp et al., 1979	Gallagher Peak/ Juniper Gulch	S. Beaverhead Range	*Fusulinella* *Triticities* *Eowaeringella*	Late Desmoinesian to Wolfcampian
Skipp et al., 1979	Bloom	S. Beaverhead Range	*Beedeina* *Fusulinella* *Globivalvulina* *Millerella?* *Pseudostaffella* *Staffella*	Upper Morrowan to Desmoinesian
Groves, 1984	Bloom	S. Lemhi Range	*Pseudostaffella* *Profusillinella*	Upper Morrowan to Atokan
Verville et al., 1990	Juniper Gulch	E. Beaverhead Range	*Triticites* *Schwagerina* *Pseudoschwagerina*	Virgilian to Wolfcampian

Figure 13: Published biostratigraphic data from the Snaky Canyon Formation.

Pennsylvanian Conodont Biostratigraphy:

A multitude of workers have reported on the biostratigraphic occurrences of conodonts within the middle to upper Carboniferous. In the western United States studies that have defined conodont ranges and biozonation frameworks for the mid-upper Carboniferous include (earliest to most recent): Murray and Chronic (1965), Dunn (1966), Webster (1969), Dunn (1970a), Dunn (1970b), Dunn (1971), Dunn (1976), Webster (1984), Baesemann and Lane (1985), Davis and Webster (1985), Savage and Barkeley (1985), Morrow and Webster (1992), Krumhardt et al. (1996), Titus et al. (1997), Ritter et al. (2002), Keairnes et al. (2003), Abplanalp (2006), and Abplanalp et al. (2009). Studies conducted in the midcontinent of the United States include: Gunnell (1931), Stauffer and Plummer (1932), Gunnell (1933), Harris and

Hollingsworth (1933), Jones (1941), Ellison (1941), Merrill (1962), Lane (1967), Straka and Lane (1970), Thompson (1970), Merrill and King (1971), Lane et al. (1971), Lane et al. (1972), von Bitter (1972), Merrill (1973), Baesemann (1973), Lane and Straka (1974), Merrill (1975), Heckel and Baesemann (1975), Merrill and von Bitter (1976), Merrill and Martin (1976), Lane (1977), Landing and Wardlaw (1981), Lane and Baesemann (1982), Grubbs (1984), Merrill et al. (1987), Barrick et al. (1989), Grayson et al. (1989), Boardman et al. (1991), Lambert and Heckel (1991), Lambert (1992), Ritter (1994), Heckel (1994), Ritter (1995), Barrick and Boardman (1989), Barrick et al. (1996), Barrick and Lambert (1999), Barrick and Walsh (1999), Barrick et al. (1999), Heckel (2002), Lambert and Heckel (2002), Lambert et al. (2003), Barrick et al. 2004), Roscoe (2005), and Roscoe (2008). In the eastern United States: Globensky (1967), Rhodes et al. (1969), Merrill (1972), Merrill and Wentland (1994). Notable studies conducted in Europe include that of Higgins (1975), who investigated a carbonate succession in Northern England as well as Mendez (2006), who published a paper reporting on a upper Carboniferous succession of conodonts recovered from the mountains of northern Spain. See Figure 14 for Pennsylvanian conodont biozones defined nationally and globally.

Several workers have reported on the occurrence of conodonts in the Donets Basin and Eastern Europe. Kosenko (1975), Kozitskaya et al. (1978), and Barskov et al. (1979) first described Carboniferous conodonts from this region. Barskov et al. (1981) and Chernykh and Ritter (1997) defined boundary intervals of the Donets Basin based on conodont biostratigraphy. Groves et al. (1999), Nemirovska and Kozitska (1999), Nemirovska (1999), Nemirovska et al. (1999), Ekmekci and Kozur (1999), and Heckel et al. (2007) established a truly cosmopolitan assemblage of upper Carboniferous conodonts by correlating biota from the midcontinent of the United States to that of the Donets Basin. See Figure 14 for internationally recognized conodont biozones established by these workers.

Most recently, workers have utilized conodonts in the construction and application of sequence biostratigraphy and isotopic chemostratigraphy. Sequence biostratigraphy is a concept first identified by Loutit et al. (1991) and Posamentier and Goodman (1992) and states that definable biologic assemblages may be used to correlate individual stratigraphic cycles. Students of the conodont have recently attempted to correlate high amplitude glacio-eustatic cycles of Pennsylvanian strata from the Paradox Basin in Utah to those of the midcontinent (Ritter et al., 2002). This concept is further investigated and discussed in the following text.

Chemostratigraphic studies have utilized the stable apatitic chemistry of conodont elements in order to extract isotopic values for oxygen and strontium. It is believed that the carbonate-fluorapatite elements of the conodonts have a very high potential to preserve the primary isotopic values of original sea water due to their dense structure and high crystallinity value (Kolodny et al., 1983; Puceat et al., 2004; Joachimski et al., 2006). Notable Studies reporting on the utility of conodonts as a recorder of sea-level fluctuations and climate change through isotopic analysis include Joachimski and Buggisch (2002), Puceat et al. (2004), Joachimski et al. (2006), Buggisch et al. (2008), Elrick et al. (2009), Zigaite et al. (2009), Rigo and Joachimski (2010), and Wheeley et al. (2012).

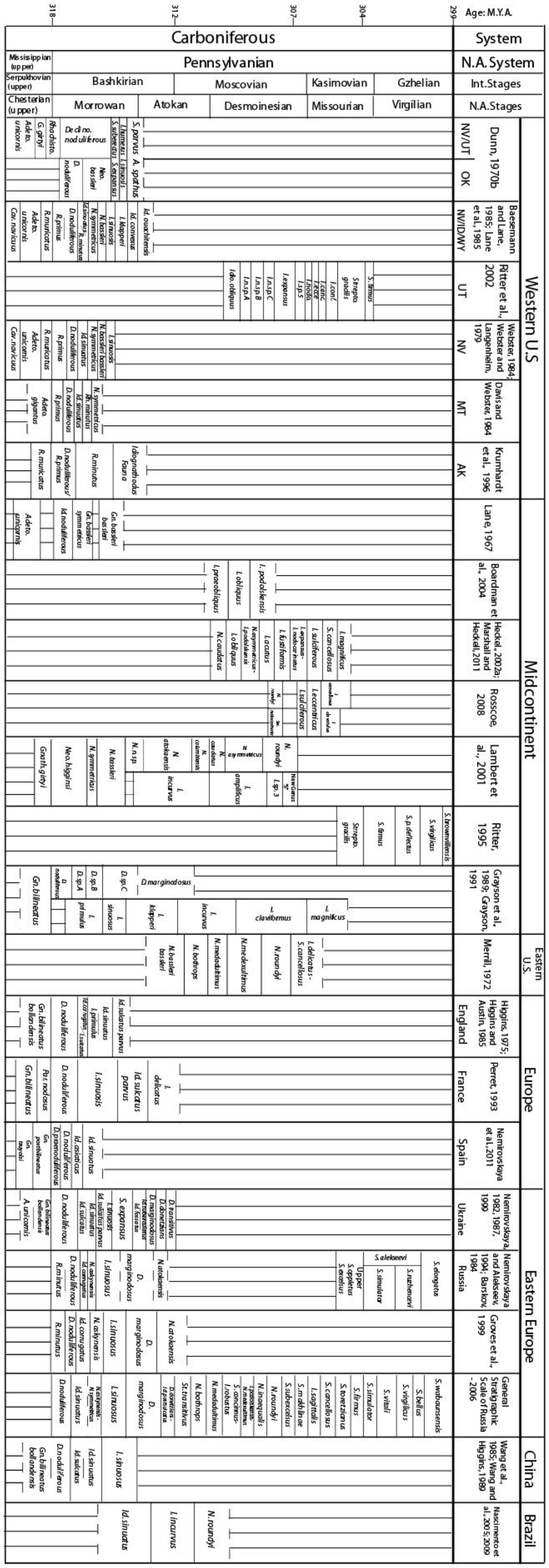


Figure 14: Domestic and international Pennsylvanian conodont biozones identified by previous workers.

Chapter 6: Methods and Procedures

In this study, eight sections of the upper Carboniferous Snaky Canyon Formation were measured, described, and sampled for biostratigraphic analysis during the summers of 2007, 2008, and 2009 (Figure 15). These sections are described along a west to east transect in the Basin and Range province of east-central Idaho (Appendices I, II, and VI). Mountain ranges investigated (from west to east) in study include the White Knob, Lost River, Lemhi, and Beaverhead ranges (Figure 15).

Field descriptions of these formations and sections include the lithologic classification based on Dunham (1962) and later modified by Embry and Klovan (1971). Each measured section was described in detail at a bed-by-bed scale and important characteristics such as lithology, bedding thicknesses and internal structure, lateral continuity, sequence stratigrahical surfaces (flooding surfaces and erosional surfaces), megafaunal assemblages, grain type, sorting, and color were recorded and noted in order to achieve a greater understanding of the depositional framework of the Snaky Canyon Formation. See Appendix I for the complete measured sections of each locality investigated.

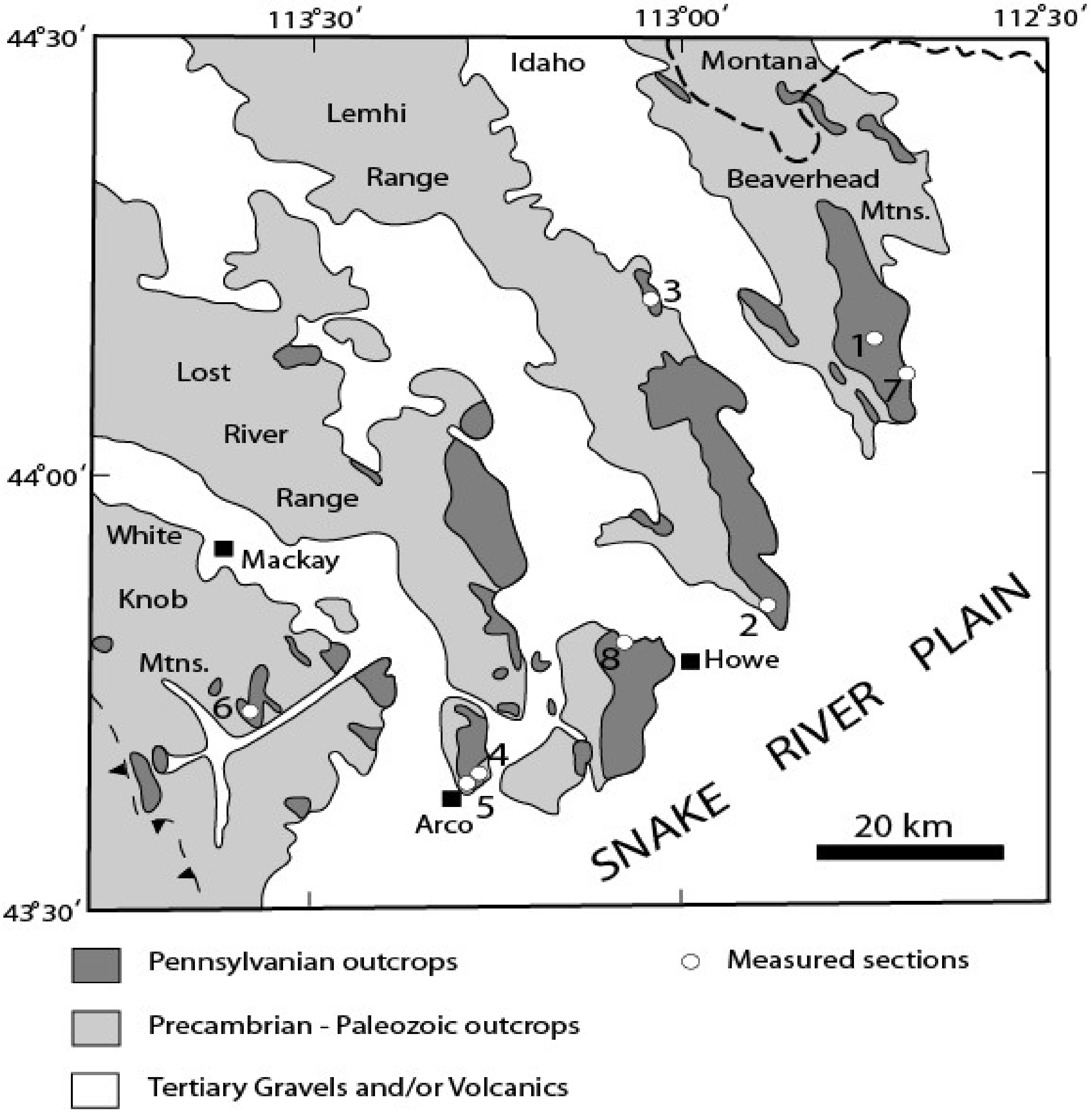


Figure 15: Locations of the measured sections of the Pennsylvanian Snaky Canyon Formation biostratigraphically analyzed.

Conodont biostratigraphic samples were generally taken every 5 to 15 meters within each section (Appendix II). Conodont outcrop sampling frequency for biostratigraphic analysis is predominately determined by stratigraphic position, outcrop availability, and lithology. Lithologies representing relatively moderate to low energies, with high in-situ or locally transported faunal content (including bryozoans, brachiopods, and mollusks), produce more complete and better preserved conodont assemblages than high energy, well sorted packstones or grainstones. These lithologies generally yield poor conodont assemblages due to heavy abrasion and hydraulic sorting of the conodont elements. Flooding surfaces (mfs) and high-energy carbonates from the absolute basal members of individual 4th order sequences were generally avoided when sampling in order to eliminate the potential for condensed assemblage and reworked assemblage recovery. See Appendix II for the complete measured sections with conodont recovery data for each of the localities investigated.

For each sample, at least 2 kilograms of rock were taken and labeled for further analysis in order to permit multiple episodes of processing if additional specimens are required for interpretation. The following guidelines and steps outline the procedure utilized for the recovery and concentration of conodonts in this study (see figures 16 and 17):

1) Recovery/Extraction of Conodonts:

   a. Cleanly crush exactly one kilogram of each rock sample into one to two centimeter fragments for acid digestion. Methods include the utilization of jaw crushers set to produce larger aggregate and hand crushing using a hammer and plate.

   b. Rinse crushed sample in water through a very coarse (20 mesh) sieve to remove small rock chips and any carbonate dust coating rock fragments (promotes rapid digestion, conserves expensive acidic digestion solution, and may further diminish the risk of cross-contamination).

c. Place one kilogram samples into ten liter buckets for acid digestion. For this study, formic acid (90%) is employed at a ratio of around 11:1 with water. These samples are initially run for 24 hours in the solution.

d. After initial digestion, insoluble residues are washed through a combined 20 and 200 mesh sieve. Insoluble residues caught in the 200 mesh sieve is thoroughly washed, then dried and processed for concentration of conodonts (see part 2 below). Material retained in the 20 mesh sieve is examined for megafauna and then should be run to completion (repeat step c above until acid/water mixture is neutralized).

2) Concentration of Conodonts:

a. The dried residue recovered from the 200 mesh sieve is first gently dry sieved in a 200 mesh sieve to remove any excess dust particles.

b. Dependent on the quantity of insoluble grains, the sample may be directly picked if few grains are recovered (see part d below) or may be floated in a heavy liquid if grains are great in quantity. For heavy liquid separation, sodium polytungstate is employed at a density of 2.75 g/ml. Insoluble grains are added to the sodium polytungstate in a funnel, stirred, and allowed to separate for around 30 minutes. Heavy fractions are then filtered out and dried for conodont picking (see part d below).

c. If the amount of heavy constituents (including apatite, iron oxides, metal sulfides, etc.) recovered from heavy liquid separation is great, magnetic separation may be employed to remove the magnetic iron-based constituents.

d. The non-magnetic and heavy (greater than 2.75g/ml) residues are now picked for conodonts with the use of a very fine paintbrush and binocular microscope. Conodont elements are mounted on block gridded slides and recorded for identification.

e. Throughout the process, attention to cleanliness is necessary to avoid the potential for contamination.

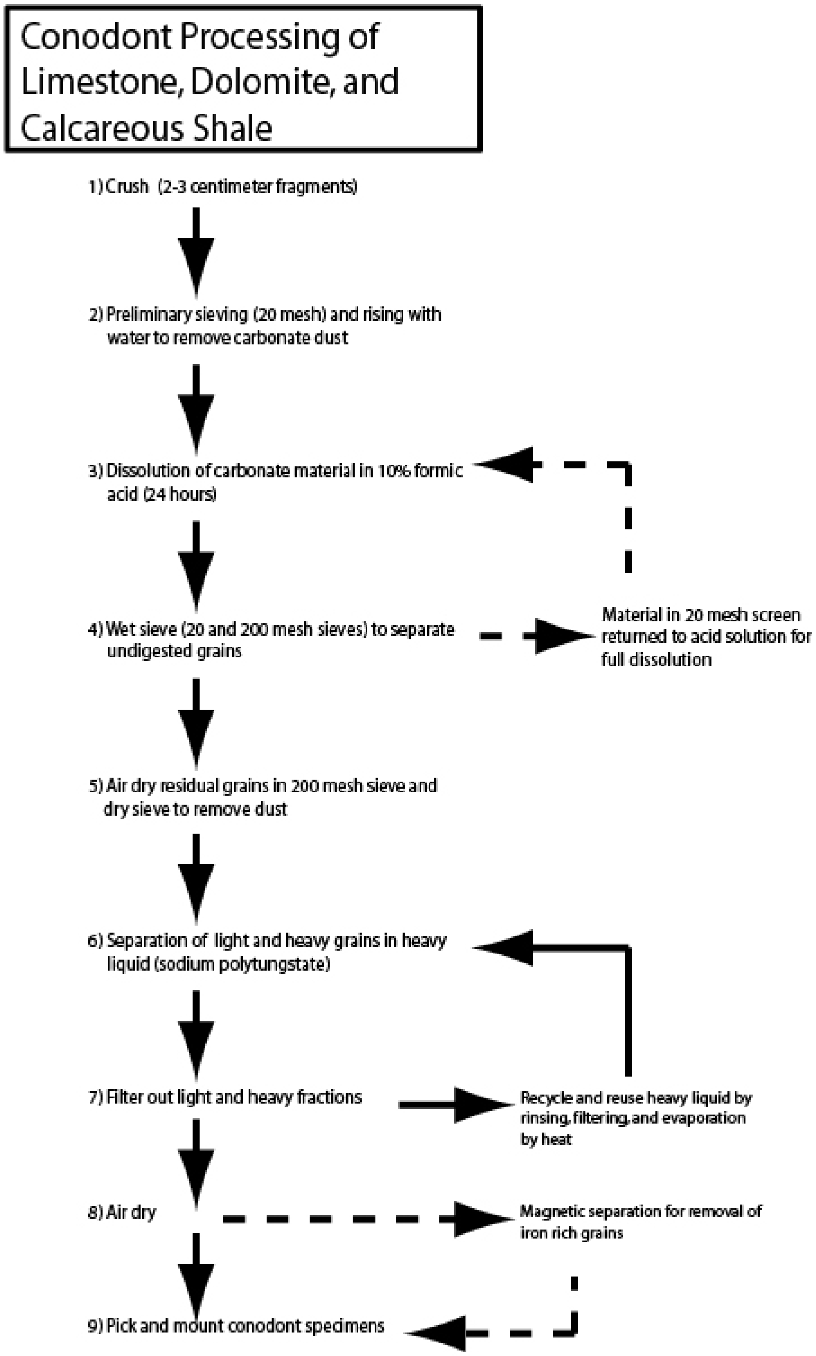


Figure 16: Sequence of laboratory procedures and processes used in the disaggregation and dissolution of carbonate based sedimentary rocks and the separation of conodont elements from the undigested grains recovered (adapted from Collinson, 1964).

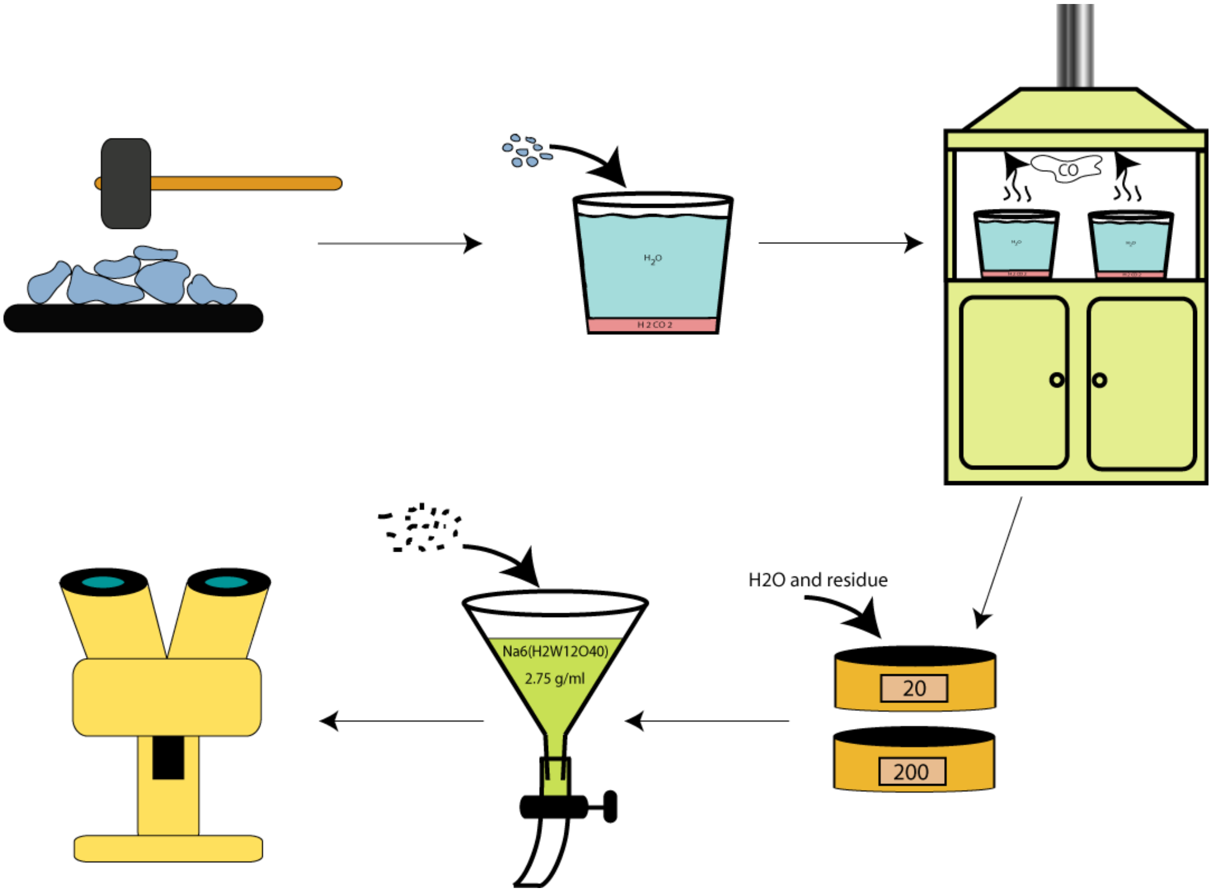


Figure 17: A pictorial outline of the steps necessary to extract and condense carbonate samples for conodonts. For further guidelines, see Figure 16.

Chapter 7: Depositional Setting

The Snaky Canyon Formation records a thick succession of Lower Pennsylvanian to Lower Permian interbedded carbonates and siliciclastics deposited in deep subtidal to peritidal nearshore environments (Skipp et al., 1979a/b, Canter and Isaacson, 1991, Tremblay, 1996; Archuleta, 2004; Archuleta et al., 2006). The carbonates are primarily thin to medium bedded, of a light blue to light gray color, and often record siliciclastic input. The thin siliciclastic beds are calcareous, often very fine to fine grained, and are gray to light brown in color. Nodular chert is abundant in the carbonates and may comprise upwards of 40% of the volume of individual beds (Skipp et al., 1979a). Sedimentary structures common in the Snaky Canyon Formation include cross-bedding and lamination of siliciclastics, carbonate hard grounds, solution lamellae, salt casts, bioturbation, symmetrical ripple marks, and rip-up intraclasts (Skipp et al., 1979a/b, Canter and Isaacson, 1991, Tremblay, 1996; Archuleta, 2004).

This stratigraphic succession contains a diverse and rich marine biota comprised of echinoderms, bryozoans, brachiopods, corals, fusulinids and conodonts that are indicative of a normal marine depositional setting (Skipp et al., 1979a; Canter, 1984). Rare stratigraphic occurrences of stromatolites near the base and *Palaeoaplysina* algae near the top of the formation are recorded from specific localities and may indicate restricted deposition (Breuninger, 1976). Upwards in the formation, open marine fauna becomes less abundant and algal buildups increase in frequency (Breuninger, 1976; Skipp et al., 1979a).

The depositional setting of east-central Idaho during the

Morrowan to early Atokan was inherited from the Late Mississippian. At this time, deposition occurred along a shallow marine continental margin within a generally open foreland basin (Skipp and Hall, 1980). The siliciclastic influence on carbonate bank during this time is of likely eolian origin from the Quadrant sand sea to the east (Saperstone and Ethridge, 1984). For a full description of the Late Mississippian depositional setting for the region, see the dissertation of Batt (2007).

By the Desmoinesian, the depositional and tectonic setting drastically changed. To the west of the Snaky Canyon carbonate bank, the Copper Basin Highlands became emergent and began contributing sediment to the eastern carbonate complex (Skipp and Hall, 1980). In the White Knob Mountains to the west, carbonate and siliciclastic beds of the Snaky Canyon Formation deposited around this time contain abundant coarse, angular sand and rounded quartz pebble conglomeratic intervals (Skipp et al., 1979a; Canter and Isaacson, 1991). At the same time, siliciclastic input may have been sourced from the continental craton to the east (Figure 10). The uplift of the Copper Basin Highlands also caused the once open-marine foreland basin to become partitioned and restricted (Geslin, 1998)(Figure 6).

Depositional Facies

Canter and Isaacson (1991) identified five carbonate facies from the Juniper Gulch Member of east-central Idaho. These depositional facies are the carbonate shoal, carbonate buildup, lagoon, restricted platform/peritidal, and supratidal/marginal marine facies. When stacked in the order presented, these facies create an idealized carbonate dominated depositional cycle for the member. The basal carbonate shoal facies of these depositional cycles are composed of skeletal and peloidal packstones and grainstones, often containing a large echinoderm component. The carbonate buildup and lagoonal depositional facies of Canter and Isaacson (1991) were characterized by the whole megafaunal (brachiopod and bryozoan dominated) wackestones and biosturbated packestones (Breuninger et al., 1989). The restricted inner platform facies is characterized by sandy to dolomitic beds containing abraded bioclastic material, intraclasts, and coated grains. The supratidal/marginal marine facies is distinguished by the presence of stromatolitic boundstones and sandy dolomitic mudstones containing solution features. The carbonates of the restricted platform and supratidal/marginal marine facies are often capped with fine-grained, cross-stratified quartz sandstones. These cycles were interpreted to represent a shallowing upward succession of dominantly peritidal carbonates capped by eolian siliciclastics (Canter and Isaacson, 1991).

Archueleta (2004) and Archuleta et al. (2006) expanded on the work accomplished by Canter (1984) and Canter and Isaacson (1991) and grouped the wide assemblage of depositional fabrics into three main categories. Her work identified a siliciclastic-dominated, mixed carbonate and siliciclastic-dominated, and carbonate-dominated facies for transgressive system tract and highstand system tract deposits. Archuleta (2004) subdivided the siliciclastic-dominated facies into four subunits to represent terrestrial to subtidal deposition based on skeletal, nonskeletal, sedimentary structure, and color components. The siliciclastic-carbonate mixed facies was subdivided into six subunits and represents tidal flat to shallow subtidal deposition. The carbonate-dominated facies was subdivided into seven facies codes and these sub-facies are interpreted to record shallow subtidal to deep subtidal deposition (Archuleta, 2004).

To date, no workers have sufficiently identified individual depositional facies from the Bloom or Gallagher Peak members of the Snaky Canyon Formation. Skipp et al. (1979b) provided generalized descriptions of depositional settings when interpreting the paleogeographic and paleotectonic significance of the rock unit, although this was at the member level and not the individual sequence, cycle, or facies level.

Cyclothems

Wanless (1931) introduced the term cyclothem to describe the repeated meter-scale succession of Pennsylvanian coal-bearing strata in the U.S. midcontinent. Later workers modified this definition to include all Upper Mississippian to Lower Permian meter-scale alternating stratigraphic assemblages of marine and non-marine sediments stacked in repeating sequences and bound by erosional or nondepositional surfaces (Heckel, 1986). Recent studies (Heckel, 1986; deV Klein, 1989; Soreghan, 1994; Birgenheier et al., 2007; Grader et al., 2008) have identified the global extent of cyclothems and correlated the affinity of cyclic deposition during the Upper Paleozoic to the waxing and waning of widespread continental glaciation primarily in the southern hemisphere.

Rankey (1996, 1997) briefly defined and interpreted the Upper Pennsylvanian cyclothems from the Juniper Gulch Member of the Snaky Canyon Formation and compared them to those of the midcontinent in order to determine the effect of provincial and regional processes on the global eustatic stratigraphic signal (Figure 18). Archuleta (2004) and Archuleta et al. (2006) described several high-frequency cyclothems from the Juniper Gulch Member and described a decrease in sediment cyclicity as the member decreased in age. The lower cyclothems of the Juniper Gulch Member were interpreted to represent subtidal carbonates that were capped by eolian to subtidal siliciclastics (Archuleta, 2004). These cyclothems are very similar to those noted from other localities in the Western United States (Rankey, 1996, 1997; Ritter et al., 2002; Cecil et al., 2003)(Figure 18). A overall deepening event in the middle of the Juniper Gulch produced cyclothems dominated by subtidal carbonates. By the top of the Juniper Gulch Member, cyclicity is interpreted to have decreased and this may have been the result of a decrease in the amplitude of sea-level fluctuations and/or a decrease in siliciclastic sediment supply (Archuleta, 2004; Archuleta et al., 2006).

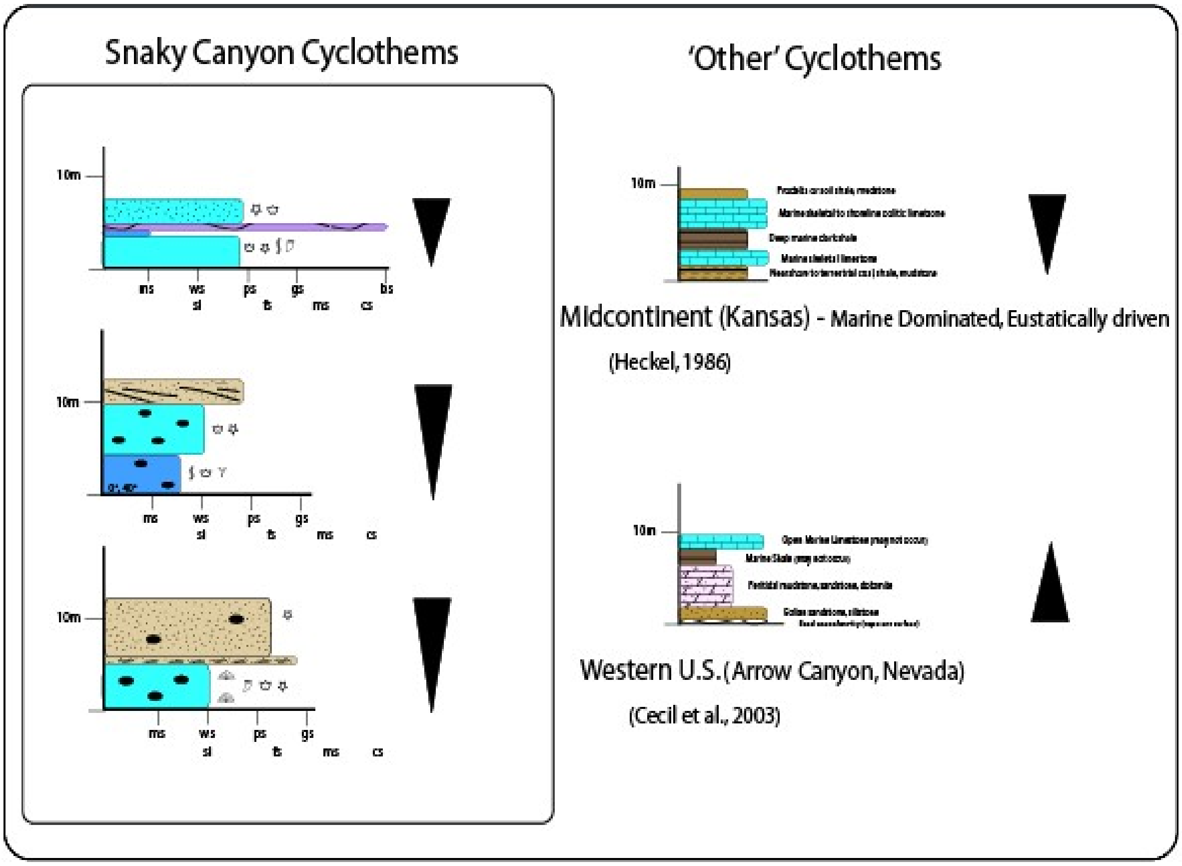


Figure 18: Examples of Snaky Canyon Formation cyclothems compared to correlative stratigraphic cycles located in the midcontinental and western United States.

Chapter 8: Conodont Biostratigraphy

Biostratigraphy

The occurrence, distribution, and magnitude of conodonts recovered throughout this study from the Snaky Canyon Formation in east-central Idaho aid in the establishment of a biostratigraphic framework for the upper Carboniferous of the northern Rocky Mountains. This framework provides a greater understanding of Pennsylvanian tectonic and eustatic influences on the Laurentian margin by refining relative age relationships from a relatively continuously deposited succession of near-shore marine strata.

The continuous range conodont biozones for each stage of the Pennsylvanian are individually described in the following text. At the conclusion of individual stage discussions, a complete biozonation based on conodonts will be presented for the Morrowan to Missourian stages of the Pennsylvanian. These data will then be combined with other interpretations from the University of Idaho/Dr. Peter Isaacson research team in order to develop a biozonation for the majority of the Carboniferous.

Conodont Biozonation in the West: Why the West is Better

To date, no other high-resolution, bed-scale biostratigraphic study has been conducted on the upper Carboniferous of Idaho. The conodont biozonation presented below represents a detailed biostratigraphic analysis of shallow-water carbonates recording few hiatuses, as in the Pennsylvanian stage type sections within the midcontinent of the United States (Lane, 1967; Lane and Straka, 1974). The Morrowan to Missourian (Lower to Upper Pennsylvanian) conodont assemblages recovered are a combination of North American midcontinental and Eurasian species.

Previous studies and workers from the U.S. midcontinent have based conodont biozonation frameworks on assemblages recovered from stratigraphic successions characterized by periods of subaerial exposure and emergence. These 3rd and 4th (cyclothem) order sequences from the U.S. midcontinent are generally sampled from the basal marine limestone member, which most likely contain condensed assemblages and have a high risk of recording reworked assemblages from the strata below. Although Snaky Canyon deposition was not immune to the same eustatic fluctuations that caused emergence in other parts of the continent during the upper Carboniferous, very little evidence exists supporting massive hiatuses (2nd to 3rd order) and prolonged periods of emergence that produced the condensed assemblages often recorded from the midcontinent (Skipp, 1979a; Cecil et al., 2003).

Studies from the middle to upper Carboniferous from other regions of the western United States include reports from the Honaker Trail section in the Paradox Basin of Utah (Ritter et al., 2002) and the Arrow Canyon section of southern Nevada (Dunn, 1966). These studies offer great utility, although the sections of strata referenced do not offer the continuous duration (Morrowan to Virgilian) that is stratigraphically recorded in the Snaky Canyon Formation of east-central Idaho.

Methods for the Determination of Individual Conodont Biozones

A succession of formal and established concurrent and continuous range conodont biozones has been established for the Pennsylvanian strata of the northern Rocky Mountain region

(Figures 24-27). The investigation of recovered conodonts from the Snaky Canyon Formation has resulted in the recognition, establishment, definition, and application of fifteen distinct conodont zones for the Pennsylvanian (Figure 37).

In this study, all interpretations and conclusions are based on Smith and Cuvier's Principle (Law) of Faunal Succession (1813/1815). Conodont biozones are primarily based on first occurrence datum (FOD). These continuous range interval zones are based on the taxonomic range of the fauna of which each zone is identified prior to the FOD of the overlying taxon biozone (Figure 19). In order to establish these biozones, overlapping assemblages (Oppel assemblage zones) were compared from each measured section and widespread occurrences were noted. FODs and overlapping assemblages were used to establish and confirm the biozones presented in the following text. All of the biozones recognized by this study are based on the initial occurrence of the conodont species that defines each biozone.

It is important to note that Oppel assemblage zones initially used to define the interval zones may be used in the correlation of individual 4th order sequences (cyclothems) (Ritter et al., 2002). This concept is discussed later in this work.

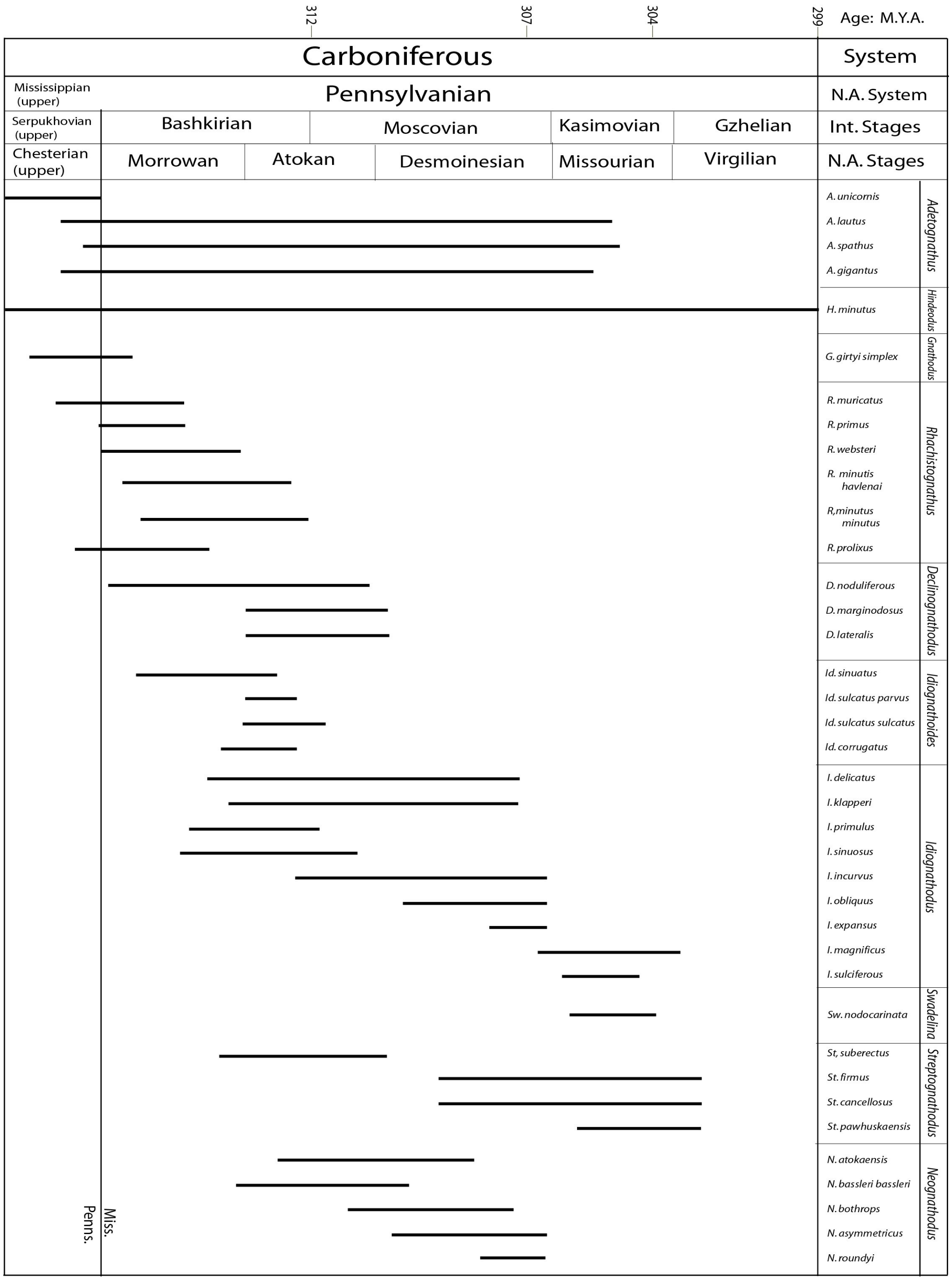


Figure 19: Previously published Pennsylvanian conodont stratigraphic ranges and first occurrence datum (FOD) points (From Thompson (1970), Merrill (1972), Baesemann (1973), Higgins (1975), Baesemann and Lane (1985), Savage and Barkeley (1986), Grayson et al. (1989), Barrick (1996), Krumhardt et al. (1996), Nemirovska (1999), Roscoe (2005, 2008).

Conodont Biozones of the Snaky Canyon Formation

Biozone 1: *Rhachistognathus primus* Biozone

Introduction

The lower limit of the basal Morrowan *Rhachistognathus primus* biozone (Lane and Straka, 1975) marks the Mississippian/Pennsylvanian boundary (Figure 24) and has been identified and applied in numerous other studies (Lane and Straka, 1975; Webster, 1984; Davis and Webster, 1984; Baesemann and Lane, 1985; Krumhardt et al., 1996; Abplanalp et al., 2009). Davis (1983) used the initial first appearance of *R. primus* to define the Mississippian/Pennsylvanian boundary in the lower part of the Alaska Bench Limestone of central Montana, located to the east of the study area.

In this study the occurrence of the *R. primus* zone marks the Mississippian/Pennsylvanian boundary and the stratigraphically oldest units of interest (Figure 24).

Limits

The lower limit of the *Rhachistognathus primus* Biozone is marked by the appearance of Early Pennsylvanian (Morrowan) species *R. primus*. The upper limit of this zone is marked by the appearance of *Declinognathodus noduliferous*.

Characteristic species

Typical conodont species recovered in conjunction with *Rhachistognathus primus* include; *Adetognathus lautus, A. spathus, A. gigantus, A. unicornis, Hindeoudus critula, H. minutus, Gnathodus girtyi simplex, G. defectus, Rhachistognathus muricatus, R. minutis harlendhi*, *R. minutis minutis*, and *R. websteri* (Figures 20 and 21).

Global Correlations

The *Rhachistognathus primus* zone overlaps with the lowermost global foraminifera biozone 20. This zone also is concurrent with the entire H2 zone and lower half of the R1 zone marking the basal Bashkirian in the western European Faunal zonation scheme (Nemirovaka, 1999)(Figure 24).

Remarks

The *Rhachistognathus primus* zone represents the basal and therefore oldest Pennsylvanian biozone recognized in this study (Figure 24). The utility of *R. primus* as a biostratigraphic indicator has been widely recognized along the Laurentian margin by previous workers (Lane and Straka, 1975; Webster, 1984; Davis and Webster, 1984; Baesemann and Lane, 1985; Krumhardt et al., 1996; Abplanalp et al., 2009) and is recognized as a widely established biostratigraphic zone for the lowermost Pennsylvanian (Figure 24). The biozone is not recognized at the midcontinental United States or in Europe, as there is a general absence of *R. primus* recovered (Lambert et al., 2001).

The occurrence of *R. primus* within the succession of Snaky Canyon strata overlaps with the lower Pennsylvanian foraminiferal assemblage recovered by Skipp et al. (1979a) from the same stratigraphic intervals. The work by Skipp et al. (1979a) determined that the lower Bloom Member was likely within the upper zone 19 and lower zone 20 of the Mamet et al. (1970) microfossil zones. The presence and recognition of *R. primus* biozone further refines the work of Skipp et al. (1979a) and indicates that the Mississippian/Pennsylvanian boundary occurs below the beds of the basal Snaky Canyon Formation.

The initial appearance of *R. primus* indicates that the system boundary occurs within the Arco Hills Formation and the lowermost part of the Bluebird Mountain Formation of east-central Idaho, which are stratigraphically below the Snaky Canyon Formation (Abplanalp, 2006; Abplanalp et al., 2009). From west to east, the zone comprises the Arco Hills and Bluebird Mountain formations in the White Knob Mountains and the Bluebird Mountain and lowermost Snaky Canyon formations in the Lost River, Lemhi, and Beaverhead ranges (Figure 5).

Occurrence

The 5 to 20 meter interval immediately above the last prominent sand of the White Knob section is representative of the *R. primus* biozone. In the Arco Hills of the Lost River Range, the initial appearance of *R. primus* occurs in fine siliciclastic bounded subtidal carbonates at meter 13 and ranges to meter 24. To the north in the Lost River Range at the carbonate dominated VAH section, the biozone is represented from 0 m. To 23 m. At the Snaky Canyon Bloom Member locality in the Beaverhead Range, the basal 2 to 20 meters above the last significant fine grained siliciclastic bed of the Bluebird Mountain Formation is within the *R. primus* biozone (Appendix II).

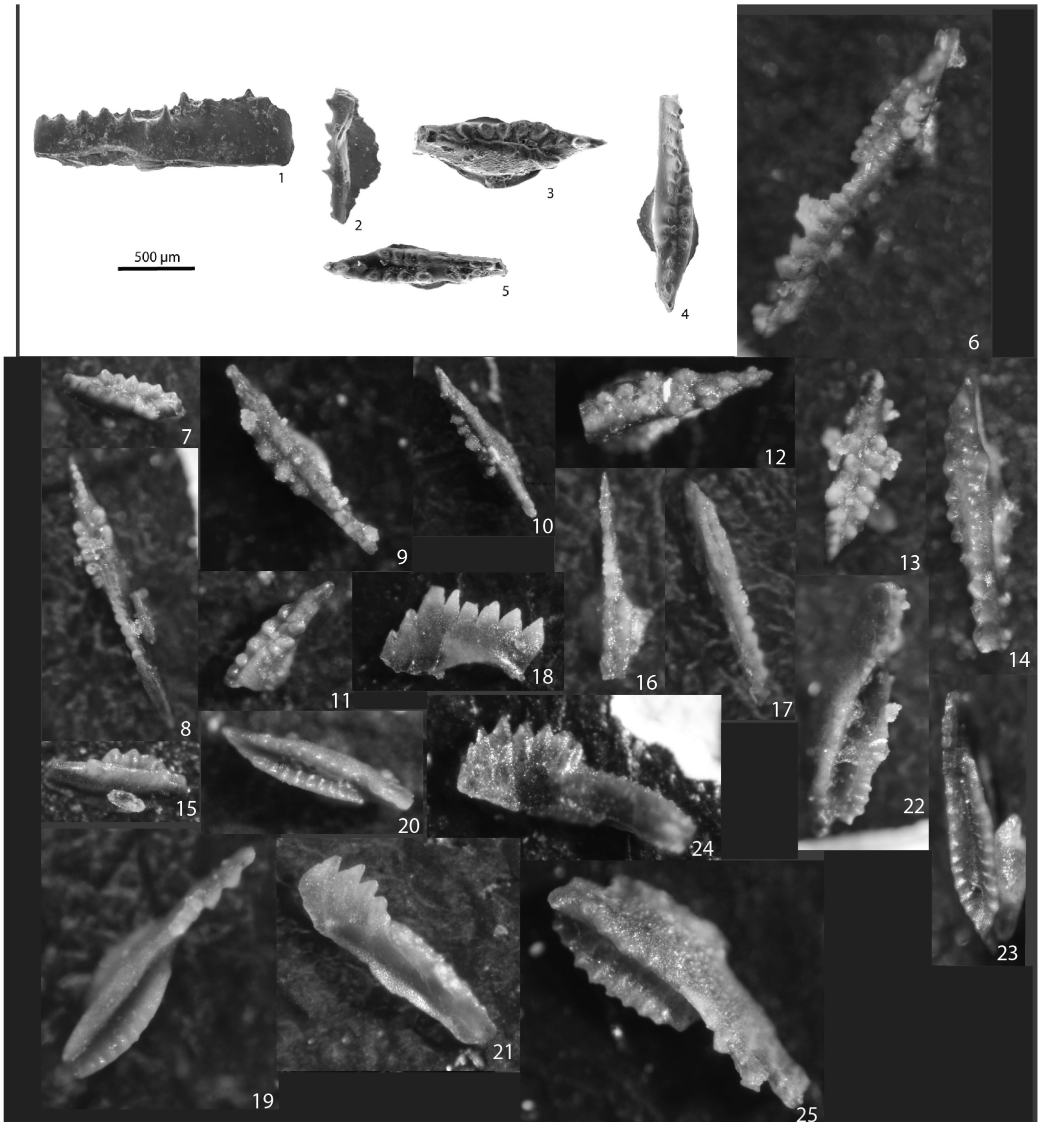


Figure 20: Plate I conodonts: 1,2,7-11 *Rhachistognathus primus*; 3,4,12-14 *Rhachistognathus websteri*; 5, 15 *Rhachistognathus minutis havlenai*; 16, 17 *Rhachistognathus minutis minutis*; 6 *Rhachistognathus muricatus*; 18 *Hindeodus minutus*; 19-23 *Adetognathus lautus*; 24, 25 *Adetognathus gigantus*. All specimens are magnified 40x. Specimen images 1-5 taken using scanning electron microscope (SEM). Specimen images 6-25 taken using plain-light microscope combined with digital imaging.

Biozone 2: *Declinognathodus noduliferous* Biozone

Introduction

The lower Morrowan *Declinognathodus noduliferous* biozone was first defined by Lane (1967) from middle Carboniferous rocks in the midcontinent. Along the western margin, Webster (1969) defined the biozone as the *Streptognathodus noduliferous* biozone and was again identified by Dunn (1970b) from rocks of the eastern Great Basin in the western United States as the *D. noduliferous* biozone. The *D. noduliferous* biozone is globally recognized and is the most universally applied biozone of the lower Pennsylvanian (Figure 24). Studies have recognized the biostratigraphic utility of *D. noduliferous* from the western U.S. (Webster, 1969; Dunn, 1970; Webster and Langenheim, 1979; Davis and Webster, 1984; Baesmann and Lane, 1985; Lane et al., 1985; Morrow and Webster, 1992; Krumhardt et al., 1996; Harris et al., 1997, and Lane et al., 1999), the Midcontinent (Grayson et al., 1989; Grayson, 1991; Lambert et al., 2001), the United Kingdom (Higgins, 1975; Higgins and Austin, 1985), France (Perret, 1993), Spain (Nemyrovska et al., 2011), Eastern Europe (Nemirovskaya, 1982, 1987, 1999; Barskov, 1984; Nemirovskaya and Alekseev, 1994), and Asia (Wang et al., 1987; Koike, 1967).

Declinognathodus noduliferous has been recommended as the primary micropaleontologic guide for the Lower Pennsylvanian due to the widely published cosmopolitan occurrence and distinct morphology of the species (Lane and Manger, 1985). At the 10th International Congress of Carboniferous Stratigraphy and Geology in 1983, *D. noduliferous* was chosen as the global indicator of the Mid-Carboniferous boundary (Lane et al., 1999).

In this study, the *D. noduliferous* biozone marks the lower Morrowan and is stratigraphically younger than the underlying *R. primus* biozone that marks the Mississippian/Pennsylvanian boundary in east-central Idaho (Figure 24).

Limits

The lower limit of the *Declinognathodus noduliferous* Biozone is marked by the appearance of Early Pennsylvanian (Morrowan) species *D. noduliferous*. The upper limit of this zone is marked by the first initial appearance of *Idiognathoides sinuatus*.

Characteristic species

Typical conodont species recovered in conjunction with *Declinognathodus noduliferous* include; *Adetognathus lautus, A. spathus, A. gigantus, H. minutus, Gnathodus girtyi simplex, G. defectus, Rhachistognathus primus, R. minutis harlendhi*, R. minutis minutis, and *R. websteri* (Figures 20 and 21).

Global Correlations

The *Declinognathodus noduliferous* zone overlaps with the middle of the global foraminifera biozone 20. This zone also is concurrent with the upper H1 and the complete H2 division of the Global Goniatite zones marking the lower Bashkirian (Nemirovska, 1999)(Figure 24).

Remarks

In this study, the occurrence of *R. primus* marks the Mississippian/Pennsylvanian boundary and the first occurrence of *D. noduliferous* represents a separate and definable biozone stratigraphically above the *R. primus* biozone. Some paleontologists have used *R. primus* to subdivide the *D.noduliferous* biozone (ie. Baesemann and Lane, 1985; Lane et al., 1985; Krumhardt, 1996). In this study, the two species each define their own stratigraphic position.

Multiple investigations along the western margin of Laurentia (Lane and Straka, 1975; Webster and Langenheim, 1979; Webster, 1984; Baesemann and Lane, 1985; Krumhardt et al., 1996; Lambert et al., 2001, Abplanalp et al., 2009) have utilized *R. primus* to establish the middle Carboniferous boundary. Paleontologists studying the rocks of and near Arrow Canyon in Nevada reported a occurrence of *D. noduliferous* preceding the first occurrence of *R. primus* (Lane et al., 1999; Titus et al., 1997). This may be the result of facies control, as the initial occurrences of *D. noduliferous* and *R. primus* are reported to be heavily dependent on depositional environment (Morrow and Webster, 1991; Krumhardt et al., 1996). The strata immediately below the first occurrence of *D. noduliferous* at this locality record shallow water deposition.

Some workers (Higgins, 1975, 1982; Grayson, 1984) have subdivided the various morphological features of *D. noduliferous* into up to four defined subspecies. For this study, only the original initially occurring *D. noduliferous* (S1) is recognized for biostratigraphic utility.

Occurrence

The initial appearance of *D. noduliferous* occurs within the basal Snaky Canyon Formation at all localities containing lowermost Pennsylvanian strata. From west to east, the *D. noduliferous* biozone occurs between 20 meters and 47 meters at the White Knob section; from 24 m. to 59 m. at the Arco Hills section; between 35 m. and 66 m. at the VAH section; from 1 m.

to 53 m. at Unknown Canyon, and between 21 m. and 36 m. at the Gallagher Peak type section (Appendix II).

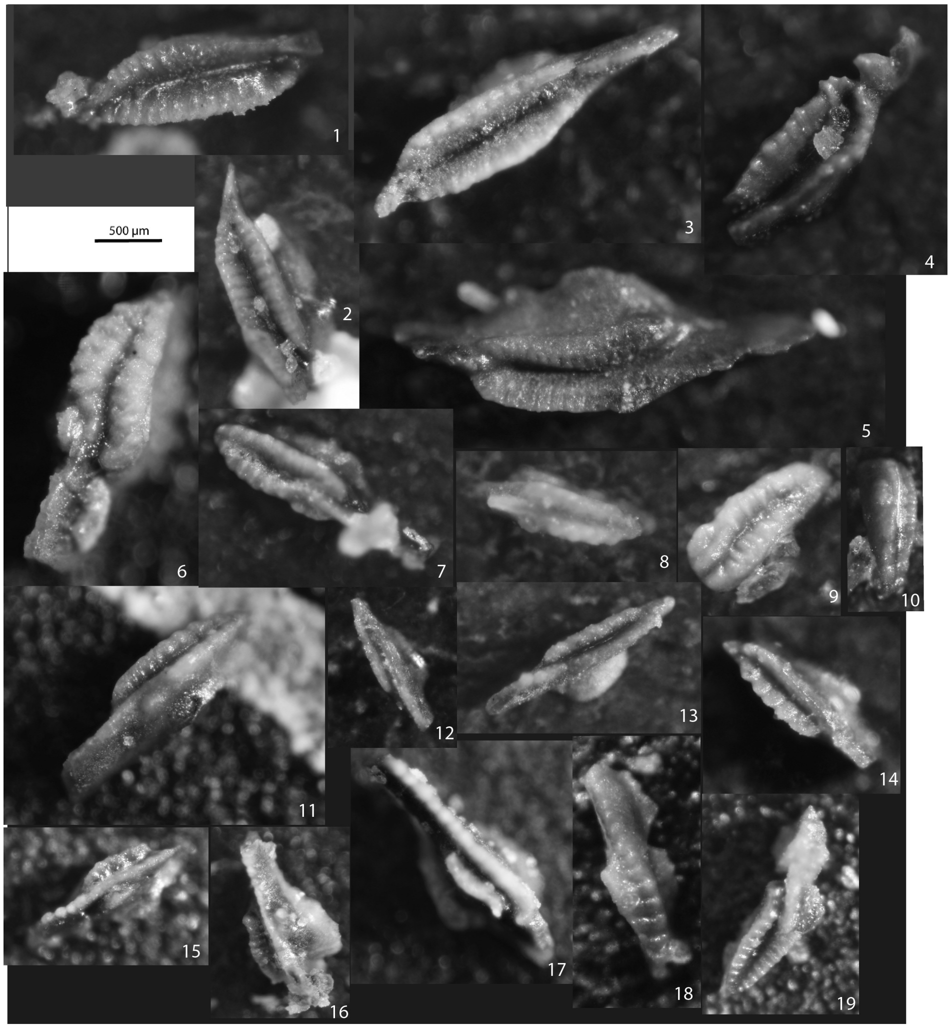


Figure 21: Plate II conodonts: 1-5 *Adetognathus spathus*; 6-11 *Declinognathodus noduliferous*; 12-14 *Idiognathoides sinuatus*; 15 *Idiognathoides ineaqualis*; 16,17 *Idiognathoides sulcatus sulcatus*; 18 *Idiognathoides corrugatus*; 19 *Idiognathoides excelsus*. All specimens are magnified 40x. All specimen images taken using plain-light microscope combined with digital imaging.

Biozone 3: *Idiognathoides sinuatus* Biozone

Introduction

The middle Morrowan *Idiognatoides sinuatus* biozone was first delineated by Lane (1977) from U.S. midcontinental strata in Arkansas and Oklahoma. Baesemann and Lane (1985) defined the biozone on the first occurrence of *Id. sinuatus* or the first occurrence of the concurrently appearing *Rh. minutis* from a measured section at Timber Dome in southern Idaho. Paleontologists in the western United States (Webster and Langenheim, 1979; Webster, 1984; Davis and Webster, 1984; Baesemann and Lane, 1985; and Lane et al., 1985), the U.S. midcontinent (Lane, 1977; Lane and Baesemann, 1982), the United Kingdom (Higgins and Austin, 1985), Brazil (Nascimento et al., 2009), Spain (Nemirovska, 2011), the Donets Basin of Eastern Europe (Nemirovska, 1982, 1987, and 1999)and Asia (Wang, 1987; Wang and Higgins, 1989) have recongized the biostratigraphic utility of the cosmopolitan *Id. sinuatus* species (Figure 24).

The *Id. sinuatus* biozone marks the middle Morrowan and stratigrahically occurs above the *Declinognathodus noduliferous* biozone and below the *Idiognathodus sinuosus* biozone (Figure 24)

Limits

The lower limit of the *Idiognathoides sinuatus* Biozone is marked by the appearance of the Early Pennsylvanian (Morrowan) species *Id. sinuatus*. The upper limit of this zone is marked by the first initial appearance of *Idiognathodus sinuosus*.

Characteristic species

Typical conodont species recovered in conjunction with

Idiognathoides sinuatus include; *Adetognathus lautus, A. spathus, A. gigantus, Declinognathodus noduliferous, Hindeodus minutus, Idiognathoides sulcatus sulcatus, Rhachistognathus* minutus minutus, *R. minutus havlendhi, and Vogelgnathodus campbelli* (Figures 21 and 22).

Global Correlations

The *Idiognathoides sinuatus* biozone overlaps with the middle to upper global foraminifera biozone 20 of Mamet (1972). This biozone also is concurrent with the entire R1 and R2 zones marking the middle Bashkirian in the western European Faunal zonation scheme (Nemyrovska, 1999)(Figure 24).

Remarks

The *Idiognathoides sinuatus* biozone has been widely recognized globally, although there is minor disagreement on stratigraphic placement of the biozone. The work completed in the United Kingdom by Higgins (1975) and Higgins and Austin (1985) place the *Id. sinuatus* biozone stratigraphically above the first appearance of *Idiognathodus* genera. In this study, we do not see this relationship and this observation seems to correspond with the work of others (Webster, 1985; Lane, 1977; Baesemann and Lane, 1985; Nemyrovska, 1999)(Figure 24).

The initial appearance of *Id. sinuatus* occurs within the Bloom Member of the lower Snaky Canyon Formation.

Occurrence

The initial appearance of *Id. sinuatus* occurs within the lower Snaky Canyon Formation at all investigated localities with exposed Lower Pennsylvanian (Morrowan) strata. The *Id. sinuatus* biozone occurs (from west to east) from meters 46 to 71 at the White Knob section; from 61 m. to 92 m. at the Arco

Hills section; within the 65 m. to 76 m. interval at the VAH section; from the 53 m. to 74 m. interval at the Unknown Canyon section; and from 36 m. to 49 m. at the Gallagher Peak type section (Appendix II).

Biozone 4: *Idiognathodus sinuosus* Biozone

Introduction

The upper Morrowan (late-Early Pennsylvanian) *Idiognathodus sinuosus* biozone was first identified from strata in Nevada and Oklahoma by Dunn (1970b). This biozone was originally delineated by the first occurrence of either *I. sinuosus* or *I. humerus*. Paleontologists following the work of Dunn later rejected the concept of *I. humerus* and defined the zone on the first occurrenc of *I. sinuosus*. This biozone has been recognized in the western United States (Dunn, 1970b; Barrie, 1975; Webster and Langenheim, 1979; Lane et al., 1985), the U.S. midcontinent (Dunn, 1970b; Lane and Straka, 1974; Lane, 1977; Grayson et al., 1984; Lambert et al., 2001), Eastern Europe (Nemyrovska, 1999; Nemyrovska and Alekseev, 1994), and Northern Asia (Wang et al., 1985, 1987; Wang and Higgins, 1989)(Figure 24).

The *I. sinuosus* biozone represents the upper Morrowan (Baesemann and Lane, 1985) and stratigraphically occurs above the *Idiognathoides sinuatus* biozone and below the *Streptognathodus suberectus* biozone (Figure 24)

Limits

The lower limit of the *Idiognathodus sinuosus* Biozone is marked by the appearance of the Early Pennsylvanian (Morrowan) species *I. sinuosus*. The upper limit of this zone is marked by the first initial appearance of *Streptognathodus suberectus*.

Characteristic species

Typical conodont species recovered from the Idiognathodus sinuosus *biozone* include; *Adetognathus lautus, A. spathus, A. gigantus, Declinognathodus noduliferous, Hindeodus minutus, Idiognathodus parvus, I. primulus, Idiognathoides sinuatus, Id. sulcatus sulcatus*, *Rhachistognathus minutis minutis, Rh. minutis havlendhi*, and *Rh. prolixus* (Figures 20-22).

Global Correlations

The *Idiognathoides sinuatus* biozone overlaps with the upper global foraminifera biozone 20 of Mamet (1972). This zone also is concurrent with a majority of the G1 biozone marking the middle Bashkirian in the western european faunal zonation scheme (Nemyrovska, 1999)(Figure 24).

Remarks

The *I. sinuosus* biozone marks the first appearance of the *Idiognathodus* genus and this occurrence is a global phenomenon. The appearance of *I. sinuosus* in the Snaky Canyon Formation also coincides with the first appearance of other species of Idiognathodus such as *I. primulus* and *I. parvus* at specific localities (Appendix II).

The species concept of the *Idiognathodus* genus was revised by Grayson et al. (1989, 1990). This endeavor has attempted to eliminate much of the controversy surrounding the improper identification and subsequent renaming of Idiognathodus specimens on the basis of miniscule morphological differences. This study follows the *Id. sinuosus* species concept proposed by Grayson et al. (1989) when identifying and describing representative specimens of the *Idiognathodus* genus.

The *I. sinuosus* biozone is globally recognized, although it's stratigraphic placement is variable among workers and localities. Workers in the U.S. midcontinent (Lane, 1977) and Eastern Europe (Nemyrovska et al., 1999) have defined the *I. sinuosus* zone to be stratigraphically older that studies from the western margin of Laurentia (Dunn, 1970b). In order to eliminate the differences in stratigraphic occurrences, the first initial appearance of *Idiognathodus* genera is used to defined the stratigraphic position of this biozone as suggested by Krumhardt et al. (1996).

The initial appearance of *I. sinuosus* occurs within the lower Snaky Canyon Formation.

Occurrence

The initial appearance of *I. sinuosus* occurs within the lower Snaky Canyon Formation at all investigated localities with exposed Early Pennsylvanian (Morrowan) strata. The *I. sinuosus* biozone occurs (from west to east) from meters 71 to 109 at the White Knob section; from 92 m. upwards at the exposed strata at the Arco Hills section; within the 76 m. to 92 m. interval at the VAH section; from the 74 m. to 86 m. interval at the Unknown Canyon section; and from 49 m. to 72 m. at the Gallagher Peak type section (Appendix II).

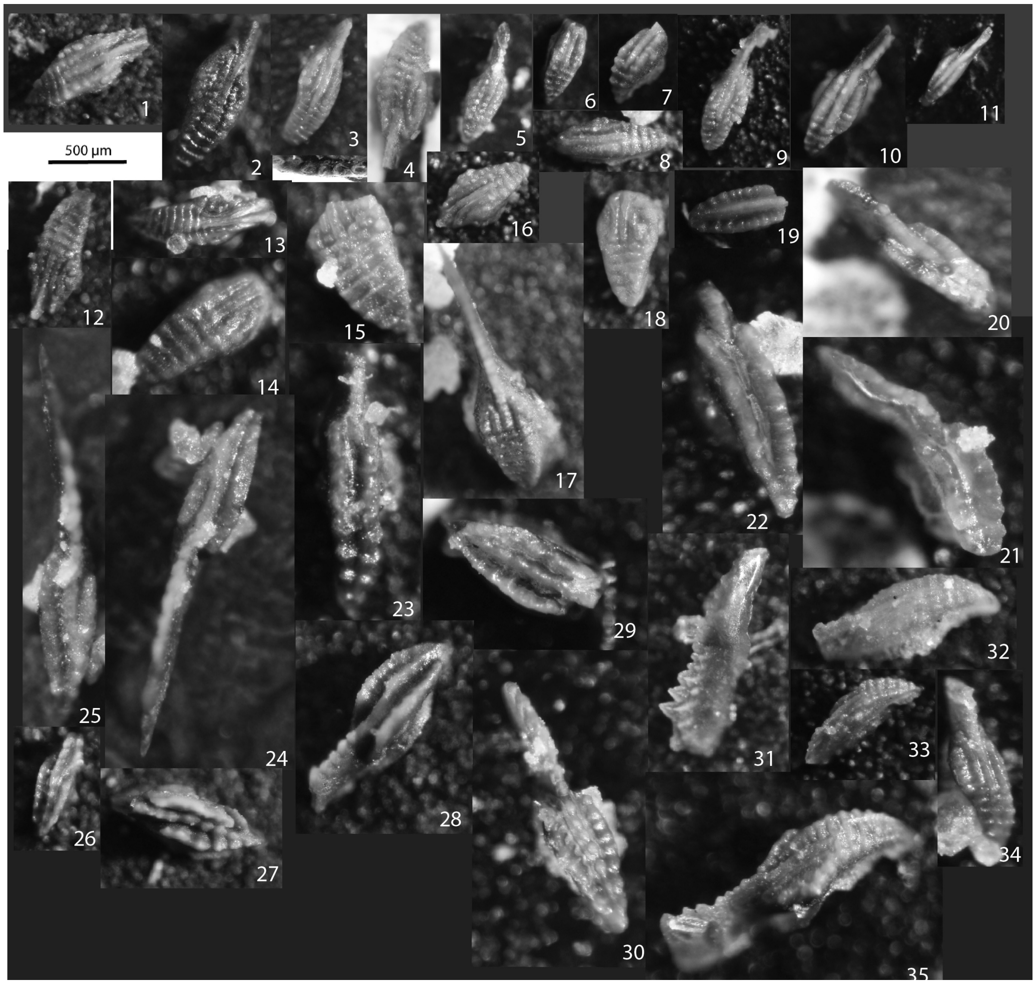


Figure 22: Plate III conodonts: 1-4 *Idiognathodus sinuosus*; 5 *Idiognathodus primulus*; 6-8 *Idiognathodus parvus*; 9-11 *Streptognathodus suberectus*; 12-15 *Idiognathodus delicatus*; 16-18 *Idiognathodus klapperi*; 19 *Neognathodus bassleri bassleri*; 20-23 *Declinognathodus marginodosus*; 24,25 *Declinognathodus lateralis*; 26-31 *Neognathodus atokaensis*; 32-35 *Idiognathodus incurvus*. All specimens are magnified 40x. All specimen images taken using plain-light microscope combined with digital imaging.

Biozone 5: *Streptognathodus suberectus* Biozone

Introduction

The upper Morrowan *Streptognathodus suberectus* biozone was first established by Dunn (1970b) as the *St. expansus/St.*

suberectus biozone from strata in Nevada and Oklahoma. The *St. suberectus* biozone marks the first appearance of the distinctive and cosmopolitan *Streptognathodus* genus. Studies from the western U.S. (Dunn, 1970b; Dunn, 1976), the U.S. midcontinent, (Dunn, 1970b; Lane and Straka, 1974), Eastern Europe (Nemyrovska, 1999), and Asia (Rui et al., 1987) have identified the *St. suberectus/expansus* biozone and it's stratigraphic location as upper Morrowan (middle to upper Bashkirian)(Figure 24).

The *St. suberectus* biozone marks the upper Morrowan and stratigraphically occurs above the *Idiognathodus sinuosus* biozone and below the *Declinognathodus marginodosus*/*Idiognathodies sulcatus parvus* biozone (Figure 24).

Limits

The lower limit of the *St. suberectus* Biozone is marked by the first intial appearance of the Early Pennsylvanian (Morrowan) *Streptognathodus* genus. The upper limit of this zone is marked by the first initial appearance of *Declinognathodus marginodosus* and/or *Idiognathoides sulcatus parvus*.

Characteristic species

Typical conodont species recovered in conjunction with *Streptognathodus suberectus* include; *Adetognathus lautus, A. spathus, A. gigantus, Declinognathodus noduliferous, Hindeodus minutus, Idiognathodus sinuosus, I. parvus, I. primulus, Idiognathoides corrrugatus; Id. sulcatus sulcatus, Neognathodus bassleri bassleri, Rhachistognathus minutus minutus, and Vogelgnathodus campbelli* (Figures 20-22).

Global Correlations

The *Streptognathodus suberectus* biozone overlaps with the uppermost global foraminifera biozone 20 of Mamet (1972). This zone also is concurrent with the upper G1 to lowermost WA biozone indicating middle to upper Bashkirian of the western European Faunal Biozonation framework (Nemyrovska, 1999) (Figure 24).

Remarks

St. suberectus is widely accepted to be of short stratigraphic range, which makes the it's appearance an ideal stratigraphic indicator (Nemyrovska, 1999). The correlative *St. expansus* zone was first described by Dunn (1970b) and was initially reported to occur stratigraphically below the first occurrence of *I. sinuosus*. Lane and Straka (1974) also indicated that *St. expansus* and *St. suberectus* occurred below the first appearance of *I. sinuosus* in strata of Oklahoma and Arkansas. Subsequent studies conducted in Eastern Europe (Nemyrovska et al., 1999) and China (Rui et al., 1987) have disputed this stratigraphic positioning. In the Snaky Canyon Formation, the appearance of *I. sinuosus* occurs stratigraphically below that of *St. suberectus* at all localities. From comparison with other studies conducted on correlative continuously deposited carbonate rocks (Dunn, 1970b; Dunn, 1976; Nemirovska, 1999) it is determined that *St. suberectus* is stratigraphically younger than *I. sinuosus* and the conflicting results from the U.S. midcontinent may be the result of biofacies control or recovery from condensed intervals.

The *St. suberectus* biozone is distinctly recognized in all of the measured sections of the Snaky Canyon Formation reported by this study. The biozone marks a distinct transition in recovered conodont assemblages from collections dominated by Pa conodont elements marked by deep troughs to those with significantly flatter platforms (*Idiognathodus* dominated vs. *Adetognathus/Idiognathoides/ Declinognathodus* dominated). This relationship is addressed and discussed in the Snaky Canyon conodont biofacies section.

Occurrence

The initial appearance of *St. suberectus* occurs within the lower Snaky Canyon Formation at all investigated localities of Lower Pennsylvanian (upper Morrowan) Snaky Canyon Formation. The *St. suberectus* biozone occurs (from west to east) from meters 109 to 142 at the White Knob section, from the 92 m. to 112 m. interval at the VAH section; from the 86 m. to 108 m. interval at the Unknown Canyon section; and from 72 m. to 90 m. at the Gallagher Peak type section (Appendix II).

Biozone 6: ***Declinognathodus marginodosus/Idiognathoides sulcatus parvus*** Biozone

Introduction

The Early Pennsylvanian (Atokan) *Declinognathodus marginodosus/Idiognathoides sulcatus parvus* Biozone (Grayson, 1984 – *D. marginodosus*; Higgins, 1975 – *Id. sulcatus parvus*) marks the Morrowan/Atokan North American stage boundary and this relationship has been recognized by several recent workers (Nemyrovska and Alekseev, 1994; Nemyrovska, 1999; Groves et al., 1999)(Figure 25). Paleontologists studying the lower Atokan of the U.S. midcontinent (Grayson, 1984; Grayson et al., 1989, 1991), Northern England (Higgins, 1975; Higgins and Austin, 1985;); the Donets Basin of eastern Europe

(Barskov, 1984; Nemyrovska, 1999; Nemirovska and Alekseev, 1994; Groves et al., 1999; Kulagina et al., 2008) and Asia (Wang et al., 1985, 1987; Wang and Higgins, 1989) have identified and utilized the first occurrence of *D. marginodosus* and/or *Id. sulcatus parvus* to identify strata within this stratigraphic interval (Figure 25).

In this study, the occurrence of the *D. marginodosus/Id. sulcatus parvus* biozone marks the Morrowan/Atokan stage boundary. This is the stratigraphically oldest biozone representing the Atokan (Figure 25).

Limits

The lower limit of the *Declinognathodus marginodosus/ Idiognathoides sulcatus parvus* Biozone is marked by the appearance of Early Pennsylvanian (Atokan) species *D. marginodosus* and/or *Id. sulcatus parvus*. The upper limit of this zone is terminated by the initial appearance of *Neognathodus atokaensis*.

Characteristic species

Typical conodont species recovered in conjunction with *Declinognathodus marginodosus* and/or *Idiognathoides sulcatus parvus* include; *Adetognathus lautus, A. spathus, A. gigantus, Declinognathodus noduliferous, D. lateralis, Hindeodus minutus, Idiognathodus sinuosus, I. delicatus, I. primulus, I. parvus, Idiognathoides corrugatus, Id. sinuatus, Id. sulcatus sulcatus, Id. ineagualis, Neognathodus symmetricus, Rhachistognathus minutis minutis, Rh. prolixus*, and *Streptognathodus suberectus*, (Figures 20-22).

Global Correlations

The *Declinognathodus marginodosus* and/or *Idiognathoides* *sulcatus parvus* biozone of the Snaky Canyon Formation overlaps with the lower global foraminifera biozone 21. This zone also is concurrent with the WA and lower WB ammonoid genozone marking the upper Bashkirian in the western European Faunal zonation scheme (Nemyrovska, 1999)(Figure 25).

Remarks

In all but one section of strata recording the late Morrowan to early Atokan, *Id. sulcatus parvus* and *D. marginodosus* are synchronous in their initial occurrence (Appendix II). At the White Knob section, there is a overall absence of specimens representing *Declinognathodus* throughout the upper Morrowan to Atokan succession of strata and therefore no specimens of *D. marginodosus* were recovered within this interval. The White Knob section is the geographically farthest west section presented in this study and therefore represents the deepest water facies (Figures 28 and 29). It is determined that biofacies control may restrict the occurrence of *Declinognathodus*, as specimens of the genus appear in lower strata at this section that record slightly shallower deposition.

To date, no studies conducted on the strata of the western United States have defined or identified a lower Atokan conodont biozone based on the first occurrence of *D. marginodosus* or *Id. sulcatus parvus*. The Morrowan/Atokan is somewhat obscure and this problem is discussed in the following section describing the placement of the Morrowan/Atokan stage boundary. The use of *D. marginodosus* to defined this boundary is recognized from continuously deposited successions in eastern Europe and the assemblages recovered in this study closely mimic those of these workers. *Id. sulcatus parvus* occurs simultaneously with *D. marginodosus* in all of the sections recording strata of this age that have favorable biofacies. Therefore, it is determined that the presence of *Id. suclatus parvus* and/or *D. marginodosus* may be used to define lower Atokan strata of the Northern Rocky Mountains.

The initial appearance of *Declinognathodus marginodosus* and/or *Idiognathoides sulcatus parvus* indicates that the stage boundary occurs within the lower strata of the Snaky Canyon Formation (Skipp et al.'s (1979a) Bloom Member).

Occurrence

The initial appearance of *Declinognathodus marginodosus* and/or *Idiognathoides sulcatus parvus* occurs within all investigated localities of upper-Lower Pennsylvanian (Atokan) Snaky Canyon Formation. The *D. marginodosus/Id. sulcatus parvus* biozone occurs (from west to east) from meters 142 upwards (end of exposed strata) at the White Knob section, from the 112 m. to 129 m. interval at the VAH section; between 4 m. and 30 m. at the Hawley Mountain section, from the 108 m. to 122 m. interval at the Unknown Canyon section; and from 90 m. to 143 m. at the Gallagher Peak type section (Appendix II).

Biozone 7: *Neognathodus atokaensis* Biozone

Introduction

The middle Atokan *Neognathodus atokaensis* biozone was first defined by Grayson (1984) from Carboniferous strata located in the Arbuckle Mountains of southern Oklahoma. The *Neo. atokaensis* biozone has been recognized by paleontologists conducting studies in the western United States (Saelen, 2013); the U.S. midcontinent, (Grayson, 1984; Lambert et al., 2001; Lambert et al., 2002; Barrick et al., 2011), Brazil

(Nascimento et al., 2009), and the Donets Basin of Eastern Europe (Nemirovska and Alekseev, 1994)(Figure 25). *Neo. atokaensis* first appears just below the Bashkirian/Moscovian global stage boundary and the first occurrence of the species is chosen to represent definitive Atokan age strata (Menning et al., 2006).

The *Neognathodus atokaensis* biozone marks the lower-middle Atokan stage and stratigraphically occurs above the *Declinognathodus marginodosus/Idiognathoides sulcatus parvus* biozone and below the *Idiognathodus incurvus* biozone (Figure 25).

Limits

The lower limit of the *Neognathodus atokaensis* biozone is defined by the appearance of Middle Pennsylvanian (Atokan) species *Neo. atokaensis*. The upper limit of this biozone is marked by the appearance of *Idiognathodus incurvus*.

Characteristic species

Typical conodont species recovered in conjunction with *Neognathodus atokaensis* include; *Adetognathus lautus, A. spathus, A. gigantus, Declinognathodus marginodosus, D. noduliferous, D. lateralis, Diplognathodus coloradensis, Hindeodus minutus, Idiognathodus sinuosus, I. delicatus, I. klapperi, I. primulus, I. parvus, Idiognathoides sulcatus parvus, Id. sulcatus sulcatus, Id. ineaqualis, Id. sinuatus (late), Neognathodus bassleri bassleri, Neo. symmetricus, Rhachistognathus minutus minutus*, *Rh. prolixus*, and *Streptognathodus suberectus* (Figures 20-22).

Global Correlations

The *Neognathodus atokaensis* biozone of the Snaky Canyon

Formation overlaps with the middle of the global foraminifera biozone 21. This zone also is concurrent with the uppermost WB and WC ammonoid genozones marking the uppermost Bashkirian to lower Moscovian in the western European Faunal zonation framework (Nemirovska, 1999)(Figure 25).

Remarks

Neo. atokaensis is considered to be an index fossil marking the lower Atokan stage (Nascimento et al., 2005). Most workers use the presence of the *Neo. atokaensis* to identify lower-middle Atokan/uppermost Bashkirian strata and to further refine and support the biozones that they recognize (ie. *Neognathodus bassleri bassleri/Neo. columbiensis* biozones). Only limited workers (Grayson, 1984; Nemiroska and Alekseev, 1994) have used the first occurrence or range of *Neo. atokaensis* to define a biostratigraphic zone. Due to the widespread occurrence, limited range, and easily distinguishable morphology, this study recognizes the utility of using *Neo. atokaensis* to define a distinct biozone.

Diplognathodus coloradensis occurs at HM section 12m above first occurrence of *Neo. atokaensis*. The first appearance of species of *Diplognathodus* was once used to identify the Morrowan/Atokan boundary (Dunn, 1976; Lane 1977). More recent workers have proven this observation to be incorrect and extended the range of the facies controlled *Diplognathodus* species to stratigraphically older rocks (von Bitter and Merrill, 1990; Lambert et al., 2001).

The *Neognathodus atokaensis* biozone has been recognized globally as an indicator of lower-Middle Pennsylvanian age strata. The biozone represents the lower Atokan and likely spans the Bashkirian/Moscovian international stage boundary (Nemyrovska and Alekseev, 1994)(Figure 25). The initial appearance of *Neo. atokaensis* indicates that definitive Atokan age strata is preserved the lower-mid Snaky Canyon Formation (middle Bloom Member).

Occurrence

The initial appearance of *Neognathodus atokaensis* occurs within all investigated localities of Middle Pennsylvanian (Atokan) Snaky Canyon Formation. The *Neo. atokaensis* biozone occurs (from west to east) from meters 129 to 166 at the VAH section; between 30 m. and 60 m. at the Hawley Mountain section, from the 122 m. to 146 m. interval at the Unknown Canyon section; and from 143 m. to 216 m. at the Gallagher Peak type section (Appendix II).

Biozone 8: *Idiognathodus incurvus* Biozone

Introduction

The middle Atokan *Idiognathodus incurvus* conodont biozone was first defined by Grayson (1989/1991) from Carboniferous strata located in north-central Texas. The *I. incurvus* biozone and stratigraphic utility of *I. incurvus* has been defined and recognized by a limited amount of studies conducted on Middle Pennsylvanian strata, although the appearance of *I. incurvus* is considered to be a indicator of the middle and upper Atokan to lower Desmoinesian (Rexroad et al., 1997; Nascimento et al., 2005). The biozone has been identified in the midcontinental United States (Grayson et al., 1989; Grayson, 1991; and Lambert et al., 2001), Turkey (Ekmekci and Kozur, 1999), and the Amazonas Basin (Scomazzon, 1999; Lemos and Scomazzon, 2001)(Figure 25).

The *Idiognathodus incurvus* biozone marks the middle Atokan stage and stratigraphically occurs above the

Neognathodus atokaensis biozone and below the *Neo. bothrops* (columbiensis) biozone. It is likely that the *I. incurvus* biozone is the last conodont biozone identified by this study wholly contained within the Atokan stage boundaries (Figure 25).

Limits

The lower limit of the *Idiognathodus incurvus* biozone is marked by the initial appearance of Middle Pennsylvanian (Atokan) species *I. incurvus*. The upper limit of this zone is marked by the appearance of *Neognathodus bothrops (columbiensis)*.

Characteristic species

Typical conodont species recovered in conjunction with *Idiognathodus incurvus* include; *Adetognathus lautus*, *A. spathus*, *A. gigantus*, *Declinognathodus marginodosus*, *Diplognathodus coloradensis*, *Hindeodus minutus*, *Idiognathodus sinuosus*, *I. delicatus*, *I. klapperi*, *I. primulus*, *I. parvus*, *Idiognathoides sulcatus parvus*, *Id. ineaqualis*, *Id. sinuatus (late)*, *Neognathodus bassleri bassleri*, *Neo. atokaensis*, and *Streptognathodus suberectus* (Figures 20-22).

Global Correlations

The *Idiognathodus incurvus* biozone of the Snaky Canyon Formation overlaps with the upper limits of the global foraminifera biozone 21. This zone also is concurrent with the upper *Diaboloceras-Winslowoceras* and the lower P*aralegoceras-Eowellerites* ammoinod genozones marking the lower Moscovian of the western European megafaunal zonation (Ganelin and Durante, 2002)(Figure 25).

Remarks

Lambert et al. (2001) assigned the first appearance of *I. incurvus* to the lower Atokan. Based on the first occurrence of *I. incurvus* above that of lower Atokan conodont assemblages and stratigraphically above the first occurrence of *Neognathodus atokaensis* at all measured stratigraphic sections, it is determined that the initial appearance of the distinctive *I. incurvus* likely represents the middle Atokan within the Snaky Canyon carbonate succession. This observation is similar to that of Grayson et al. (1989), who recognized that the appearance of definitive *I. incurvus* specimens occurred in middle Atokan strata of north-central Texas. Studies conducted in Australia (Rexroad et al., 1997) and the Amazonian basin of Brazil (Nascimento et al., 2005; 2009) have also recognized the synchronous occurrence of *I. incurvus* with middle Atokan to lowermost Desmoinesian conodont assemblages. Limited studies conducted in Alaska have recovered *I. incurvus* in conjunction with *Rh. minutis minutis*, indicating a possible early Atokan age. These specimens were heavily abraded and the authors were speculative of this interpretation (Krumhardt et al., 1996).

The *Idiognathodus incurvus* biozone has not been recognized in other studies investigating the Carboniferous conodont successions of the western United States. This study represents the first proposal of this biozone for the Pennsylvanian of western Laurentia. Based on overlapping conodont occurrences and stratigraphic positioning combined with the comparison of other studies conducted in South America and the midcontinental United States, it is determined that the morphologically distinct *I. incurvus* represents the best available species for middle Atokan biozonation from the Snaky Canyon Formation of east-central Idaho.

Occurrence

The initial appearance of *Idiognathodus incurvus* occurs within all investigated localities of Middle Pennsylvanian (upper Atokan) Snaky Canyon Formation. The *I. incurvus* biozone occurs (from west to east) from meters 166 to 252 at the VAH section; between 60 m. and 131 m. at the Hawley Mountain section, from the 146 m. to 184 m. interval at the Unknown Canyon section; and from 216 m. to 236 m. at the Gallagher Peak type section (Appendix II).

Biozone 9: ***Neognathodus bothrops (columbiensis)*** Biozone

Introduction

The uppermost Atokan *Neognathodus bothrops (columbiensis)* biozone is a modified biozone that was first proposed by Merrill (1972) from rocks of the Appalachian Basin. This biozone and defined stratigraphic positioning was later utilized in studies conducted on Middle Pennsylvanian strata of the western U.S. (Barrie, 1975), the U.S. midcontinent (Lambert et al., 2001; Lambert et al., 2002), British Columbia (Orchard and Struik, 1985), Turkey (Ekmekci and Kozur, 1999), Russia (Gradstein et al., 2004), Korea (Lee, 1992), and Australia (Rexroad et al., 1997)(Figures 25 and 26).

The *Neognathodus bothrops (columbiensis)* biozone marks the upper Atokan to lowermost Desmoinesian stages and stratigraphically occurs above the *Idignathodus incurvus* biozone and below the *Neognathodus asymmetricus* biozone (Figures 25 and 26). It is likely that the *Neo. bothrops (columbiensis)* biozone spans the Atokan/Desmoinesian North American stage boundary within the Snaky Canyon Formation.

Limits

The lower limit of the *Neognathodus bothrops (columbiensis)* biozone is marked by the initial appearance of Middle Pennsylvanian (Atokan) specimens of *Neo. bothrops (columbiensis)*. The upper limit of this zone is marked by the appearance of *Neognathodus asymmetricus*.

Characteristic species

Typical conodont species recovered in conjunction with *Neognathodus bothrops (columbiensis)* include; *Adetognathus lautus, A. spathus, A. gigantus, Declinognathodus marginodosus, Diplognathodus coloradensis, Hindeodus minutus, Idiognathodus sinuosus (late), I. delicatus, I. klapperi, I. incurvus, I. parvus, Idiognathoides ineaqualis, Neognathodus bassleri bassleri, Neo. atokaensis, and Streptognathodus cancellosus* (Figures 20-22).

Global Correlations

The *Neognathodus bothrops (columbiensis)* biozone of the Snaky Canyon Formation overlaps with the upper limits of the global foraminifera biozone 21 and the lower limits of the global foram zone 22. This zone also is concurrent with the *Paralegoceras-Eowellerites* ammoinod genozone marking the middle Moscovian of the western European megafaunal zonation (Ganelin and Durante, 2002)(Figure 25).

Remarks

Lambert et al. (2001) grouped several upper Atokan morphotypes of *Neognathodus* (ie., Merrill's (1971) *Neo. pre-bothrops*, *Neo. bothrops)* containing relatively even, symmetrical upper surfaces into the revived species concept of *Neognathodus columbiensis* originally identified by Stibane

(1967). This concept has been adopted and this study recognizes the utility of merging all symmetrical and morphologically similar late Atokan to earliest Desmoinesian forms of *Neognathodus* into one designation.

The occurrence of the *Neognathodus bothrops (columbiensis)* biozone is recognized by the General Stratigraphic Scale of Russia as being indicative of the lower middle Moscovian international stage (Gradstein et al., 2004). During this time, it is commonly observed that *Declinognathodus* and *Idiognathoides* generas become extinct (Lambert et al., 2001). Although limited in abundance, specimens of *D. marginodosus* and *Id. ineaqualis* still occur synchronously with specimens of *Neo. bothrops (columbiensis)*. It is determined that in the Snaky Canyon Formation, the *Declinognathodus* and *Idiognathoides* generas become extinct within or near the basal Desmoinesian (the biozone 10: *Idiognathodus obliquus* biozone of this study).

The *Neognathodus bothrops* biozone has very limited recognition (Barrie, 1975) in other studies investigating the Carboniferous conodont successions of the western margin of Laurentia. This study represents the second proposal of this biozone for the Carboniferous of western Laurentia (first proposal by Barrie (1975)). Based on overlapping conodont occurrences and comparison with other studies conducted in the midcontinental and eastern United States, it is determined that the morphologically distinct *Neo. bothrops (columbiensis)* represents the best available species for upper Atokan to lowermost Desmoinesian biozonation within the Snaky Canyon Formation of east-central Idaho.

Occurrence

The initial appearance of *Neognathodus bothrops (columbiensis)* occurs within all investigated localities of Middle Pennsylvanian (upper Atokan) Snaky Canyon Formation. The *N. bothrops (columbiensis)* biozone occurs (from west to east) from meters 252 to 297 at the VAH section; between 131 m. and 168 m. at the Hawley Mountain section, from the 184 m. to 205 m. interval at the Unknown Canyon section; and from 236 m. to 250 m. at the Gallagher Peak type section (Appendix II)

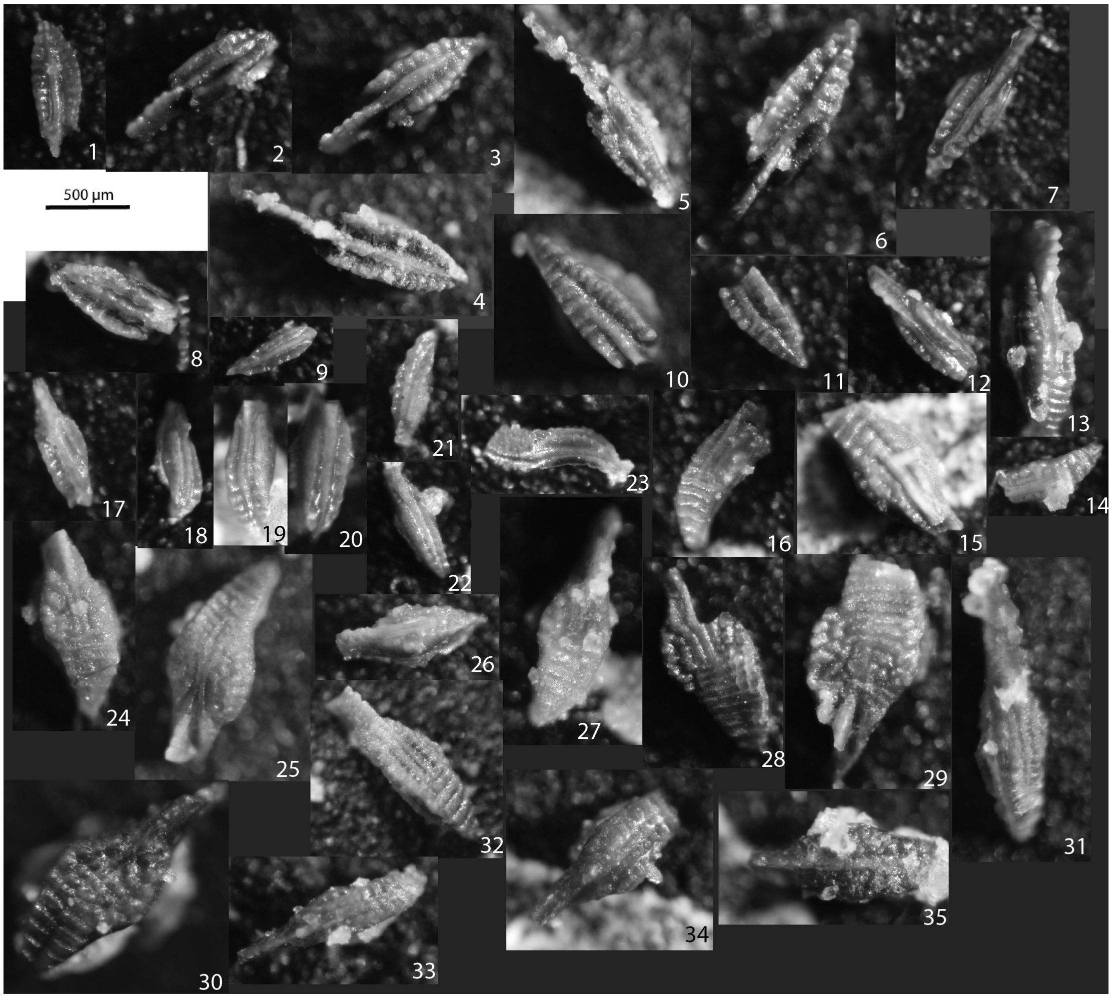


Figure 23: Plate IV conodonts: 1-5 *Neognathodus bothrops*; 6-12 *Neognathodus asymmetricus*; 13-16 *Idiognathodus obliquus*; 17 *Neognathodus roundyi*; 18-20 *Streptognathodus cancellosus*; 21-23 *Streptognathodus firmus*; 24-27 *Idiognathodus expansus*; 28-30 *Idiognathodus magnificus*; 31-33 *Idiognathodus* sp. *"X"*; 34-35 *Swadelina nodocarinata*. All specimen images are magnified 40x. All specimens taken using plain-light microscope combined with digital imaging.

Biozone 10: Neognathodus asymmetricus Biozone

Introduction

The lower Desmoinesian *Neognathodus asymmetricus* biozone is a modified biozone from the *Neognathodus*-based succession originally proposed by Merrill (1972) from rocks of the

Appalachian Basin. Lambert et al. (2001) proposed the renewal of the *Neognathodus asymmetricus* species concept of Stibane (1967) in order to eliminate stratigraphic issues surrounding the morphologically similar *Neo. medadaltimus* and *Neo. medexultimus* species for biostratigraphic application. Multiple workers have utilized the *Neo. asymmetricus* blanketed species for conodont based biozonation and as a indicator of stratigraphic location. These studies include those conducted in the midcontinental United States (Swade, 1985; Lambert et al., 2001; Lambert et al., 2002; Marshall, 2011), the eastern United States (Merrill, 1972), and the Donets Basin of eastern Europe (Alekseev et al., 2004; Alekseev and Goreva, 2006) (Figure 26).

The *Neognathodus asymmetricus* biozone marks the lower Desmoinesian stage and stratigraphically occurs above the *Neognathodus bothrops (columbiensis)* biozone and below the *Idiognathodus obliquus* biozone (Figure 26).

Limits

The lower limit of the *Neognathodus asymmetricus* biozone is marked by the initial appearance of Middle Pennsylvanian (lower Desmoinesian) species *Neo. asymmetricus* (Lambert et al., 2001). The upper limit of this zone is marked by the appearance of *Idiognathodus obliquus*.

Characteristic species

Typical conodont species recovered in conjunction with *Neognathodus asymmetricus* include; *Adetognathus lautus, A. spathus, A. gigantus, Diplognathodus coloradensis, Hindeodus minutus, Idiognathodus delicatus* (late)*, I. klapperi, I. incurvus, Neognathodus bassleri bassleri, Neo. bothrops (columbiensis), and Neo. atokaensis* (latest) (Figures 20-23).

Global Correlations

The *Neognathodus asymmetricus* biozone of the Snaky Canyon Formation overlaps with the upper global foraminifera biozone 22. This zone also is concurrent with the middle to upper *Paralegoceras-Eowellerites* ammoinod genozone marking the middle Moscovian of the western European megafaunal zonation framework (Ganelin and Durante, 2002)(Figure 26).

Remarks

The concept of *Neognathodus asymmetricus* recognized by this study eliminates the morphologically similar and inconsistently identified *Neo. medadultimus* and *Neo. medexultimus* species (Lambert et al., 2001). These morphological similarities have been noted by previous workers and discussions have addressed the synonymy of *Neo. medadultimus* and *Neo. medexultimus* (Savage and Barkeley, 1985). Recent studies by Lambert et al. (2001, 2002) have proposed the adoption and recognition of Stibane's (1967) species concept of *Neo. asymmetricus* in order to encompass all morphologically similar *Neognathids* and eliminate the subjective morphologic differences used to differentiate *Neo. medadultimus* from *Neo. medexultimus*.

The exact relationship of *Neognathodus medadultimus* and *Neo. medexultimus* cannot be discerned from the observed succession of Snaky Canyon strata in east-central Idaho. At the Unknown Canyon and Hawley Mountain sections, *Neo. medexultimus* occurs below the first occurrence of *Neo. medadultimus*. At the VAH and Gallagher Peak sections, the inverse occurs and *Neo. medadultimus* occurs stratigraphically below that of *Neo. medexultimus* (Appendix II). Due to this disparity in initial occurrence between the two morphologically similar species, the best way to represent the morphotypes is to place both in Lambert's (2001) *Neo. asymmetricus* conceptual species.

The occurrence of specimens of *Neognathodus asymmetricus* has been recognized as occurring in definitively lower Desmoinesian strata (Marshall, 2011; Lambert et al., 2001, 2002; Rexroad et al., 1997; Merrill, 1972). This biozone is the first wholly Desmoinesian age biozone recognized by this study. During this time, both the *Idiognathoides* genus and *Declinognathodus* genus become extinct in strata of the Snaky Canyon Formation succession.

Very little work has been conducted on stratigraphic successions of Western Laurentia during this time interval. No other workers conducting biostratigraphic investigations in the western United States have recognized and/or defined the stratigraphic utility of the *Neognathodus asymmetricus* biozone. By comparison of the conodont assemblages recovered from this time interval with other correlative studies conducted on stratigraphic successions in the U.S. midcontinent and the Donets Basin, it is determined that the first occurrence of *Neo. asymmetricus* represents the best available means for biozonation within the lower Desmoinesian of the Snaky Canyon Formation (Figure 26).

Occurrence

The initial appearance of *Neognathodus asymmetricus* occurs within all investigated localities of Middle Pennsylvanian (lower Desmoinesian) Snaky Canyon Formation. The *Neo. asymmetricus* biozone occurs (from west to east) from meters 297 to 321 at the VAH section; between 168 m. and 189 m. at the Hawley Mountain section, from the 205 m. to 228 m. interval at the Unknown Canyon section; and from 250 m. to 278 m. at the Gallagher Peak type section (Appendix II).

Biozone 11: *Idiognathodus obliquus* Biozone

Introduction

The middle Desmoinesian *Idiognathodus obliquus* conodont was first recognized and described by Kossenko and Kozitskaya (1978) from Pennsylvanian strata located within the Donets Basin of Eastern Europe. *I. obliquus* has been recognized as a cosmopolitan species and representative of the Desmoinesian (Boardman et al., 2004). The species has been utilized for biozonation and as an indicator of stratigraphic position in studies conducted upon Middle Pennsylvanian stratigraphic successions in the western United States (Stevens et al., 2001; Ritter et al., 2002), the midcontinental U. S. (Lambert, 1992; Boardman et al., 2004; Marshall, 2011), and in Eastern Europe (Nemyrovska et al., 1999; Ekmekci and Kozur, 1999; Goreva and Alekseev, 2001)(Figure 26).

The *Idiognathodus obliquus* biozone marks the lower-middle Desmoinesian stage and stratigraphically occurs above the *Neognathodus asymmetricus* biozone and below the *Idiognathodus expansus* biozone (Figure 26).

Limits

The lower limit of the *Idiognathodus obliquus* biozone is marked by the initial appearance of Middle Pennsylvanian (middle Desmoinesian) species *I. obliquus*. The upper limit of this biozone is marked by the appearance of *Idiognathodus expansus*.

Characteristic species

Typical conodont species recovered in conjunction with *Idiognathodus obliquus* include; *Adetognathus lautus, A. spathus, A. gigantus, Diplognathodus coloradensis, Hindeodus* *minutus, Idiognathodus delicatus* (late), *I. klapperi, I. incurvus, I. amplificus, Neognathodus bassleri bassleri, Neo. bothrops (columbiensis), Neo. asymmetricus, Neo. roundyi, Streptognathodus cancellosus* and *St. firmus* (Figures 20-23).

Global Correlations

The *Idiognathodus obliquus* biozone of the Snaky Canyon Formation is concurrent with the lower half of the *Pseudoparalegoceras-Wellerites* ammonoid genozone marking the middle to upper Moscovian of the western European megafaunal zonation (Ganelin and Durante, 2002)(Figure 26).

Remarks

The *Idiognathodus obliquus* conodont biozone of the Snaky Canyon Formation is a globally recognized stratigraphic interval of the Middle Pennsylvanian (Boardman et al., 2004; Ritter et al., 2002; and Goreva and Alekseev, 2001). Boardman et al. (2004) recognized the cosmopolitan occurrence of *I. obliquus* in middle Desmoinesian (upper Moscovian) stratigraphic successions through the comparison of conodont assemblages from work conducted on the Pennsylvanian of the midcontinental U.S. And Donets Basin in Eastern Europe (Goreva and Alekseev, 2001). Work completed in the Hermosa Basin of Utah by Ritter (2002) identified the *I. obliquus* biozone from middle Desmoinesian carbonates. Ritter et al.'s (2002) assemblage for this interval included late forms of *Neognathodus asymmetricus* and *I. meekerensis*, which closely resembles the *I. obliquus* concurrent assemblages recovered from the Snaky Canyon Formation by this study.

The *I. obliquus* biozone coincides a distinct shift in sedimentation to the east (Figure 39). The thickness of Snaky Canyon strata represented by the *I. obliquus* biozone greatly increases in the Unknown Canyon and Gallagher Peak sections (Figure 39). This phenomenon and a interpretation are discussed in the section on revised depositional trends of the Snaky Canyon Formation.

The initial occurrence of the morphologically distinct *Idiognathodus obliquus* occurs within the middle of the Snaky Canyon carbonate succession and is recognized at all localities with exposed Desmoinesian strata.

Occurrence

The initial appearance of *Idiognathodus obliquus* occurs within all investigated localities of Middle Pennsylvanian (Desmoinesian) Snaky Canyon Formation. The *I. obliquus* biozone occurs (from west to east) from meters 321 to 343 at the VAH section; between 189 m. and 211 m. at the Hawley Mountain section, from the 228 m. to 293 m. interval at the Unknown Canyon section; and from 278 m. to 347 m. at the Gallagher Peak type section (Appendix II).

Biozone 12: *Idiognathodus expansus* Biozone

Introduction

The upper Desmoinesian (upper-Middle Pennsylvanian) *Idiognathodus expansus* conodont species was first recognized by Stauffer and Plummer (1932) from the Pennsylvanian of Texas. This morphologically distinct species of *Idiognathodus* has been utilized by workers in the Paradox Basin of Utah (Ritter et al., 2002) and the midcontinental United States (Barrick and Walsh, 1999; Barrick et al., 1996) as an indicator of stratigraphic position within the upper-Middle Pennsylvanian (Figure 26). This study recognizes the *I. expansus* biozone as a taxon range zone and this concept is discussed in the remarks section.

The *Idiognathodus expansus* biozone marks the upper Desmoinesian stage and stratigraphically occurs above the *Idiognathodus obliquus* biozone and below the *I. magnificus* biozone (Figure 26).

Limits

The lower limit of the *Idiognathodus expansus* biozone is marked by the initial appearance of Middle Pennsylvanian (upper Desmoinesian) species *I. expansus*. The upper limit of this zone is marked by the extinction of *I. expansus* and the first initial appearance of *I. magnificus*.

Characteristic species

Typical conodont species recovered in conjunction with Idiognathodus obliquus include; *Adetognathus lautus, A. spathus, A. gigantus, Diplognathodus coloradensis, Hindeodus minutus, Idiognathodus klapperi (late), I delicatus (late), I. incurvus, I. amplificus, I. meekerensis, I. obliquus, I. claviformus, Neognathodus asymmetricus, Neo. roundyi, Streptognathodus cancellosus* and *St. firmus* (Figures 20-23).

Global Correlations

The *Idiognathodus expansus* biozone of the Snaky Canyon Formation is concurrent with the lower *Dunbarites-Parashumardites* ammonoid genozone marking the lowermost Kasimovian Global Stage of the western European megafaunal zonation framework (Ganelin and Durante, 2002)(Figure 26).

Remarks

Studies of Pennsylvanian midcontinental stratigraphic successions and their associated conodont assemblages have indicated that the full range of *Idiognathodus expansus* is likely restricted to the upper Desmoinesian. Heckel (1999) reported the initial occurrence and full taxon range of *I. expansus* from the Marmonton sequence of the upper Desmoinesian. Barrick et al. (1996) also reported a similar taxon range zone for *I. expansus* from the upper Desmoinesian of the U.S. midcontinent. Both of these studies revealed the synchronous demise of *I. expansus* and *Neognathodus* species at the top of the Marmonton sequence. This extinction event within the uppermost Desmoinesian has been recognized throughout the U.S. midcontinent (Boardman and Barrick, 1999) and may be used for stratigraphic positioning within the Snaky Canyon Formation.

During the stratigraphic interval represented by the *I. expansus* biozone, recovered assemblages were heavily dominated by specimens of *I. expansus*. A similar phenomenon was also observed by Ritter et al. (2002) from studies conducted on Middle to Upper Pennsylvanian strata within the Paradox Basin of Utah. This rapid rise of *I. expansus* combined with the abrupt extinction of the species may be used as a stratigraphic indicator of the upper Desmoinesian. Further studies will be required from additional localities in order to correlate and define this phenomenon along the western Laurentian margin.
Regionally.

Occurrence

The initial appearance of *Idiognathodus expansus* occurs within all investigated localities of Middle Pennsylvanian (upper Desmoinesian) Snaky Canyon Formation. The *I. expansus* biozone occurs (from west to east) from meter 343 to the end of exposure at the VAH section; between 211 m. and 234 m. at the Hawley Mountain section, from the 293 m. to 337 m. interval at the Unknown Canyon section; and from 347 m. to 468 m. at the Gallagher Peak type section (Appendix II).

Biozone 13: *Idiognathodus magnificus* Biozone

Introduction

The use of the initial occurrence of *Idiognathodus magnificus* as a stratigraphic indicator has been recognized by workers conducting studies in the western United States (Ritter et al., 2002), the midcontinent (Barrick and Walsh, 1999; Heckel, 2002; Boardman and Barrick, 2013), and in Asia (Barrick et al., 2013)(Figures 26 and 27). This study recognizes the morphologically distinct *I. magnificus* as a stratigraphic indicator from the upper Bloom Member of the Snaky Canyon Formation.

The *I. magnificus* biozone marks the uppermost Desmoinesian to lowermost Missourian stages and stratigraphically occurs above the *I. expansus* biozone and below the *I.* sp. *"X"* biozone (Figures 26 and 27)

Limits

The lower limit of the *Idiognathodus magnificus* biozone is marked by the initial appearance of Upper Pennsylvanian (lower Missourian) species *I. magnificus*. The upper limit of this zone is marked by the first initial appearance of *I*. sp. *"X"*.

Characteristic species

Typical conodont species recovered in conjunction with *Idiognathodus magnificus* include; *Adetognathus lautus*, *A. spathus*, *A. gigantus*, *Diplognathodus coloradensis*, *Hindeodus* *minutus*, *Idiognathodus sulciferous*, *I. eccentricus*, *I. sp. A*, *Streptognathodus cancellosus*, *St. elegantulus*, and *St. firmus* (Figures 20-23).

Global Correlations

The *Idiognathodus magnificus* biozone of the Snaky Canyon Formation is concurrent with the lower *Dunbarites-Parashumardites* ammonoid genozone marking the lower Kasimovian Global Stage of the western European megafaunal zonation framework (Ganelin and Durante, 2002)(Figures 26 and 27).

Remarks

At the base of the *Idiognathodus magnificus* biozone of the Snaky Canyon Formation, the *Neognathodus* genus becomes extinct (Boardman and Barrick, 1999; Heckel et al., 2002). *I. delicatus* and *I. expansus* also becomes extinct directly below the first appearance of *I. magnificus* within the Snaky Canyon succession. This phenomenon has been reported by previous workers (Boardman and Barrick, 1999; Heckel et al., 2002) as the Desmoinesian/Missourian extinction event and has been widely recognized across the midcontinental United States.

Grayson et al. (1989) reported the first initial occurrence of *Idiognathodus magnificus* directly at or just below the Desmoinesian/Missourian North American Stage Boundary within the midcontinental United States. Recent midcontinental work conducted by Boardman and Barrick (2013) and Barrick (2002) reported on a likely early to middle Missourian age of first occurrence of *I. magnificus*. During this time (Upper Pennsylvanian) within the midcontinent, major glacially driven eustatic fluctuations may have controlled the distribution and occurrence of specific conodont species (Roscoe, 2009). Based on the first occurrence of *I.*

magnificus directly above the last occurrence of *Neognathodus* and *I. expansus* within the Snaky Canyon Formation, it is determined that *I. magnificus* likely represents the uppermost Desmoinesian and spans the Desmoinesian/Missourian stage boundary (Figure 27).

Limited specimens of *I. eccentricus* were recovered from one sample interval at one locality (the Gallagher Peak type section) of the Snaky Canyon Formation. Heckel (2002) has proposed using the first occurrence of *I. eccentricus* to mark the Desmoinesian/Missourian stage boundary across the North American continent. Due to the limited recovery of this species, this study can only use the presence of *I. eccentricus* as further evidence to establish the stratigraphic position of *I. magnificus*.

Based on the conodont assemblages recovered in conjunction with *I. magnificus*, the limited occurrence of *I. eccentricus*, and the decline of *Neognathodus* species, *I. delicatus*, and *I. expansus*, it is determined that *I. magnificus* first appears in uppermost Desmoinesian to lowermost Missourian age Snaky Canyon Formation strata. This study recognizes the first occurrence of *I. magnificus* as a general indicator of the Desmoinesian/Missourian stage boundary (Figures 26 and 27).

Occurrence

The initial appearance of *Idiognathodus magnificus* occurs within all investigated localities of Middle Pennsylvanian (upper Desmoinesian) Snaky Canyon Formation. The *I. magnificus* biozone occurs (from west to east) from meter 234 to 249 at the Hawley Mountain section, from the 337 m. to the end of exposure at the Unknown Canyon section; and from meters 468 to 516 at the Gallagher Peak type section (Appendix II).

Biozone 14: *Idiognathodus* sp. *"X"* Biozone

Introduction

The *Idiognathodus* species *"X"* identified by this study is a morphologically distinct form of *Idiognathodus* of relatively unknown affinity. A full discussion of the Snaky Canyon *I.* sp. *"X"* and a possible assignment of species based on recent discoveries from the U.S. midcontinent is included in the following remarks section.

The *I.* sp. *"X"* biozone of the Snaky Canyon Formation likely indicates a lower Missourian stage assignment and stratigraphically occurs above the *I. magnificus* biozone and below the *Swadelina nodocarinata* biozone (Figure 27)

Limits

The lower limit of the *Idiognathodus* sp. *"X"* biozone is marked by the initial appearance of Upper Pennsylvanian (lower Missourian) species *I.* sp. *"X"*. The upper limit of this zone is marked by the first initial appearance of *Swadelina nodocarinata*.

Characteristic species

Typical conodont species recovered in conjunction with *Idiognathodus* sp. *"X"* include; *Adetognathus lautus*, *A. spathus*, *A. gigantus*, *Hindeodus minutus*, *Idiognathodus sulciferous*, *I. magnificus*, *I. eccentricus*, *Streptognathodus cancellosus*, *St. elegantulus*, *St. pawhuskaensis*, and *St. firmus* (Figures 20-23).

Global Correlations

The *Idiognathodus* sp. *"X"* biozone of the Snaky Canyon Formation is most likely concurrent with the middle

Dunbarites-Parashumardites ammonoid genozone marking the lower Kasimovian Global Stage of the western European megafaunal zonation framework (Ganelin and Durante, 2002)(Figure 27).

Remarks

The morphologically distinct species of *Idiognathodus* designated initially by this study as *I.* sp. *"X"* is characterized by a relatively elongated and flat platform marked by transverse ridges that are often partially disrupted by a very shallow caudal central groove. In the specimens identified by this study, the straight adcarinal ridges are parallel and equal in length to the medial carina. The rostral lobes are diminished and have only slight ornamentation that occurs in a single row as round nodes. The dorsal margin of the platform is sharply pointed and all specimens recovered were of diminished size in comparison with other forms of *Idiognathodus* or *Swadelina* concurrently recovered.

The informally named *Idiognathodus* sp. *"X"* recognized by this study was originally identified as an unknown Upper Pennsylvanian *Idiognathodus* species when reconnaissance samples were taken directly below the Gallagher Sandstone Member. Later comparison with recent studies conducted on the Upper Pennsylvanian of the midcontinental United States revealed that the *I.* sp. *"X"* shared similar affinities with juvenile specimens of Roscoe and Barrick's (2008) recently identified *I. swadei*. From comparison of the recovered specimens from the Snaky Canyon Formation to those of Roscoe and Barrick (2009), it is likely a majority of the specimens identified by this study as *I.* sp. *"X"* are likely juvenile forms of *I. swadei*. This study choses to retain the *I.* sp. *"X"* designation until further information and specimens are available to confirm an *I. swadei* assignment.

Roscoe (2008) reported from a succession of U.S. midcontinental strata that *Sw. nodocarinata* first appears one sequence below that of the uppermost *I. swadei (I.* sp. "X") biozone recognized by his study. Assuming that the *I.* sp. *"X"* cf. *swadei* is correlative with Roscoe's *I. swadei*, it is determined that there is a likely delay in occurrence of *Sw. nodocarinata*. This phenomenon is discussed in the *Swadelina nodocarinata* biozone.

Occurrence

The initial appearance of *Idiognathodus* sp. *"X"* occurs within two investigated stratigraphic sections of Upper Pennsylvanian (lower Missourian) Snaky Canyon Formation. The *I.* sp. *"X"* biozone occurs (from west to east) from meter 249 to 278 at the Hawley Mountain section and from meters 516 to 578 at the Gallagher Peak type section (Appendix II).

Biozone 15: *Swadelina nodocarinata* Biozone

Introduction

The conodont species *Swadelina nodocarinata* was first recognized by Lambert et al. (2003) from the Upper Pennsylvanian of the midcontinent. Studies conducted in the western U.S. (Ritter et al. 2002), the midcontinental U.S. (Barrick et al., 1996; Heckel, 2002; Lambert et al., 2003), and Russia (Alekseev et al., 2004) have recognized the utility of *Sw. nodocarinata* or it's correlatives (see Remarks section in the proceeding text) as a stratigraphic indicator for the Upper Pennsylvanian (Figure 27).

The *Sw. nodocarinata* biozone of the Snaky Canyon Formation likely indicates a lower Missourian stage assignment and stratigraphically occurs above the *Idiognathodus* sp. *"X"* biozone and the upper limit is not defined by this study (Figure 27).

Limits

The lower limit of the *Swadelina nodocarinata* biozone is marked by the initial appearance of Upper Pennsylvanian (lower Missourian) species *Sw. nodocarinata*. The upper limit of this biozone is marked by the termination of exposed Snaky Canyon Formation strata and is not defined by this study.

Characteristic species

Typical conodont species recovered in conjunction with *Swadelina nodocarinata* include: *Adetognathus lautus, A. spathus, A. gigantus, Hindeodus minutus, Idiognathodus sulciferous, I. magnificus, I. sp. "X", Streptognathodus cancellosus, St. elegantulus,St. pawhuskaensis*, and *St. firmus* (Figures 20-23).

Global Correlations

The *Swadelina nodocarinata* biozone of the Snaky Canyon Formation is most likely concurrent with the middle to lower-upper *Dunbarites-Parashumardites* ammonoid genozone marking the lower Kasimovian Global Stage of the western European megafaunal zonation framework (Ganelin and Durante, 2002) (Figure 27).

Remarks

At the midcontinental United States, workers have placed *Swadelina nodcarinata* at the uppermost Desmoinesian to lowermost Missourian (Barrick et al., 2004). This biozone likely occurs solely within the lowermost Missourian of the Snaky Canyon. The first appearance of *Sw. nodocarinata* in the uppermost Bloom Member occurs within strata determined by Skipp et al. (1979a) to be of uppermost Desmoinesian to lower Missourian on the basis of recovered foraminifera and megafauna. Skipp et al.'s (1979a) work identified the lower-Upper Pennsylvanian (lower Missourian) fusulinid assemblage *Fusulinella* sp., *Eowaeringella* sp., *Millerella* sp., and *Triticites* sp. from the uppermost Snaky Canyon carbonates exposed at the Gallagher Peak type section and within the Arco Hills (Figure 13). This is the same interval in which *Sw. nodocarinata* first appears and combining this with the first occurrence of *Sw. nodocarinata* above *I. magnificus*, it is likely that the biozone represents lower Missourian (Upper Pennsylvanian) age strata. This observation also partially overlaps with Ritter's et al.'s (2002) first occurrence of *Idiognathodus nodocarinatus* from the Paradox Basin of Utah at the Desmoinesian/Missourian stage boundary. *I. nodocarinatus* was the original designation for the morphologically distinct *Sw. nodocarinata* prior to the adoption of the *Swadelina* genus by Lambert et al. (2003).

Roscoe (2005) reported on the initial occurrence of *Sw. nodocarinata* below that of *Idiognathodus expansus* from the Lost Branch Formation in Kansas and Oklahoma. This relationship has not been observed in the Snaky Canyon stratigraphic succession and *Sw. nodocarinata* occurs stratigraphically above *I. expansus* at all investigated localities with upper Desmoinesian to lower Missourian strata exposed. Barrick et al. (1996) also recognized that *I. expansus* first appears directly below *Sw. nodocarinata* from strata of the northern U.S. midcontinent.

Paleontologists in Russia recognized the first occurrence of *Swadelina makhlinae* at the Desmoinesian/Missourian boundary (Alekseev et al., 2004). It is likely that this biozone correlates with the *Swadelina nodocarinata* biozone of Barrick et al. (2004) located at the midcontinental United States (Alekseev et al., 2004). This reported relationship combined with that observed by Roscoe (2005, 2008) indicates that the initial occurrence of *Sw. nodocarinata* is likely delayed or restricted along the western margin of Laurentia during the Late Pennsylvanian. This concept deserves increased investigation before definitive relationships can be established and it is clear from conflicting reports that significant disparities exist when determining stratigraphic positioning of conodont biozones during this time interval.

Heckel et al. (2002) reported on the extinction of the genus Swadelina at the upper Desmoinesian of the U.S. midcontinent. Due to the initial occurrence of *Sw. nodocarinata* above the last occurrence of species of *Neognathodus, I. expansus,* and *I delicatus*, it is determined that *Swadelina* has no relation to the upper Desmoinesian extinction event and that the termination of the genus at the midcontinent may be a regional phenomenon. The observations from the Snaky Canyon are similar to that of Ritter et al.'s (2002) *I. nodocarinatus*, which spans the Desmoinesian/Missourian stage boundary in the Paradox Basin of Utah.

The *Sw. nodocarinata* biozone is the uppermost biozone recognized from the Snaky Canyon Formation by this study. There is no upper limit currently identified for this biozone, although it likely occurs within the Gallagher Peak Sandstone Member at the type section. At the Gallagher Peak type section in the Beaverhead Range, the *Sw. nodocarinata* biozone indicates that the age of the Bloom Member/Gallagher Peak Member contact is of lower Missourian age (Figure 31).

Occurrence

The initial appearance of *Swadelina nodocarinata* occurs within two investigated stratigraphic sections of Upper Pennsylvanian (Missourian) Snaky Canyon Formation. The *Swadelina nodocarinata* biozone occurs (from west to east) from meter 278 to the end of exposure (322 m.) at the Hawley Mountain section and from meters 578 to the end of exposure (619 m.) at the Gallagher Peak type section (Appendix II).

Conodont Biostratigraphy of the Snaky Canyon Formation: North American Stages and Stage Boundaries

The Morrowan

Lane (1967) proposed the first Morrowan conodont based biozonation from strata located in northwestern Arkansas. By 1971, Lane, Merrill, Straka, and Webster established and applied several biozonation successions from Lower Pennsylvanian strata in the midcontinental and western United States. The conodont biozonation established by these studies provided the background for all subsequent workers and defined the boundaries of the Morrowan using standards recognized by this study. Morrowan strata is first recognized by the first initial appearance of *Rhachistognathus primus* and the upper boundary is defined by the first occurrence of *Idiognathoides sulcatus parvus* and/or *Declinognathodus marginodosus* (Figure 24).

The beginning of the Morrowan of the Snaky Canyon Formation is defined by the first occurrence of *Rh. primus* and termination of the series is defined by the first occurrence of Atokan species. The biostratigraphic framework identified closely resembles that of the type Morrowan conodont biozonation proposed by Lane (1977) for correlative strata of the midcontinent and also overlaps with biozones defined by recent workers conducting studies on the Donets Basin in Eastern Europe (Nemyrovska, 1999). It is believed that the Morrowan/Atokan boundary occurs near the initial occurrence of the *Declinognathodus marginodosus/Id. sulcatus parvus* biozone and that the first appearance of *Neo. atokaensis* occurs within the lower Atokan series.

The Morrowan conodont biozones identified by this study are concurrent or partially concurrent with biozones established and defined by workers studying the Carboniferous in the western United States (Dunn, 1970b; Baesemann and Lane, 1985; Lane et al., 1985; Krumhardt et al., 1996; Webster, 1984; Webster and Langeneheim, 1979; and Davis and Webster, 1984). Studies conducted in the midcontinent (Lambert et al., 2001; Lane, 1967; and Grayson et al., 1989), Europe (Higgins, 1975; Higgins and Austin, 1985; Perret, 1993; and Nemyrovska, 1999), the Donets Basin (Nemyrovska, 1999; Nemirovska and Alekseev, 1994; Barskov, 1984; and Groves et al., 1999), and China (Wang et al., 1985; and Wang and Higgins, 1989) have also delineated and defined Morrowan (Lower Pennsylvanian) conodont biozones correlative or partially correlative to the biozones established for the Snaky Canyon Formation (Figure 24).

The strata of the Snaky Canyon is generally devoid of Morrowan species of *Neognathodus*. Studies conducted on Morrowan strata of the U.S. midcontinent have identified several biozones for this time frame based on the occurrences of *Neognathodus* genera (Lane, 1977; Lane et al., 1985; Lambert, 2001; Lambert, 2002). Only limited specimens of *Neo. bassleri bassleri* were recovered from Morrowan strata of the

Snaky Canyon Formation.

This study proposes the recognition of five previously recognized biozones from the Morrowan stratigraphic interval of the Snaky Canyon Formation. From the lower to upper Morrowan, the biozones are the *Rh. primus* biozone, the *D. noduliferous* biozone, the *Id. sinuatus* biozone, the *I. sinuosus* biozone, and the *St. suberectus* biozone (Figure 24).

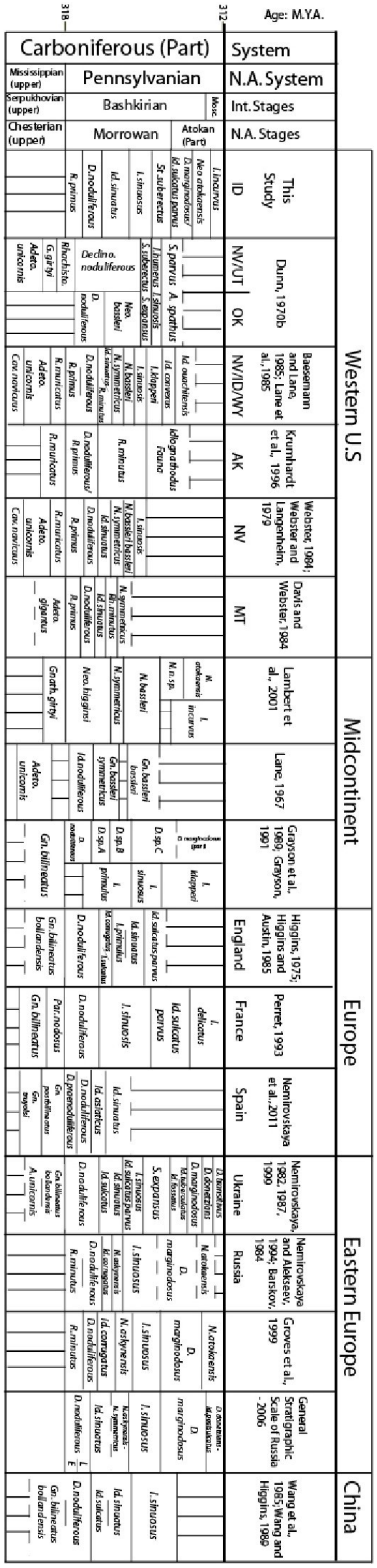


Figure 24: Comparison of Morrowan conodont biozones of previous workers and identified by this study.

The Morrowan/Atokan Stage Boundary

The Morrowan/Atokan stage boundary is poorly defined at the midcontinent due to the lack of adequate stage boundary definition and stratigraphically disrupted biostratigraphic information recovered from the Atokan type section (Lane and West, 1984; Lambert et al., 2001). The biostratigraphic analysis of the Snaky Canyon Formation in east-central Idaho offers the opportunity to document conodont assemblages recovered from a relatively continuous succession of open marine carbonates deposited across the Morrowan/Atokan boundary. The Snaky Canyon may represent the best complete section of upper Morrowan to lower Atokan strata for study in the western and midcontinental United States.

Paleontologists have used the appearance of *Declinognathodus marginodosus, Idiognathodus incurvus,* and *Neognathodus atokaensis* to define the Morrowan/Atokan stage boundary. In this study, the occurrence of *D. marginodosus* and the synchronously occurring *Idiognathoides sulcatus parvus* are chosen to define the transition into Atokan age strata. See the preceding text describing Biozone 6: *D. marginodosus/Id. sulcatus parvus* biozone for a full description and list of previous workers that used this assemblage to define the Morrowan/Atokan stage boundary.

Lambert (2002) and Lambert et al. (2001) established the Morrowan/Atokan boundary based on the first initial appearance of *Idiognathodus incurvus*. The assemblages recovered from the Snaky Canyon Formation indicate that the first appearance of *I. incurvus* occurs stratigraphically above that of lower Atokan species such as *D. marginodosus, Id. sulcatus parvus,* and *Neo. atokaensis*. It is determined that the initial occurrence of *I. incurvus* along the western margin of

Laurentia represents middle to upper Atokan age. This stratigraphic disagreement may be the result of delayed *Idiognathodus incurvus* emergence along the western margin, unlikely biofacies control, and/or condensed intervals within the midcontinent. The work of Grayson et al. (1989) established a middle to upper Atokan initial appearance for *I. incurvus* within the U.S. midcontinent and this relationship is correlative to the data recovered from the Snaky Canyon Formation.

The *Neognathodus atokaensis* biozone was first defined by Grayson (1984) from the Atokan succession of U.S. midcontinental strata. *Neo. atokaensis* initially was used to define the Morrowan/Atokan stage boundary, although later workers in the midcontinent and Eastern Europe recognized that the initial appearance of *Neo. atokaensis* likely occurred within strata of middle Atokan age (Nemirovska and Alekseev, 1994; Groves et al., 1999; Lambert et al., 2001). From the stratigraphic position of the first occurrence of *Neo. atokaensis* in the Snaky Canyon stratigraphically above that of *Declinognathodus marginodosus*, *Idiognathoides sulcatus parvus*, and *Idiognathodus delicatus* and combined with the concurrent stratigraphic occurrence with *I. klapperi* it is determined that the first initial appearance of *Neo. atokaensis* represents deposition during the middle Atokan stage.

The Atokan

The section of Atokan age carbonates preserved in the Snaky Canyon Formation is likely one of the most complete successions of continuously deposited Atokan age carbonate rocks available for study in the United States. Other strata located in the midcontinent and the southwestern United States records periods of emergence, nondeposition, nonmarine deposition, and/or deposition dominated by siliciclastics (Grayson, 1984; Saelens et al., 2013). Only limited indicators of hiatuses and proximal shore facies do exist in the form of carbonate hardgrounds and fine sandstone intervals within Atokan age Snaky Canyon Formation strata (Appendix I and II).

To date, there have been limited conodont based biostratigraphic studies reporting on the Atokan of western North America. Studies conducted in Alaska (Savage and Barkeley, 1985; Krumhardt et al., 1996) and preliminary studies from the lower Atokan of Nevada and Idaho (Groves et al., 1999) have identified limited biostratigraphic assemblages and stratigraphic relationships. Most domestic work has focused on the Atokan of the U.S. midcontinent (Landing and Wardlaw, 1981; Grayson, 1984; Manger and Sutherland, 1984; Lambert et al., 2001; Lambert et al., 2008; Marshall, 2011). Merrill (1972) established a succession of Atokan *Neognathodus* species from the Pennsylvanian of the eastern United States. Recent work from eastern Europe (Groves et al., 1999; Nemyrovska, 1999) and Brazil (Nascimento et al., 2005) has provided a age correlative biostratigraphic framework outside of North America (Figure 25).

Lambert et al. (2001) recognized three biozones from the Atokan of the U.S. midcontinent; the lowermost*Idiognathodus incurvus* biozone, the *Neognathodus atokaensis* biozone (Merrill, 1972) of lower-middle Atokan, and the upper Atokan *Neognathodus columbiensis* biozone that was proposed by the study. Earlier midcontinental work by Grayson (1991) and Grayson et al. (1989) identified three biozones; the lower Atokan *I. klapperi* biozone, the lower to middle Atokan *Declinognathodus marginodosus* biozone, and the upper Atokan *I.*

incurvus biozone. Recent work conducted on the Atokan of the Donets Basin in Eastern Europe proposed three conodont based biozones based on the initial occurrence of *D. marginodosus*, *D. donetzians/Id. postsulcatus*, and *St. transitivus* (Nemyrovska, 1999)(Figure 25). These studies were influential in the proposal of the Snaky Canyon Formation biozones identified and several of the biostratigraphic relationships reported by these studies are correlative with that observed in the Snaky Canyon succession of Idaho.

No Atokan gondolellids (ie *Mesogondolella* sp.) were recovered from the Snaky Canyon Formation. Previous studies conducted in the midcontinent (von Bitter and Merrill, 1977) and Japan (Koike, 1967) recognized the occurrence of gondolellids within the *Neognathodus atokaensis* biozone. Lambert et al. (2001) recognized that the occurrence of gondellids was extremely limited within the Atokan stage of the United States and that appearances were rare and discontinuous.

Neognathodids greatly increase in diversity and occurrence as the Snaky Canyon Formation progresses upwards into Desmoinesian age strata. This observation is true for all sections recording the complete Atokan except for the farthest west White Knob section. Similar patterns of *Neognathodus* diversification and stabilization has been documented from the eastern United States by Merrill (1972) and from the midcontinent (Lambert et al., 2001).

This study proposes four biozones from the Atokan stratigraphic interval of the Snaky Canyon Formation. These biozones, in stratigraphic order from lower to upper Atokan, are the *D. marginodosus/Id. sulcatus parvus* biozone, the *Neo. atokaensis* biozone, the *I. incurvus* biozone, and the *Neo. bothrops (columbiensis)* biozone (Figure 25).

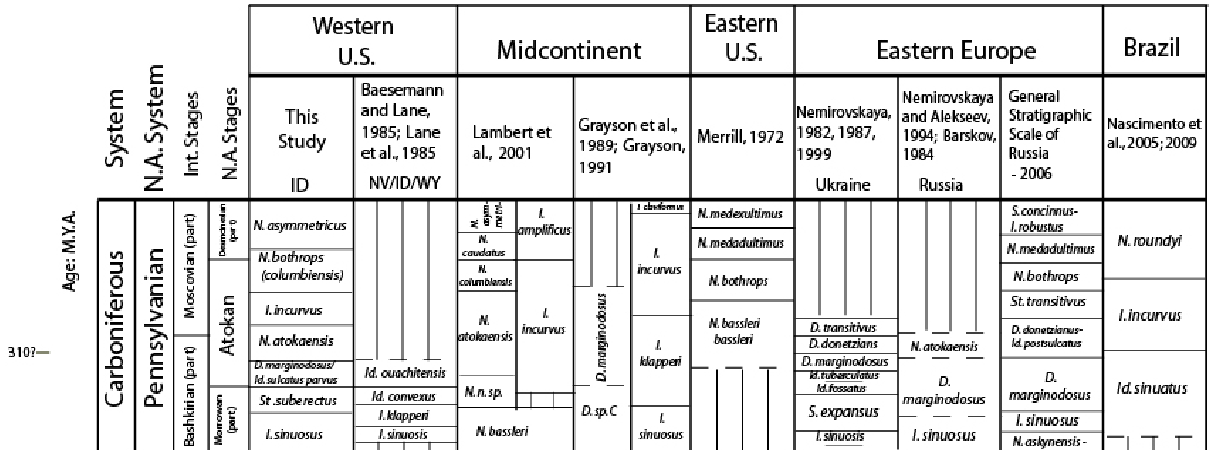


Figure 25: Comparison of Atokan conodont biozones identified by this study and of previous workers.

The Atokan/Desmoinesian Stage Boundary

The exact location and the definition of the Atokan/Desmoinesian stage boundary is not easily placed or universally recognized. In this study, the boundary occurs within the upper Biozone 9: *Neognathodus bothrops (columbiensis)* biozone. Lambert et al. (2001 and 2002) placed the Atokan/Desmoinesian stage boundary at the first occurrence of *Neognathodus caudatus*. *Neo. caudatus* is absent from all sampled localities of the Snaky Canyon Formation and the lower Desmoinesian *Neo. asymmetricus* biozone is directly above the *Neo. bothrops (columbiensis)* biozone. It is therefore concluded that the stage boundary likely lies within the uppermost *Neo. bothrops (columbiensis)* biozone.

Merrill (1971) used the first occurrence of *Neognathodus medadultimus* to mark the Atokan/Desmoinesian stage boundary in Appalachian foreland basin strata of eastern Ohio. *Neo. medadultimus* is included in the species concept of *Neo. asymmetricus* proposed by Lambert (2001) and recognized by this study to eliminate confusion surrounding similar morphotypes of this genus (see biozone 10 remarks in the preceding text). Based on the systematic definition of *Neo. medadultimus* and *Neo. medexultimus*, there is no overlap in occurrence between measured sections of the Snaky Canyon Formation and no hierarchy can therefore be definitively established for recognizing these two species as independent of the other.

The Desmoinesian

The conodont biozonation established for the Desmoinesian of the Snaky Canyon Formation is dominated by species of *Idiognathodus*. *Idiognathodus* species become increasingly diversified during this stratigraphic interval and similar patterns have been observed by workers in the western (Barrick et al., 2002; Ritter et al., 2002) and the midcontinental United States (Lambert et al., 2001; Grayson et al., 1989; Barrick and Heckel, 1996; Heckel, 2002; Boardman et al., 2004; Roscoe, 2005, 2008) United States (Figure 26).

The late Desmoinesian extinction event described by Heckel et al. (2002) and Boardman and Barrick (1999) marks the termination of the *Neognathodus* genus and the *Idiognathodus* species *I. delicatus* and *I. expansus*. This event is recognized within the Snaky Canyon Formation and occurs at the lowermost *I. magnificus* biostratigraphic interval. Limited species of *Neognathodus* were recovered in conjunction with the *I. expansus* biozone, as were specimens of *I. delicatus*. At the contact of the *I. expansus* and *I. magnificus* biozones, *I. expansus*, *I. delicatus*, and all *Neognathodus* species become extinct within the Snaky Canyon Formation.

This study proposes four Desmoinesian age biozones and one partial Desmoinesian biozone from the Snaky Canyon stratigraphic succession. These biozones and/or the stratigraphic interval of the species that defines each biozone have been previously recognized and reported. These biozones, in decreasing age from lowermost Desmoinesian to uppermost Desmoinesian, are the *Neo. asymmetricus* biozone, the *I. obliquus* biozone, the *I. expansus* biozone, and the *I. magnificus* biozone (Figure 26).

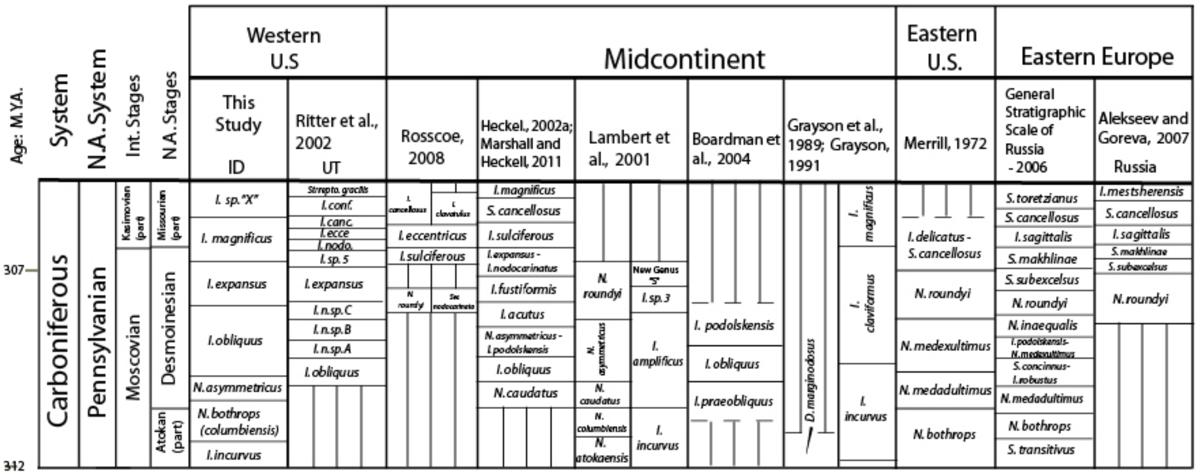


Figure 26: Comparison of Desmoinesian conodont biozones identified by this study and of previous workers.

The Desmoinesian/Missourian Stage Boundary

At present, there is ongoing debate surrounding the exact stratigraphic positioning of the Desmoinesian/Missourian stage boundary (Barrick et al., 1996; Heckel, 2002). Heckel (2002) proposed a new stage boundary based on the first initial occurrence of *I. eccentricus*. Recovery of *I. eccentricus* from the Snaky Canyon Formation is restricted and limited specimens from one horizon occurred just above the first occurrence of *I. magnificus* at the Gallagher Peak locality. As a result of this occurrence, it is determined that the stage boundary may occur directly above the first occurrence of *I. magnificus* within the Snaky Canyon stratigraphic succession.

Boardman and Barrick (1999) reported a late Desmoinesian extinction event just below the Desmoinesian/Missourian boundary from the Pennsylvanian of the U.S. midcontinent. Assuming that this absence of *Neognathodus* species, *Idiognathodus delicatus*, and *I. expansus* from the *I. magnificus* biozone is a global phenomenon, it is recognized that the *I. magnificus* biozone represents the uppermost Desmoinesian to lower Missourian. Heckel (2002) recognized a lower Missourian only occurrence of *I. magnificus*. Within the Snaky Canyon Formation, *I. expansus* occurs directly above the last occurrence of *I. expansus* and *Neognathodus* and likely initially appears in slightly older strata that at the midcontinent. This study proposes to use the initial occurrence of *I. magnificus* as a general indicator of the Desmoinesian/Missourian stage boundary within the Snaky Canyon Formation.

The Missourian

The conodont biozonation proposed by this study for the Missourian stratigraphic interval of the Snaky Canyon Formation only represents the lower third of the stage. One partial, one complete, and one incomplete Missourian biozone have been proposed and due to the termination of available exposure, these biozones only represent a limited duration of the lower Missourian (Figure 27).

The three Missourian biozones proposed by this study include the *I. magnificus* biozone, the lowermost Missourian *I.* sp. *"X"* biozone, and the *Sw. nodocarinata* biozone. Of these, the *I. magnificus* biozone and the *Sw. nodocarinata* biozones have been recognized by previous workers. The *I*. sp. *"X"* biozone is newly proposed by this study for the lowermost Missourian of the Snaky Canyon Formation (Figure 27).

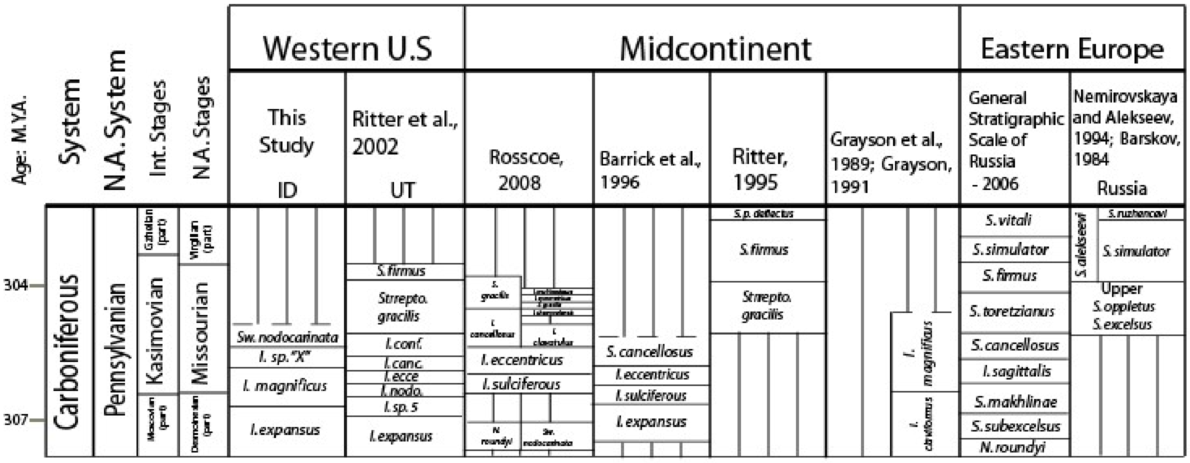


Figure 27: Comparison of Missourian conodont biozones identified by this study and of previous workers.

The Idiognathodus Problem

A ongoing issue surrounding Middle to Upper Pennsylvanian conodont biostratigraphy is the existence of over 70 identified individual species of the genus *Idiognathodus.* A majority of the *Idiognathodus* species are defined by subtle morphological differences and due to the lack of widespread recognition and occurrence of these species, most have little to no utility for stratigraphic positioning. Often, these species are defined by very minute morphological variations and differences that are not recognized outside of the basin of study. Recent studies (Roscoe, 2004, 2008;, Heckel, 2002;) that have identified new species of *Idiognathodus* from well studied successions of rock exemplify the issues and problems associated with the specimens of the *Idiognathodus* faunal succession. This problem is also apparent in the liberal identification and definition of new species of the genus Streptognathodus as well (ie., Ritter, 1995; Ritter et al., 2002).

The establishment of “boutique” species often limited by geographical constraints and found only at singular localities is not recognized by this study. These morphological disparities are attributed to ontogenically induced variations and/or sexual dimorphism and cannot be used to stratigraphically define rocks due to the lack of widespread occurrence and stratigraphic range recognition. Although scientific progress requires new discoveries, it is determined to be a regression in scientific thought and procedure when conodont occurrence data are misinterpreted and cannot be duplicated.

The definitions of members of the *Idiognathodus* genus (and lesser members of the *Streptognathodus* genus) applied by this study follow the concepts outlined by Grayson et al. (1989) and further elaborated by Lambert (1992). These workers defined the morphology of members of the *Idiognathodus* genus based on the basic descriptions provided by the paleontologists responsible for the initial discovery of each species (ie., Gunnell (1931), Stauffer and Plummer (1932), and Ellison and Graves (1941)). This study chooses to follow the phylogenetic basis for species recognition defined by Grayson et al. (1989) and added to by Lambert (1992) in order to establish a Pennsylvanian biozonation succession that is reproducible and able to be applied and incorporated globally.

For additional discussions regarding the issues, problems, and possible solutions to the synonymic nomenclature surrounding the *Idiognathodus* genus, see Grayson et al. (1989), Lambert (1992), and Rexroad et al. (1997).

The Streptognathodus/Idiognathodus Problem

From the Atokan and into the lower Missourian, a majority of *Idiognathodus* specimens of diminished overall size were observed. These specimens record morphological similarities as juveniles that overlap with defined morphological traits of members of *Streptognathodus*. Juvenile forms of *Idiognathodus* from the Atokan through the Desmoinesian/Missourian boundary may share overlapping morphologies with smaller examples of *Streptognathodus*.

These generalized morphological traits that are recorded by juvenile forms of *Idiognathodus* and later manifested by adult forms of *Streptognathodus* in upper Desmoinesian to lower Missourian strata have been interpreted to be a result of paedomorphisis (Merrill and King, 1971). It is important that this is recognized, as the improper identification of *Streptognathodus* due to the presence of early juvenile examples of *Idiognathodus* species can hamper the accurate determination of stratigraphic position when investigating Middle to Upper Pennsylvanian sedimentary successions.

Due to the paedomorhic relationship between *Idiognathodus* and *Streptognathodus* genera, this study limits the use of *Streptognathodus* as a stratigraphic indicator. Most of the specimens initially identified as *Streptognathodus* species were of diminished overall size and may be of juvenile *Idiognathodus* affinity. Only the *Streptognathodus suberectus* biozone 5 is defined and applied in this study, as it represents a clear emergence and initial appearance of the *Streptognathodus* genus in the succession of Snaky Canyon strata.

The initial stratigraphic occurrence of *Streptognathodus cancellosus* and *St. firmus* appears in much lower strata than has been previously recognized by workers in the western and midcontinental United States (Ritter, 1995; Ritter et al., 2002). This relationship requires additional investigation, although the problems discussed in the preceding text may be influential in the resolution of this disagreement. Due to this disparity, this study has chosen not to utilize the appearances of *Streptognathodus* species when establishing stratigraphic position within the upper Snaky Canyon Formation.

The succession of Snaky Canyon carbonates investigated by this study spans from the basal Morrowan to lower Missourian in stratigraphic age. Ritter (1994) and Chernykh and Ritter (1997) recognized the genus *Streptognathodus* as reaching its greatest biostratigraphic utility from the middle to upper Missourian into the Virgilian within the midcontinental United States and Eastern Europe. This concept, combined with the low diversity and limited occurrence of *Streptognathodus* species within the Snaky Canyon Formation have resulted in a biostratigraphic framework recognized by this study that is generally devoid of *Streptognathodus* based biozones.

Chapter 9: Biofacies

It has been recognized that variations in diversity and abundance in recognized conodont assemblages of the Carboniferous may be indicators of vertical stratification, water depth, and energy levels at the time of deposition (von Bitter, 1972; Davis and Webster, 1985; Morrow and Webster, 1991, 1992). Based on the comparison of sampled Snaky Canyon Formation stratigraphic horizon lithology to the conodont assemblages recovered from each interval, it is determined that depositional facies likely had control on the occurrence of certain conodont genera.

The recovered conodont assemblages in this study seem to overlap with the shallow water, marginal marine *Cavusgnathus/Adetognathus* biofacies of Merrill (1973) and Chamberlain and Clark (1973), the transitional *Rhachistognathus* biofacies of Webster (1984), the shallow, open-marine *Idiognathodus/Streptognathodus* biofacies (Merrill, 1973; Merrill and von Bitter, 1977) and the deeper water and offshore Carboniferous *Idiognathoides* and/or *Declinognathodus* biofacies of Rexroad and Horowitz (1984). A thorough investigation of similar Pennsylvanian biofacies from the Wahoo Limestone of Alaska has been reported by Krumhardt et al. (1996). This study recognizes that during the Early Pennsylvanian, significant differences in energy levels and depth likely controlled conodont occurrences (Figures 28 and 29).

Early Pennsylvanian (Morrowan to Mid-Atokan) Conodont Biofacies

Lower Pennsylvanian conodont biofacies recognized by this study are the *Rhachistognathus* biofacies, the *Adetognathus* biofacies, the *Idiognathodus* biofacies, and the *Declinognathodus/Idiognathoides* biofacies. These biofacies are individually discussed in the following sections.

***Rhachistognathus* Biofacies**

The *Rhachistognathus* biofacies is defined by the high occurrence of *Rhachistognathus muricatus, R. prolixus, R. primus, R. websteri*, *R. minutis havlendhi,* and/or *R. minutis minutis*. Species of *Rhachistognathus* dominate shallow, high energy environments and are interpreted to represent a transitional zone between the shallow, euryhaline *Cavusgnathus/Adetognathus* biofacies and the deep, foreslope normal marine *Declinognathodus/Idiognathoides* biofacies (Webster, 1984; Davis and Webster, 1985). Krumhardt et al. (1996) recognized *Rhachistognathus* as being confined to a near-shoal or shoal setting from the investigated sections of the Wahoo Limestone in Alaska.

The stratigraphic range of the *Rhachistognathus* genus is restricted to the Lower Pennsylvanian and becomes completely extinct in the early Atokan. The biofacies is prevalent in the lower Snaky Canyon Formation, although occurrence and abundance of *Rhachistognathus* is heavily controlled by the depositional facies. Snaky Canyon lithologies dominated by *Rhachistognathus* record high energy, near shore conditions recording shoaling or close proximity to shoaling conditions (Figures 28 and 29). These lithologies include skeletal grainstones, sandy skeletal packstones, and laminated sandy grainstones to packstones. None of the intervals dominated by *Rhachistognathus* contained significant in-situ megafauna and the presence of *Rhachistognathus* greatly increased upwards in each shallowing upwards parasequence.

Specimens of *Rhachistognathus* are most commonly recovered in conjunction with specimens of *Adetognathus*. Rare and limited occurrences of *Rhachistognathus* were noted in concurrence with early specimens of *Idiognathodus* and *Neognathodus*, indicating a possible lateral facies relationship and/or conodont reworking (see Disclaimer section). Lower Pennsylvanian assemblages completely devoid of *Rhachistognathus* specimens are marked by low diversity assemblages of open-marine *Declinognathodus* and *Idiognathoides* from deeper water facies. Limited occurrences of high-salinity tolerant *Adetognathus* dominated lower Pennsylvanian stratigraphic intervals are devoid of *Rhachistognathus* and this may be the result of elevated salinity that limited the occurrence of *Rhachistognathus* (Webster and Morrow, 1991).

In this study, the abundance of specimens of *Rhachistognathus* slightly increased in the measured sections near the eastern limits of the study area. This represents the transition from the slightly deeper water dominated assemblages to the west to proximinal near shore, higher energy environments in the east. This phenomenon was also recognized from the succession of Upper Mississippian strata biostratigraphically investigated by previous workers of east-central Idaho (Abplanalp, 2004; Abplanalp et al., 2009) (Figures 28 and 29).

Adetognathus **Biofacies**

The *Cavusgnathus/Adetognathus* biofacies of the middle to upper Carboniferous is marked by the occurrence of *Cavusgnathus unicornis*, *C. naviculus, C. alta, Adetognathus unicornis, A. gigantus; A. lautus,* and *A. spathus*. In previous studies on the mid-Carboniferous Alaska Bench Formation of Montana, this assemblage was interpreted to represent deposition in lagoonal, tidal flat, and barrier bar environments with euryhaline conditions and low to moderate energies (Davis and Webster, 1985; Morrow and Webster, 1991). The *Adetognathodus* dominated conodont assemblage has been recognized as occurring within the proximity to a back shoal, shallow water facies in the Lower Pennsylvanian Wahoo Limestone of Alaska. (Krumhardt et al., 1996). Heckel (1999) recognized the domination of *Adetognathodus* species from shallow water, upper and lower shoreface facies of the Desmoinesian in the U.S. midcontinent. Heckel's (1999) work determined that during the Middle Pennsylvanian, *Adetognathodus* was generally restricted to shoreface, highly oxygenated conditions with abundant open marine fauna. This work noted the presence of sparse to heavily restricted conodont diversity associated with this biofacies (Heckel, 1999). The Snaky Canyon Formation does have exclusive occurrence of the *Adetognathodus* biofacies, although this could be a factor of reworking (see Disclaimer section).

The range of the *Adetognathus* genus spans the entire stratigraphic succession of Snaky Canyon Formation investigated by this study and this biofacies generally dominates throughout the succession. Very few samples were entirely devoid of *Adetognathodus* specimens and the stratigraphic intervals that did not yield species of

Adetognathus were completely dominated by low diversity assemblages of *Declinognathodus, Idiognathoides,* and/or *Swadelina*. Notable quantities of *Adetognathodus* specimens were always recovered in conjunction with *Idiognathodus, Rhachistognathus, Hindeodus*, and *Neognathodus* specimens.

This shallow water biofacies agrees with the textural data observed at the measured sections. *Adetognathus* associated depositional features include solution lamellae, evaporite mineral salt casts, rare mud cracks, and a lack of open-marine megafauna. Sampled intervals most notably dominated by specimens of *Adetognathus* were often comprised of skeletal packstones containing medium to fine grained quartz sand (Figures 28 and 29). Intervals generally devoid of *Adetognathus* are characterized by clean to silty open-marine wackestone containing abundant in-situ brachiopods, bryozoans, and/or corals. Offshore shaley intervals are rare within the Snaky Canyon Formation, although do exist at the Gallagher Peak type section. These intervals also did not yield specimens of *Adetognathus*, indicating a potential near-shore, shallow water control on the genus (Figure 28 and 29). Due to the high occurrence of *Adetognathus* throughout the Snaky Canyon succession, there is no indication that *Adetognathus* was absent from high energy environments and restricted to protected lagoonal facies as observed from the Mid-Carboniferous of Montana and Utah by Davis and Webster (1985) and Morrow and Webster (1991). The recognition of the occurrence of *Adetognathus* associated with moderate to high energy near-shore normal to euryhaline environments of deposition is concurrent with observations from the Upper Mississippian to lowermost Pennsylvanian from east-central Idaho (Abplanalp, 2006; Abplanalp et al., 2009).

***Idiognathodus* Biofacies**

The Upper Pennsylvanian *Idiognathodus/Streptognathodus* biofacies of Merrill (1972) and Merrill and von Bitter (1976, 1979) is marked by the occurrence and abundance of species of *Idiognathodus* and *Streptognathodus*. These studies determined that the occurrences of *Idiognathodus* from Middle to Upper Pennsylvanian strata of the midcontinent were most often from stratigraphic horizons recording deposition in open, offshore to generally shallow carbonate mud dominated marine conditions of relatively low energy. Heckel (1999) reported on the association of *Idiognathodus* with *Neognathodus* from shallow to moderate depth offshore carbonates and shales of the midcontinent. Heckel's (1999) work indicated that *Idiognathodus* and *Neognathodus* were indicators of depth stratification and likely preferred warm, surficial open-marine waters of normal salinity levels. Roscoe (2005) contributed to this understanding by determining that a majority of *Idiognathodus* species preferred the uppermost surficial thermocline, with *Neognathodus* dominating the lower reaches of the upper thermocline.

The *Idiognathodus* genus does not first appear until the upper-Lower Pennsylvanian (upper Morrowan). Significant assemblages of *Idiognathodus* were most often recovered in conjunction with species of *Adetognathus, Neognathodus, Hindeodus*, and *Swadelina*. A limited amount of Middle Pennsylvanian stratigraphic intervals were completely devoid of specimens of *Idiognathodus* and these were dominated by later species of *Declinognathodus* and *Idiognathoides*. Intervals containing only *Adetognathus* of Middle to Upper Pennsylvanian are considered to be of restricted, euryhaline conditions on the association of conodont assemblage and associated depositional features (ie. solution lamellae, “salt” casts, and a overall lack of preserved open-marine megafauna).

The open marine, upper level thermocline interpretation for the *Idiognathodus* genus corresponds to the textural lithologic data observed by this study (Figure 29). Stratigraphic intervals dominated by species of *Idiognathodus* range from lower shoreface, open marine to mid-shelf, open marine foreshore facies (Figure 28 and 29). The lithologies of *Idiognathodus* dominated stratigraphic intervals range from offshore, in-situ bryozoan and brachiopod dominated wackestones to sandy skeletal packstones and grainstones recording conditions adjacent to areas of shoaling. Highly abraded specimens of *Idiognathodus* were consistently recovered with well preserved specimens from the same stratigraphic intervals. This may indicate that *Idiognathodus* was likely restricted by depth, not energy or proximity to the shoreline. The occurrence of *Idiognathodus* with *Adetognathus* and *Swadelina* in the uppermost investigated stratigraphic intervals of the Snaky Canyon Formation also indicates that *Idiognathodus* was likely controlled by depth and preferred the uppermost, near surface thermocline. The work of Barrick (1999) and Roscoe (2005) recognized the offshore affinity of *Swadelina* and several workers have recognized the near-shore affinity of *Adetognathus* (Davis and Webster, 1991; Barrick, 1999). The occurrence of Idiognathodus within both biofacies indicates shallow depth stratification that was not controlled by shoreline proximity (Figure 29).

Declinognathodus/Idiognathoides **Biofacies**

The Lower to Middle Pennsylvanian *Idiognathoides* and *Declinognathodus* biofacies of Rexroad and Horowitz (1984) is marked by the occurrence and high relative abundance of species of *D. noduliferous, D. marginodosus, D. lateralis, Id. sinuatus, Id. corrugatus, Id. sulcatus sulcatus*, and *Id. sulcatus parvus*. Rexroad and Horowitz (1984) recognized the occurrence of *Declinognathodus* and *Idiognathoides* dominated assemblages from strata recording offshore open marine conditions from the Beaver Bend Limestone in Indiana. Davis and Webster (1985) documented the limited occurrence of *Declinognathodus* and *Idiognathoides* from relatively shallow, low energy offshore deposits within the Alaska Bench Formation of central Montana. Krumhardt et al. (1996) interpreted *Declinognathodus* dominated assemblages from the Wahoo Limestone of Alaska as being restricted to generally open-marine settings of the low energy outer platform.

Declinognathodus and *Idiognathoides* are stratigraphically limited to the Lower Pennsylvanian (lowermost Morrowan to uppermost Atokan) in the Snaky Canyon Formation. *Declinognathodus* and *Idiognathodus* dominated assemblages most often include specimens of *Idiognathodus* and *Neognathodus*, with occasional specimens of *Adetognathus* and *Rhachistognathus* primarily occurring from specific stratigraphic horizons. Several stratigraphic horizons yielded only species of *Declinognathodus* and *Idiognathoides* and these have been interpreted to represent the basal beds of individual shallowing-upwards parasequences. The abundance of *Declinognathodus* and *Idiognathoides* from the Lower Pennsylvanian also slightly increases westwards across the study area, indicating a potential ramp gradient east to west

(Figures 28 and 29).

The open marine, low energy outer-ramp biofacies interpretation for the *Idiognathodus* genus corresponds to the textural and faunal data observed by this study (Figures 28 and 29). The stratigraphic intervals recording high abundances of *Declinognathodus* and *Idiognathoides* are most often characterized by in-situ bryozoan, brachiopod, and pelmetazoan sparse wackestones. These horizons are often carbonate mud dominated and very rare shaley to silty thin bedded limestone intervals from the Arco Hills vicinity have also yielded high numbers of *Declinognathodus* specimens. Intervals representing this biofacies are often devoid of significant skeletal fragments and quartz sand and are often heavily bioturbated. A high majority of specimens of *Declinognathodus* and *Idiognathoides* are very well preserved. Little to no evidence of reworking and transport is recorded, indicating direct deposition within a relatively low energy environment below wave base.

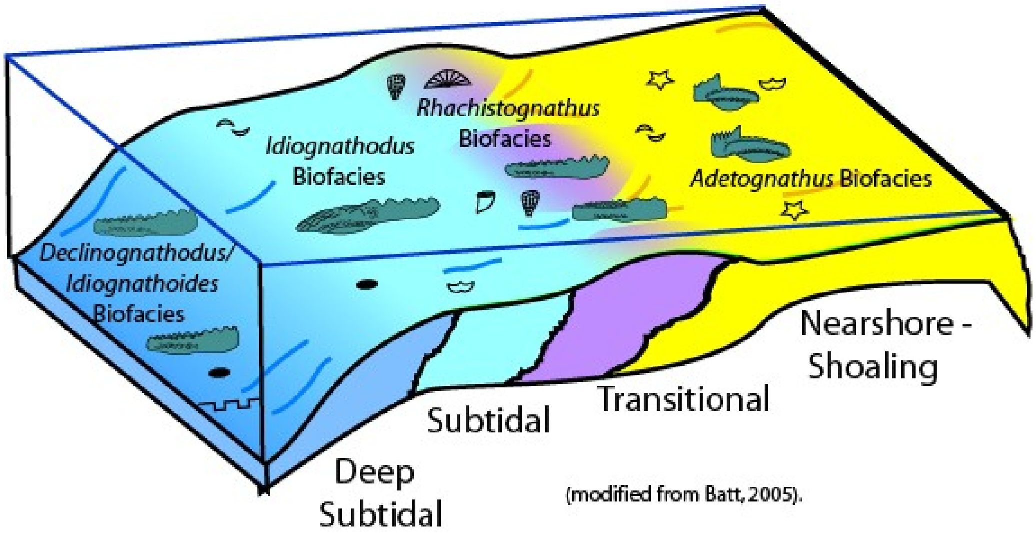


Figure 28: Middle Pennsylvanian Snaky Canyon ramp profile and associated conodont biofacies.

Disclaimer on Snaky Canyon Conodont Biofacies

Throughout the Late Mississippian to Early Pennsylvanian of Idaho, it has been recognized that carbonate deposition likely occurred on a open marine homoclinal to gently sloping carbonate ramp along the western Laurentian margin (Batt et al., 2008). Due to the lack of significant reefal boundaries due to ramp geometry and general absence of major reef building biota during this time, significant reworking and redistribution of conodont elements is likely through agitation by storms and surges (Osleger, 1991; Krumhardt et al., 1996). A significant proportion of the conodont specimens recovered from the Lower Pennsylvanian Snaky Canyon Formation exhibit widespread evidence of abrasion indicating possible reworking. As the Snaky Canyon succession progresses upward into younger strata, the levels of conodont element abrasion slightly decrease. This may indicate a change in ramp geometry and/or increase in biotic buildups that offer a energy restricted or shadowed environment of deposition (Figure 29).

The reworking of sediments may also restrict the ability to decipher the exact depositional facies (Osleger, 1991). This makes it difficult to accurately associate biofacies with depositional facies. It is determined that there is a need to further investigate facies control on conodont occurrences within a relatively continuous deposited succession of Pennsylvanian age carbonates. This study proposes that a very high resolution, bed by bed scale investigation be conducted that represents a complete suite of depositional facies from each identified biozone recorded by the Snaky Canyon Formation in order to define the association of lithology, reworking, and conodont occurrence.

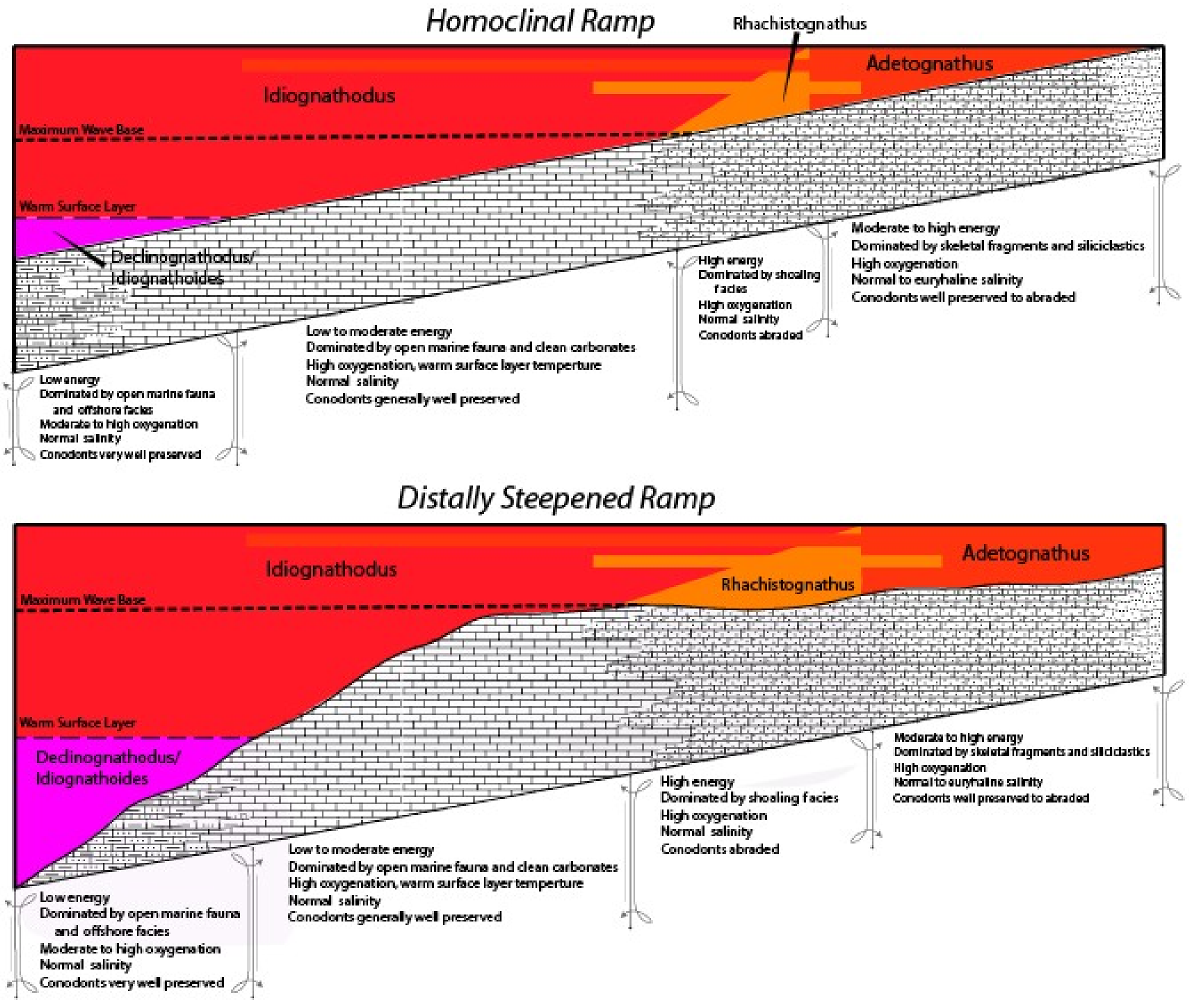


Figure 29: Biofacies and ramp profile of the Snaky Canyon Formation from the Lower (Morrowan)and hypothetical Upper (Desmoinesian) Pennsylvanian. Note: *Declinognathodus* and *Rhachistognathus* are extinct in the Desmoinesian and remain to show the relationship between biofacies and ramp geometry.

Chapter 10: Pennsylvanian Conodont Lineages and Phylogeny of the Platform Species

The stratigraphic interval spanning the Mississippian/ Pennsylvanian boundary records a dramatic evolutionary shift and the beginning of distinct upper Carboniferous conodont lineages. Species of *Cavusgnathus*, *Vogelgnathus*, and *Gnathodus* become extinct at or just below the mid-Carboniferous boundary (Abplanalp, 2006; Abplanalp et al., 2009). This minor conodont extinction event allowed for species of *Rhachistognathus*, *Adetognathus*, *Declinognathodus*, and *Idiognathoides* to first appear and dominate at or just above the transition from the Mississippian to the Pennsylvanian. By the Middle Pennsylvanian, a major transition occurred again and species of *Idiognathodus*, *Streptognathodus*, and *Neognathodus* dominated. A late Desmoinesian extinction event created a bottleneck that limited the occurrence of the dominant *Idiognathodus* genus and also terminated all species of *Neognathodus* (Boardman and Barrick, 2003).

These events greatly controlled the evolutionary framework of the conodont species identified in this study for biostratigraphic correlation. As a result of the high-resolution nature of this study combined with the relatively continuously deposited sequence of Snaky Canyon strata, several examples of conodont phylogenetic transition have been recovered and documented. These specimens provide additional insight into the evolutionary sequence of Lower to Middle Pennsylvanian conodonts and the locality offers a rare glimpse of upper Carboniferous conodont lineages that are not hindered by significant depositional hiatuses.

The recognized, revised, and proposed conodont lineages by this study are based on appearance and dominance in the Lower Pennsylvanian (Morrowan to middle Atokan) or Upper Pennsylvanian (upper Atokan to lowermost Missourian)(Figures 30-32). This division follows the two major groupings of recovered conodont elements from the Snaky Canyon Formation. The suggestions presented are based on observations made throughout this study and in order to confirm the phylogenetic relationships presented, additional work should be conducted on other continuously deposited carbonate successions along the western margin of Laurentia and globally. See Figures 31 and 32 for a complete lineage reconstruction based on observations made by this study.

Lower Pennsylvanian Conodont Lineages

The Lower Pennsylvanian is a globally recognized time of conodont diversification (Dunn, 1966; Dunn, 1970; Higgins, 1975; Baesemann and Lane, 1985; Nemyrovska, 1999). At the Mid-Carboniferous boundary, species of *Adetognathus* first appear from the *Cavusgnathus* lineage of the Middle to Late Mississippian (Lane, 1967). The *Adetognathus* genus globally dominates throughout the entire Pennsylvanian and is utilized as a general stratigraphic indicator of the upper Carboniferous. The genus *Rhachistognathus* first appears at the Mississippian/Pennsylvanian boundary and for a complete and thorough description of the evolution of the *Rhachistognathus* genus, consult the work of Baesemann and Lane (1985). Species of *Declinognathodus* and *Idiognathoides* also first appear and then decline in abundance during this time interval (Figure 19).

Adetognathus/Declinognathodus **Lineage**

Species of *Declinognathodus* have been utilized globally as stratigraphic indicator species for the Lower Pennsylvanian (Lane et al., 1999; Nemyrovska, 1999)(Figure 24). *Declinognathodus noduliferous* is defined as a global boundary indicator for the mid-Carboniferous (Lane et al., 1999) and this study recognizes the occurrence of *D. noduliferous* at or near the boundary. Observations from the Snaky Canyon succession in east-central Idaho indicate a close affinity of early *D. noduliferous* with *A. spathus*. Several morphological similarities exist between the two species, including a distinct posterior tail or blade. Species of *A. spathus* characteristically contain a more nodular platform dentition than other species of *Adetognathus* and this form of dentition closely resembles that of members of the *Declinognathodus* genus. Several specimens of *A. spathus* have been recovered from lower to middle Morrowan Snaky Canyon Formation strata that possess a anterior freeblade that is migrating toward the centralized position that is characteristic of *Declinognathodus*. This migrating freeblade is often separated from the outer parapet by a shallow trough that may indicate a early transition to the characteristic outer isolated node of the *D. noduliferous* species (Figure 30).

Ellison and Graves (1941) first recognized a relationship between *D. noduliferous* and the *Cavusgnathus/Adetognathus* lineage when they first described the species as *C. nodulifera*. Subsequent workers debated on the generic assignment of the species until Dunn (1966) suggested the *Declinognathodus* genus. Dunn (1970a) and Higgins (1975) reported on the affinity of *Declinognathodus noduliferous* to that of the stratigraphically older *Gnathodus girtyi girtyi* and *Gnathodus girtyi simplex*. Although certain affinities exist between *Gnathodus* and *Declinognathodus*, there is a general lack of platform curvature in *Gnathodus* and the characteristic large basal cavity of species of *Gnathodus* is absent in *Declinognathodus*. The general morphology of *D. noduliferous* is more similar to that of *A. spathus* and the transitional forms described above and presented in Figure 30 may indicate a close affinity of these two species. To date, no other workers have recognized a morphological or evolutionary relationship between *Declinognathodus noduliferous* and *Adetognathus spathus*.

***Declinognathodus/Neognathodus* Lineage**

Species of *Neognathodus* have been globally recognized from Lower to Middle Pennsylvanian sediments (Merrill and King, 1971; Merrill, 1972; Grayson, 1984; Nemyrovska, 1999; Nascimento et al., 2005). Several specimens recovered throughout this study indicate a close affinity of species of *Declinognathodus* with species of *Neognathodus* (Figure 30). Transitional species of *Declinognathodus* possess a notably triangular shaped platform that is characteristic of all species of *Neognathodus*. These transitional forms also possess notable latitudinal elongated platform nodes that are terminated by a deep central groove that continues to the posterior point of the platform (Figure 30, no. 6). A limited amount of *Declinognathodus* specimens also exhibit an elongated central carina and continuous outer parapet ridges that characterize early specimens of *Neognathodus*.

Several workers have recognized the close affinity and evolutionary connection of *Declinognathodus* and *Neognathodus*. Straka and Lane (1970) and Dunn (1970a) recognized transitional species connecting *D. noduliferous* to *N. bassleri symmetricus*. Earlier work by Higgins and Bouckaert (1968) identified and defined the species *D. lateralis* as a transitional species separating *D. noduliferous* from *Neognathodus*. Merrill (1972) reported on the close affinity of later *Declinognathodus* species to *Neognathodus bassleri bassleri* from rocks of the Appalachian Basin.

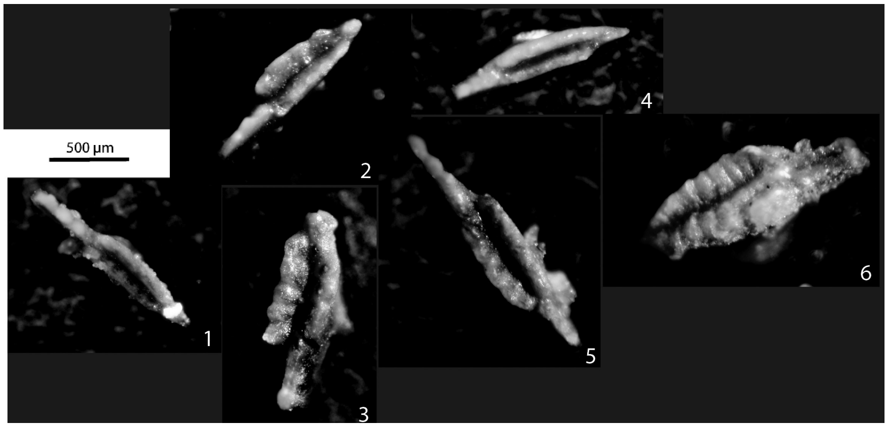


Figure 30: Plate V: Transitional Lower Pennsylvanian conodonts. 1-5 *Adetognathus spathus* cf. *Declinognathodus noduliferous*; 6 *Declinognathodus* sp. cf. *Neognathodus* sp.

Middle Pennsylvanian Conodont Lineages

The evolutionary history and lineages of Middle Pennsylvanian conodonts has been widely studied by workers conducting studies on Carboniferous of the midcontinental United States (Grayson et al., 1989; Rexroad et al., 1997; Heckel, 2002; Roscoe, 2008). At the close of the Atokan, species of *Idiognathodus* and *Neognathodus* increase in diversity and dominate until the late Desmoinesian conodont extinction event (Boardman and Barrick, 2002). After the late

Desmoinesian extinction event, *Idiognathodus* and *Streptognathodus* rapidly diversify throughout the Upper Pennsylvanian. This rapid diversification is the basis for the comprehensive biozonation established for the Upper Pennsylvanian.

***Idiognathodus* Lineage**

As mentioned in the preceding section The *Idiognathodus* Problem, species of *Idiognathodus* exhibit high degrees of morphologic variation and homeomorphism (Merrill and King, 1972; Grayson et al., 1989). Specimens of *Idiognathodus* recovered from the Snaky Canyon Formation likely all have ancestral ties to *I. sinuosus*, which is the earliest appearing species (upper Morrowan) of *Idiognathodus* from this succession of strata. By the close of the Morrowan and through the Atokan, the *I. sinuosus* lineage branches to include the commonly recognized *I. delicatus* by the distinct development of increased ornamentation of the accessory lobes. From morphologic comparison and stratigraphic occurrence, *I. delicatus* seems to be the ancestral source of *I. klapperi* and *I. incurvus*. The rise from *I. delicatus* to *I. klapperi* is characterized by a overall shortening of the platform, the development of a rounded posterior point, and a shortening of the rostral ridges. *I. klapperi* may then have been the ancestral source of *I. magnificus* and *I. expansus* through the development of increased ornamentation, restriction of rostral accessory lobes, and the flaring of the rostral ridges. *I. incurvus* represents the development of extreme platform curvature and the lengthening of the rostral ridges inherited from *I. delicatus* during the Middle Pennsylvanian. The evolution of *I. obliquus* from *I. incurvus* is most notably marked by the development of oblique transverse ridges and increased development of the inner lobe while maintaining distinct platform curvature (Figures 31 and 32).

Evidence from this study suggests a evolutionary link between *I. delicatus* and *I. klapperi*. Grayson et al. (1989) reported on a distinct evolutionary connection directly between *I. sinousus* and *I. klapperi* and Grayson's study did not recognize the widely documented *I. delicatus* species. *I. delicatus* (Gunnell, 1931) holds seniority over *I. sinuosus* and *I. klapperi* and this study recognizes the direct evolutionary lineage of *I. sinuosus* to *I. delicatus* to *I. klapperi* based on stratigraphic occurrence and morphologic comparison. Grayson et al. (1989) also recognized a evolutionary connection between *I. klapperi* and *I. incurvus*. From the specimens recovered by this study, a lineage for *I. incurvus* based on a *I. delicatus* ancestor seems more likely. *I. incurvus* retains many of the distinct morphological traits inherited from *I. delicatus* such as a overall elongated platform, distinct rostral ridges, and a pointed posterior and lacks the shortened and rounded posterior platform characteristics of the morphologically distinct *I. klapperi*.

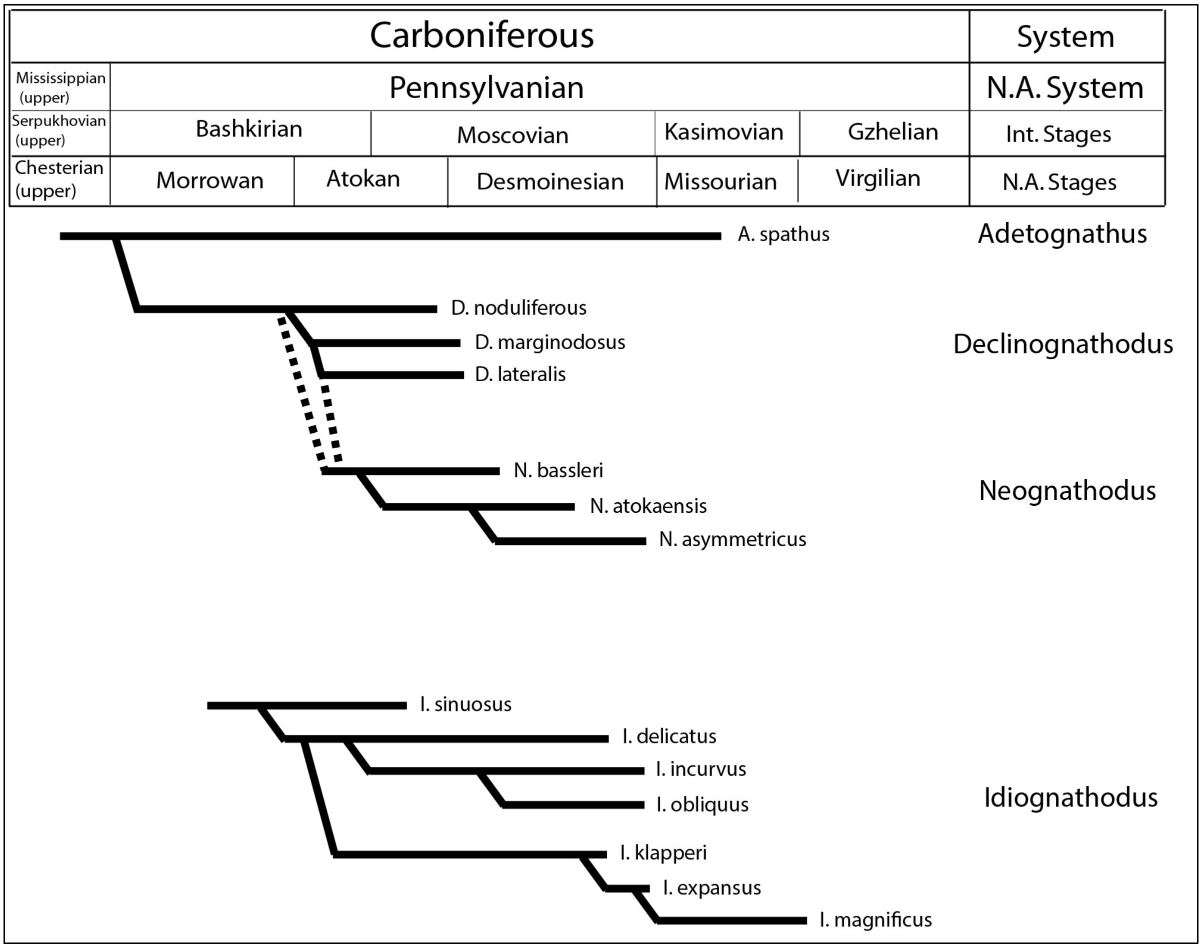


Figure 31: *Adetognathus, Declinognathodus, Neognathodus,* and *Idiognathodus* Pennsylvanian conodont lineages observed and proposed by this study.

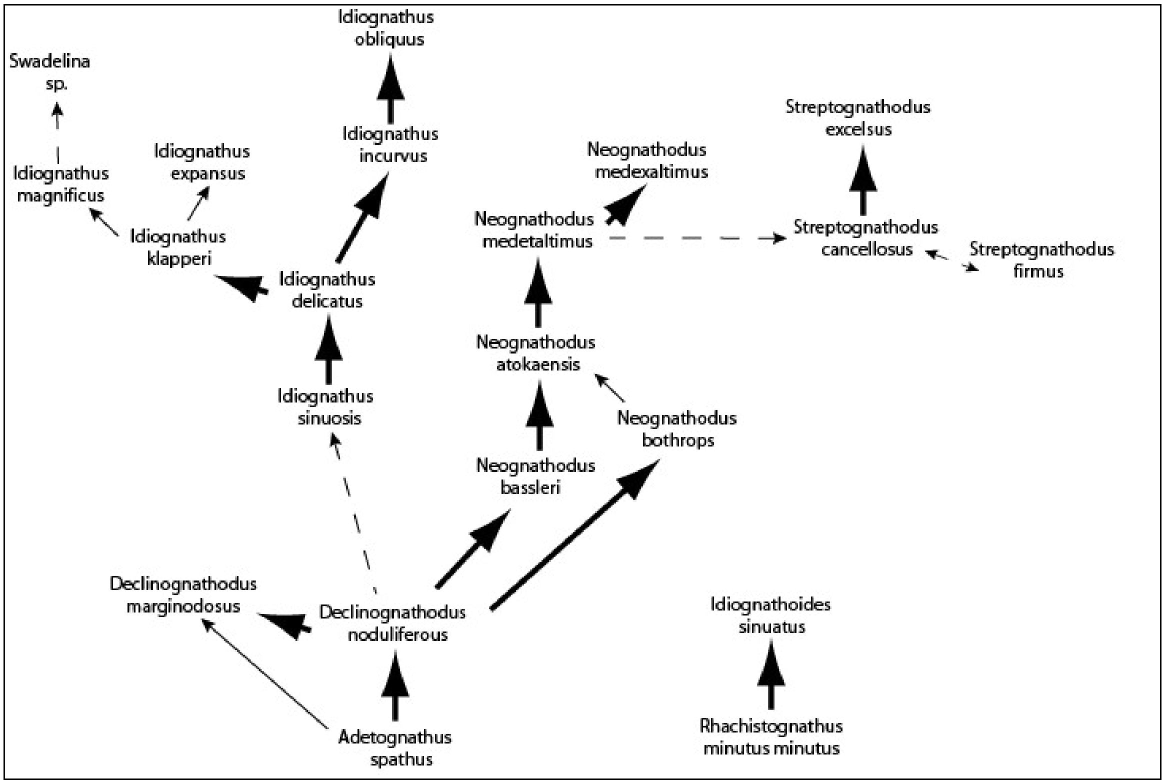


Figure 32: Interpreted conodont faunal successions of the Pennsylvanian Snaky Canyon Formation based on observed morphologies and stratigraphic position. Heavy arrows indicate a higher degree of certainty while dashed arrows indicate a lower degree of certainty.

Chapter 11: Sequence Biostratigraphy

Recent conodont based biostratigraphic investigations of the Pennsylvanian stratigraphic succession of Utah's Paradox by Ritter et al. (2002) have identified and practiced the concept of conodont sequence biostratigraphy. This concept was first proposed by Loutit et al. (1991) and Posamentier and Goodman (1992) in order to further understand the relationship between biofacies and depositional sequence architecture. Posamentier and Goodman (1992) recognized the biologic signature of individual systems tracts and determined that certain biota was useful in the correlation of stratigraphic elements of these system tracts. Ritter et al. (2002) further expanded this concept to that of conodont sequence biostratigraphy, which may regionally correlate depositional events based upon their signifying conodont assemblages. This concept was proposed from Pennsylvanian age strata in order to correlate cyclothems across North America and to resolve the incomplete and inaccurate biozonation framework interpreted from stratigraphic successions that record glacially driven eustatic fluctuations. Ritter et al.'s (2002) work attempted to correlate individual parasequences (cyclothems) with those of the hiatus abundant midcontinent based on recovered conodont assemblages from each cyclothem.

The conodont assemblages recovered from the Snaky Canyon Formation indicate a high degree of facies control (see Biofacies section) that likely restricts the ability to practice the sequence biostratigraphic concept at the parasequence (4th order) at this locality. The use of conodont abundance and complete assemblages to correlate parasequences of the Snaky Canyon Formation is likely hindered by the same principles used to define the concept. Lateral facies relationships have been shown to control the occurrence and relative abundance of conodont specimens (see Biofacies discussion) and this may be especially true when considering the homoclinal to distally steepened ramp geometry interpreted to be recorded by the Snaky Canyon Formation. In these settings, well recognized conodont occurrence controlling parameters such as energy level, salinity, and depth stratification are highly variable over short (100 meter to kilometer scale) distances.

In order to test this theory and its utility for correlating the parasequences of the Snaky Canyon Formation, a west to east comparison of basal Pennsylvanian (Morrowan) conodont assemblages was made from the lowermost parasequence located directly above the sandstones of the Bluebird Mountain Formation. At the far western White Knob section, the basal open-marine carbonate bed yields a conodont assemblage containing multiple species of *Rhachistognathus* and only one species of *Adetognathus*. At the easternmost section (the Gallagher Peak section) from the same basal open-marine carbonate bed at the top of the Bluebird Mountain Formation, an assemblage dominated by *Adetognathus* and with only a minor *Rhachistognathus* component was recovered. The measured sections from the Lost River Range to the west of the Gallagher Peak section yielded similar assemblages to that of the White Knob section. This comparison from a easily correlatable parasequence at the Mississippian/Pennsylvanian boundary indicates the control facies may have on the concept of sequence biostratigraphy. Moving closer the paleoshoreline, the conodont assemblages drastically change and may provide a false signature for correlation.

Conodont sequence biostratigraphy is useful for the correlation of the 1 to 2 my. sequences identified from the Snaky Canyon Formation. The duration of these sequences corresponds to the average time interval of the individual conodont based biozones proposed by this study. The Snaky Canyon Formation lacks the major hiatuses recorded in the Pennsylvanian of the U.S. midcontinent, making the rock unit ideal for establishing a continuous biozonation framework for the Lower to Middle Pennsylvanian of western North America. It is determined that using recovered Pennsylvanian conodont assemblages to correlate 4th order (cyclothems) may be limited by biofacies and depositional controls. Recovered conodont assemblages likely have the greatest utility correlating 3rd to 2nd order depositional sequences.

Chapter 12: New Stratigraphic and Depositional Interpretations of the Snaky Canyon Formation

The identification and application of conodont based biozones allows for the revision of the stratigraphic age of the Pennsylvanian Snaky Canyon Formation. An updated stratigraphic positioning of the Juniper Gulch and Gallagher Peak members is proposed and presented based on conodonts. A generalized positioning of the well published (Breuninger et al., 1989; Brueninger, 1971, 1976; Canter, 1984; Canter and Isaacson, 1991) *Palaeoaplysina* algal mounds of the Middle to Upper Pennsylvanian is also presented based on limited conodont assemblages recovered above and below these build-ups.

Revised Depositional Age of the Juniper Gulch Type Section

From the conodont assemblages recovered from Juniper Gulch type section located in the southern Beaverhead Mountains in east-central Idaho, it is determined that deposition of the strata recorded in this succession occurred during the Morrowan to Atokan time (Figure 33). Conodont assemblages from the Juniper Gulch section are dominated by species of *Adetognathus, Idiognathoides, Declinognathodus, Rhachistognathus,* and early *Neognathodus* species that characterize the Lower to lower-Middle Pennsylvanian.

Archuleta's (2004) preliminary conodont analysis at the Juniper Gulch type section and three other Juniper Gulch sections suggested a time of deposition much younger than that of previous workers (Skipp et al., 1979a). The conodont assemblages recovered during this study were characteristic of Morrowan to Desmoinesian strata (Archuleta, 2004; Webster pers. comm., 2004). The assemblages recovered by Archuleta (2004) at the Juniper Gulch type section were limited in abundance and diversity and were only briefly mentioned in this analysis of the Juniper Gulch Member.

Skipp et al. (1979a) reported on a limited collection of biostratigraphically useful fauna from the Juniper Gulch type section (Figure 13). The fusulinids *Fusulinella* sp. and *Triticites* sp. were identified by Skipp et al. (1979a) from the basal beds (initial 58 meters) of the type locality and were used to establish a initial Upper Pennsylvanian age of deposition. Only limited biostratigraphic data was identified and reported on for the determination of a Upper Pennsylvanian age for the strata at this locality identified by Skipp et al. (1979a)(Figure 13). All other biostratigraphic data utilized for the stratigraphic placement of the Juniper Gulch Member was from the Arco Hills and Lemhi localities located to the west of the Snaky Canyon type section (Skipp et al., 1979a).

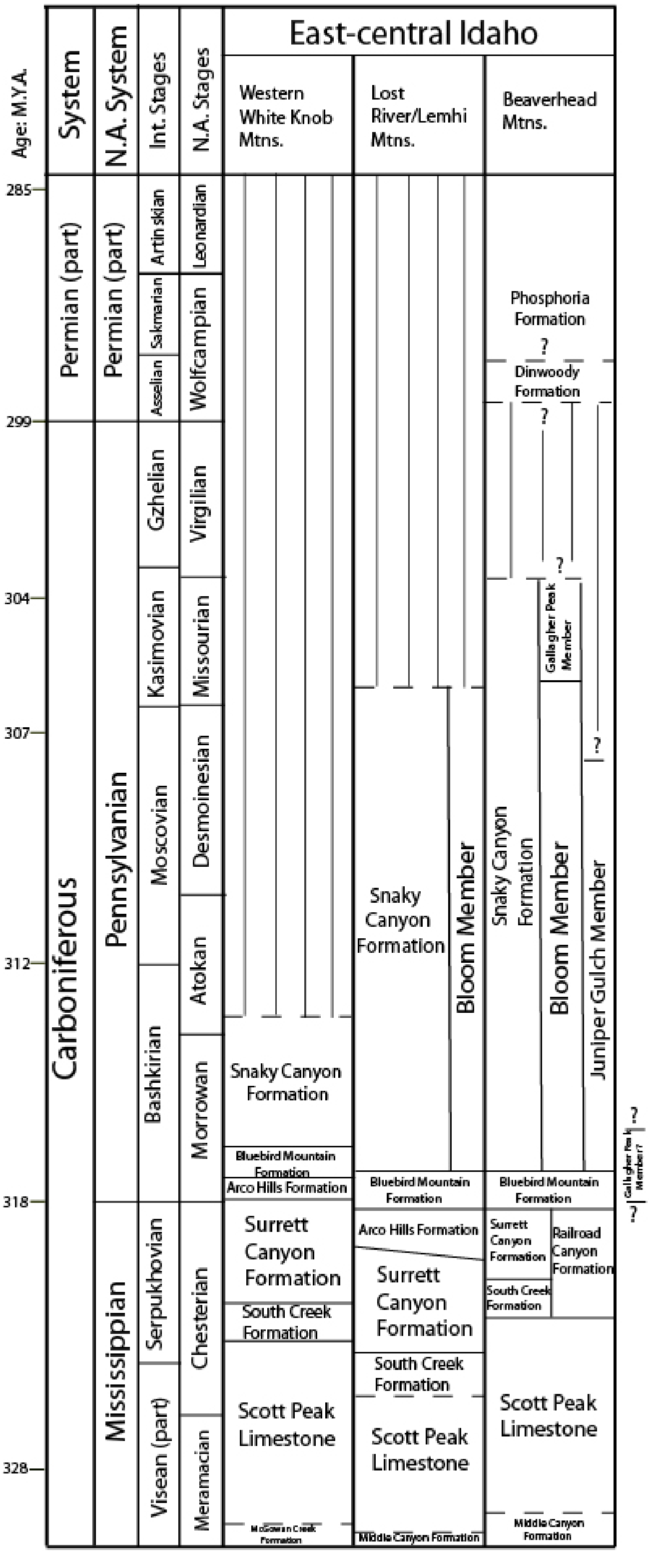


Figure 33: Updated stratigraphic positioning of the Snaky Canyon Formation.

Conodonts from the Juniper Gulch Type Section

This study recovered conodont assemblages from the Juniper Gulch type section that are indicative of a Lower Pennsylvanian time of deposition (Appendix II). Multiple specimens of *Adetognathus unicornis, Adetognathus lautus, Gnathodus girty simplex*, and *Rhachistognathus muricatus* were recovered from the basal beds of the Juniper Gulch Member 36 meters above the uppermost beds of the stratigraphically lower sandstone unit (previously identified as Gallagher Peak Member) capping the ridge. This assemblage is characteristic of the uppermost Mississippian to lowermost Pennsylvanian throughout the region (Abplanalp, 2006; Abplanalp et al., 2009). Specimens recovered from this interval were of high preservation quality, indicating a overall lack of significant post-mortem transport. 215 meters above this sampled stratigraphic locality, the upper Morrowan *Rh. minutis minutis, Rh. websteri*, and *N. bassleri* species were recovered from a bioclastic carbonate bed. The interval between these two beds did not yield conodont specimens and due to the overall absence of a significant open marine megafaunal component throughout this interval, it is likely that a period of restricted deposition is recorded from meters 37 to 215 (Appendix I).

Just below meter 319, a significant increase in open-marine fauna is present and at this location, conodonts of uppermost Morrowan and lowermost Atokan were recovered. The occurrence of *Declinognathodus noduliferous, D. marginodosus* (Atokan), *Idiognathoides sinuatus, Id. sulcatus parvus*, and *N. bassleri* indicate a low stratigraphic position at the Morrowan/Atokan stage boundary and a maximum stratigraphic position of middle Atokan. The biofacies of this assemblage also indicates a significant deepening event, which may correlate with the initial eustatic sea-level rise of the basal Atokan. This observation at this stratigraphic position coincides with the maximum flooding zone identified by Archuleta (2004) from this exposure of Snaky Canyon Formation.

No additional beds above this stratigraphic interval yielded a biostratigraphically useful assemblage of conodonts. Above this location, megafaunal occurrences generally decline and there is a increase in fine to medium sized siliciclastic input and dolomitization. It is interpreted that the remaining 400 plus meters of exposed Snaky Canyon Formation record near-shore restricted facies (Archuleta, 2004).

Implications of a Lower Pennsylvanian Juniper Gulch Type Section

From the recovered conodont assemblages at this locality, it is apparent that the Juniper Gulch Member at the type section is depositionally synchronous to the Bloom Member (Figure 33). While the Bloom Member records deposition in a generally open marine setting, the facies recorded by the section of Snaky Canyon Formation at the Juniper Gulch type locality records highly restricted and shallow near-shore lagoonal deposition. The Juniper Gulch type section is the easternmost section of Pennsylvanian strata investigated by this study and therefore may record conditions most proximal to the paleoshoreline. The nearby Bloom Member at the Gallagher Peak type section is within the Beaverhead overthrust sheet and was likely transported to the east during the Cenozoic (Skipp, 1985).

This concept definitely warrants increased future investigation. To date, no high-resolution biostratigraphic studies have been conducted on the Juniper Gulch Member of east-central Idaho. Previous investigations have been limited to sparse biostratigraphic control and have mainly correlated the Snaky Canyon Formation using lithology (Skipp et al., 1979a; Skipp and Hall, 1980; Tremblay, 1996; Archuleta, 2004). In order to fully understand the complex lateral facies relationships of the Snaky Canyon Formation, high-resolution biostratigraphic data must be recovered from additional localities defined as the Juniper Gulch Member. Comparing biostratigraphic data to that of the data presented by this study and recent work from the western margin of Laurentia (Ritter et al., 2002) will provide a framework necessary for the full comprehension of the upper Carboniferous carbonate ramp of east-central Idaho.

The Gallagher Peak Sandstone Conundrum at the Snaky Canyon Locality

Skipp et al. (1979a) and Archuleta (2004) reported on the occurrence of the overturned Gallagher Peak Sandstone Member at the base of the Juniper Gulch Member at the Snaky Canyon locality in the Beaverhead Range. Skipp et al. (1979a) reported on the occurrence of Late Pennsylvanian brachiopods, corals, and fusulinids near the top of the Gallagher Peak Sandstone at the Bloom Member type section locality. These occurrences were reported as being rare and of limited availability due to the overall lack of a faunal component in this strata. Other biostratigraphic data utilized by Skipp et al. (1979a) in the defining and determination of the stratigraphic positioning of the Gallagher Peak Sandstone Member came from exposures of the member located in the southern Lemhi and Lost River ranges and from the Bloom Member type section at Gallagher Peak in the Beaverhead Range (Figure 15).

The beds located stratigraphically above this ridge capping sandstone yielded well preserved and multiple specimens of *A. unicornis, Gnathodus girtyi simplex*, and *Rh. muricatus*, indicating a latest Chesterian to basal Morrowan age of deposition. Stratigraphically above this interval, the Lower Pennsylvanian (Morrowan) species *D. noduliferous, Id. sinuosus, Rh. minutis minutis*, and *Rh. websteri* dominate. Based on the high quality of preservation, diversity, and occurrence of this well documented Mid-Carboniferous assemblage just above the upper limits of the sandstone dominated interval, it is determined that the unit once defined as the Gallagher Peak Sandstone Member is most likely the Mid-Carboniferous Bluebird Mountain or Arco Hills Formation. Lithologic comparisons from the mid-Carboniferous of the Lost River and Beaverhead ranges suggest similarities more like that of the Arco Hills Formation.

The conodont assemblages recovered from this location also correlate with the conodont assemblages reported by Abplanalp (2006) and Abplanalp et al. (2009) from within or stratigraphically adjacent to the Bluebird Mountain and Arco Hills formations at other nearby localities. These units (especially the Arco Hills Formation) share similar characteristics with the Gallagher Peak Sandstone Member. All of these units record near-shore marine fine-grained quartzitic deposition containing a high carbonate influence. Due to the limited biostratigraphic data available when the member was first identified by Skipp et al. (1979a) at the Juniper Gulch type locality and the similarities in lithology to the Mid-Carboniferous siliciclastic dominated Arco Hills and Bluebird Mountain formations, it is determined that this locality is absent of the Gallagher Peak Sandstone Member.

A Time Transgressive Interpretation for the Gallagher Peak Sandstone Member

The Gallagher Peak Sandstone Member of the Snaky Canyon Formation was first identified and defined by Skipp et al. (1979a). Skipp et al's. (1979a) study identified a thin, discontinuous and lensoidal sandstone unit that thins to the west and does not likely occur west of the Lost River Range.

In concurrence with the observations of Skipp et al. (1979a) it is suggested that the Gallagher Peak Member is not laterally continuous throughout the study area and is likely time transgressive from west to east (Figure 34). At the VAH measured section in the Arco Hills of the Lost River Range, recovered conodont assemblages directly below the Gallagher Peak Sandstone Member indicate a time of deposition during the uppermost Desmoinesian to lower Missourian *Idiognathodus magnificus* and *I.* sp. *"X"* biozones identified by this study. To the east at the Gallagher Peak Sandstone Member type location in the Beaverhead Range, recovered conodont assemblages indicate initial deposition of the member during the Missourian *Swadelina nodocarinata* biozone. This relationship indicates that the deposition of the Gallagher Peak Sandstone Member was time transgressive from west to east (Figure 34). Initial formation of the sandstone unit occurred to the west at the Desmoinesian/Missourian stage boundary and the by the Missourian, deposition had shifted to the east (Figure 34). The recognition of the time transgressive nature of the Gallagher Peak Sandstone combined with the presence of open-marine carbonates surrounding the unit may indicate a eastward migrating barrier complex affinity for the member.

This concept warrants increased future investigation in order to determine the stratigraphic geometry of the Gallagher Peak Member.

The west to east time transgressive interpretation based on conodonts recovered by this study correlates with the limited biostratigraphic data reported by Skipp et al. (1979a) from these localities. Skipp et al. (1979a) recovered fusulinids of late Desmoinesian to early Missourian from the investigated Gallagher Peak locality within the Arco Hills of the Lost River Range. Upper Pennsylvanian (Missourian) fusulinids and megafauna were identified from the Gallagher Peak type section to the east of the Arco Hills in the Beaverhead Range above and below the Gallagher Peak Sandstone Member contacts.

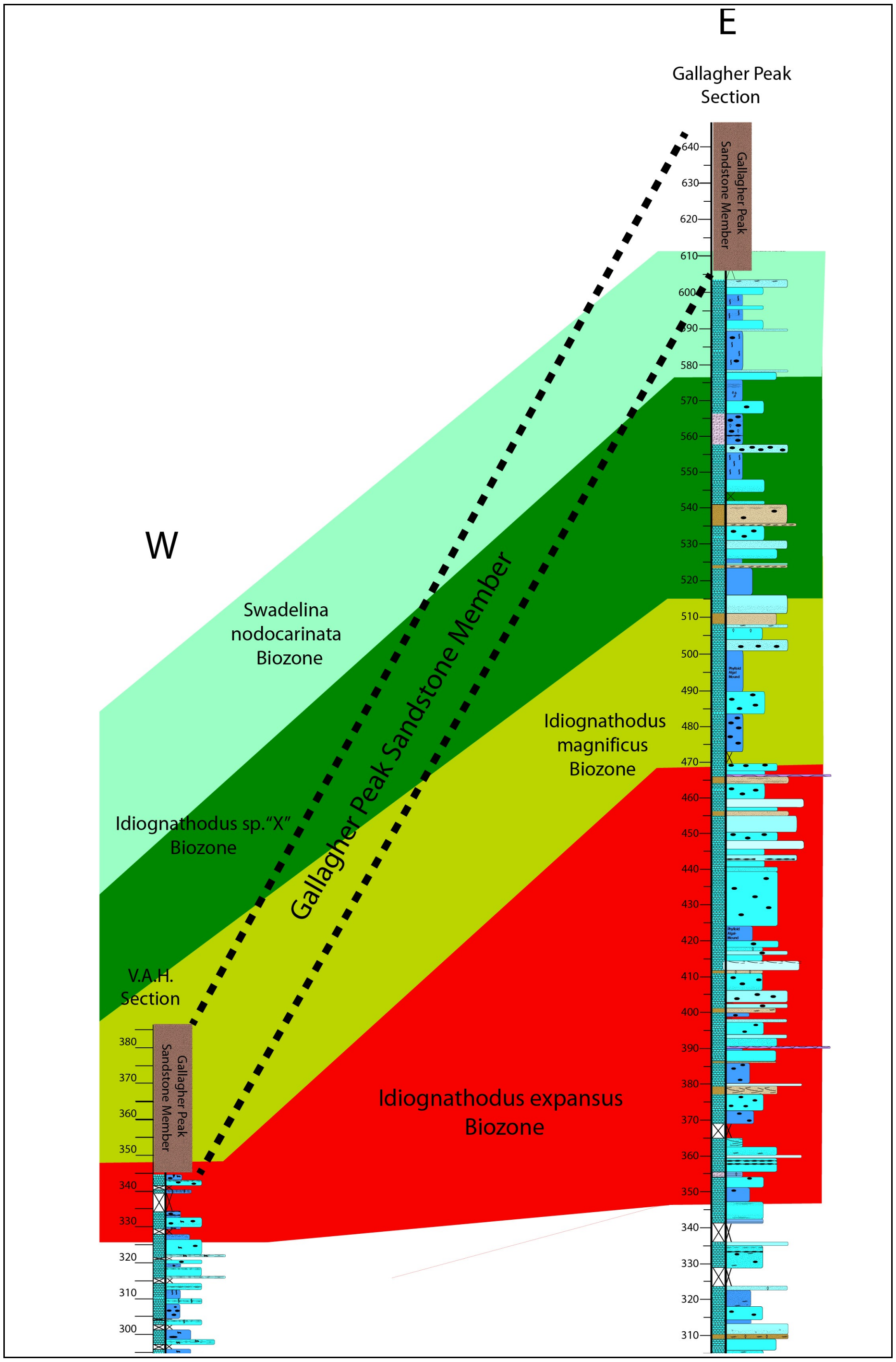


Figure 34: A west to east transgressive relationship of the Gallagher Peak Sandstone Member. Western locality is from the VAH section in the southern Lost River Range and the eastern section is from the Gallagher Peak type section in the Beaverhead Range.

Algal Mounds: Pennsylvanian **Palaeoaplysina** *Buildups*

Within the Snaky Canyon Formation, several localities contain massive phylloidal algal and *Palaeoaplysina* buildups. These algal and *Palaeoaplysina* bioherms average 2-25 meters in thickness and may be tens to hundreds of meters in width. Smaller, bed-scale biostromes average 2-10 meters in thickness and have been laterally traced over 15 kilometers (Breuninger et al., 1989).

Previous workers have interpreted the algal and *Palaeoaplysina* buildups of central Idaho to be of Upper Pennsylvanian (Virgilian) to Early Permian (Wolfcampian) in occurrence age (Breuninger et al., 1989; Brueninger, 1971, 1976; Canter, 1984; Canter and Isaacson, 1991). These studies used limited fusulinid collections reported by Shannon (1961) and Skipp et al. (1979a) for the determination of age by bio- and lithologic correlation. Ritter and Morris (1997) identified the occurrence of *Palaeoaplysina* bioherms from the Middle Pennsylvanian (Desmoinesian) strata of the Ely Limestone of western Utah. This study utilized the presence of limited Middle Pennsylvanian conodonts (*Idiognathodus* sp.) and definitive collections of early Desmoinesian fusulinids and other megafauna. The work of Ritter and Morris (1997) is the oldest published global occurrence of *Palaeoaplysina.*

Age Determination of Algal Buildups in the Snaky Canyon Formation

Conodont assemblages recovered from the Snaky Canyon Formation at several localities containing phylloidal algal and *Palaeoaplysina* buildups indicate a middle Desmoinesian stratigraphic age more closely resembling that of *Palaeoaplysina* occurrences in the Ely Limestone of Nevada reported on by Ritter and Morris (1997). The biofacies directly containing these buildups is determined to be a hindrance limiting the presence of diverse conodont assemblages as a result of minimal recovery rates associated with proximity to these buildups. At the Gallagher Peak section, *Palaeoaplysina* dominated intervals are marked by the absence of invertebrate megafauna, conodonts, and evidence of significant bioturbation. The hydrozoans and algae excluded conodonts, among other shelly faunas. Directly above and below the occurrence of *Palaeoaplysina*, indicators of restricted marine conditions exist in the form of solution lamellae, evaporite mineral salt casts, and the presence of significant laminated siliciclastics. Viable conodont assemblages were recovered from the wackestone/packstone reef foundations and often in the buildup capping Biofacies "C" of Breuninger et al. (1989).

In order to constrain the occurrence of the Pennsylvanian agal and *Palaeoaplysina* buildups, biostratigraphic samples were systematically taken from facies conducive to producing high conodont yields above and below the buildups. At the Howe Dump *Palaeoaplysina* buildup located to the northwest of Howe, ID. (Figure 15, no. 8), samples were collected from buildup foundation packestones and/or wackestones containing abundant shelly fauna and bryozoans at the 1.5m., 2m., 2.5m., and 3m. increments below the first occurrence of the mounds. At the localities containing stratigraphic biostromal occurrences of *Palaeoaplysina* (such as at the Gallagher Peak type section) samples were collected from ideal facies above and below the occurrence of the biostrome.

At the Gallagher Peak type section, *Palaeoaplysina* biostromes located at meters 305, 390, and 465 are within the lower-middle *I. obliquus* biozone and the complete *I. expansus* *biozone*. The biostrome at meter 305 indicates a first appearance of *Palaeoaplysina* during the middle Desmoinesian at this locality (Figure 35). At the Howe Dump *Palaeoaplysina* bioherm, limited conodont assemblages were recovered from the reef foundation carbonates. Specimens of *A. lautus, I. expansus, I. obliquus, H. minutus, Neognathodus* sp., and *Streptognathodus* sp. were identified from this interval, indicating a likely middle to late Desmoinesian initial age for the buildup (Figure 35). All species of *Neognathodus* and *I. expansus* and *I. obliquus* become extinct near the top of the Desmoinesian, indicating a age no younger than uppermost Desmoinesian for this locality (Figure 35).

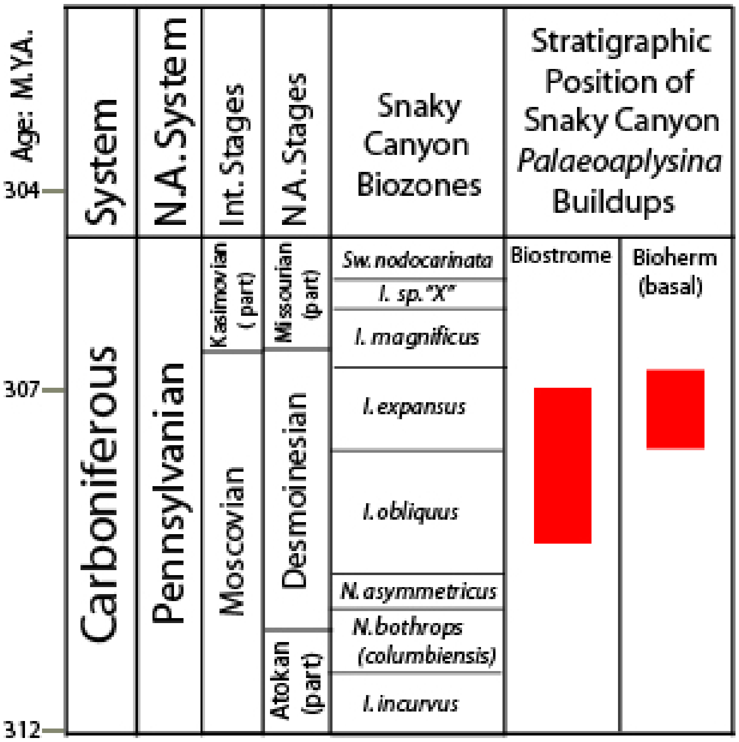


Figure 35: Stratigraphic positioning of *Palaeoaplysina* buildups within the Snaky Canyon Formation.

Chapter 13: Depositional Facies of the Bloom Member

Bloom Member depositional facies and the architecture of these facies is interpreted to have been influenced by extrabasinally controlled short- and long-term sea level fluctuations and a tectonically evolving foreland basin. Unlike the Juniper Gulch Member the facies characteristic of the Bloom Member are dominantly open marine. The complete facies assemblage records nearshore peritidal, shoreface deposition to deep, offshore subtidal deposition. Individual facies recognized from the Bloom Member listed in a shallowing upward sequence are the deep subtidal, subtidal carbonate, subtidal mixed carbonate-siliciclastic, carbonate shoaling, carbonate buildup, restricted peritidal carbonate, marginal marine mixed carbonate-siliciclastic, siliciclastic dominated, and eolian influenced siliciclastic facies. A complete description of the depositional facies recognized from the Bloom Member is provided in Table 1 and photographs of each facies are provided in Appendix V.

This report does not recognize the utility of facies codes (as in Archuleta's (2004) description of the Juniper Gulch Member) due to the confusing and complex nature of variously defined and therfore confusing codes. Instead, facies are defined on a purely genetically descriptive foundation in order to provide a clear and concise understanding without the unnecessary referencing of regional and single-use facies codes. The discussion of the use of facies codes versus genetically and/or descriptively assigned facies is ongoing and for a complete investigation of this issue, please consult the work and subsequent discussion and reply by Miall (1985).

Facies Name	**Color**	**Lithologies**	**Average Thickness**	**Skeletal Components**	**Nonskeletal Components**	**Sedimentary Structures**	**Depositional Environment**
Deep Subtidal	Dark to medium blue	Wackestone	1 to 6 meters	Whole corals, brachiopods, ramose and fenestral byrozoans, and echinoderm fragments	Limited chert	Carbonate hardgrounds, limited bioturbation	Deep (> 30m) subtidal, offshore open marine, well circulated deposition
Subtidal Carbonate	Dark to medium blue and gray	Wackestone to packstone	1 to 9 meters	Skeletal fragments of brachiopods and echinoderms. Whole brachiopods, and ramose byrozoans. Limited fenestral bryozoans.	Limited chert, pelloids, and oolites.	Bioturbation, limited carbonate hardgrounds	Moderate depth (>10m) offshore open marine, well circulated deposition.
Subtidal Mixed Carbonate-Siliciclastic	Light to medium blue and gray	Wackestone to packstone	1 to 8 meters	Skeletal fragments of brachiopods and echinoderms. Whole brachiopods, and ramose byrozoans. Limited fenestral bryozoans.	Fine grained, well sorted and rounded quartzose sand, limited pellets and oolites, nodular chert	Bioturbation, limited carbonate hardgrounds	Moderate depth (>10m) offshore open marine, well circulated deposition.
Carbonate Shoaling	Light blue to gray	Grainstone	1 to 3 meters	Echinoderm fragments, limited fragmented brachiopod and unidentifiable fine to coarse bioclasts.	Oolites, pellets, limited fine to medium siliciclastics	Limited laminations	Shoaling along the flanks of carbonate buildups; open marine, well circulated
Carbonate Buildup	Medium to light blue and gray	Wackestone, packstone, boundstone	1 to 15 meters	Whole brachiopods, colonial and solitary corals, ramose and and limited fenestral bryozoans, palaeoaplysina algae and fragmented echinoderms	Limited pellets, oolites, and siliciclastics, nodular chert	Bioturbation	Carbonate buildups, bioherms, and biostromes inboard of shoaling
Restricted Peritidal Carbonate	Dark blue to medium blue	Mudstone to wackestone	1 to 4 meters	Limited skeletal fragments, fusulinids	Nodular to bedded chert, limited silt	Rip-ups, solution features, bioturbation	Inner platform very shallow deposition, restricted circulation
Marginal Marine Mixed Carbonate-Siliciclastic	Dark blue to medium blue	Mudstone to wackestone	1 to 4 meters	Limited skeletal fragments, fusulinids	Nodular to bedded chert, limited silt	Rip-ups, solution features, bioturbation	Inner platform very shallow deposition, restricted circulation, nearshore
Siliciclastic Dominated Marginal Marine	Dark blue to medium blue and brownish gray	Mudstone to wackestone	1 to 6 meters	Limited skeletal fragments	Nodular to bedded chert, well sorted fine grained quartzone sand	Rip-ups, solution features, cross-lamination, parallel lamination, bioturbation	Inner platform nearshore deposition, restricted circulation, proximal to shoreline
Eolian Influenced Siliciclastics	Gray to brownish orange	Carbonate cemented quartz arenite	2 to 9 meters	Not present or highly limited	Very fine to fine grained, well rounded and sorted quartzose sand	Cross-lamination, Limited parallel lamination	Nearshore to terrestrial eolian dominated deposition

Table 1: Descriptions of the depositional facies of the Bloom Member identified by this study. See Appendix V for image examples of select facies.

Chapter 14: Revised Depositional Setting

The establishment and correlation of the fifteen conodont based biozones identified by this study aid in the determination of distinct sedimentologic shifts, tectonic events, and major eustatic shifts recorded by the succession of Snaky Canyon carbonates in East-Central Idaho (Figure 39). These events may leave a signature in the rock record in the form of condensed intervals, as thick packages of strata deposited over relatively short time frames, and/or the complete absence of biozones identified from other localities of the same age strata. Many workers (Skipp et al., 1979a/b; Skipp and Hall, 1980; Mahoney, 1991; Geslin, 1999; and Link et al., 2002) have identified major changes in the Pennsylvanian sedimentary package from localities within or adjacent to the area of study, although none of these studies has integrated high-resolution biostratigraphy when interpreting the mechanisms for the depositional trends. This study represents the first bio-chronostratigraphic interpretation of the upper Carboniferous of east-central Idaho.

Five Shaw diagrams are presented in Appendix III and graphically identify major shifts in accommodation space and rate of sedimentation. Through the comparison of biozone occurrence to the representative thickness of each measured section during these defined time intervals, depositional trends and shifts can be identified (Figure 39; Appendix III). Shaw diagrams have been constructed and interpreted along the east to west transect of measured sections in east-central Idaho comparing the Gallagher Peak type section to the Unknown Canyon section, the Hawley Mountain section, and the VAH section. Diagrams are also prepared for the comparison of the

Unknown Canyon section to that of the Hawley Mountain section to the north and the VAH section to the west (Appendix III). Sharp rises in the single graphed line indicate increased rates of sedimentation and accommodation space at the measured section locality represented along the vertical axis of the diagram. A shallow rise or relatively flat graphed line indicates increased deposition at the locality represented along the horizontal axis of the diagram. A line with a 45 degree rate of rise indicates deposition was relatively uniform at both localities for the time interval identified.

From the interpretation of the Shaw diagrams, a greater understanding of the tectonic and eustatic controls on the Snaky Canyon Formation is identified. This is presented in the text based on North American series boundaries. No discussion is presented for the Missourian, as correlation is limited to two stratigraphic sections, conodont recovery was not of high-resolution results, and the stratigraphic thickness represented by these Missourian biozones is relatively similar.

The Morrowan

Batt et al. (2008) identified a complex evolution of the continental margin from Upper Mississippian (Chesterian) carbonates located in east-central Idaho and southwest Montana. This study recognized a rapid shift from homoclinal ramp to distally steepened, tectonically influenced ramp and back to homoclinal geometry during the Upper Mississippian and into the lowermost Pennsylvanian (basal Morrowan). Skipp and Hall (1980) recognized that the paleotectonic setting from the Upper Mississippian was inherited by the Lower Pennsylvanian, with limestone deposition dominating into the Wood River Basin to the west.

The Morrowan portion of the Snaky Canyon Formation is represented by the most consistent deposition to biozone pattern recognized across the study area (Figure 39; Appendix III). Generally, there are no major changes in the thicknesses of the strata represented by each biozone, which likely indicates deposition along a homoclinal ramp due to the lack of major swings in deposition and sedimentary features associated with embayments and distally steepened ramps. This homoclinal ramp geometry was inherited from the uppermost Mississippian and continued into the middle Atokan. Compared to the work of Abplanalp et al. (2009) and Batt (2006) from the Upper Mississippian carbonate succession of the region, limited accommodation space throughout the Morrowan is recorded. This condensed interval may be the result of very low global eustatic sea levels that are combined with a overall lack tectonic activity influencing the continental margin.

The overall thicknesses associated with the farthest west White Knob section are thicker than those to the east during the Morrowan, which indicates that there may have been a slight increase in accommodation space basinward. A major increase in stratigraphic thickness represented by the lower Morrowan *Declinognathodus noduliferous* biozone is recorded in the Unknown Canyon section (Figure 39; Appendix III). This phenomenon is likely independent of eustatic and tectonic control and is interpreted to be a result of poor conodont recovery due to heavy siliciclastic influence at this locality during this time.

The Atokan

The homoclinal continental margin ramp geometry of the Morrowan likely extends through the early Atokan. Skipp and Hall (1980) recognized that the tectonic setting of the Mississippian/Pennsylvanian boundary likely remained until the end of the Atokan within the region of study. The high-resolution biostratigraphic data recovered by this study likely indicates a cessation of the inherited conditions of the middle Carboniferous and sedimentologic shift during the Middle Atokan.

The initial lower Atokan increase in sediment thickness recorded in the easternmost Gallagher Peak section during the *Neognathodus atokaensis* and *Declinognathodus marginodosus/Idiognathoides sulcatus parvus* biozone intervals may be a result of a significant global eustatic increase (Figure 39; Appendix III). Globally, workers have identified a significant rise in eustatic sea-level during the lower-middle Atokan (uppermost Bashkirian – lowermost Moscovian) from carbonate successions located in the United States and Russia (Alekseev et al., 2004) and Rygel et al. (2008) identified a brief non-glacial interval during the lower Atokan. This event corresponds to the increase in sedimentation eastward and open marine megafaunal increases in the Gallagher Peak section indicate a overall deepening event eastward during this time.

The middle Atokan *Idiognathodus incurvus* biozone marks the first major indication of a changing tectonic basin. The stratigraphic thickness of the the *I. incurvus* biozone greatly increases to the west, from 19 meters thick at the easternmost Gallagher Peak section to over 85 meters in thickness at the westernmost Atokan VAH section (Figure 39; Appendix III).

This rapid shift in sedimentation to the west may be the result of increased accommodation space due to flexural downwarping associated with the reactivation of the Antler/Wood River Basin to the west and/or the initial shift from homoclinal ramp geometry to a distally steepened ramp geometry. Open marine fauna still exists from west to east, indicating that open circulation remained and that subsidence to the west did not drown or compensate marine megafaunal assemblages. This depositional pattern continues to the Atokan/Desmoinesian boundary, although the rate of accommodation decreases after the *I. incurvus* interval (Figure 39; Appendix III).

Previous workers studying the succession of sedimentary rocks of the Wood River Basin have noted a early Desmoinesian age for the initial reactivation of the foreland basin to the west of the study area (Mahoney, 1991; Geslin, 1998; Link et al., 2002). These reports have been primarily based on sedimentologic and textural data from very limited exposures of Atokan age strata with little to no biostratigraphic control. Skipp and Hall (1980) based their early Desmoinesian reactivation interpretation on the appearance of coarse clastics within the westernmost Desmoinesian Snaky Canyon carbonate succession. If downwarping and basin development did occur, this submergence would have likely initially trapped coarse siliciclastics from the Copper Basin Highlands from reaching the carbonate dominated continental margin (Figure 4). Geslin (1998) recognized a dominant southeasterly transport of Copper Basin Highland shed sediments parallel to the continental margin that may have also delayed the appearance of western sourced siliciclastics from reaching the carbonate bank. By the Desmoinesian, initial subsidence may have been outpaced by sedimentation and siliciclastic influence reached the Snaky Canyon carbonate bank long after the initial reactivation identified by this study during the middle Atokan.

The Desmoinesian

Several workers (Mahoney, 1991; Geslin, 1998; and Link et al., 2002) have identified a distinct shift in sedimentologic patterns during the Desmoinesian of the Wood River Basin located to the west of the Snaky Canyon Carbonate bank. It is believed that significant subsidence of the this reactivated Antler basin occurred during the early Desmoinesian and extended into the earliest Permian (Mahoney, 1991). Although this study proposes a middle Atokan initial reactivation and basin development based on the change from homoclinal to distally steepened Snaky Canyon ramp geometry, continued Desmoinesian basin development and tectonic influence to the west of the study area is evident through the comparison of biozone stratigraphic thicknesses (Figure 39; Appendix III).

The lowermost Desmoinesian *Neognathodus asymmetricus* biozone records a time of likely tectonic and eustatic stablility due to the uniform stratigraphic thickness of Snaky Canyon strata during this time interval (Figure 39; Appendix III). By the middle to upper Desmoinesian *I. obliquus* and *I. expansus* biostratigraphic intervals, accommodation space greatly increased to the east and thick stratigraphic successions are recorded from this biostratigraphic interval at the Gallagher Peak type section (Figure 39; Appendix III). At these intervals, the Gallagher Peak section contains abundant open marine megafauna, shows signs of substantial siliciclastic influence from the continental craton to the east, and is dominated by relatively thick (2+ meter) beds.

To the west of the Gallagher Peak section at the Hawley Mountain and Unknown Canyon sections, open marine fauna is still dominant although bed thickness is greatly diminished and there is a general absence of siliciclastics. These two sections also record several carbonate hardgrounds and significant bioturbation (Appendix I).

These data suggest that a significant deepening event had occurred to the west of the Gallagher Peak section due to of eustatic fluctuations and/or tectonic controls as a result of middle Carboniferous sediment loading or the reactivation of the Copper Basin Highlands to the west. During the Desmoinesian, it is globally recognized that eustatic sea levels were generally upwards of 40 to 50 meters above that of the Morrowan and early Atokan (Klein, 1994). This flooding could have caused a shoreward increase in sedimentation and created the condensed intervals recorded westward of the Gallagher Peak section. The continued filling of the Wood River Basin with kilometer scale successions of sediments may have also caused the migration of the basin hinge-line eastward due to sediment loading, causing the relationships recorded by the upper Desmoinesian Snaky Canyon Formation. At the Gallagher Peak section, the upper Desmoinesian to lower Missourian deposits are dominated by restricted, tidal flat facies. A transition from the megafaunal rich open marine dominated depositional facies of the Morrowan and Atokan to restricted, poorly circulated tidal flat dominated depositional facies occurred at the upper Desmoinesian. This may indicate the timing of the basin partitioning the development of restricted circulation within the reactivated Wood River Basin. Further regional study is likely necessary to differentiate the relationship of eustatic and tectonic controls on the continental margin during this time interval.

Chapter 15: Carboniferous Conodont Biostratigraphy of Idaho – A Synopsis of the University of Idaho's Carboniferous Group

The University of Idaho's Carboniferous Research Group led by Dr. Peter E. Isaacson has produced several works since the 1980s that establish a biostratigraphic framework for the Carboniferous of Idaho. These studies investigated the Carboniferous carbonate bank of east-central Idaho, a world-class carbonate-dominated succession of strata along the equatorial continental margin of western Laurentia. From the biostratigraphic data recovered, a succession of conodont-based biozones has been proposed that spans a majority of the Carboniferous.

The first study conducted under the guidance of Dr. Isaacson was that of Stamm (1985). This work identified conodonts from the Middle Mississippian (Meramecian) Scott Peak Formation and proposed three biozones based on the occurrence of species of *Hindeodus* and *Gnathodus* (Figure 36). Subsequent works by Abplanalp (2006) and Abplanalp et al. (2009) and contributed to by Gilmour (2005) identified five biozones from the Upper Mississippian (upper Meramecian) to Lower Pennsylvanian (basal Morrowan) of the east-central Idaho carbonate bank (Figure 36). This study recognized the stratigraphic utility of species of *Hindeodus, Cavusgnathus, Adetognathus*, and *Rhachistognathus*. An unpublished preliminary study by Abplanalp and Isaacson identified two Middle Mississippian (Osagean) conodont assemblage biozones from the White Knob Limestone based on species of *Polygnathus, Pseudopolygnathus*, and *Clydagnathus* (Figure 36). The complete succession of conodont based biozones from the Carboniferous carbonates in east-central Idaho identified by the University of Idaho's Carboniferous Research Group is presented in Figure 36.

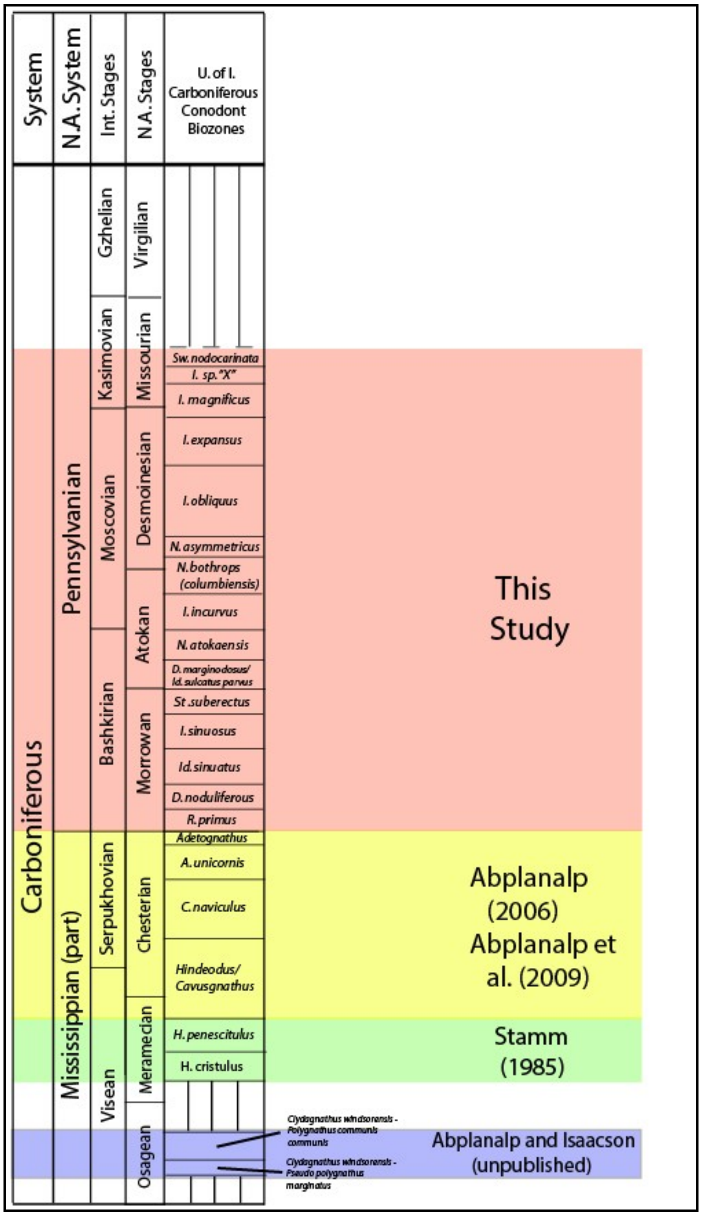


Figure 36: Carboniferous conodont biozones defined and identified from east-central Idaho by the University of Idaho's Carboniferous Research Group

Chapter 16: Discussion

Conodont assemblages recovered from the Snaky Canyon Formation of east-central Idaho provide new information concerning:

1) the age and stratigraphic relationship of the Bloom, Gallagher Peak Sandstone, and Juniper Gulch members of the formation (Figures 33 and 39),
2) the conodont biostratigraphy of the rock unit (Figures 37 and 38),
3) a new western U.S. conodont biozonation framework from a continuously deposited succession of nearshore carbonates (Figures 37 and 38),
4) a new biostratigraphic framework that may be utilized by future workers for high-resolution sequence and chemostratigraphic application and analysis,
5) the conodont biofacies during the Pennsylvanian (Figures 28 and 29),
6) the timing of 3rd and 4th order sequences and parasequences,
7) the timing of major tectonic and eustatic events that controlled Snaky Canyon deposition,
8) the stratigraphic placement of phylloid algae and *Palaeoaplysina* buildups (Figure 35),
9) the recognized conodont lineages and phylogeny of the platform groups (Figures 31 and 32),
10) the correlation of east-central Idaho's Snaky Canyon Formation along a west to east transect (Figure 39), and
11) an updated understanding of the time transgressive

nature of the Gallagher Peak Sandstone Member (Figure 34).

This study has identified 15 conodont biozones from the succession of Snaky Canyon carbonates located in east-central Idaho (Figures 37 and 38). Most of these biozones have been recognized by previous workers in the western U.S., the midcontinental U.S., and Eastern Europe. Three new biozones from the succession of Snaky Canyon carbonates are proposed and these biozones are the Middle to Upper Pennsylvanian *Idiognathodus magnificus*, *I. sp. "X"*., and *Swadelina nodocarinata* biozones.

High-resolution conodont biostratigraphy has refined the existing stratigraphic framework and positioning of the Snaky Canyon Formation (Figure 33). Based on the recovered conodont assemblages, the Juniper Gulch Member type section in the southern Beaverhead Range is now determined to be depositionally synchronous with the Bloom Member. It is suggested that additional studies investigate the stratigraphic positioning of the Juniper Gulch Member in the Lost River and Lemhi ranges in order to fully interpret the relationship recognized in the Beaverhead Range. New age constraining data for the Gallagher Peak Sandstone Member indicate that the unit is time transgressive, with older deposits located to the west and younger appearances of the member to the east (Figure 34). Refined age data from biostratigraphic analysis has also provided a better understanding of the timing and occurrence of the enigmatic *Palaeoaplysina* algal mounds within the Snaky Canyon Formation. It is now interpreted that the initial occurrence of the algal buildups was during the middle to upper Desmoinesian, making the Snaky Canyon Formation one of the oldest globally recognized occurrences of *Palaeoaplysina* (Figure 35).

The establishment of a biostratigraphic framework for the Snaky Canyon Formation allows for the accurate lateral correlation of numerous measured sections of the rock unit (Figure 39). This west to east correlation provides information regarding the depositional rate, available accommodation space, and the tectonic and eustatic influences actively controlling the unit. Through the comparison of biostratigraphically defined individual measured sections (Appendix III) and all of the sections (Figure 39) it is determined that during the Morrowan, Snaky Canyon deposition likely occurred along a nearshore and well circulated, open-marine carbonate ramp with accomodation influenced by middle Carboniferous sediment loading (Batt, 2006; Batt et al., 2008). At the early Atokan, a globally recognized eustatic increase shifted sedimentation shoreward to the east. By the middle to late Atokan, a significant shift in accumulated sediment thickness is recorded to the west, likely correlating with the reactivation of the Antler Foreland Basin to the west and a change in ramp geometry. Along with the evidence from the interpretation of the Shaw (Appendix III) and correlation diagrams (Figure 39), evidence recorded by the preservation quality of recovered conodonts and identified biofacies also indicates a distinct shift in deposition and tectonic setting during the Middle Pennsylvanian. By the late Desmoinesian sedimentation had shifted slightly to the east, although it is likely that basin partitioning created restricted environments at these localities.

Nine distinct depositional facies have been identified from the Bloom Member spanning the Morrowan, Atokan, and Desmoinesian stages (Table 1). The juxtaposition of subtidal facies with nearshore eolian facies between individual parasequences indicates high-frequency sea level fluctuations of moderate amplitude. The stacking patterns, duration, and facies relationships of the parasequences indicates that the stratigraphic relationships recorded by the Snaky Canyon Formation were a likely result of the waxing and waning of Gondwanan glaciers. The upper Carboniferous glacially driven eustatic fluctuations caused the global deposition of cyclic strata. This study provides an increased understanding of Upper Carboniferous eustatically controlled cyclicity of a nearshore equatorial succession of mixed carbonates and siliciclastics through the determination of stratigraphic positioning and timing. Over 50 meter-scale shallowing-upward and flooding surface bound cycles (parasequences) ranging from 2 to 16 meters in thickness have been identified from the Bloom Member type section measured at Gallagher Peak (Appendix IV). These parasequences are grouped into 50 to 80 meter parasequence sets (sequences) containing 5 to 10 individual parasequences (Pope et al., 2007).

The establishment of a high-resolution biostratigraphic framework for the Bloom Member of the Snaky Canyon Formation allows for the accurate stratigraphic positioning and age determination for the rock unit. Based on the 318 Ma to 306 Ma duration of the Bloom Member type section at Gallagher Peak it is determined that the identified 50+ parasequences likely record 4th order (100-200 k.y.) eustatic variations from a relatively tectonically quiescent passive margin. The parasequence sets (sequences) range from 1 to 2 Ma. each (3rd order) and indicated moderate to high amplitude (> 30m) sea level fluctuations. These 50 to 80 m. thick sequences record an initial lowstand facies, followed by a transgression, and then capped by general highstand facies into the latest Desmoinesian to earliest Missourian.

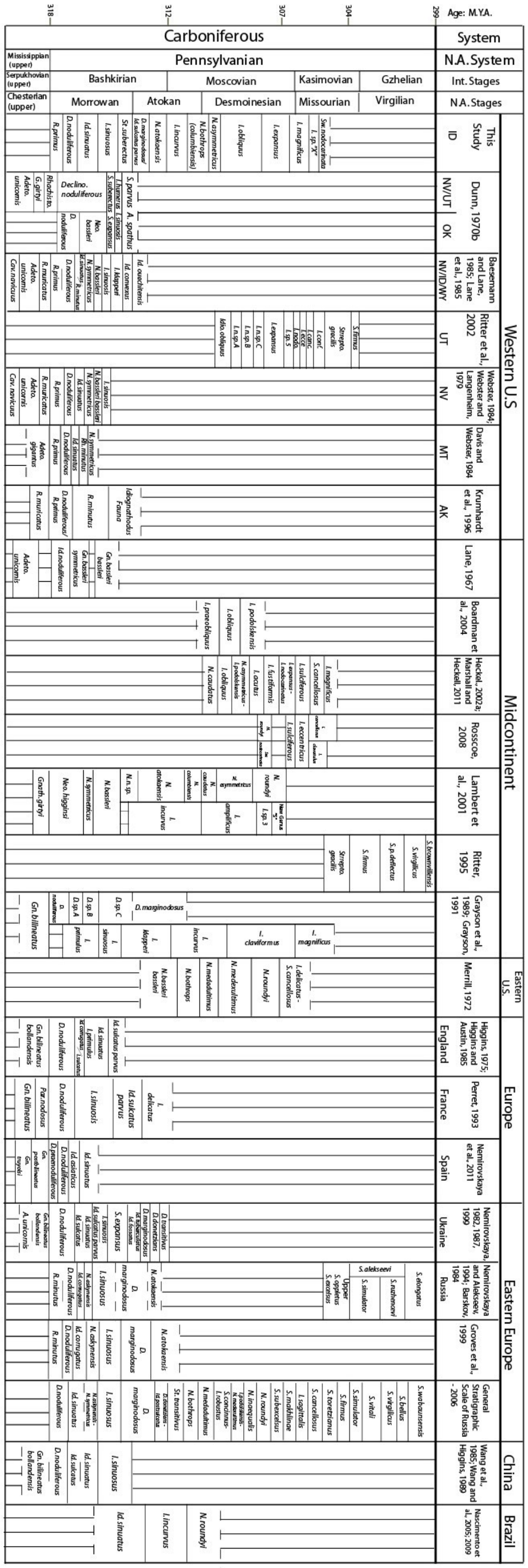


Figure 37: Pennsylvanian conodont biozones identified by this study and by previous global workers.

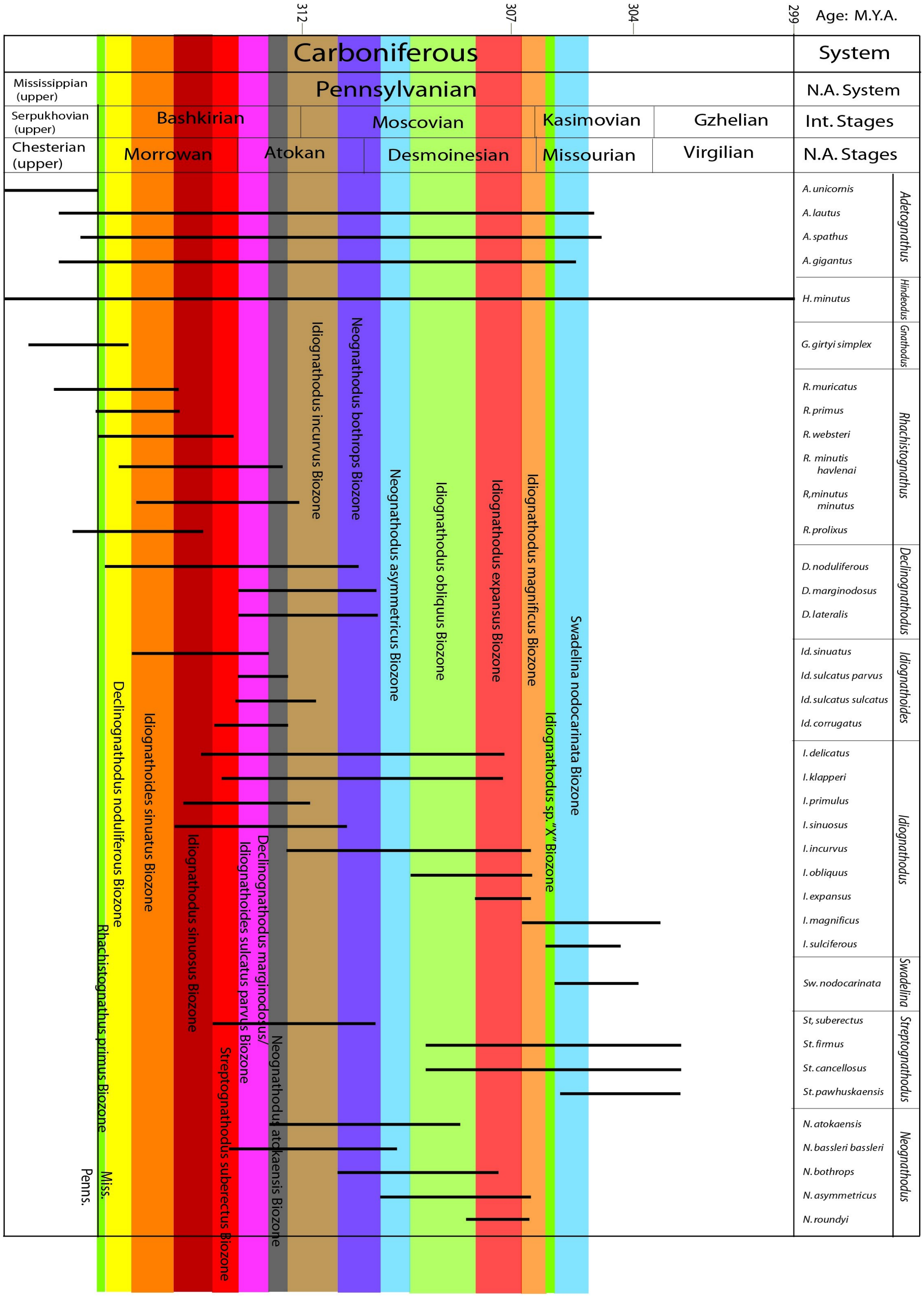


Figure 38: Conodont stratigraphic ranges and conodont biozones identified by this study.

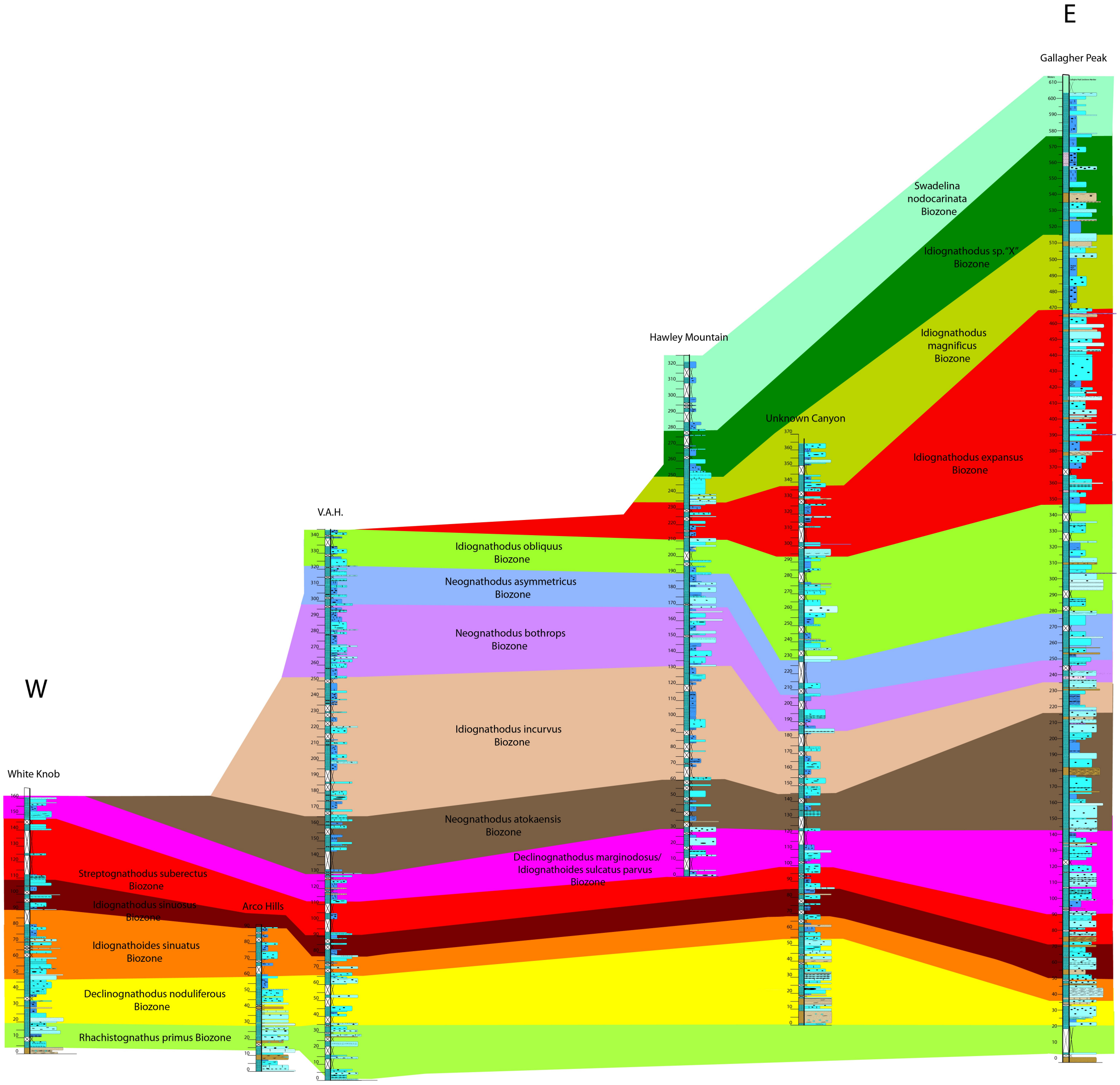


Figure 39: Conodont biozones correlated from west to east across the study area.

Chapter 17: Systematic Descriptions

Species of *Adetognathodus, Declinognathodus, Diplognathodus, Hindeodus, Idiognathodus, Idiognathoides, Noegnathodus,* and *Rhachistognathus* recovered from each of the measured sections of the Snaky Canyon Formation and utilized for stratigraphic positioning are described and discussed in this section. Published synonymies listed for each species may be incomplete as a result of the inability to accurately use specific specimen descriptions. Diagnostic Pa element descriptions of each species are provided, along with the observed and published stratigraphic ranges.

Genus Adetognathus

Genus *Adetognathus,* Lane, 1967
Type species-*Cavusgnathus lautus*, Gunnell, (1933, p. 286)

Diagnosis:

The genus *Adetognathus* includes species possessing Class II and III symmetries (Lane 1968). Apparatuses are seximembrate. Diagnostic Pb elements (platforms) have a deep, median longitudinal trough that runs the entire length of the platform. If developed and present, the freeblade is much longer than the attached fixed blade that often rises in height anteriorly. In this form, no carina is developed (Lane and Straka, 1974).

Adetognathus differs from *Cavusgnathus* by the complete absence or weak development of a fixed blade in *Cavusgnathus* forms. *Cavusgnathus* has a fixed blade equal to, or longer than, the free blade and in lateral profile the short free blade rises to its apex in the posterior half. The longer free blade of the genus *Adetognathus* has its apex in the anterior half (Webster, pers. com.).

Adetognathus lautus

Cavusgnathus lautus Gunnell, 1933.

Figure 20, nos. 19-23

Cavusgnathus lautus Gunnell, 1933, p. 286, Pl. 31, figs. 67, 68; Pl. 33, fig. 9; Webster, 1969, p. 28, Pl. 4, fig. 9a, 9b.

Cavusgnathus lautus (Gunnell), Ellison, 1941, p. 126, Pl. 21, figs. 47, 48.

Cavusgnathus sp. A. Koike, 1967, Pl. 1, fig. 5 (= form species *A. lautus*)

Adetognathus lautus (Gunnell), Lane, 1967, p. 933, Pl. 121, figs. 1-3, 7, 10, 11, 15, 17.

Adetognathus lautus (Gunnell), Dunn, 1970a, p. 327, Pl. 61, figs. 1, 4; Lane and Straka, 1974, p. 64, Pl. 36, figs. 17, 21, 22, 25-31, Pl. 38, figs. 1-4, 6-8, 10-15, 20, Pl. 39, 1-3, 7-14; Merrill and King, 1971, p. 655, Pl. 75, figs. 23-29; Grayson, 1984, Pl. 2, 3, figs. 8-9, 26-27; Morrow and Webster, 1992, p. 65, Pl. 1, fig. 12; Nemirovskaya, 1999, p. 51, Pl. 1, fig. 4.

Discussion-*Adetognathus lautus* is characterized by a deep, median longitudinal trough throughout its length. This trough is surrounded by margins or parapets ornamented by nodes or short transverse ridges that do not extend into the trough, except at the posterior of the platform where the parapets may coalesce. In lateral view, the free blade and platform are arched. The fixed blade is much shorter than the long free blade that rises in height anteriorly. In lower view, the basal cavity is a large and sub-equally flared depression under the platform that continues to the anterior tip of the free blade as a slit. No carina is developed in this species.

Remarks- *Ad. lautus* differs from *Ad. lautus* subsp. *gigantus* by lacking a large denticle on the posterior end of the free blade. The attachment of the free blade of *Ad. lautus* is exclusively left sided and that of *Ad. lautus* subsp. *gigantus* is exclusively right sided. Both may belong to one paired multielement apparatus of *Ad. lautus.*

Later specimens recovered from the Middle to Upper Pennsylvanian are dominated exclusively by short, small transverse ridge ornamentation along the parapets.

Range- Uppermost Chesterian (latest Mississippian) to Lower Permian.

Occurrence- In east-central Idaho, *Ad. lautus* first occurs within the last 2 m. of the Bluebird Mountain Formation of the Arco Hills type section; within the last 2 m. of the Surrett Canyon Formation and within the lowermost Arco Hills Formation at the Antelope Creek section. *A. lautus* occurs throughout the Snaky Canyon Formation.

Material Studied- 135 specimens

Adetognathus gigantus

Adetognathus lautus subsp. *gigantus*

Cavusgnathus gigantus Gunnell, 1933

Figure 20, nos. 24,25

Cavusgnathus gigantus Gunnell, 1933, p. 286, Pl. 33, figs. 7, 8; Webster, 1969, Pl. 4, figs. 6a, 6b.

Cavusgnathus giganta (Gunnell), Ellison, 1941, p. 126, Pl. 21, figs. 44, 45, 49; Ellison and Graves, 1941, Pl. 3, fig. 3; Youngquist and Downs, 1949, p. 162, Pl. 30, figs. 18-20; McLaughlin, 1952, p. 126, Pl. 21, figs. 42, 43, 46.

Cavusgnathus sp. A. Koike, 1967, p. 295, Pl. 1, figs. 4a, 4b (form species *A. gigantus*)

Adetognathus gigantus (Gunnell), Lane, 1967, p. 931, Pl. 120, figs. 16, 18, 19; Pl. 121, figs. 8, 12, 13, 16; Dunn, 1970a, p. 326, Pl. 61, figs. 2, 3; Merrill and King, 1971, p. 654, Pl. 75, figs. 19-22, 30-32; Higgins, 1975, p. 27, Pl. 8, figs. 6, 7, 9, 11; Nemirovskaya, 1999, p. 51, Pl. 1, fig. 10.

Discussion-Very large element; median groove broad and deep; sides with transverse ridges or distinct nodes except left posterior side which may bear a single, abnormally large thin denticle and anterior to which occur smaller denticles on the blade. Basal cavity has a broad, asymmetrical flange. This sub-species may display features characteristic of the species *Ad. lautus* (Lane, 1969) and are exclusively right sided.

Remarks-*Adetognathus lautus* subsp. *gigantus* is easily distinguished from *A. lautus* on the basis of size, coarse dentition, and right side blade attachment. The subspecies is recognized in this study to aid in the recognition of distinct assemblages and in order to delineate its relationship with *Ad. lautus*, for which it may be paired.
Later specimens recovered from the Middle to Upper Pennsylvanian are dominated exclusively by short, small transverse ridge ornamentation along the parapets.

Range-Uppermost Chesterian (Late Mississippian) to Lower Permian.

Occurrence-In east-central Idaho, *Ad. lautus* subsp.

gigantus first occurs within the last 2 m. of the Bluebird Mountain Formation of the Arco Hills type section and within the uppermost Bluebird Mountain at the Antelope Creek section. *A. gigantus* occurs throughout the Snaky Canyon Formation.

Material Studied- 78 specimens

Adetognathus spathus

Cavusgnathus spatha Dunn, 1966

Figure 21, nos. 1-5

Cavusgnathus spatha Dunn, 1966, p. 1297, Pl. 157, figs. 3, 7, 8; Webster, 1969, p. 28, Pl. 4, figs. 1, 4, 5.
Adetognathus lautus, Lane, 1967, p. 932, Pl. 121, fig. 4.
Adetognathus spathus (Dunn), Dunn, 1970a, p. 327, Pl. 61, figs. 11-13; Lane and Straka, 1974, p. 65, Pl. 38, figs. 5, 9, 16-19, Pl. 40, figs. 4-6; Morrow and Webster, 1991, p. 104, Pl. 2, figs 1-4; Morrow and Webster, 1992, p. 64, Pl. 1, fig. 13.

Discussion-*Adetognathus spathus* is characterized by a deep, median longitudinal trough throughout its length. This trough is surrounded by margins or parapets ornamented by distinct coarse nodes or short transverse ridges that do not extend into the trough. The free blade thickens anteriorly and in lateral view, the platform and free blade are slightly arched. *Ad. spathus* is mainly characterized by increased size and by the presence of a short free blade or tail at the posterior end of the platform.

Remarks- *Ad. spathus* is distinguished from other *Adetognathus* species by the short free blade or tail at the posterior end of the platform where the parapets coalesce. Specimens of *Ad. spathus* also often show increased size and distinction of nodes and transverse ridges.

Range-Uppermost Chesterian (Late Mississippian) to Upper Pennsylvanian

Occurrence-In east-central Idaho, *A. spathus* first occurs within the mid-upper Bluebird Mountain Formation at the Arco Hills type section; and within the lowermost Arco Hills Formation (Pennsylvanian) at the Antelope Creek section. A. spathus occurs throughout the Snaky Canyon Formation, although decreases in abundance upwards and becomes rare in uppermost horizons (upper Desmoinesian to lower Missourian).

Material Studied- 85 specimens

Adetognathus unicornis

Streptognathus unicornis Rexroad and Burton, 1961

Streptognathus unicornis (Rexroad and Burton), 1961, p. 1157, Pl. 138, figs. 1-9; Collinson et al, 1962, p. 27, Ch. 1, 4; Dunn, 1965, p. 1149, Pl. 140, figs. 5, 6, 13, 14; Webster, 1969, p. 49, Pl. 4, figs. 13a, 13b.

Adetognathus unicornis (Rexroad and Burton), Lane, 1967, Pl. 119, figs. 16-20; Dunn, 1970a, p. 327, Pl. 61, figs. 20-22; Lane and Straka, 1974, p. 66, Pl. 33, figs. 14-18; Morrow and Webster, 1992, p. 64, Pl. 1, fig. 10, 11; Nemirovskaya, 1999, p. 52, Pl. 1, fig. 11.

Discussion-*Adetognathus unicornis* is characterized by a deep, longitudinal trough the runs along the median of the platform. The platform is narrow and outer parapets are ornamented by nodes or transverse ridges that do not extend into the median trough except near the posterior where the parapets may coalesce. The anterior free blade may be of varying length, thickens posteriorly, and is distinctively positioned in the median of the platform where the outer parapets become diminished. No carina is developed and in lateral view the unit is unarched.

Remarks- *Ad. unicornis* is distinguished from other species of *Adetognathus* by the transitional attachment of the free blade between the parapets and by positioning of the largest denticle on the posterior end of the free blade. Most specimens are also of smaller size.

Range- Middle Chesterian to lowermost Morrowan

Occurrence-In east-central Idaho, *A. unicornis* occurs within the Surrett Canyon Formation at the Antelope Creek section; within the upper Surrett Canyon Formation and throughout the Arco Hills Formation at the Arco Hills type section; throughout the Arco Hills Formation at the Box Canyon section; and within the upper Railroad Canyon Formation at the Railroad Canyon section (Abplanalp, 2006). *A. unicornis* is present in the lower (basal Morrowan) Snaky Canyon Formation directly above the contact with the underlying Bluebird Mountain Formation.

Material Studied- 7 specimens

Genus *Cavusgnathus*

Harris and Hollingsworth, 1933

Type species- *Cavusgnathus alta*, Harris and Hollingworth, 1933

Diagnosis:

Members of this genus display Class IV symmetry and characteristic short, pronounced free blades (fixed blade). *Cavusgnathus* may be distinguished from *Adetognathus* by the lack of a distinct free blade that extends well beyond the platform anteriorly.

Cavusgnathus naviculus

Polygnathus navicula Hinde, 1900.

Polygnathus navicula Hinde, 1900, p. 342, Pl. 9, fig. 5; Holmes, 1928, p. 18, Pl. 7, fig. 14.

Cavusgnathus navicula (Hinde), Clarke, 1960, p. 23, 24, Pl. 4, figs. 1-3; Rexroad and Burton, 1961, p. 1151, Pl. 139, figs. 4-13; Rexroad and Nicoll, 1965, p. 17, Pl. 1, figs. 24, 25; Higgins and Bouckaert, 1968, p. 29, Pl. 2, figs. 7, 8.

Cavusgnathus naviculus (Hinde), Dunn, 1965, p. 1147, Pl. 140, figs. 10, 11; Rhodes, Austin, and Druce, 1969, p. 81, Pl. 13, figs. 12a-d, Pl. 14, figs. 1a-d, 4a-d; Webster, 1969, p. 28, Pl. 4, fig. 3; Reynolds, 1970, p. 7, Pl. 2, fig. 3; Dunn, 1970a, p. 329, Pl. 61, fig. 24, 25; Lane and Straka, 1974, p. 68, Pl. 32, figs. 6, 8, 10, 14-18; Higgins, 1975, p. 27, Pl. 8, figs. 3-5, 12, 13.

Discussion-The species *Cavusgnathus naviculus* is characterized by a broad, massive platform that is relatively flat across the upper surface. The trough is narrow or slit-like, and is generally restricted to the anterior half of the platform. In aboral view, the blade attaches to the right margin, forming a straight right margin. The margins have broad transverse ridges or distinct and random nodes as ornamentation. In lateral view, the profile of the blade is marked by a large and prominent posterior denticle that is directly vertical. From the tip of the denticle, the profile rapidly descends to the lowermost of three to five denticles at the anterior of the blade. Denticles along the blade are generally fused. In basal view, the pulp cavity is narrow and relatively deep.

<u>Remarks</u>- *C. naviculus* is restricted to the uppermost Mississippian (Chesterian). Specimens recovered were characterized by heavily abraded elements and often were of darker CAI than concurring species. This indicates a high likelihood of hydraulic transport and reworking.

<u>Range</u>–Middle Chesterian to the Chesterian/Morrowan boundary (Late Mississippian/Early Pennsylvanian).

<u>Occurrence</u>-In east-central Idaho, *Cavusgnathus naviculus* occurs throughout the South Creek and Surrett Canyon formations at the Antelope Creek section and at the Copper Mountain section; throughout the Surrett Canyon, Arco Hills, and lower Bluebird Mountain formations at the Arco Hills section; throughout the Surrett Canyon Formation at the Deadman Canyon and Taylor Mountain sections; within the Surrett Canyon and Arco Hills formation at the Box Canyon section; and throughout the Railroad Canyon Formation at the Railroad Canyon section (Abplanalp, 2006). In Snaky Canyon Strata, C. naviculus occurs in basal stratigraphic horizons (lowest Morrowan) directly above the contact with the underlying Bluebird Mountain Formation.

<u>Material Studied</u>- 4 specimens

Genus *Declinognathodus*

Genus *Declinognathodus*, Dunn, 1966

Type species–*<u>Cavusgnathus nodulifera</u>*, Ellison and Graves, 1941

Diagnosis:

Members of the genus *Declinognathodus* are characterized by scaphate and elongate, narrow platforms exhibiting two unequal parapets and a medial junction position of the free blade with the platform. Platform elements are symmetrically paired and exhibit deep basal cavities. The median carina fuses with the outer parapet and the outer parapet is commonly reduced to nodes or diminished ridge near the anterior margin of the platform.

Declinognathodus lateralis

Streptognathodus lateralis, Higgins and Bouckaert, 1968.

Figure 22, nos. 24,25

Streptognathodus lateralis, Higgins and Bouckaert, 1968, p. 45, Pl. 5, figs. 1-4,7;
Declinognathodus lateralis (Higgins and Bouckaert), Dunn, 1970a, p. 330, Pl. 62, figs. 5-7;
Streptognathodus lateralis (Higgins and Bouckaert), Higgins, 1975, p. 73, Pl. 12, fig. 9; Pl. 17, figs. 10-11, 13-14;
Declinognathodus lateralis (Higgins and Bouckaert), Wang and Higgins, 1989, p. 276, Pl. 1, figs. 10-13; Nemyrovska and Alekseev, 1993, Pl. 4, figs. 19,23; Nemyrovska, 1999, p. 53, Pl. 1, figs. 13-14, Pl. 2, figs. 5,13;

Discussion- Specimens of *D. lateralis* are characterized by elongate platforms with rounded to slightly pointed posterior ends. Equally high outer parapets are marked by straight, parallel transverse ridges. The declining carina migrates to the outer parapet and continues to the posterior end of the platform as a longitudinal row of distinct nodes adjacent to the transverse ridges of the outer parapet.

Remarks- *D. lateralis* may be differentiated from other species of *Declinognathodus* by the presence of a declining carina that parallels the outer parapet and does not completely merge with this parapet.

Range- Morrowan to Atokan (Early Pennsylvanian)

Occurrence- In east-central Idaho, *D. lateralis* occurs from the middle Morrowan *Idiognathoides sinuatus* biozone to the middle Atokan *Idiognathodus incurvus* biozone of the Snaky Canyon Formation.

Material Studied- 19 specimens

Declinognathodus marginodosus

Cavusgnathus marginodosus, Grayson, 1984.

Figure 22, nos. 20-23

Idiognathoides marginodosus, Grayson, 1984, p. 50, Pl. 1, figs. 3,4,7,9-11,13,14, Pl. 2, figs. 8,9,17;
Declinognathodus marginodosus, Grayson et al., 1990, p. 365, Pl. 1, fig. 28;
Declinognathodus marginodosus (Grayson), Nemyrovska, 1999, p. 54, Pl. 2, figs. 2,8,11,12,17;

Discussion- Specimens of *Declinognathodus marginodosus* are characterized by long and narrow platforms and coarse, large blades. The free blade most often merges with the outer parapet and outside of this parapet, a distinct longitudinal node is present. The attachment of the blade to the platform and the outer parapet is linear or near linear. Parapets are ornamented with coarse, distinct rounded nodes with noticeable gap between nodes. The median groove separating the parapets is wide and very deep. The posterior end of the platform is pointed.

Remarks- *D. marginodosus* can be differentiated from specimens of *D. noduliferous* based on the linear relationship between the blade and the outer parapet. The isolated nodes of *D. marginodosus* is distinctly separated from the parapet. The nodes along the parapets of *D. marginodosus* also show greater spacing.

Range- Uppermost Morrowan to Atokan (Early Pennsylvanian)

Occurrence- In Snaky Canyon strata of east-central Idaho, *D. marginodosus* occurs from the base of the Atokan and marks the *D. marginodosus/Id. sulcatus parvus* biozone. The stratigraphic range of *D. marginodosus* extends into the middle to upper Atokan *I. incurvus* biozone at the Unknown Canyon measured section.

Material Studied- 27 specimens

Declinognathodus noduliferous

Cavusgnathus nodulifera, Ellison and Graves, 1941.

Figure 21, nos. 6-11

Cavusgnathus nodulifera Ellison and Graves, 1941, p. 4, Pl. 3, fig. 4;

Gnathodus nodulifera (Ellison and Graves), Koike, 1967, p. 297,298, Pl. 3, figs. 9-11;

Gnathodus nofuliferus (Ellison and Graves), Higgins and Bouckaert, 1968, p. 33,34, Pl. 2, figs. 6,12;

Idiognathoides noduliferus (Ellison and Graves), Igo and Koike, 1968, p. 28, 29, Pl. 3, figs. 7, 8; Thompson, 1970, p. 1046, Pl. 139, figs. 2,3,8,16; Higgins, 1975, p. 54, Pl. 14, figs. 15,16;

Declinognathodus noduliferous (Ellison and Graves), Dunn, 1970, p. 330, Pl. 62, fig. 2; Grayson, 1984, p. 47, Pl. 3, fig. 20; Nemirosvskaya, 1999, p. 55, Pl. 1, figs. 7,9,12, Pl. 2, figs. 1,3-4,6,10;

Discussion- Specimens of *Declinognathodus noduliferous* are characterized by possessing a nodular median carina that is terminated posteriorly by deflecting and merging with the outer parapet. On the outer anterior carina, several nodes or a diminished ridge marks the extension of the outer parapet. Platform is elongate, oval in shape, and narrow with nodular, parallel parapets. Median groove becomes deeper posteriorly and posterior tip is generally pointed, but may be rounded.

Remarks- The appearance of *Declinognathodus noduliferous* marks the Pennsylvanian/Mississippian boundary across the study area as defined at the IUGS carboniferous boundary (Lane et al., 1999). Previous workers (Higgins, 1975) have identified three *D. noduliferous* subspecies (*D. noduliferous noduliferous, D. noduliferous japonicus, D. noduliferous inaequalis)* based on the distance between the posterior end of the platform and the point of parapet/carina mergence. *D. noduliferous inaequalis* is the oldest (first occurring) subspecies (lowermost Morrowan) and is marked by the longest carina that merges near the posterior end of the platform. *D. noduliferous noduliferous* is characterized by a medial mergence of carina and parapet. *D. noduliferous japonicus* is the youngest occurring subspecies (upper Morrowan) and is marked by a very short carina that merges with the outer parapet well within the anterior half of the platform. These subspecies are not described separately, but have been listed independently in certain figures in order to aid in the zonation and correlation of the Morrowan.

Range- Morrowan to Atokan (Early Pennsylvanian)

Occurrence- In Snaky Canyon strata of east-central Idaho, *D. noduliferous* occurs from the base of the Morrowan (*D. noduliferous* biozone) to the middle Atokan (lower I. incurvus biozone).

Material Studied- 53 specimens

Genus *Gnathodus*

Genus *Gnathodus*, Pander, 1856

Type species – *Gnathodus mosquensis*, Fieber, 1866

Diagnosis:

Members of the genus *Gnathodus* are characterized by seximembrate apparatuses. The pectiniform element is the most diagnostic and platforms contain a medial free blade that is either straight or slightly curved. The free blade is also usually at least one half the full length of the element. Carinas are distinct and aboral ornamentation is highly variable and may be in the form of isolated nodes, transverse ridges, adcarinal grooves, or a combination of these.

The genus *Gnathodus* can be differentiated from *Neognathodus* by an uninterrupted median carina that joins the posterior tip of the platform with weak, unequal development of adcarinal troughs.

Gnathodus bilineatus bilineatus

Polygnathus bilineatus, Roundy, 1926

Polygnathus bilineatus Roundy, 1926, p. 13, Pl. 3, figs. 10a-c.

Gnathodus bilineatus (Roundy), Hass, 1953, p. 78, Pl. 14, figs. 25, 26; Stanley, 1958, p. 464, Pl. 68, fig. 7; Voges, 1959, p. 282, Pl. 33, figs. 29, 30; Globensky, 1967, p. 440, Pl. 58, fig. 9; Boogaert, 1967, p. 178, Pl. 3, figs. 2-4; Webster, 1969, p. 30, Pl. 5, figs. 11, 12; Rhodes et al, 1969, p. 94, Pl. 18, figs. 14a-17d.

Gnathodus bilineatus bilineatus (Roundy), Bischoff, 1957, p. 21, Pl. 3, figs. 11, 20, Pl. 4, fig. 1; Higgins, 1975, p. 29, Pl. 11, figs. 1-4, 6, 7.

Discussion-Species of *Gnathodus bilineatus bilineatus* are characterized by major variations in size and morphology. All specimens of *Gn. bilineatus bilineatus* exhibit a highly pronounced and flared outer lobate platform that is ornamented by concentric nodose ridges that parallel the outer margin of the platform in all growth stages. Parapets may be ornamented by nodes or oblate nodes that may merge posteriorly and are separated by a distinct trough throughout a majority of the platform. In lateral view, the blade may be up to one-half the total length of the element and generally thickens anteriorly. In basal view, the pulp cavity follows the lobate flare and deepens inwards.

Remarks- *Gn. bilineatus bilineatus* differs from *Gn. bilineatus bollandensis* by having a strongly ornamented and dramatically expanded outer cup.

Range-Low-middle Chesterian (Late Mississippian) to lowermost Morrowan (Early Pennsylvanian).

Occurrence-In east-central Idaho, *Gnathodus bilineatus bilineatus* occurs within the middle to upper Railroad Canyon Formation at the Railroad Canyon section; and within the lowermost Arco Hills Formation at the Box Canyon section (Abplanalp, 2006). In Snaky Canyon Formation strata, limited specimens of *Gn. bilineatus bilineatus* occur in the basal Morrowan (Rh. primus biozone) at the Unknown Canyon section.

Material Studied- 3 specimens

Gnathodus bilineatus bolendensis

Polygnathus bilineatus, Roundy, 1926

Polygnathus bilineatus Roundy, 1926, p. 13, Pl. 3, figs. 10a-c.

Gnathodus bilineatus (Roundy), Hass, 1953, p. 78, Pl. 14, figs. 25, 26; Voges, 1959, p. 282, Pl. 33, figs. 29, 30; Globensky, 1967, p. 440, Pl. 58, fig. 9; Boogaert, 1967, p. 178, Pl. 3, figs. 2-4.

Gnathodus bilineatus bolendensis (Roundy), Higgins and Bouckaert, 1968, p. 29, Pl. 2, figs. 10, 13, Pl. 3, figs. 4-8, 10; Higgins, 1975, p. 28, Pl. 11, figs. 5, 8-13; Nemirovskaya, 1999, Pl. 1, fig. 8.

Discussion-Pectifinform elements of *Gnathodus bilineatus bolendensis* are characterized by a narrow, retangular to semi-ovate outer platform. Ornamentation on the outer platform consists of a narrow row of nodes, never ridges, or one or two distinct nodes. Parapets may be ornamented by nodes or oblate nodes that may merge posteriorly and are separated by a distinct trough throughout a majority of the platform. In lateral view, the blade may be up to one-half the total length of the element and generally thickens anteriorly. In basal view, the pulp cavity follows the lobate flare and deepens inwards.

Remarks- *Gn. bilineatus bolendensis* is differentiated from *Gn. bilineatus bilineatus* by the lack of the posterior lateral row of nodes adjacent to the carina in *G. bilineatus bolendensis* forms.

Range-Upper Chesterian (Late Mississippian) to lowermost Morrowan (Early Pennsylvanian)

Occurrence-In east-central Idaho, *Gnathodus bilineatus bolendensis* occurs within the lowermost Arco Hills Formation at the Box Canyon section (Aplanalp, 2006). In Snaky Canyon Formation strata, one specimen occurs in the basal Morrowan (*Rh. primus* biozone) at the Unknown Canyon section.

Material Studied- 1 specimen

Gnathodus girtyi simplex

Gnathodus girtyi, Hass, 1953

Gnathodus girtyi Hass, 1953, p. 80, Pl. 14, figs. 22-24; Bischoff, 1957, p. 24, Pl. 4, figs. 17, 22, 23.

Gnathodus girtyi simplex (Hass), Dunn, 1965, p. 1158, Pl. 140, figs. 2, 3, 12; Webster, 1969, p. 32, Pl. 5, fig. 8; Dunn, 1970a, p. 331, Pl. 62, fig. 17; Higgins, 1975, p. 33, Pl. 9, figs. 6, 7, 11.

Discussion- The platform of *Gnathodus girtyi simplex* is characterized by an oral surface that exhibits a larger inner parapet and a very diminished smaller outer parapet positioned on the sides of a median carina. The small outer parapet contains only one or two very distinct nodes and does not extend as far posteriorly as the larger, inner parapet. In basal view, the cavity flares outward toward the smaller outer parapet (node) and is large and asymmetrical. In lateral view, the freeblade is equal to or longer than the length of the platform and thickens anteriorly.

Remarks- *Gnathodus girtyi girtyi* is distinguished from *Gn. girtyi simplex* by the much greater development of the small outer parapet along the platform in *Gn. girtyi girtyi*. The outer parapet on the platform of *Gn. girtyi simplex* consists of only one or two prominent nodes extending onto the flare of the basal cavity.

Range-Upper Chesterian (Late Mississippian) to lower

Morrowan (Early Pennsylvanian)

Occurrence-In east-central Idaho, *Gnathodus girtyi simplex* occurs within the middle Surrett Canyon Formation at the Antelope Creek section (Abplanalp, 2006). In Snaky Canyon Formation strata, limited specimens occur in the basal Morrowan (*Rh. primus* biozone) at the Unknown Canyon section.

Material Studied-3 specimens

Genus *Idiognathodus*

Genus *Idiognathodus*, Gunnell, 1931
Type species- *Idiognathoides claviformis*, Gunnell, 1931

Diagnosis:

Members of the genus *Idiognathodus* are distinguished by a lanceolate, slightly curved platform that may be straight or arched. The anterior blade attaches medially and may continue for a short distance onto the convex, flat or slightly concave oral surface. The oral surface is marked by continuous transverse ridges at the posterior of the platform and distinct patterns of nodes or rostral ridges ornamenting the anterior of the platform. Early occurring species (middle Morrowan) are marked by the parallel arrangement of rostral ridges and carina within anterior half of the platform. Later occurring species (Atokan and younger) are marked by rostral ridges that curve outward and flair out away from the blade.

Idiognathodus delicatus

Idiognathodus delicatus, Gunnell, 1931

Figure 22, nos. 12-15

Idiognathodus delicatus, Gunnell, 1931, p. 250, Pl. 29, figs. 235

Idiognathodus delicatus (Gunnell) Ellison and Graves, 1941, Pl. 3, figs. 20,23; Koike, 1967, p. 304, Pl. 2, figs. 18-23; Webster, 1969, p. 35, Pl. 6, figs. 6-12; Baesemann, 1974, Pl.1 figs. 10-17,19,20,23,24; Higgins, 1975, p. 46, Pl. 17, fig. 7, Pl. 18, figs. 1-3,7; Landing, 1981, p. 1260, Pl. 2, figs. 1-5; Grayson, 1984, p. 49, Pl. 1, figs. 1,2,12, Pl. 3, figs. 2,3,5,6,21-23,25, Pl.4, figs. 1,6-8,17,24; Savage, 1985, p. 1464, Pl. 8, figs. 1-4; Nemyrovska, 1999, p. 61, Pl. 9, figs. 5-8,10, Pl. 10, fig. 6, Pl. 11, fig. 17;

Discussion- Platform element specimens of *Idiognathodus delicatus* are subsymmetrical and slightly curved and are most distinctively identified by the presence of two nodular and well developed accessory lobes. These accessory lobes are most often shifted to the posterior and the inner lobe is always larger than the outer accessory lobe. The platforms are slightly curved and the posterior end is pointed. The rostral ridges parallel the carina and extend beyond the anterior limit of the platform while merging or declining outwards away from the blade/carina.

Remarks- Previous workers have noted a wide morphologic variability of *I. delicatus* elements. This study is choosing to follow the studies of Nemyrovska (1999) and designate all specimens of *Idiognathodus* with two posterior shifted accessory lobes and posterior outward-trending rostral ridges of relatively equal length as *I. delicatus*. *I. delicatus* may be distinguished from *I. primulus* and *I. sinuosus* on the basis of displaying two accessory lobes and outward flaring rostral ridges. *I. delicatus* may be distinguished from *I. incurvus* on the basis of greater ornamentation and lack of noticeable platform curvature.

Range- Uppermost Morrowan to Desmoinesian (Early to Middle Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *I. delicatus* first occurs within the lower Atokan *D. marginodosus /Id. sulcatus parvus* biozone. The youngest stratigraphic occurrence of *I. delicatus* occurs within the uppermost *I. expansus* biozone (upper Desmoinesian).

Material Studied- 38 specimens

Idiognathodus expansus

Idiognathodus expansus, Stauffer and Plummer, 1932

Figure 23, nos. 24-27

Idiognathodus expansus, Stauffer and Plummer, 1932, p. 197, Pl. 3, figs. 1,3;
Idiognathodus expansus (Stauffer and Plummer), Ritter et al., 2002, p. 507, Pl. 7, figs. 3, 7, 12, 14, 16; Pl. 8, figs. 9, 22, 23; Lambert et al., 2003, Pl. 1, figs. 1, 3, 5; Rosscoe, 2005, p. 81, Pl. 34, figs. 2-18;

Discussion- Platform elements of *Idiognathodus expansus* are asymmetrical, have a rounded to blunt posterior tip, and possess 6-10 fine transverse ridges at the posterior of the platform. These transverse ridges are very fine and are separated by large grooves that may be twice the width of the ridges. The carina and rostral ridges are markedly short and rostral ridges may only show faint flaring. The inner rostral ridge may be longer. The outer lobe is very weakly developed and is terminated by the anterior most transverse ridge. The inner accessory lobe is much more developed and contains fine nodes that are much more distinct along the inner part of the lobe. All ornamentation (accessory lobes and carina) is terminated or restricted by the oblique intersection of the transverse ridges to the anterior ornamentation of the platform.

Remarks- *I. expansus* may be differentiated from *I. delicatus* by the lack of a developed outer accessory lobe and prominent, outward flaring rostral ridges. *I. expansus* may be differentiated from other species of *Idiognathodus* by the posterior termination of the accessory lobes by the transverse ridges.

Range- Upper Desmoinesian (Late Pennsylvanian)

Occurrence- *I. expansus* occurs in upper Desmoinesian Snaky Canyon strata at the Unknown Canyon, VAH, and Gallagher Peak measured sections. It is considered a marker species for the upper Desmoinesian.

Material Studied- 16 specimens

Idiognathodus incurvus

Idiognathodus incurvus, Dunn, 1966

Figure 22, nos. 32-35

Idiognathodus incurvus, Dunn, 1966, p. 1301, Pl. 158, figs. 1,2;

Idiognathodus incurvus (Dunn), Grayson et al., 1989, p. 87, Pl. 1, figs. 21-25; Nemyrovska, 1999, p. 62, figs. 3-4, Pl. 11, figs. 1-8, 10-12;

Discussion- Platform elements of *Idiognathodus incurvus* are distinguished by strong inward curvature, subsymmetry, and a pointed posterior end with transverse ridges separated by a shallow medial or near medial light groove. The anterior end has two long and narrow accessory lobes that contain distinct nodes parallel to the platform margin. Inner lobe may show increased ornamentation. Rostral ridges are long, and parallel the carina and carina may be 1/3 length of platform. The inner rostral ridge is much longer and extends into the posterior half of the platform. Rostral ridges curve downwards and outwards.

Remarks- *I. incurvus* can be distinguished from other species of *Idiognathodus* by the simple ornamentation, posteriorly shifted nodes, and distinct platform curvature. *I. incurvus* is also distinguished by the noticeably lengthened inner rostral ridge. For this study, the concept of *I. incurvus* proposed by Dunn (1966) is utilized as opposed to the *I. incurvus* complex proposed by Grayson et al. (1989).

Range- Middle Atokan to upper Desmoinesian (Early to Middle Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *I. incurvus* initially appears in the above the lower Atokan *Neognathodus atokaensis* biozone. The youngest stratigraphic occurrence of *I. delicatus* occurs within the uppermost *I. expansus* biozone (upper Desmoinesian).

Material Studied- 39 specimens

Idiognathodus klapperi

Idiognathodus klapperi, Lane and Straka, 1974

Figure 22, nos. 16-18

Idiognathodus klapperi, Lane and Straka, 1974, p. 80, Pl. 42, figs. 12-16;

Idiognathodus klapperi (Lane and Straka), Grayson et al., 1987, Pl. 8, figs. 14,18,28; Grayson et al., 1990, Pl. 2, fig. 2;

Idiognathodus aff. *klapperi* (Lane and Straka), Nemyrovska, 1999, p. 62, Pl. 8, fig. 11;

Discussion- Specimens of *Idiognathodus klapperi* are distinguished by short, wide platforms with a very short carina. The carina may extend posteriorly as very discreet nodes or as a very faint trough within the middle of the platform along the transverse ridges. The relatively short rostral ridges are incorporated into the platform and the inner rostral ridge may be much longer and projects outward away from the carina. The accessory lobes are very wide, subround to round, and are poorly developed with simple ornamentation of irregular nodes. Some specimens have only a weakly developed inner lobe that is located on the forward of the platform. The posterior point is highly rounded and the posterior platform is covered by discontinuous transverse ridges.

Remarks- *I. klapperi* can be differentiated from other species of *Idiognathodus* based on the short and wide platform possessing very simple accessory lobes. The short rostral ridges and rounded posterior tip separate *I. klapperi* from *I. delicatus* and *I. sinuosus.*

Range- Upper Morrowan to upper Desmoinesian (Early to Middle Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *I. klapperi* first occurs at the Morrowan/Atokan boundary. The youngest stratigraphic occurrence of *I. klapperi* occurs within the uppermost *I. expansus* biozone (upper Desmoinesian).

Material Studied- 33 specimens

Idiognathodus magnificus

Idiognathodus magnificus, Stauffer and Plummer, 1932

Figure 23, nos. 28-30

Idiognathodus magnificus, Stauffer and Plummer, 1932, p. 46, 47, Pl. 3, figs. 8,18-20;
Idiognathodus magnificus (Stauffer and Plummer), Barrick and Boardman, 1989, Pl. 1, figs. 1,2; Ritter et al., 2002, p. 509, Pl. 9, figs. 16, 20-23;

Discussion- Platforms elements of *Idiognathodus magnificus* are distinguished by two very large, round, and prominent accessory lobes located within the anterior most portion of the platform. These accessory lobes are heavily ornamented by distinct, small nodes that may or may not be arranged linearly. The inner lobe is often larger and is protruding. Overall, the platform is very wide anteriorly and thins sharply to the posterior tip. The platform is slightly longer than wider. Rostral ridges are diminished and are short and most often do not exist at all. The carina may exist, but it often does not extend past the anterior 1/4 of the platform. The posterior is covered by numerous thin, patterned transverse ridges.

Remarks- *I. magnificus* is differentiated from other species of *Idiognathodus* by the very noticeable and distinctly ornamented large anterior-shifted accessory lobes. *I. magnificus* may be separated from the similar *I. claviformis* based on the lack of distinct rostral ridges.

This study has rejected the concept of the *I. magnificus* complex of Grayson (1985). This concept is very broad and seems to generalize key morphological differences between species of *Idiognathodus.* The recognition of *I. magnificus* in this study is based on distinct and repeating morphological data from numerous measured sections.

Range- Upper Desmoinesian to Missourian (Late Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *I. magnificus* first occurs near the Desmoinesian/Missourian boundary. The youngest stratigraphic occurrence of *I. magnificus* occurs within the *Swadelina nodocarinata* biozone (middle Missourian) at the Gallagher Peak section.

Material Studied- 18 specimens

Idiognathodus obliquus

Idiognathodus obliquus, Kosenko and Kozitskaya, 1978

Figure 23, nos. 13-16

Idiognathodus obliquus, Kosenko and Kozitskaya, 1978, p. 45, Pl. 22, figs. 6-9;

Idiognathodus obliquus (Kosenko and Kozitskaya), Lambert, 1992, p. 124, Pl. 2, figs. 13-22; Myrovka and Kozitska, 1999, p. 73, fig. 1.1; Ritter et al., 2002, p. 511, figs. 6.6, 6.13, 6.24;

Discussion- Specimens of *Idiognathodus obliquus* are characterized by a distinct inward platform curvature, especially dextral elements. Overall, platforms are narrow to moderate in width and contain well developed inner and outer lobes. The outer lobes are long and narrow and the inner lobes are often marked with small lobes positioned in rows paralleling the inner adcarinal ridge. The centralized carina is flanked by anteriorly divergent adcarinal ridges. These ridges extend up to one-third of the length of the free blade. Ten to fifteen transverse, closely spaced ridges obliquely cross the posterior half to the platform. The posterior end of the platform is pointed.

<u>Remarks</u>- *I. obliquus* is differentiated from other species of *Idiognathodus* by the strong inward curvature of the platform, oblique transverse ridges, and well developed accessory lobes. *I. obliquus* is easily differentiated from *I. incurvus* by the oblique transverse ridges and comparison of inner lobes.

<u>Range-</u> Desmoinesian to Missourian (Middle to Upper Pennsylvanian)

<u>Occurrence</u>- In Snaky Canyon Formation strata, *I. obliquus* first occurs near the in the lower Desmoinesian (Middle Pennsylvanian). The youngest stratigraphic occurrence of *I. magnificus* occurs within the *Swadelina nodocarinata* biozone (middle Missourian) at the Gallagher Peak section.

<u>Material Studied-</u> 29 specimens

Idiognathodus parvus

Idiognathodus parvus, Dunn, 1966

Figure 22, nos. 6-8

<u>*Streptognathodus parvus*</u>, Dunn, 1966, p. 1302, Pl. 158, figs. 9,10;

<u>*Streptognathodus parvus*</u> (Dunn), Nemyrovska, 1999, p. 81, Pl. 6, figs. 8-11;

<u>*Idiognathodus parvus*</u> (Dunn), Igo and Koike, 1967, p. 306, Pl. 2, figs. 12; Grubbs, 1984, p. 69;

<u>Discussion</u>- Specimens of *Idiognathodus parvus* have noticeably small platforms that are narrow and symmetrical. The carina is very long and typically extends from over one-

half to two-thirds of the length of the platform. The carina may extend and translate posteriorly as nodes located medially within the transverse ridges. Adcarinal grooves parallel the carina and the grooves are generally shallow. The posterior tip is pointed and the posterior platform is covered with 2-6 straight and parallel transverse ridges. Some specimens may have a small accessory lobe consisting of 1-4 diminished or discrete nodes arranged linearly parallel to the inner margin of the platform.

Remarks- *I. parvus* may be distinguished from other species of *Idiognathodus* on the basis of small size, very long and straight carina, and lack of ornamented and distinguishable accessory lobe incorporated into the platform. Due to the continuous nature of the transverse ridges within the posterior of the platform, this study is choosing to assign these specimens to *Idiognathodus*, not *Streptognathodus.*

Range- Pennsylvanian

Occurrence- In Snaky Canyon Formation strata, *I. parvus* first occurs at the base of the Morrowan *I. sinuosus* biozone. The youngest stratigraphic occurrence of *I. parvus* occurs within the *Swadelina nodocarinata* biozone (middle Missourian) at the Gallagher Peak section.

Material Studied- 74 specimens

Idiognathodus primulus

Idiognathodus primulus, Higgins, 1975

Figure 22, no. 5

Idiognathodus primulus, Higgins, 1975, p. 46, Pl. 18, figs. 10-13

Idiognathodus primulus (Higgins), Nemyrovskaya, 1999, p. 64, Pl. 8, figs. 1,8;

<u>Discussion</u>- Specimens of *Idiognathodus primulus* are characterized by long, narrow platforms that are almost symmetrical. Accessory lobes are absent from the anterior of the platform and the blade may be the same length or slightly shorter than the platform and extends onto the platform as the carina. The carina is very short, but may extend up to half the length of the platform. The anterior of the platform is unornamented except for two very short sharp-edged rostral ridges that parallel the carina. There may be one or two nodes along the ridge on the inner side of the platform. Posterior end is pointed and posterior half to three quarters is covered by transverse ridges. In lateral view, the platform is strongly convex.

<u>Remarks</u>- *I. primulus* may be differentiated from other species of *Idiognathodus* by the lack of ornamented anterior lobes.

<u>Range</u>- Morrowan to Atokan (Early Pennsylvanian)

<u>Occurrence</u>- In Snaky Canyon Formation strata, *I. primulus* first occurs within the Morrowan *I. sinuosus* biozone. The youngest stratigraphic occurrence of *I. parvus* occurs within the Atokan *I. incurvus* biozone.

<u>Material Studied</u>- 24 specimens

Idiognathodus sinuosus

Idiognathodus sinuosus, Ellison and Graves, 1941

Figure 22, nos. 1-4

<u>*Idiognathodus sinuosus*</u>, Ellison and Graves, 1941, p.6, Pl. 3, fig. 22;

Idiognathodus humerus, (Ellison and Graves), Dunn, 1966, p. 1300, Pl. 158, figs. 6,7; Dunn, 1970a, p. 334, Pl. 63, figs. 1,2;

Idiognathodus sinuosis (Ellison and Graves), Dunn, 1970a, p. 334, Pl. 63, figs. 3,4;

Idiognathodus sinuosus (Ellison and Graves), Lane and Straka, 1974, p. 81, Pl. 37, figs. 10-13,21, Pl. 42, figs. 1-11, Pl. 43, figs. 1,4-8,10-13,20; Nemirovskaya, 1999, Pl. 8, figs. 3,4,6,10,12,15, Pl. 11, fig. 13;

Discussion- Elements of *Idiognathodus sinuosus* are characterized by slight inward curving asymmetrical platforms with outer side convex. Carina is more than one third of the length of the platform and rostral ridges parallel the carina and do not extend beyond anterior half of platform. Anterior platform may have inner accessory lobe and outer side of platform may have several nodes that parallel the outer platform margin. The posterior platform is marked by transverse ridges that are parallel and sinuous in nature (form chevrons).

Remarks- *I. sinuosus* may be differentiated from other Idiognathodids by the presence of posterior sinuous and parallel transverse ridges and by the presence of only one accessory lobe.

Range- Middle Morrowan to Atokan (Early Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *I. sinuosus* first occurs in the upper Morrowan. The youngest stratigraphic occurrence of *I. parvus* occurs within the Atokan *I. incurvus* biozone a the Unknown Canyon and Gallagher Peak sections.

Material Studied- 41 specimens

Idiognathodus sp. "X"

cf. *Idiognathodus swadei*, Roscoe and Barrick, 2008

Figure 23, nos. 31-33

<u>Discussion</u>- The morphologically distinct species of *Idiognathodus* designated initially by this study as *I.* sp. *"X"* is characterized by a relatively elongated and flat platform marked by transverse ridges that are often partially disrupted by a very shallow caudal central groove. In the specimens identified by this study, the straight adcarinal ridges are parallel and equal in length to the medial carina. The rostral lobes are diminished and have only slight ornamentation that occurs in a single row as round nodes. The dorsal margin of the platform is sharply pointed and all specimens recovered were of diminished size in comparison with other forms of *Idiognathodus* or *Swadelina* concurrently recovered.

<u>Remarks</u>- The informally named *Idiognathodus* sp. *"X"* recognized by this study was originally identified as an unknown Upper Pennsylvanian *Idiognathodus* species when reconnaissance samples were taken directly below the Gallagher Sandstone Member. Later comparison with recent studies conducted on the Upper Pennsylvanian of the midcontinental United States revealed that the *I.* sp. *"X"* shared similar affinities with juvenile specimens of Roscoe and Barrick's (2008) recently identified *I. swadei*. From comparison of the recovered specimens from the Snaky Canyon Formation to those of Roscoe and Barrick (2009), it is likely a majority of the specimens identified by this study as *I.* sp. *"X"* are likely juvenile forms of *I. swadei*. This study choses to retain the *I.* sp. *"X"* designation until further information and specimens

are available to confirm an *I. swadei* assignment.

Roscoe (2008) reported from a succession of U.S. midcontinental strata that *Sw. nodocarinata* first appears one sequence below that of the uppermost *I. swadei (I.* sp. "X") biozone recognized by his study. Assuming that the *I.* sp. *"X"* cf. *swadei* is correlative with Roscoe's *I. swadei*, it is determined that there is a likely delay in occurrence of *Sw. nodocarinata*.

Range- Missourian (Upper Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *I.* sp *"X"* first occurs in the lower Missourian. The youngest stratigraphic occurrence of *I. parvus* occurs within the Missourian *Sw. nodocarinata* biozone at the Unknown Canyon and Gallagher Peak sections.

Material Studied- 8 specimens

Genus *Idiognathoides*

Genus *Idiognathoides*, Harris and Hollingworth, 1933

Type species- *Idiognathoides sinuata*, Harris and Hollingworth, 1933

Diagnosis:

Members of the genus *Idiognathoides* are characterized by scaphate high platform elements with two predominantly ridged or nodular parapets separated by a distinct medial groove. The true free blade continues into the outer parapet and extends to the posterior of the platform. The basal cavity is asymmetrical, wide, and distinctly deep.

Idiognathoides corrugatus

Idiognathoides corrugatus, Harris and Hollingworth, 1933

Figure 21, no. 18

Idiognathoides corrugatus, Harris and Hollingworth, 1933, p.202, Pl. 1, figs. 7,8a,8b;
Idiognathoides corrugata (Harris and Hollingworth), Lane, 1967, p. 929, Pl. 122, figs. 1,2,4-7,9-11; Higgins and Bouckaert, 1968, p. 39, Pl. 5, fig. 9;
Idiognathoides corrugatus (Harris and Hollingworth), Higgins, 1975, p. 48, Pl. 15, figs. 2-9; Grayson, 1984, Pl. 4, figs. 4,10; Nemirovskaya, 1999, p. 70, Pl. 3, figs. 2,4,21, Pl. 4, fig. 8;

Discussion- Specimens of *Idiognathoides corrugatus* are distinguished by exclusively dextral lanceolate platforms bearing continuous transverse ridges separated by a short and deep anterior groove. Blade continuous with outer side of platform and overall platform is flat or slightly concave with sides of equal height. Posterior end pointed and platform may decline downwards posteriorly.

Remarks- *Id. corrugatus* may be distinguished from *Id. sinuatus* and *Id. sulcatus* by possessing almost completely continuous transverse ridges and a very short medial anterior groove. *Id. corrugatus* may be distinguished from *Id. sinuatus* by having parapets of equal height.

Range- Morrowan to lower Atokan (Early Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Id. corrugatus* first occurs in the upper Morrowan *Streptognathodus suberectus* biozone. The youngest stratigraphic occurrence of *Id. corrugatus* occurs within the lower Atokan *Neognathodus atokaensis* biozone.

Material Studied- 11 specimens

Idiognathoides ineaqualis

ldiognathoides noduliferus ineaqualis, Higgins, 1975

Figure 21, no. 15

ldiognathoides noduliferus inaequalis, Higgins, 1975, p.53, Pl.12, figs. 1-7; Pl.14, figs. 11-13; Pl.15, figs. 10,14; *ldiognathoides noduliferus inaequalis*, Metcalfe, 1980, p.306, Pl. 38, fig. 15.

Declinognathodus noduliferus inaequalis, Nemirovskaya, 1987, Pl. 1, figs. 6,9,13-14; Nemirovskaya et al., 1991, Pl. 4, figs. 3,5,15;
Declinognathodus inaequalis, Mizuno, 1997, p.248, fig. 12 nos. 1-5;

Discussion- Specimens of *Id. ineaqualis* are characterized by long and large platforms that possess two distinctly nodular parapets separated by a deep medial groove. The outer parapet is much longer, extends to the posterior tip, and is a linear extension of the free blade. Outside of the outer parapet, 1-3 distinct nodes are isolated parallel to the parapet and along the anterior outer margin of the platform. The inner parapet is much shorter and does not extend to the pointed posterior tip.

Remarks- Platforms of *Id. ineaqualis* may represent the later development of *D. noduliferous* into laterally blade attached forms with completely isolated outer margin nodes. *Id. ineaqualis* is recoverable from multiple horizons and may represent a new species.

<u>Range</u>- Morrwan to Atokan (Early Pennsylvanian)

<u>Occurrence</u>- In Snaky Canyon Formation strata, *Id. ineaqualis* first occurs in the upper Morrowan *Streptognathodus suberectus* biozone. The youngest stratigraphic occurrence of *Id. ineaqualis* occurs within the lower Atokan *Neognathodus atokaensis* biozone.

<u>Material Studied</u>- 17 specimens

Idiognathoides sinuatus

Idiognathoides sinuata, Harris and Hollingworth, 1933

Figure 21, nos. 12-14

<u>*Idiognathoides sinuata*</u>, Harris and Hollingworth, 1933, p. 201, Pl. 1, fig. 14; Lane, 1967, p. 937-938, Pl. 119, figs. 1-9,12-15, Pl. 123, figs. 7,8,12; Higgins and Bouckaert, 1968, p. 40, Pl. 2, fig. 14, Pl. 4, figs. 5,8,9, Pl. 5, fig. 11; <u>*Idiognathoides sinuatus*</u>, Ebner, 1977, p. 474, Pl. 6, figs. 4-6; Grayson, 1984, Pl. 4, figs. 3,13,14,19,20; Dunn, 1970a, Pl. 63, figs. 14,15,21-23; Higgins, 1975, p. 54, Pl. 16, figs. 1-7,9-14, Pl. 15, figs. 11,16, Pl. 14, figs. 4-6; Grayson, Merrill, and Lambert, 1990, p. 366, Pl. 1, fig. 26; Nemirovska and Alekseev, 1994, Pl. 1, figs. 14,16; Nemyrovska, 1999, p. 71, Pl. 3, figs. 3,8,10,13;

<u>Discussion</u>- Platform elements of *Idiognathoides sinuatus* are characterized by two transversely ridged step-like parapets separated by a narrow medial groove of variable length that shallows posteriorly. Parapets fully join at the pointed posterior end of the platform where the element is narrowest and outer parapet is taller than inner one. Aboral

surface generally flat, but may slope inwards and ridges may be fused on the higher outer side. The Free blade is same length as platform or slightly longer and bears around ten fused denticles. *Id. sinuatus* is exclusively sinistral (left-side blade attachment) and the outer parapet is continuous with the blade.

Remarks- Previous workers (Lane, 1967; Higgins, 1975) have stated a wide morphologic variability in *Id. sinuatus. Id. sinuatus* is differentiated from *Id. sulcatus* on the basis of sinistral blade attachment and by having ridged parapets. *Id. sinuatus* differs from *Id. corrugatus* by the presence of two parapets separated by a distinct groove extending to the posterior end of the platform. Previous workers have stated that *Id. sinuatus* and *Id. corrugatus* may be asymmetrically paired. In this study, each will be considered independent of the other.

Id. sinuatus is distinguished from species of *Adetognathus* on the basis of noticeable unequal parapet height, domination of ridges, and opposite side flair of pulp cavity.

Range- Middle Morrowan to Atokan (Early Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Id. sinuatus* first occurs in the middle to upper Morrowan. The youngest stratigraphic occurrence of *Id. sinuatus* occurs within the lower Atokan *Neognathodus atokaensis* biozone.

Material Studied- 30 specimens

Idiognathoides sulcatus parvus

Idiognathoides sulcatus, Higgins and Bouckaert, 1968
Idiognathoides sulcatus parvus, Higgins and Bouckaert, 1968

Idiognathoides sulcatus parva, Higgins and Bouckaert, 1968, p. 41, Pl. 6, figs. 1-6;
Idiognathoides sulcatus parvus, Lane and Straka, 1974, p. 92, Pl. 39, figs. 5,6,9,10; Higgins, 1975, p. 56, Pl. 13, figs. 13,14,18, Pl. 14, figs. 2,3; Nemirovskaya, 1999, p. 72, Pl. 3, figs. 6,16;

Discussion- Roughly symmetrical narrow platforms of smaller size consisting of nodular parapets of equal height, although inner parapet is distinctively shorter and does not extend to the pointed posterior end. Inner parapet is also very smooth and may flair outwards at the middle of the platform. Inner parapet may also consist of a row of fused nodes that grade into one or two isolated nodes in the posterior half of the platform.

Remarks- *Id. sulcatus parvus* differs from the subspecies *Id. sulcatus sulcatus* by possessing a shorter and poorly developed smooth inner parapet. *Id. sulcatus parvus* is also generally of much smaller overall size. *Id. sulcatus parvus* can be distinguished from *Id. sinuatus* by having parapets of equal height.

Range- Atokan (Early Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Id. sulcatus parvus* first occurs at the Morrowan/Atokan boundary. The youngest stratigraphic occurrence of *Id. sulcatus parvus* occurs within the lower Atokan *Neognathodus atokaensis* biozone.

Material Studied- 20 specimens

Idiognathoides sulcatus sulcatus

Idiognathoides sulcatus, Higgins and Bouckaert, 1968
Idiognathoides sulcatus sulcatus, Higgins and Bouckaert, 1968

Figure 21, nos. 16, 17

Gnathodus opimus, Igo and Koike, 1967, p. 298, Pl. 1, figs. 20,21;
Idiognathoides sulcata, Higgins and Bouckaert, 1968, p. 41, Pl. 4, figs. 6,7;
Idiognathoides opimus (Igo and Koike), Dunn, 1970, p. 335, Pl. 63, figs. 24,28-30;
Idiognathoides sulcatus sulcatus (Higgins and Bouckaert), Lane and Straka, 1974, figs. 1-16,18-20,23,24; Higgins, 1975, p. 56, Pl. 13, figs. 11,12,16, Pl. 15, fig. 15; Nemiroskaya, 1999, p. 72, Pl. 3, figs. 1,5,7,12,15,17;

Discussion- *Idiognathoides sulcatus sulcatus* may be diagnosed by possessing a narrow platform marked with straight and parallel parapets of equal height and length. A deep and narrow medial groove separates the parapets and the parapets are ornamented with nodes.

Remarks- Specimens of *Id. sulcatus sulcatus* may be differentiated from specimens of *Id. sulcatus parvus* by possessing straight and parallel parapets of equal length. *Id. sulcatus* differs from *Id. sinuatus* by having nodular parapets of equal height.

Range- Morrowan to lower Atokan (Early Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Id. sulcatus sulcatus* first occurs at the Morrowan/Atokan boundary. The youngest stratigraphic occurrence of *Id. sulcatus sulcatus* occurs at the base of the lower Atokan *Idiognathodus incurvus* biozone.

Material Studied- 11 specimens

Genus *Neognathodus*

Genus *Neognathodus*, Dunn, 1970
Type species- *Polygnathus bassleri*, Harris and Hollingworth, 1933

Diagnosis:

Specimens of *Neognathodus* are distinguished by laceolate platforms with a subtriagular to arrow outline. The blade is attached at a medial position to the platform and the carina is nodular. The carina may extend to the posterior tip or be deflected and may consist of longitudinal nodes near the posterior of the platform. The tall platform consists of two parapets with nodes or coarse ridges and deep adcarinal grooves separating the parapets and carina. The outer parapet may be reduced and the basal cavity is asymmetrical, deep, and of increased size.

Neognathodus asymmetricus

Neognathodus asymmetricus, Stibane, 1967
Neognathodus medadultimus, Merrill, 1972
Neognathodus medexultimus, Merrill, 1972

Figure 23, nos. 6-12

Neognathodus medadultimus, Merrill, 1972, p. 824-825, Pl. 1, figs. 2-7; Pl. 2, fig. 19;
Neognathodus medexultimus, Merrill, 1972, p. 825-826, Pl. 2, figs. 20-26;
Neognathodus medexultimus (Merrill), Savage and Barkeley, 1985, p. 1470, Pl. 11, figs. 1-12;
Neognathodus medadultimus *(Merrill), Ritter et al.*, 2002, p. 513, Pl. 6, fig. 1;

Neognathodus medexultimus (Merrill), Ritter, 2002, p. 513, Pl. 6, fig. 5; Pl. 8, figs. 5-7;

Neognathodus asymmetricus (Stibane), Boardman, Heckel and Marshall, 2004, p. 633, Pl. 3, figs. 1-4; Lambert et al., 2013, p. 51; Pl. 1, fig. 3;

Discussion- Platforms are slightly bowed and have the greatest width anteriorly. Platforms are asymmetrically lanceolate, arrowed shaped, and have a pointed posterior tip. Blade continues as a slightly sinuous carina that bends towards the outer parapet for up to the posterior one-half to one-third of the platform. Nodes of the carina and outer parapet may merge and may become a single row of wide nodes at the posterior. Outer groove separating carina and outer parapet may shallow posteriorly and become discrete at the posterior terminus or inner groove may be terminated by the mergence of the carina and outer parapet. Inner groove is continuous and shallows posteriorly.

In lateral view, the carina is about the same height or just slightly taller than the surrounding parapets.

Remarks-The concept of *Neognathodus asymmetricus* recognized by this study eliminates the morphologically similar and inconsistently identified *Neo. medadultimus* and *Neo. medexultimus* species (Lambert et al., 2001). These morphological similarities have been noted by previous workers and discussions have addressed the synonymy of *Neo. medadultimus* and *Neo. medexultimus* (Savage and Barkeley, 1985). Recent studies by Lambert et al. (2001, 2002) have proposed the adoption and recognition of Stibane's (1967) species concept of *Neo. asymmetricus* in order to encompass all morphologically similar *Neognathids* and eliminate the subjective morphologic differences used to differentiate *Neo.*

medadultimus from *Neo. medexultimus*.

The exact relationship of *Neognathodus medadultimus* and *Neo. medexultimus* cannot be discerned from the observed succession of Snaky Canyon strata in east-central Idaho. At the Unknown Canyon and Hawley Mountain sections, *Neo. medexultimus* occurs below the first occurrence of *Neo. medadultimus*. At the VAH and Gallagher Peak sections, the inverse occurs and *Neo. medadultimus* occurs stratigraphically below that of *Neo. medexultimus* (Appendix II). Due to this disparity in initial occurrence between the two morphologically similar species, the best way to represent the morphotypes is to place both in Lambert's (2001) *Neo. asymmetricus* conceptual species.

N. asymmetricus may be distinguished from N. roundyi by possessing a outer parapet that extends to the posterior terminus.

Range- Middle to upper Desmoinesian (Middle Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Neo. asymmetricus* first occurs in the lower-middle Desmoinesian. The youngest stratigraphic occurrence of *Neo. asymmetricus* occurs near the base of the upper Desmoinesian *Idiognathodus magnificus* biozone.

Material Studied- 48 specimens

Neognathodus atokaensis

Neognathodus atokaensis, Grayson, 1984

Figure 22, nos. 26-31

Gnathodus wapanuckensis, Ellison and Graves, 1941, Pl. 2, fig. 14

Neognathodus atokaensis, Grayson, 1984, p. 52, Pl. 1, fig. 8, Pl. 2, figs. 1,5,10-12,16,23, Pl. 3, figs. 1,7,11; *Neognathodus atokaensis* (Grayson), Grayson et al., 1985, p. 126, Pl. 1, figs. 2,34; Grayson, 1990, Pl. 4, figs. 14-16; Nemyroska, 1999, p. 77, Pl. 5, figs. 18,22

Discussion- Specimens of the *Neognathodus atokaensis* are distinguished by a wide, asymmetrical platform with ridged parapets of unequal length that decline downwards anteriorly. The inner parapet extends to the pointed posterior tip and the outer parapet is shorter and higher (taller). The carina is marked by fused nodes and extends to meet the inner parapet at or near the posterior tip. The carina may be a nearly straight projection of the blade or may be slightly sinuous. The carina terminates within the posterior of the platform and may become diminished for one-third of its length poeteriorly. In side view, the platform is slightly arched.

Remarks- *N. atokaensis* can be separated from other species of *Neognathodus* on the basis of having two parapets of unequal length and height. Due to the wide variation in recovered specimens from individual horizons, this study is not choosing to follow Grayson’s (1984) concept of *N. atokaensis* n. sp. *N. medatultimus* (Merrill) and *N. medexultimus* (Merrill) are assigned independently as done by Merrill (1972).

Range- Atokan to Desmoinesian (Early to Middle Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Neo. atoakensis* first occurs in the lower Desmoinesian. The youngest stratigraphic occurrence of *Neo. asymmetricus* occurs near the base of the upper Desmoinesian *Idiognathodus magnificus* biozone.

Material Studied- 49 specimens

Neognathodus bassleri bassleri

Neognathodus bassleri, Dunn, 1970

Figure 22, nos. 19

Polygnathus bassleri, Harris and Hollingsworth, 1933, p.198, Pl. 1, figs. 13a-e;

Gnathodus wapanuckensis, Ellison and Graves, 1941, Pl. 2, figs. 13-17;

Gnathodus bassleri (Harris and Hollingsworth), Lane, 1967, Pl. 120, figs. 1-5,9-15,17; Pl. 121, figs. 6,9; Pl. 123, figs. 1-6; Webster, 1969, p. 29-30, Pl. 5, figs. 9,14,15;

Neognathodus bassleri (Harris and Hollingsworth), Dunn, 1970, p. 336, Pl. 64, figs. 1,13,14;

Gnathodus bassleri bassleri (Harris and Hollingsworth), Lane and Straka, 1971, p. 402, Pl. 1, figs. 9,10; Merrill, 1971, p. 410, Pl. 1, fig. 30;

Neognathodus bassleri (Harris and Hollingsworth), Higgins, 1975, p. 64, Pl. 12, figs. 8,10,11, Pl. 17, figs. 12,15;

Discussion- Platforms of *Neognathodus bassleri* are lanceolate, show the greatest width within the anterior one-third, and have a pointed to acutely rounded posterior. The blade is relatively straight and continues onto the platform as a semi-straight carina that consists of a series of rounded nodes. These nodes may be slightly compressed and become less evenly spaced towards the posterior where the carina may die out before reaching the posterior tip. Parapets are separated from the carina by deep medial grooves. Outer parapet parallels the carina and consists of discrete, transverse wedge-shaped nodes that merge with the medial groove and may be arranged in a loose radial pattern. Inner parapet may be slightly longer and wider. Basal cavity is wide and deep, with deepest point at the widest. Basal cavity may continue anteriorly as a slit along the aboral edge of the blade. In lateral view, parapets are as high or higher than the carina and the overall platform is as high as it is wide.

Remarks- *N. bassleri* may be distinguished from *N. symmetricus* on the basis of subsymmetry. Specimens of *N. bassleri* have an asymmetrical platform.

Range- Upper Morrowan to Atokan (Early Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Neo. bassleri bassleri* first occurs at the Morrowan/Atokan boundary. The youngest stratigraphic occurrence of *Neo. asymmetricus* occurs within the lower Atokan *Declinognathodus marginodosus/Idiognathoides sulcatus parvus* biozone.

Material Studied- 7 specimens

Neognathodus bothrops (columbiensis)

Neognathodus bassleri, Merrill, 1972

Figure 23, nos. 1-5

Neognathodus n. sp. A, Merrill and King, 1971, p. 659,660, Pl. 76, figs. 7-10;

Gnathodus n. sp. A, Merrill, 1971, p. 409, Pl. 1, fig. 31;

Neognathodus bothrops, Merrill, 1972, p. 823, Pl. 1, figs. 8-15;

Neognathodus bothrops (Merrill), Grayson, 1984, p. 52, Pl. 2, figs. 2,14a,14b,15,18,20, Pl. 3, figs. 17,24a,24b;

Discussion- Specimens of *N. bothrops* are characterized by elevated inner and outer platform margins that form the parapets and merge posteriorly to form the posterior tip. At the posterior point of mergence between the nodular near-medial carina and parapets, a single distinct posterior node is present at the point of fusion. The platform is lanceolate and the rounded nodose carina is fairly straight and may become less distinct posteriorly. Outer parapet parallels the carina and consists of transversely shaped nodes that become diminished toward the carina and merge into the medial grooves bordering the carina. Inner parapet similar to outer and may have nodes that are increasingly transverse compared to outer parapet. In side view, parapets are as high or higher than carina.

Lambert et al. (2001) grouped several upper Atokan morphotypes of *Neognathodus* (ie., Merrill's (1971) *Neo. pre-bothrops*, *Neo. bothrops)* containing relatively even, symmetrical upper surfaces into the revived species concept of *Neognathodus columbiensis* originally identified by Stibane (1967). This concept has been adopted and this study recognizes the utility of merging all symmetrical and morphologically similar late Atokan to earliest Desmoinesian forms of *Neognathodus* into one designation.

Remarks- *N. bothrops* may be separated from *N. bassleri bassleri* on the basis of by the distinct fusion of the carina and parapets together at the posterior tip. The lack of symmetry allows for the differentiation of *N.* bothrops and *N.* symmetricus. For this study, we are rejecting the *N. bothrops* complex of Grayson (1984) and consider *N. bothrops* and *N. bassleri* bassleri as distinct species.

Range- Upper Atokan to Desmoinesian (Middle Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Neo. bothrops (columbiensis)* first occurs within the upper Atokan. The youngest stratigraphic occurrence of *Neo. bothrops (columbiensis)* occurs within the middle Desmoinesian

Idiognathodus obliquus biozone.

Material Studied- 30 specimens

Neognathodus roundyi

Neognathodus roundyi, Gunnell, 1931

Figure 23, no. 17

Gnathodus roundyi, Gunnell, 1931, p. 249, Pl. 29, figs. 19, 20;
Gnathodus roundyi (Gunnell), Merrill, 1971, p. 409, Pl. 1, fig. 34;
Neognathodus roundyi (Gunnell), Dunn, 1970, p. 336-337, Pl. 64, figs. 2,3; Merrill and King, 1971, p. 660, Pl. 76, figs. 2-4; Merrill, 1972, p. 826, Pl. 2, figs. 11-16; Sweet, 1975, p. 211-212; Ritter, 2002, p. 513, Pl. 6, figs. 2,4;

Discussion- Specimens of *Neognathodus roundyi* are distinguished by lanceolate, arrow-shaped platforms that are widest anteriorly and possess a pointed posterior tip. The blade continues on to the platform as a slightly sinuous carina and beds to meet the outer parapet just ahead of the midpoint of the platform. This creates a very distinct isolated node or isolated row of nodes (2-3). The inner and outer margins are marked by uneven development and the outer margin is ornamented with the long node or nodes in the anterior portion of the platform.

In lateral view, the carina is greater in height than the parapets. The outer node or nodes are considerably shorter and overall platform is slightly arched.

Remarks- *N. roundyi* can be distinguished from other species of *Neognathodus* based on the isolation of distinct nodes by the mergence of the carina within the anterior of the platform.

Range- Desmoinesian (Middle Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Neo. roundyi* first occurs in the upper Desmoinesian *Idiognathodus obliquus* biozone. The youngest stratigraphic occurrence of *Neo. roundyi* occurs within the upper Desmoinesian *Idiognathodus expansus* biozone just below the Desmoinesian/Missourian boundary.

Material Studied- 18 specimens

Neognathodus symmetricus

Neognathodus symmetricus, Lane, 1967

Gnathodus wapanuckensis, Ellison and Graves, 1941, Pl. 2, fig. 13;
Gnathodus bassleri symmetricus, Lane, 1967, p. 935, Pl. 120, figs. 2,13,14,17, Pl. 121, figs. 6,9;
Gnathodus bassleri, Webster, 1969, p. 29, Pl. 5, fig. 14;
Neognathodus bassleri, Dunn, 1970a, p. 336, Pl. 64, fig. 13; Merrill, 1980, Pl. 6, figs. 10-12;
Neognathodus symmetricus, Grayson, 1990, Pl. 3, figs. 8-13; Nemyrovska, 1999, p. 78, Pl. 5, figs. 1-9,11,13,14;

Discussion- Specimens representing *Neognathodus symmetricus (columbiensis)* have a very elongate and narrow platform that is symmetrical or closely symmetrical. The platform is pointed posteriorly and contains parapets of equal height separated by deep adcarinal grooves and a medial nodular carina that extends to the posterior tip. Carina may be composed of discrete nodes towards the posterior. Parapets may have nodes or ridges at the anterior.

Remarks- *N. symmetricus* is distinguished from other species of *Neognathodus* by the symmetrical platform and by the central location of the carina. The parapets of *N. symmetricus* are of equal height and are not as tall as those of *N. bassleri*. The overall platform shape of *N. symmetricus* is less arrow-shaped than that of other species of *Neognathodus*.

Range- Atokan to Desmoinesian (Early to Middle Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Neo. symmetricus* first occurs within the lower Desmoinesian. The youngest stratigraphic occurrence of *Neo. symmetricus* occurs within the middle Desmoinesian *Idiognathodus obliquus* biozone.

Material Studied- 22 specimens

Genus *Streptognathodus*

Genus Streptognathodus, Stauffer and Plumber, 1932

Type species- *Streptognathodus excelsus*, Stauffer and Plumber, 1932

Diagnosis:

Platform elements of *Streptognathodus* are distinguished by the presence of a long free blade attaching to the platform at a medial position, a platform usually dominated with transverse ridges split by a distinct median oral trough for the full platform length, and by having parapets. Parapets on both sides of trough have transverse corrugations. Sides of the platform flair out and are expanded as a basal apron. Some specimens may have lateral lobes that may be ornamented with nodes. *Streptognathodus* specimens may be distinguished from specimens of *Idiognathodus* on the basis of having parapets, a noteworthy oral groove, and the domination of the posterior platform by distinct discontinuous transverse ridges.

Steptognathodus cancellosus

Idiognathodus cancellosus, Gunnell, 1933

Figure 23, nos. 18-20

Idiognathodus cancellosus, Gunnell, 1933, p. 77, Pl. 31, fig. 10;

Streptognathodus cancellosus (Gunnell), Barrick and Boardman, 1989, p. 10, Pl. 1, figs. 11, 18; Ritter et al., 2002, p. 513, Pl. 8, figs. 13,16,17.

Discussion- Platform elements of *St. cancellosus* are characterized by slender and biconvex outlines and high outer platform margins. The platform surface is concave and contains one or two longitudinal rows of nodes that extend to the posterior point. Platform margins join the adcarinal ridges and the outer platform margin are taller than the middle or inner platform. The inner adcarinal ridge is tall, turns inward, and is distinctly separated from the rest of the platform (creating a "frill). Only the posterior most transverse ridges may completely cross the platform.

Remarks- Specimens of *St. cancellosus* are differentiated from other species of *Streptognathodus* and *Idiognathodus* by the characteristic flaring of of the adcarinal ridges at the anterior margins of the platforms. *St. cancellosus* may also be morphologically identified from by possessing a concave upper surface and by presence of a carinal row of nodes that extends to the posterior point.

Range- Desmoinesian to Missourian (Middle to Upper Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *St. cancellosus* first occurs at the base of the Desmoinesian *Idiognathodus obliquus* biozone. The youngest stratigraphic occurrence of *St. cancellosus* occurs within the upper *Idiognathodus sp. "X"* biozone.

Material Studied- 19 specimens

Steptognathodus firmus

Streptognathodus firmus, Kozitskaya, 1978

Figure 23, nos. 21-23

Steptognathodus firmus, Kozitskaya, 1978, p. 45, Pl. 24, figs. 1-6;
Streptognathodus firmus (Kozitskaya), Barrick and Boardman, 1989, p. , Pl. 3, figs. 1, 2, 4, 5, 12, 17, 18, 25; Ritter, 1995, p. , Pl. 9, fig. 5; Nemyrovska and Kozitska, 1999, p. , Pl. 2, fig. 4; Ritter et al., 2002, p. 515, Pl. 9, figs. 3, 4;

Discussion- Platform elements of *St. firmus* are elongate, slender, and may be straight or slightly curved inwards. The blade is attached at a medial position and continues as the medial carina fully to the pointed posterior tip. The carina may be a solid ridge or a ridge composed of very discrete and small nodes that increase posteriorly. Deep troughs are present on both sides of the carina and separate the carina from the nodular to transversely ridged ornamented parapets. The inner parapet may terminate just before the junction of the carina and outer parapet.

<u>Remarks</u>- Specimens of *St. firmus* are differentiated from other species of *Streptognathodus* by the presence of a continuous carina that extends the full length of the platform to the posterior tip. *St. firmus* is also distinguished by the lack of any accessory lobes or accessory ornamentation.

<u>Range</u>- Desmoinesian to Missourian (Middle to Upper Pennsylvanian)

<u>Occurrence</u>- In Snaky Canyon Formation strata, *St. firmus* first occurs within the middle of the Desmoinesian *Idiognathodus obliquus* biozone. The youngest stratigraphic occurrence of *St. firmus* occurs within the upper limits of the upper Desmoinesian *Idiognathodus sp. "X"* biozone.

<u>Material Studied</u>- 17 specimens

Steptognathodus pawhuskaensis

Streptognathodus pawhuskaensis, Harris and Hollingsworth, 1933

<u>Polygnathus pawhuskaensis</u>, Harris and Hollingsworth, 1933, p. , Pl. 1, figs. 12a, 12b;
<u>Streptognathodus alekseevi</u>, Barrick and Boardman, 1989, p. , Pl. 3, figs. 3, 6, 19, 22, 24;
<u>Streptognathodus pawhuskaensis</u> (Harris and Hollingsworth) Ritter, 1994, p. , Pl. 5, fig. 1; Ritter, 1995, p. , Pl. 9, fig. 21; Ritter et al., 2002, p. 515, Pl. 9, figs. 5-7;

<u>Discussion</u>- Pa elements of *St. pawhuskaensis* are elongate, narrow, and may have slight inward curvature. The posterior tip is broad and pointed. The blade attaches the platform at a medial position and extends as the medial carina. The carina extends around one-half of the platform and consists of a ridge or ridge of nodes that most often terminates

posteriorly as isolated, distinct nodes located within the medial trough. Both sides of the carina are flanked by deep, narrow grooves that meet at about one-half of the platform length and form a deep 'U'-shaped trough at the posterior that continues to the posterior tip. Parapets are ornamented by nodes and/or transverse ridges.

<u>Remarks</u>- *St. pawhuskaensis* may be distinguished from other species of *Streptognathodus* by possessing a deep, U-shaped posterior trough and the lack of an accessory lobe. *St. pawhuskaensis* may be differentiated from *St. firmus* by the discontinuous medial carina.

<u>Range</u>- Missourian to Virgilian (Late Pennsylvanian)

<u>Occurrence</u>- In Snaky Canyon Formation strata, *St. pawhuskaensis* first occurs at the Hawley Mountain locality within the upper *Idiognathodus sp. "X"* biozone.

<u>Material Studied</u>- 5 specimens

Steptognathodus suberectus

Streptognathodus suberectus, Dunn, 1966

Figure 22, nos. 9-11

<u>*Steptognathodus suberectus*</u>, Dunn, 1966, p. 1303, Pl. 157, figs. 4, 5, 6, 10;
<u>*Streptognathodus suberectus*</u> (Dunn), Groves, 1984, P. 71; Nemyrovska, 1999, p. 82, Pl. 6, figs. 3-5, 7;

<u>Discussion</u>- Pa elements of *St. suberectus* display distinct long axis curvature inward, are elongate, and have a short carina. The blade attaches at a medial position and continues as a fused carina for one-third of the length of the platform. The parapets contain nodes and are separated from the carina

by distinct troughs. These troughs merge at the termination of the carina to form a medial trough that extends fully to the posterior tip or shallows at the posterior tip. The inner anterior of the platform may contain an elongate node of several nodes arranged linearly to the margin. This accessory lobe is shifter posteriorly. The posterior of the platform is covered with wide transverse ridges separated by the medial trough.

Remarks- *St. suberectus* may be distinguished from other specimens of *Streptognathodus* on the basis of platform curvature, posterior shifted inner accessory lobe, and the short length of the carina.

Range- Morrowan to lower Atokan

Occurrence- In Snaky Canyon Formation strata, *St. suberectus* first occurs within the upper Morrowan. The youngest stratigraphic occurrence of *St. suberectus* occurs within the lower Atokan.

Material Studied- 30 specimens

Genus *Swadelina*

Genus *Swadelina*, Lambert, Heckel, and Barrick, 2003
Type species- *Streptognathodus nodocarinatus*, Jones, 1941

Diagnosis:

Platform elements representing the genus *Swadelina* are distinguished from other Idiognathodids by possessing a posterior platform that contains transverse ridges separated by a distinct medial or near-medial shallow trough. The anterior platforms of specimens representing *Swadelina* have a very short and simple carina surrounded by mixed, but distinct ornamentation that are not consistently patterned. All ornamentation is concentrated within the anterior of the platforms.

Swadelina nodocarinata

Streptognathodus nodocarinatus, Jones, 1941

Figure 23, nos. 34-35

Steptognathodus nodocarinatus, Jones, 1941, p. 38, Pl. 3, fig. 2;
Idiognathodus sp. 6, Swade, 1985, p. 62, Pl. 18, figs. 6, 7;
Idiognathodus nodocarinatus (Jones), Ritter et al., 2002, P. 509-510; Pl. 8, figs. 14, 18;
Swadelina nodocarinata (Jones), Lambert et al, 2003, p. 154, Pl. 1, figs. 2, 4, 7, 8, 12, 13, 16-19;
Swadelina nodocarinata (Jones), Roscoe, 2005, p. 86-87, Pl. 35, fig. 10; Pl. 35, figs. 12-17;

Discussion- Platform elements of *Swadelina nodocarinata* are straight to slightly curved, are broad, and have a blunt posterior tip. Platforms have a high raised margin and very short rostral (adcarinal) ridges that separates that ornamented platform from the accessory lobes. The accessory lobes are well developed and are restricted to the anterior of the platform. The inner lobe is larger, bears numerous coarse nodes that may be fused into short ridges, and projects sharply from the platform margin. The outer lobe bears less ornamentation and projects only slightly from the platform. The posterior of the platform is covered by 7 to 10 transverse ridges that are separated by a distinct narrow medial trough. This trough extends the full length of the platform and the transverse ridges may be deflected at the junction of the trough and ridges.

In lateral view, the short medial carina is the tallest part of the platform.

Remarks- Species of *Swadelina* may be differentiated from species of *Idiognathodus* by the presence of a medial trough that disrupts the transverse ridges. *Swadelina* may be distinguished from species of *Streptognathodus* on the basis of possessing a very short and high carina that does not extend beyond the anterior limit of the platform.

Range- Upper Desmoinesian to lower Missourian (Late Pennsylvanian)

Occurrence- In Snaky Canyon Formation strata, *Sw. nodocarinata* first occurs in the lower Missourian. The youngest stratigraphic occurrence of *Sw. nodocarinata* is not defined.

Material Studied- 9 specimens

Genus *Rhachistognathus*

Genus *Rhachistognathus*, Dunn, 1966

Type species- *Rhachistognathus primus*, Fieber, 1866

Diagnosis:

The genus *Rhachistognathus* is characterized by a lanceolate, scaphate platform and a laterally compressed uniform blade that joins the platform in a lateral position. In aboral view, platform ornamentation consists of a combination of carina and distinct rounded nodes or diminished ridges. The carina is laterally discontinuous along the platform. There is a general lack of a deep median trough and marginal rims.

In Snaky Canyon Formation strata, all species of *Rhachistognathus* become extinct within the upper Morrowan.

Rhachistognathus primus

Rhachistognathus prima Dunn, 1966

Figure 20, nos. 1,2,7-11

<u>*Rhachistognathus prima*</u> Dunn, 1966, p. 1301, Pl. 157, figs. 1, 2.

<u>*Rhachistognathus primus*</u> (Dunn), Dunn, 1970, p. 338, Pl. 63, figs. 26, 27; Lane and Straka, 1974, p. 98, Pl. 35, figs. 18, 20, 22, 25-27, 32-34, 36, 38, 40; Metcalfe, 1980, p. 308, Pl. 38, fig. 23; Baesemann and Lane, 1985, p. 114, Pl. 4, figs. 6-11; Webster, 1992, p. 64, Pl. 1, fig. 7.

<u>Discussion</u>- The elements of *Rhachistognathus primus* are all left-sided with respect to blade attachment and lack a distinct trough running along the median platform. A carina is strongly developed in the posterior portion of the platform and can be continuous with the blade as a ridge. The upper surface is characterized by development of irregular sized and spaced nodes, or ridges along the margins, or both. In lateral view the species is highly variable, although commonly has a straight basal margin.

<u>Range</u>-Lower Morrowan (Early Pennsylvanian)

<u>Occurrence</u>-In east-central Idaho, *Rhachistognathus primus* first occurs within the lowermost Arco Hills Formation at the Antelope Creek section (Abplanalp, 2006). In Snaky Canyon Formation strata, *Rh. primus* first occurs at the

Mississippian/Pennsylvanian boundary. The youngest stratigraphic occurrence of *Rh. primus* occurs within the middle Morrowan Idiognathoides sinuatus biozone.

Material Studied- 26 specimens

Rhachistognathus prolixus

Cavusgnathus transitoria, Dunn, 1966

Cavusgnathus transitoria Dunn, 1966, p. 1299, Pl. 157, fig. 9.
Rhachistognathus sp. B. Tynan, 1980, p. 1305, Pl. 1, figs. 28-36.
Rhachistognathus prolixus (Dunn), Baesemann and Lane, 1985, p. 115, Pl. 2, fig. 12, Pl. 5, figs. 3-7; Webster, 1992, p. 64, Pl. 1, fig. 9.

Discussion-In upper view, *Rhachistognathus prolixus* elements are characterized by a laterally compressed blade that is left-sided in all specimens. The platforms are generally short and narrow, with the freeblade being over half the length of the entire element. The left (blade) parapet consists of a row of nodes that are discrete or fused. The right parapet contains three to five discrete nodes and the parapets are separated by a very narrow trough. In lateral view, the blade, left parapet, and nodes are aligned to form a linear unit that is usually bowed or arched.

Range-Upper Chesterian (Late Mississippian) to Morrowan (Early Pennsylvanian)

Occurrence-In east-central Idaho, *Rhachistognathus prolixus* occurs in the lowermost Arco Hills Formation at the Antelope Creek section; and within the Bluebird Mountain Formation at the Arco Hills type section (Abplanalp, 2006).

In Snaky Canyon Formation strata, *Rh. prolixus* first occurs in the basal Morrowan (*Rh. primus* biozone). The youngest stratigraphic occurrence of *Rh. prolixus* occurs within the upper *Declinognathodus noduliferous* biozone.

Material Studied- 8 specimens

Rhachistognathus websteri

Rhachistognathus websteri, Baesemann and Lane, 1985

Figure 20, nos. 3,4,12-14

Rhachistognathus websteri Baesemann and Lane, 1985, p. 117, Pl. 5, figs. 1, 2, 8-12; Webster, 1992, p. 64, Pl. 1, fig. 8.

Discussion-In upper view, *Rhachistognathus websteri* elements exhibit a carina that is strongly developed with evenly spaced oval shaped nodes or slightly transverse ridges trending toward the anterior. A laterally compressed blade, which comprises half the total length of the element, is attached to the left parapet. Ornamentation consists of two rows of nodes along both margins separated by an intervening trough. In lateral view, the point of blade attachment is equal with the upper surface of the platform. The blade continues to rise anteriorly from this point and reaches maximum projection at the anterior portion. The upper surface may be straight or slightly bowed. In aboral view, the basal cavity broadens anteriorly.

Remarks- This species is distinguished from other species of *Rhachistognathus* by the centrally located row of denticles at the posterior end within the carina truncating in the middle of the first two oval shaped nodes of the ridges towards the anterior.

Range- Upper Chesterian (Late Mississippian) to lower

Morrowan (Early Pennsylvanian)

<u>Occurrence</u>- In east-central Idaho, *Rhachistognathus websteri* occurs within the lower Arco Hills Formation at the Antelope Creek section (Abplanalp, 2006). In Snaky Canyon Formation strata, *Rh. websteri* first occurs in the basal Morrowan (*Rh. primus* biozone). The youngest stratigraphic occurrence of *Rh. websteri* occurs within the upper *Declinognathodus noduliferous* biozone. .

<u>Material Studied</u>- 25 specimens

Genus *Hindeodus*

Genus Hindeodus, Rexroad and Furnish, 1964

Type species- <u>*Spathognathodus cristulus*</u>, Youngquist and Miller, 1949

Diagnosis:

The genus *Hindeodus* is characterized by seximembrate apparatuses. Diagnostic elements are scaphate, short and compressed, arched, and always exhibit single rows of denticles. Specimens are notably marked by narrow platforms and narrow, deep basal cavities. Platforms are generally curved with fused denticles running along the entire element. Many previous studies include the genus *Hindeodus* with the genus *Spathognathodus*.

Hindeodus minutus

Spathognathodus Ellison, 1941

Spathognathodus minutus Ellison, 1941, p. 120, Pl. 20, figs. 50-52.

Spathognathodus minutus (Ellison), Ellison and Graves, 1941, Pl. 2, figs. 1, 3, 5; Youngquist and Downs, 1949, p. 169, Pl. 30, fig. 4; Sturgeon and Youngquist, 1949, p. 385, Pl. 74, figs. 9-11, Pl. 75, fig. 19; Rexroad and Burton, 1961, p. 1156, Pl. 141, figs. 10, 11; Murray and Chronic, 1965, p. 606, Pl. 72, figs. 29, 30; Igo and Koike, 1965, p. 88, Pl. 9, figs. 16-18; Koike, 1967, p. 311, Pl. 3, figs. 39-42; Webster, 1969, p. 44, Pl. 7, fig. 4; Dunn, 1970a, p. 339, Pl. 61, figs. 27, 30; Lane and Straka, 1974, p. 101, Pl. 44, figs. 7, 12.

Hindeodus minutus (Ellison), Savage and Barkeley, 1985, p. 1472, Pl. 12, figs. 1-8;

Discussion- *Hindeodous minutus* is characterized by a short, thin, and laterally straight blade. The lower margin is broadly arched with the aboral edge in the anterior half being nearly straight and attaining its greatest height at the anterior superior denticle. The upper denticulated margin gradually decreases posteriorly to about the fourth from the last denticle at which it drops sharply to the aboral margin. The basal cavity is broadly rounded anteriorly with the posterior point reaching near the end of the blade. The cavity is traversed by a longitudinal groove that extends along the aboral edge of blade anteriorly and posteriorly.

Remarks *H. minutus* can be distinguished from *H. cristulus* by the presence of a stepped superior denticle. This denticle exhibits one to two smaller denticles along the anterior most margin.

Range- Upper Chesterian (late Mississippian) to Permian

Occurrence- In east-central Idaho, *Hindeodus minutus* occurs within the low-middle Surrett Canyon Formation at the

Antelope Creek section; middle to upper Surrett Canyon Formation at the Taylor Mountain section; throughout the Arco Hills Formation at the Box Canyon section; and within the uppermost South Creek Formation at the Copper Mountain section (Abplanalp, 2006). *H. minutus* sparingly occurs throughout the entire succession of Snaky Canyon Strata.

Material Studied- 22 specimens

Genus *Diplognathodus*

Genus *Diplognathodus*, Kozur and Merrill, 1975

Type species- *Spathognathodus coloradoensis*, Murray and Chronic, 1965

Diagnosis:

Platform elements representing the genus *Diplognathodus* are distinguished by being scaphate, having a free blade that is equal in length and fused to the carina of the platform, and by having a basal cavity that is subelliptical in shape. The deepest part of the basal cavity is located directly behind where the blade is fused to the platform.

Diplognathodus coloradoensis

Spathognathodus coloradoensis, Murray and Chronic, 1965

Spathognathodus coloradoensis, Murray and Chronic, 1965, p. 606, Pl. 72, figs. 11-13 ;
Spathognathodus orphanus, Merrill, 1971, p. 309, Pl. 3, figs. 45,46 ;

Diplognathodus orphanus, Grayson, 1984, p. 48, Pl. 1, fig. 6, Pl. 2, figs. 24,25;

Diplognathodus coloradoensis (Murray and Chronic), Merrill, 1975, p. 48, Pl. 16, fig. 40, Pl. 17, fig. 16; Landing and Wardlaw, 1981, p. 1257, Pl. 1, fig. 7; Savage and Barkeley, 1985, p. 1473, Pl. 13, figs. 9-16 ;

Remarks- Due to limited data availability, this report will not differentiate between *D. coloradoensis* and *D. orphanus*. Merrill (1972) subdivided *D. coloroadoensis* and *D. orphanus* on the basis of degree of posterior denticulation. Due to variability and overall poor preservation quality of *Diplognathodus* specimens, it is currently not possible or acceptable to differentiate between species in this study.

Range- Atokan to Desmoinesian (Early to Middle Pennsylvanian)

Material Studied- 7 specimens

Chapter 18: Conclusions

Fifteen high-resolution conodont biozones are proposed from the investigation of eight measured sections of the Snaky Canyon Formation in east-central Idaho. The establishment of a biozonation framework for the Snaky Canyon Formation allows for stratigraphic positioning of the Bloom Member as Morrowan to lower Missourian. The framework also indicates that the Gallagher Peak Sandstone Member was time transgressive from west to east and that the Juniper Gulch Member may have been synchronously deposited with the Bloom Member.

A depositional framework has been determined for the Snaky Canyon Formation and is based on recovered conodont data indicating stratigraphic positioning and identified depositional facies. In the Morrowan, deposition occurred within a ecstatically controlled homoclinal ramp and the setting was similar to that inherited from the Mississippian. By the middle of the Atokan, it is postulated that significant tectonic changes combined with eustatic fluctuations influenced Snaky Canyon Formation deposition.

The establishment of Snaky Canyon biozones allows for a greater understanding of Pennsylvanian depositional sequences. Based on the recovered data, it is determined that based on the 318 Ma to 306 Ma duration of the Bloom Member type section at Gallagher Peak the identified 50+ parasequences from the Bloom type section likely record 4th order (100-200 k.y.) eustatic variations from a relatively tectonically quiescent passive margin.

Recommendations for Future Studies

The completion of this high-resolution conodont biostratigraphic study on the Snaky Canyon Formation of east-central Idaho creates significant opportunity for future research studies and endeavors. In order to fully understand the Pennsylvanian of east-central Idaho, it is recommended that future studies investigate:

1. Isotope geochemistry of whole rock and biologic Snaky Canyon Formation sources. Geochemical data can be integrated into the biostratigraphic framework identified by this study in order fully understand eustatic and tectonic controls on deposition and provide additional means of global correlation.
2. Additional biostratigraphic contribution based on fusulinids. Billets have been prepared from each conodont sampled horizon and are ready for identification, analysis, and integration into the conodont biozonation proposed by this study.
3. The Pennsylvanian carbonate succession south of the Snake River Plain for conodont biostratigraphic correlation.
4. The limited carbonate intervals of the Wood River Group located to the west of the study area for biostratigraphic analysis and correlation with the framework identified by this study. This may further refine the understanding of the upper Carboniferous development of Idaho's foreland basin.
5. Additional upper Bloom Member stratigraphic successions in order to identify and categorize the *Idiognathodus* sp. *"X"* species. The additional investigation of this stratigraphic interval may also resolve issues surrounding the differences between first occurrences of

Swadelina nodocarinata within the midcontinental and western United States.

6. The relationship between *Idiognathodus* and *Streptognathodus* from a relatively continuous deposited succession of Pennsylvanian strata.
7. The conodont lineages of the Pennsylvanian. The sediments of the Snaky Canyon Formation may reveal crucial evolutionary transitions that are nonexistent in the disrupted stratigraphic successions of the midcontinental United States.
8. The concept of biosequence stratigraphy. A in-depth study correlating Pennsylvanian depositional cycles based on conodont assemblages will contribute to the understanding of the biosequence stratigraphy concept and may provide increased understanding of depositional controls during the Pennsylvanian.
9. The biostratigraphy of the Gallagher Peak Sandstone and the Juniper Gulch members of the Snaky Canyon Formation. This study proposes a lower stratigraphic assignment for the Juniper Gulch Member and a time transgressive placement for the Gallagher Peak Sandstone Member. Additional studies are necessary to fully position each member and reconstruct the depositional history for the region.

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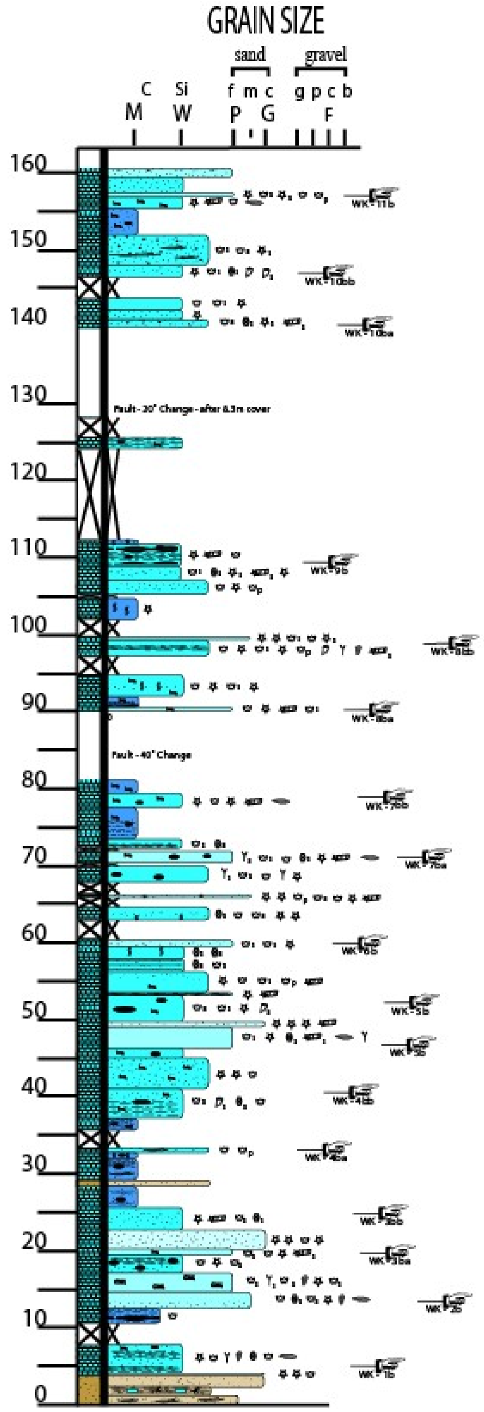
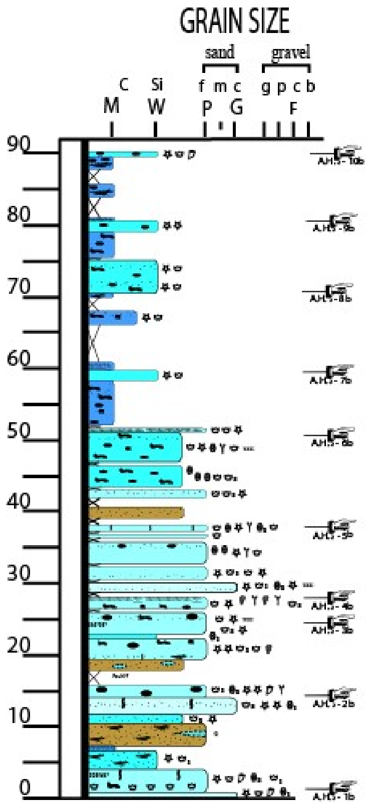
Appendix I: Snaky Canyon Measured Sections – West to East

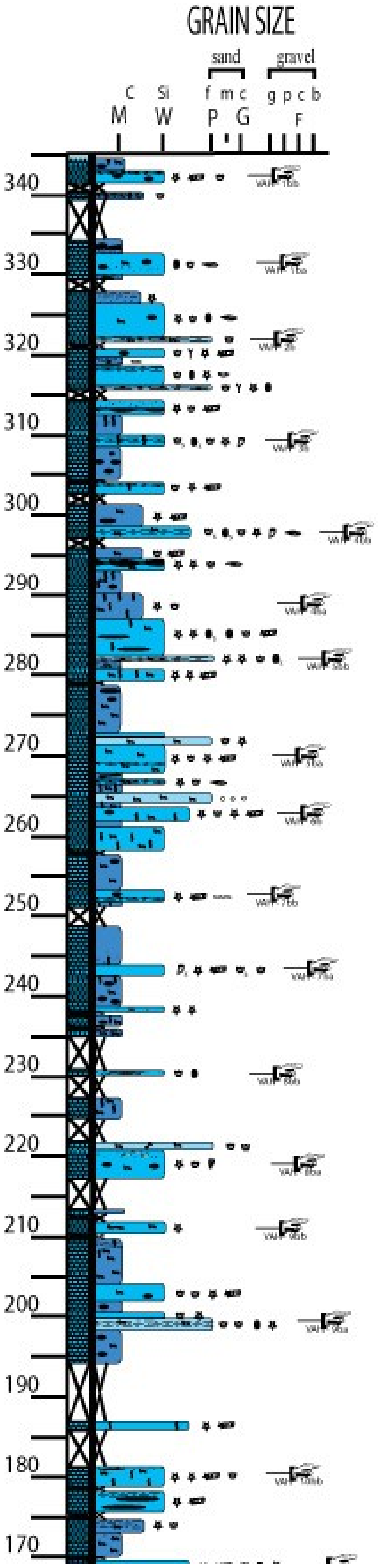
White Knob Measured Section

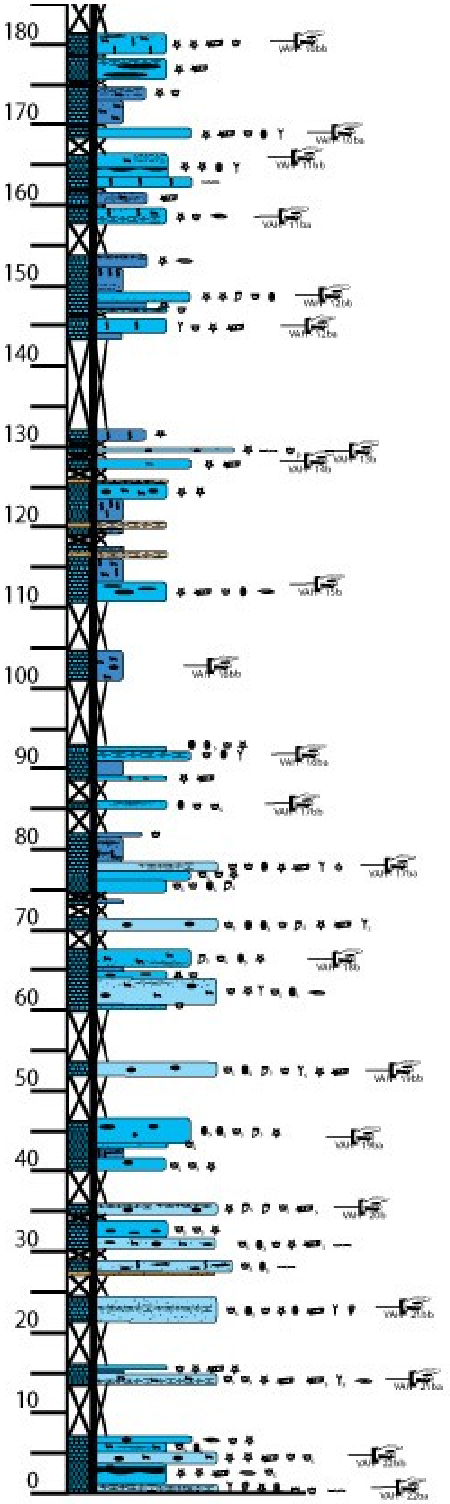


Arco Hills Measured Section



Vertical Arco Hills (VAH) Measured Section

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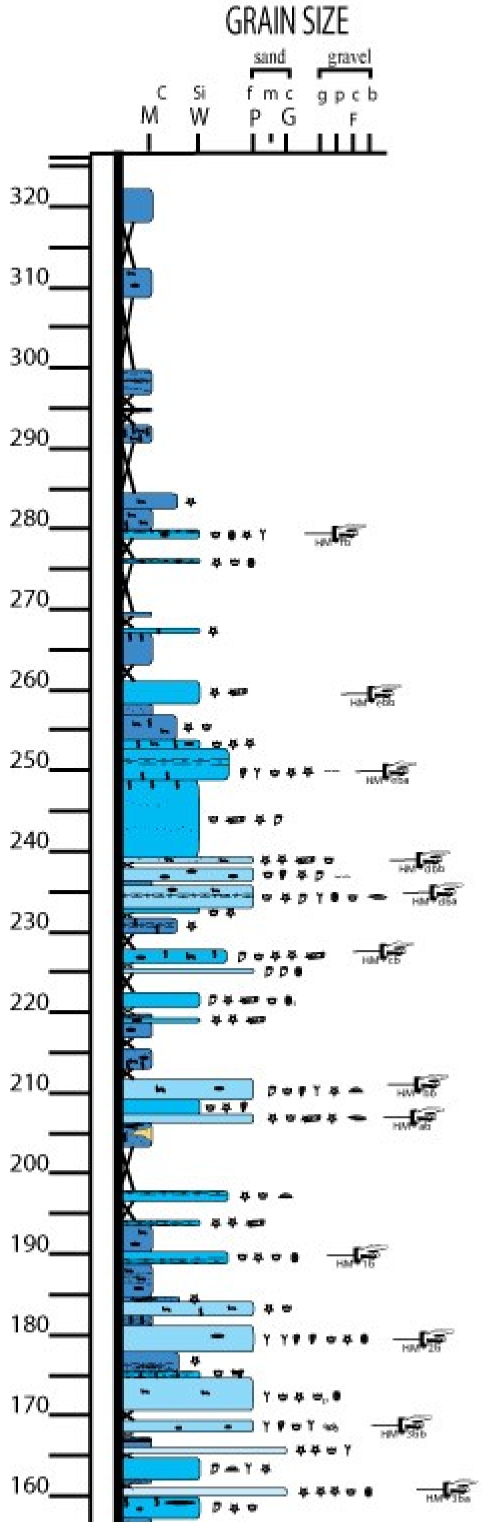
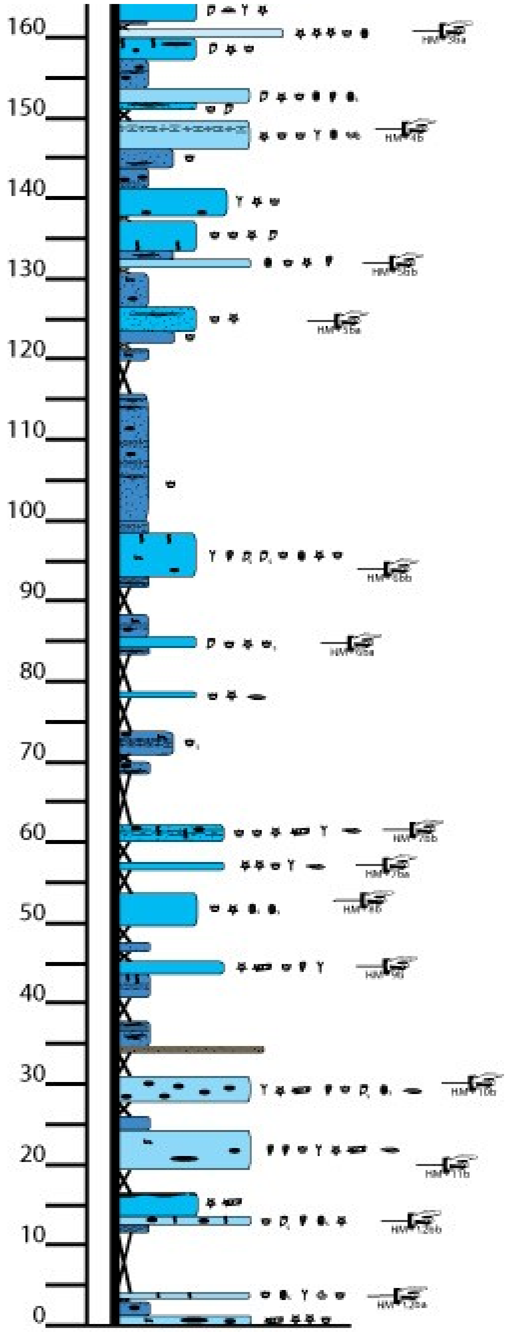
Hawley Mountain Measured Section

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HM-5a
HM-6b
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HM-10b
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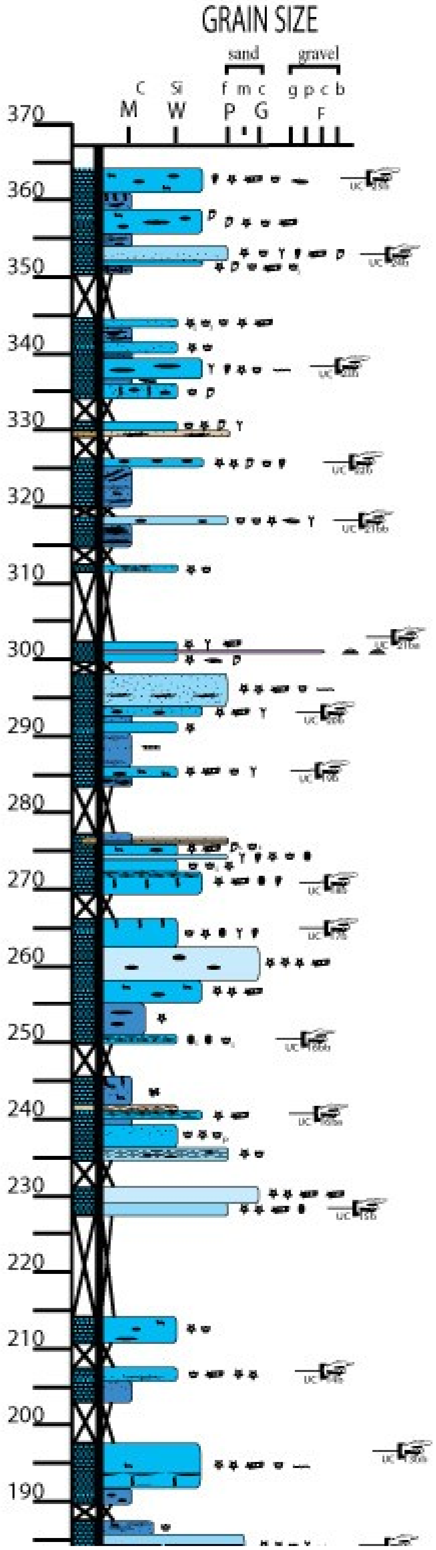
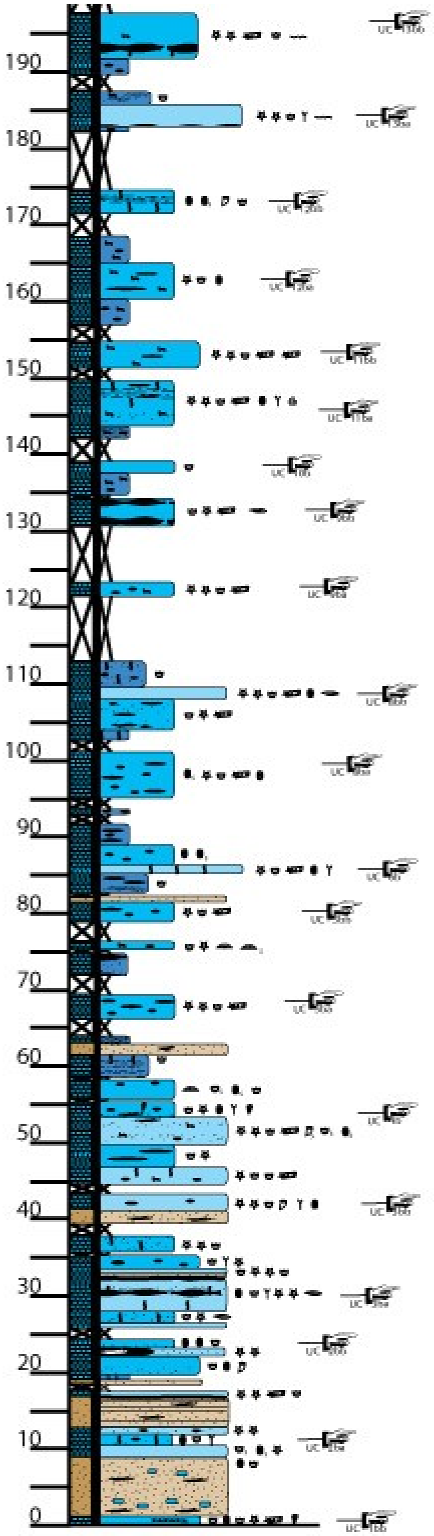
HM-12b
HM-12a

Unknown Canyon Measured Section

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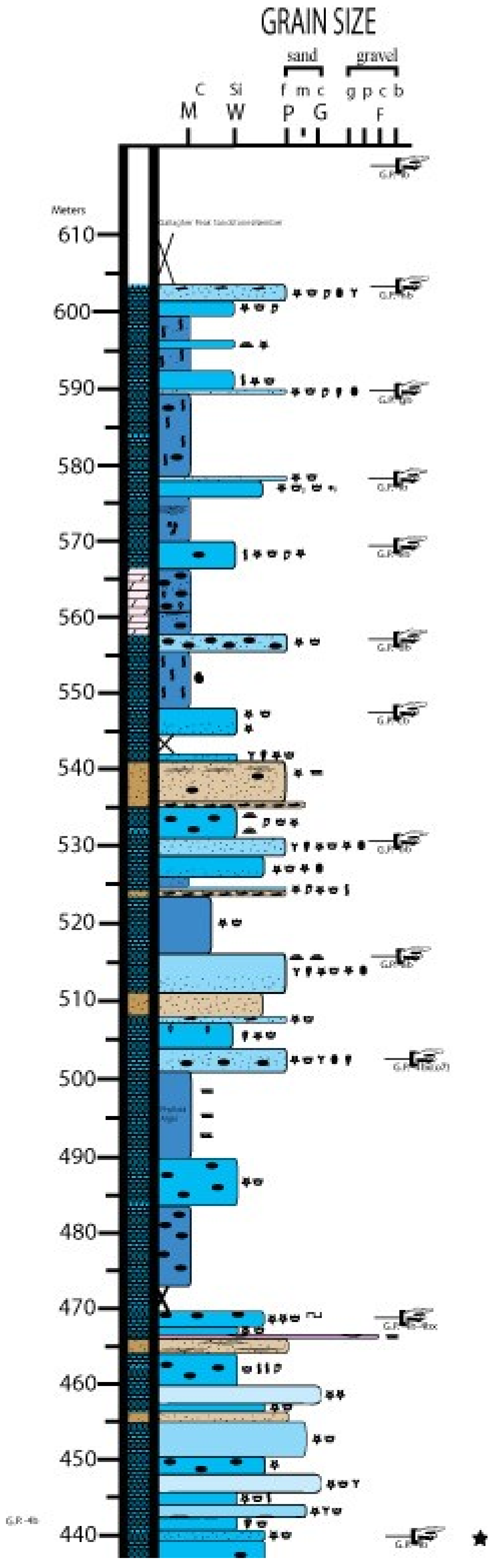
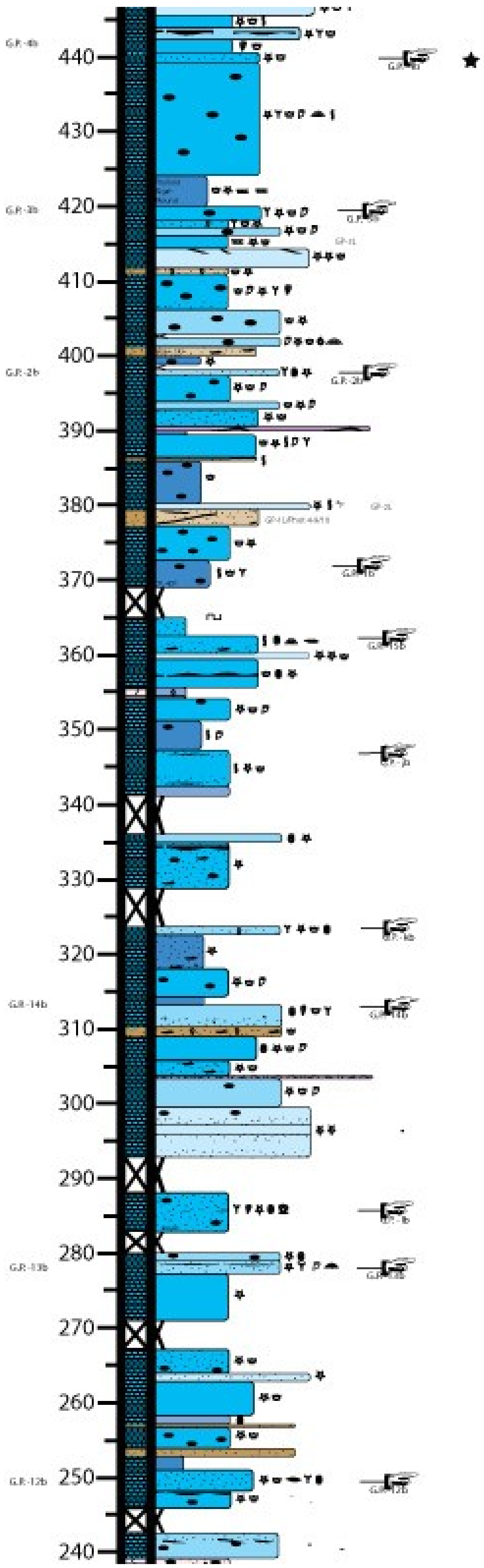
Gallagher Peak Type Measured Section




G.R.-4b
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G.R.-3b
410
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G.R.-2b
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G.R.-13b
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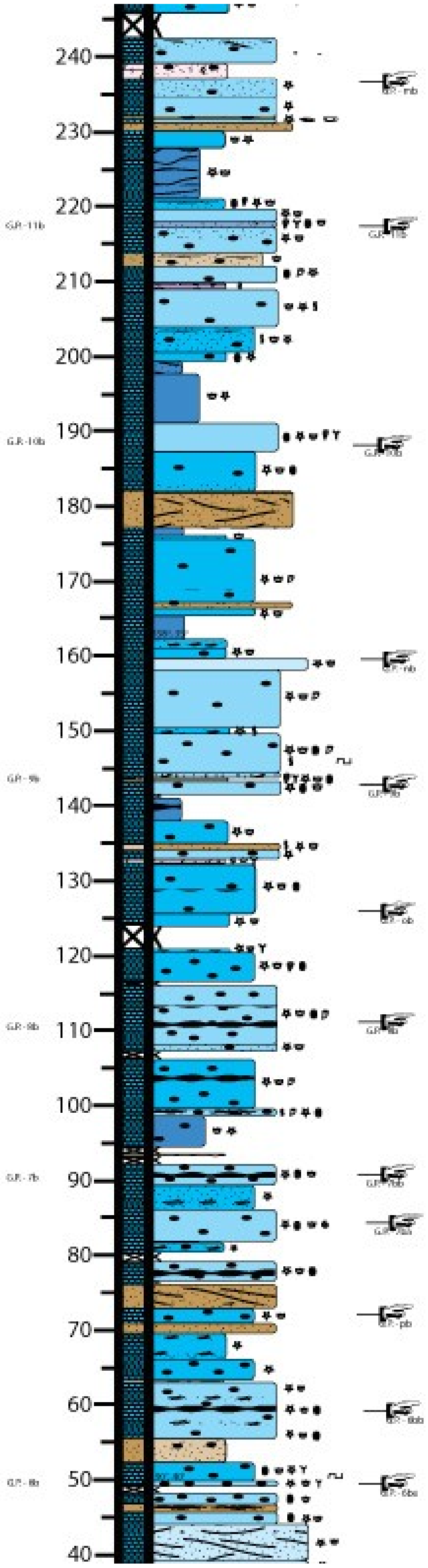
G.R.-12b
240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G.R.-10b
G.R.-9b
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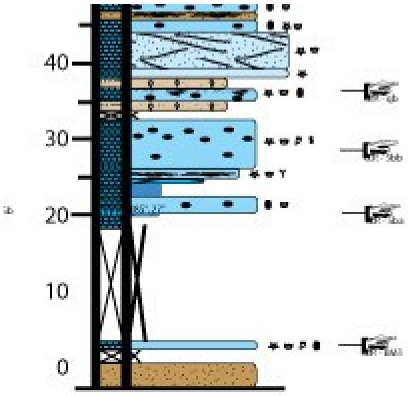
G.R.-pb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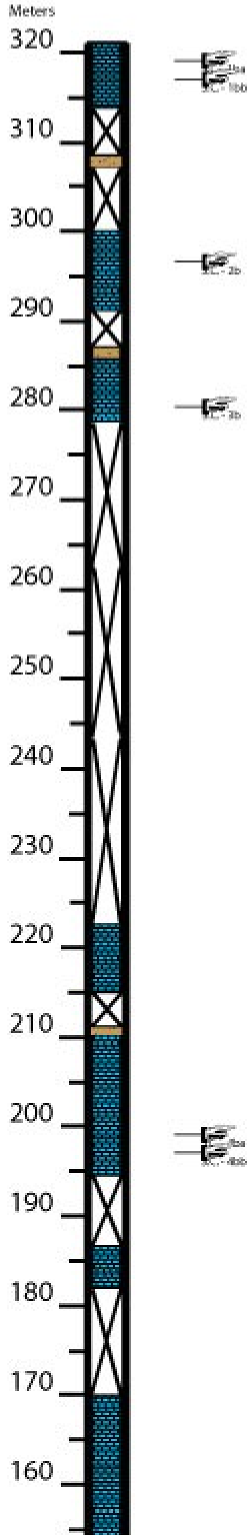
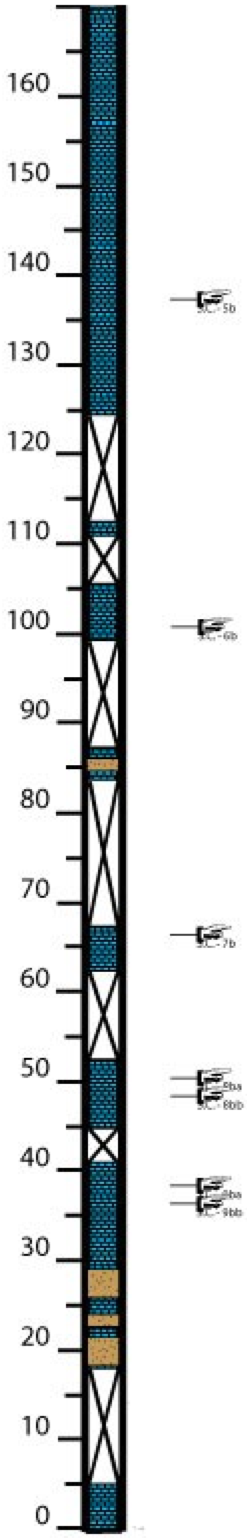
Juniper Gulch Type Biostratigraphic Section

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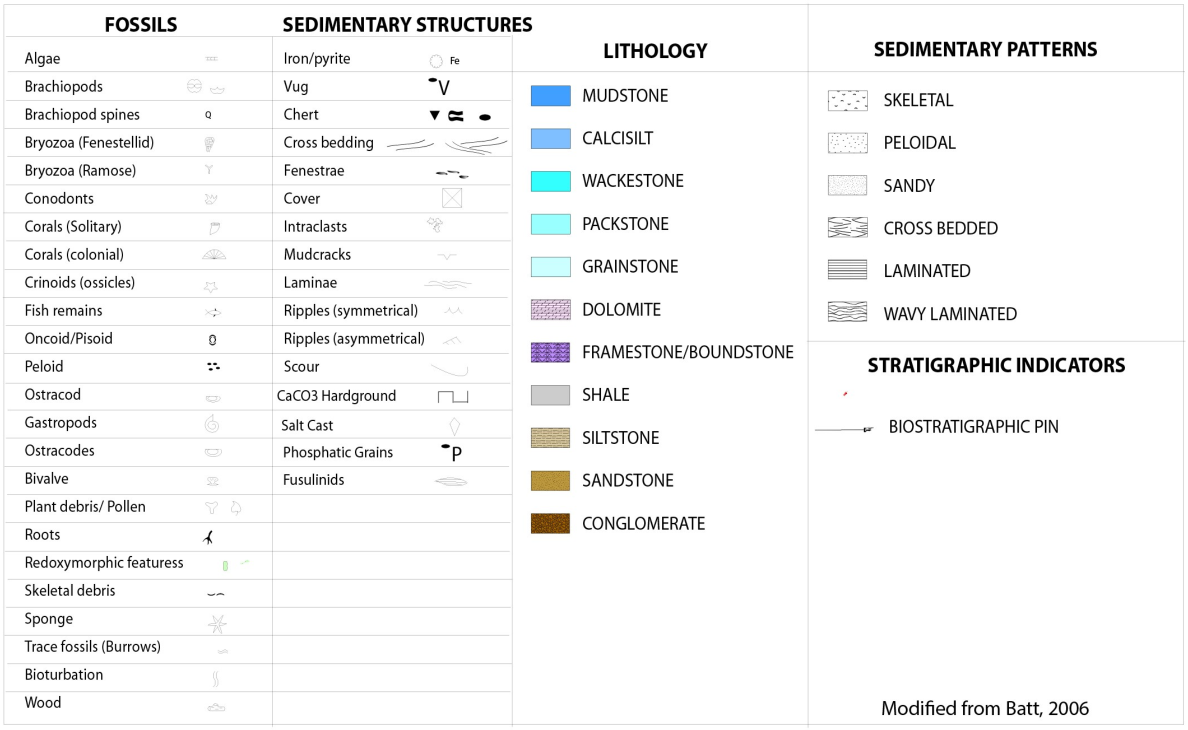
SC - 8bb
9ba
SC - 9bb

Symbols Key

LITHOFACIES KEY FOR STRATIGRAPHIC COLUMNS



FOSSILS	SEDIMENTARY STRUCTURES
Algae	Iron/pyrite Fe
Brachiopods	Vug V
Brachiopod spines	Chert
Bryozoa (Fenestellid)	Cross bedding
Bryozoa (Ramose)	Fenestrae
Conodonts	Cover
Corals (Solitary)	Intraclasts
Corals (colonial)	Mudcracks
Crinoids (ossicles)	Laminae
Fish remains	Ripples (symmetrical)
Oncoid/Pisoid	Ripples (asymmetrical)
Peloid	Scour
Ostracod	CaCO3 Hardground
Gastropods	Salt Cast
Ostracodes	Phosphatic Grains P
Bivalve	Fusulinids
Plant debris/ Pollen	
Roots	
Redoxymorphic featuress	
Skeletal debris	
Sponge	
Trace fossils (Burrows)	
Bioturbation	
Wood	

LITHOLOGY
MUDSTONE
CALCISILT
WACKESTONE
PACKSTONE
GRAINSTONE
DOLOMITE
FRAMESTONE/BOUNDSTONE
SHALE
SILTSTONE
SANDSTONE
CONGLOMERATE

SEDIMENTARY PATTERNS
SKELETAL
PELOIDAL
SANDY
CROSS BEDDED
LAMINATED
WAVY LAMINATED

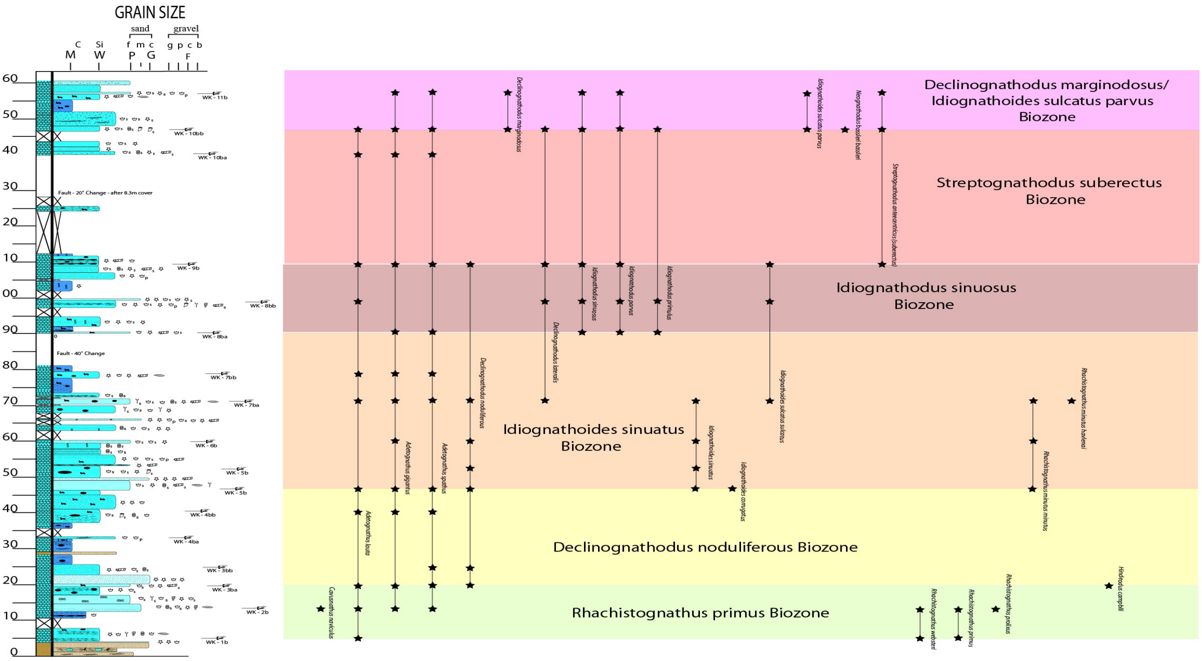
STRATIGRAPHIC INDICATORS

BIOSTRATIGRAPHIC PIN

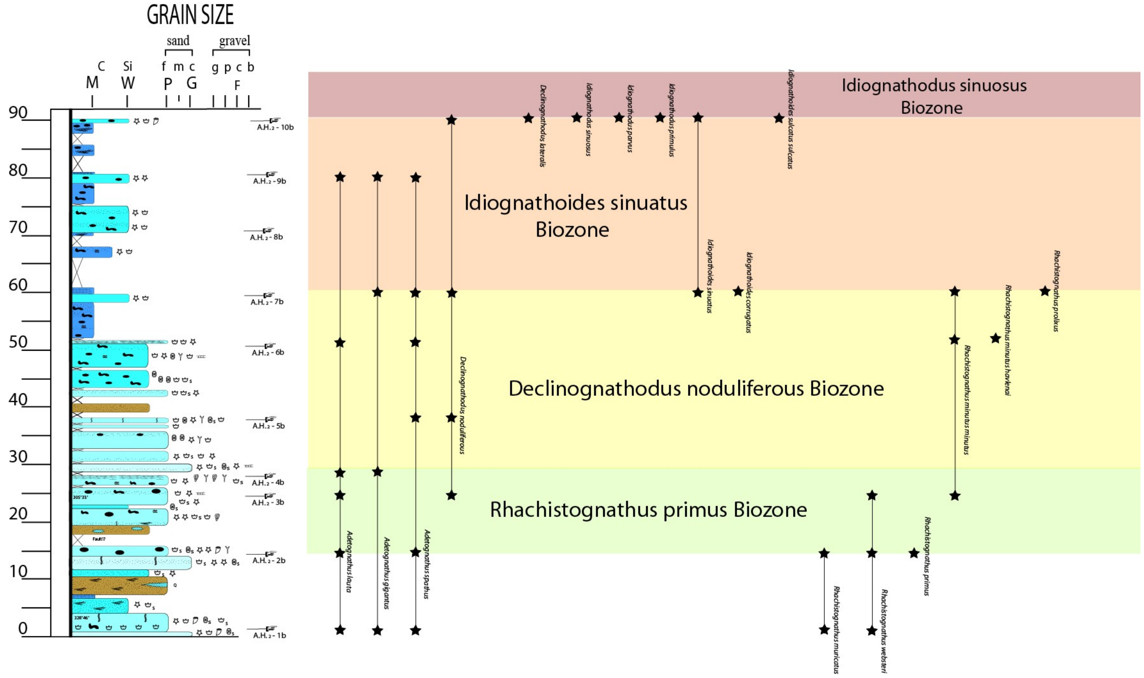
Modified from Batt, 2006

Appendix II: Measured Sections with Recovery Data and Conodont Biozones – West to East

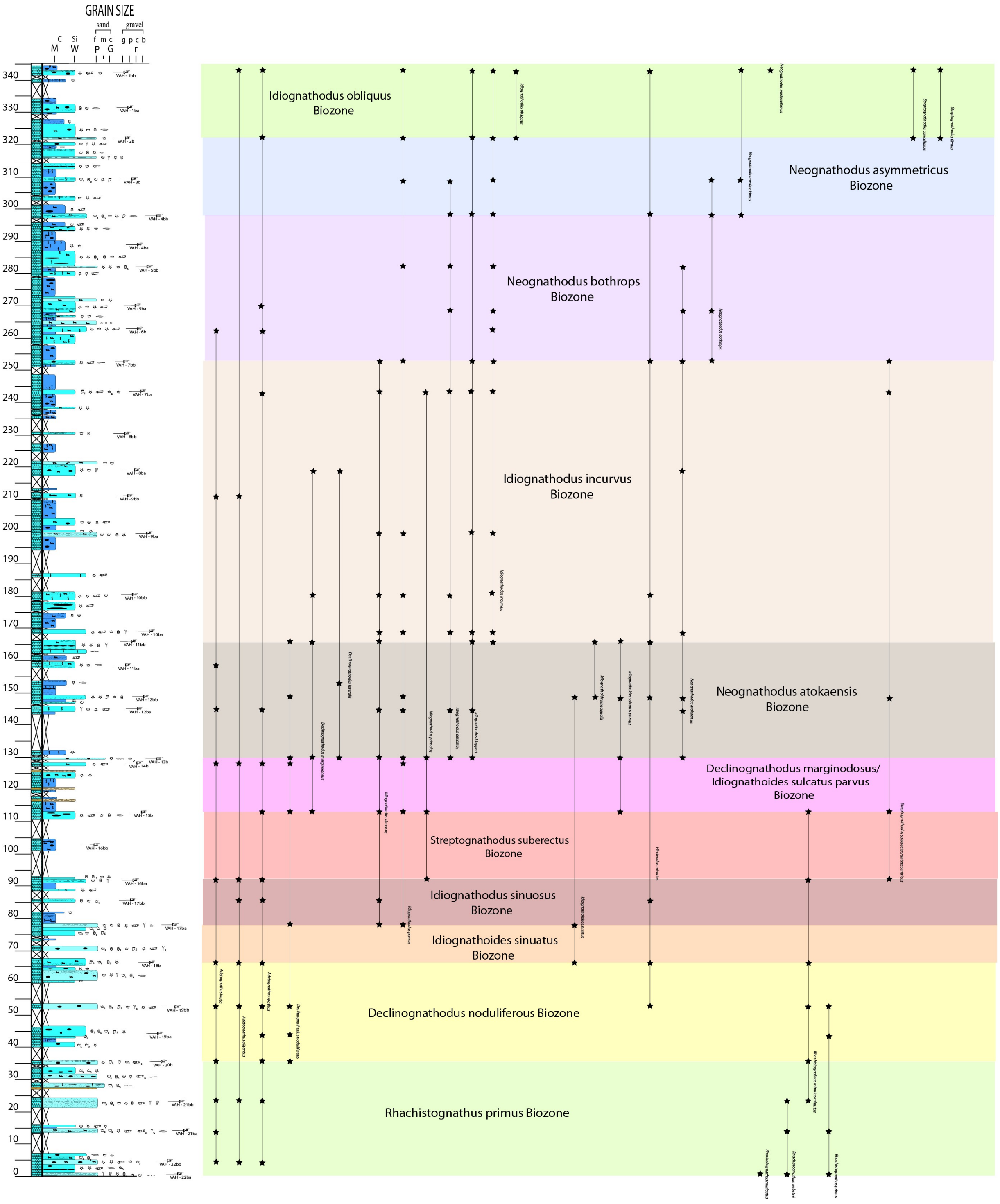
White Knob Section



Arco Hills Section



VAH Section


GRAIN SIZE
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VAH - 1bb
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VAH - 5ba
VAH - 6b
VAH - 7bb
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VAH - 18b
VAH - 19bb
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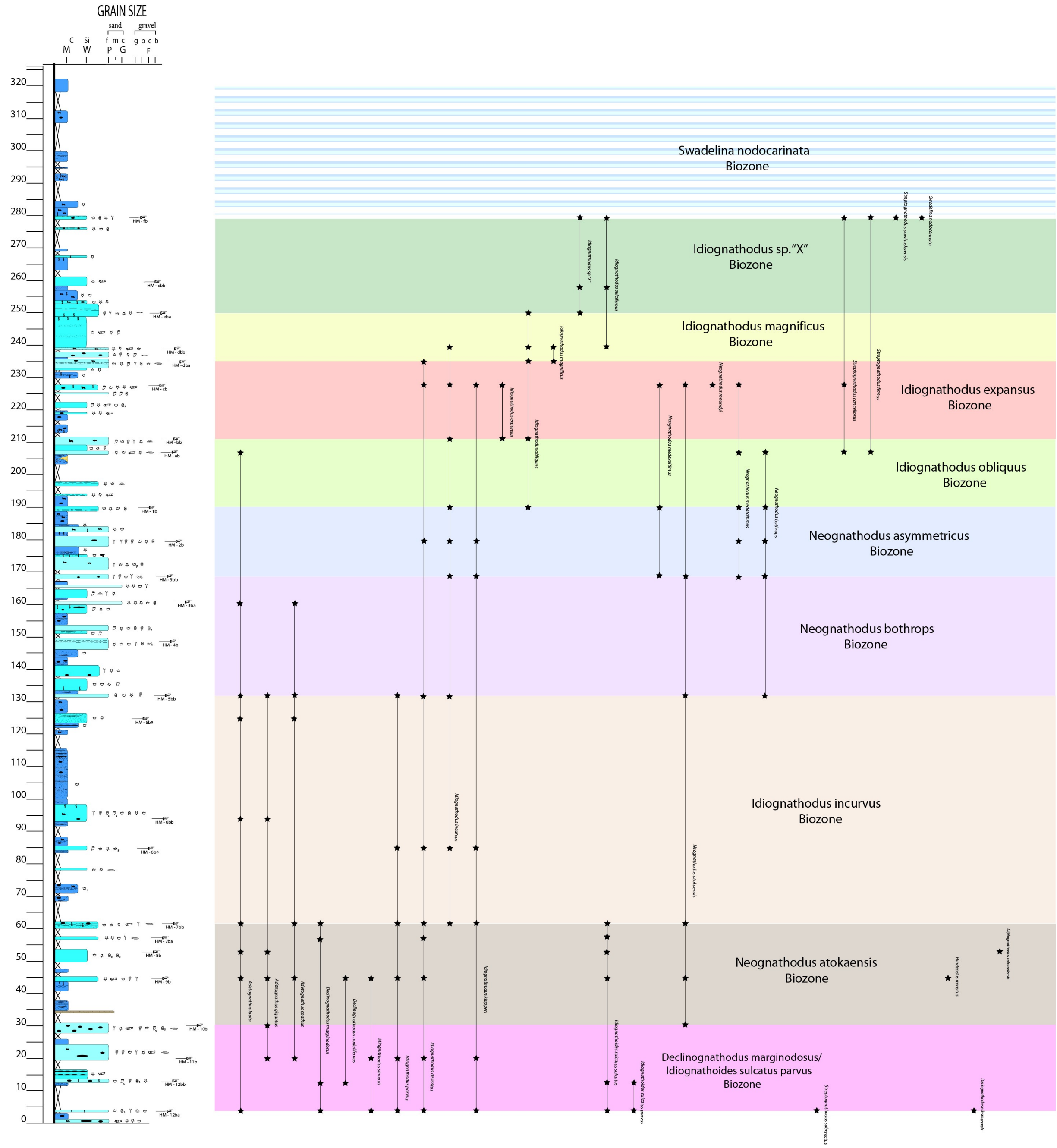
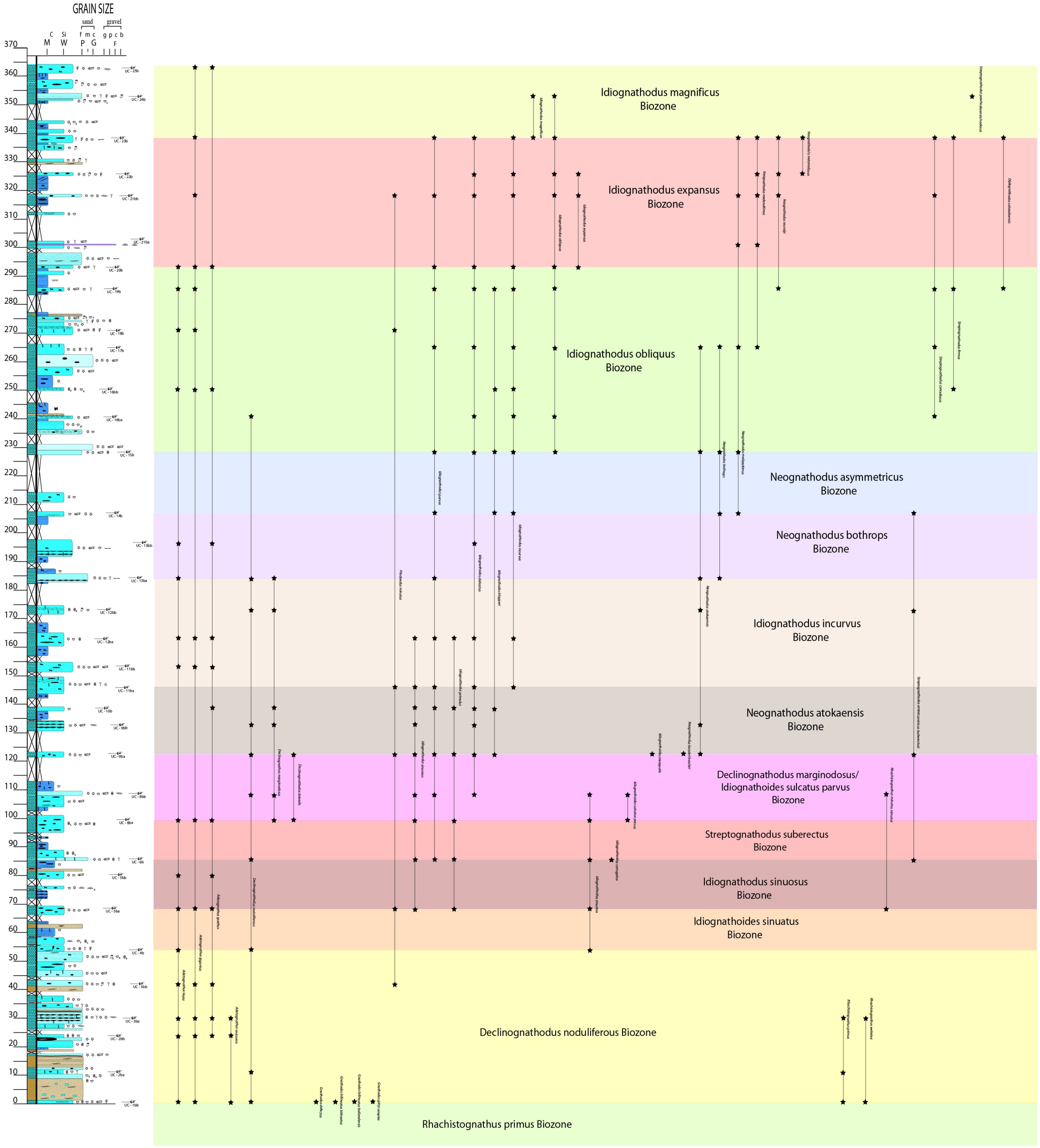
VAH - 20b
VAH - 21bb
VAH - 21ba
VAH - 22bb
VAH - 22ba
Idiognathodus obliquus Biozone
Neognathodus asymmetricus Biozone
Neognathodus bothrops Biozone
Idiognathodus incurvus Biozone
Neognathodus atokaensis Biozone
Declinognathodus marginodosus/ Idiognathoides sulcatus parvus Biozone
Streptognathodus suberectus Biozone
Idiognathodus sinuosus Biozone
Idiognathoides sinuatus Biozone
Declinognathodus noduliferous Biozone
Rhachistognathus primus Biozone
Idiognathodus obliquus
Neognathodus medexultimus
Streptognathodus cancellosus
Streptognathodus firmus
Neognathodus medadultimus
Neognathodus bothrops
Idiognathodus incurvus
Declinognathodus lateralis
Declinognathodus marginodosus
Idiognathodus primulus
Idiognathodus delicatus
Idiognathodus klapperi
Idiognathoides ineaqualis
Idiognathoides sulcatus parvus
Neognathodus atokaensis
Streptognathodus suberectus/anteeccentricus
Idiognathodus sinuosus
Hindeodus minutus
Idiognathodus parvus
Idiognathoides sinuatus
Adetognathus lauta
Adetognathus gigantus
Adetognathus spathus
Declinognathodus noduliferous
Rhachistognathus minutus minutus
Rhachistognathus muricatus
Rhachistognathus websteri
Rhachistognathus primus

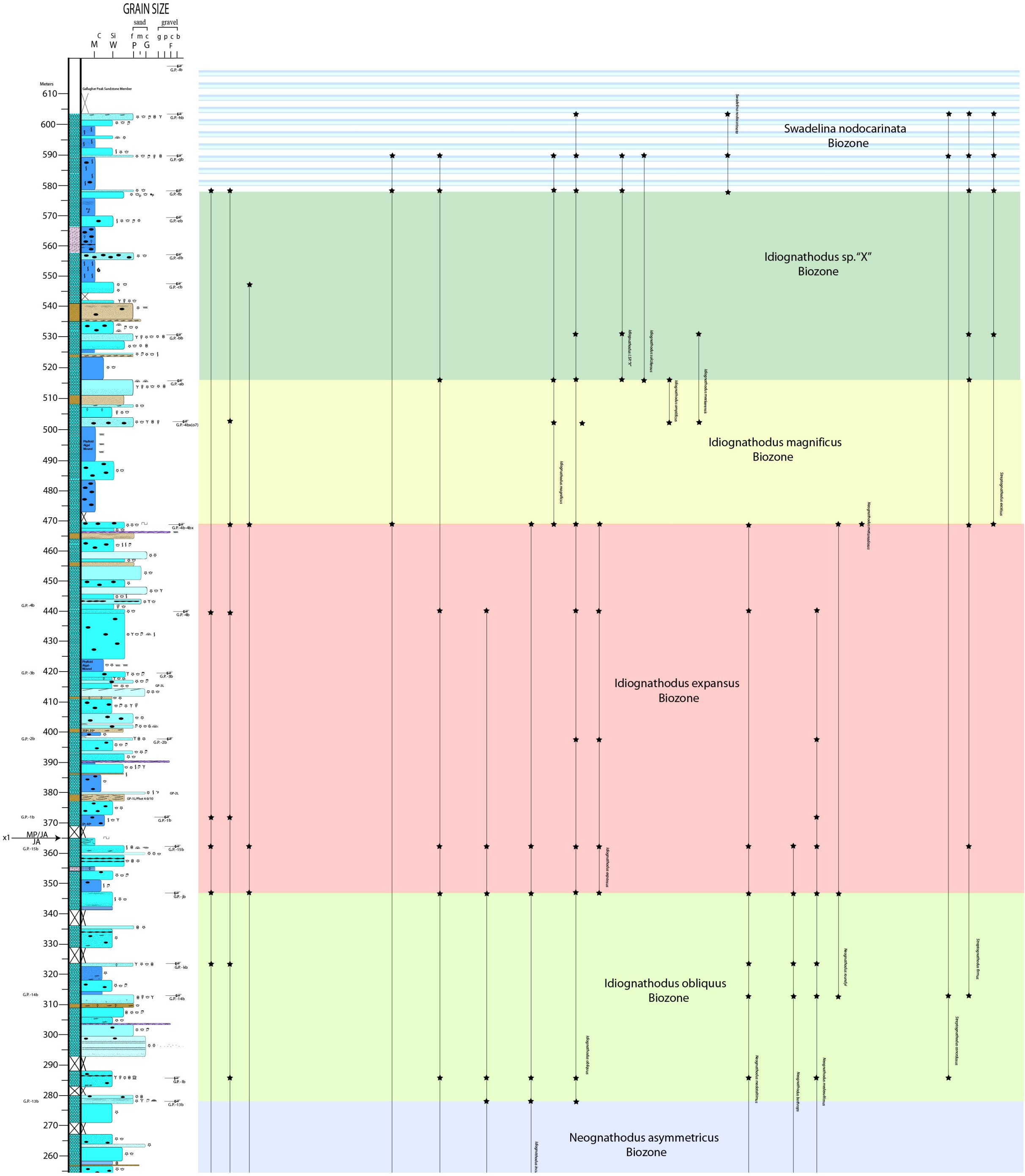
Hawley Mountain Section

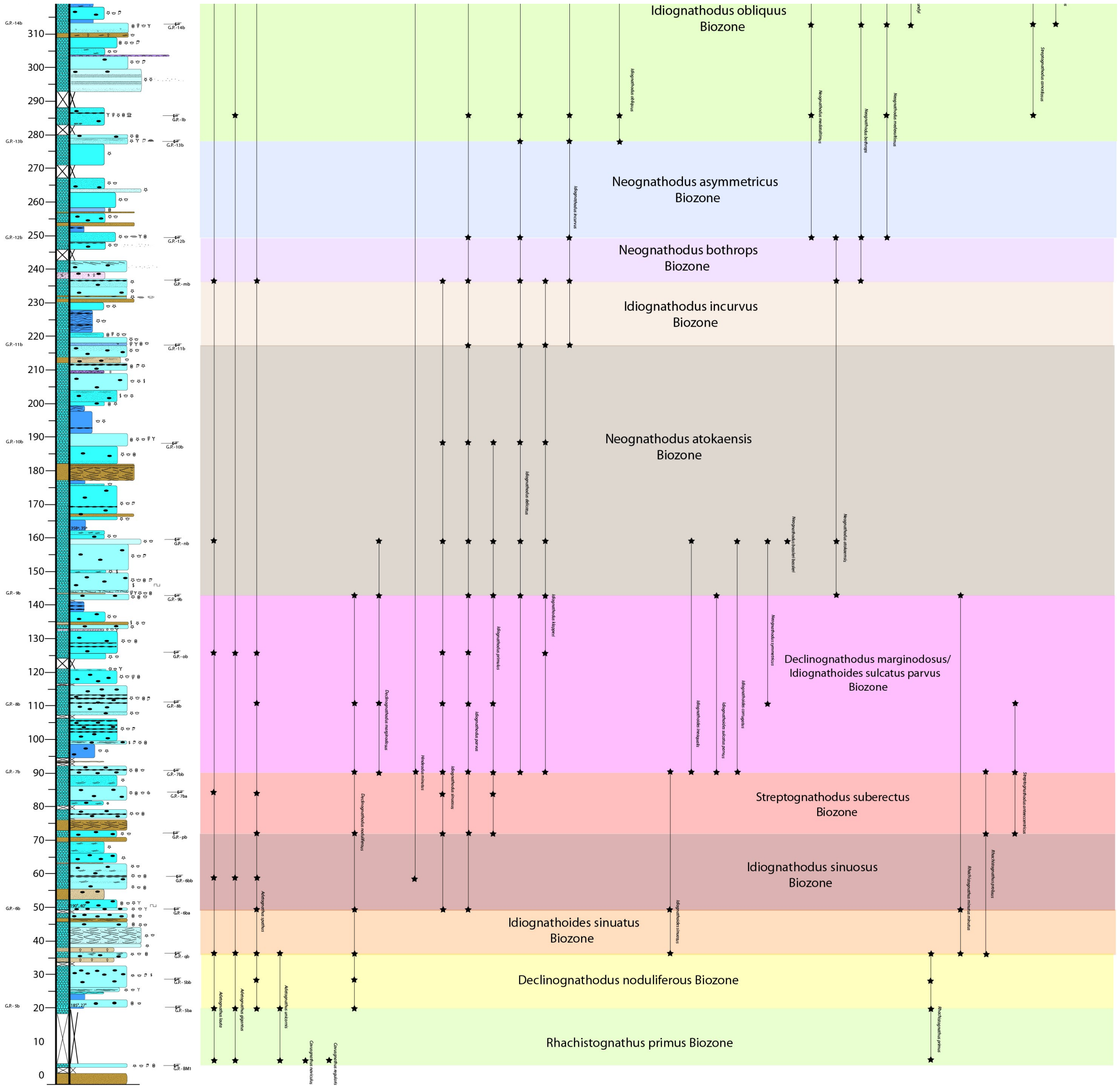


Unknown Canyon Section



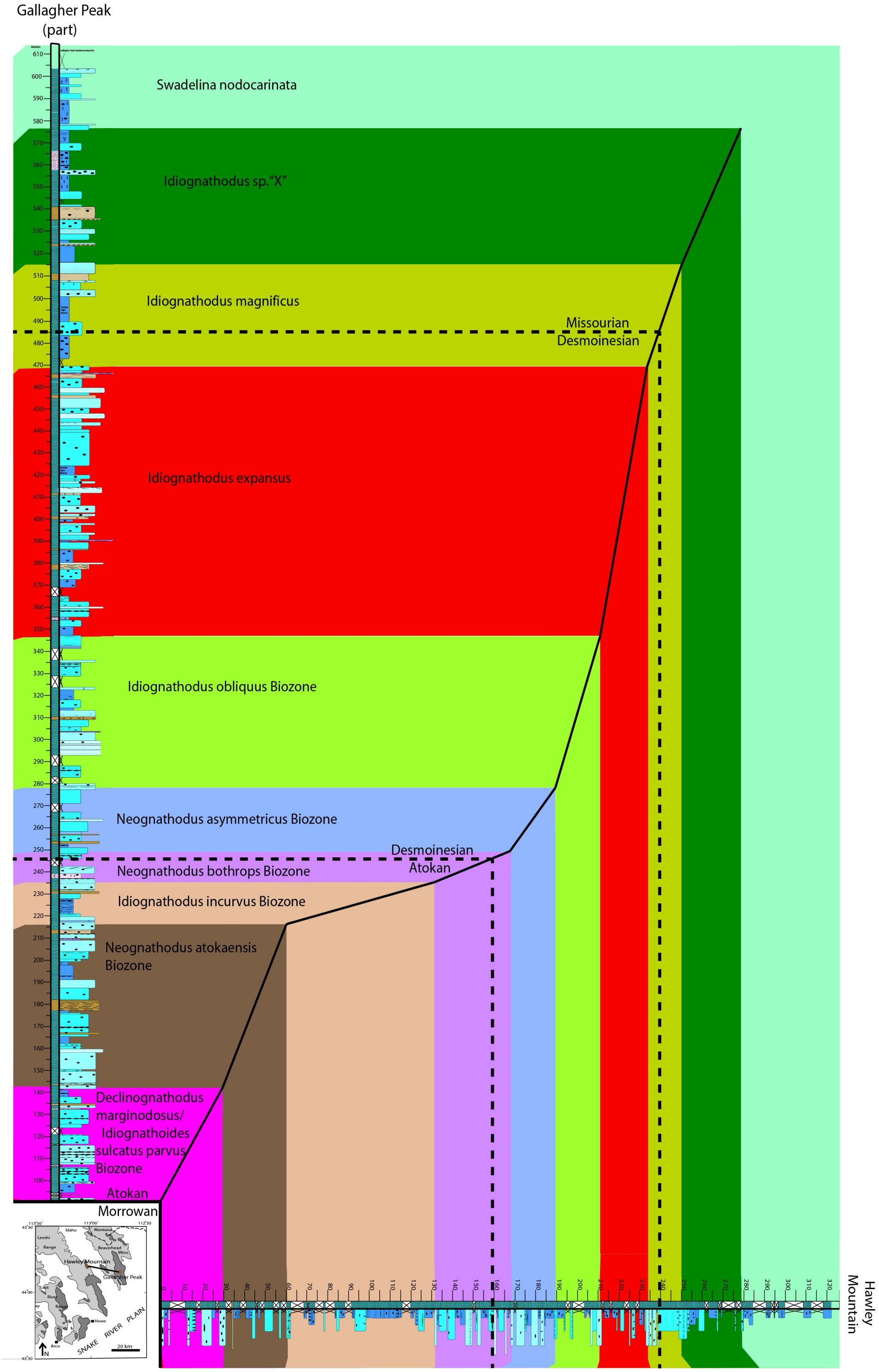
Gallagher Peak Type Section



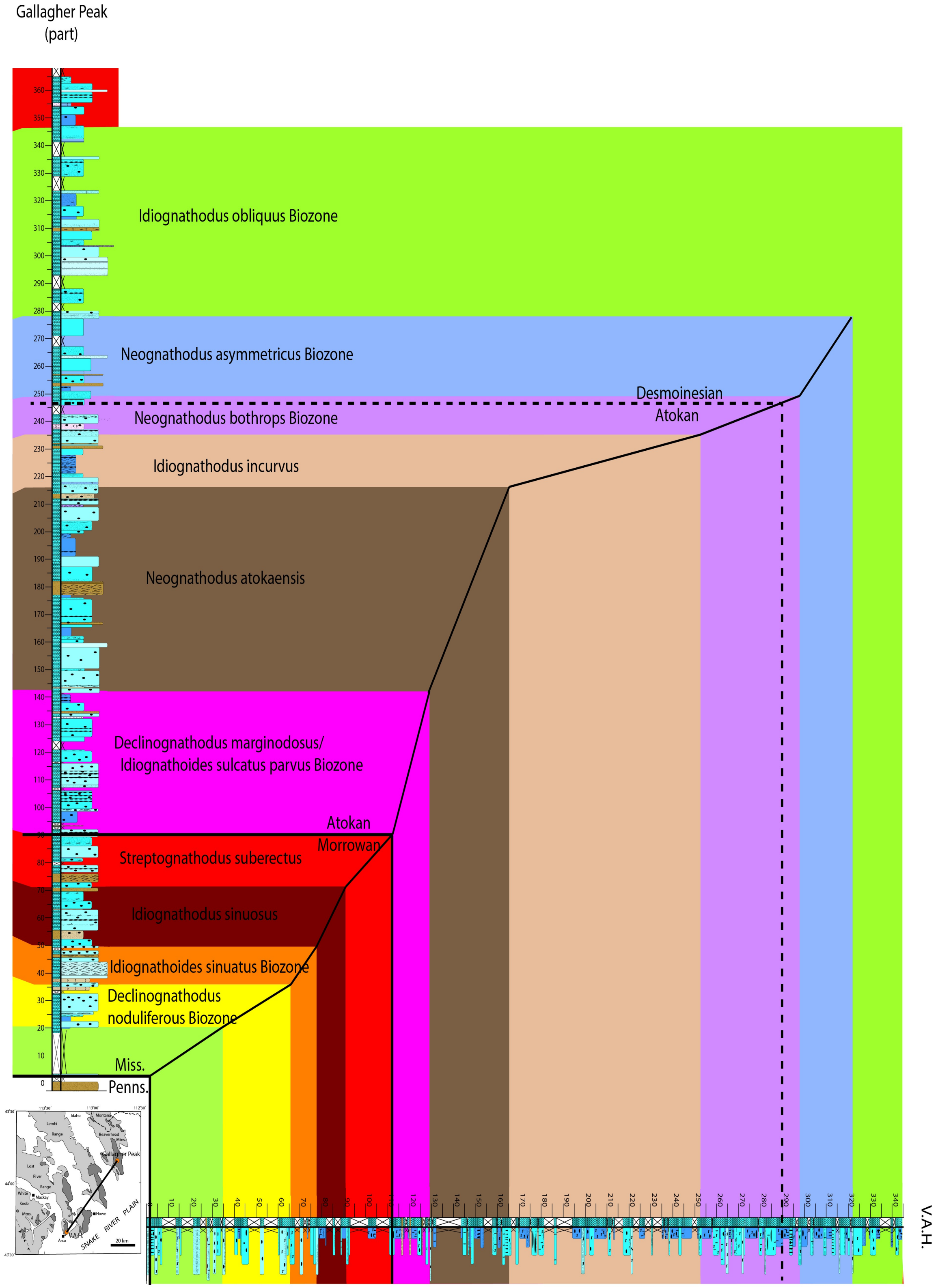

Idiognathodus obliquus Biozone
Neognathodus asymmetricus Biozone
Neognathodus bothrops Biozone
Idiognathodus incurvus Biozone
Neognathodus atokaensis Biozone
Declinognathodus marginodosus/ Idiognathoides sulcatus parvus Biozone
Streptognathodus suberectus Biozone
Idiognathodus sinuosus Biozone
Idiognathoides sinuatus Biozone
Declinognathodus noduliferous Biozone
Rhachistognathus primus Biozone
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
G.P.-14b
G.P.-13b
G.P.-12b
G.P.-11b
G.P.-10b
G.P.-9b
G.P.-8b
G.P.-7b
G.P.-6b
G.P.-5b

Appendix III: Shaw Depositional Diagrams

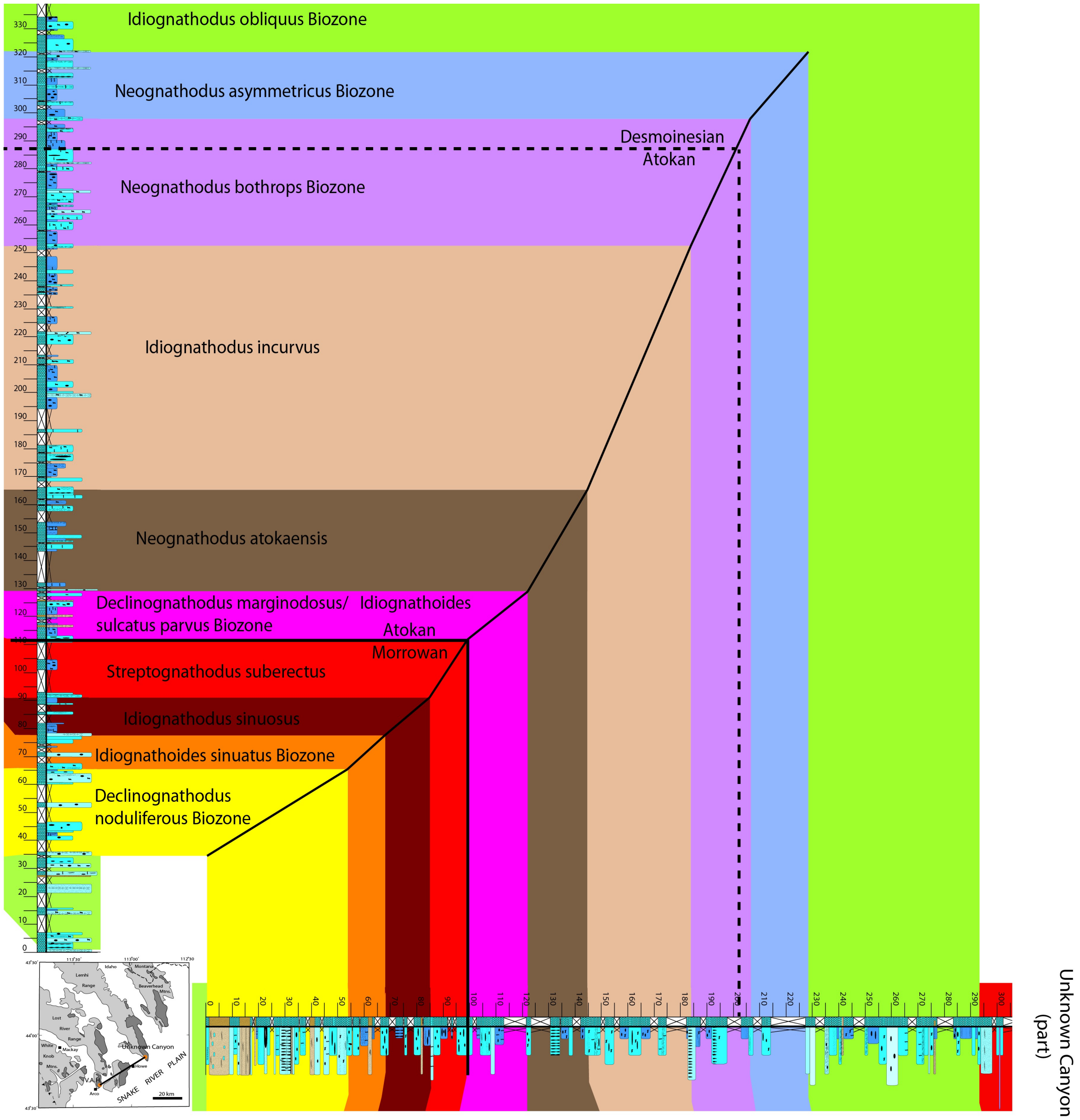
Gallagher Peak Type/Hawley Mountain



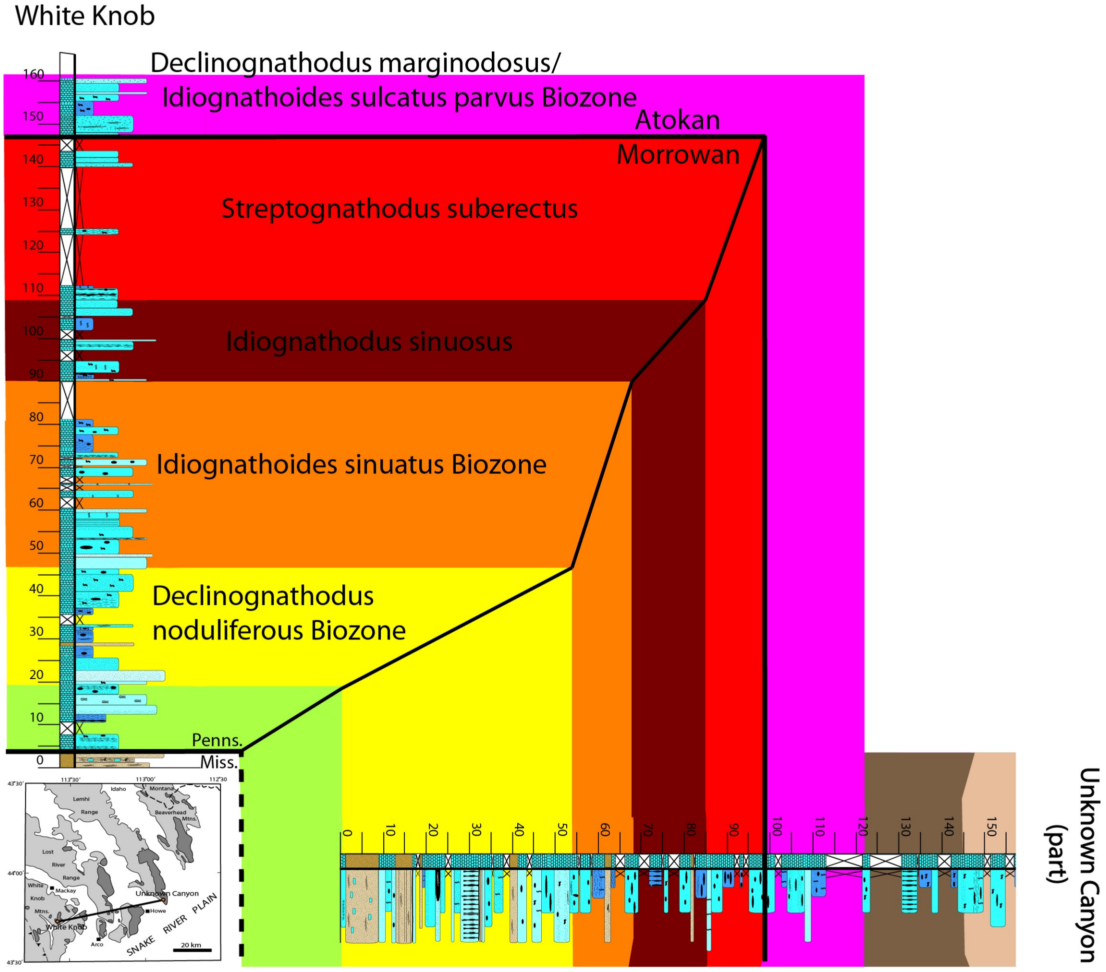
Gallagher Peak Type/VAH



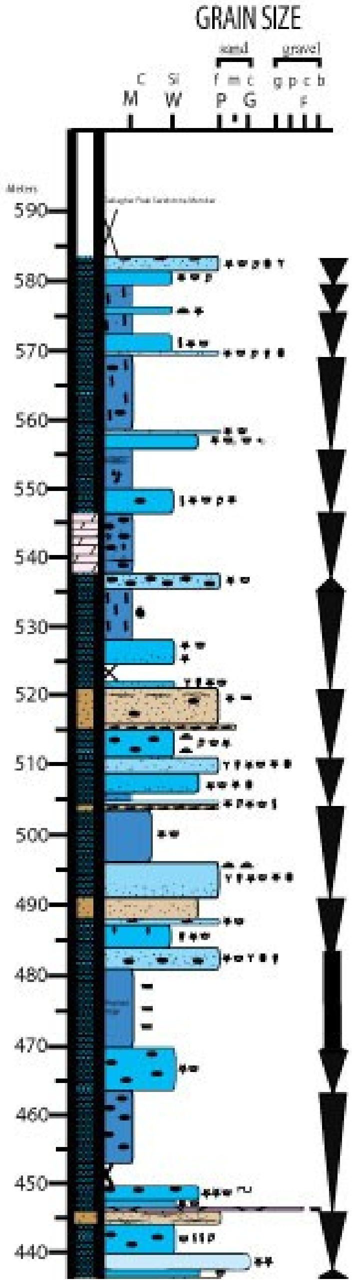
VAH/Unknown Canyon



White Knob/Unknown Canyon



Appendix IV: Parasequences of the Gallagher Peak Type Measured Section, Beaverhead Range


GRAIN SIZE
sand
gravel
C
Si
f m c
g p c b
M
W
P
G
F
Meters
590
580
570
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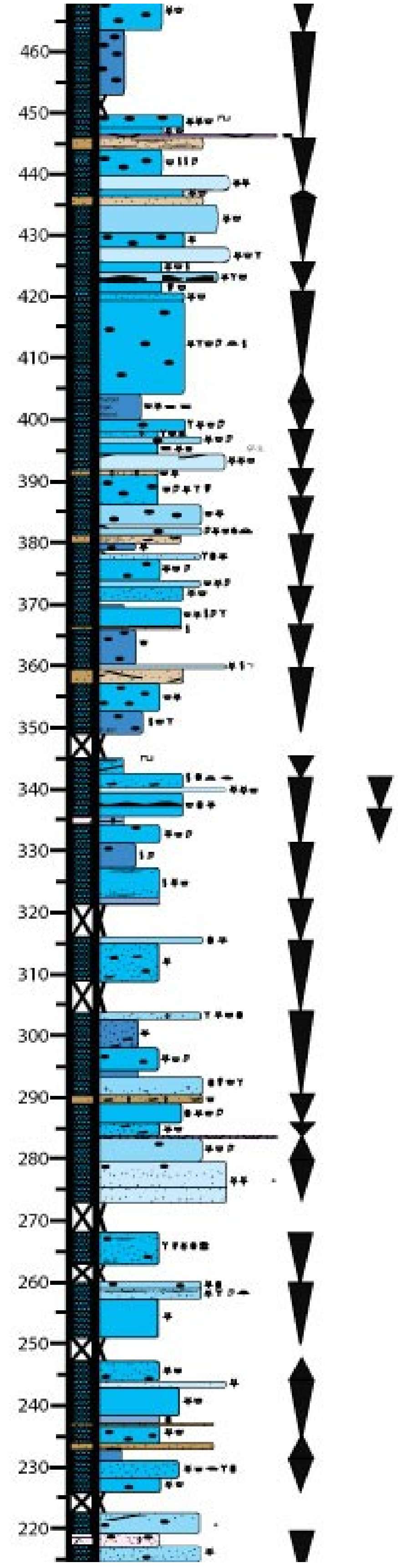
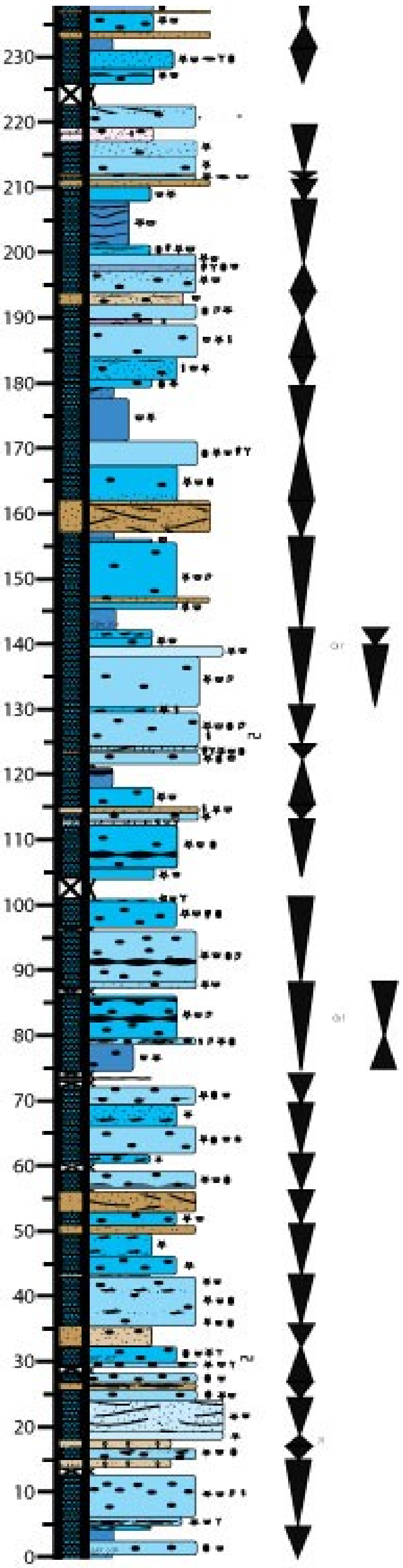
550
540
530
520
510
500
490
480
470
460
450
440


460
450
440
430
420
410
400
390
380
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220


230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

Appendix V: Photographs of Select Snaky Canyon Formation (Bloom Member) Depositional Facies at the Gallagher Peak Type Section

Plate 1: A) Fusulinid rich restricted peritidal carbonate, upper Bloom Member. B) Bioturbated restricted peritidal carbonate, middle Bloom Member. C) Marginal marine mixed carbonate/siliciclastic, middle Bloom Member. D) Skeletal subtidal mixed carbonate/siliciclastic, lower Bloom Member.

Plate 2: A) Skeletal subtidal mixed carbonate/siliciclastic, lower Bloom Member. B) Crossbedded marginal marine mixed carbonate/siliciclastic, upper Bloom Member. C) Encrinitic carbonate shoaling overlain by bioturbated subtidal mixed carbonate/siliciclatic. D) Near-shoaling skeletal subtidal packstone capped by carbonate hardground and overlain by whole megafauna rich deep subtidal wackestone, middle Bloom Member.

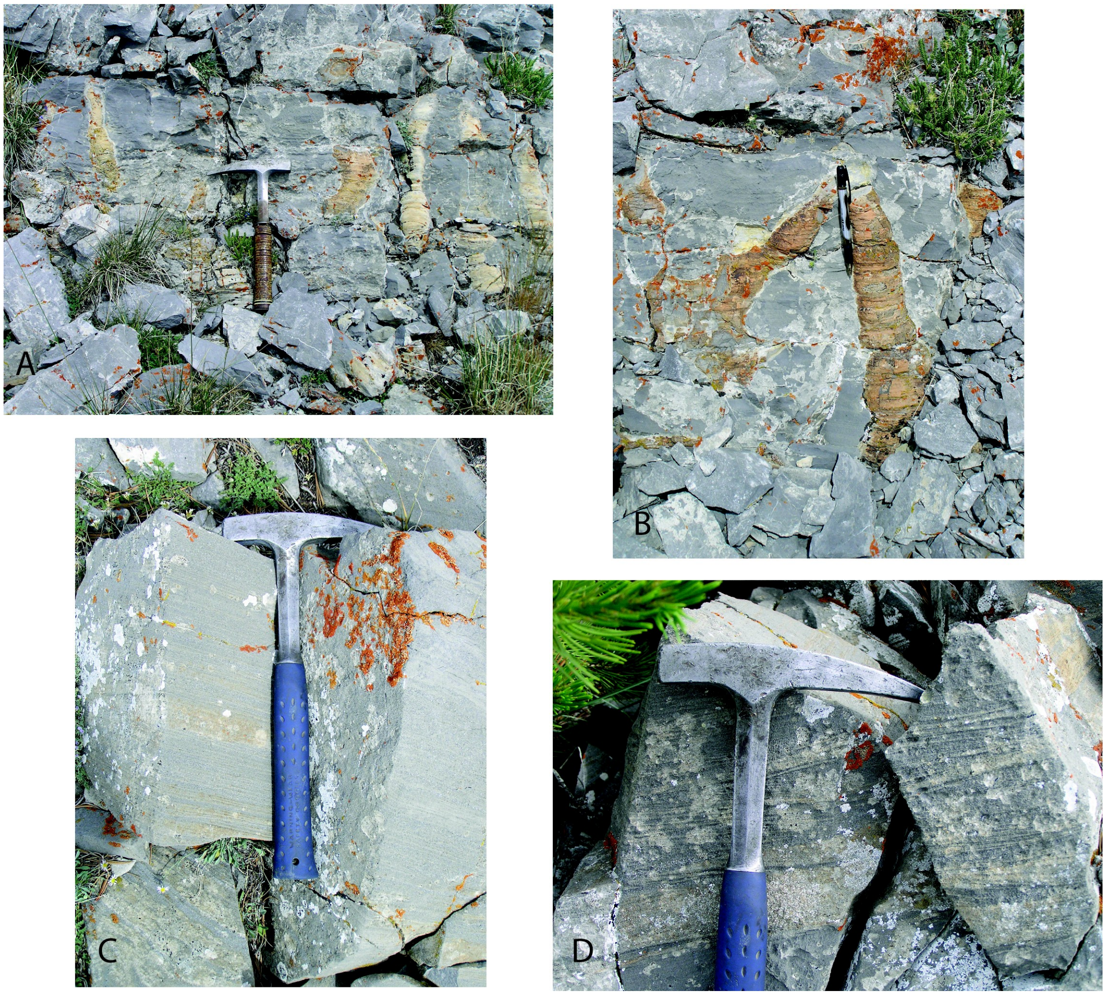


Plate 3: A) Bioturbated restricted carbonate, middle Bloom Member. B) Bioturbated restricted carbonate, middle Bloom Member. C) Crossbedded marginal marine mixed carbonate/siliciclastic, lower Bloom Member. D) Crossbedded marginal marine mixed carbonate/siliciclastic, lower Bloom Member.

Plate 4: A) Algal(?) buildup capped by mixed carbonate/ siliciclastic, middle Bloom Member. B) *Palaeoaplysina* bioherm, upper Bloom Member. C) *Palaeoaplysina* bioherm, upper Bloom Member. D) *Palaeoaplysina* bioherm, upper Bloom Member

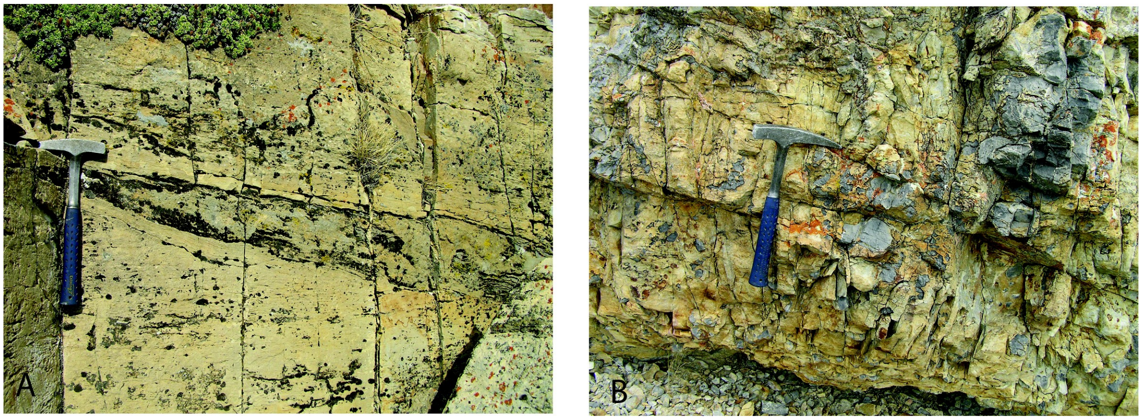
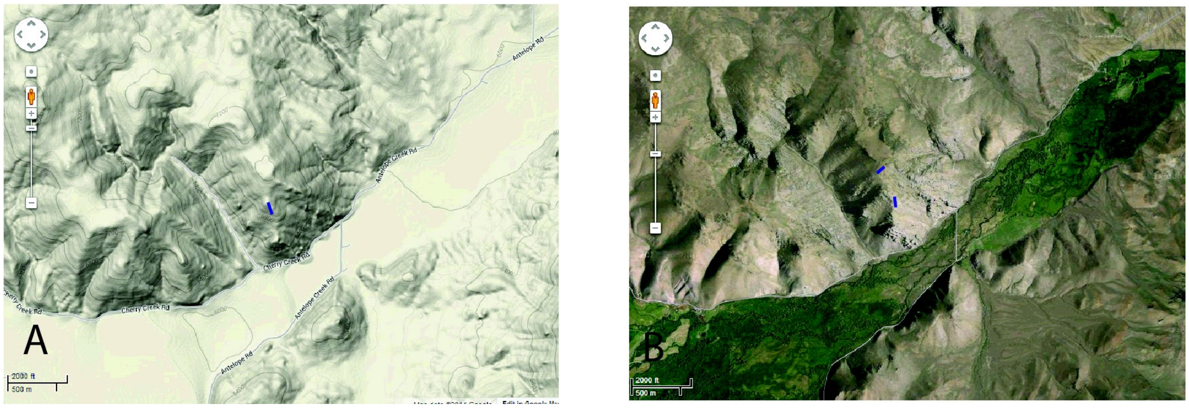


Plate 5: A) Crossbedded eolian fine grained sand with mixed carbonate/siliciclastic lens, upper Bloom Member. B) Bioturbated siliciclastic dominated marginal marine, lower Bloom Member.

Appendix VI: Map Locations of Measured Sections in East-Central Idaho

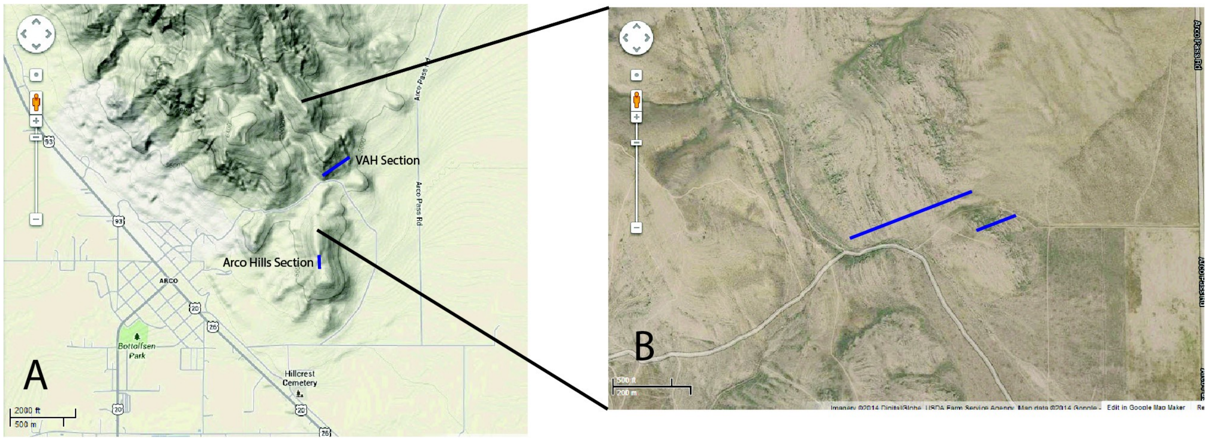
White Knob Measured Section



Map 1: White Knob measured section topographic (A) and satellite (B) maps. Blue lines indicate location of measured Snaky Canyon Formation.

White Knob measured section PLSS location:
E ½, NE ¼, Section 3, T4N, R28E

Arco Hills/VAH Measured Sections

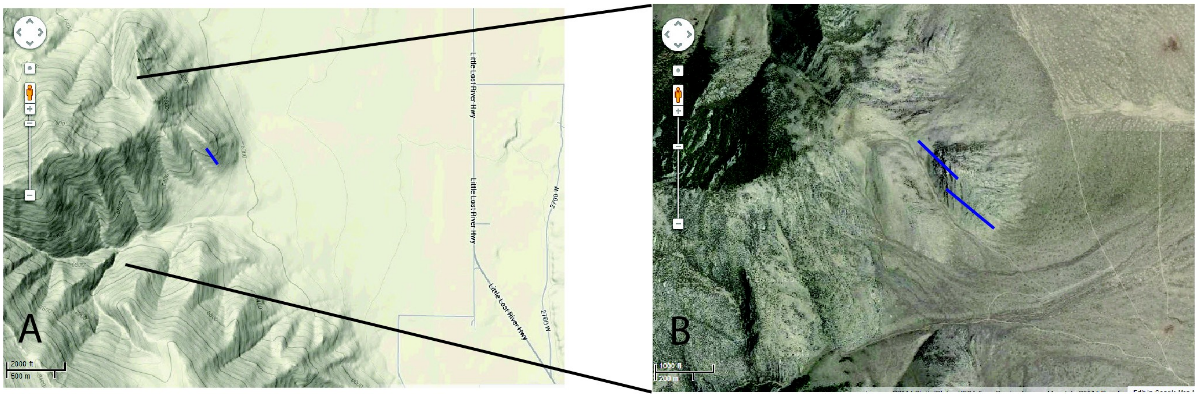


Map 2: Arco Hills and VAH measured sections topographic (A) and VAH section satellite (B) maps. Blue lines indicate location of measured Snaky Canyon Formation.

Arco Hills measured section PLSS location:
SW ¼, SE ¼, Section 30, T4N, R27E

VAH measured section PLSS location:
S ½, SW ¼, Section 30, T4N, R27E

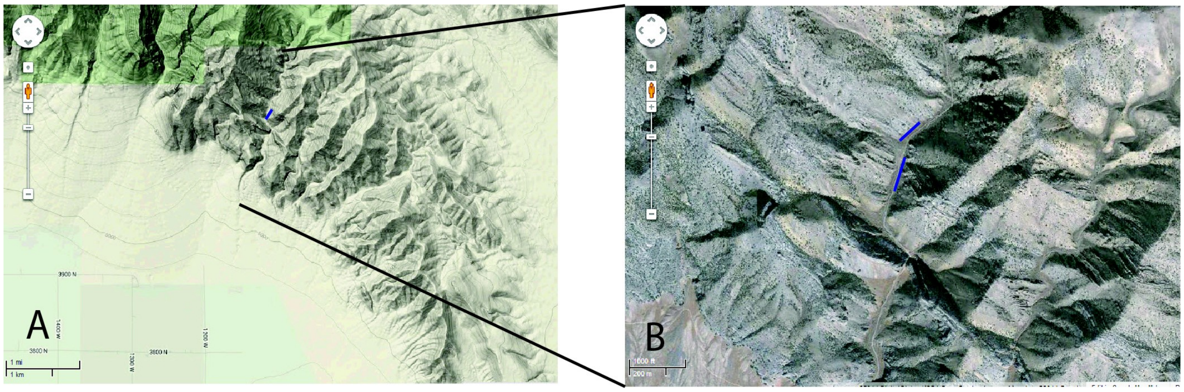
Hawley Mountain Measured Section



Map 3: Hawley Mountain measured section topographic (A) and satellite (B) maps. Blue lines indicate location of measured Snaky Canyon Formation.

Hawley Mountain measured section PLSS location:
SE ¼, NE ¼, Section 19, T9N, R27E

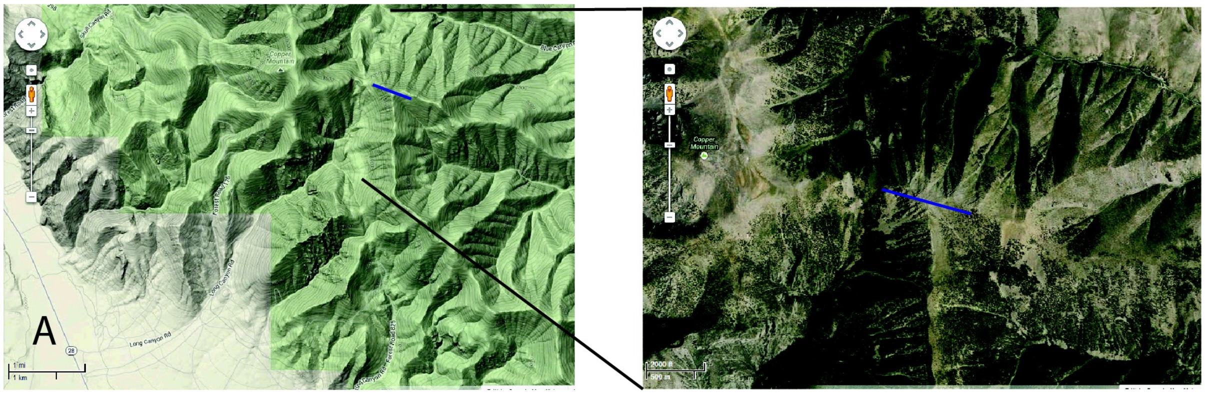
Unknown Canyon Measured Section



Map 4: Unknown Canyon measured section topographic (A) and satellite (B) maps. Blue lines indicate location of measured Snaky Canyon Formation.

Unknown Canyon measured section PLSS location:
SE ¼, SE ¼, Section 6, T6N, R30E

Gallagher Peak Measured Section



Map 5: Gallagher Peak type measured section topographic (A) and satellite (B) maps. Blue lines indicate location of measured Snaky Canyon Formation.

Gallagher Peak type measured section PLSS location:

Not surveyed: Located directly east of the SE ¼, SE ¼, Section 25, T10N, R30E

Appendix VII: Geologic Map of the Snaky Canyon Type Localities; Southern Beaverhead Range

Insert Map Folder Here