CHONDRICHTHYES FROM THE UPPER PART OF THE MINNELUSA FORMATION (MIDDLE PENNSYLVANIAN: DESMOINESIAN), MEADE COUNTY, SOUTH DAKOTA

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ABSTRACT

Numerous teeth, denticles, and scales of selachians and holocephalans have been recovered from an outcropping of the upper Minnelusa Formation in Meade County, South Dakota. Specimens include the denticles *Petrodus patelliformis* and *Listracanthus histrix,* the scale *Holmesella quadrata,* and teeth of *Caseodus* aff. *C. eatoni, Edestus* sp., cf. *"Cladodus"* sp., and *Janassa* sp. Associated conodont elements of *Idiognathodus "delicatus"* and *Idioprioniodus conjunctus* indicate a middle Pennsylvanian (Desmoinesian) age. A similar chondrichthyan assemblage has been reported from temporally equivalent rocks of Arkansas, Kansas, Missouri, Illinois, Oklahoma, and Iowa.

Keywords

Minnelusa Formation, Pennsylvanian, Chondrichthyes, South Dakota

INTRODUCTION

The material presented in this report was obtained during field trips conducted by the Department of Geology and Geological Engineering, South Dakota School of Mines and Technology, Rapid City, South Dakota. Matrix was collected to recover conodont fossils, although it had been known that fossil vertebrates occurred at the locality (Elder 1993). The outcrop is located on the north side of Little Elk Creek, approximately 2.5 km west of Piedmont, and approximately 30 km north of Rapid City (Fig. 1).

Fossils were recovered from green and gray silty shale referred to as the *Petrodus* II bed by Elder (1993) (Fig. 2). This shale occurs approximately 0.7 m above the *Petrodus* I bed (Elder 1993) and consists of 1-2.5 cm of light green

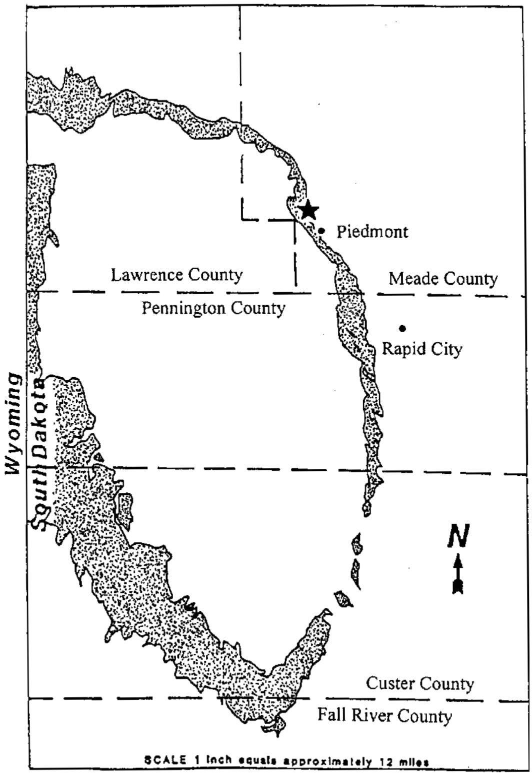

Figure 1. Generalized geologic map of the Black Hills region showing surface outcrops of the Minnelusa Formation (stippled area). The large star indicates the Little Elk Creek locality. Modified from Darton (1951) and Elder (1993).

shale underlying 10–15 cm of dark gray shale. The shale unit is slightly calcareous, blocky, and moderately indurated, becoming soft and fissile where weathered. The upper and lower contacts are wavy and irregular. Selachian fossils have been found throughout the green shale, with concentrations in depressions along the lower contact of the green shale and an underlying dolomite. Fossils appear to be less abundant in the overlying dark gray shale. The lower, irregular contact represents a disconformity between the shale and dolomite, and concentrations of fossils may represent a lag deposit. The light green color is due to secondary reduction of iron resulting from water movement through fractures and along bedding contacts. Unfortunately, the *Petrodus* II shale bed is now difficult to sample because weathering and previous collecting efforts for conodonts have resulted in the shale being removed up to 0.75 m into the outcrop, with the adjacent limestone and dolomitic limestone beds restricting access.

GEOLOGIC SETTING

Elder (1993) proposed that during periods of higher sea level, the remains of deceased animals fell to the bottom and were worked by higher energy currents, which would account for the lag deposit that is thought to be present at the base of the *Petrodus* II bed. However, the teeth and denticles do not show signs of abrasion that would be expected if they were subjected to such actions.

Based on associated lithologies, it is believed that the *Petrodus* shale beds were deposited under reducing conditions in a semi-restricted lagoonal environment, and in close proximity to tidal flats. The presence of delicate *Listra-*

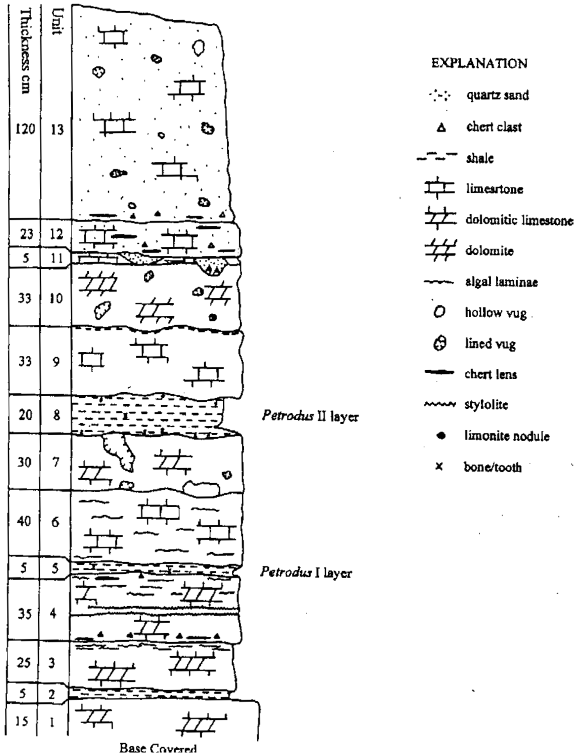

Figure 2. Stratigraphic section of a portion of the Minnelusa Formation exposed at Little Elk Creek, Meade County, South Dakota. See following for lithologic descriptions:

13) Limestone, 90-120 cm thick, with abundant coarse, rounded, quartz sand. Contains many hollow and calcite-lined vugs and boxwork structures. Thin chert lenses and sub-angular chert clasts occur near the base. Very irregular upper contact.

12) Limestone, 17.5-22.5 cm thick, light gray to brown, very fine-grained. Contains abundant chert lenses and sub-angular chert clasts; minor quartz sand. Flat upper contact.

11) Limestone, 5 cm thick, white to beige, very fine grained, chalky. Contains lenses of coarse, well-rounded sand and sub-angular chert clasts; some lenses cut into the subjacent unit. Moderately irregular upper contact.

10) Dolomite, 32.5 cm thick, light beige, medium- to coarse-grained. Contains abundant moldic texture and calcite-lined vugs to 20 cm diameter.

9) Limestone, 32.5 cm thick, white to whitish gray, very fine grained. Contains very fine moldic texture. A 0.5-1 cm thick green shale occurs along the irregular upper contact. Massive with angular, blocky weathering.

8) Shale and silty shale, 20 cm thick, black to gray with thin, reddish to maroon laminae and associated limonite nodules to 1 cm diameter, especially in the upper half. Fissile. Thin purple laminations also present. Lower 4 cm of unit is greenish yellow fissile shale, thickest in low spots along the irregular lower contact. Irregular, wavy upper contact. Equivalent to the *Petrodus* II bed of Elder (1993).

7) Dolomitic limestone, 7.5-30 cm thick, beige to tan, fine- to medium-grained. Contains moldic texture of crinoid columnals and brachiopod fragments. Lobate and irregular, hollow to calcite lined vugs to 30 cm diameter occur throughout. Irregular, wavy upper contact. Massive.

6) Limestone, 40 cm thick, beige to orange gray, very fine grained. Contains planar stromatolites with crenulated laminae weathering in relief. Irregular, wavy upper contact. Flaggy, angular weathering.

5) Shale, 5 cm thick, gray with purple staining. Moderately irregular upper contact. Fissile to flaggy weathering. Equivalent to the *Petrodus* I bed of Elder (1993).

4) Dolomitic limestone, 35 cm thick, upper half beige, lower half grayish white, very fine grained. Fine planar stromatolites occur in the upper half; lacks fine laminae in the lower half. Stylolite surfaces separate some beds. Thin orange chert lenses and sub-angular chert clasts occur along the moderately irregular upper and lower contacts.

3) Dolomitic limestone, 25 cm thick, beige to light tan, very fine grained. Fine planar stromatolites occur in the upper 5-7.5 cm. Upper contact moderately irregular.

2) Shale, 5 cm thick, gray with maroon staining. Fissile. Irregular upper contact.

1) Dolomitic limestone, 15 cm thick, gray with maroon staining, very fine-grained. Massive, dense. Moderately flat upper contact, lower contact covered.

canthus denticles and slightly disturbed conodont assemblages in the shale beds indicate very low energy conditions, with minimal current action or periods of quiescence. The fragile spines and conodont assemblages would not have survived intact if subjected to strong currents or reworking. The shale beds probably represent periods of very slow clastic deposition between cycles of carbonate deposition, possibly related to cyclothemic sequences or a maximum flooding episode during a highstand system tract.

METHODS

Matrix was disaggregated using a solution of 1% acetic acid in water. The concentrate was placed in water to remove calcium acetate residue, then screened through 5 mm, 3 mm, and 1 mm mesh sieves. The remaining material was dried and sorted through a binocular microscope. Specimens that had been broken were repaired with thinned Butvar (B-76 in acetone).

The classification scheme follows Zangerl (1981). All referred specimens are housed in the Bob Campbell Geology Museum (BCGM), Clemson Univer-

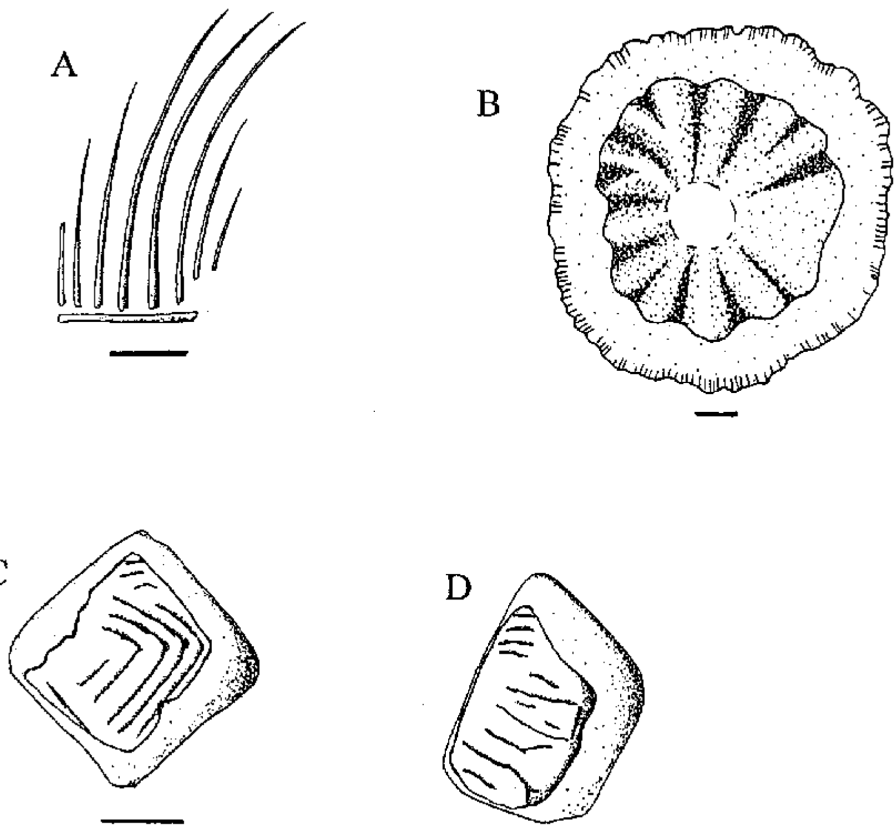

Figure 3. A: *Listracanthus histrix* denticle, BCGM 2935; B: *Petrodus patelliformis* denticle, BCGM 4425, dorsal view; C and D: *Holmesella quadrata* scales, BCGM 4747 and BCGM 4748, dorsal views with anterior at right. Scale lines = 1mm.

sity, South Carolina. Additional specimens are housed at the Museum of Geology (SDSM), South Dakota School of Mines and Technology. Precise sample locality information is on file at both institutions. The specimens are the property of the U.S. Forest Service.

SYSTEMATIC PALEONTOLOGY

Chondrichthyes Huxley, 1880
Holocephali Bonaparte, 1832-41
Cochliodontiformes Obruchev, 1953
Menaspidae Woodward, 1891
Listracanthus histrix Newberry and Worthen, 1870
Figure 3, A

Referred specimens: BCGM 2934, isolated denticle in matrix; BCGM 2935, isolated denticle in matrix.
Additional specimens: SDSM 26057, one denticle; SDSM 26058, one denticle with four associated *Petrodus.*
Description: BCGM 2934 and BCGM 2935 are compound denticles consisting of an elongate base supporting six or seven curved, needle-like spines arranged in a row, forming a comb-like structure. Both specimens are preserved as impressions on the matrix, with some of the original material remaining.
Discussion: Zangerl (1981) stated that *Listracanthus* is a common component of Upper Carboniferous rocks in the Midwestern United States, where it is often associated with *Petrodus.* Chorn and Reavis (1978) and Zangerl (1981) noted that *Listracanthus* and *Petrodus* denticles occurred on different types of chondrichthyans, and were therefore merely form genera. *Listracanthus*-type denticles were described by Patterson (1965) and Moy-Thomas (1936) as occurring on the dorsal surface of *Deltoptychius* (illustrated by Stahl 1999).

Euselachii Hay, 1902
Hybodontoidea Zangerl, 1981
Hybodontidae Owen 1846
Petrodus patelliformis M'Coy, 1848
Figure 3, B

Referred specimens: BCGM 2932, 170 incomplete denticles; BCGM 2933, 90 denticle fragments; BCGM 2950, 30 denticles; BCGM 4425, one denticle.
Additional specimens: SDSM 26051, one denticle; SDSM 26052, one denticle, SDSM 26053, 125 denticles.
Description: This type of denticle ranges in size from 2-11 mm in diameter, and 1–9 mm in height. They are circular to elliptical in outline. The crown of small to medium-sized denticles has a conical cross-section, pointed, smooth apices, and coarse radiating ridges that bifurcate basally. Larger denticles have fewer but more massive bifurcating ridges that coalesce at the apex, forming a large rounded surface. The base of the denticle extends outwards a short distance from the crown, and the attachment surface may be flat, weakly convex, or concave.

Discussion: According to Zidek (1973), North American occurrences of *Petrodus* were typically referred to *P. occidentalis*. When originally described, it was with some reservation that *P. occidentalis* was considered as being distinct from *P. patelliformis* M'Coy 1848 (Newberry and Worthen 1866). We assign the Minnelusa specimens to *P. patelliformis* because this specific designation has seniority over *P. occidentalis*.

Petrodus is the dominant vertebrate fossil at the Little Elk Creek locality. This type of denticle morphology is not necessarily unique to a single taxon, and for this reason Chorn and Reavis (1978) considered the generic designation a *nomen dubium*. *Petrodus*-like denticles were described by Patterson (1965) as occurring on the body of *Deltoptychius,* but Zangerl (1981) suggested that *Petrodus* was a single, very large taxon whose skin was covered exclusively with this type of denticle.

Chorn and Reavis (1978) described a mat of *Petrodus* (a cluster of articulated denticles) in which smaller denticles were intermingled with much larger ones, and the diversity in size of the denticles therefore does not necessarily indicate populations containing juvenile and adult individuals.

Protacrodontoidea Zangerl, 1981
Tamiobatidae Glickman, 1964
Holmesella quadrata Gunnel, 1931
Figure 3, C and D

Referred specimens: BCGM 2931, 8 scales; BCGM 4747, scale; BCGM 4748, scale.

Description: This type of scale typically has a rhombohedral shape, although one specimen having a hexagonal outline was collected. The long axis ranges from 2–4 mm and the short axis ranges from 1.5–3 mm. The height varies between one and two millimeters. The crown is very low, flat, or weakly concave, and highly ornamented with tubercles and/or longitudinal ridges. The base of the scale is much thicker and wider than the crown, having a convex basal surface. Concentric zonation is visible on the basal surface of some specimens.

Discussion: The scales described above are identical in morphology to scales of *Holmesella* in the collections of the Field Museum of Natural History (FMNH), Chicago (PF 2367). Zangerl (1981) noted that this type of scale is common in black carbonaceous shales of the Midwestern United States. Mertiniene (1999) described the histology of *Holmesella* as consisting of a primordial odontode surrounded by later odontodes. The odontodes are composed of mesodentine, whereas the base consists of acellular bone tissue.

As with *Listracanthus* and *Petrodus,* this type of scale may not be characteristic of any one selachian taxon and can be considered a form genus (Mertiniene 1999).

Eugeneodontida Zangerl, 1981
Edestoidea Hay, 1930
Edestidae Jaekel, 1899
Edestus sp. Agassiz, 1833
Figure 4, A

Referred specimen: BCGM 2938, symphyseal tooth with associated root fragment.

Description: The tooth has a very laterally compressed, labially inclined crown with nearly flat faces. Cutting edges have large, apically directed serrations that become finer toward the apex. These larger serrations are themselves more finely serrated. The root is fragmentary but appears to have been elongated, extending posteriorly.

Discussion: BCGM 2938 is part of a symphyseal tooth whorl, which was an unusual feature of several Paleozoic shark taxa (Zangerl,1981). The basal edge of the root of BCGM 2938 forms a sharp ridge that would sit in a dorsal groove in the root of the preceding tooth, a characteristic of some edestoid sharks (particularly *Edestus*) rather than agassizodontid sharks. When viewed anteriorly, agassizodontid symphyseal teeth are bifurcated basally (Zangerl 1981). BCGM 2938 is not as heavily serrated as specimens of *Edestus minor* and *E. heinrichi* in the FMNH collection (UC 2092 and UC 14345 respectively), but the weak serrations and small size probably reflects the anterior position of the tooth in the whorl (i.e. older part). Zangerl (1981) reported this taxon from Upper Carboniferous (Pennsylvanian) rocks of the United States, parts of Europe, and Russia.

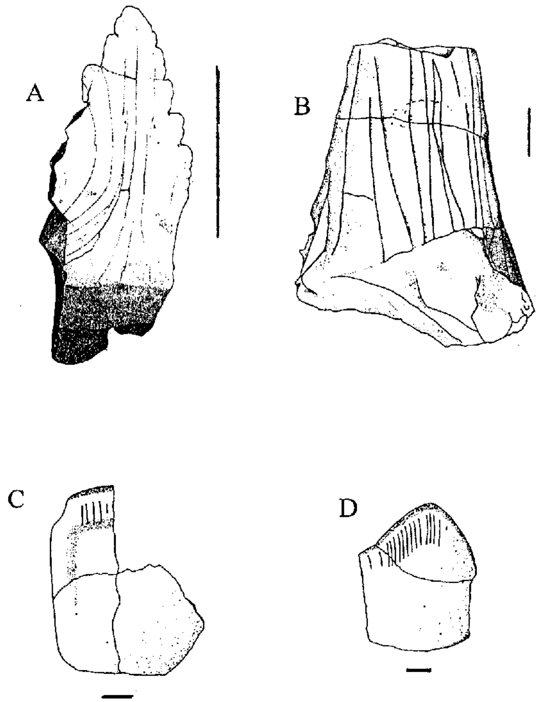

Figure 4. A: *Edestus* sp. symphyseal tooth, BCGM 2938, lateral view with anterior at right; B: cf. "*Cladodus*" sp. tooth fragment, BCGM 2936, lingual view; C: *Janassa* sp. incomplete tooth, BCGM 2940, labial view; D: *Janassa* sp. incomplete tooth, BCGM 2939, labial view. Scale lines = 1 mm in B-D, 5 mm in A.

Caseodontoidea Zangerl, 1981
Caseodontidae Zangerl, 1981
Caseodus aff. C. *eatoni* Zangerl, 1981
Figure 5, A - D

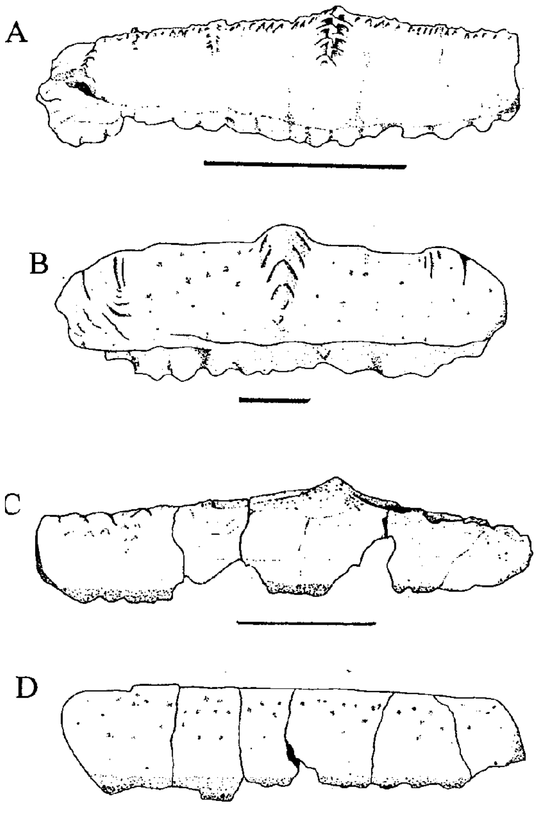

Figure 5. *Caseodus* aff. *C. eatoni* - A: BCGM 2493, incomplete anterior tooth, lingual view; B, BCGM 2944, anterior tooth, lingual view; C, BCGM 2946, incomplete lateral tooth, lingual view; D, BCGM 2948, posterior tooth, lingual view. Scale lines = 5 mm in A and C, 1 mm in B and D.

Referred specimens: BCGM 2942, 16 tooth fragments; BCGM 2943, incomplete anterior tooth; BCGM 2944, incomplete anterior tooth; BCGM 2945, incomplete anterior tooth; BCGM 2946, lateral tooth; BCGM 2947, incomplete lateral tooth; BCGM 2948, incomplete posterior tooth, BCGM 2949, incomplete posterior tooth.

Description: Anterolateral teeth are mesiodistally elongated with low crown. There is a central cusp, as well as one or two indistinct lateral cups. The labial crown face is convex, the lingual face is flat to convex, with crenulations occurring on both the labial and lingual faces. Large longitudinal protuberances are found on the labial face, with corresponding smaller protuberances on the lingual face. An unserrated cutting edge is continuous along the entire mesiodistal width of the crown, with smaller transverse cutting edges extending out onto the labial and lingual buttresses. An unusual feature is the alternating nature of short vertical ridges that are perpendicular to the cutting edges (see Fig. 5A). The ends of the crown are rounded and there is a weak central bulge on the labial face.

Lateral teeth are similar to anterior teeth except that the main cusp is lower, situated more distally on the crown, and distally inclined.

Posterior teeth are very small, having a very low, straight crown with rounded ends. There are no cusps, and the cutting edge is unserrated and straight across the crown. The labial and lingual crown faces are only slightly convex, and crenulation is much reduced. Labial protuberances are only weakly developed, and lingual protuberances are nearly absent.

Though roots are incomplete, they are nearly as long as the crown, labio-lingually compressed, with numerous vertical ridges and grooves.

Discussion: Unfortunately all of the teeth are incomplete, making precise taxonomic assignments difficult. However, they are similar to several eugeneodontid genera, namely *Agassizodus, Bobbodus, Campodus,* and *Caseodus.* In *Agassizodus,* the crowns are arched (Zangerl 1981, Case 1982), which is a feature not seen in the teeth of our sample. The Minnelusa specimens have smaller labial buttresses, and the vertical ridges on the cutting edge are stronger than in *Bobbodus* (Zangerl 1981, Schultze and West 1996). In *Campodus,* the labial and lingual buttresses are nearly the same size, giving the teeth a symmetrical appearance in occlusal view (Zangerl 1981). The teeth in our sample have much larger labial buttresses compared to those on the lingual face. Based on these comparisons, we assign our specimens to the genus *Caseodus.*

Of the two species, *Caseodus eatoni* and *C. basalis*, the large lateral teeth in our sample compare most closely with the ornamented teeth of *C. eatoni.* Both taxa are known from the Desmoinesian Series and could theoretically occur together (Zangerl 1981). However, we regard the smaller, simpler teeth in our sample as distal lateral and posterior teeth of *C. eatoni,* rather than *C. basalis.*

Petalodontida Zangerl, 1981
Janassidae Munster, 1839
Janassa sp.
Figure 4, C and D

Referred specimens: BCGM 2939, incomplete tooth; BCGM 2940, incomplete tooth; BCGM 2941, incomplete tooth.

Description: The teeth are very labio-lingually compressed with a weakly convex labial face and slightly concave lingual face. There may be some lingual flexure of the crown. The cutting edge is smooth and weakly to strongly convex. Fine longitudinal striations are found on the lingual face, and there are very short longitudinal grooves on the labial face that are restricted to an area just below the cutting edge.

Discussion: Schaumberg (1979) presented a ray-like reconstruction of *Janassa,* with a ventral mouth and large, expanded pectoral fins. Zangerl (1981) reported *Janassa* from Permian rocks of Germany and Greenland, and documented a Mississippian to Permian range for the taxon in the United States and Britain. The teeth in our sample compare favorably with those of *Janassa bituminosa* figured by Case (1982) from Upper Pennsylvanian rocks of Nebraska. However, with such a small sample size (n=3) and incomplete specimens, we hesitate to make a more specific identification.

Symmoriida Zangerl, 1981
cf. *"Cladodus"* sp.
Figure 4, B

Referred specimens: BCGM 2936, incomplete central cusp; BCGM 2937, incomplete tooth.
Additional specimens: SDSM 26054, tooth base with two tooth fragments; SDSM 26055, incomplete tooth.
Description: BCGM 2936 is an incomplete central cusp having a nearly flat labial face and very convex lingual face. The lower portion of the labial face possesses very fine longitudinal striations, whereas coarse striations extend nearly the entire height of the lingual face. Cutting edges are smooth.

BCGM 2937 is a tooth fragment preserving part of the root and the bases of two lateral cusplets. The cusplets have an elliptical cross-section and several longitudinal striations on the labial face. The root is shelf-like and extends lingually beyond the lateral cusplets.
Discussion: Zangerl (1981) considered *Cladodus* a *nomen dubium* because several distinct Paleozoic shark taxa possessed a cladodont dentition. Our specimens are so fragmentary that it is difficult to make even a generic identification.

DISCUSSION

The present chondrichthyan assemblage of the Minnelusa Formation consists of at least seven taxa including *Listracanthus, Petrodus, Holmesella, Edestus, Caseodus, Janassa,* and *"Cladodus".* We have also found small fragments of fin spines that are distinctly channeled and could be referrable to *Acondylacanthus* St. John and Worthen, 1875 or *Ctenacanthus* Agassiz, 1835. More complete material is needed for a precise taxonomic assignment. Elder (1993) illustrated a tooth that was tentatively identified as *Cranodus.* Unfortunately the specimen could not be located, and the illustration is not clear enough to confirm the identification.

Semi-articulated conodont assemblages and the good preservation of delicate *Listracanthus* denticles indicate that deposition of the *Petrodus* II bed took place in relatively quiet water. The apparent lag deposit at the base of this bed may be due to scouring or dissolution of the underlying dolomite beds during an initial transgression, followed by very slow deposition of fine-grained sediment and selachian remains as sea level rose. The sandstone-shale-carbonate "cycles" at the Little Elk Creek locality may be related to widespread cyclothemic deposition occurring during the Pennsylvanian. Conodants associated with the chondrichthyan remains, such as *Idioprioniodus conjunctus, Neognathodus roundyi-dilatus plexus*, and *Idiognathodus "delicatus"* morphotypes, indicate a Middle Pennsylvanian, middle to late Desmoinesian age (Rowe and Fox 1997).

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