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# Paleontology of Crow Creek Member, Upper Cretaceous (Campanian) Pierre Shale, South Dakota: impact-induced tsunami or basal transgressive deposit?

## Background

Meteorite impacts and their effects are gaining recognition as an important process in Earth's history. Although impact craters, the direct evidence for an impact, are common throughout the solar system, few Earthly craters are well-documented due to weathering and resurfacing processes. For this reason, impact geology is evolving to identify the traces of impacts as an alternative to crater exploration (Simonson and Glass, 2004). An analogy to help recognize trace-impacts can be drawn from existing craters including the Manson Impact Structure (MIS), north-central Iowa. The MIS is thought to have caused a regional tsunami in the Late Cretaceous (Campanian) Western Interior Seaway. The adjacent Crow Creek member of the Pierre Shale has been hypothesized as this impact-induced tsunami deposit because of its chronological link with the MIS, abundance of shock-metamorphosed mineral grains, graded lithology, hummocky cross-bedding, and reworked fossil assemblage (Izett *et al.*, 1998). This study is designed to test the tsunami-deposit hypothesis as well as an alternative hypothesis that the Crow Creek member is a basal transgressive deposit for the Bearpaw eustatic sea-level cycle in the Western Interior Seaway.

The Manson Impact Structure (MIS) is a 35 km diameter crater covered by 30-70 m of glacial till near Manson, IA. MIS coring led to subsequent radiometric analyses that dated the MIS to 74.1 ± 0.1 Ma using laser total-fusion $^{40}Ar/^{39}Ar$ of sanidines within melt layers (Izett *et al.*, 1998). A unique paleomagnetic signature was noticed within the MIS places it at the end of Chron 33N or Chron 32R polarity events (Steiner and Shoemaker, 1993). Upper Cretaceous strata have been found in cores taken within the structure, including undifferentiated Pierre Shale (Anderson and Witzke, 1994). Erosion of the Western Interior Seaway's eastern margin causes an indeterminable environment in which the impact collided with. At any rate, the impact is likely to have caused a regional tsunami based on MIS proximity to the Interior seaway (Steiner and Shoemaker, 1996). MIS distal impact ejecta including shock-metamorphosed mineral grains, altered tektites, and possible tsunami deposits were discovered in the adjacent Crow Creek member of the Pierre Shale (Izett *et al.*, 1993).

The 1-3 m thick light gray, chalky Crow Creek member lies between black mud-rock of the Pierre Shale making the Crow Creek an excellent stratigraphic marker. The distribution of the Crow Creek member is confined to eastern South Dakota and northeast Nebraska with numerous outcrops along the Missouri River and tributaries between Pierre, SD and Sioux City, IA (Fig 1; Crandell, 1950; Mendenhall, 1952). In eastern South Dakota, lower Crow Creek is poorly sorted siltstone that quickly fines up to brownish-orange marl composed mostly of calcareous nannofossils (Hammond *et al.*, 1994). Farther west, however, the siltstone is replaced by thicker cross-bedded calcarenite (Izett *et al.*, 1993). Shocked-metamorphosed minerals and sand-sized grains appear in the siltstone unit and decrease in abundance with greater distances from the MIS (Izett *et al.*, 1993, 1998).

After the discovery of impact ejecta, multiple analyses aimed to accurately date the Crow Creek member investigated its relation to the MIS. Izett *et al.* (1998) radiometrically dated Pierre Shale bentonite layers surrounding the Crow Creek member giving a range between 73.8 ± 0.3 Ma and 74.5 ± 0.1 Ma. This member also shows the same unique polarity signature as the MIS (Steiner and Shoemaker, 1993). Pierre Shale ammonite biostratigraphy puts the member in the *D. nebrascense* zone (Izett, 1998). Nannofossil species *T. phacelosus* and *A. parcus constrictus* within the marl unit are indicative of Perch-Nielson's (1985) CC23a nannofossil zone (Hammond *et al.*, 1994). All chronologic analyses place Crow Creek deposition within the 74.1 ± 0.1 Ma Campanian age given for the MIS (Fig 2; Izett *et al.*, 1998). This chronologic link and its unique lithology strongly suggest that the Crow Creek member is coincident with the MIS. The Crow Creek member could be a rare tsunami deposit easily accessible and identifiable in outcrop.

However, there is insufficient evidence to discard the member as a transgressive deposit with an MIS sediment source. This member appears stratigraphically similar to transgressive deposits of older Upper Cretaceous eustatic cycles along the interior seaway's eastern margin suggesting the sub-Crow Creek unconformity is the base of the Bearpaw eustatic sea-level cycle (Fig 3). Seaway lowstands between Bearpaw/Claggett, Claggett/Niobrara, and

Niobrara/Greenhorn eustatic cycles apparently eroded the eastern shore, and rising sea level deposited coarser material followed by finer material (Hammond *et al.*, 1994; Witzke *et al.*, 1996). Furthermore, the basal Crow Creek unconformity (Bearpaw/Claggett) correlates to the Judith River progradation along the interior seaway's western margin, much like the Claggett/Niobrara unconformity correlating to the Milk River progradation (Fig 4; Witzke *et al.*, 1996). The Crow Creek member may be stratigraphically correlated to older transgressive deposits, thus testing this hypothesis is vital to understanding the stratigraphy of the interior seaway's eastern margin.

To support the transgressive deposit hypothesis, a significant time interval is needed to explain an apparent faunal change from foraminifera to radiolarians upward through the Crow Creek member (Witzke *et al.*, 1996). Kastens and Cita (1981) noted a similar upward change from large foraminifera to small nannofossils in deep sea sediments cored from the Mediterranean Sea floor. Supported by Cita and Aloisi, (2000), Kastens and Cita (1981) concluded that these "homogenites" were deposited by gravitational settling after a tsunami ripped up the sea floor triggered by the explosion of the Santorini caldera (3.5 Ka). This similarity poses a question whether the Crow Creek member is a lithostratigraphic unit or was deposited by gravitational settling, possibly after turbid tsunami currents.

Hammond et al. (1994) noticed two distinct nannofossil assemblages. A Late Campanian autochthonous nannofossil assemblage unique to the Crow Creek member was discovered through the presence of *Reinhardtites levis*, *Aspidolithus parcus constrictus*, and *Tranolithus phacelosus*. An allochthonous assemblage with species extinct before Crow Creek deposition was differentiated by *Marthasterites furcatus*, *Lithastrinus grillii*, *Reinhardites anthophorus*, and *Seribiscutum primitivum*. The allochthonous assemblage, assumed to be reworked Niobrara Chalk based on Late Cretaceous biostratigraphy and the unique floral elements of the Niobrara, is concentrated at the base of the Crow Creek member and decreases upward, suggesting that the allochthonous assemblage deposited as rock instead of individual nannofossils (Fig 5; Hammond *et al.*, 1994). Unpublished data suggests that this stratigraphic distribution of the allochthonous assemblage may change with respect to distance from MIS. Further investigation of the allochthonous assemblage can be used to define the sedimentation model.

**Research**

This study is designed to collect paleontologic data to test the two Crow Creek hypotheses. For the tsunami-deposit hypothesis, this data will be compared to the tsunami deposits triggered by the Holocene explosion of Santorini (Cita and Aloisi, 2000). The member's similarity to older transgressive deposits warrants a data comparison to basal transgressive deposits of older, Late Cretaceous eustatic cycles. To test these hypotheses, this study aims to:

- Investigate the **stratigraphic size distribution of foraminifera and radiolarians** upward through the Crow Creek member. If the observed assemblage is due to gravitational settling after turbid tsunami currents resembling the Santorini tsunami deposits large foraminifera will constitute the base, decrease in size upward through the member, yielding to large radiolarians decreasing in size (Cita and Aloisi, 2000). If the observed assemblage is due to a faunal change, the assemblages will show a random size distribution.
- Investigate the **stratigraphic and proximal-to-distal distribution of reworked calcareous nannofossils** assumed to be Niobrara Chalk. The discovery of Niobrara chalk in Crow Creek would help validate the assumption. This assemblage will be used as a proxy for reworked sediment to define the sedimentation model. The tsunami-deposit model supposes the reworked nannofossils, acting as rock, will settle before *in situ* nannofossils. This translates to a gradual proximal-to-distal and stratigraphic decline of reworked nannofossils to be indicative of a high-energy tsunami deposit. The transgressive-deposit model postulates a gradual influx of reworked sediment until the supply is cut off. This converts to a gradual increase of reworked nannofossils followed by a sharp reduction implying a transgressive deposit.
- **Compare Bearpaw/Claggett, Claggett/Niobrara, and Niobrara/Greenhorn eustatic cycle unconformities** to assess the Crow Creek member as the Bearpaw basal transgressive deposit. If so, the lithology and stratigraphy will appear similar between these three unconformities.

**Methods**

An extensive field survey in central and eastern South Dakota will visit numerous outcrops to observe Pierre Shale stratigraphy (Fig 1). A minimum of six sites will be chosen to collect samples from the Crow Creek member at 10-cm increments. Sampling cores, stored in Vermillion, SD, will provide nicely preserved specimens without the weathering found in outcrop. The samples will be used for foram/radiolarian size and nannofossil count analyses.

- Foram and radiolarian size analysis will utilize 125, 63, 38, and 25-μm sieves to find size percentages in each sample for comparison with other samples within the section.
- Nannofossil count analysis will be based on autochthonous and allochthonous per random 500 species in each sample. Again, sample counts will be compared with other samples within the section. The double-slurry slide preparation method will provide adequate flocculation reduction for count and statistical analyses.
- Both analyses will be compared in a proximal-to-distal distribution using the spatial relationship between the six sampled sections.

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## Figure Captions

FIGURE 1: Location of Crow Creek outcrops (stars and lettered) published by Crandell, 1950, 1952; Tourtelot, 1962; Schultz, 1965; Bretz, 1979; and Izett *et al.*, 1993. Stars with bold names are favorable sampling areas for this study. The names and location of cores stored in Vermillion, SD are also noted (©). Outcrop names: A, Lake Marindahl; B, House of Mary Shrine; C, Crofton; D, Tabor; E, Devils Nest; F, Verdigree; G, Verdel; H, Wagner; I, Rising Hall; J, Fort Randall Creek; K Wheeler Bridge; L, Wetstone Creek; M, Landing Creek; N, Iona; O, Elm Creek; P, Crow Creek; Q, Fort Thompson; R, Lower Brule; S, DeGrey; T, Pierre; U, Fort Pierre (modified after Steiner and Shoemaker, 1996).

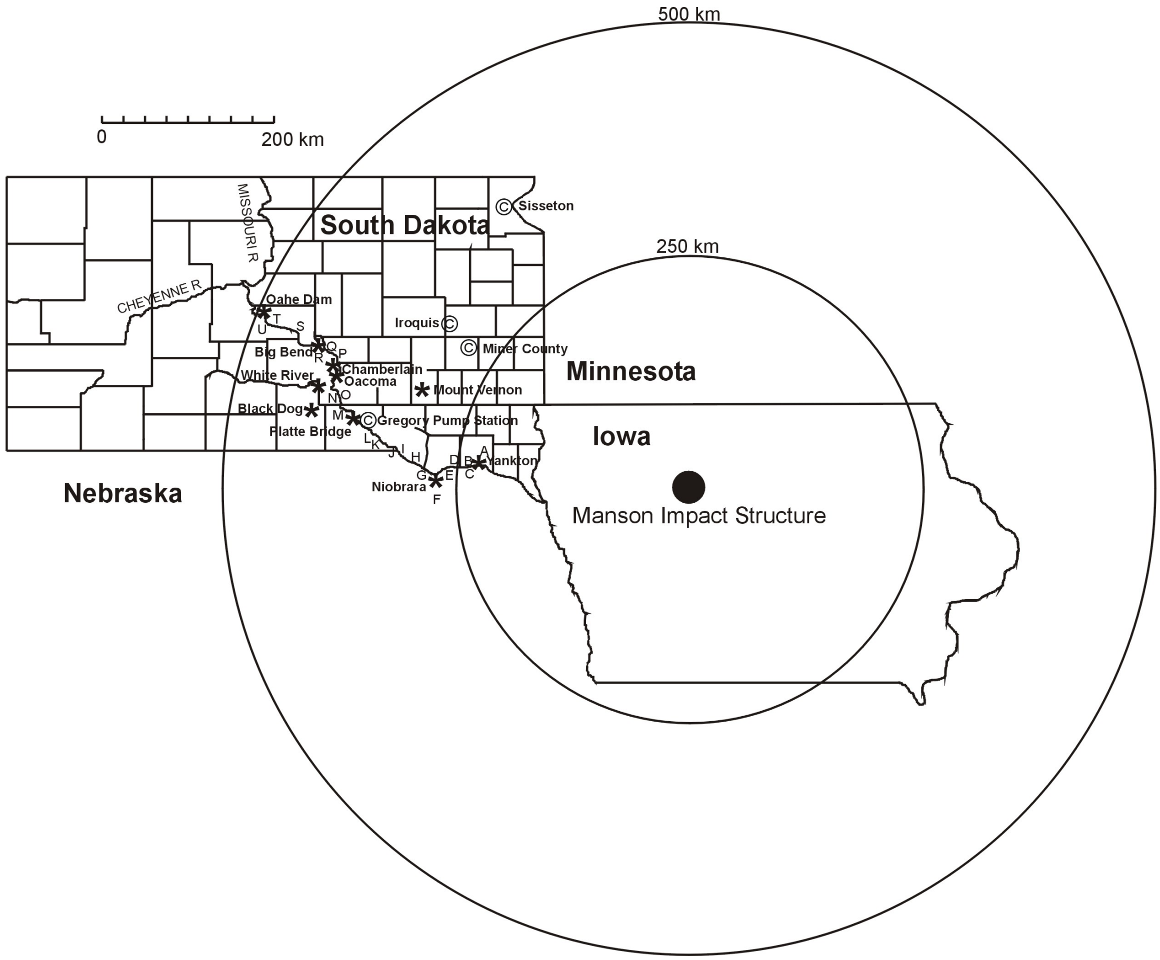
FIGURE 2: Generalized stratigraphy for the Pierre Shale showing ammonite, nannofossil, and magnetostratigraphic zones beside $^{40}Ar/^{39}Ar$ ages of sanidine and biotite crystals calibrated with the new Campanian/Maastrichtian boundary based on the first appearance of ammonite *Pachydiscus nebergicus* in Europe and *Baculites eliasi* in North America (Gradstein, *et al.*, 2004; Odin and Lamaurelle, 2001; Hardenbol *et al.*, 1998; modified after Izett *et al.*, 1998).

FIGURE 3: Generalized stratigraphy and relative sea-level curve for eastern margin of Western Interior Seaway. Abbreviations: T, transgressive; R, regressive; S.L., sea-level lowstand; E.E., eastern erosion; max transgr., maximum transgression; prograd., progradation; Ma, million years; L, lower; M, middle; U, Upper; Cenoman., Cenomanian; Con., Coniacian; Santon., Santonian; Pu., Puercan; To., Torrejonian; Tf., Tiffanian; Skull Cr., Skull Creek; Crow Cr., Crow Creek; Mobr., Mobridge; Elk B., Elk Butte; Jud. Riv., Judith River; Milk Riv., Milk River; *D*., *Discoscaphites*; *H*., *Hoploscaphites*; *B*., *Baculites*; *Di*., *Didymoceras*; *E*., *Exiteloceras*; *S*., *Scaphites*; *De*., *Desmoscaphites*; *Cl*., *Clioscaphites*; *P*., *Prionocyclus*; *Co*., *Collignoniceras*; *M*., *Mamites*; *Wat*., *Watinoceras* (after Witzke *et al.*, 1996)

FIGURE 4: Generalized west-to-east relations of Upper Cretaceous and Paleocene strata across the Western Interior Basin. Vertical axis is time. Regressive phases are marked by progradation in the west correlated with erosion in the east. Note the position of the Crow Creek and Judith River progradation. Abbreviations: w, western; c, central; e, eastern; Mont., Montana; Blk. Hills, Black Hills, South Dakota; S.Dak, South Dakota; Minn., Minnesota; K-T, Cretaceous-Tertiary boundary; fm., formation; mbr., member; ss., sandstone; sdy, sandy; sh., shale; calc., calcareous (after Witzke *et al.*, 1996)

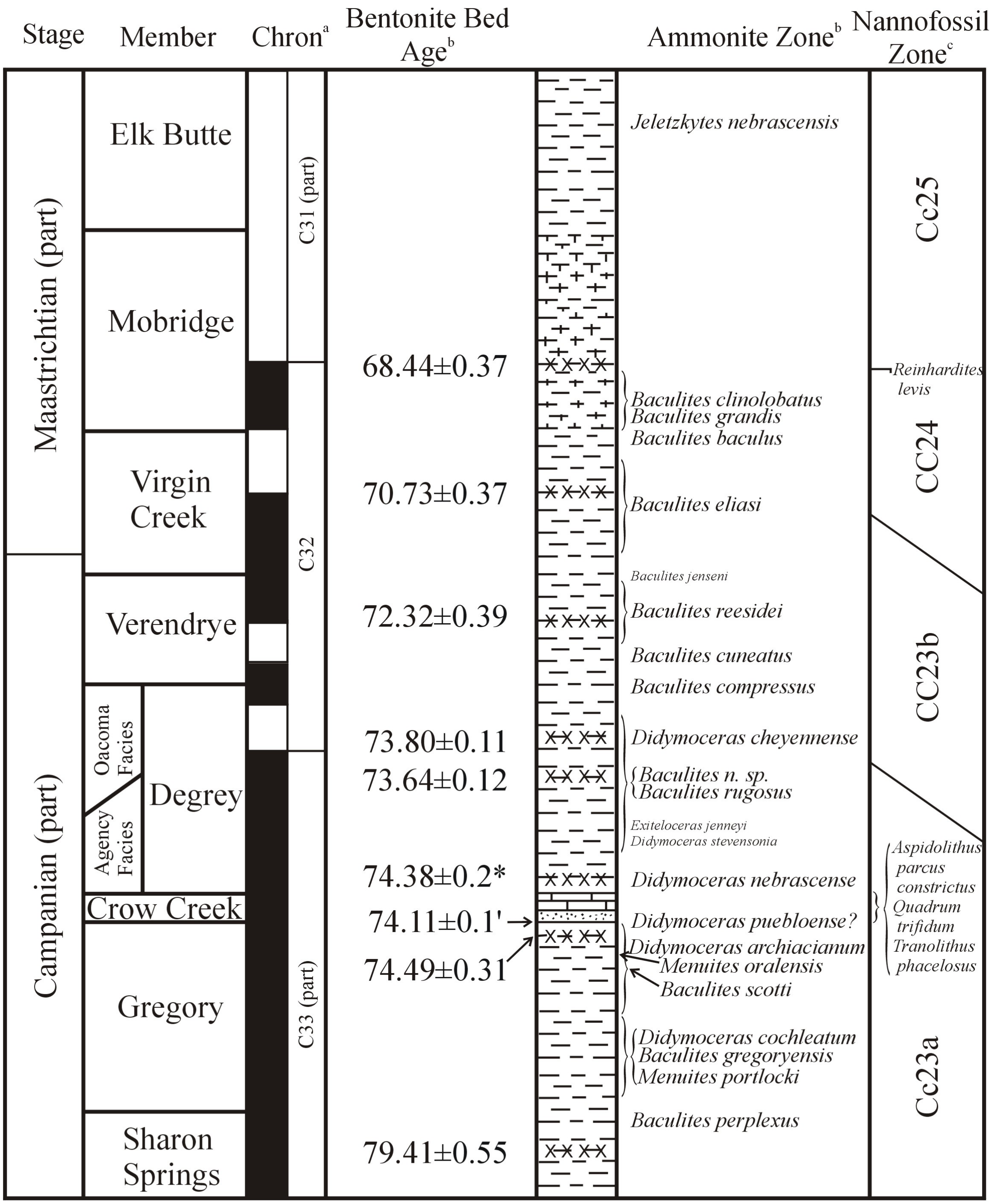
FIGURE 5: Stratigraphic distribution of reworked nannofossils in the Crow Creek member assumed to be Niobrara Chalk sediment near Yankton, SD (after Hammond *et al.*, 1994)

## Figure 1



500 km
250 km
0
200 km
South Dakota
Minnesota
Iowa
Nebraska
Manson Impact Structure
MISSOURI R
CHEYENNE R
Sisseton
Oahe Dam
Iroquis
Miner County
Big Bend
Chamberlain
Oacoma
White River
Mount Vernon
Black Dog
Gregory Pump Station
Platte Bridge
Yankton
Niobrara

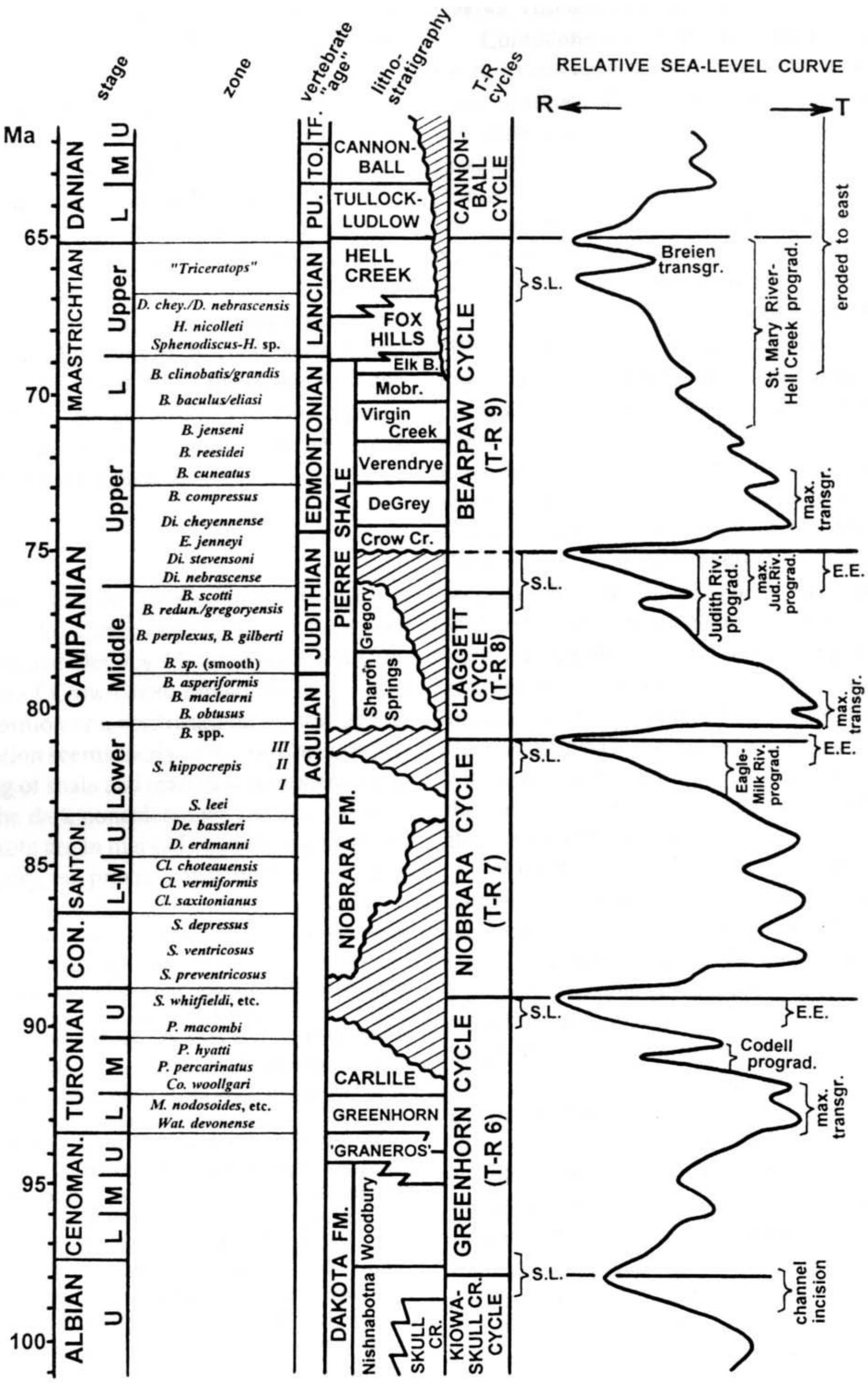
**Figure 2**




[a] after Bralower et al. (1995) using Gradstein et al. (1994)
[b] after Izett et al. (1998)
[c] after Watkins (1989) using Perch-Nielsen (1985) zonation

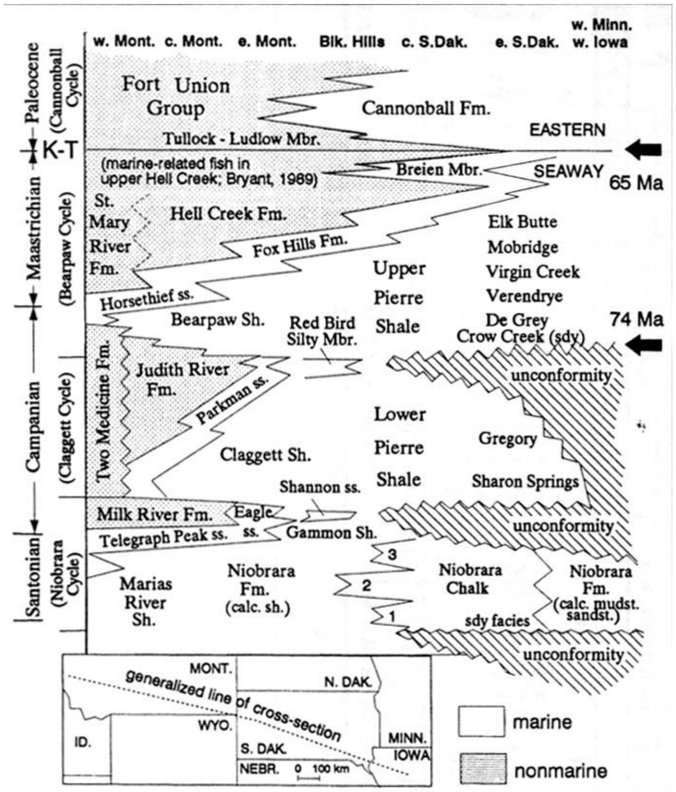
*contaminated with older minerals
' Manson Impact
Note: Ammonite names in small font not found

**Figure 3**



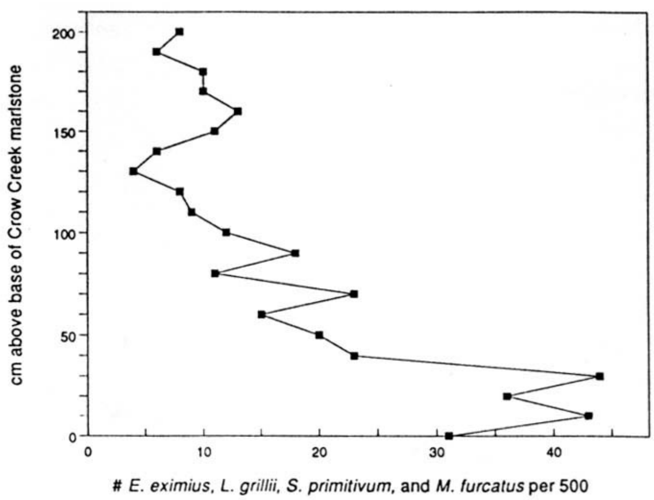
stage
zone
vertebrate "age"
litho-stratigraphy
T-R cycles
RELATIVE SEA-LEVEL CURVE
R
T
Ma
65
70
75
80
85
90
95
100
DANIAN
MAASTRICHTIAN
CAMPANIAN
SANTON.
CON.
TURONIAN
CENOMAN.
ALBIAN
"Triceratops"
D. chey./D. nebrascensis
H. nicolleti
Sphenodiscus-H. sp.
B. clinobatis/grandis
B. baculus/eliasi
B. jenseni
B. reesidei
B. cuneatus
B. compressus
Di. cheyennense
E. jenneyi
Di. stevensoni
Di. nebrascense
B. scotti
B. redun./gregoryensis
B. perplexus, B. gilberti
B. sp. (smooth)
B. asperiformis
B. maclearni
B. obtusus
B. spp.
S. hippocrepis
S. leei
De. bassleri
D. erdmanni
Cl. choteauensis
Cl. vermiformis
Cl. saxitonianus
S. depressus
S. ventricosus
S. preventricosus
S. whitfieldi, etc.
P. macombi
P. hyatti
P. percarinatus
Co. woollgari
M. nodosoides, etc.
Wat. devonense
TF.
TO.
PU.
LANCIAN
EDMONTONIAN
JUDITHIAN
AQUILAN
CANNON-BALL
TULLOCK-LUDLOW
HELL CREEK
FOX HILLS
Elk B.
Mobr.
Virgin Creek
Verendrye
DeGrey
Crow Cr.
PIERRE SHALE
Gregory
Sharon Springs
NIOBRARA FM.
CARLILE
GREENHORN
'GRANEROS'
DAKOTA FM.
Woodbury
Nishnabotna
SKULL CR.
CANNON-BALL CYCLE
BEARPAW CYCLE (T-R 9)
CLAGGETT CYCLE (T-R 8)
NIOBRARA CYCLE (T-R 7)
GREENHORN CYCLE (T-R 6)
KIOWA-SKULL CR. CYCLE
Breien transgr.
S.L.
St. Mary River-Hell Creek prograd.
eroded to east
max. transgr.
Judith Riv. prograd.
max. Jud.Riv. prograd.
E.E.
Eagle-Milk Riv. prograd.
Codell prograd.
channel incision

## Figure 4



w. Mont.
c. Mont.
e. Mont.
Blk. Hills
c. S.Dak.
e. S.Dak.
w. Minn.
w. Iowa
Paleocene
(Cannonball Cycle)
K-T
Maastrichtian
(Bearpaw Cycle)
Campanian
(Claggett Cycle)
Santonian
(Niobrara Cycle)
Fort Union Group
Cannonball Fm.
Tullock - Ludlow Mbr.
EASTERN
SEAWAY
65 Ma
(marine-related fish in upper Hell Creek; Bryant, 1989)
Breien Mbr.
St. Mary River Fm.
Hell Creek Fm.
Fox Hills Fm.
Elk Butte
Mobridge
Virgin Creek
Verendrye
De Grey
Crow Creek (sdy)
Upper Pierre Shale
Horsethief ss.
Bearpaw Sh.
Red Bird Silty Mbr.
74 Ma
Two Medicine Fm.
Judith River Fm.
Parkman ss.
unconformity
Lower Pierre Shale
Gregory
Claggett Sh.
Shannon ss.
Sharon Springs
Milk River Fm.
Eagle ss.
Telegraph Peak ss.
Gammon Sh.
unconformity
Marias River Sh.
Niobrara Fm. (calc. sh.)
3
2
1
Niobrara Chalk
sdy facies
Niobrara Fm. (calc. mudst. sandst.)
unconformity
MONT.
N. DAK.
generalized line of cross-section
WYO.
ID.
S. DAK.
MINN.
IOWA
NEBR.
0 100 km
marine
nonmarine

**Figure 5**


cm above base of Crow Creek marlstone
200
150
100
50
0
0
10
20
30
40
# E. eximius, L. grillii, S. primitivum, and M. furcatus per 500