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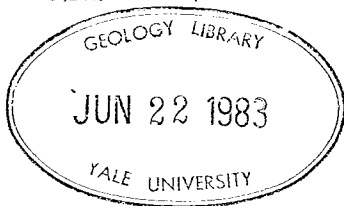
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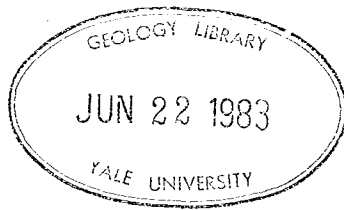
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Occurrence and Fossilization of the *Dakoticancer* Assemblage, Upper Cretaceous Pierre Shale, South Dakota

Gale A. Bishop

ABSTRACT

Five thousand decapods were collected from six localities in the Upper Cretaceous Pierre Shale of South Dakota. The decapods and associated fossils are preserved enclosed in apatite concretions. The concretions are distributed through 3 to 7m of shale and are laterally persistent over areas of 15 to 15,000 km.

The decapods may have been buried as corpses or molts. A few molts are preserved in "Salter's position." After or during burial the thin membranes between segments were destroyed and the decomposing crustaceans were partly or completely filled with sediment. The sediment in and around the hard parts was ingested by deposit-feeding organisms and extruded as fecal pellets. Compression due to the weight of overburden then flattened, broke, and rearranged the parts of the decapods. The concentration of phosphates in the fecal material and the micro-environment of enclosed spaces within the skeletons of the animals caused the formation of the concretions.

The uniformity of distribution, faunal composition, and mode of preservation of the faunas suggest that they are parts of a recurrent community dominated by the decapod *Dakoticancer overanus* Rathbun, baculitid cephalopods, and inoceramids. Less-common taxa are the decapods *Homolopsis punctata* Rathbun, *Necrocarcinus pierrensis* Rathbun, *Raninella oaheensis* Bishop, *Sodakus tatankayotankaensis* Bishop, *Palaeonephrops browni* Whitfield, *Callianassa* sp., and *Homolopsis* n. sp.; the bivalves *Nucula* and *Ostrea* s. l.; cephalopods other than baculitids; bony fish; sharks; and reptiles. The abundance of several types of fecal pellets suggests that soft-bodied organisms were common.

The consistency of the *Dakoticancer* Assemblage repeated at numerous localities stands in marked contrast to the preservation of other fossil decapods from the Pierre Shale that occur as isolated, single specimens.

INTRODUCTION

Marine shales, deposited in a shallow epeiric sea, should contain numerous animals common to continental shelves. Among these animals

should be many decapods. The apparent rarity of fossil decapod crustaceans in the Upper Cretaceous Pierre Shale has been a puzzle. I believe the apparent absence of fossil crabs is due primarily to lack of adequate conditions for preservation and secondarily to inadequate collecting techniques. The presence of numerous crab fossils in a few laterally persistent and vertically restricted intervals of the Pierre Shale and the mode of preservation of these fossils indicate that crabs were either present at many times in great numbers, but were only preserved periodically in areas of exceptional conditions, or they existed periodically in large populations at several different times and perhaps initiated conditions that led to their preservation.

The geologic history of the Western Interior Basin was summarized by Reeside (1957) and by Kauffman (1977), and the geologic history of the Pierre Shale was summarized by Gill and Cobban (1966, 1973). The basin occupied a north-south trough through the Western United States and Canada from the Tethys Seaway in Texas northward to the Arctic Ocean (Figure 13-1). The seaway was 4,800 km long and averaged 1,600 km wide. The size, shape, and physical conditions of the seaway varied greatly with eustatic and tectonic fluctuations. These fluctuations caused variation in sedimentation patterns that we today interpret as cyclothems (Kauffman 1967, 1977). Each major transgressive-regressive pulse contained small-scale fluctuations that gave rise to small cyclothems superimposed on major ones. The basin has been divided into the following tectonic zones (Kauffman, 1977:84):

1. A tectonically active western margin characterized by rapid subsidence and thick, coarse, progradational clastic wedges.
2. A west-central zone of rapid subsidence and thick sediments.
3. A hinge zone where sediments thin, become finer (and begin picking up numerous disconformities), and
4. An eastern, stable platform characterized by numerous disconformities within a relatively thin sedimentary package.

Occurrences of the *Dakoticancer* Assemblage are all confined to the Pierre Shale deposited during Late Cretaceous (Campanian and Maastrichtian ages) on the stable eastern shelf.

THE PIERRE SHALE

Rocks deposited on the stable eastern shelf during Coniacian through Maastrichtian time in South Dakota include (from older to younger) the Niobrara Chalk, the Pierre Shale, the Fox Hills Formation, and the Hell Creek Formation (Figure 13-2), a marine to continental sequence deposited during the final withdrawal of the sea from the Western Interior.

The Pierre Shale is a body of fine clastic sediments up to 2,400 m thick found throughout the eastern half of the Western Interior. In western South Dakota the upper part of the Pierre Shale consists of noncalcareous gray shale, calcareous gray shale, and silty shale. Thin bentonite beds and layers of concretions, commonly fossiliferous, occur throughout the Pierre Shale. These fine clastics appear to be water and wind transported sediment and volcanic ash derived from the tectonically active western shore. The Pierre Shale, particularly the concretions, contain abundant, beautifully preserved fossils.

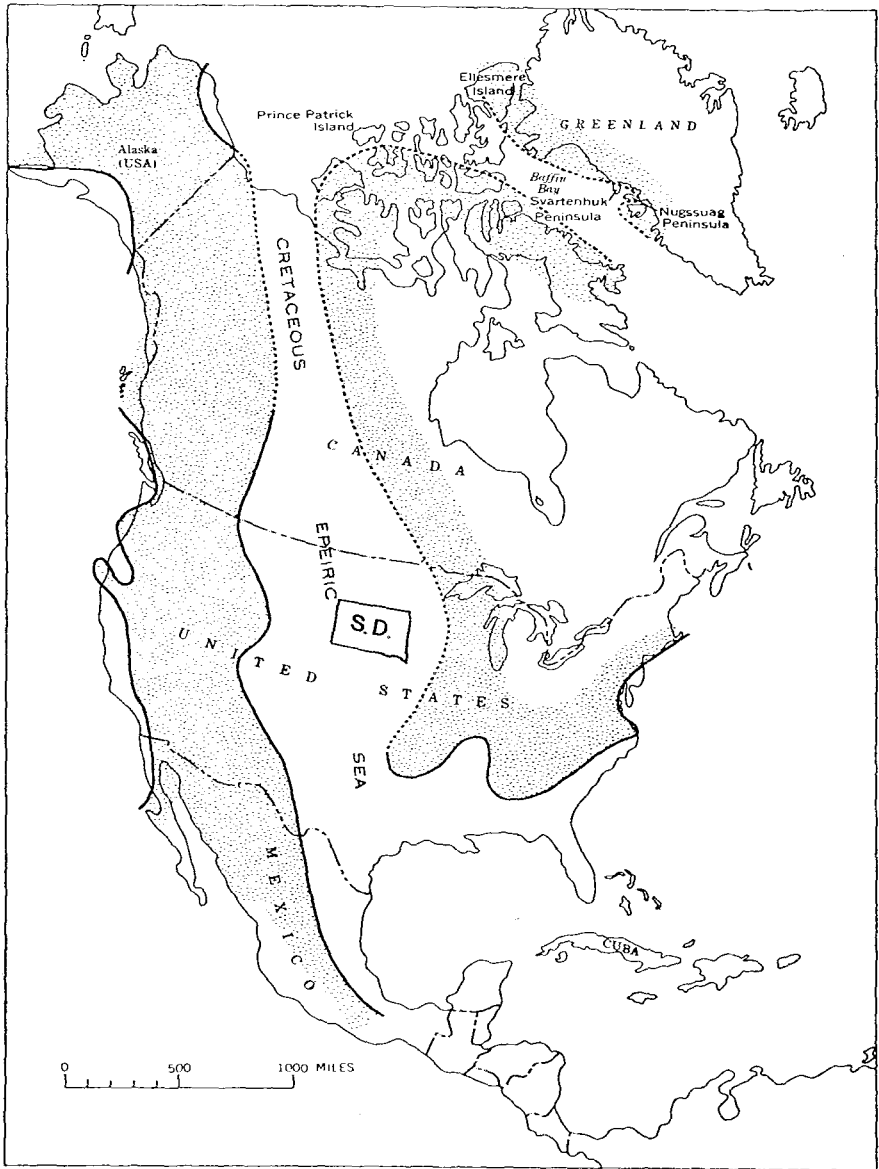
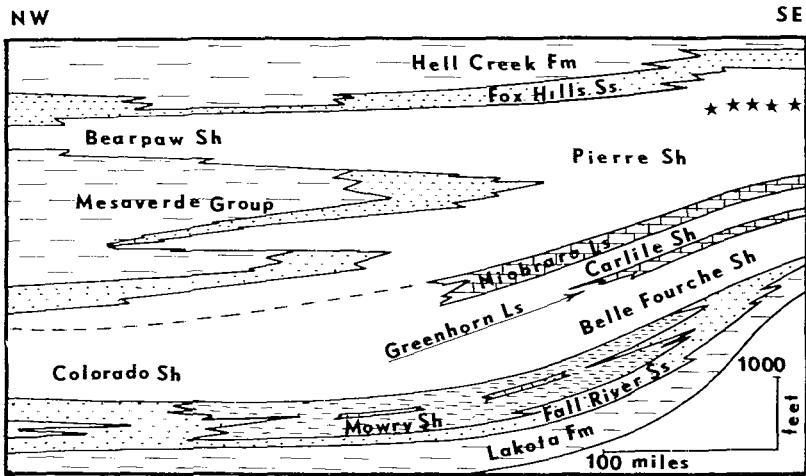


Figure 13-1
 Late Cretaceous paleogeography of North America (after Gill and Cobban, 1966:A44).

The marine faunas of the Pierre Shale have been known and studied for many years. Many authors (Sohl, 1967, 1969; Kauffman, 1967, 1977; Scott, 1970) have commented on the depauperate nature of the faunas because of the rarity of such marine organisms as sponges, corals, bryozoans, brachiopods, some molluscs, and echinoderms. We should add decapods to this list as they remain poorly represented in most



b

Figure 13-2

Stratigraphic relationship of the *Dakoticancer* Assemblage (asterisks) to the Pierre Shale and other Cretaceous rocks of the Western Interior (after Dunbar and Waage, 1970:383).

of the Western Interior Cretaceous.

The geochronology of the Western Interior Cretaceous is one of the most detailed in the world with a resolution of 0.25 to 0.33 million years per biostratigraphic zone (Kauffman, 1977:97). The biostratigraphic net is based primarily on abundant ammonoid cephalopods (particularly baculites) and inoceramid bivalves (Cobban et al., 1966, 1973, 1975, 1977; Kauffman, 1977). Numerous bentonite beds, each an isochronous surface and many regionally correlative, provide independent time-stratigraphic correlation. Many of the bentonite beds have been radiometrically dated (Gill and Cobban, 1966; Obradovich and Cobban, 1975; Kauffman, 1977) and thus provide a method to calculate the approximate absolute age and duration of the biostratigraphic zones.

The paleogeography of the Western Interior Basin is well documented (Gill and Cobban, 1973) during the deposition of the Pierre Shale (Bearpaw Cyclothem of Kauffman, 1977:89). During this time, the nearest shoreline to the *Dakoticancer* assemblages was several hundred kilometers away. The sea was probably warm-temperate (Kauffman, 1977; Tourtelot and Rye, 1969; Sohl, 1967; Jeletzky, 1969) about 100 m or less deep (Gill and Cobban, 1966:938; Mello, 1969:35; Asquith, 1970:1219; Kauffman, 1977:84), and of normal to brackish salinity. The salinity may have varied vertically (Kauffman, 1977) and changed through time with variable conditions. Local flooding on the basin margins may have had considerable effect on the salinity of parts of the basin. Circulation patterns for the Western Interior Sea have been postulated and usually include a northward-flowing warm current originating in the Tethys. This influx of warm Tethyan waters pushed biogeographic boundaries far to the north and provided the source for and means of transportation of Tethyan faunas, which periodically

mixed with the boreal faunas to the north in a broad boundary separating two general Western Interior biologic subprovinces, Northern and Southern (Kauffman, 1977:96).

In each subprovince, fossil assemblages have been described by many authors (Kauffman, 1967, 1977; Sohl, 1967, 1969; Scott, 1973, 1977; Waage, 1968; Kauffman et al., 1977). Kauffman (1977:96) grouped these and other citations of "Paleocommunities" into the following types:

1. Low diversity assemblages dominated by and nearly restricted to one or a few taxa.
2. High diversity assemblages containing up to fifty or more taxa.

PREVIOUS INVESTIGATIONS

The literature on stratigraphy, sedimentation, mineralogy, and paleontology of the Pierre Shale is extensive (bibliographies in Searight, 1937; Reeside, 1957; Robinson et al., 1959; Weimer, 1960; Gill and Cobban, 1966; Kauffman, 1977). The literature on fossil decapods from the Western Interior is limited although many authors mention the presence of fossil decapods in concretions near Mobridge, South Dakota. Fossil decapods were first collected in 1914 and 1915 by W. H. Over, and those specimens were described as *Dakoticancer overana*, *Homolopsis punctata*, and *Campylostoma pierreense* by M. J. Rathbun in 1917. Rathbun (1930) described an additional species, *Callianassa cheyennensis*, from the Pierre Shale from specimens collected by W. L. Russell. Subsequent authors (Russell, 1930; Searight, 1937; Gries, 1939, 1942; Rothrock, 1947; Crandell, 1958) were interested in the fossil decapods of the Pierre Shale as stratigraphic markers. Roberts recognized a new species of *Raninella* from the Red Bird Reference Section (Gill and Cobban, 1966:A26) in Wyoming. Bishop studied the crabs and lobsters from these rocks (Bishop, 1972a, 1972b, 1973, 1974, 1975, 1976, and 1977; Feldmann et al., 1977).

COLLECTION LOCALITIES

Six collections of decapods were made from the *Dakoticancer* Assemblage in the Pierre Shale in western South Dakota (Figure 13-3, Table 13-1). Three of these consist of several hundred specimens and were used for this study. The other three collections were much smaller and are not described here.

The largest collection was made in the Mobridge area, north-central South Dakota. Specimens were collected at three sites. Because the three sites are at the same stratigraphic and biostratigraphic level, they are treated as a single collection. The Mobridge collection is composed of collections from the Sitting Bull locality (GAB 4), the Promise Locality (GAB 9), and the U.S. Coast and Geodetic Survey (U.S.C.G.S.) BM J304 locality (GAB 10). This collection of 2,400 numbered and about 2,000 unnumbered specimens is from the zone of *Baculites grandis* (Table 13-1). The interval of shale containing the fossil decapods is laterally continuous over at least 1,500 km².

The second largest collection was made 24 km southeast of Rapid City around Thomson Butte (GAB 1). About 1,100 specimens were

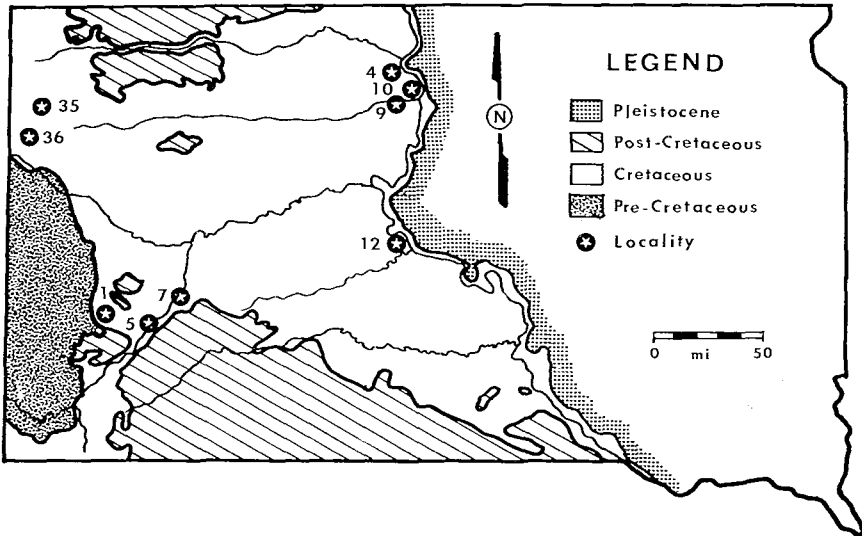


Figure 13-3
Selected decapod collection localities in South Dakota.

collected in an area of 15 km². The crabs were found associated with *Baculites rugosus* Cobban, which ranges through the zones of *Exiteloceras jenneyi* and *Didymoceras cheyennense* (Table 13-1).

The third collection is from outcrops near the town of Creston (GAB 5, 6). The fossil decapods were traced over an area of 330 km². This collection consists of about 500 specimens from the zone of *Didymoceras cheyennense* (Table 13-1).

Small collections were made at Wasta (GAB 7), north of Pierre (GAB 12), and north of Belle Fourche (GAB 35). They are from the zones of *Baculites compressus*, *Baculites grandis*, *Exiteloceras jenneyi*, respectively (Table 13-1).

The following decapod taxa were found in these collections (Figure 13-4 A-H): *Dakoticancer overanus* Rathbun, *Homolopsis punctata* Rathbun, *Homolopsis* n. sp., *Necrocarcinus pierrensis* Rathbun, *Raninella oaheensis* Bishop, *Sodakus tatankayotankaensis* Bishop, *Callianassa* sp., and *Palaeonephrops browni* (Whitfield).

SUMMARY OF THE DATA

DISTRIBUTION

The fossil decapods occur in thin, continuous intervals of rock that are laterally persistent over hundreds of square kilometers and vertically restricted to intervals a few meters thick.

The Creston locality (Figure 13-5) covers 330 km², and the limits have been accurately delineated on three sides. The interval containing *Dakoticancer* extends from 15 to 20 m above the base of the section. Eighty-one single claws of *Callianassa* (Figure 13-4D) were collected in an interval from near the top of the *Dakoticancer* zone to 29 m

Table 13-1

Summary of distribution of localities with *Dakoticancer* Assemblage.

Locality	Distribution Area (sq km)	Thickness (m)	No. Specimens	Absolute Age mybp	Biostratigraphic Zone
Mobridge (GAB 4,9,10)	1500	3	3400		<i>Baculites clinolobatus</i>
Peoria Bottom (GAB 12)	?	3	19	68.5	<i>Baculites grandis</i>
					<i>Baculites baculus</i>
<u>MAASTRICHTIAN STAGE</u>					
<u>CAMPANIAN STAGE</u>					
					<i>Baculites eliasi</i>
					<i>Baculites jenseni</i>
					<i>Baculites reesidei</i>
					<i>Baculites cuneatus</i>
Wasta (GAB 7)	?	?	51	71.5	<i>Baculites compressus</i>
Creston (GAB 5,6)	337	7.6	500	71.75	<i>Didymoceras cheyennense</i>
Thomson Butte (GAB 1,2)	15.5	1.5	1100		<i>Exiteloceras jenneyi</i>
				72	<i>Didymoceras stevensoni</i>
					<i>Didymoceras nebrascense</i>
Baresch (GAB 35)	?	?	9		<i>Baculites scotti</i>
(earliest known <i>Dakoticancer</i> from Western Interior)					

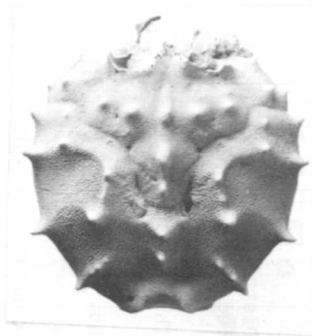
above the base of the section. The measured section was the only locality where *Callianassa* was found in great concentrations; therefore, this occurrence is judged atypical.

Fossils, preserved both in the shale and in concretions, are common throughout this interval of the Pierre Shale (Table 13-1). The ammonites *Didymoceras cheyennense* (Meek and Hayden) and *Baculites rugosus* Cobban were found at nearly all collecting sites in the Creston area. These two taxa place the mapped interval in the zone of *Didymoceras cheyennense*.

The collections from the Thomson Butte locality (Figure 13-7) are from an interval of Pierre Shale that was intensively weathered and eroded before the Early Oligocene Chadron Formation was deposited. This erosion and weathering formed a surface of rolling topography and a weathered interval of variable thickness. The weathered interval was called the "Interior Formation" by Ward (1922) and recognized as a soil zone by Wanless (1923:197). This interpretation has been generally accepted (Clark et al., 1967:9), and the soil zone is called the "Interior Paleosol."



A



B



C



D



E



F



G



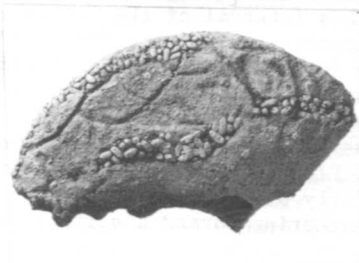
H



I



J



K



L

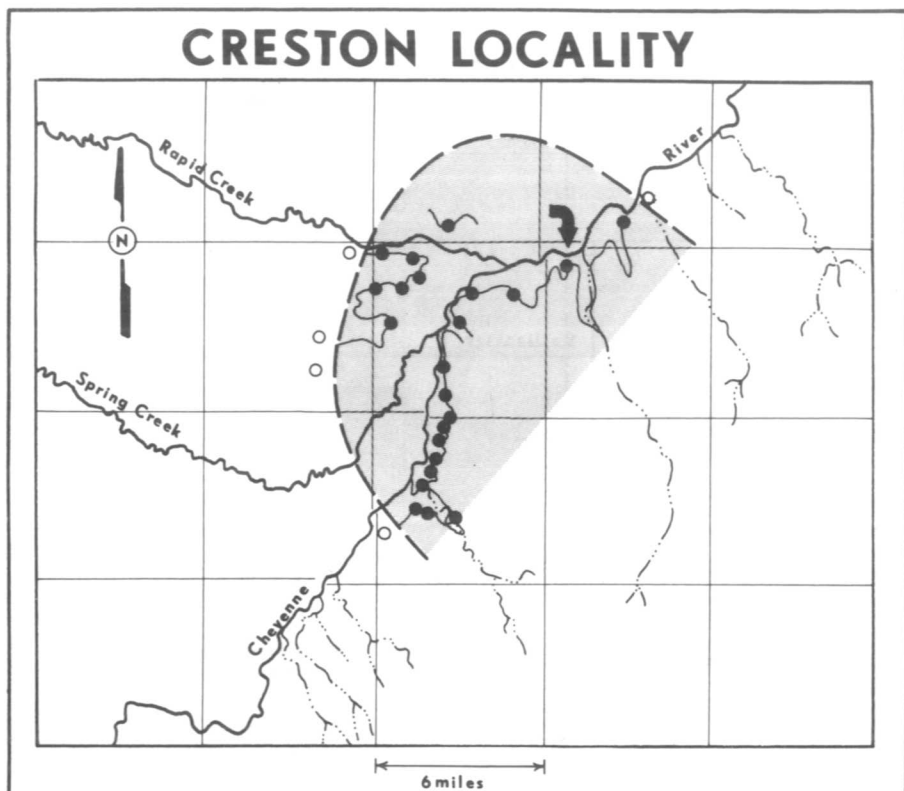


Figure 13-5

The Creston locality showing the collection sites yielding crabs (solid circles) and those not yielding crabs (open circles) and the inferred distribution of the *Dakoticancer* Assemblage (shaded).

Figure 13-4 (at left)

Decapod crustaceans of the *Dakoticancer* Assemblage. A. *Dakoticancer overanus* Rathbun, GAB 4-2006 (USNM 173529) X1.5. B. *Necrocarcinus pierrensis* Rathbun, GAB 4-509, X1.5. C. *Homolopsis punctata* Rathbun, GAB 2-2, X1.5. D. *Callianassa* sp., GAB 14-33, X1.5. E. *Raninella oahaensis* Bishop, lying within a partial carapace of *D. overanus*, GAB 4-1967, X1.5. F. *Sodakus tatankayotankaensis* Bishop, GAB 4-2036, X1.5. G. *Homolopsis* n. sp., anterior of carapace only, GAB 4-2192, X1.5. H. *Palaeonephrops browni* (Whitfield), cheliped enclosed in concretion from rostrum to end of concretion, GAB 11-26 (USNM 239936) X0.3. Common noncrustacean elements of *Dakoticancer* Assemblage. I. *Inoceramus* sp., steinkern with two sizes of trails, GAB 4-1998, X1. J. *Baculites grandis* Hall and Meek, steinkern of air chambers, GAB 4-198, X1. K. *Hoploscaphites* sp., steinkern with open trails and fecal pellet filled trails, GAB 4-1989, X1. L. *Inoceramus* sp., steinkern with two sizes of open trails, the larger preserving an impression of the segmented burrower, GAB 4-1991, X1.

CRESTON SECTION

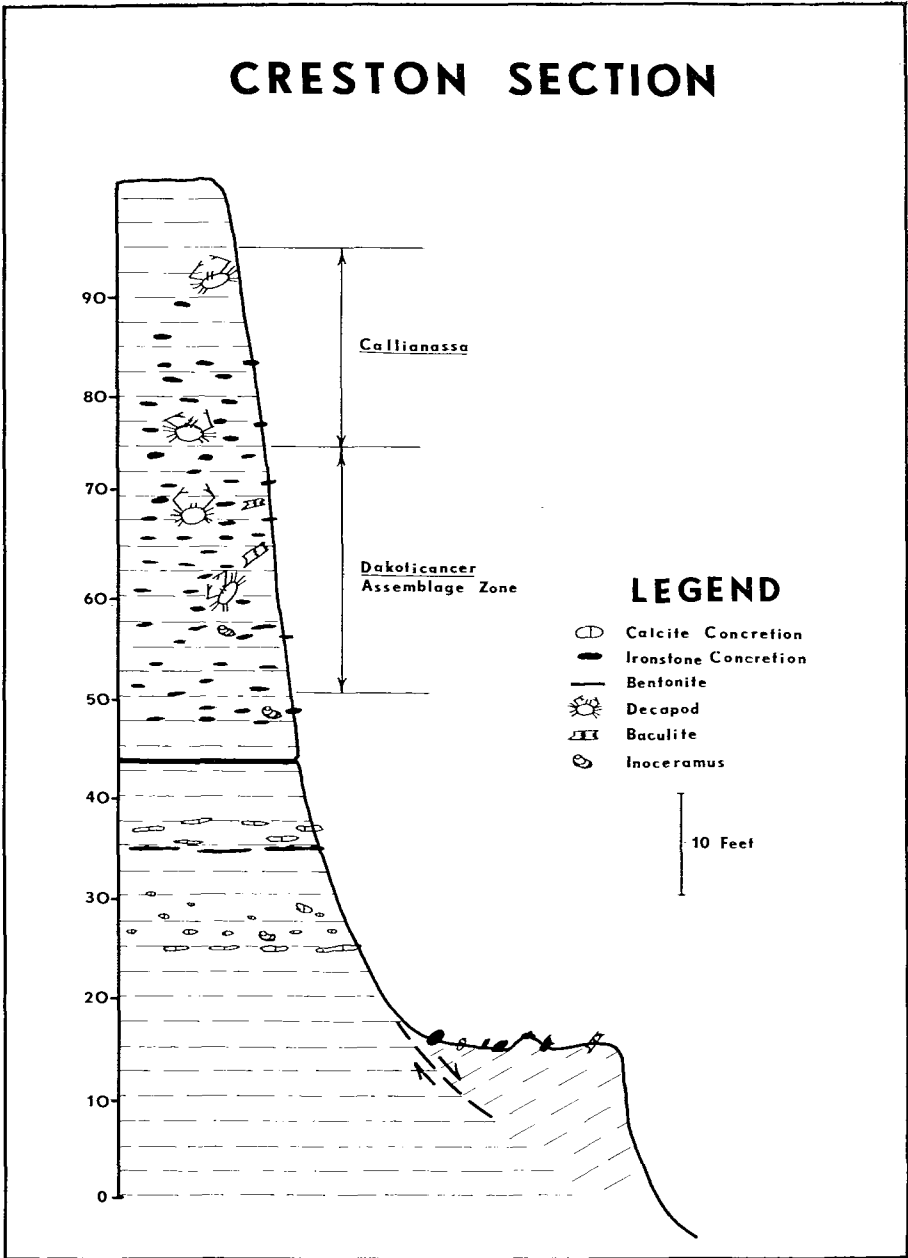


Figure 13-6
Measured section, Creston locality (at arrow on Figure 13-5).

Small apatite concretions (Figure 13-9A, D, P-S) and steinkerns occur within the weathered zone (Figure 13-8). Their exact strati-

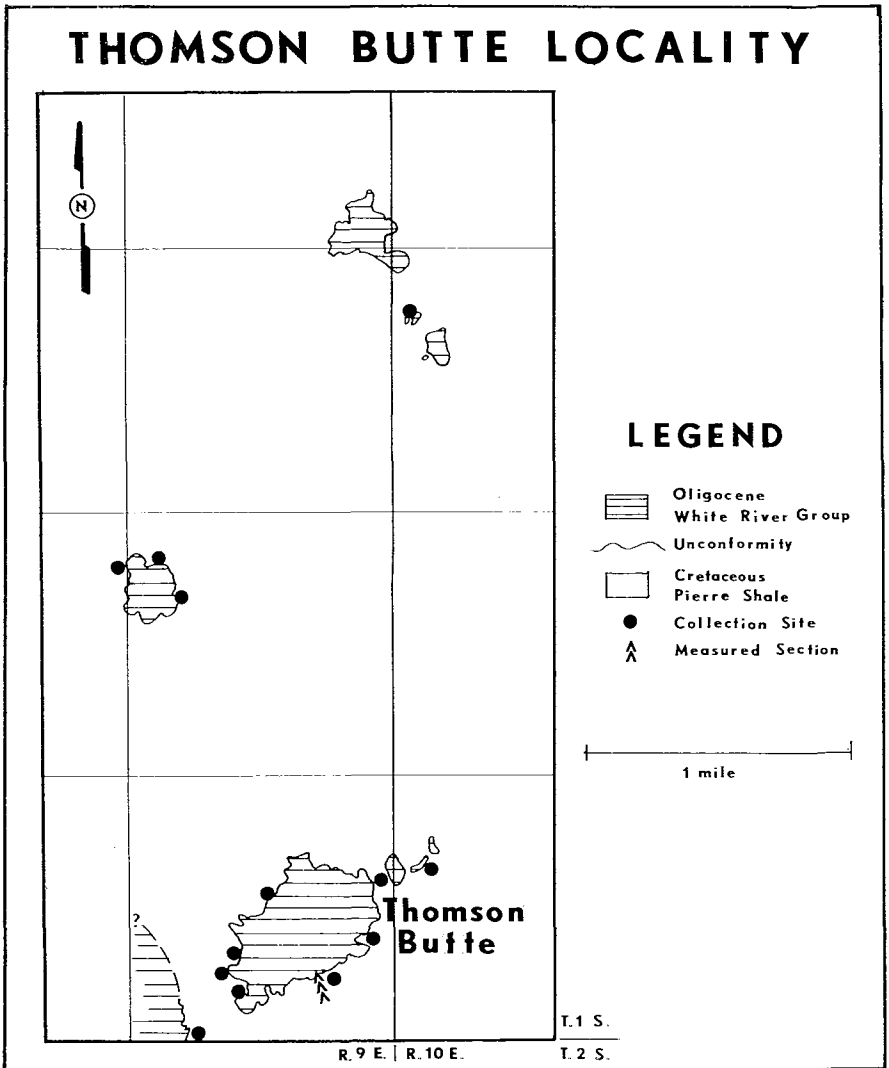


Figure 13-7
The Thomson Butte locality.

graphic range is uncertain as only one apatite concretion was found at the measured section, and it was float. Exposures are poor where concretions containing decapods are concentrated in saddles and on gentle slopes. I believe the decapod concretions occur above the large oxidized concretions in the position indicated on the measured section (Figure 13-8). The crab interval is sometimes cut out by the disconformity.

The biostratigraphic position of the Thomson Butte locality is not known precisely because no index ammonites were found. The few poorly

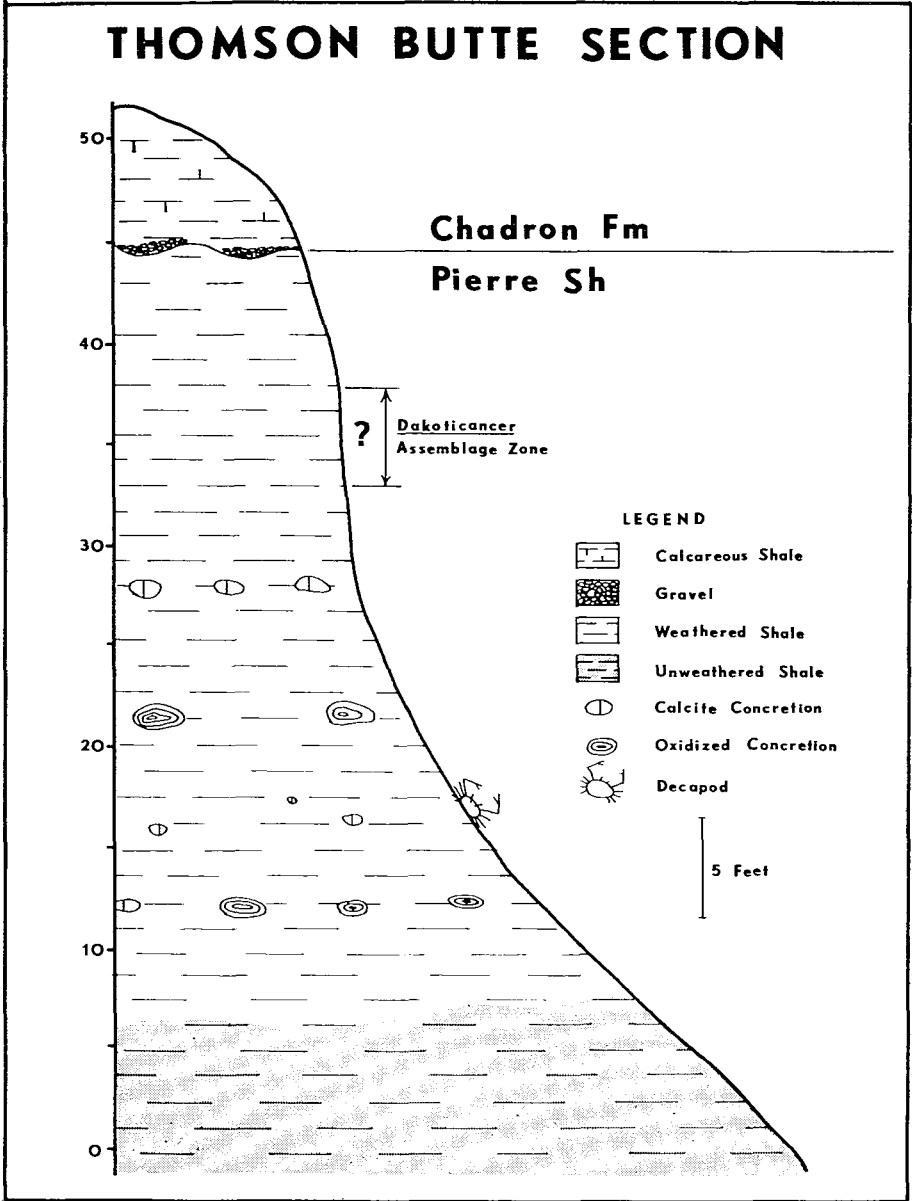


Figure 13-8
Measured section, Thomson Butte locality.

preserved ammonites that were found were submitted to Dr. W. A. Cobban in 1969 for comment. He replied:

The badly weathered ammonites from Thomson Butte suggest the zone of *Didymoceras cheyennense*. Many of the baculites have well-ribbed venters and narrow cross sections suggesting *Baculites rugosus* Cobban. This species is best developed in the zone of *Exiteloceras jenneyi*, but it persists into the younger zone of *D. cheyennense*. The two scaphites, which can be assigned to *Scaphites (Hoploscaphites) nodosus* Owen s. l., are best matched by specimens from the *D. cheyennense* beds. The *Placentoceras* is *P. intercalare* Meek.

The locality may be slightly younger or the same age as the Creston locality. The fauna is presented in Table 13-2.

Fossil decapods from the Mobridge localities are persistent over 1,500 km² in north-central South Dakota. Three collections were made in this area: at the Sitting Bull Burial Site across from Mobridge, at Promise, and north of the Moreau River (Figure 13-10). Sections were measured at Mobridge (Figure 13-11) and Promise.

Rothrock (1947) mapped the crab zone at Mobridge. Fossil crabs occur at the same biostratigraphic position in Potter County (Russell, 1930) and near Pierre (GAB 12) (Crandall, 1958). I suspect that the distribution is continuous. If this is so, the distribution would cover about 3,000 km².

The Sitting Bull locality is on the west bank of the Missouri River (Oahe Reservoir) opposite the town of Mobridge, South Dakota. Specimens were collected from 3 m of gray, slightly calcareous to noncalcareous, bentonic shale interbedded with at least four, thin bentonite beds. Concretions that contain fossil decapods and steinkerns of molluscs (Figure 13-4A, B, F, G, I-L; Figure 13-9B, C, E, F, H-K, M, N, T) including *Baculites grandis* Hall and Meek (Figure 13-4I) are found throughout the interval.

The Promise locality is located near the community of Promise where a section was measured and collected at the type locality of the Virgin Creek Member of the Pierre Shale. Decapods were found in 1.5 m of gray, calcareous, bentonitic shale interbedded with thin bentonite beds near the top of the section. Steinkerns of *Baculites grandis* Hall and Meek are present throughout the interval of the bentonite beds.

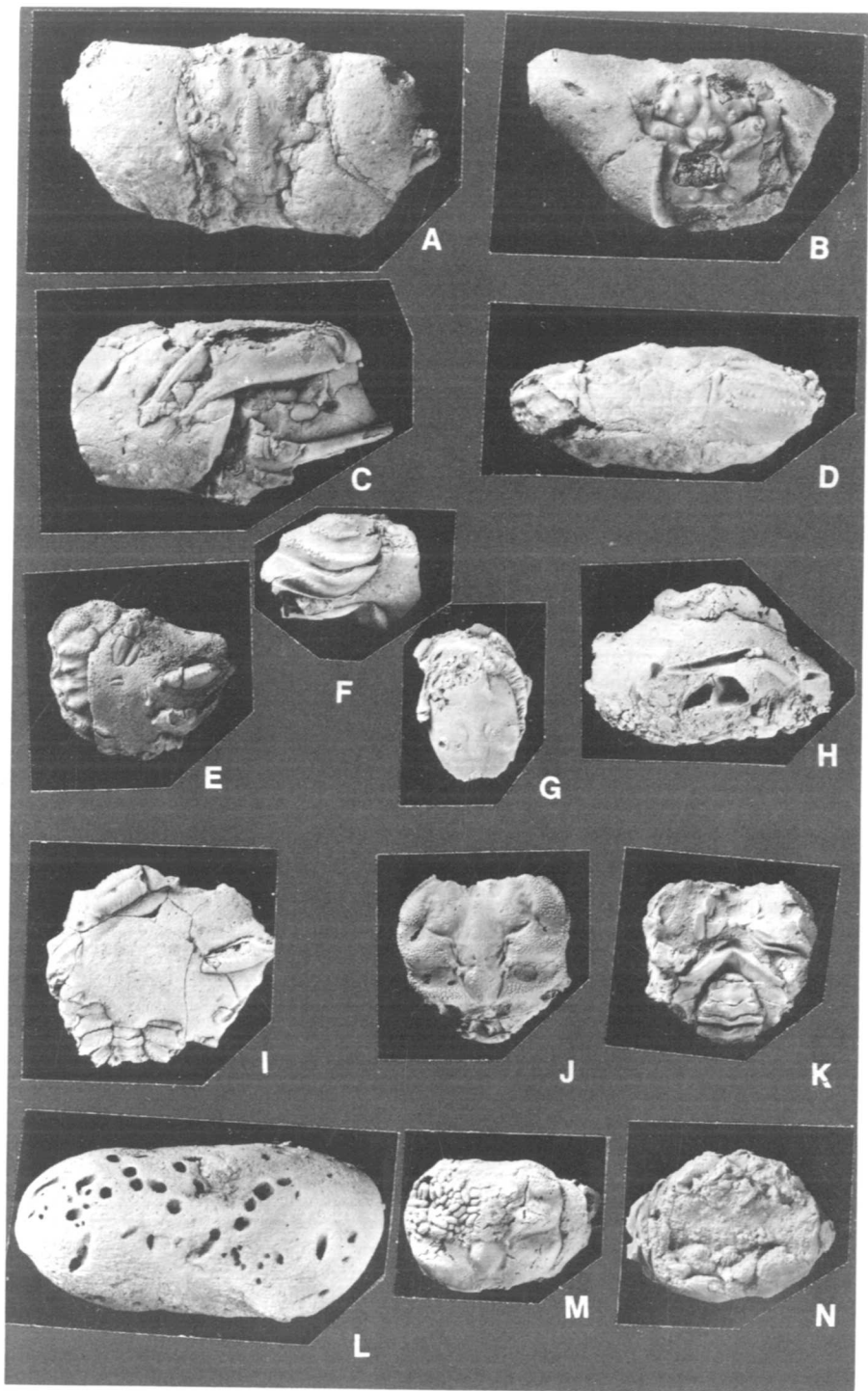
The U.S.C.G.S. BM J 304 locality is situated on the bluffs on the north side of the Moreau River. This locality lies between the Mobridge and Promise localities. Numerous steinkerns of *B. grandis* were collected with the decapods.

LITHOLOGY

The fossil crabs at all three localities were collected as float. The fossils, preserved in apatite concretions, weather out of the shale and are concentrated as a lag deposit on the surface.

The shale at the Creston locality varies from a blocky claystone to a semifissile shale. Fresh exposures at the locality show that local concentrations of very fossiliferous shale contain many fragments of inoceramid pelecypods. Ironstone concretions are common throughout the interval that yielded the crab fauna.

The unweathered Pierre Shale at the Thomson Butte locality is olive gray, noncalcareous, fissile, and contains concretions of two types: large, 30 to 60 cm, spheroidal, calcareous concretions; and



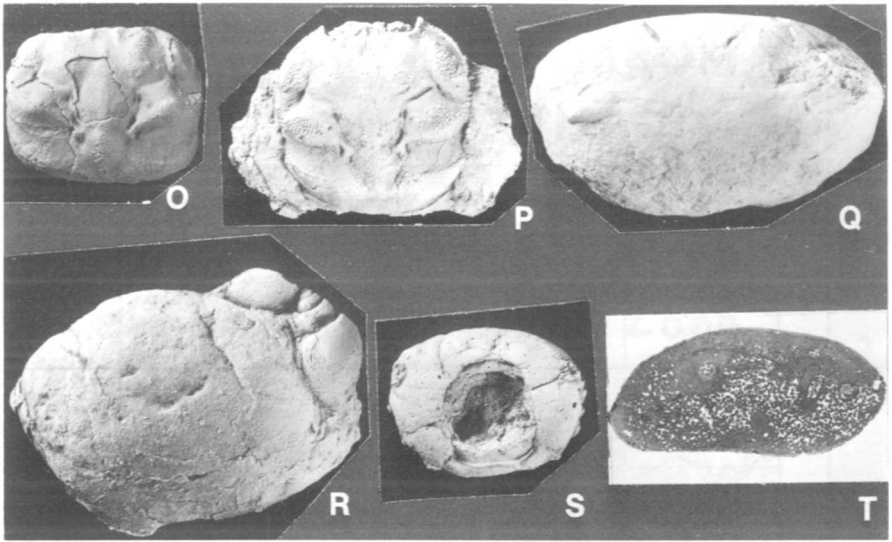


Figure 13-9

Death of the crabs. A. *Dakoticancer overanus* in relaxed position with walking legs extended in normal position and enclosed proximally by concretion, GAB 1-239, Xl. B. *Homolopsis punctata* in relaxed position with walking legs extended in normal position and enclosed proximally by concretion, GAB 1-138, Xl. C. Venter of *D. overanus* showing walking legs in normal position and left claw tucked beneath front of carapace, GAB 4-383, Xl. D. Anterior of *H. punctata* with claws folded in front of carapace (enclosed in concretion) and forming part of concretion boundary, GAB 3-400, Xl. E. Molt of *D. overanus* preserved in "Salter's Position" with carapace flipped over and rotated above the sternum, GAB 4-1039, Xl. F. *Dakoticancer overanus* showing split along pleural suture on right anterior, GAB 4-1531, Xl. G. Carapace of *Raninella oaheensis* exhibiting bite marks, GAB 12-3, Xl. H. *Dakoticancer overanus* disarticulated by predation, GAB 4-1206, Xl. I. Alignment of chelipeds of *D. overanus*, GAB 4-33, Xl. J-K. Dorsum and venter of *D. overanus* showing minor effects of early compaction, GAB 4-661, Xl.

Preservation of the fauna. L. Ovoid concretion devoid of megafossils preserving open burrows, GAB 4-1999, Xl. M. Steinkern of *D. overanus* partly filled by large fecal pellets, GAB 4-1935, Xl. N. Partly filled carapace of *D. overanus* forming right-side-up geopetal, GAB 6-52, Xl. O. *Dakoticancer overanus* preserved by concretion formed along exterior of exfoliating exoskeleton, GAB 6-50, Xl. P. *Dakoticancer overanus* preserved by concretion formed along exterior of carapace exoskeleton and enclosing the proximal part of legs, GAB 1-498, Xl. Q. *Dakoticancer overanus* in concretion enclosing carapace and sternum and extending to the distal part of thoracopods and along the exoskeleton of the claws, GAB 1-358, Xl. R. *Dakoticancer overanus* preserved in concretion enclosing carapace, sternum, most of the legs and extending into nearby gastropods, GAB 1-233, Xl. S. *Dakoticancer overanus* enclosed in concretion and crushed in over carapace by late compaction, GAB 1-443, Xl. T. Transverse thin section of *D. overanus* showing ubiquitous fecal pellets filling and surrounding the telescoped carapace, GAB 9-436, Xl.

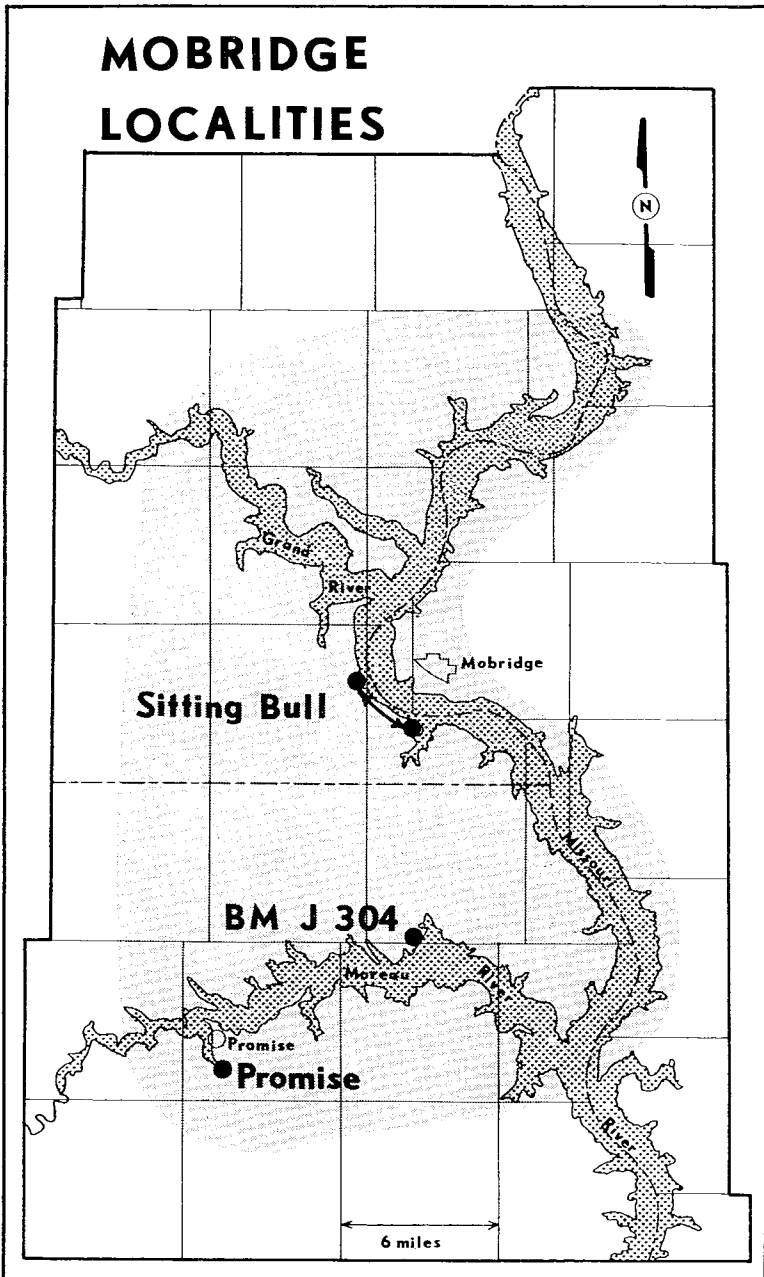


Figure 13-10
The Mobridge localities and the distribution of the *Dakoticancer* Assemblage as mapped by Rothrock, 1947.

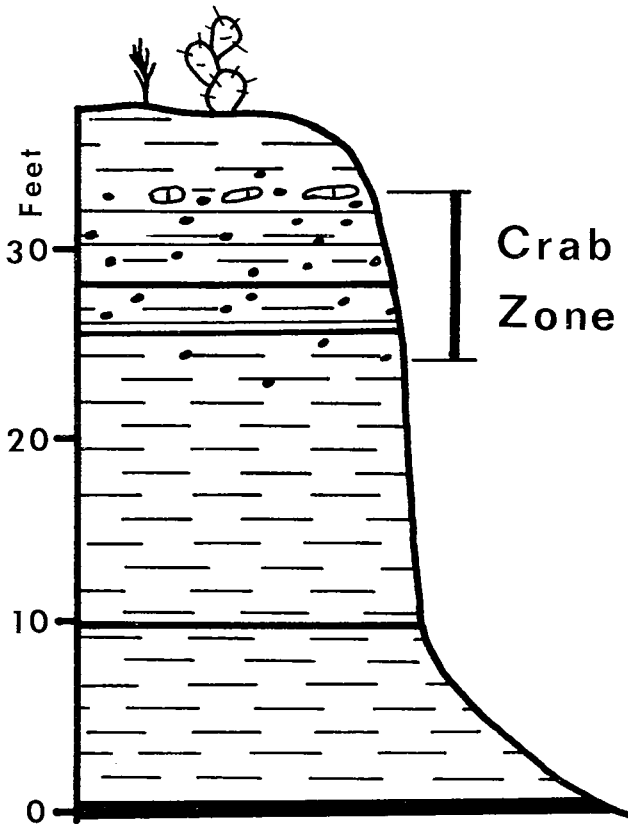


Figure 13-11
Measured sections at the Sitting Bull locality.

small, apatite concretions measuring a few centimeters. The weathered Pierre Shale, or Interior Paleosol, is light olive gray with fractures stained grayish orange. Large concretions in this interval are intensely oxidized, dark brown, and banded. The banding parallels the outside of the concretion and fractures within it. The crab zone at Mobridge is an interval of gray, fissile shale interbedded with a series of thin bentonite beds. The apatite concretions that contain the crabs are found through an interval of 3 m of shale. Bentonite beds are generally thin with a sharp lower boundary and a gradational upper boundary. The bentonites are commonly graded, coarse at the bottom, and much of the coarse fraction is composed of euhedral crystals of dark mica, probably biotite. These beds are usually some shade of yellow or green. The bentonites are devoid of body fossils. However, one bentonite in the crab interval at Mobridge contained a few burrows that were filled with gray mud.

Table 13-2

Fauna collected at each of the three localities with estimates of their relative abundance.

MOBRIDGE LOCALITIES		Zone of <i>Baculites grandis</i> Hall and Meek	
Infaua	Semi-infauna	Epifauna	Plankton and Nekton
Fecal Pellets	<i>Inoceramus</i> (0.8)	* <i>Dakoticancer</i> (75)	<i>Baculites</i> (20)
* <i>Callianassa</i> (0.5)	<i>Dentalium</i> (0.04)	Foraminifera	Foraminifera
<i>Nuculana</i> (0.2)	<i>Drepanochilus</i> (0.08)	<i>Ostrea s. l.</i> (1.5)	Bony fish (2.8)
	<i>Turritella</i> (0.04)	* <i>Necrocarcinus</i> (7.6)	(scales in coprolites)
	* <i>Raninella</i> (0.3)	* <i>HomoLopsis</i> (0.8)	<i>Scaphites</i> (0.6)
		* <i>Sodakus</i> (0.04)	(<i>Hoploscaphites</i>)
n = 3,380		* <i>Lobsters</i> (0.4)	<i>Belemnites</i> (1.7)
		<i>Chlamys</i> (0.04)	Reptiles (0.3)
		<i>Pteria</i> (0.08)	<i>Eutrophoceras</i> (0.08)
		<i>Acmaea</i> (0.08)	Sharks (0.17)
		<i>Hercothyneus?</i> (0.04)	
		<i>Cryptorhytis</i> (0.13)	
		Ostracods	
		<i>Micrabacia</i> (0.04)	
CRESTON LOCALITY		Zone of <i>Didymoceras cheyennense</i> (Meek and Hayden)	
Fecal Pellets	<i>Inoceramus</i> (1.2)	* <i>Dakoticancer</i> (79)	<i>Baculites</i> (4.2)
* <i>Callianassa</i> (1.0)	<i>Durania?</i> (0.1)	* <i>HomoLopsis</i> (0.1)	<i>Didymoceras</i> (3.6)
<i>Nuculana</i> (0.1)	<i>Graphidula?</i> (0.1)	* <i>Lobsters</i> (3.1)	<i>Scaphites</i> (1.2)
<i>Thetis?</i> (0.5)		<i>Acmaea</i> (0.5)	(<i>Hoploscaphites</i>)
<i>Breviarca</i> (0.1)		<i>Syncyclonema</i> (0.3)	<i>Placenticeras</i> (0.3)
		<i>Ostrea s. l.</i>	<i>Osybeloceras</i> (0.3)
n = 650		Bryozoa (0.1)	<i>Eutrophoceras</i> (0.3)
		Worms (0.3)	Wood Fragments
		(Calcareous tube)	
		<i>Necrocarcinus</i> (0.1)	

Fecal Pellets	<i>Inoceramus</i> (0.6)	* <i>Dakoticancer</i> (90)	<i>Baculites</i> (5.8)
* <i>Callianassa</i> (1.6)	<i>Vanikropsis?</i> (2.0)	* <i>Homolopsis</i> (2.4)	<i>Scaphites</i> (0.3)
<i>Nuculana</i> (1.8)	(or <i>Euspira</i>)	* <i>Necrocarinus</i> (0.1)	(<i>Hoploscaprites</i>)
Burrow fillings		* <i>Lobsters</i> (1.1)	<i>Placenticerus</i> (0.2)
"Indiana Bead" (2.5)			<i>Eutrephoceras</i> (0.3)
"Ophiomorpha" (1.0)			Fish (0.3)
			Reptiles (0.1)
			Vertebrate (bone) (0.3)

n = 1,200

Note: The collections were not made for statistical analysis and are biased. Estimates of relative abundance were made from data on hand and are reported in percentages. Infauna = animals that spend most of their lives in the substrate. Semi-infauna = animals partly buried in the substrate. Epifauna = animals that live on the bottom. Plankton = floating animals. Nekton = swimming animals. Asterisks indicate decapods. n = number of specimens.

CONCRETIONS

The majority of the crab specimens are preserved in small light-brown to gray concretions. Only organisms with mineralized tissues composed of apatite or calcite are commonly preserved outside the concretions. Crabs preserved in concretions are in excellent condition, but those not preserved in concretions are commonly crushed almost beyond recognition.

Concretions, in the sense used here, are patches of mineral cement that bind the shale together in coherent masses. The concretions preserving the specimens described in this chapter differ from concretions usually found in the Pierre Shale in the following ways: composed of apatite instead of calcite or siderite, small and measured in centimeters rather than decimeters, and their shape closely conforms to the shape of a single enclosed animal rather than a spherical or discoidal shape independent of enclosed fossils. Concretions from the three localities are remarkably similar to one another. They are all composed of apatite, they are all small, and most of them have their shape determined by enclosed remains. The following generalities can be made about these concretions:

1. The concretions are cemented by apatite.
2. Concretions with no obvious organic remains tend to be spherical, discoidal, or irregular (Figure 13-9L).
3. Concretions that enclose large pieces of organic remains, such as lobsters or vertebrate bones, have a size and shape that closely conforms to that of the enclosed fossil (Figure 13-4H).
4. Small animals are filled with concretionary material. Steinkerns of molluscs are common. Occasionally the shell of the mollusc is preserved. Crabs are commonly preserved as steinkerns (Figure 13-9M) or with their exoskeleton present and forming the boundary of the concretion (Figure 13-9O). The concretionary material may extend beyond the exoskeleton and partly enclose the animal (Figure 13-9P).
5. Very small molluscs are preserved in concretions that formed around nearby larger animals (Figure 13-9R).
6. There are two types of burrow fills. An *Ophiomorpha* type was found in small numbers only at Thomson Butte. Cylindrical burrows with a concentric layering (Indian Beads or *Serpula? wal-lencensis*) were found at Mobridge and Thomson Butte.
7. Coprolites (Bishop, 1977) are included as concretions because they have the same mineralogic composition. Half-cylinders (which contain concentric layers of fish scales), spiral coprolites, and fecal pellets are present.

FAUNAL ASSOCIATIONS

The taxa collected at the three localities are remarkably similar (Table 13-1 and Figure 13-4). The consistency of the composition of the fossil assemblages suggests that they are community fractions killed and preserved by similar processes. *Dakoticancer overanus* Rathbun is dominant at each locality and comprises the major portion of each collection. Many other taxa are present in relatively insignificant quantities (Table 13-1). The stratigraphic and geographic proximity of the Creston and Thomson Butte localities is

reflected in similarities in faunal assemblages. Also, the temporal and geographic separation of the Mobridge locality from these two is reflected by significant differences.

SYNTHESIS OF THE DATA

The faunal assemblages found in the Pierre Shale are interpreted as community fractions because of their similarity in distribution, faunal composition, and mode of preservation. Characterization of the community fraction according to trophic levels, consistent associations, and mode of life was attempted. The arrangement of the taxa according to their probably mode of life was most productive (Table 13-2). This arrangement resembles "Assemblage R" described by Kauffman (1967:126) from the Western Interior Cretaceous.

THE DAKOTICANCER ASSEMBLAGE

"Assemblage R" is interpreted as a "diverse, moderately deep water, middle and outer shelf assemblage" composed of the following elements (Kauffman, 1967:126):

1. Oysters reduced to small, flat, thin-shelled encrusting types.
2. A few, large, ornate ammonites.
3. Consistently occurring scaphites and smooth, involute ammonites such as *Placenticerus*.
4. Common *Baculites* and small, finely ornate ammonites.
5. *Lucina*; *Nucula*; *Nuculana*; *Pteria*; *Tellina*; *Syncyclonema*; subequivalved, thin-shelled inoceramids like *Mytiloides*; and large, flat, thin-shelled inoceramids.
6. The gastropods *Certithiella*, *Lispodesthes*, *Acmaea*, *Bellifusus*, and *Euspira* may be present.

This assemblage is postulated to have inhabited the seabottom at a depth of 92 to 150 m.

Kauffman's "Assemblage R" and the *Dakoticancer* assemblages are very similar and differ principally by the addition of the decapods to the molluscan assemblage.

Waage (1964, 1968:160) also described assemblages from the Upper Cretaceous of South Dakota. The assemblages are from the Maastrichtian Fox Hills Formation and have the following characteristics:

1. A great abundance of specimens and one or two species numerically dominant.
2. Excellent preservation of most specimens in which the bivalves commonly are preserved with unseparated valves.
3. Random orientation and lack of size sorting of specimens in individual concretions, but a tendency for dominant bivalve species to occur in size-group aggregations.
4. Distribution over a limited area beyond which the horizon is unfossiliferous.
5. Dominance of one particular faunal association in a settlement with patterned distribution of subdominant associations relative to it.
6. Aggregation of individual species in clusters.

The *Dakoticancer* assemblage resembles Waage's assemblages, but differs from them because the *Dakoticancer* assemblage was a community composed of a large proportion of vagrant benthos whereas Waage's molluscan assemblages were sessile benthos.

The *Dakoticancer* assemblage has the following characteristics:

1. Infauna: Restricted, consisted of soft-bodied organisms, a few burrowing crustaceans (*Callinassa*, burrow fills), and bivalves *Lucina*, *Nucula*, *Thetis?*, and *Breviarca*.
2. Semi-infauna: Numerous subequivalve, convex, thin-shelled inoceramids; gastropods *Turritella*, *Vanikoropsis*, and *Drepanochilus*; decapods *Raninella*, and lobsters.
3. Epifauna: Dominated by decapods, especially *Dakoticancer*; gastropods *Herctorheycus*, *Cryptorhytis*, and *Acmaea*. The bivalves *Syncyclonema*, *Pecten*, *Pteria*, and *Ostrea s. l.* are present in small numbers. A few scaphopods and benthonic foraminifer are also present. The rest of the epifauna is composed of the decapods *Homolopsis*, *Necrocarcinus*, and *Sodakus*.
4. Plankton: Dominated by planktonic foraminifer, the bulk of the plankton probably was not preserved.
5. Nekton: Dominated by *Baculites*; other cephalopods, *Scaphites*, *Placenticerus*, *Didymoceras*, *Oxybeloceras*, *Eutrephoceras*, and *Belemnitella*; bony fish; sharks; and reptiles.

In the *Dakoticancer* assemblages, it is likely that the worms or small, soft-bodied defactors and crabs lived at the same time in the same area.

These assemblages resemble Holocene communities in their consistent faunal composition and the numerical dominance of one or two species in each assemblage (Thorson, 1957:519). Decapod communities have been described only from warm seas, which are therefore somewhat characterized by their presence. Miyadi (1941) described the *Pinnixa rathbuni* Community from Ise Wan and Mikawa Wan, Japan. The community, reaching a density of 3,000 mature crabs per square meter was found in water depths of 7 to 37 m on gravel, sand, and muddy-sand substrates. Thorson (1957:518) described the *Xenophthalmus pinnotheroides* Community in the Persian Gulf. The crab *Xenophthalmus pinnotheroides* reaches densities of 1,500 mature crabs per square meter in 20 m of water on a loose-sand substrate. Other taxonomic members of these communities are quantitatively insignificant. Thorson interpreted both communities as enormous populations that could exist only in warm, shallow, turbulent water where they fed on highly productive plankton. Although these communities are not completely analogous to the *Dakoticancer* Assemblage, parallels are extremely suggestive of the *Dakoticancer* community that we see preserved in the Pierre Shale.

DEATH OF THE CRABS

The crab specimens preserved in the *Dakoticancer* Assemblage often have considerable portions of their appendages preserved. These crabs are usually preserved with claws loosely drawn in front of the carapace and the walking legs extended in a normal manner away from their body (Figure 13-9A-D). Because none were found in an escape

position (Schäfer, 1972:138) with appendages raised and claws open, I assume the crabs were dead when buried. They, therefore, must be buried corpses or molts. Criteria are available to distinguish corpses from molts only if the crab is preserved with the carapace flipped upward and forward on the sternum (Salter's Position) as the body decomposes and currents or scavengers move the carapace. Molts are split along the plural suture whereas corpses are separated from the sternum with the pleural suture intact (Schäfer, 1972:139). Bishop (1972b) described molts from the *Dakoticancer* Assemblage and concluded that about 0.5 percent of the specimens from the Mobridge localities are definitely molts (Figure 13-9E). The rest of the specimens (99.5 percent) do not present clear evidence of their condition at time of burial. The specimens of *Dakoticancer* are usually split along the pleural suture (Figure 13-9F) and the carapace is pushed down with the edges of the pleural suture overlapping (Figure 13-9T). One specimen of the 5,000 examined crabs shows evidence of predation (Bishop, 1972a) tooth marks (Figure 13-9G). The jumbled condition of a few others (Bishop, 1975:277) may also be evidence for predation, scavenging, or postecdysis ingestion (to recover the nutrients by the molter). Only one specimen (Figure 13-9I) shows any evidence of appendage alignment reminiscent of movement of the exoskeleton by scavengers or currents. The preservation of the vast majority of crabs of all sizes (that is, all ages) combined with the lack of evidence of scavenging seems to point toward the conclusion that the crabs were killed in catastrophic mass-killing events. The occurrence of crab fossils interbedded with several bentonite beds (isochronous surfaces) necessarily means that the *Dakoticancer* Assemblage did not accumulate at one time. I, thus, suggest that *Dakoticancer* communities occasionally inhabited parts of the stable eastern shelf and existed in an unstable environment that fluctuated between conditions favorable to the decapod community and those that repeatedly killed large parts of the community. This hypothesis is confounded by limited quarry data that indicates the crabs are not concentrated along bedding planes as one might expect in a mass killing. However, because this data is limited to one quarry between two bentonites at the Sitting Bull locality, the hypothesized repeated mass killings seems to be the best hypothesis now available.

Brongersma-Sanders (1957) presents a comprehensive discussion of mass mortalities. She divides them into the following categories:

- *1. Vulcanism
- *2. Salinity changes
- *3. Temperature changes
- *4. Noxious waterbloom
- *5. Oxygen depletion or poisonous gases
6. Sea or earthquake
7. Spawning
8. Stranding
9. Storms
10. Vertical currents

Any combination of the first five categories (starred) seems possible (or probable) in the faunas collected from the Pierre Shale. As mentioned previously, transport of sediment by fresh surface currents would allow large amounts of fine sediment to be transported great distances. This would allow local conditions in one part of the bas-

in to affect other parts by transfer of large quantities of water and sediment. It, also, would locally change salinity, temperature, and nutrient levels. Local flooding due to terrestrial rains could cause these drastic changes.

Waage (1964:541) concluded that the assemblages described from the Fox Hills are the result of mass killings of recurrent benthonic communities by "conditions of excessive turbidity and lowered salinity, possibly brought about by repeated influx of sediment-charged fresh water from rivers in flood."

BURIAL

The decapods were probably buried by a rapid rain of fine-grained sediment. The lack of alignment of skeletal elements and the discrete thin beds of bentonite indicate the bottom was unaffected by currents strong enough to move the volcanic ash or the dead animals. Possibly the mud was transported by low-salinity surface currents and flocculated at the contact with more saline, deep waters. This mechanism would allow for rapid changes in temperature, salinity, and turbidity and could affect levels of gas in the water and the growth of phytoplankton. Any combination of these factors could have exceeded the tolerance limits of the biota and caused mass deaths.

Shortly after burial, the soft parts of the decapods and other animals began decaying. The thin articulating membranes of the decapods probably decomposed fairly rapidly. Mud began filling the inside of the shells and exoskeletons. The sediment was reworked by several kinds of soft-bodied organisms as the remains filled (Bishop, 1977). The organisms included segmented worms as evidenced by impressions (Figure 13-4L). The organisms moved through the sediment ingesting it and extruding it as feces (Figures 13-4I, K, L; Figure 13-9L, M, T). The intensity of burrowing in the sediment filled decapods and molluscs indicates that great numbers of burrowers were present shortly after burial. The amount of time before burial and concretion formation was relatively short because the decapods are still articulated (Zangerl, 1971:1207). The infaunal burrowers were probably not affected by mass mortalities of the epibiota.

Some of the crabs were only partly filled with sediment. These specimens usually collapsed during diagenesis (Figure 13-9S). Fragments of the crushed carapace are preserved on the sediment surface inside the cephalothorax. The effects of compaction due to the weight of overburden slightly disarranged skeletal elements of most specimens (Figure 13-9J, K). The carapace and ventral side are commonly crushed together, which results in the ventral side sliding backward (Figure 13-9K). Other compaction effects are a split carapace along lines of weakness (Figure 13-9F, T); a disarrangement of abdomen somites, either as a crushing against the sternum or a twisting of the somites out of their relative positions (Figure 13-9K); and a crushing of appendages where exposed at the surface of concretions (Figure 13-9D).

Thin sections of Mobridge concretions often show that the exoskeleton has been removed by dissolution and the void space squeezed shut with no fracturing of the concretion (Figure 13-9T); on some specimens the exoskeleton is completely missing.

CONCRETION FORMATION

The formation of concretions is, at least in part, directly related to organic remains. A progressive tendency in the degree of concretion growth is present at the three localities; concretions from the Creston locality are body fillings (Figure 13-90), those from Moberidge commonly extend beyond the exoskeleton (Figure 13-9A-C), and those from Thomson Butte often completely enclose the decapods except for the distal ends of the appendages (Figure 13-9D, P-S).

Apparently, the inside of decapods and molluscs were especially susceptible to concretion formation. The interior of decapods and molluscs have the following characteristics in common:

1. They are relatively closed spaces.
2. They were once living and contained decaying organic matter.
3. The sediment filling the spaces has been burrowed and pelleted.

Some concretions grew only until they filled the interior of the shells or exoskeletons, as at the Creston locality. Others continued to grow outside the skeletons of the animals, as at Moberidge and Thomson Butte. The size and shape of the concretions were strongly influenced by the type of organic remains they grew in or around. The factor controlling shape of the concretions seems to be the relative thickness of the concretionary material compared to the size of the enclosed fossil. The factors that controlled the amount of material precipitated are unknown. They undoubtedly include physical-chemical conditions and available time.

The processes of preservation can be summarized in a model from the time of embedding to discovery (Figure 13-12; Table 13-3).

Table 13-3

Evidence and summary of events in the preservation of the *Dakoticancer* assemblages.

OBSERVATION	DEDUCTION
1. The specimens that have appendages show them to be in a "normal" position, not raised above the carapace in the escape position.	1. Most crabs were not buried alive.
2. One-half of one percent of the Moberidge specimens are preserved in "Salter's position" and several of them have the carapace split along the pleural sutures with the lower part of the carapace sitting on the sternum.	2. Some specimens are molts.
3. Crabs of all sizes (=ages) are present in the collections.	3. The decapods were probably involved in a series of mass

Table 13-3 (continued)

OBSERVATION	DEDUCTION
There is little evidence that scavengers survived to prey on the dead animals. The decapods are found interspersed among several bentonites at Mobridge indicating a series of events must have happened.	killings.
4. Only one specimen was seen that showed any alignment of appendages. Geopetal structures inside the crabs are right-side-up.	4. The dead animals were rapidly buried by a process that did not involve currents of sufficient strength to rearrange appendages.
5. The carapaces on some specimens are crushed onto the flat sediment surface that was inside the crabs. Some specimens are partly filled and not crushed.	5. The specimens were filled with sediment. Some were partially filled.
6. Nearly all decapods and molluscs have been intensely burrowed and pelleted.	6. Soft-bodied organisms moved through the sediment ingesting it and extruding it as fecal pellets.
7. In most specimens, the abdomen and sternum are crushed into the carapace. The carapace of most specimens has broken along the pleural sutures.	7. There was some compaction of the specimens before concretions formation.
8. Many specimens from the Mobridge localities have the carapace dissolved away in some areas and the resulting void closed without fracturing the overlying concretionary material.	8. Early diagenesis involved dissolution of the carapace of some specimens.
9. Parts of decapods extending beyond the concretions are crushed. Specimens from Thomson Butte have concretionary material brecciated and pushed down into the crabs' interiors.	9. There was some crushing of the specimens after the concretions formed.
10. Thomson Butte specimens that were not completely filled with sediment have the void spaces filled with euhedral barite crystals. Weathering rinds are present on nearly all specimens.	10. Late diagenesis involved filling void spaces with barite and weathering effects.

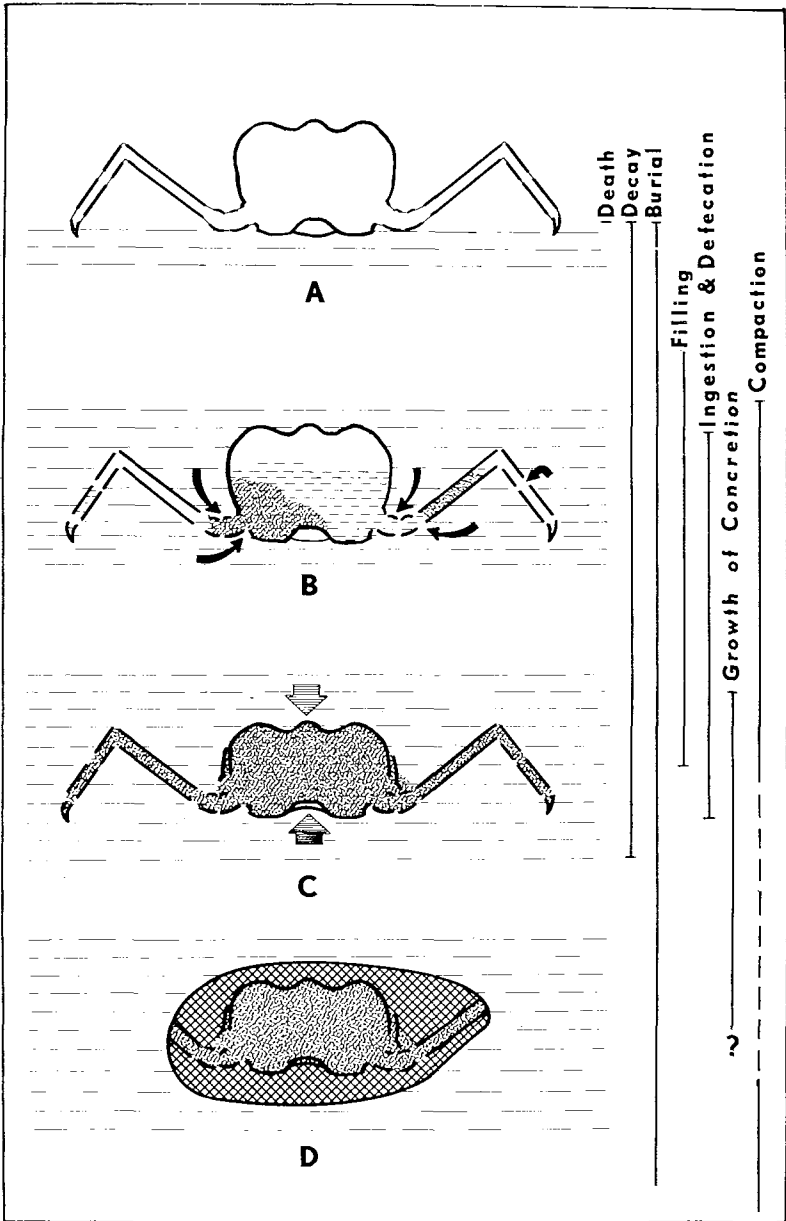


Figure 13-12

Fossilization of specimens from the *Dakoticancer* Assemblage. Transverse cross section of dead decapod lying on the bottom (A) and decapod after articulating membranes have broken down (B). Mud begins to fill the interior and be ingested and extruded as fecal pellets (mottled). Completely filled burrowed, and pelleted decapod undergoing pre-concretion compaction (C). Specimen enclosed in apatite concretion with portions extending beyond concretion destroyed by Diagenesis (D).

After burial of the remains by a gentle rain of sediment, the thin articulating membranes were destroyed allowing sediment to enter the interior of the decomposing decapods. Sediment also probably entered through the buccal frame and through openings between the carapace and the sternum.

The sediment in and around the decapods was then ingested by worms and extruded as fecal pellets. The presence of fecal pellets and their probable phosphate enrichment (Moore, 1939:522) may be related to the formation of apatite in the enclosed organic environments inside shells and exoskeletons. The prominence of phosphates in fossil fecal material is emphasized by Hantzschel et al. (1968, Text-Figure 35).

Some solution of the exoskeletons of some specimens occurred concurrently with concretion formation. If the crabs were not completely filled with sediment, the growing partially hardened concretion could be collapsed by compaction (Figure 13-9S). Remaining void spaces were then filled with barite. All other diagenetic changes seem to be the result of weathering phenomena; a thin rind around the outside of the concretions is characteristic.

The preservation of decapods in phosphatic concretions is not unique to the Pierre Shale. Other collections of decapods preserved in apatite concretions from the Pierre have been made at Wasta (GAB 7), Belle Fourche (GAB 36), and Fort Pierre (GAB 12), South Dakota; and Albion, Montana. A collection from the Carlile Formation (Turonian) north of the Black Hills, South Dakota, includes numerous lobsters preserved in apatite concretions. Bachmayer and Mundlos (1968) described a decapod fauna preserved in apatite concretions from the Tertiary near Helmstedt, Lower Saxony.

Mundlos (1975) described the processes of preservation of the Helmstedt specimens as a process remarkably similar to those envisioned for the *Dakoticancer* assemblages from the Pierre Shale. The basic scenario presented by Mundlos postulates the following sequence of events:

1. Burial in the substrate.
2. Death.
3. Sediment infilling of corpses.
4. Enrichment by phosphate matrix due to small worms.
5. Precipitation of four types of apatite concretions based on degree of crab preservation.

The preservation of decapods in phosphatic concretions seems to be a common mode of preservation, but it is not the only one. Decapods from the Pierre Shale have recently been discovered (GAB 35) preserved in calcite concretions that bear a remarkable resemblance to the apatite concretions in size, shape, and perhaps distribution.

DISCUSSION

The hypothesized accumulation as corpses is challenged (Richards, 1975:1855) on the basis that most of the specimens collected are probably molts and not corpses. The common occurrence of carapaces split along pleural sutures and the lack of preserved internal skeletons support this possibility. I currently interpret these phenomena to be the result of differential decomposition exhibited first by

thin membranes and zones of weak mineralization. Research currently underway should develop criteria useful in distinguishing molts from corpses when not preserved in "Salter's Position" and at advanced stages of decomposition.

Should the specimens prove to be molts, the hypothesis presented here will have to be modified somewhat. The reality of the *Dakoticancer* Assemblage and the hypothesized preservation will remain unchanged. The hypothesized, repeated mass killings would have to be rejected in favor of acculations of molts in great numbers and without evidence of postmolting ingestion of the exuviae that is so common in the behavior of the decapods.

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