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Paleontology and stratigraphy of upper Coniacian–middle Santonian ammonite zones and application to erosion surfaces and marine transgressive strata in Montana and Alberta

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Abstract

Erosional surfaces are present in middle and upper Coniacian rocks in Montana and Alberta, and probably at the base of the middle Santonian in the Western Interior of Canada. These erosional surfaces are biostratigraphically constrained using inoceramid bivalves and ammonites, which are used to define lower, middle, and upper substages of both the Coniacian and Santonian stages of the Upper Cretaceous in this region. The most detailed biostratigraphy associated with these erosional surfaces concerns the MacGowan Concretionary Bed in the Kevin Member of the Marias River Shale in Montana, where the bed lies disconformably on middle or lowermost upper Coniacian strata, and is overlain by upper Coniacian beds. Surface and subsurface investigations in west-central Alberta reveal that the Bad Heart Formation, bounded by unconformities, is about the age of the MacGowan Concretionary Bed. Coniacian and Santonian strata are present elsewhere in Alberta and adjoining areas, but little has been published concerning the Santonian megafossils.

Keywords: Coniacian; Santonian; Cretaceous; MacGowan Concretionary Bed; Western Interior; Unconformities

1. Introduction

Two erosional surfaces in Coniacian–Santonian age marine sequences can be traced over much of west-central Montana and western Alberta (Fig. 1). In terms of the standard stages of the Upper Cretaceous, the older erosional surface is within upper Coniacian rocks, and the younger surface is at or near the base of middle Santonian strata. The surfaces are interpreted as having formed during relative sea-level lowstand events, and thus represent potential sequence boundaries within the marine section.

Although these erosion surfaces are present at least as distant as southwestern Utah (Peterson, 1969), the Black Hills (Tourtelot and Cobban, 1968), and northeastern Nebraska (Hattin, 1982), they are more conspicuous and dated better in Montana and Alberta, where many beds of concretions below and above the surfaces contain useful inoceramid and ammonoid guide fossils. In addition, the surfaces are marked by conglomerates easily recognized in sequences of shale in contrast to their presence in sandstone beds farther south.

In this report, we (1) discuss the paleontology and biostratigraphy of the Coniacian–Santonian interval in central Montana and Alberta using new faunal data and

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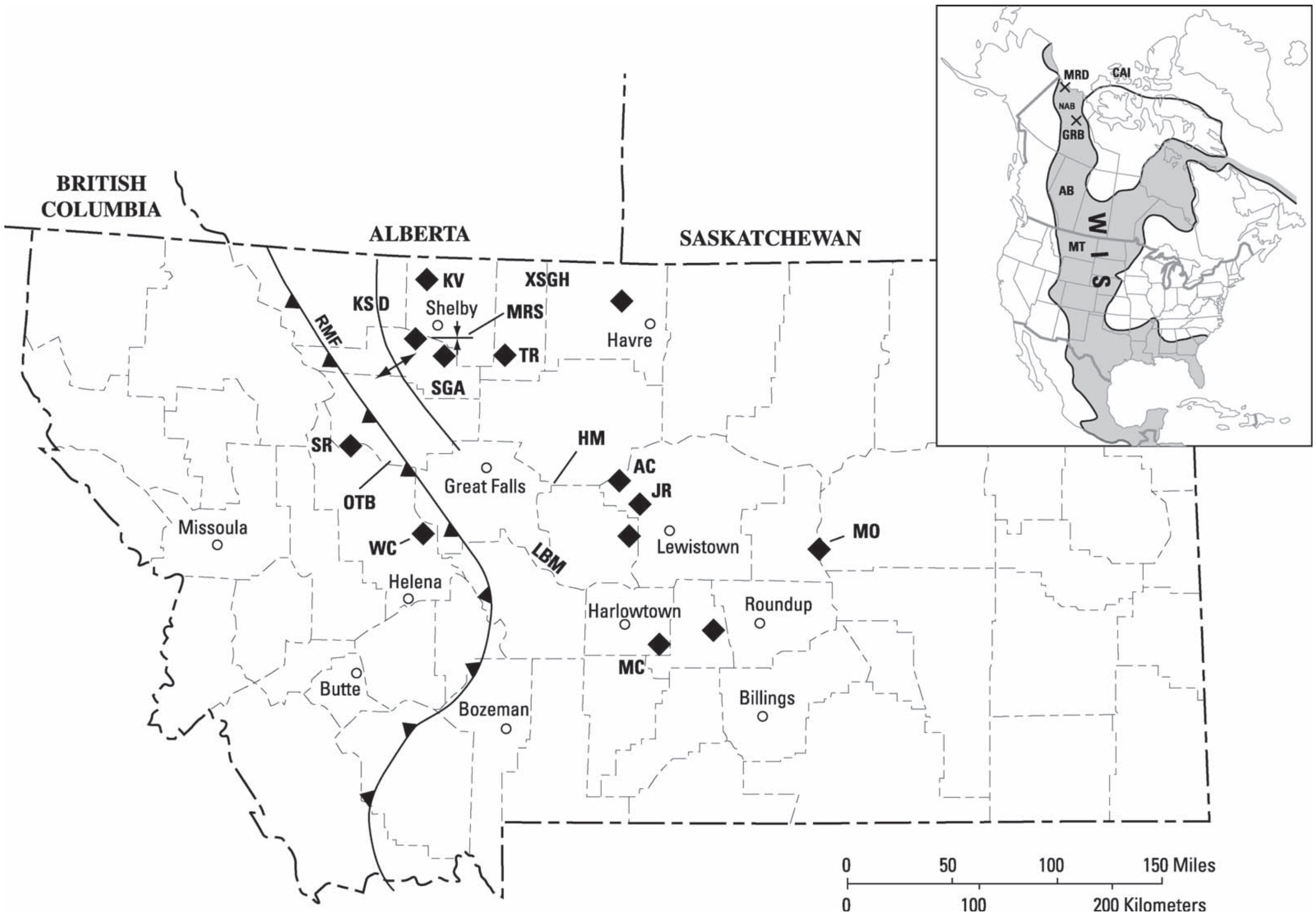

Fig. 1. Map of known localities of MacGowan Concretionary Bed in Montana (solid diamonds, labeled if referenced in this report). Abbreviations: KV, Kevin measured section; TR, Tiber Reservoir measured section; AC, Arrow Creek measured section; SR, Sun River measured section; JR, Judith River measured section; MO, Mosby measured section; MC, Mud Creek measured section; WC, Wolf Creek; LBM, Little Belt Mountains; HM, Highwood Mountains; SGH, Sweetgrass Hills; MRS, Marias River Shale; KSD, Kevin-Sunburst Dome; SGA, Sweetgrass Arch; OTB, Overthrust belt; MRD, Mackenzie River delta; GRB, Great Bear Lake; CAI, Canadian Arctic Islands; NAB, Northern Alberta Foothills; RMF, Rocky Mountain front; AB, Alberta; MT, Montana; WIS, Western Interior seaway.

revisions to previous work; (2) describe measured sections within the Coniacian–Santonian stratigraphic interval in central Montana and integrate our findings with previously published data for the same interval elsewhere in the Western Interior of North America; (3) show the mapped distribution of the Coniacian–Santonian shorelines in central Montana and Alberta in relation to the same shorelines delineated elsewhere in the Western Interior; and (4) emphasize recent developments in defining the boundaries of the Coniacian and Santonian stages.

Fig. 2 shows (1) the subdivisions of Coniacian and Santonian stages, (2) the ammonite and inoceramid zonation for these stages in the Western Interior of the United States, and (3) critical rock sequences in Montana and Alberta.

2. Study area

Central Montana is generally referred to as the area lying between the Montana thrust belt on the west and the Plains region of eastern Montana on the east (Fig. 1). The area includes many small and large uplifts and intrusive centers, around some of which there are excellent exposures of the thick marine Cretaceous rocks that are commonly deeply dissected by modern drainages. The outcrop localities reported on here extend from the Kevin-Sunburst Dome on the Sweetgrass Arch of north-central Montana southeastward to Tiber Reservoir and farther eastward to Mosby, Montana (Fig. 1). Some of these localities are here described for the first time.

3. Paleontology and biostratigraphy

At the Second International Symposium on Cretaceous Stage Boundaries held in Brussels, Belgium, 1995, the following recommendations were made regarding the Coniacian Stage (Kauffman et al., 1996): (1) the Coniacian Stage should be subdivided into lower, middle, and upper substages, (2) the base of the Coniacian is the first appearance of the inoceramid bivalve *Cremnoceramus rotundatus*, (3) the base of the middle Coniacian is the first appearance of the coiled inoceramid *Volviceramus koeneni*, and (4) the base of the upper Coniacian is the first appearance of the inoceramid *Magadiceramus subquadratus*. *Cremnoceramus rotundatus*, originally described as *Inoceramus inconstans rotundatus* Fiege (1930), has recently been shown to be a junior synonym of *I. erectus* Meek (1877), and thus the base of the Coniacian is also the first appearance of *C. erectus* (Meek) (Walaszczyk and Cobban, 1998). *Cremnoceramus erectus* is abundant in the basal part of the Kevin Member of the Marias River Shale in north-central Montana (Fig. 2). The species is also in the Leyland Member of the Cardium Formation in Alberta (Collom, 1998). Irish (1965, p 73) reported "*Inoceramus*" sp. indet. (cf. *erectus* Meek) "from the Muskiki Formation of the northern Alberta Foothills". Specimens of *Cremnoceramus erectus* from the Wapiabi Formation of the northern Foothills (Fig. 2) are present in the collections of the Geological Survey of Canada in Ottawa.

Volveramus koeneni, of early middle Coniacian age, is present in the Kevin Member of the Marias River Shale in Montana and in the Wapiabi Formation in Alberta (Collom, 1998). The species gave rise to *V. involutus*, a coiled species that is abundant in the upper middle Coniacian zone of *Scaphites ventricosus* in Montana and Alberta (Fig. 2). As noted by Jeletzky (1968), the various coiled species named by Meek and Hayden (1858, 1862) as *Inoceramus umbonatus*, *I. exogyroides*, and *I. undabundus*, from rocks now included in the Kevin Member in north-central Montana, may be all junior synonyms

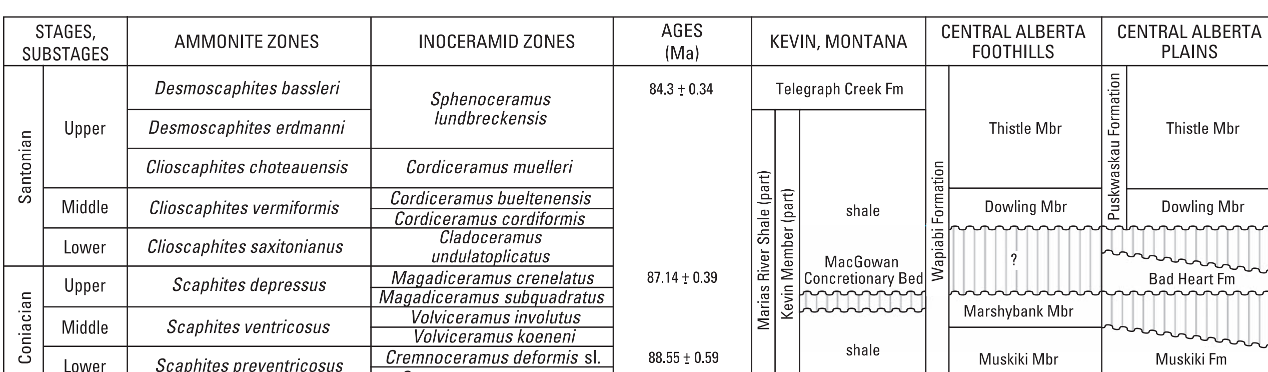

Fig. 2. Coniacian and Santonian substages, ammonite and inoceramid zones, and key stratigraphic sequences in Montana and Alberta. The inoceramid zonation is tentative. Some additional zones are present in the lower Coniacian (e.g., Collom, 1998; Walaszczyk and Cobban, 1998), but the species are closely related to *Cremnoceramus erectus* and *C. deformis*. The species in the upper Coniacian and Santonian are presently under study by Cobban and I. Walaszczyk. Wapiabi Formation includes the Marshybank and Muskiki members based on work by Braumberger and Hall (2001). Radiometric ages based on work by Obradovich (1993) and unpublished data of Obradovich.

of *V. involutus* (Sowerby, 1828). The upper Coniacian inoceramid *Magadiceramus subquadratus* (Schlüter, 1887), based on a specimen from the Austin Chalk of Texas, has not been observed in Montana or Alberta, but there are ample other molluscan species restricted to that substage that can serve as guide fossils such as "*Inoceramus*" *stantoni* Sokolow.

Regarding the Santonian Stage, the following recommendations were made at the Brussels Meeting (Lamolda and Hancock, 1996): (1) a threefold division (lower, middle, and upper) should be used for the Santonian, (2) the inoceramid bivalve *Cladoceramus undulatoplicatus* should be used as a guide fossil for the base of the lower Santonian, (3) the inoceramid *Cordiceramus cordiformis* was suggested as a guide to the base of the middle Santonian, and (4) the first appearance of the crinoid *Uintacrinus socialis* should define the base of the upper Santonian. *Cladoceramus undulatoplicatus* has long been accepted as a guide to the lower Santonian. That species, characterized by its large size and ornamentation of concentric and radial folds, was first described from the Austin Chalk as *Inoceramus undulatoplicatus* Roemer (1852). It is also present in the Niobrara Formation in Colorado and Kansas, but has not been recorded farther north in the United States, although Stelck (1962) reported it from the Wapiabi Formation in northeastern British Columbia.

Cordiceramus cordiformis, first described as *I. cordiformis* J. de C. Sowerby (1823) from the Upper Chalk of England, has a squarish outline with one or two radial sulci. The species is widely distributed in the Western Interior of the United States, where it seems to be restricted to the ammonite zone of *Clioscaphites vermiformis*. The species described by McLearn (1926) as *I. pontoni* from the Bad Heart Formation of Alberta appears to be a *Cordiceramus*, as already noted by Jeletzky (1968). Other forms from the Bad Heart described by McLearn (1926) as *I. coulthardi* and *I. selwyni* may be variants of *C. cordiformis*. The crinoid *Uintacrinus socialis* Grinnell (1876) is widely distributed in Europe and in the Gulf coastal region and the Western Interior of the United States. Local concentrations have been found in the Smoky Hill Chalk Member of the Niobrara Formation in western Kansas and in the equivalent part of the Mancos Shale in western Colorado. In north-central Montana, *U. socialis* was collected near the top of the Kevin Member of the Marias River Shale in the ammonite zone of *Desmoscaphites erdmanni* and farther south in Montana from the zone of *D. bassleri* (Cobban, 1995). The Kansas specimens may be from the slightly older *Clioscaphites choteauensis* Zone (Hattin, 1982). The crinoid has also been found in the Wapiabi Formation in Alberta (Warren and Crockford, 1948).

The ammonite zonation shown in Fig. 2 is from Cobban (1993). Although other generic names have been proposed for some of the scaphitid species (Cooper, 1994), we are retaining the older, well-established nomenclature for this report. The inoceramid zonation is tentative. The lower Coniacian zones are from Walaszczyk and Cobban (1998), but the stratigraphically higher zones are presently under study by those authors.

3.1. Scaphites depressus *Zone in Montana*

Scaphites depressus was described as *S. ventricosus* Meek and Hayden var. *depressus* by Reeside (1927). The type was among a collection of fossils made by Edwin Binney, Jr., from the Cody Shale 220–250 m (720–820 ft) above the base at Oregon Basin oil field in northwestern Wyoming (Hewett, 1926). A Coniacian age was indicated by the presence of coiled inoceramid bivalves and ammonites identified as *Mortoniceras shoshonense* Meek and *Phlycticrioceras oregonense* Reeside. The coiled inoceramid bivalves, now assigned to *Volviceramus*, are confined to rocks of middle and late Coniacian age, and the ammonites, now assigned to *Protexanites bourgeoisianus* (d'Orbigny) and *Phlycticrioceras trinodosum* (Geinitz) by Kennedy and Cobban (1991), are known from the upper Coniacian of Europe. Reeside (1927) also included the ammonite *Scaphites vermiformis* Meek and Hayden in the fauna from the Oregon Basin locality and assigned it to the Coniacian. This species, later transferred to *Clioscaphites*, was determined to be of middle Santonian age (Cobban, 1951, 1952). *Scaphites depressus* was first proposed as a distinct zone by Cobban (1951) and placed in the basal part of the Santonian below a Santonian zone of *C. vermiformis* and above a Coniacian zone of *S. ventricosus*. In the following year Cobban and Reeside (1952a,b) assigned the zone of *S. depressus* to the upper part of the Coniacian. Scott and Cobban (1964) reported *S. depressus* with *Cladoceramus undulatoplicatus*, a lower Santonian fossil, at one locality near Pueblo, Colorado, which prompted Obradovich and Cobban (1975) to reassign the zone of *S. depressus* to the basal Santonian. Kennedy and Cobban (1991) noted that *C. undulatoplicatus* is not in the large collections of *S. depressus* from Wyoming, and they placed the *depressus* Zone back into the top of the Coniacian. The single specimen figured by Scott and Cobban (1964, pl. 5) as *S. depressus* from the *undulatoplicatus* locality near Pueblo is a fragment of the older part of a body chamber. It appears to be *S. depressus*, but without more convincing material, the presence in the *depressus* Zone is suspect; the specimen was possibly collected a little lower than *C. undulatoplicatus*.

Ammonites of the *S. depressus* Zone were monographed by Kennedy and Cobban (1991). Species restricted to the zone include *Protexanites bourgeoisianus* (d'Orbigny), *Phlycticrioceras trinodosum* (Geinitz), *Scaphites depressus* Reeside, and *S. binneyi* Reeside. *Baculites*

codyensis Reeside is abundant, but ranges a little below and a little above the *S. depressus* Zone. Inoceramid bivalves that seem to be restricted to this zone in Montana include *Inoceramus stantoni* Sokolow and *Magadiceramus subquadratus* (Schlüter). *Volviceramus involutus* (Sowerby), which is abundant in the underlying *S. ventricosus* Zone, ranges up into the *S. depressus* Zone, where it is rare. Other fossils from the *S. depressus* Zone are listed by Cobban et al. (1958).

Scaphites depressus is known from many localities in Montana as well as in northwestern Wyoming (Fig. 3). Farther south, the species is represented by sparse specimens in the Niobrara Formation in southeastern Colorado and in the Mancos Shale in western Colorado and eastern Utah.

3.2. Scaphites depressus *Zone in Alberta*

Scaphites depressus is known from several localities in the Foothills of southwestern Alberta and farther north in the Plains region (Fig. 3). An occurrence much farther north was noted by Jeletzky (1971), who recorded the species from the Kanguk Formation in the Canadian Arctic Archipelago. Specimens from the Kanguk on Axel Heiberg Island were later described and illustrated by Hills et al. (1994).

J.A. Jeletzky (1971) reported on many collections of invertebrate fossils collected by D.F. Stott and others of the Geological Survey of Canada during the period 1948–1988. Although he figured a splendid specimen of *S. depressus* from Alberta (Jeletzky, 1970, pl. 26), Jeletzky interpreted the species in a very broad sense, assigned it to the Santonian, and apparently included in it specimens of *Clioscaphites montanensis* Cobban of middle Santonian age (*Clioscaphites vermiformis* Zone). As a result, Stott reported *S. depressus* as a Santonian fossil from the upper part of the Muskiki Member of the Wapiabi Formation (Stott, 1967), from the overlying Marshybank Member (Stott, 1961, 1963), and from the still younger Dowling Member (Stott, 1961), all in western Alberta. Jeletzky (1968) reported that *S. depressus* and *S. saxitonianus* occur together in the Bad Heart Sandstone in central western Alberta, and that both forms ranged up into the lower part the *Clioscaphites vermiformis* Zone. Stelck (1962) had earlier shown the Bad Heart as lying in the *S. depressus* Zone of late Coniacian age. In recent works (e.g. Donaldson et al., 1998), *S. depressus* has been recorded from the Bad Heart, and a late Coniacian age accepted.

3.3. Clioscaphites saxitonianus *Zone in Montana*

Scott and Cobban (1962) observed that the zone of *Clioscaphites saxitonianus* (McLearn) separates the zones of *S. depressus* and *C. vermformis*. The type specimens of *C. saxitonianus*, originally described as *Scaphites ventricosus* var. *saxitonianus* McLearn (1929), came from the ‘‘Colorado shale of Crowsnest river’’ in southwestern Alberta. Cobban (1952) elevated McLearn’s variety to full species rank and assigned it to *Clioscaphites*. Scott and Cobban (1964) recorded *C. saxitonianus* within the inoceramid zone of *Cladoceramus undulatoplicatus*, of early Santonian age.

Ammonites found with *C. saxitonianus* in the Niobrara Formation in southeastern Colorado by Scott and Cobban (1964) were identified as *Texanites americanus* (Lasswitz), *Placenticeras pseudocostatum* Johnson, and *Baculites codyensis* Reeside. Inoceramid bivalves in the *C. saxitonianus* Zone include *Cladoceramus undulatoplicatus* (Schlüter) and *Cordiceramus cordiformis* (Sowerby).

Clioscaphites saxitonianus has been recorded from Montana at only two localities (Fig. 4). Two specimens from the Kevin Member of the Marias River Shale were illustrated by Cobban (1952); these came from southeast of the Kevin-Sunburst Dome in the structural feature known as the Marias River Saddle (Dobbin and Erdmann, 1955) (Fig. 1). Rocks of *C. saxitonianus* age are probably present in the Kevin Member at its type section on the Kevin-Sunburst Dome, where a thin bed of sandstone (bed 124) and a bed of concretions (bed 129) about 2 m (about 6.5 ft) apart (Figs. 4, 6) yielded incomplete specimens of *Clioscaphites* sp. and *Cordiceramus* cf. *cordiformis* that indicate a Santonian age. A barren unit of about 7.5 m (25 ft) separates the lower collection from the highest collection of *S. depressus*, and a barren unit of about 10 m (33 ft) separates the upper collection from the lowest collection of the middle Santonian *C. vermiformis*. By splitting the thickness of these barren units, an interval of 10.5 m (35 ft) might be a rough estimate of possible *C. saxitonianus* time (Fig. 4). That the type specimen of *C. saxitonianus* came from the Crowsnest River area in southwestern Alberta, not far from the Montana border, further indicates the probable presence of the zone on the Kevin-Sunburst Dome.

The other Montana locality is in the southwestern part of the state, where a specimen was collected by R.G. Tysdal from the Virgelle Sandstone. Tysdal et al. (1987) noted that the specimen occurred with *S. depressus* at the top of the range of that species.

Outside Montana, *Clioscaphites saxitonianus* is known from the Niobrara Formation in Colorado and New Mexico (Cobban, 1952), the Mancos Shale in central Utah, and from the Hilliard Shale in northeastern Utah, where the species was listed as *Scaphites ventricosus* (Hansen, 1965). *Clioscaphites saxitonianus* is probably widely distributed over much of the western part of the Western Interior of the United States. Identifiable specimens, however, require a complete or nearly complete adult body chamber. There are scaphitid phragmocones

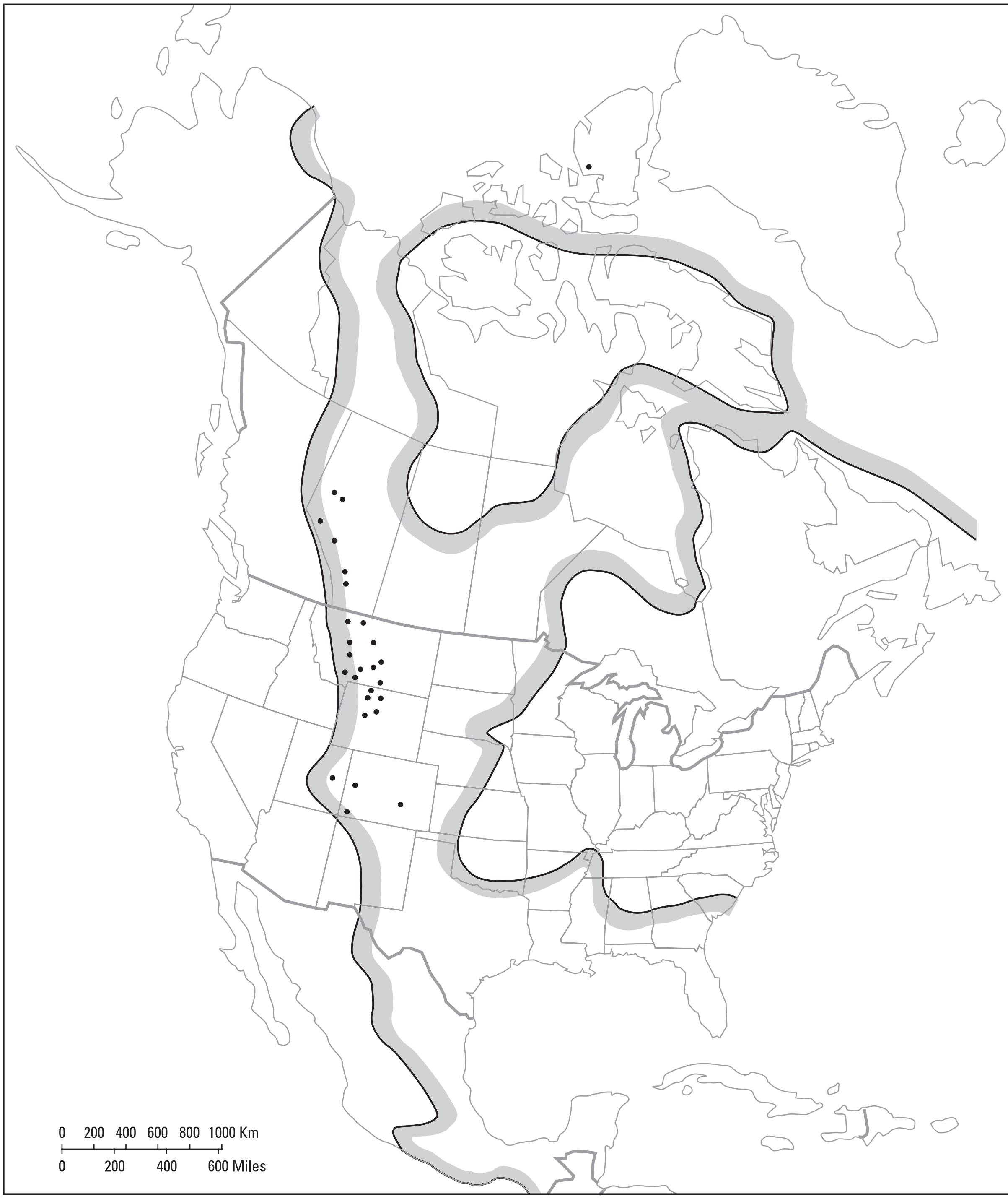

Fig. 3. Map illustrating probable extent of late Coniacian seaway (*Scaphites depressus* Zone). Dots represent localities of *S. depressus*; one dot may represent several nearby localities. Canadian shorelines modified from Ziegler and Rowley (1996); Mexican shorelines from Young (1983); Gulf shorelines of the United States from Sohl et al. (1991).

(septate coils) in many of the US Geological Survey (USGS) collections that cannot be assigned to any one species because the coils of *Scaphites depressus*, *C. saxitonianus*, and *C. vermiformis* are too much alike. At Pueblo, Colorado, *C. saxitonianus* ranges through 67 m (220 ft) of the middle shale unit of the Niobrara Formation (Scott and Cobban, 1962, 1964).

3.4. *Clioscaphites saxitonianus Zone in Alberta*

Jeletzky (1968, p. 36) regarded *Scaphites saxitonianus* McLearn as possibly ‘‘an extreme morphological variety of *S. depressus*’’, and noted that both forms were present in the Bad Heart Sandstone (also listed by Stott, 1967; Plint, 1990, 1991). A similar co-occurrence of

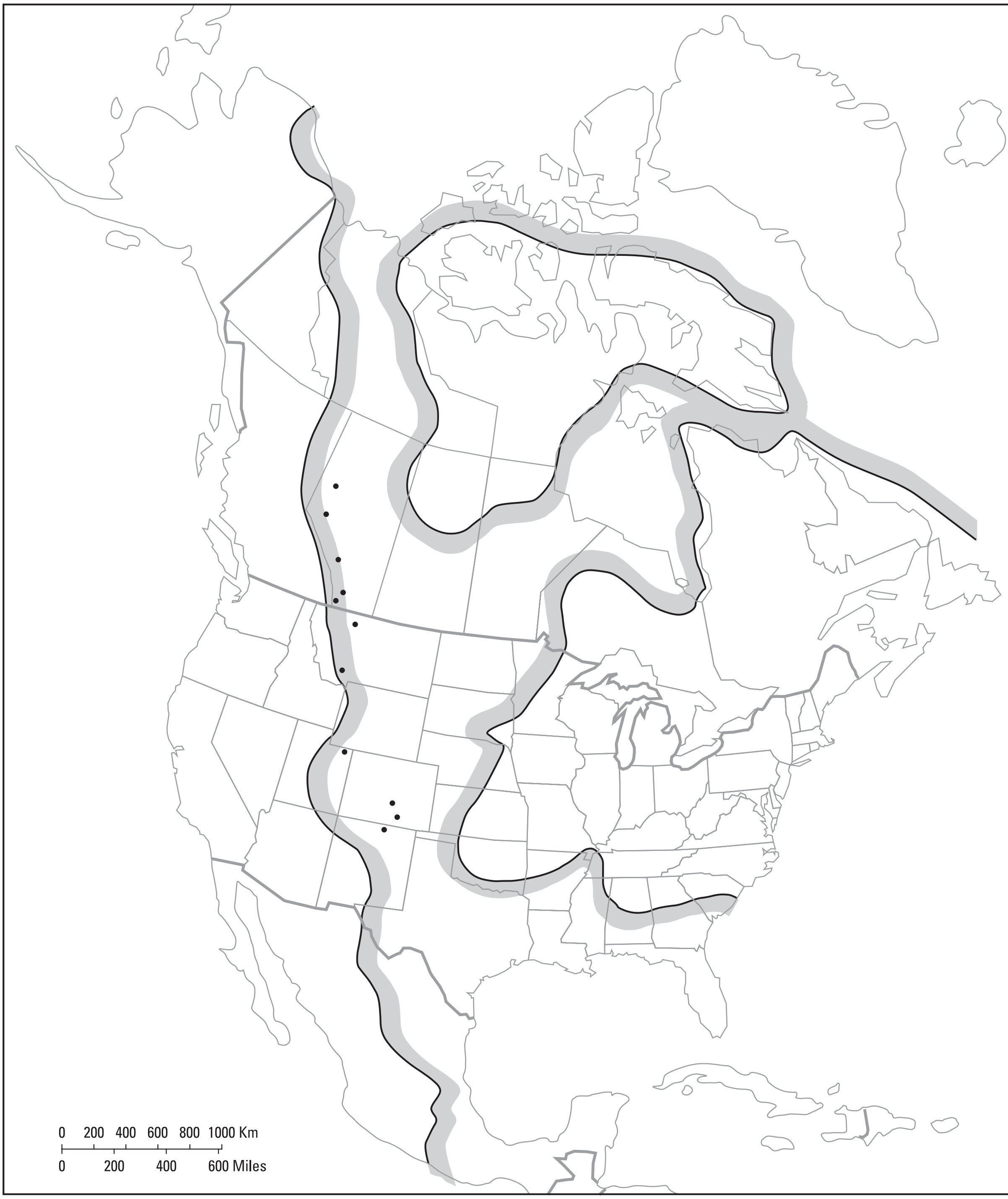

Fig. 4. Map of probable extent of early Santonian seaway (*Clioscaphites saxitonianus* Zone). Dots represent localities of *C. saxitonianus*; one dot may represent several nearby localities. Canadian shorelines modified from Coniacian seaway of Ziegler and Rowley (1996); Mexican shorelines from Young (1983); Gulf shorelines of the United States from Sohl et al. (1991).

these species was reported by Tysdal et al. (1987) in southwestern Montana. Inoceramid bivalves from the Bad Heart Sandstone described by McLearn (1926) represent *Cordiceramus* of Santonian age. The Coniacian/Santonian boundary thus appears to lie within that formation as earlier suggested by Wall (1960) (Fig. 2). Plint et al. (1990) and Donaldson et al. (1998, 1999) have shown that the Bad Heart is a complex unit of shallow-water, ferruginous, oolitic, silty sandstone "localized over the crests and flanks of a subtle intrabasinal arch; in part interpreted as a forebulge and partly attributed to reactivation of the long-lived Peace

River Arch'' (Donaldson et al., 1999, p. 1159). These authors pointed out that there are two upward-shoaling members bounded by regional ravinement surfaces. Possibly the lower member is Coniacian and the upper one Santonian.

Clioscaphites saxitonianus has been collected at several localities in the Alberta Foothills (Fig. 4). The southernmost locality (McLearn, 1929) is from rocks now assigned to the Wapiabi Formation, and the northernmost Foothills locality is from the Dowling Member of the Wapiabi (Stott, 1963). The species may possibly occur much farther north in the Mackenzie River area, where Stott (1960) reported a specimen identified by J.A. Jeletzky as *Scaphites* (*Clioscaphites*?) cf. *S. saxitonianus* from the Kotaneelee Formation, an equivalent of the Wapiabi-Bad Heart Formations. *Clioscaphites saxitonianus* is also known in West Greenland, where Birkelund (1965) described the new subspecies *saxitonianus septentrionalis* as well as another form referred to as *C.* sp. aff. *saxitonianus*. Birkelund's specimens tend to be slightly less ribbed than those from Montana and Colorado, but there are specimens from the Alberta Foothills in the collections of the Geological Survey of Canada (Ottawa) that resemble the Greenland specimens.

3.5. Clioscaphites vermiformis *Zone in Montana*

This middle *Santonian* zone is well represented in Montana by numerous collections (Fig. 5). At the type section of the Kevin Member of the Marias River Shale on the Kevin-Sunburst Dome, *C. vermiformis* was found in several beds of concretions about 50–60 m (160–200 ft) below the top of the member (Fig. 6). Associated fossils include *Inoceramus* cf. *I. lesginensis* Dobrov and Pavlova, the oyster *Pseudoperma congesta* (Conrad), *Baculites codyensis* Reeside, and *Clioscaphites montanensis* Cobban. Farther west and southwest, *C. vermiformis* was observed in sandy beds in the uppermost part of the Kevin Member (Mudge, 1972, his fig. 37). The top of the Kevin is older in age westward owing to a middle Santonian regression. There, the Kevin is overlain by the Telegraph Creek Formation that is comprised largely of thin beds of sandstone. Southwest of Great Falls and in central Montana, where the regression is more pronounced, *C. vermiformis* is present in the Telegraph Creek and equivalent rocks (McGrew, 1977). In southern Montana, *C. vermiformis* is in concretions in the Cody Shale.

3.6. Clioscaphites vermiformis *Zone in Alberta*

Clioscaphites vermiformis has been reported from several localities in the Foothills in southwestern Alberta (Fig. 5). The southernmost record is from the Thistle Member of the Wapiabi Formation in Waterton Lakes National Park (Wall and Germundson, 1963). The species was also recorded from the upper part of the Kevin Member north of the Sweetgrass Hills at the Alberta-Montana border by Russell and Landes (1940). Stott (1963) reported the species from the upper part of the Dowling Member of the Wapiabi Formation in the Foothills almost to the latitude of Edmonton, Canada. The zone is probably present in the subsurface across the Plains region of Alberta and Saskatchewan inasmuch as an outcrop of the Niobrara Formation on the Etomami River in eastern Saskatchewan has yielded *C. vermiformis* (Geological Survey of Canada, collection 9280).

4. MacGowan Concretionary Bed and equivalent rocks

One or more erosion surfaces are identified within the Kevin Member of the Marias River Shale of central Montana and within equivalent strata in southern Canada. These surfaces are recognized in outcrop by the presence of conglomerate and concretionary beds comprising ferruginous, concretionary limestone and dolostone, and conglomerate beds containing chert pebbles, well-rounded fossils, and phosphatic nodules. The age of these surfaces can be constrained using the biostratigraphic relations identified in the previous section. In central Montana, the lithologically distinct MacGowan Concretionary Bed of middle Coniacian age marks one of these surfaces (Cobban et al., 1959). The following discussion includes lithologic and biostratigraphic characteristics of this unit at its type locality and at other localities in central Montana studied for this report. In the following section we also discuss the Bad Heart Formation of Canada and its relations to the MacGowan Concretionary Bed.

4.1. Type section of Kevin Member

The type section of the Kevin Member of the Marias River Shale is located in NE section 4, NE section 17, and NW section 3, T35N, R3W, Toole County, Montana, within the Kevin oil field about 4 miles north of Kevin, Montana (Fig. 1). The Kevin is 57 m (188 ft) thick at the type section, but our measured section is 26 m (85 ft) thick (Figs. 6, 7) and lies entirely within the middle shale unit of the member (Cobban et al., 1976). This unit is characterized by numerous beds of reddish-weathering ferruginous concretions and concretionary limestones and dolostones 15–45 cm (6–18 in) thick that are interbedded with dark-gray shale and a few occasional thin beds of gray, fine-grained sandstone. The MacGowan Concretionary Bed lies about 6 m (20 ft) above the base of our measured section (Fig. 7).

The MacGowan Concretionary Bed (here referred to informally as the ''MacGowan bed'') was named by

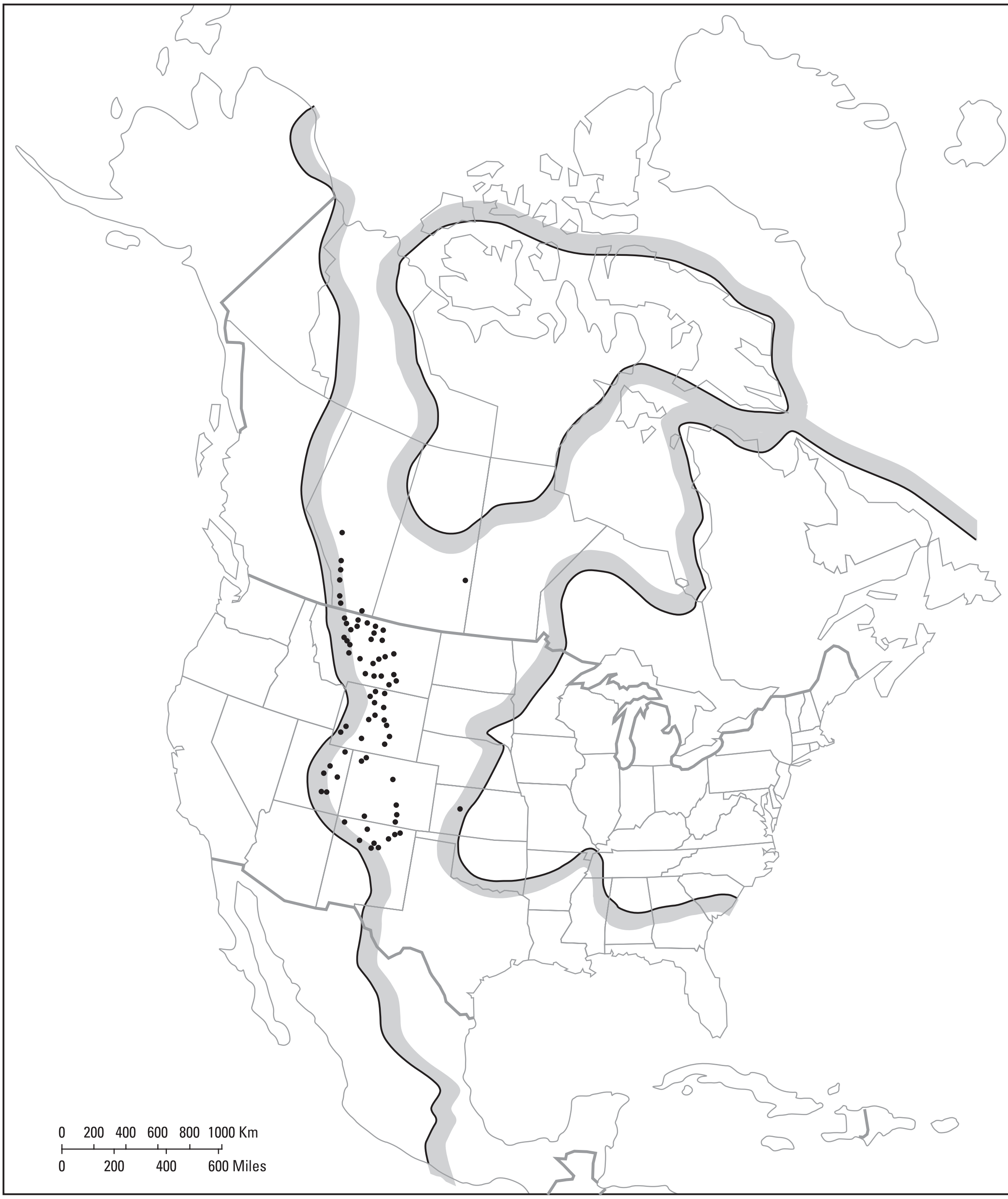

Fig. 5. Map of probable extent of middle Santonian seaway (*Clioscaphites vermiformis* Zone). Dots represent localities of *C. vermiformis*; one dot may represent several nearby localities. Canadian shorelines modified from Coniacian seaway of Ziegler and Rowley (1996); Mexican shorelines from Young (1983); Gulf shorelines of the United States from Sohl et al. (1991).

Cobban et al. (1959) for exposures on the MacGowan lease in the Kevin-Sunburst oil and gas field in Toole County, north-central Montana. At the type locality, the bed consists of a concretionary dolostone and limestone about 45 cm (18 in.) thick that weathers orange-brown to dusky-red and contains abundant silty, phosphatic nodules and lesser amounts of small gray or black chert pebbles; it lies in the middle of the 189-m-thick (620 ft) Kevin Member of the Marias River Shale (Fig. 8). The bed was first noted by Clark (1923, p. 267) as a "yellow lime chert conglomerate". In the course of detailed mapping of parts of the

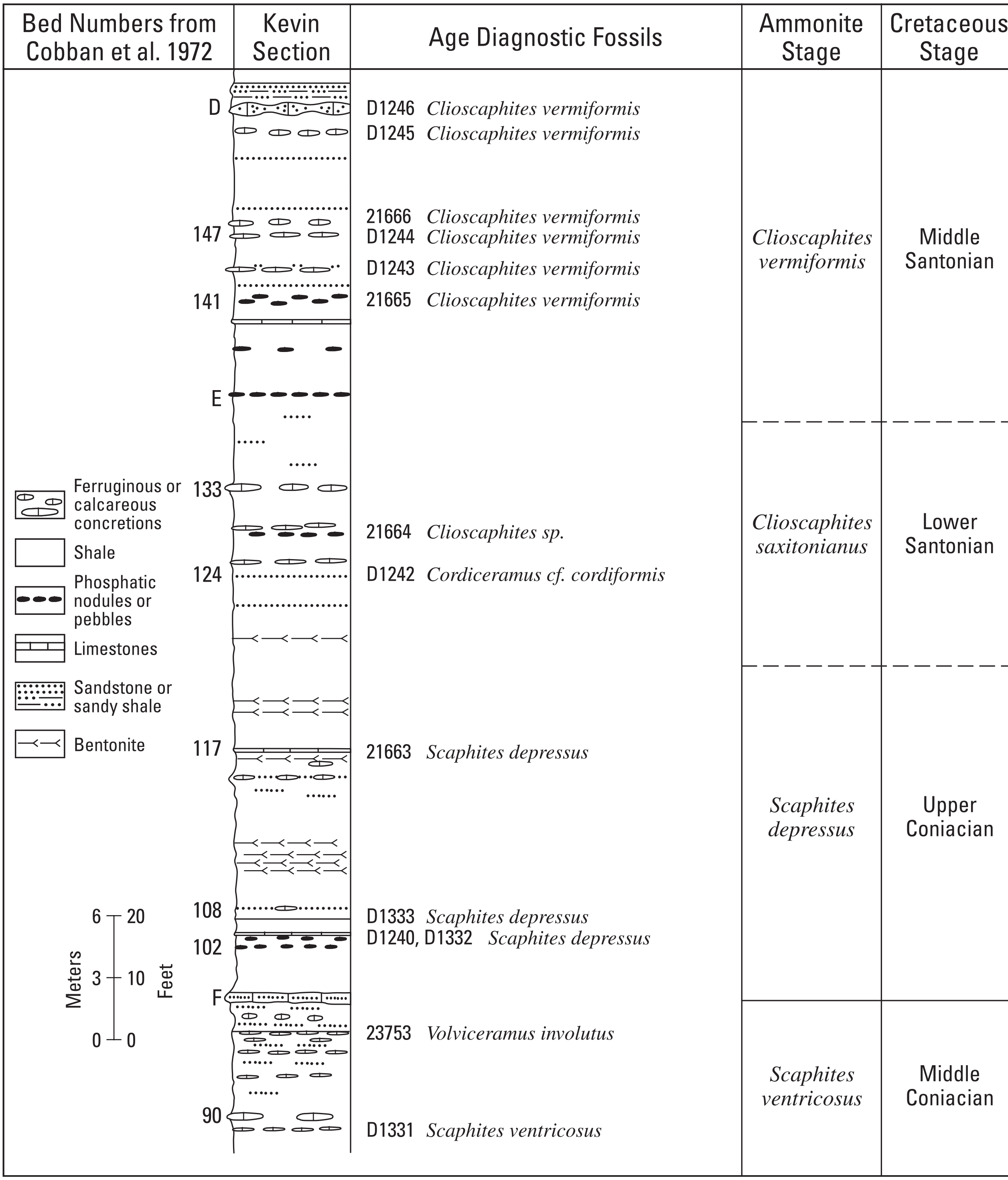

Fig. 6. Columnar section showing most of the middle Coniacian–middle Santonian part of the type section of the Kevin Member of the Marias River Shale, Toole County, Montana. Bed numbers and letters from Cobban et al. (1976). Boundaries of *Clioscaphites saxitonianus* Zone and lower Santonian are provisional. F, MacGowan Concretionary Bed (Bed F of Erdmann et al., 1946a, 1947).

Kevin-Sunburst field by Erdmann et al. (1946a,b, 1947), the bed was referred to as "Bed F", and other key beds (beds A–K) in the Kevin Member were shown in a columnar section. Stratigraphic positions of these key beds are shown in the type section of the Kevin Member by Cobban et al. (1976). The chert pebbles are gray to black with diameters as much as 3 cm (1 in.), and there are also larger pebbles of gray, phosphatic siltstone as much as 8 cm (3 in.) in diameter as well as some rounded fragments of ammonites and clams. One

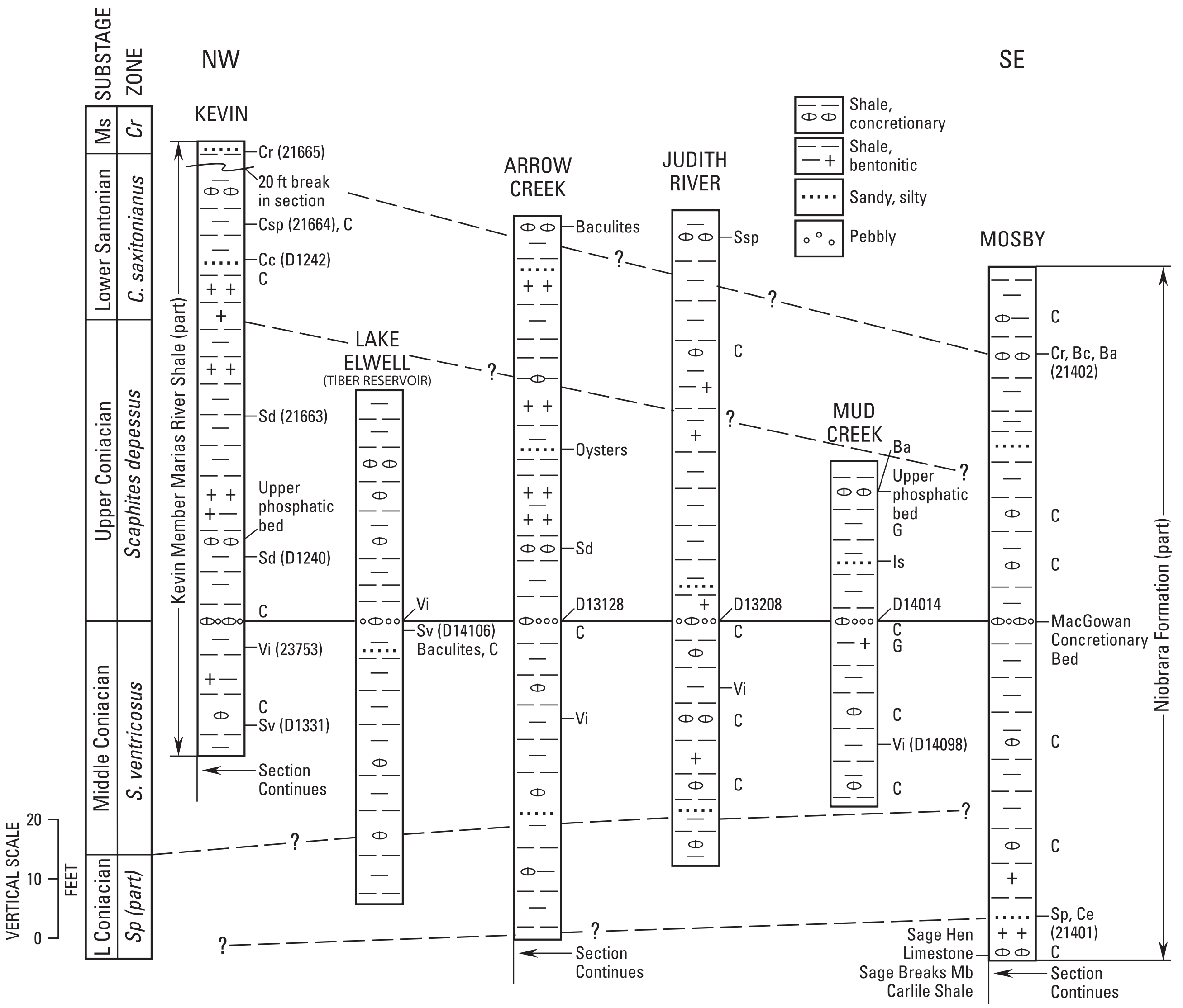

Fig. 7. Northwest to southeast stratigraphic cross section of MacGowan Concretionary Bed and adjacent rocks from Kevin area in northwest Montana to Mosby in central eastern Montana (see also Fig. 9). Strata are referred to as Niobrara Formation at the Mosby measured section and to the Kevin Member of Marias River Shale in all other measured sections. Datum (solid line) is the MacGowan Concretionary Bed. Dashed lines represent approximate time lines for substage boundaries based on presence of key zonal fossils discussed in text. Question marks indicate uncertainty of position within measured section. Abbreviations: Ms, middle Santonian; Con, Coniacian; G, glauconitic; C, calcareous; Ba, *Baculites asper*; Bc, *Baculites codyensis*; Cc, *Cordiceramus* cf. *cordiformis*; Ce, *Cremnoceramus erectus*; Csp, *Clioscaphites* sp.; Cv, *Clioscaphites vermiformis*; Is, *Inoceramus stantoni*; Sd, *Scaphites depressus*; Sp, *Scaphites preventricosus*; Ssp, *Scaphites* sp.; Sv, *Scaphites ventricosus*; Vi, *Volviceramus involutus*. Numbers in parentheses next to fossil abbreviations are US Geological Survey Mesozoic localities.

or more beds of phosphatic siltstone, as much as 5 cm (2 in) thick, and sandstone pebbles are present above the MacGowan bed at the type section and are interbedded with concretionary limestones and dolostones and dark-gray shale.

No diagnostic fossils were observed in the MacGowan bed at the type section of the Kevin Member, nor have any been reported by others to our knowledge. However, the middle Coniacian ammonite *Scaphites ventricosus* was collected from 7, 12, 17, and 25 m (23, 39, 56, and 82 ft) below the MacGowan bed in the type section, and the dominantly middle Coniacian inoceramid bivalve *Volviceramus* was collected less than 1.5 m (5 ft) below the bed. *Scaphites depressus* was found at 3, 3.6, and 13 m (10, 12, and 43 ft) above the MacGowan bed. The bed itself is highly fossiliferous elsewhere in central Montana.

4.2. Other central Montana localities

The MacGowan Concretionary Bed is widely distributed throughout central Montana (Fig. 1). For example, Mudge (1972) showed it a little below the middle of the Kevin Member in the Disturbed Belt

Fig. 8. Photograph of Kevin Member of Marias River Shale at the type section of the Kevin, NE section 4, NE section 17, and NW section 3, T35N, R3W, Toole County, Montana, within the Kevin oil field about 4 miles north of Kevin, Montana (Fig. 1). Lighter colored bench in middle part of photograph represents position of MacGowan bed. Middle part of photo about 300 m (1000 ft) across.

west of Great Falls in Sun River Canyon, Schmidt (1978) noted it near the middle of the member farther southeast near Wolf Creek, Montana, and Reeves (1929, p. 162) reported it around the Highwood Mountains in central Montana as a "Brown calcareous bed with small black pebbles". In central-northern Montana, Pierce and Hunt (1937, p. 247) noted a "10-inch-thick peculiar reddish-brown bed of limestone containing pebbles of black, gray, and green chert from one-fourth to 3 cm (1 in.) in diameter" in the upper part of the Colorado Shale exposed in a faulted area that we consider to be a correlative unit. The southernmost known outcrops are in the area between Harlowton and Roundup in south-central Montana (Fig. 1).

The MacGowan bed was described by us during our study of several localities in central Montana, where it exhibits a wide range of lithologic and biostratigraphic characteristics from place to place, as indicated below.

4.2.1. Tiber Reservoir

The measured section is located in SW NE section 24, T30N, R1W, Pondera County, Montana, approximately 3.2 km (2 mi) southwest of Tiber Reservoir. Shales of the Kevin Member of the Marias River Formation are exposed on both sides of a county road in a long, steep ravine; the MacGowan bed is near the top of these exposures, and one additional overlying concretionary bed is also present.

The MacGowan bed is the lowest pebble-bearing concretionary bed, the base of which is marked by a surface lying above a dark-gray, fissile shale. The shale is deeply weathered, lumpy, cemented by calcite, and contains a few fist-size gray septarian limestone concretions with dark-red calcite veins. The MacGowan bed forms a modest bench traceable around the canyon walls. It consists of a rusty-orange, discontinuous concretionary limestone, generally less than 15 cm (6 in.) thick, containing many chert pebbles, ranging from 0.25–3.8 cm (0.1–1.5 in.) in diameter, that are commonly phosphatized and litter the slope below the bed. Chert is dominantly black, but some pebbles are tan, gray, or green. Overlying the bed is dark-gray fissile shale containing numerous white specks of an undetermined but noncalcareous material and a few gray septarian limestone concretions and an overlying upper concretionary limestone. This uppermost unit of our measured section, like the MacGowan bed, forms a small bench traceable around the canyon walls and is discontinuous, orange-weathering, concretionary, less than 30 cm (12 in.) thick, and commonly fragmented into angular blocks; it contains abundant chert pebbles and specimens of *Volviceramus involutus*. The bed is overlain by dark-gray fissile shale that forms the top of the exposures, where a large float block of fine-grained cherty sandstone was observed.

4.2.2. Arrow Creek Bench

The measured section is located in SE SW section 15, and NW and NW SE section 22, T19N, R12E, Fergus County, Montana, on both sides of Montana State Highway 80 as it traverses a steep ravine on the north side of Arrow Creek Bench. The Kevin Member of the Maria River Shale forms the entire outcrop of dark-gray to black, slightly lighter gray-weathering, fissile to slightly blocky shale. The MacGowan bed, which appears as a light-colored band near the middle of the exposure, is 10–15 cm (4–6 in.) thick and consists of light yellow to tan-weathering sandy and pebbly limestone that displays sharp lower and upper contacts (Fig. 9). Pebbles are of chert, 0.3–5 cm (0.1–2 in.) in diameter, commonly having amorphous shapes; and some are phosphatized; they litter the slope for many meters below the bed. Below the MacGowan bed is a 30-cm-thick (1 ft) blocky-weathering, sandy shale that is in turn underlain by fissile shale containing many dark rusty-red ironstone concretions 5–15 cm (2–6 in.) in diameter. Above the MacGowan bed lies a 3.6-m-thick (12 ft) unit of gray fissile shale containing numerous rusty, dolostone concretions, 5–10 cm (2–4 in.) diameter, and a capping bed of orange-brown-weathering concretionary limestone lacking fossils and pebbles. Some float of black chert pebbles is on the surface of the shale below the limestone, but no source was identified.

4.2.3. Judith River

The measured section is located in NW NE NE section 5, T17N, R16E, Fergus County, Montana on a steep south-facing slope of dark-gray shale forming the Judith River Valley; the rusty-weathering MacGowan bed can be traced along this south-facing valley slope. Measurements were made at the place where the bed forms a thin rusty-colored resistant cap on a small flat-topped bench about one-third of the way up the slope (Fig. 10).

The lowest unit, measured from base of the exposure to base of the MacGowan bed, is 19 m (36 ft) thick and consists of dark-gray, medium gray-weathering clayey fissile noncalcareous shale (Fig. 10). A laterally persistent horizon of gray-weathering concretionary limestone is about 1 m (3 ft) above the base of this lowest unit. An 8–10-cm-thick (3–4 in.) concretionary limestone bed is present in the upper 25 cm (10 in.); it is medium-gray to dark purple, weathers tan to purplish gray, and is partly septarian with dark-red vein filling. An unidentified scaphite fragment was collected in float in the lower part of the unit.

The MacGowan bed is 28–38 cm (11–15 in.) thick, forming a prominent rusty interval within the overall dark shale of the slope. It is a concretionary, conglomeratic, glauconitic, fine-grained sandy limestone and limy sandstone containing coarse sand grains, granules, and small to large pebbles of chert as well as shell fragments.

Fig. 9. Photograph of MacGowan Concretionary Bed, Kevin Member of Marias River Shale at the Arrow Creek measured section, SE SW section 15, NW and NW SE section 22, T19N, R12E, Fergus County, Montana (Fig. 1). The MacGowan bed is 10–15 cm (4–6 in.) thick, light yellow to tan-weathering sandy chert-pebbly limestone with sharp lower and upper contacts. Pencil for scale.

Fig. 10. Photograph of Kevin Member of Marias River Shale at the Judith River measured section, NW NE NE section 5, T17N, R16E, Fergus County, Montana (Fig. 1) on a steep south-facing slope of dark-gray shale forming the Judith River valley. The rusty-weathering MacGowan concretionary bed can be traced along the south-facing valley slope shown here in the middle-upper part of the photograph. Photograph about 10 m (30 ft) across at the level of the MacGowan bed.

The chert pebbles are as much as 11 cm (4 in) in diameter, but more commonly are 1.3–3.8 cm (0.5–1.5 in). The interior parts of the pebbles are light olive-gray, but the exteriors are darker gray with extensive networks of small, light-gray to white burrows that are generally less than 0.3 cm (0.1 in) in diameter and commonly filled by very fine-grained sandstone. Some pebbles are oolitic. The upper surface of the MacGowan bed is a lag of phosphatized chert pebbles and worn shell fragments.

Fossils are abundant in the MacGowan bed at the Judith River locality (D13294), as well as at the nearby USGS Mesozoic locality D13208 along the Deerfield Colony Road in NW section 4, T17 N, R16 E. The following phosphatized fossils were collected at these localities: bivalves: *Phelopteria* sp., *Inoceramus* sp., *Veniella* sp., *Pholadomya* sp.; gastropods: *Turritella* sp., *Rostellites*? sp., *Xenophora* sp.; cephalopods (ammonites): *Protexanites* sp., *Baculites codyensis* Reeside, *B. asper* Morton, *Scaphites* sp.; arthropods: *Necrocarcinus* sp. (crab), bits of other crabs and lobsters; vertebrates: shark tooth, fish vertebra, bit of reptilian bone.

At both the Judith River and Deerfield Colony localities we collected fragments of *Baculites codyensis* Reeside, a straight ammonite that has narrow, concentric flank ribs or node-like swellings. The fragments show differing degrees of phosphatization and wear; some are well preserved and display little-worn ornamentation, whereas others are worn to rod-like pebbles.

The upper Coniacian ammonite *Protexanites* is also represented by several septate fragments preserved as black, silicified, phosphatic pebbles. The presence of these specimens is of particular importance, in that they provide evidence that upper Coniacian beds older than the MacGowan bed once existed in the area.

Phosphatic fragments of *Scaphites* are also present but too incomplete for species determination. All phosphatic molluscan fossils are internal molds that lack shell material. Unphosphatized molluscan fossils collected from the MacGowan bed at the Judith River measured section (locality D13208) include the following: *Volviceramus involutus* (Sowerby)?; *Inoceramus* sp.; *Pycnodonte* sp.; *Turritella* sp.; one or two other gastropods; and *Scaphites* sp. All of these specimens have retained some shell material and are interpreted to have been alive when the MacGowan bed was formed. The scaphitids are too incomplete for species determination, but farther south, in the area between Harlowton and Roundup (Fig. 1), two nearly complete specimens from the bed are assignable to *S. depressus*.

Overlying the MacGowan bed at the Judith River section is an 11-cm-thick (4-in.) interval of dark-gray, fissile non-calcareous shale that is overlain in turn by an 8–20-cm-thick (3–8-in.) concretionary, sandy limestone bed containing *Turritella*, *Pseudoperna*, and *Scaphites* sp. The remaining exposure to the top of the slope consists of 27 m (89 ft) of medium-gray weathering, dark-gray fissile, noncalcareous shale (Fig. 10) that is

predominantly clayey but locally sandy and exhibits blocky weathering; shiny dark biotite grains, as well as scattered *Inoceramus* fragments, lie on bedding planes. A 0.3-m-thick (1 ft), medium-gray and tan-weathering gray limestone bed lies 2 m (11 ft) above the base of this unit, and the shale is sandy at about 4 m (13 ft) above the base. At 7 m (24 ft) above the base, there are several thin 0.6 cm (0.25 in.) orange-weathering bentonites, and 24 m (80 ft) above the base is a 0.3–0.6-m-thick (1–2 ft) concretionary, calcareous, massive to thin-bedded sandstone containing a few unidentified shell fragments.

4.2.4. Mud Creek

The measured section is located in NW NE and SW NE section 11, T6N, R17E, Wheatland County, along the south side of Mud Creek on the Shawmut Anticline about 8 km (5 mi) southwest of Shawmut, Montana. The section is well exposed, beginning in a vertically cut bank of the creek where 8 m (25 ft) of medium-gray weathering, dark-gray noncalcareous clayey shale forms the base of the section (Fig. 11). The shale contains numerous, large light-gray-weathering, dark-gray fossiliferous limestone concretions from which a *Scaphites* sp. and *Cremnoceramus crassus* were collected (Fig. 12). The upper 1 m (3 ft) is sandy and contains small, rounded, rust-colored dolostone concretions. Above the shale is a prominent 0.6-m-thick (2 ft) light-weathering coarsely crystalline, fine-grained, bentonitic sandstone that contains biotite and is locally highly calcareous and concretionary. Above the sandstone are 2.5 m (8 ft) of medium-gray shale with numerous small rust-colored dolostone concretions and a greenish cast imparted by abundant glauconite.

The MacGowan bed forms the base of the overlying 24 m (78 ft) of green-gray glauconitic shale and orange-weathering concretionary dolostone beds mapped as the Eldridge Creek Member of the Cody Shale by Porter and Wilde (2000). The MacGowan bed is 21 cm (8 in.) thick and forms a prominent south-dipping bench traceable around the recessed exposures above Mud Creek. It is a rust-colored to orange-weathering, dark-gray concretionary limestone or dolostone containing both worn and unworn fossil fragments and chert pebbles. Chert pebbles are commonly phosphatized, showing small white blebs and thin threads within the chert.

The overlying 7.3 m (24 ft) is greenish-gray, glauconitic, bioturbated, muddy sandstone with common shell fragments and local occasional lenses of platy, glauconitic, fine-grained sandstone, one bed of which yielded *I. stantoni*. A minor ledge-forming concretionary bed 3 m (10 ft) above the MacGowan bed contains phosphatized chert pebbles, and about 4 m (13 ft) above that is an orange-weathering concretionary dolostone bed forming a modest ledge and dip slope. The latter contains

Fig. 11. Lower part of Mud Creek measured section, NW NE and SW NE section 11, T6N, R17E, Wheatland County, along the south side of Mud Creek on the Shawmut anticline about 8 km (5 mi) southwest of Shawmut, Montana (Fig. 1). The lower part of the section is well exposed, beginning in a vertical cut bank of the creek where 8 m (25 ft) of medium-gray weathering, dark-gray noncalcareous clayey shale forms the base of the measured section.

Fig. 12. Photograph of inoceramid specimens in creek bottom at the base of the Mud Creek measured section shown in Fig. 11.

abundant chert pebbles as much as 5 cm (2 in.) in diameter, some of which are phosphatized; *Baculites asper* was collected from it.

The remaining part of the Eldridge Creek Member is approximately 15 m (53 ft) of largely bioturbated muddy sandstone and sandy mudstone that contain some concretionary zones but no fossils or pebbles.

4.2.5. Mosby

The measured section is located in SW NW section 8, T14N, R31E, Garfield County, Montana, in bluffs beneath a dissected bench above Sage Hen Creek on the south side of Montana State Highway 200 (Fig. 1). Exposures are poor and the MacGowan bed is mostly recognized in float slabs and rare small outcrops. The bed lies within 1.5–3 m (5–10 ft) of the top of the bench. The float and rare exposures indicate that the MacGowan bed is principally an orange-tan-weathering, medium- to coarse-grained, chert-rich sandstone. A few 0.6–5.0-cm (0.25–2 in.) in diameter, black chert pebbles litter the slopes below the bed, but no pebbles were seen within the sandstone float blocks. Other float blocks interpreted as part of the MacGowan bed are a sedimentary breccia of large, angular, tan-colored mudclasts in coarse-grained sandstone. The thickness of the MacGowan bed here is uncertain but appears to be at least 10 cm (4 in). The underlying strata, which are poorly exposed, are blocky, medium gray-weathering silty shale. At least two horizons of prominent gray, red-veined septarian limestone concretions form small ledges within the shale. The MacGowan bed is about 3 m (10 ft) above the upper horizon of concretions. A third prominent zone of concretions is near the base of the exposures, close to the valley floor. These concretions are large, orange-gray-weathering, and commonly are highly fractured silty limestone concretions that display cone-in-cone structure. A few concretions in this zone are of the gray septarian type, similar to those in the upper two horizons.

5. Bad Heart Formation of Alberta and British Columbia

The Bad Heart Formation, originally defined as the Bad Heart sandstone member of the Smoky River Formation, was named by McLearn (1919) for outcrops along the Bad Heart and Smoky Rivers in the Plains region of west-central Alberta. Farther west, in the Foothills of British Columbia, Stott (1967) applied the name Bad Heart to a unit of sandstone that he considered to be equivalent to the Bad Heart of the Alberta Plains and also to correlate with the MacGowan Concretionary Bed of the Kevin Member of the Marias River Shale of north-central Montana. Plint et al. (1990) revised the Bad Heart and restricted it to the Plains region, where the formation has chert pebbles at the base and rests disconformably on the beveled middle–upper Coniacian Marshybank Formation or on the lower and middle Coniacian Muskiki Formation. The basal pebble bed of the Bad Heart was traced westward from Alberta and observed to overstep

the "Bad Heart" of the Foothills of British Columbia. Where traced northward in the Plains region, the erosion surface at the base of the Bad Heart truncates the Muskiki and Cardium Formations and rests on the underlying Cenomanian–Turonian Kaskapau Formation (Donaldson et al., 1999). An important erosion surface also bevels the Bad Heart in the Plains region, where a thin pebble lag is present at the base of the overlying Dowling Member of the Puskwaskau Formation (Fig. 2; Plint and Walker, 1987; Donaldson et al., 1998). Plint (1991) correlated most of the Marshybank Formation with the MacGowan bed combined with a few meters of overlying beds. Braumberger and Hall (2001) placed the Marshybank as a member of the Wapiabi Formation (Fig. 2).

6. Other regional localities and correlation

In the southeastern corner of Montana, the Niobrara Formation crops out around the north flank of the Black Hills uplift. There, the formation consists of about 60 m (200 ft) of calcareous shale and marl, with phosphatic nodules at the base resting disconformably on the upper Turonian part of the Carlile Shale. Diagnostic fossils have not been reported from the Niobrara in this area, but farther south along the southwestern flank of the Black Hills uplift in eastern Wyoming, the lower part of the Niobrara is of middle Coniacian age and is in sharp contact with the upper Turonian part of the underlying Carlile Shale (Merewether and Cobban, 1986). Along the southeast flank of the Black Hills uplift in western South Dakota, phosphatic pebbles at the base of the Niobrara contain fossils that are reworked from upper Turonian rocks (Tourtelot and Cobban, 1968). Much farther east in northeastern Nebraska, *Volviceramus involutus* was collected 1.5 m (5 ft) above the base of the Niobrara, which indicates a middle or late Coniacian age. There, the Niobrara rests sharply on the middle Turonian part of the Carlile Shale (Hattin, 1982; Merewether, 1983). A similar lowstand unconformity may be present in the northeastern part of Montana, where Rice (1976) showed substantial eastward thinning of the Niobrara in the subsurface, and Shurr and Rice (1987) indicated that the *S. depressus* Zone was possibly missing below the zone of *C. saxitonianus* in the subsurface of the central Williston Basin in western North Dakota.

7. Coniacian–Santonian transgressions and shorelines

Sea level was high during the Coniacian and Santonian, and much of the Western Interior as well as the eastern half of Mexico was flooded (Figs. 3–5). In northwestern Montana and southwestern Alberta, the western Coniacian and Santonian shorelines are unknown owing to the lack of Cretaceous outcrops west of the Rocky Mountain Front. In southwestern Montana, however, the shoreline of the *S. depressus* Zone is transgressive, whereas the zones of *C. saxitonianus* and *C. vermiformis* are clearly progradational (Dyman et al., 1997). In addition, a hiatus seems to mark the base of the Santonian lower part of the Beaverhead Group and underlying Cenomanian through lower Santonian Frontier Formation (Perry et al., 1989; Dyman et al., 1997).

The Santonian is probably regressive in southeastern Alberta, where a sandy unit (Sweetgrass Member of the White Speckled Shale) was recently described by Schröder-Adams et al. (1997). Jeletzky (1971, 1978), however, noted that the Coniacian–Santonian was the time of greatest marine transgression in the Canadian Western Interior, and that the transgression peaked in the middle and late Santonian (also see Stott, 1984).

In western Canada (Fig. 3), Ziegler and Rowley (1996) documented a widespread Coniacian transgression. They showed a western arm of the sea extending north from Montana through the Mackenzie River area to the Arctic and then extending eastward across the Canadian Arctic islands to West Greenland. Another arm (Hudson seaway) was shown extending northeastward from Montana and North Dakota through Hudson Bay to the Atlantic Ocean via a narrow Hudson Strait. Ziegler and Rowley (1996) did not mention fossils of Coniacian age, but they noted the presence of Santonian microfossils in glacial till just west of Hudson Bay. Added support for a Coniacian–Santonian transgression across Hudson Bay, not mentioned by Ziegler and Rowley (1996), is the presence of Coniacian–Santonian foraminifera in outcrops of glacial till in northeastern Minnesota south of the Ontario border reported by Merewether (1983). Ziegler and Rowley (1996) also drew attention to Cretaceous fossils in kimberlite pipes near Lac de Grass in the Northwest Territories, where Nassichuk and McIntyre (1995) recorded Albian, Turonian, lower Campanian, and Maastrichtian pollen and dinoflagellate fossils as well as fossil wood and fish remains.

In the central Alberta Plains, two erosional surfaces have been documented (Fig. 2), one in the upper Coniacian *S. depressus* Zone and the other appearing to be at the base of the middle Santonian. The latter may be the most widespread. Caldwell et al. (1978) revealed a pronounced hiatus in the subsurface that is traceable completely across Saskatchewan and much of Manitoba, where the lower Santonian, all of the Coniacian, and much of the upper Turonian are missing beneath the middle part of the Santonian. From a mine shaft near Saskatoon, Saskatchewan, Jeletzky (in Price and Ball, 1971) identified several Santonian inoceramid bivalves that are probably from the *C. vermiformis*

Zone. Farther northeastward in central eastern Saskatchewan, Collom (2000) illustrated a float specimen referred to as *Scaphites* aff. *ventricosus* from the Niobrara Formation in the Pasquia Hills area; it could be *Clioscaphites montanensis* of middle Santonian age. Far to the northwest in the Mackenzie River Delta and in the adjacent Anderson Plain, microfossils are in Santonian rocks unconformably overlying upper Albian or Turonian strata (Chamney, 1970, 1971; McIntyre, 1974; Young, 1975; Yorath et al., 1975; Yorath and Cook, 1981; Dixon et al., 1992). Santonian rocks are also present farther south, in the Great Bear Lake area, District of Mackenzie (Balkwill, 1971), and in the Canadian Arctic islands (Balkwill, 1983).

An origin for these Coniacian and Santonian surfaces is not yet evident to us. Published reports on erosion surfaces in the underlying Turonian Cardium Formation in Alberta (Bergman and Walker, 1987, 1988; Walker and Eyles, 1991; Pattison and Walker, 1991) indicate that erosion probably did not take place in an open marine environment, but rather by an initial marine regression and lowstand followed by transgression and shoreface reworking. Gravels were introduced by rivers during lowstand events and later reworked during subsequent sea-level rise. The origin of surfaces in the Kevin Member of the Marias River Shale and in the Niobrara Formation in northern and central Montana is speculative. They may have been formed by similar processes, but resolution of their origin depends on a better understanding of their regional distribution and correlation. These surfaces may be important regional seals and traps for petroleum accumulations.

8. Conclusions

Both the Coniacian and Santonian stages of the Upper Cretaceous are divided into lower, middle, and upper substages defined mainly by the first appearance of inoceramid bivalves, except for the upper Santonian, for which the widely distributed crinoid *Uintacrinus* serves as a guide. The base of the Coniacian Stage is marked by the first appearance of *Cremnoceramus erectus*, and the lowest occurrence of the coiled inoceramid *Volviceramus koeneni* marks the base of the middle Coniacian. A descendant of *V. koeneni*, *V. involutus*, is abundant through the rest of the middle Coniacian, and in much of the Western Interior it is accompanied by the ammonite *Scaphites ventricosus*. *Magadiceramus subquadratus* has been recommended as a guide to the base of the upper Coniacian, but this species has not been reported from Montana or Alberta. The ammonites *Protexanites bourgeoisianus* and *Phlycticrioceras trinodosum*, restricted to the upper Coniacian in Europe, are associated with the ammonite *Scaphites depressus* in Montana. The latter species is known from many localities in Alberta and serves as a good index fossil to the upper Coniacian. *Cladoceramus undulatoplicatus*, found mainly in the southern part of the Western Interior and in Europe, is regarded as a useful guide to the lower Santonian, and occurs with *Clioscaphites saxitonianus*, an ammonite known from Montana and Alberta. The inoceramid *Cordiceramus cordiformis* has been recommended as a guide to the middle Santonian. This species, first described from Europe, has been observed in the ammonite zone of *Clioscaphites vermiformis* in Montana and Alberta.

Erosional surfaces are present in the middle and upper Coniacian rocks in Montana and Alberta, and probably at the base of the middle Santonian in the Western Interior of Canada. The most detailed study in Montana concerns the MacGowan Concretionary Bed in the Kevin Member of the Marias River Shale, where the bed typically rests disconformably on middle Coniacian strata and is overlain by upper Coniacian beds. Surface and subsurface investigations in west-central Alberta reveal that the Bad Heart Formation, bounded by unconformities, is about the age of the MacGowan Concretionary Bed. Coniacian and Santonian strata are present elsewhere in Alberta and adjoining areas, but little has been published concerning the Santonian megafossils. Similar conditions are present in eastern Montana. The origin of these surfaces is not yet well understood.

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