

Cretaceous stage boundaries in the southern Interior Plains of Canada

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Caldwell, W. G. E. and North, B. R.: Cretaceous stage boundaries in the southern Interior Plains of Canada. *Bull. geol. Soc. Denmark*, vol. 33, pp. 57-69, Copenhagen, September, 10th, 1984.

Marine Cretaceous rocks of Berriasian to Aptian age are restricted to northwestern Alberta and northeastern British Columbia where many stage and substage boundaries may be drawn only tentatively on the basis of limited molluscan faunas. A complete marine Albian succession is similarly restricted, although the middle and upper divisions of the stage are much more widespread. The complete Albian succession of the Peace River district contains a refined and well-documented sequence of ammonite and foraminiferal zones and would be a most suitable continental standard.

The Albian-Cenomanian (Lower-Upper Cretaceous) boundary has been reliably established in the continuous foraminifer- and mollusc-bearing sequences of the northwestern plains, but eastward it becomes enclosed in a hiatus. The same is true of successive stage boundaries from the Cenomanian-Turonian to the Santonian-Campanian. The bases for establishment of these boundaries, therefore, can be fully considered only on the western flank of the basin. The Campanian-Maastrichtian boundary may be precisely drawn in western Saskatchewan and traced westward to the Rocky Mountain front.

Zones based on ammonites and inoceramid bivalves form the cornerstone of the biostratigraphy and chronostratigraphy of the southern Interior Plains and hold the key to the stage boundaries. Zones based on assemblages of benthonic foraminifers, rarely of planktonic foraminifers, supplement the molluscan zones. The foraminiferal zones are less reliable and less useful, however, because some benthonic assemblages are weakly diachronous, most foraminiferal zones span several molluscan zones, and many stage boundaries fall within individual foraminifer zones.

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Zones and stages

Molluscan fossils, particularly ammonites and inoceramid bivalves, form the cornerstone of zonal schemes for Cretaceous rocks in most parts of the world. Nowhere have these fossils been used with greater effect biostratigraphically and chronostratigraphically than in the Western Interior basin of North America. Having been described for well over one hundred and fifty years, they are now sufficiently well known to allow recognition of more than sixty reliably tested biozones in the Upper Cretaceous Series alone. Although the North American Code of Stratigraphic Nomenclature (1983) suggests a clear distinction between such zones, which are biostratigraphic divisions, and stages, which are chronostratigraphic divisions, the two are intimately related; zones form the basis of the relative time-scale used in the basin, and boundaries between stages are drawn in the original d'Orbigny sense to coincide with boundaries between zones.

Kaufmann *et al.* (1977, p. 12) demonstrated that sections within the Western Interior of the United States permit precise delineation of certain stage and substage boundaries and proposed that these and other sections be considered important reference sections in any attempt to finalize definition of the inter-stage boundaries originally defined in Europe. The portion of the Western Interior basin in the United States unquestionably offers the best sections for the establishment of regional (if not international) standards for most of the Upper Cretaceous Series. Only in the Canadian portion of the Western Interior basin, however, do sections exist in marine facies suitable for the establishment of similar standards through the Lower Cretaceous Series. The Peace River district of northwestern Alberta and northeastern British Columbia, in particular, offers an unmatched section through the Albian Stage into the Cenomanian Stage and must be given further consideration as a standard for (at least) the continent. The purpose of this

summary, therefore, is to offer a synopsis of how inter-stage boundaries currently are discriminated in marine sections of the southern Interior Plains of Canada and to identify segments of the basin that may warrant further study in the interests of better defining stages and substages for continental and intercontinental correlation.

The Western Interior basin and the epeiric sea that occupied it throughout most of the Cretaceous Period were of truly continental proportions. When most widespread, the Western Interior seaway extended in length some 4800 km, linking what is now the Beaufort Sea and the Gulf of Mexico, and in width some 1600 km, from what is now Utah to Iowa. Composition of the molluscan faunas and of other elements of the biotas were not uniform throughout so vast a seaway, and variations in the composition are attributable to two main factors. Firstly, once the seaway was established, faunas of northern and of southern provenance migrated so deeply into the basin that a broad and fluctuating zone of overlap was established between them. That zone became an important endemic centre (Kauffman 1973, p. 368, fig. 2; 1977, p. 96). Secondly, a northward declining palaeo-temperature gradient, based on oxygen-isotope measurements, has been established, and the geographic grid for the entire basin has been reconstructed from palaeomagnetic measurements of polar position. Superimposed, gradient and grid reveal a gradual decrease in palaeotemperature with increase in palaeolatitude and offer support for the long-held, but hitherto unsubstantiated, view that northward decline in the number and variety of molluscs and other biotic elements could be attributed to palaeolatitudinal (and therefore palaeoclimatic) variation (Caldwell 1982, p. 301–303). The existence of two biogeographical provinces within the basin, one of northern or 'Boreal' ancestry, the other of southern or 'gulfian' ancestry, long has been recognized. These now have been formalized as the North American Interior Subprovince, which generally extends southward through Wyoming, and the Southern Interior Subprovince, which generally extends northward through Colorado. Both are components of the North American Province and lie within the global North Temperate Realm (Kauffman 1973). Differences in the faunas of the biogeographical subprovinces find expression

in somewhat different zonal schemes for the northern (Canadian) and southern (United States) portions of the basin. The sequence of molluscan zones applied in the United States has been compiled and refined mainly by W. A. Cobban of the United States Geological Survey. It has been published widely. Particularly pertinent to this contribution is the version by Cobban (*in* Obradovich and Cobban 1975, tab. 1) in which ammonite zones and isotopic ages are related to the discrimination of stage boundaries. Kauffman *et al.* (1977, p. 7–12) have described in detail their zones and their concept of the stages and substages from Late Albian to Late Coniacian in the Western Interior of the United States. The sequence of molluscan zones applied in Canada has been compiled mainly by J. A. Jeletzky of the Geological Survey of Canada. The basis for the biostratigraphic framework is discussed by Jeletzky (1968) and a good tabular summary is available in Jeletzky (1971, fig. 3). Illustrations of the more important molluscan species may be found in Jeletzky (1964, 1970). Kauffman (1979, figs 3B,E, 4B,E) has outlined a zonal framework for the Arctic and Western Interior of North America that draws heavily on Cobban's and Jeletzky's schemes.

In the last thirty years, attempts have been made to complement the molluscan zonal sequences with those based on foraminifers. A foraminiferal biostratigraphic framework for much of the Cretaceous System in the Western Interior of the United States may be compiled mainly from the contributions of Eicher (1960, 1965, 1966, 1967, *in* Kaufmann *et al.* 1977) and Eicher and Worstell (1970), and a preliminary framework of zones for the southern Interior Plains of Canada is available (Caldwell *et al.* 1978). Difficulties with the foraminiferal zonal schemes arise because so many of the zonal assemblages are composed of agglutinated or mixed agglutinated and calcareous benthonic elements, and the chronostratigraphic reliability of many of these assemblages for correlation has not yet been sufficiently tested. Assemblages dominated by planktonic elements are comparatively rare and, throughout much of the basin, lack the keeled species proven elsewhere to have the greatest chronostratigraphic reliability. Nonetheless, the foraminiferal zones are particularly useful in the southern Interior Plains of Canada (fig. 1), where

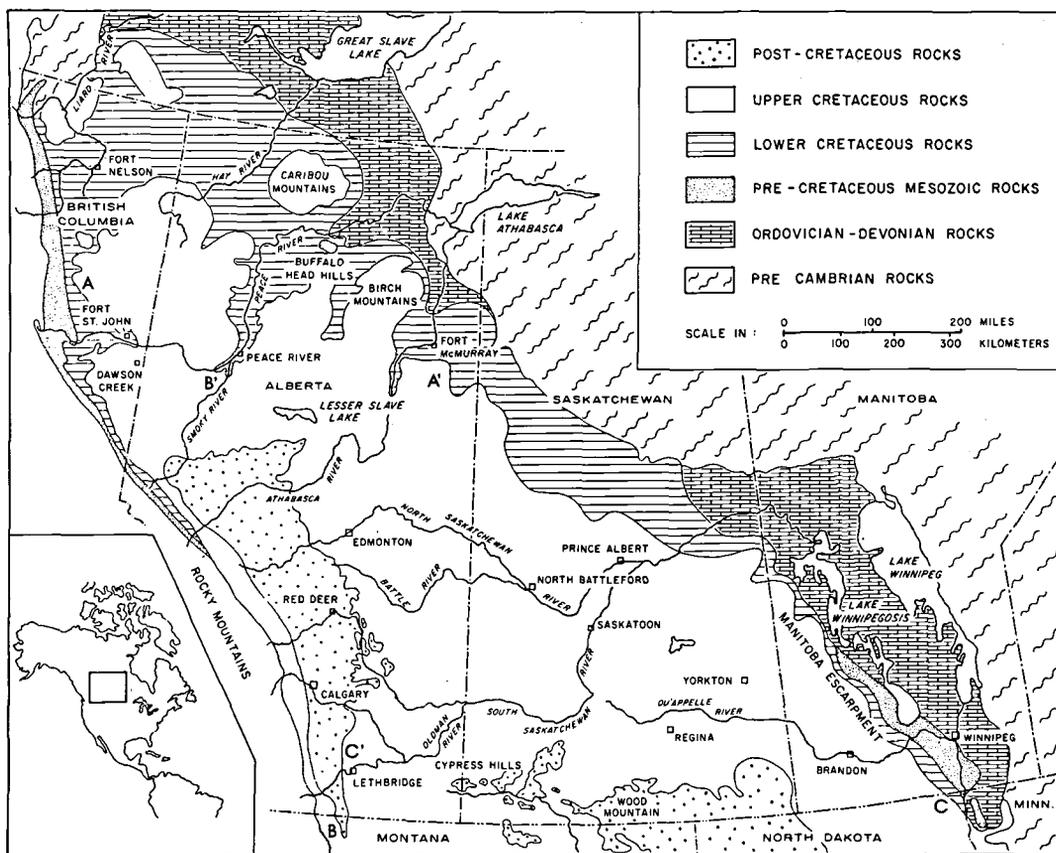


Figure 1. Geological sketch map of the southern Interior Plains of Canada to show the distribution of Lower and Upper Cretaceous rocks and the principal geographical localities.

Cretaceous rocks are largely buried beneath glacial deposits of Pleistocene age, where many key sections have been cored in the subsurface, and where the yield of molluscs has been appreciably lower than in the interior plains of the United States.

Table 1 summarizes the position of inter-stage boundaries, as these are interpreted in the Western Interior of Canada, relative to the key molluscan zones and to the foraminiferal zones and subzones.

Stage boundaries within the Lower Cretaceous Series

Although rocks of Berriasian to Aptian age may be widely distributed in the southern Interior Plains of Canada (Rudkin 1964), these rocks are

mainly in continental and marginal-marine facies and not amenable to dating by foraminiferal and molluscan fossils. Age (or stage) has been ascertained from palaeobotanical evidence or inferred by lithostratigraphic correlation with dated deposits in adjacent regions.

Only in the Rocky Mountain foothills and adjacent plains of northwestern Alberta and, particularly, northeastern British Columbia is the proportion of marine rocks in the Lower Cretaceous Series sufficient to warrant biostratigraphic analysis in terms of Jeletzky's molluscan zonal scheme. Even in this portion of the region broadly defined as the southern Interior Plains, however, the palaeontological grounds for identifying the stage and substage boundaries are weak, and many of the boundaries can be drawn only tentatively. Stott (1975) has summarized the variable sequences of this belt and

STAGES		SELECTED MOLLUSCAN ZONES	FORAMINIFERAL ZONES	SUBZONES
PALEOCENE			NON-MARINE DEPOSITS	
MAESTRICHTIAN		[<i>Triceratops dinosaurs</i>]		
		<i>Baculites grandis</i> <i>Baculites baculus</i> <i>Baculites eliasi</i> <i>Baculites jenseni</i> <i>Baculites reesidei</i>	<i>Haplophragmoides excavata</i>	
CAMPANIAN		<i>Baculites cuneatus</i>	<i>Anomalinoidea sp.</i>	
		<i>Baculites compressus</i>	<i>Haplophragmoides fraseri</i>	<i>Praeulimina kickapoensis</i> <i>Gaudryina bearpawensis</i> <i>Dorothia cf. smokyensis</i>
		<i>Didymoceras cheyennense</i> <i>Exileoceras jemeyi</i> <i>Didymoceras stevensoni</i>	<i>Eoepontidella linki</i>	
		<i>Baculites gregoryensis</i> <i>Baculites perplexus</i> <i>Baculites asperiformis</i> <i>Baculites maclearni</i> <i>Baculites obtusus</i> <i>Baculites sp.</i> <i>Scaphites hippocreptis</i>	<i>Clomospira corona</i>	<i>Quinqueloculina sphaera</i> <i>Spiroplectamina sigmoidina</i>
			<i>Trochammina ribstonensis</i>	
SANTONIAN		<i>Desmoscapites bassleri</i> <i>Desmoscapites erdmanni</i> <i>Clisocapites choteauensis</i> <i>Clisocapites vermiformis</i> <i>Scaphites depressus</i>	<i>Globigerinelloides sp.</i>	<i>Heterohelix cf. reussi</i> <i>Cavelinella henbesti</i>
CONIACIAN		<i>Scaphites ventricosus</i> <i>Scaphites preventricosus</i>	<i>Bullopore laevis</i>	
TURONIAN		<i>Collignoniceras woolgari</i>	<i>Trochammina sp.</i>	
		<i>Inoceramus labiatus</i> <i>Watinoceras reesidei</i>	<i>Pseudoclavulina sp.</i>	
CENOMANIAN		<i>Dunveganoceras hagei</i> <i>Dunveganoceras cf. parvum</i> <i>Dunveganoceras albertense</i> <i>Dunveganoceras cf. conditum</i> <i>Aanthoceras athabascense</i> <i>Beattonoceras beattonense</i>	<i>Hedbergella loetterlei</i>	<i>Whiteinella aprica</i> <i>Clavithedbergella simplex</i>
			<i>Flabellamina gleddiei</i>	<i>Haplophragmoides spiritense</i> <i>Ammobaculites pacalis</i>
			<i>Verneuilinoidea perplexus</i>	<i>Gaudryina irenensis</i> <i>Ammobaculites gravenori</i>
			<i>Textularia alcesensis</i>	
ALBIAN		<i>Neogastrolites maclearni</i> <i>Neogastrolites muelleri</i> <i>Neogastrolites cornutus</i> <i>Neogastrolites haasi</i>	<i>Miliammina manitobensis</i>	<i>Haplophragmium swareni</i> <i>Haplophragmoides postis goodrichi</i> <i>Verneuilina canadensis</i>
		<i>Inoceramus comancheanus</i> <i>Stelkiceras liardense</i> <i>Gastrolites allani</i> <i>Gastrolites kingi</i> <i>Pseudopulchellia pattoni</i>	<i>Haplophragmoides gigas</i>	
		<i>Arthropilites macconnelli</i> <i>Arthropilites irenense</i> <i>Lemuroceras cf. L. indicum</i> <i>Cleoniceras cf. C. subbaylei</i> <i>Rachygrya spp.</i>	<i>Gaudryina nanushukensis</i>	<i>Ammobaculites wenonahae</i> <i>Ammobaculites sp.</i> <i>Haplophragmoides multiplum</i> <i>Marginulinopsis collinsi-Verneuilinoidea cummingensis</i> <i>Trochammina murrayensis</i> <i>Rectobolivina sp.</i>
APTIAN		Absent <i>Aucellina cf. aptiensis-caucasica sp.</i>	FORAMINIFERA POORLY KNOWN.	
NEOCOMIAN	BARREMIAN	<i>Crioceratites cf. C. lardii</i> <i>Crioceratites cf. C. nolani</i> & <i>Oxyteuthis cf. O. jakikovi</i>	ZONE NOT YET ESTABLISHED.	
	HAUTERIVIAN	<i>Craspedodiscus cf. C. discofolatus</i> <i>Simbrakites cf. S. kleini</i> Unnamed zone Marine rocks unknown		
	VALANGINIAN	<i>Buchia inflata</i> <i>Buchia cf. B. keyserlingi</i>		
	BERRIASIAN	<i>Buchia n. sp. aff. B. volgensis</i> <i>Buchia okenis</i>		
TITHONIAN		<i>Buchia fischeriana</i> <i>Buchia piochii</i>		

Table 1. Summary of the international stages as these are recognized in the southern Interior Plains of Canada in relation to molluscan zones and to foraminiferal zones and subzones as established by Caldwell *et al.* (1978). To avoid excessive crowding, only a section of the molluscan zones are shown, but this includes all key zones for discrimination of the stage boundaries. For a full sequence of molluscan zones, see references cited in text.

shown their correlation in terms of relative ages.

The Tithonian-Berriasian stage and inter-systemic boundary, together with the Berriasian-Valanginian and Valanginian-Hauterivian substage boundaries, are drawn within Jeletzky's (1968, p. 6–10, fig. 1; 1971, fig. 3) sequence of zones based mainly on *Buchia*. The boundary between the *Buchia fischeriana* Zone and the *B. okensis* Zone, the latter containing also *Subcraspedites* aff. *S. suprasubditus*, is regarded tentatively as the stage boundary; that between the *B. n. sp. aff. B. volgensis* Zone and the *B. cf. B. keyserlingi* Zone, the latter containing also *Polyptychites* cf. *P. keyserlingi*, is taken as the lower of the substage boundaries; and the top of the *B. inflata* Zone, where it is in contact with non-marine rocks, is regarded as a close approximation of the upper of the substage boundaries (Stott 1975, text-fig. 3). The Berriasian and Valanginian ammonites, bivalves, and belemnites are of north Pacific affinity and suggest a connecting strait from the Peace River marine embayment, through the meso-Cordilleran uplift, to the western ocean (Jeletzky 1971, p. 35–38; Williams and Stelck 1975, p. 3, 4; Stott 1975, p. 447–449).

Hauterivian and Lower Barremian rocks generally are absent from northwestern Alberta and northeastern British Columbia, and the inference that the Hauterivian-Barremian boundary would coincide with that between the Zone of *Craspedodiscus* cf. *C. discofalcatus* and that of *Crioceratites* cf. *C. nolani* and *Oxyteuthis* cf. *O. jaskowi* is based on marine sections well to the north of the southern Interior Plains.

Like the lower boundary of the Berriasian Stage, the Barremian-Aptian boundary can only be placed questionably within the molluscan zonal sequence of Jeletzky; it lies within the Zone of *Aucellina* of the *aptiensis-caucasica* group (Stott 1975, text-fig. 3). More recent work implies a somewhat more precise position within this broad aucellinid zone, however; Stott (1982, fig. 5) showed it tentatively to lie within an unnamed subzone underlain by the Subzone of *Arcotheuthis* (?) cf. *A. mitchelli* and *A. kernensis* and overlain by the Subzone of *Tropaeum hillsi*.

Foraminifera from the Berriasian-Barremian and Aptian sequences of the southern Interior Plains are poorly known and do not yet permit the establishment of a series of zones to supple-

ment the molluscan zones. Chamney (1973, p. 67–72), recorded numerous foraminifers from the marine facies of the Barremian-Aptian Gething Formation in northeastern British Columbia, but his species (*in* Stott 1973, p. 146 ff.) are mainly *nomina aperta* and not illustrated. Hence it is impossible to assess his suggested zones and relate them either to the molluscan zones or to the post-Aptian foraminiferal zones of Caldwell *et al.* (1978).

Much better known in the southern Interior Plains than the Berriasian-Barremian and Aptian stages, the Albian Stage is substantially present in marine facies throughout the region and has an exceedingly thick and near-continuous development in northwestern Alberta and northeastern British Columbia. The stage records two major southward transgressions of the Boreal sea into the southern Interior Plains. The younger transgression – a phase of the Kiowa-Skull Creek marine cycle of Kauffman *et al.* (1977, p. 3, 4, fig. 2) and of the T₅-R₅ global cycle of Kauffman (1977, p. 89, fig. 7) – extended through the Western Interior of the United States to become confluent, early in Late Albian time, with a northward transgression of marine waters from the Gulf Coast to establish the Western Interior seaway. The Lower Albian is characterized by the *Arcthoplites* ammonite fauna, although this fauna makes its appearance above the base of the stage; the Middle Albian is distinguished by various gastroplitinid ammonites, with zones based on *Pseudopulchellia pattoni*, *Gastroplites* spp. (*sensu stricto*), and *Stelckiceras* ["*Paragastroplites*"] *liardense*; and the Upper Albian is identified by successive species of *Neogastroplites*.

Jeletzky and Stelck (1981, fig. 1) suggested that the Aptian-Albian boundary might be drawn coincident with base of the new Zone of *Pachygrycia* spp. It replaces the old Zone of *Sonneratia* cf. *kitchini* of Jeletzky (1968, 1971), overlies the broad Aptian zone distinguished by *Aucellina* of the *aptiensis-caucasica* species group, and underlies the Zone of *Arcthoplites* spp. An external homoeomorph of *Sonneratia*, the new ammonite genus, *Pachygrycia*, is a cleoniceratinid, referred to the desmoceratid family, and probably derived from a still-unknown, Boreal, beudanticeratinid stock. The Zone of *Pachygrycia* spp. is correlated with the lower part of the European basal Albian Zone of

Leymeriella tardefurcata. The *Pachygrycia* fauna may be anticipated wherever basal Albian beds in marine facies are present in the southern Interior Plains. At present, however, it has been recorded only from the most northerly limit of this region (Jeletzky and Stelck 1981, p. 10, fig. 20).

Foraminiferal faunas do not assist in delimiting the Aptian-Albian boundary in the southern Interior Plains; the lowest zones in the preliminary zonal scheme of Caldwell *et al.* (1978) correspond to the Zone of *Archoplites* spp. in the ammonite scheme, and the foraminiferal fauna of the Zone of *Pachygrycia* spp. is unknown.

Jeletzky's (1980) and Jeletzky and Stelck's (1981) revision of the Albian molluscan zones and substage assignments in northwestern Canada, does, however, require some changes in the ages assigned to the foraminiferal zones of Caldwell *et al.* (1978, p. 502-519). The *Gaudryina nanushukensis* Zone now may be assumed to mark the sequence from early Early Albian through Middle Albian, with the *Rectobolivina* sp. Subzone being of early Early Albian Age, the *Trochammina mcmurrayensis* Subzone of middle Early Albian Age, the *Marginulinopsis collinsi-Verneuilinoides cummingensis* Subzone of late Early Albian Age, the *Haplophragmoides multiplex* Subzone of early to middle Middle Albian Age, the *Ammobaculites* sp. Subzone of middle Middle Albian Age, and the *Ammobaculites wenonahae* Subzone of late Middle Albian Age. The widespread *Haplophragmoides gigas* Zone remains early Late Albian in age, but the equally widespread *Miliammina manitobensis* Zone must now be regarded as ranging from early to late Late Albian, with the *Verneuilina canadensis* Subzone as early to middle Late Albian in age, the *Haplophragmoides postis goodrichi* Subzone as middle Late Albian in age, and the *Haplophragmium swareni* Subzone as middle to late Late Albian in age. The *Haplophragmoides gigas* and *M. manitobensis* zones may be traced well into the Western Interior of the United States (Eicher 1960; in Kauffman *et al.* 1977, p. 7, 8, fig. 6). Save for a few elements appearing late in the stage, the Albian foraminifers and molluscs are exclusively Boreal in origin and belong to the North American Interior Subprovince.

Albian-Cenomanian (Lower-Upper Cretaceous) boundary

Across the southern Interior Plains of Canada, the Albian-Cenomanian boundary beds are sandy to silty and packed with fish scales. Collectively, these beds compose the fish-scale marker, the top of which usually is taken as the stage boundary. To read the boundary in such simplistic lithostratigraphic terms, however, ignores the complexities of the age relations.

Warren and Stelck (1958, 1969), working in the relatively continuous and thick sections of northwestern Alberta and northeastern British Columbia, laid the foundation for a detailed succession of ammonite zones through the Upper Albian-Lower Cenomanian. Sequential species of *Neogastropilites*: *N. haasi*, *N. cornutus*, *N. muelleri*, *N. americanus*, *N. maclearni*, and *N. septimus* distinguish sequential subzones of the *Neogastropilites* Zone in the uppermost Albian-lowermost Cenomanian, and *Irenicoceras bahani* Warren and Stelck and *Beattonoceras beattonense* Warren and Stelck distinguish zones in the overlying Lower Cenomanian. Ammonites are unknown in the Lower Cenomanian of the Western Interior of the United States and exceedingly rare in the Western Interior of Canada. The *Irenicoceras* and *Beattonoceras* beds, therefore, are of unusual importance. Both genera are believed to be gastropilitinid derivatives (Warren and Stelck 1958, p. 38, 41) and are inferred to be of Early Cenomanian Age because they occur in beds beneath those containing Middle to Late Cenomanian *Acanthoceras* and *Dunveganoceras*. According to Warren and Stelck (1969, p. 532), *Neogastropilites maclearni* is present in the 'fish-scale marker' of the Peace River valley. The slightly older *N. americanus* usually occurs just below the base of the marker, although at some localities the base may be as low as the *N. americanus* Subzone. Neogastropilitid ammonites have not been found eastwards across the plains of Saskatchewan or Manitoba where Upper Albian-Lower Cenomanian rocks, if present, are buried in the subsurface; nor have they been found in outcrops of the Manitoba escarpment (McNeil and Caldwell 1981).

Three foraminiferal zones come under consideration in attempting to elucidate the nature and

position of the Albian-Cenomanian boundary; these are the *Miliammina manitobensis* Zone of Late Albian Age, the *Textularia alcesensis* Zone of latest Albian and Early Cenomanian Age, and the *Verneuilinoides perplexus* Zone of Middle to Late Cenomanian Age. Most of the zonal elements, like so many of the molluscs, are Boreal or endemic in origin and belong to the North American Interior Subprovince. It is in the continuous and thick sedimentary sequences of northwestern Alberta and northeastern British Columbia that the *M. manitobensis* Zone is divisible into the *Verneuilina canadensis* Subzone (oldest), the *Haplophragmoides postis goodrichi* Subzone, and the *Haplophragmium swareni* Subzone (youngest) (Caldwell *et al.* 1978, p. 514–519). The 'fish-scale marker' lies within the *T. alcesensis* Zone (Stelck *et al.* 1958, p. 20), which in terms of the ammonite zones spans the *N. maclearni* and *N. septimus* subzones of the *Neogastropplites* Zone and the overlying *I. bahani* Zone and *B. beattonense* Zone. Recognized in cored boreholes, the 'fish-scale marker' has been projected through the subsurface into eastern Saskatchewan and Manitoba (Williams and Burk 1964), and it appears in the Manitoba escarpment as the lowest few meters of the Belle Fourche Member of the Ashville Formation (McNeil and Caldwell 1981, p. 48–50, text-fig. 11). These lowest few meters contain the *Verneuilina canadensis* foraminiferal fauna which marks the lowest subzone of the *M. manitobensis* Zone of Late Albian Age.

Seemingly conformable, overlying beds of the Belle Fourche Member contain the *Verneuilinoides perplexus* foraminiferal fauna which distinguishes the zone of that name of Middle to Late Cenomanian Age. Hence in the Manitoba escarpment and across most of the southern Interior Plains, the *Haplophragmoides postis goodrichi* Subzone and the *Haplophragmium swareni* Subzone of the *M. manitobensis* Zone and the entire *T. alcesensis* Zone are missing. Stelck *et al.* (1958, p. 13) first proposed that the 'fish-scale marker' may mark an unconformity. North and Caldwell (1975, p. 315) and Caldwell *et al.* (1978, p. 520) suggested the marker may denote a horizon of regional paraconformity. In northeastern British Columbia, where the *Verneuilina canadensis* Subzone of the *M. manitobensis* Zone contains ammonites, it corresponds to the lower part

of the *N. haasi* Subzone of the *Neogastropplites* Zone. Hence, if the late Albian-Early Cenomanian foraminiferal zones are chronostratigraphically reliable across the southern Interior Plains, the 'fish-scale marker' must be diachronous in addition to containing one or more paraconformities.

The Late Albian was a time of shrinking of the Western Interior seaway as the regressive phase of the Kiowa-Skull Creek marine cycle reached its acme. Unconformities, usually expressed as disconformities, tend to be concentrated in deposits of the regressive maxima, and commonly a number of these disconformities when traced eastwards are found to anastomose into a single discontinuity of considerable temporal magnitude (Kauffman 1977, p. 89; Kauffman *et al.* 1977, p. 3, 4, fig. 2). Such circumstances may explain the loss of Late Albian-Early Cenomanian section eastwards from northeastern British Columbia, across the southern Interior Plains, to the Manitoba escarpment, although obvious erosional surfaces have not been identified.

Stage boundaries within the Upper Cretaceous Series

Just as the position of the Albian-Cenomanian boundary can be reliably established in the continuous foraminifer- and mollusc-bearing sections of the western flank of the basin and becomes enclosed eastward in an expanding depositional hiatus, the same is true in more or less degree of the Cenomanian-Turonian, Turonian-Coniacian, Coniacian-Santonian, and Santonian-Campanian boundaries. Not only are the sections of the eastern platform (foreland bulge) of the basin less complete than those of the western foredeep in Canada, they are markedly less complete than those of the eastern platform in the United States (fig. 2), where Kauffman *et al.* (1977) established their series of detailed zones and substages within the Late Albian-Late Coniacian succession. Some local disconformities, which map regionally in the Manitoba escarpment and adjacent plains as weak angular unconformities must be attributed to tectonic effects probably linked to the developing Rocky Mountains far to the west. Other disconformities and paraconformities may be expressions of non-deposition or, locally, of

submarine erosion or sedimentary by-pass. Whatever their cause, they diminish the value of Late Cenomanian to Early Campanian sections in the eastern plains for refining criteria that would aid in delineation of the intervening stage boundaries.

Based on molluscs, Jeletzky (1968, fig. 2) drew the Cenomanian-Turonian boundary at the top of *Dunveganoceras* Zone of Warren and Stelck (1940). In 1971 (fig. 3), he raised the position slightly, almost to the base of his *Watinoceras* and *Inoceramus labiatus* Zone, including beds with *Sciponoceras gracile* (an important marker of the boundary farther south in the United States) in the Turonian Stage. Cobban (in Obradovich and Cobban 1975, Tab. 1) placed the boundary slightly higher still, at the base of the *Watinoceras coloradoense* Zone or *Inoceramus labiatus* (*sensu lato*) Zone and above the *S. gracile* Zone. Most workers seem to have accepted Cobban's position. The most continuous sedimentary sequence through the Cenomanian-Turonian boundary in the southern Interior Plains again seems to be that in the Peace River district of northwestern Alberta and northeastern British Columbia where all the key molluscan elements required to establish the boundary seem to be present (Stelck and Wall 1955, p. 6-28; Jeletzky 1968, p. 25-27). Farther east, across the plains, elements of the *Dunveganoceras* and *S. gracile* Zones have not been found.

In the Peace River district, the boundary falls within the foraminiferal Zone of *Flabellamina gleddiei*, which ranges from within the *Dunveganoceras albertense* Zone to within the *W. coloradoense* Zone of Cobban. The *F. gleddiei* fauna is known only from the Peace River drainage basin, and its absence from other parts of the Rocky Mountain foothills and from the plains is not easily explained. Distribution of the fauna may have been constrained by certain environmental factors, but this is difficult to accept given the known distribution of other similar faunas in the region and the expanding marine conditions of Late Cenomanian-Early Turonian time when the transgressive phase of the Greenhorn marine cycle or T₆-R₆ global cycle of Kauffman (1977, p. 89, fig. 7) was nearing its acme. Alternatively, the fauna may have been much more widely distributed and its wider record subsequently obliterated. A disconformity, pronounced in its effect

in mid-Saskatchewan where it brings the Early Turonian foraminiferal Zone of *Hedbergella loetterlei* to rest on beds as old as those of the Late Albian *Miliammina manitobensis* Zone, may be more regional in its effect and account for absence of the *F. gleddiei* deposits from the plains. Such a disconformity also could explain why elements of the *Dunveganoceras* and *S. gracile* molluscan zones have not been recovered from so much of the plains. At present, throughout most of the plains, the Early Turonian *H. loetterlei* Zone, marking the most widespread marine conditions of the Greenhorn marine cycle, rests on the early Late Cenomanian *Verneuilinoides perplexus* Zone, and there is no sign of the *F. gleddiei* Zone between them. Like the Albian-Cenomanian boundary, therefore, the Cenomanian-Turonian boundary may coincide largely with a paraconformable surface.

Jeletzky (1968, fig. 2; 1971, fig. 3) drew the Turonian-Coniacian boundary to coincide with that between his *Scaphites preventricosus-Inoceramus deformis* Zone and his *S. ventricosus-I. involutus* Zone, and the Coniacian-Santonian boundary to coincide with that between the latter zone and his *S. depressus* Zone. Cobban (in Obradovich and Cobban 1975, tab. 1), with some hesitation, placed the Turonian-Coniacian boundary a little lower, between the *S. corvensis* Zone and the *S. preventricosus-I. deformis* Zone and concurred on the position of the Coniacian-Santonian boundary. There is growing support for including occurrences of *S. preventricosus* and *I. deformis* within the Coniacian Stage (see, for example, Kauffman *et al.* 1977, p. 8-12). The key scaphitid and inoceramid molluscs for discrimination of these inter-stage boundaries have been found in the Rocky Mountain foothills and immediately adjacent plains, but not farther east across most of the basin (Jeletzky 1968, p. 32, 33).

Among the foraminiferal faunas of Turonian, Coniacian, and Santonian Age, two are of unusual importance because they are composed largely or wholly of planktonic elements. These are the *Hedbergella loetterlei* fauna, which distinguishes an Early Turonian zone, and the *Globigerinelloides* sp. fauna, which distinguishes a Santonian zone (although the ages of the lowest and highest beds carrying the fauna in places may be slightly older and slightly younger). These zones mark the times during the Greenhorn and

succeeding Niobrara marine cycles when warmer waters spread northward within the Western Interior seaway to flood the basin to its limits, bringing with them subtropical elements of the Southern Interior Subprovince (Kauffman 1977, p. 91, 92). The *H. loetterlei* and *Globigerinelloides* sp. faunas and their biostratigraphic implications have been fully discussed by Caldwell *et al.* (1978, p. 526–529, 534–542). Deposits of the regressive phase of the Greenhorn marine cycle and transgressive phase of the Niobrara marine cycle fall within three, intervening foraminiferal zones, the *Pseudoclavulina* sp. Zone, the *Trochammina* sp. Zone, and the *Bullopore laevis* Zone. These have less distinctive faunas and are confined mainly to the Rocky Mountain foothills and adjacent plains of southern Alberta. It is these zones that contain the Turonian-Coniacian and Coniacian-Santonian boundaries. Farther east, across Saskatchewan, these zones are missing, and a major disconformity brings the *Globigerinelloides* sp. Zone to rest directly on thinned remnants of the *H. loetterlei* Zone. The hiatus diminishes through Manitoba and, in the Manitoba escarpment, a thin shale carries elements of the *Pseudoclavulina* sp. fauna and possibly also of the *Trochammina* sp. fauna. Once again, therefore, like the two preceding inter-stage boundaries, the Turonian-Coniacian and Coniacian-Santonian horizons are reliably established only on the western flank of the basin, where complete, or near complete, foraminiferal and molluscan zonal sequences are preserved. If the boundary between the *S. corvensis* Zone and the *S. preventricosus-I. deformis* Zone is taken as the Turonian-Coniacian boundary, then that horizon lies high in the foraminiferal Zone of *Pseudoclavulina* sp. The Coniacian-Santonian boundary lies in the lower part of the foraminiferal Zone of *B. laevis*, which spans the upper *S. ventricosus-I. involutus* Zone and the *S. depressus* Zone (Caldwell *et al.* 1978, p. 529–534).

In terms of molluscan biostratigraphy, there is no disagreement about the position of the Santonian-Campanian boundary. Jeletzky (1968, fig. 2; 1971, fig. 3) drew it at the top of the Zone of *Desmoscaphites* spp. and base of the succeeding Zone of *Hoploscaphites hippocrepsis*. Cobban (*in* Obradovich and Cobban 1975, tab. 1) drew it at the top of the Zone of *Desmoscaphites bassleri* which is coincident with the base of the Zone of

Scaphites hippocrepsis. There seemed to be little problem in defining the boundary also in terms of foraminiferal zones when these were first established. In the southern Rocky Mountain foothills, the upper *Heterohelix* cf. *H. reussi* Subzone of the *Globigerinelloides* sp. Zone falls within the *Desmoscaphites* spp. Zone of Jeletzky and certainly within the *D. erdmanni* Zone and possibly also the *D. bassleri* Zone of Cobban. Farther east, across the plains, the succeeding foraminiferal Zone of *Trochammina ribstonensis* ranges from at least the upper part of the *S. hippocrepsis* Zone to the Zone of *Baculites obtusus*. The inter-stage boundary, therefore, lay between the two foraminiferal zones. In the Manitoba escarpment, however, McNeil and Caldwell (1981, p. 100) reported *Baculites (?) thomi* from the upper part of the *Gavelinella henbesti* Subzone of the *Globigerinelloides* sp. Zone and *B. thomi* corresponds in range to the *D. erdmanni* and *D. bassleri* zones. As the *H. cf. H. reussi* Subzone succeeds the *G. henbesti* Subzone in the Manitoba escarpment, it seems likely that the higher subzone is in part at least Early Campanian in age. In keeping with such a conclusion, the *Trochammina ribstonensis* Zone in the Manitoba escarpment has been inferred to lie in the Zones of *B. obtusus* to *B. perplexus*. It is distinctly possible, therefore, that the *Globigerinelloides* sp. Zone and overlying *Trochammina ribstonensis* Zone may be slightly diachronous across the southern Interior Plains, and the Santonian-Campanian boundary may lie between the zones on the western flank of the basin and in the upper part of the *Globigerinelloides* sp. Zone on the eastern flank of the basin. The suggestion of a disconformity between the *Globigerinelloides* sp. Zone and the *T. ribstonensis* Zone across much of the plains (North and Caldwell 1975, p. 321; Caldwell *et al.* 1978, p. 539) adds further complication. The disconformity has been assumed to lie at the top of the Santonian section and to be an expression of the Santonian-Campanian discontinuity previously recognized in many other parts of the Western Interior basin. The break now may be correlated with the regressive acme of the Niobrara or T₇-R₇ global cycle of Kauffman (1977, p. 89, fig. 7). It is entirely possible, however, that the short-lived withdrawal of the sea at the close of Niobrara deposition did not take

place until Early Campanian time and, if the disconformity extends across all or most of the southern Interior Plains, it may obfuscate at any locality a precise reading of the Santonian-Campanian boundary in terms of both foraminiferal and molluscan zones.

Cobban (*in* Obradovich and Cobban 1975, p. 47–49, tab. 1) discussed various positions, based on ammonites and foraminifers, in which the Campanian-Maastrichtian boundary had been drawn in the Western Interior basin. He gave reasons for revising its position from the base of the ammonite Zone of *Baculites baculus*, which like Jeletzky (1971, fig. 3) he previously had favoured, to one coincident with the base of the *B. reesidei* Zone. This position has won growing acceptance. It corresponds to a level slightly above the base of the foraminiferal Zone of *Anomalinoides* sp. (Caldwell *et al.* 1978, p. 558–561). The boundary can be drawn precisely in the South Saskatchewan River valley (Caldwell 1968; North and Caldwell 1970), where the stratotype of the *Anomalinoides* sp. Zone is located and where a continuous sequence of Cobban's baculitid zones has been recognized.

The *Anomalinoides* fauna, one of the most diverse and rich assemblages of benthonic species in the entire Upper Cretaceous Series, thrived when the Western Interior seaway remained expanded following the transgressive peak of the Bearpaw marine cycle or T₉-R₉ global marine cycle of Kauffman (1977, p. 89, fig. 7). Many elements described from the Gulf Coast, and thus from the Southern Interior biogeographic province, are included in the fauna. Although diversity drops toward the western margin of the seaway, the fauna remains recognizable across the western half of the basin where it occurs in association with baculitids of the *B. cuneatus* to *B. jenseni* Zones (Caldwell 1982, figs. 8, 9). Eastwards from the South Saskatchewan River valley, pre-Pleistocene erosion has removed the Campanian-Maastrichtian boundary beds from wide tracts of the plains.

The Western Interior seaway withdrew finally from what is now the southern Interior Plains of Canada in Early Maastrichtian (*B. grandis*) times. Hence the Maastrichtian-Paleocene boundary is established on quite different palaeontological criteria (ones that are excluded from consideration in this synopsis) from those

used to establish the underlying inter-stage boundaries. The Cretaceous-Tertiary (Maastrichtian-Paleocene) boundary is the subject of a voluminous literature on its own.

Conclusions

Broad gradations have been recognized in the facies and faunas of Cretaceous marine sequences throughout the Western Interior basin of North America. The gradations stem from differences in palaeoclimate and palaeogeography and from the variable influence of regional tectonics in time and place.

In contrast with the Western Interior of the United States, Berriasian to Aptian rocks are developed, and Albian rocks much more extensively developed, in marine facies in the southern Western Interior of Canada. Berriasian, Valanginian, Upper Barremian, and Aptian rocks, although thickly developed in northwestern Alberta and northeastern British Columbia, have yielded few foraminifers and molluscs, and discrimination of the stage and substage boundaries (solely on molluscs) remains tentative. The same region, however, offers a complete section through the Albian Stage and into the Cenomanian Stage, with an unmatched, well-documented sequence of ammonite and foraminiferal zones. Central to an understanding of the Albian Stage within the Boreal realm, the section would be a most suitable continental standard.

As for the Early Cretaceous, sedimentation during the Late Cretaceous Epoch was most continuous in the western foredeep of the basin. Albian and post-Albian stage boundaries are most reliably drawn in western sections using the zonal framework based on ammonites and inoceramid bivalves. The boundaries also may be interpreted in terms of zones based on assemblages of (mainly) benthonic foraminifers, although the foraminiferal zones (some of which may be weakly diachronous) usually span several molluscan zones and many of them also span stage boundaries. In more easterly segments of the basin, sedimentation was repeatedly interrupted, and disconformities and paraconformities are rife. In most known sections across the plains, the Albian-Cenomanian, Cenomanian-Turonian, Turonian-Coniacian, Coniacian-Santonian, and

Santonian-Campanian boundaries are enclosed by hiati.

Continuous, heavier sedimentation (to be correlated with intensifying proto-Laramide tectonics) marks the Campanian Stage and Maastrichtian Stage across the plains. The Campanian-Maastrichtian boundary may be precisely discriminated in western Saskatchewan, in terms of both ammonite and foraminiferal zones, and traced across the western half of the basin. The Maastrichtian-Paleocene boundary is preserved only in continental deposits.

Dansk sammendrag

Kridttidens etagegrænser i den sydlige del af Canadas "Interior Plains" beskrives og diskuteres, og der gives en oversigt over definition af grænserne på grundlag af de vigtigste grupper af index-fossiler. Etagegrænserne er i dette område primært baseret på den stratigrafiske udbredelse af ammoniter og inoceramer. Zoner baseret på bentoniske foraminiferer og, undtagelsesvis, planktoniske foraminiferer supplerer ammonit- og inoceram-zoneringen, men er ikke så anvendelige, da disse zoner spænder over længere tidsrum og yderligere er svagt diakrone.

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