# Molluscan Biostratigraphy of the Cretaceous Western Interior Basin, North America

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## Abstract

*The evolution of biostratigraphic systems in Cretaceous sequences of the Western Interior Basin has been rapid. Broad assemblage zones of early workers have been progressively replaced by more refined zonal systems based first on single lineages of ammonites or inoceramid bivalves, next on simple assemblage and concurrent range zones blending these two groups, and ultimately on composite assemblage zones utilizing diverse molluscan groups with high biostratigraphic potential. The current version of this latest and most refined system is presented herein. By taking advantage of differing evolutionary re-sponses among different taxa to environmental changes within a basin, and thus varied first and last ap-pearance datums (FADs; LADs) composite assemblage zonation achieves the highest level of temporal resolution for any biostratigraphic system. The biozonation presented herein utilizes numerous ammo-nite lineages, inoceramid, ostreid, lucinid, thyasirid, pectinid, plicatulid, cardiid, and pteriid bivalve lineages, and turritellid and aporrhaid gastropod lineages to create a system of 89 high-confidence level (HCL), 136 medium-confidence level (MCL), and 169 low confidence level (LCL) composite assemblage biozones for the Cretaceous Western Interior Basin of North America. Measured against the new radio-metric ages of Obradovich (this volume), these biozones have average zonal durations of 0.85 million years (m.y.) (HCL), 0.56 m.y. (MCL), and 0.45 m.y. (LCL), respectively, for the Western Interior Creta-ceous. Resolution for the Upper Cretaceous alone reached 0.62 m.y. (HCL), 0.37 m.y. (MCL) and 0.28 m.y. (LCL) for average biozone durations — one of the most refined biostratigraphic systems in the Phaner-ozoic. Integration of this biozonation with single crystal $^{40}Ar/^{39}Ar$ ages derived from bentonites/*

tuffs, and with a highly refined event and cycle chronostratigraphy for the Western Interior Cretaceous, can be achieved through graphic correlation. The resultant chronology for the Western Interior Cretaceous allows correlation basinwide at levels of resolution greater than 100,000 years and provides a powerful new tool of basin analysis. This chronology serves as the North American standard for the Global Sedimentary Geology Program (GSGP).

## Résumé

*L'évolution des systèmes biostratigraphiques du Crétacé du Bassin Intérieur de l'Ouest a été rapide. Les grandes zones d'assemblages des premiers chercheurs ont été peu à peu remplacées par des systèmes de zones plus précis, d'abord basés sur des lignées isolées d'ammonites ou de bivalves d'inocéramidés, puis sur un assemblage unique et des zones d'extension concomitantes résultant de l'utilisation de ces deux groupes et, finalement, sur des assemblages de zones composites utilisant divers groups de mollusques à fort potentiel biostratigraphique. Nous présentons ci-dessous la version actuelle du dernier et du plus précis des systèmes mis au point. En misant sur les façons propres aux différentes espèces de réagir à des changements environnementaux dans un bassin donné, et donc sur l'existence de niveaux particuliés de première et de dernière apparition [FAD* (first appearance datum); *LAD* (last appearance datum)], la zonation par asemblages composites permet d'atteindre la meilleure résolution quelque soit le système biostratigraphique employé. La biozonation présentée ci-dessous est basée sur de nombreuses lignées d'ammonites, d'inocéramidés, d'ostréidés, de lucinidés, de thyasiridés, de pectinidés, de plicatulidés, de cardiidés et, de lignées de ptériidés bivalves ainsi que de turritellidés et de lignées de gastropodes aporhaidés, afin de créer un système comprenant de nombreuses biozones d'assemblages composites pour le Crétacé du Bassin Intérieur de l'Amérique du Nord, soit 89 d'un niveau de confiance élevé [HLC* (high-confidence level)], *136 d'un niveau de confiance moyen [MCL* (medium-confidence level)] *et, 169 d'un niveau de confiance bas [LCL* (low-confidence level)]. *En comparant ce système avec l'échelle des nouveaux âges radiométriques de Obradovich (cette publication), on se rend compte que la durée moyenne de ces biozones est de 0,85 m.a. dans le cas des biozones (HCL), de 0,56 m.a. dans le cas des biozones (MCL) et de 0,45 m.a. dans le cas des biozones (LCL) du Crétacé de l'Intérieure de l'Ouest. Pour la partie supérieure du Crétacé, la résolution pour la durée moyenne d'une biozone atteint 0,62 m.a. dans le cas des biozones (HCL), 0,37 m.a. dans le cas des biozones (MCL) et 0,28 m.a. dans le cas des biozones (LCL) — ce qui en fait l'un des systèmes biostratigraphiques les plus raffiné du Phanérozoïque. Par corrélation graphique, on peut intégrer les résultats de cette zonation biozonique avec les datations* $^{40}Ar/^{39}Ar$ *sur cristal unique, mesurées sur des bentonites ou des tufs, de même qu'avec ceux d'une chronostratigraphie très fine d'événements et de cycles du Crétacé de l'Intérieur de l'Ouest. Le système chronologique qui en résulte permet des corrélations d'une résolution > 100,000 années, ce qui constitue un outil d'analyse de bassin très puissant. Ce cadre chronologique constitue la norme nord-américaine pour le Global Sedimentary Geology Program (GSGP) (programme de géologie sédimentaire global).*

# INTRODUCTION

Biostratigraphic systems developed for the Cretaceous Western Interior Basin of North America are among the most temporally refined and regionally applicable in the world. This precision has largely been achieved by the integration of well-studied evolutionary lineages of Mollusca, in particular ammonites and various groups of bivalves, in constructing a composite assemblage biozonation (Kauffman, 1970). At present, this zonation has an average of 0.45-0.85 m.y./biozone for all Cretaceous stages (range 0.04-2.42 m.y./biozone), and 0.28-0.62 m.y./biozone for Late Cretaceous stages only (range 0.04-2.42 m.y./biozone for both intervals), based on the new time scale of Obradovich (this volume) for the Western Interior Basin. The current Western Interior biozonal system is applicable throughout all Cretaceous paleobiogeographic divisions of the basin (Kauffman, 1973, 1984) because it incorporates numerous cosmopolitan, eurythermal ammonites, inoceramid bivalves with long-lived planktotrophic larvae and rapid, wide dispersal potential, and longer ranging calcareous plankton zones. These same widely dispersed groups allow close correlations to the global ocean plankton zonations, and to macrofossil zonations worldwide, but especially to zones of the North-Temperate Realm of Eurasia, and the northern parts of Africa and South America.

Molluscan-dominated macrofaunas of the Cretaceous Western Interior Basin also show significant endemism which is used to define paleobiogeographic subprovinces and their ecotones (Fig. 1) within the North American Interior Province of Kauffman (1984). These endemic groups are characterized by restricted paleobiogeographic dispersion within the Western Interior Basin and have very rapid evolutionary rates compared to most cosmopolitan taxa (Kauffman, 1977a, 1978, 1984). Thus, endemic molluscan taxa can be used to establish even greater refinement of regional biostratigraphic systems within and between subprovinces.

These Southern, Central, and Northern Interior subprovinces reflect the average thermal gradient of the Western Interior Seaway which encompassed warm, mild and cool temperate conditions, respectively, and are in that way similar to the provinces and subprovinces of the North American Atlantic marine margin today (Hall, 1964). The ecotonal boundaries between Western Interior Cretaceous subprovinces were typically broad, with characteristic taxa from adjacent subprovinces mixing over one to a few hundred kilometres (Sohl, 1967b; Kauffman, 1973, 1984) (Fig. 1). These broad ecotones were commonly the origination sites of rapidly evolving endemic ammonite and bivalve taxa, especially the ecotone between the Southern and Central Interior subprovinces, making possible highly refined bio-

stratigraphic correlation between subprovinces. Extremely abrupt subprovincial boundaries characterized short intervals of Western Interior Basin history, probably reflecting sharp boundaries between northern and southern watermasses (Eicher and Diner, 1985), or steep oceanic fronts (Fisher, 1991) characterized by accelerated downwelling. Kauffman (1984), and Eicher and Diner (1985, 1989) demonstrated that the water masses and thermal gradients regulating the relative positions of the paleobiogeographic subprovinces, ecotones, endemic centres, and thus local biostratigraphic systems in the Cretaceous Western Interior Seaway had a highly dynamic history, and showed rapid shifts of up to hundreds of kilometres within a million years or less. Rapid northward shifts of warm temperate and subtropical watermasses associated with eustatic sea-level rise within the basin dramatically changed the paleobiogeographic character of the seaway. Significant southward shifts of cool temperate watermasses were slower and less common

(Kauffman, 1984). Both northward and southward migrations introduced biotas from the cool-temperate 'Boreal' and the tropical-subtropical Caribbean Tethyan regions, respectively. These immigration events greatly enhance biostratigraphic correlation of Western Interior Basin sequences with those of northern and southern oceanic systems, especially among ammonites and planktonic microbiotas. There is thus a clear relationship between the paleobiogeographic history of the Cretaceous Western Interior Seaway and the complexity, refinement, and interregional correlation potential of biostratigraphic systems developed for various Cretaceous time intervals.

Biostratigraphic and paleobiogeographic systems of the Western Interior Basin have co-evolved rapidly during the past two decades. Yet there is still much work to be done, especially in high-resolution collecting through relatively unstudied intervals (*e.g.*, most of the Lower Cretaceous), modern taxonomic description and illustration of new, bio-
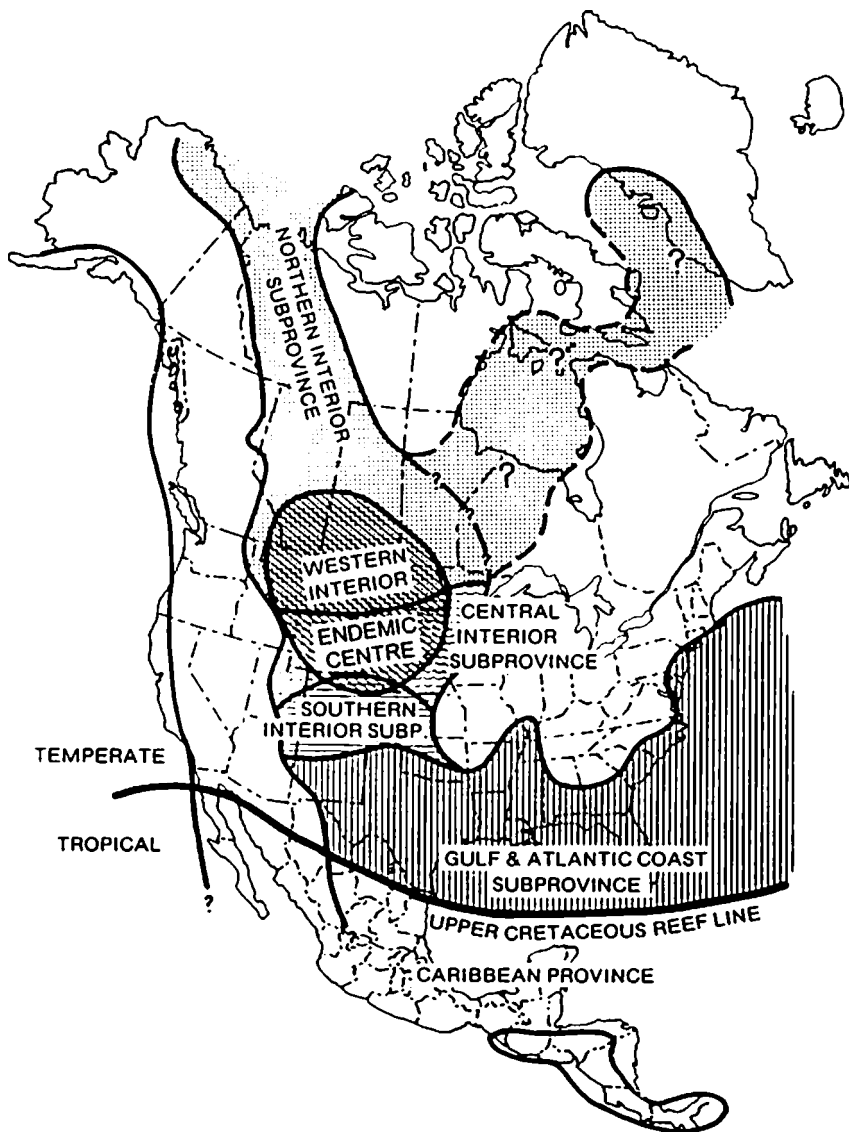


**Figure 1.** *Map showing average expression of Northern, Central and Southern Interior paleobiogeographic subprovinces from the Cretaceous Western Interior Seaway of North America (after Kauffman, 1984), as defined by percent molluscan endemism within subprovinces and provinces (10-25% and 25-50%, respectively). These subprovinces also reflect different regional biostratigraphic systems and endemic centres (especially in paleobiogeographic ecotones and Central Interior Subprovince) that are blended into composite assemblage biozones in this study.*

stratigraphically important molluscs cited here with informal nomenclature (*e.g.*, "sp. A,B," *etc.*, or "n. sp. aff./cf. a known taxon"), and development of a fully integrated graphic standard for macro- and microbiotas of the Western Interior Basin. Much of this work is in progress by the authors and their colleagues. The purpose of this paper is to provide a state-of-the-science summary of Cretaceous molluscan biostratigraphy, especially as viewed from the standpoint of new bivalve and gastropod data plotted against established ammonite and inoceramid bivalve zones. Cobban (this volume) has summarized the ammonite biozones of the Western Interior Cretaceous, and therefore the bivalve and gastropod components of the biostratigraphy are emphasized herein. Completion of this work in the coming years will clearly lead to an even more refined, biologically integrated system of biostratigraphy for the Cretaceous Western Interior Basin, and a better understanding of the important relationships between molluscan evolution, paleobiogeographic history, and the biostratigraphic potential of diverse groups of fossils.

## BIOSTRATIGRAPHIC METHODOLOGY

### Introduction

The early development of Western Interior Cretaceous biostratigraphy (summarized in Waage, 1975; Kauffman, 1979) was characterized by the recognition of temporally long-ranging, broadly defined faunas a... ~ciated with specific stratigraphic units [groups and formations; *e.g.*, the Colorado (group) fauna of Stanton, 1894]. These were essentially very broadly defined assemblage zones with durations of several million years. The second phase of biostratigraphic history (Cobban and Reeside, 1952) resulted in the development of species or genus range zones characterized by single index fossils, mainly ammonites. This was rapidly followed by refinement based on lineage studies of specific groups, and establishment of discrete ammonite (*e.g.*, Cobban, 1951, 1958, 1961, 1962a,b, 1969, 1971, 1984, 1988a,b, and this volume, among many papers; Cobban and Hook, 1980, 1984, 1989; Cobban and Scott, 1964, 1972), bivalve (Kauffman, 1975, 1977b, 1979; Kauffman *et al.*, 1976, 1985) and microfossil zonations (*e.g.*, Eicher, 1965, 1966, 1967, 1969, 1977; Leckie, 1985; Caldwell *et al.*, 1978), but without extensive integration between groups to formulate effective assemblage zonation. Whereas these independent biostratigraphic systems achieved a high level of resolution (averaging 0.54 m.y./biozone for Albian-Maastrichtian ammonites; 0.66 m.y./biozone for bivalves, and 1-3 m.y./biozone for various microplankton groups), and are still highly successful in regional and interregional correlations, they are limited in their resolution by the following factors: (1) the varying degrees to which taxa can be finely

resolved by evolutionary studies of component lineages; (2) specific ecological and preservational controls on occurrence; and (3) ultimately by the maximum evolutionary rates of the component taxa within biostratigraphically important lineages.

Kauffman (1970, 1975, 1977c, 1979) and others (*e.g.*, Kauffman *et al.*, 1976, 1985) recognized these limitations and proposed a new system of Cretaceous biostratigraphic zonation for the Western Interior of North America based on assemblage zones and composite assemblage zones (Kauffman, 1970, 1975, 1979; The North American Commission on Stratigraphy, 1983). Assemblage biozonation invariably produces a temporally more highly refined and more broadly applicable system of biostratigraphy and regional correlation because of two important factors. (1) Variations in genetic traits, adaptive ranges, and differing biological responses to the physical, chemical and biological factors of natural selection among diverse, co-existing lineages within the same basin naturally produce broad variations in evolutionary rates and patterns between lineages. This is reflected as variations in the relative stratigraphic positions of origination/first appearance and extinction/last appearance datums among biostratigraphically important taxa from different lineages. Integration of multiple lineages for the same stratigraphic sequence, in turn provides many more data points for biozone boundaries than could be defined by any single lineage within a given interval of time, increasing the potential for refinement in biozonation. It further allows integration of more slowly evolving, longer ranging taxa (*e.g.*, microplankton) into refined biostratigraphic systems by focussing on their first and last appearance datums rather than on their species range zone durations. (2) By utilizing a greater diversity of taxa with high biostratigraphic potential (*e.g.*, rapidly evolving and/or widely dispersed) within a given time interval, the potential for identification of each assemblage or composite assemblage biozone is enhanced in facies that might not contain certain key taxa (*e.g.*, ammonites or planktonic foraminifers) because of ecological or preservational factors. For example, chalky pelagic facies of the Niobrara Formation in the Western Interior Basin do not commonly preserve zonal ammonites, so that the recorded biostratigraphic ranges of ammonites in these facies are commonly shorter in comparison to the same taxa range zones established in siliciclastic facies favouring preservation of ammonites. In contrast, inoceramid and ostreid bivalves and calcareous microplankton that characterize assemblage biozones containing these zonal ammonites elsewhere are well preserved in carbonate facies, allowing identification of all major biozones, even in the virtual absence of key ammonites. For these reasons, we have applied assemblage and composite assemblage biozonation wherever possible in this study.

The biostratigraphic methodology employed herein is modelled in Figure 2, based on an example from the Cenomanian-Turonian stages of the Western Interior Basin. Composite assemblage biozonation is dependent upon high-resolution stratigraphic collecting (centimetre-scale; Kauffman, 1970, 1986b, 1988a; Kauffman et al., 1991) to obtain confident range zone data on diverse taxa, and to allow integration of local taxon range zone data to form regional composite ranges. Fortunately, nearly two decades of high-resolution stratigraphic analysis by the authors and numerous other workers has provided an unparalleled biostratigraphic data base, closely linked to detailed lithostratigraphy and event chronostratigraphy, for much of the Western Interior Cretaceous. This data base is well suited for assemblage zone biostratigraphy.

## Construction of the Biostratigraphic System

The composite assemblage biozonation presented in this paper was constructed through a series of four logical steps, as originally defined by Kauffman (1970), as follows.
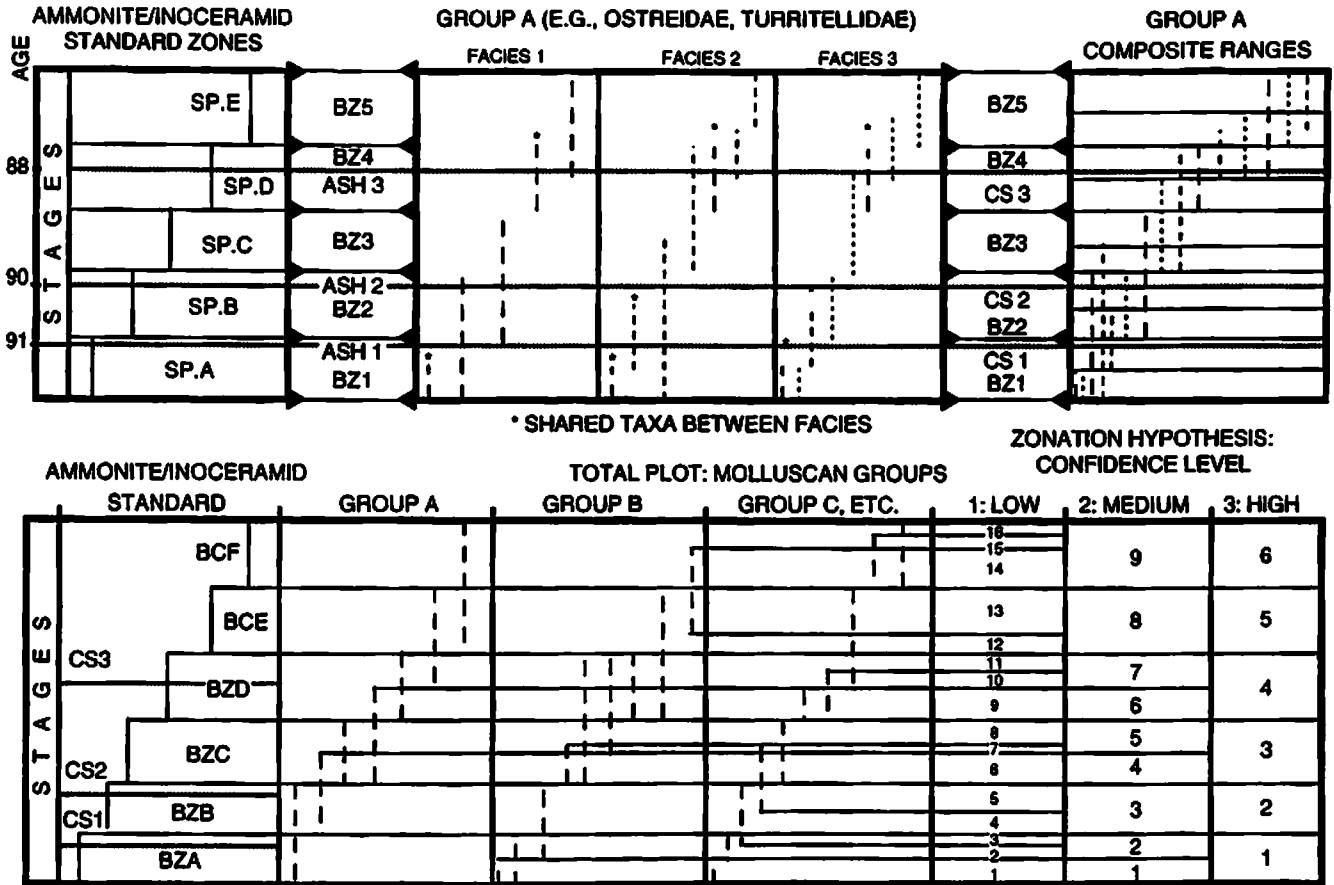
1. Groups of Cretaceous taxa with high biostrati-



**Figure 2.** *Graphic outline of the biostratigraphic methodology utilized in the construction of composite assemblage biozones for the Cretaceous Western Interior Basin (modified from Kauffman, 1970). Beginning in the upper left, a standard ammonite-inoceramid bivalve biozonation has been constructed (Cobban, this volume; and bivalve zones herein) and integrated closely with various event-chronostratigraphic markers for the basin (e.g., volcanic ashes, climate cycle beds, geochemical spikes, etc.; Kauffman, 1988a; Kauffman et al., 1991). Numerous volcanic ash beds among these event beds have also been dated (Obradovich, this volume) and closely tied to the biozonation. Next, range data is collected for other groups with biostratigraphic potential in different facies (top, centre), and the data are composited (top right) based on correlation to standard molluscan biozones, event chronostratigraphic surfaces (e.g., ashes 1-3), radiometric ages from these ashes (88, 90, 91 Ma; left column), and taxa shared between different facies (\*). In the bottom column, standard ammonite-inoceramid biozones (BZA-BZF), integrated with chronostratigraphic surfaces (CS1-CS3) and radiometric ages, are correlated against the composite range data for diverse other groups (Group A-C, etc.) with biostratigraphic potential. Utilizing visual and graphic correlation methods, the collective data are then composited into low- (LCL), medium- (MCL) and high-confidence level (HCL) assemblage biozones, depending upon the number of coincident or near-coincident first (FAD) and last appearance datums (LAD) used in the construction of zone boundaries.*

graphic potential (Kauffman, 1970, 1975) were selected from the known taxa set based on: (a) their relatively rapid evolutionary rates (average species durations less than 1 m.y.); (b) their rapid dispersal potential (planktonic larval and/or adult developmental stages; or mobile nekton); (c) their broad facies distribution reflecting a broad range of ecological tolerances and/or wide dispersion of preferred habitats; (c) consistency in species/subspecies determination among diverse workers, reflecting morphological complexity and/or a distinct set of visible characters useful in taxonomic determinations; (d) their abundance (population size and dispersion characteristics); and (e) their high preservation potential (reflecting the mineralogy, shell ultrastructure, and size/thickness of mineralized or organic skeletal material). Taxa utilized herein meet most or all of these criteria.

Of these criteria, the two most difficult things to calculate are rates of evolution and dispersal. Kauffman (1972, 1977a, 1978, 1984) utilized two measures of evolutionary rates for Western Interior Cretaceous Mollusca: average species duration within lineages; and number of new taxa produced within single lineages or species groups per million years. Dispersal rates are determined by comparing local first appearance datums (FADs) for each taxon against a chronostratigraphic marker bed or surface, normally a widespread bentonite or chemostratigraphic spike (for examples see Kauffman, 1988a; Kauffman *et al.*, 1991), and then calculating temporal variation of the FADs from this surface based on radiometric dating and/or calculation of sedimentation rates. Both methods can be relatively imprecise.

2. The biostratigraphic data chosen because of apparently rapid evolution and/or dispersal among component taxa were next integrated with and measured against a radiometric time scale to establish cross-correlations between two different stratigraphic systems, and to attempt to measure zonal durations. This comprises the most uncertain step in developing the integrated biostratigraphic system. Efforts to develop a radiometric time scale for the Cretaceous have been under way for some time (Obradovich and Cobban, 1975; Van Hinte, 1976; Kauffman, 1977c; Harland *et al.*, 1982, 1989; Odin, 1982, Haq *et al.*, 1987, among others; see Obradovich, this volume). All efforts have been limited by the quality and availability of datable material in stratigraphic sections, number and distribution of datable levels, the error factors of the analytical technique, and analytical variables between laboratories. Fortunately, the Cretaceous strata of the Western Interior Basin of North America contain abundant volcanic ashes (over 1300 currently identified) derived primarily from western and southwestern sources in and adjacent to the developing Cordilleran fold and thrust belt. Many of these contain mica, sanidine and zircon suitable for radiometric dating, and most can also be tied to well-established molluscan biostratigraphic zones. Early

attempts to establish a Cretaceous radiometric scale for the basin (Folinsbee *et al.*, 1961, 1966; Obradovich and Cobban, 1975; Kauffman, 1977c) relied heavily on K-Ar dating of mica and sanidine, which yielded ages with broad error bars. More recently, however, John Obradovich of the United States Geological Survey has utilized single crystal $^{40}Ar/^{39}Ar$ dating techniques to establish a set of 31 new Cretaceous ages with low uncertainties ($\pm 0.5$ m.y. or less) (Obradovich, this volume, and references therein). These new ages have been precisely tied to established ammonite/bivalve biozones; in middle Albian through Maastrichtian strata, there is an average of one new $^{40}Ar/^{39}Ar$ age for every 2.8 biozones, although they are not equally distributed.

These data allow the tentative development of a calculated Cretaceous time scale for the Western Interior Basin (see Figs. 4 through 12) and, from this, preliminary calculation of average zonal durations for at least major ammonite/bivalve biostratigraphic indices, and eventually for the composite assemblage zones (Table I). In doing this, we are acutely aware of the many problems and uncertainties in the interpolation of calculated ages for biozones between dated levels. In creating our time scale, we have made the assumption that the biozones between the newly dated levels of Obradovich (this volume) are of equal duration, implying a regular rate of evolution for component taxa. We are well aware that evolutionary rates may vary over short time intervals within and between biostratigraphically useful lineages, as documented by Kauffman (1977a, 1978). But in defense of our system for building a time scale, dated levels are commonly so close together that large-scale variation in evolutionary rates seems unlikely between them, and we have utilized, as primary zonal indices, the ammonite lineages of Cobban (this volume, and references therein), so that we are actually implying, in most cases, that evolutionary rates remain relatively constant within a single ammonite lineage (*e.g.*, up-section the genera *Arcthoplites, Gastroplites, Neogastroplites, Acanthoceras, Dunveganoceras, Collignoniceras, Prionocyclus, Scaphites, Clioscaphites, Desmoscaphites, Baculites, Didymoceras* and *Discoscaphites* each have a series of successive species within a single lineage, or two lineages, which are the basis for biozonation between dated levels). This comprises a "moving average" method of interpolating ages between dated levels. The resultant time scale for ammonite/inoceramid biozones provides the temporal framework for dating composite bivalve-gastropod-ammonite zones proposed herein, and for evaluation of average evolutionary rates and species durations. The senior author (E.G. Kauffman) is wholly responsible for the construction of the calculated time scale used in this paper.

3. Range zones were plotted as accurately as possible for all selected taxa at numerous (> 100) sections spread through the Cretaceous Western Interior

Basin. These sections then have been intercorrelated utilizing both event chronostratigraphy (normally bentonite beds, climate cycle deposits, concretion zones and geochemical spikes; see Kauffman, 1986b, 1988a; Kauffman *et al.*, 1991) and established ammonite/inoceramid bivalve biozones. These high-resolution correlations allowed compositing of local range zones for each taxon with biostratigraphic potential into a regional maximum range zone through both visual and graphic correlation (Miller, 1977; Edwards, 1984, 1989). Through this methodology, the range zones of many previously untested bivalve and gastropod taxa were determined and became available for composite assemblage biostratigraphy (Kauffman, 1970).

4. Points of coincident or near-coincident first and last taxon appearance datums (FADs, LADs, respectively) among the integrated species/subspecies ranges were selected as defining Regional Assemblage Zone (RAZ) boundaries within and between

## Table I

Temporal resolution (average duration of biozones/substage) of high-, medium-, and low-confidence level molluscan-based composite assemblage biozones from the Cretaceous Western Interior Basin, as defined in this study.

| Stage | Substage | Duration (m.y.) | Composite Assemblage Zones | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | HCL | | MCL | | LCL | |
| | | | N° | Avg. Duration (m.y.) | N° | Avg. Duration (m.y.) | N° | Avg. Duration (m.y.) |
| Maastrichtian | upper | 3.65 | 2 | 1.83 | 4 | 0.91 | 4* | 0.91 |
| | lower | 2.33 | 4 | 0.58 | 4* | 0.58 | 4* | 0.58 |
| Campanian | upper | 4.77 | 6 | 0.80 | 8 | 0.60 | 8* | 0.60 |
| | middle | 4.42 | 6 | 0.88 | 9 | 0.49 | 12 | 0.40 |
| | lower | 2.97 | 2 | 1.49 | 7 | 0.42 | 8 | 0.37 |
| Santonian | upper | 1.27 | 1 | 1.27 | 2 | 0.64 | 3 | 0.42 |
| | middle | 1.21 | 0.5 | 2.42 | 1 | 1.21 | 3 | 0.40 |
| | lower | 0.64 | 0.5 | 1.20 | 1 | 0.60 | 3 | 0.20 |
| Coniacian | upper | 0.65 | 1 | 0.65 | 2 | 0.33 | 3 | 0.22 |
| | middle | 1.20 | 3 | 0.40 | 3* | 0.40 | 4 | 0.30 |
| | lower | 0.23 | 2 | 0.12 | 6 | 0.04 | 6* | 0.04 |
| Turonian | upper | 1.65 | 3 | 0.55 | 5 | 0.33 | 7 | 0.24 |
| | middle | 1.76 | 6 | 0.29 | 8 | 0.22 | 9 | 0.20 |
| | lower | 1.29 | 4 | 0.32 | 9 | 0.14 | 12 | 0.11 |
| Cenomanian ** | upper | 1.31 | 7 | 0.19 | 10 | 0.13 | 19 | 0.07 |
| | middle | 1.27 | 3 | 0.42 | 6 | 0.21 | 7 | 0.18 |
| | lower | 1.19 | 1 | 1.19 | 1* | 1.19 | 3 | 0.40 |
| Albian | upper | 6.19 | 6 | 1.03 | 11 | 0.56 | 16 | 0.39 |
| | middle | 4.72 | 3 | 1.57 | 5 | 0.94 | 5* | 0.94 |
| | lower | 3.92 | 3 | 1.31 | 6 | 0.65 | 6* | 0.65 |
| Aptian | upper | 2.0 | 1 | 2.0 | 3 | 0.67 | 3* | 0.67 |
| | middle | 2.0 | 2 | 1.0 | 2* | 1.0 | 2* | 1.0 |
| | lower | 2.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Barremian | upper | 2.0 | 1 | 2.0 | 1* | 2.0 | 1* | 2.0 |
| | middle | 2.0 | 1 | 2.0 | 1* | 2.0 | 1* | 2.0 |
| | lower | 2.0 | 2 | 1.0 | 2* | 1.0 | 2* | 1.0 |
| Hauterivian | upper | 2.0 | 2 | 1.0 | 2* | 1.0 | 2* | 1.0 |
| | middle | 2.0 | 2 | 1.0 | 2* | 1.0 | 2* | 1.0 |
| | lower | 2.0 | 2 | 1.0 | 2* | 1.0 | 2* | 1.0 |
| Valanginian | upper | 2.0 | 2 | 1.0 | 2* | 1.0 | 3* | 0.67 |
| | middle | 2.0 | 4 | 0.5 | 3* | 0.67 | 3* | 0.67 |
| | lower | 2.0 | 2 | 1.0 | 2* | 1.0 | 2* | 1.0 |
| Berriasian | upper | 2.0 | 2 | 1.0 | 2* | 1.0 | 2* | 1.0 |
| | middle | 1.5 | 2 | 0.75 | 2* | 0.75 | 2* | 0.75 |
| | lower | 1.5 | 1 | 1.5 | 1* | 1.5 | 1* | 1.5 |

HCL, high-confidence level; MCL, medium confidence level; LCL, low-confidence level.

* Because there were no finer divisions of these zones, this number was carried across from higher to lower confidence level columns.

** Durations calculated on basis of traditional Albian-Cenomanian boundary at top of *Neogastroplites maclearni* range zone. See new boundary proposal of Cobban and Kennedy (1989).

paleobiogeographic subprovinces (Figs. 1 and 2). These were ranked as to confidence levels (in a non-statistical sense) based on the number of coincident or near-coincident first (FAD) and last appearance (LAD) datums, recognizable over a major portion of the basin, that were used to define them, as follows: high-confidence level (HCL) assemblage zone boundaries: 7 or more coincident or near-coincident range terminations; medium-confidence level (MCL): 4 to 6 range terminations; and low-confidence level (LCL) assemblage zone boundaries: 2 to 3 range terminations. Whereas preference in biozonation is given to medium- and high-confidence level assemblage zones, many low-confidence level biozones have great utility in cases where they are based on rapidly evolving, regionally widespread ammonites and/or inoceramid bivalves. This is especially true in more basinal organic-rich black shale and calcareous shale facies representing widespread dysoxic environments; these support very low diversity benthic and epibenthic communities, but also contain these biostratigraphically important molluscan groups in abundance. Because the data used in the definition of these assemblage zones is composited from numerous sections, there is low probability that all or even a majority of the biostratigraphic indices upon which the regional assemblage zones (RAZ) are based will be found in any one section. However, this is offset by the fact that once the regional assemblage zone is established, it can be confidently identified from the integrated range data of only a portion of its component taxa.

5. RAZ systems developed for major paleobiogeographic or facies divisions of the Cretaceous Western Interior Basin were then integrated into Composite Assemblage Zones (CAZ; Kauffman, 1970) spanning the entire basin (Figs. 2 and 4 through 12). This was accomplished by intercorrelation of biogeographically restricted taxa/biozones utilizing the stratigraphic positions of more widespread biostratigraphic indices (generally cosmopolitan ammonites and inoceramid bivalves), which occur in more than one paleobiogeographic or facies division, and/ or by relating species ranges and biozones to widespread event stratigraphic units such as volcanic ash/bentonite beds. The rest of the non-shared taxa ranges were then composited into a single biostratigraphic system, either graphically or through computer-assisted graphic correlation (Miller, 1977; Edwards, 1984, 1989). In Figures 4 through 12, which plot the latest range zone compilations for selected Cretaceous molluscs of the Western Interior Basin, composite assemblage biozones are informally coded to the right of each substage plot.

Figure 3 shows an example of the data compilation and composite assemblage zonation for the late Cenomanian and early Turonian portion of the Greenhorn Cyclothem (Hattin, 1975; Kauffman, 1977c, 1984), based on the high-resolution stratigraphic and paleontologic data of Cobban (1985), El-

der (1985, 1987), Elder and Kirkland (1985), Glenister (1985), Harries (*in* Harries and Kauffman, 1990 and in progress), Hattin (1971, 1975, 1979), Kauffman (1975, 1979), Kauffman *et al.* (1976), Kirkland (1990) and Sageman (1985, 1991), among others.

These composited assemblage zone data result in a marked increase in biostratigraphic refinement over older zonations based on key "index fossils" (*e.g.*, Cobban and Reeside, 1952), on species within single lineages or families (*e.g.*, Kauffman, 1975, for Inoceramidae), and on earlier attempts at the construction of low diversity assemblage zones (*e.g.*, Kauffman *et al.*, 1976, 1985). Our current assemblage zonation results in biozonation averaging 0.63 m.y. for high confidence level biozones, 0.37 m.y. for medium confidence level biozones, and 0.27 m.y. for low confidence level biozones in the Upper Cretaceous of the Western Interior Basin, as compared with 0.45 m.y. for ammonite biozones only, 0.51 m.y. for inoceramid bivalve zones only, and 1-3 m.y. for microplankton zones, depending upon the group used. The current assemblage zonation is much more refined than Cobban and Reeside's Cretaceous biozones (1952), established 30 years ago on the basis of key "index fossils." Significantly, the composite assemblage biozones proposed here for the Western Interior Cretaceous include many more families and lineages than any previous system, especially among gastropods and non-inoceramid bivalves. Thus, in addition to ammonites, and inoceramid and ostreid bivalves, the current system employs lineage-related species among the Pteriidae (Elder, in progress), Cardiidae (Scott, 1978; Geary, 1981, 1987; Geary and Kauffman, in manuscript), Lucinidae (work in progress by the authors), Thyasiridae (Kauffman, 1967, 1969; work in progress), Plicatulidae and Pectinidae (Sageman and Kauffman, in progress). Other bivalve groups to be considered in the near future are the Arcidae, Mactridae, Veneridae, and Corbulidae. Among gastropods new data are available on the following families with high biostratigraphic potential: the Turritellidae (Kauffman, 1961; Kirkland, 1990; Kauffman, in progress), Aporrhaidae (Sohl, 1967a, 1977), Strombidae and Volutidae. Much of this work is in progress or manuscript, but species concepts have been determined and are partially reported here under informal nomenclature. To date, other groups of macroinvertebrates are too rare, or too poorly known to be included in the current biostratigraphic revision, especially in widespread dysoxic basinal facies.

## REVIEW OF
## NEW BIOSTRATIGRAPHIC DATA
## FOR BIVALVES AND GASTROPODS

In previous and current biostratigraphic compilatons for the Cretaceous Western Interior Basin (*e.g.*, Kauffman, 1975, 1979; Kauffman *et al.*, 1976;

Cobban and Reeside, 1952; Cobban, 1984, 1985, this volume), ammonite zones have dominated the biozonation, with inoceramid bivalves as important secondary elements — except in ammonite-poor pelagic carbonate and nearshore clastic units — because of their pervasive facies occurrence, rapid evolutionary rates, and cosmopolitan distribution. With the exception of narrow stratigraphic intervals where evolutionary studies suggested short stratigraphic ranges and high biostratigraphic utility for other bivalves (*e.g., Lopha* in the middle and late Turonian: Kauffman, 1965; *Thyasira* in the Campanian: Kauffman, 1967, 1969) and gastropods (*e.g., Drepanochilus* in the Campanian and Maastrichtian: Sohl, 1967a, 1977), other molluscan groups have been used sparingly in biostratigraphy, and especially in the development of assemblage zones. However, most temperate to subtropical Cretaceous marine molluscs of the Western Interior Basin probably had abundant, long-lived planktotrophic larvae, as do their living counterparts. These larvae ensured the rapid dispersal of species within these benthic molluscan groups, and many bivalves and gastropods seem to have had evolutionary rates equivalent to those of ammonites (Kauffman, 1972, 1975, 1977a, 1978); non-ammonite Mollusca and other invertebrates with planktotrophic larvae are thus potentially useful in refined biozonation. Several groups of benthic molluscs have been suggested as targets for future evolutionary studies to better define the stratigraphic distribution of species and subspecies within lineages, and apply them to biostratigraphy. Some of these have received at least preliminary study, and provide data, discussed below, to be integrated into a more comprehensive assemblage biozonation for the Cretaceous Western Interior Basin.

## Cardiidae

Kauffman (1975, 1977a, 1978) identified the Cardiidae as a bivalve group with high biostratigraphic potential, and calculated average evolutionary rates of Cretaceous Cardiidae as one to four new species evolving per million years for known taxa from the Western Interior Basin. Geary (1981, 1987) completed a population systematics and evolutionary study of the common Albian and Upper Cretaceous genus *Pleuriocardium*, building on the original work of Scott (1978) in the Gulf Coast and southern Western Interior Basin. Kauffman (1975) had previously incorporated broadly defined cardiid species within this and other lineages in his bivalve zonation for the basin. Geary (1981, 1987) was able to recognize 3 species and 2 subspecies of *Pleuriocardium* within the Cenomanian-Santonian portion of the Western Interior sequence with an average taxon duration of 3.66 m.y., although this can be considerably refined. These are shown on Figures 7 to 10. Subsequently, some additional rare species have been found lower in the Cenomanian, and are listed in Figure 7 as species A, B, *etc.*, pending

systematic descriptions. Geary and Kauffman (in manuscript) are currently writing a systematic revision of Western Interior Cretaceous *Pleuriocardium*. The value of *Pleuriocardium* and other Cardiidae in Cretaceous biostratigraphy lies not only in their reasonably rapid evolution, but especially in their common occurrence in shoreface to proximal offshore siliciclastic facies, commonly in the virtual absence of other taxa. The Cardiidae are less common, but persistent, in offshore clay shale facies, including those indicating slightly dysoxic benthic conditions.

## Pteriidae

Kauffman (1975) identified the Pteriidae as potentially important biostratigraphic indices based on the persistence and relatively rapid evolutionary rates of known Western Interior and Gulf Coast Cretaceous species. These suspension-feeding, byssate epifaunal bivalves, almost wholly represented in the Western Interior Basin by the genus *Phelopteria*, are especially common in offshore clay and carbonate-enriched clay shales and pelagic carbonates. In these facies, they are represented by diverse, small, thin-shelled species like *P. minuta* Kauffman and Powell (1977), which most commonly co-occur with moderate to large size species of semi-erect to recumbent Inoceramidae. Small, delicate *Phelopteria* are interpreted as being predominantly byssate epibionts on inoceramid "shell islands" (Kauffman, 1982) in the Cretaceous Western Interior; their shells are commonly scattered around and even found *in situ* on top of larger inoceramids, but are rare elsewhere in these facies. This association is especially common in dysoxic basinal facies where *Phelopteria* is regarded as a member of low-oxygen-adapted successor communities (Kauffman and Sageman, 1990). Kauffman *et al.* (1977) recognized three species of *Phelopteria* with discrete biostratigraphic ranges in the late Cenomanian of Oklahoma, and these were subsequently used as components of simple assemblage zones by Kauffman *et al.* (1985). Subsequently, a very large number of Cenomanian-Coniacian *Phelopteria* specimens have been found through high-resolution stratigraphic collecting of offshore Cretaceous facies in the Western Interior United States (Sageman and Johnson, 1985; Sageman, 1985, 1991; Kirkland, 1990; Elder and Kirkland, 1985; Elder, 1985, 1987; Glenister, 1985; Glenister and Kauffman, 1985; Hattin, 1975, 1977, 1982; Harries and Kauffman, 1990), including many new species with apparently restricted stratigraphic ranges. These basinal lineages of small *Phelopteria* are currently under study for the Albian by E.G. Kauffman, and for the Cenomanian-Turonian by W.P. Elder; species decisions have been made, but descriptions are not yet published, so that an informal taxonomy is used for new taxa in Figures 6 to 8, which show the biostratigraphic distribution of offshore to distal lower shoreface *Phelopteria*. These appear to have an aver-

age species duration of 1.76 m.y. per *Phelopteria*-based biozone. Larger, more inflated *Phelopteria* and other Pteriidae are common at many levels in shallower shoreface siliciclastic facies as well, and have considerable biostratigraphic potential. These have not yet been well studied.

## Thyasiridae and Lucinidae

Families within the Lucinacea are stratigraphically persistent, though rarely common, in black, moderately organic-rich (>1-5% $C_{org}$/wt. laminated shales and calcareous shales of the Western Interior Basin. Rich accumulations of Lucinidae (*Nymphalucina*) also occur around warm methane spring vents (Tepee Buttes) of the Campanian Pierre Shale from Montana to northern New Mexico (Howe and Kauffman, 1986). Living Lucinidae are pervasively chemosymbiotic, as are most tested Thyasiridae, an adaptation that allows them to live successfully in
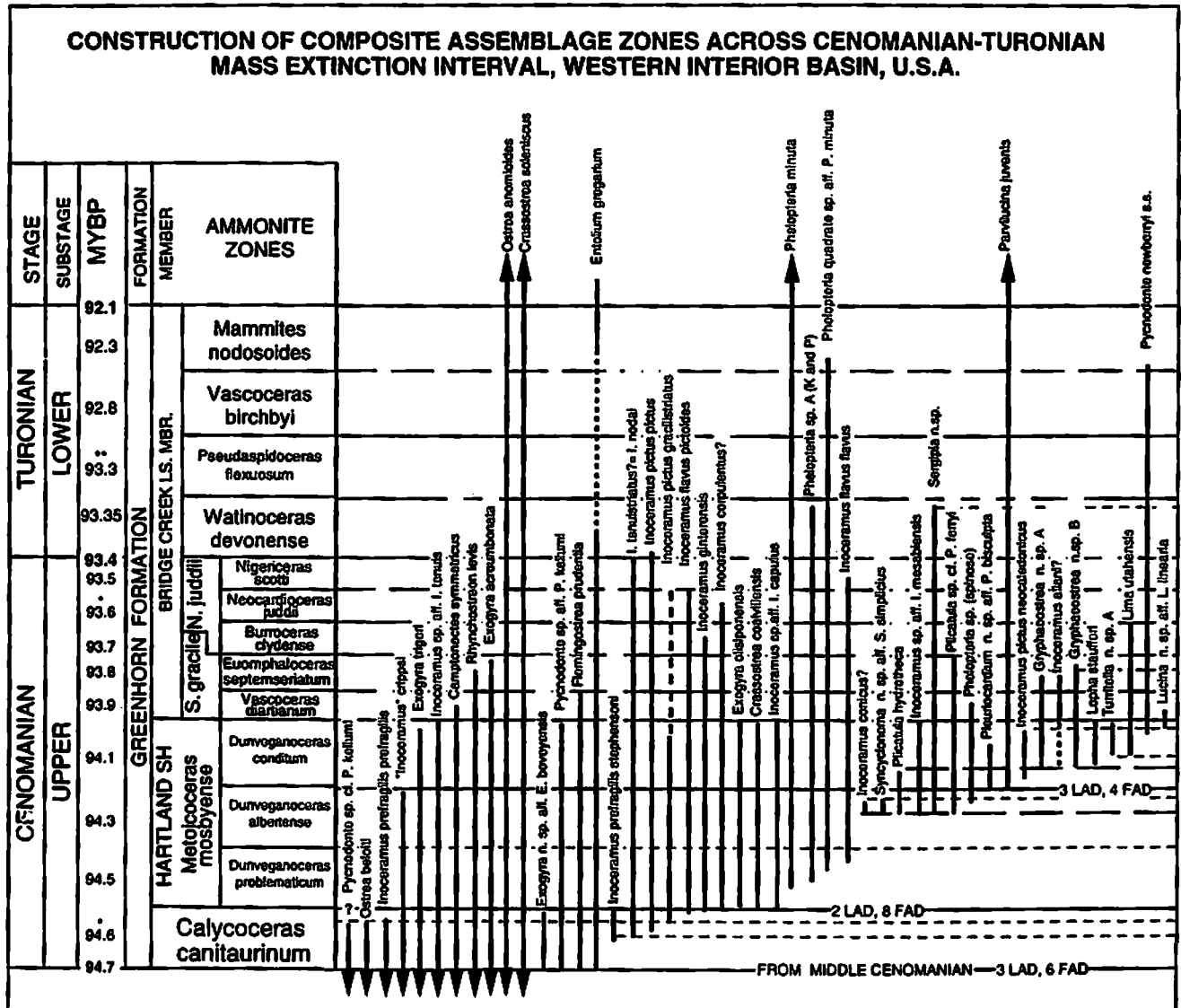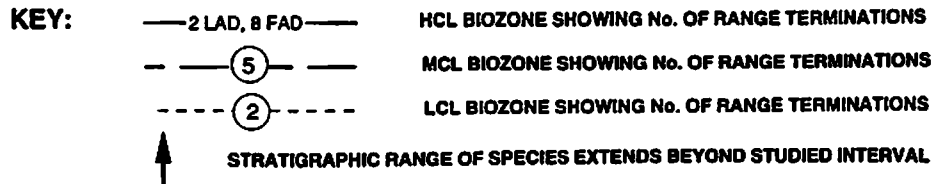


**Figure 3.** *Actual example of construction of composite assemblage zones at high-, medium-, and low-confidence levels (HCL, MCL and LCL, respectively), based on the composited data set for biostratigraphically useful macrofossils around the Cenomanian-Turonian mass extinction boundary interval in the Western Interior Basin. See key at base of figure for differentiating correlation lines for low- (short dashes), medium- (long dashes) and high-confidence level assemblage biozones. Note that high-confidence level biozone boundaries have information on number of species FADs and LADs for each boundary, whereas medium- and low-confidence level biozone boundaries have the total number of species changing at the zonal boundaries combined within a single number, circled, on each dashed line. HCL, MCL and LCL biozone summary on right. Bold-face (MX3, etc.) numbers indicate mass extinction levels, or steps, across the Cenomanian-Turonian boundary (from Kauffman, 1988c). Note improved levels of zonal resolution as compared to utilizing only standard ammonite biozones. \* = unlisted ammonite or bivalve species used in definition of zone boundary.*

chemically deleterious benthic environments low in oxygen, and high in methane and/or hydrogen sulphide. These environments contain few other molluscs today or in the past; in the Western Interior Cretaceous, epifaunal Inoceramidae (many also being possible chemosymbionts; Kauffman, 1981, 1982, 1986a, 1988b; Kauffman and Sageman, 1990; Sageman et al., 1991) and their epibionts (*Phelopteria*; small Ostreidae and Gryphaeinae; possibly small byssate Pectinidae) dominate these dysoxic paleocommunities. *Plicatula* and the gastropod

*Drepanochilus* also occur commonly with lucinaceans in oxygen-restricted facies. Because of the persistence of these facies in the Cretaceous Western Interior and elsewhere, and the low diversity of fossils found with them, the study of these lucinacean lineages is important for biostratigraphic purposes.

Kauffman (1967, 1969, 1975) demonstrated that Campanian *Thyasira* from the Northern Interior Subprovince were common, widespread, and evolved at rates only two- to three-times slower than associ-



KEY:

———2 LAD, 8 FAD———    HCL BIOZONE SHOWING No. OF RANGE TERMINATIONS

— ——(5)— ——    MCL BIOZONE SHOWING No. OF RANGE TERMINATIONS

- - - -(2)- - - -    LCL BIOZONE SHOWING No. OF RANGE TERMINATIONS

↑    STRATIGRAPHIC RANGE OF SPECIES EXTENDS BEYOND STUDIED INTERVAL
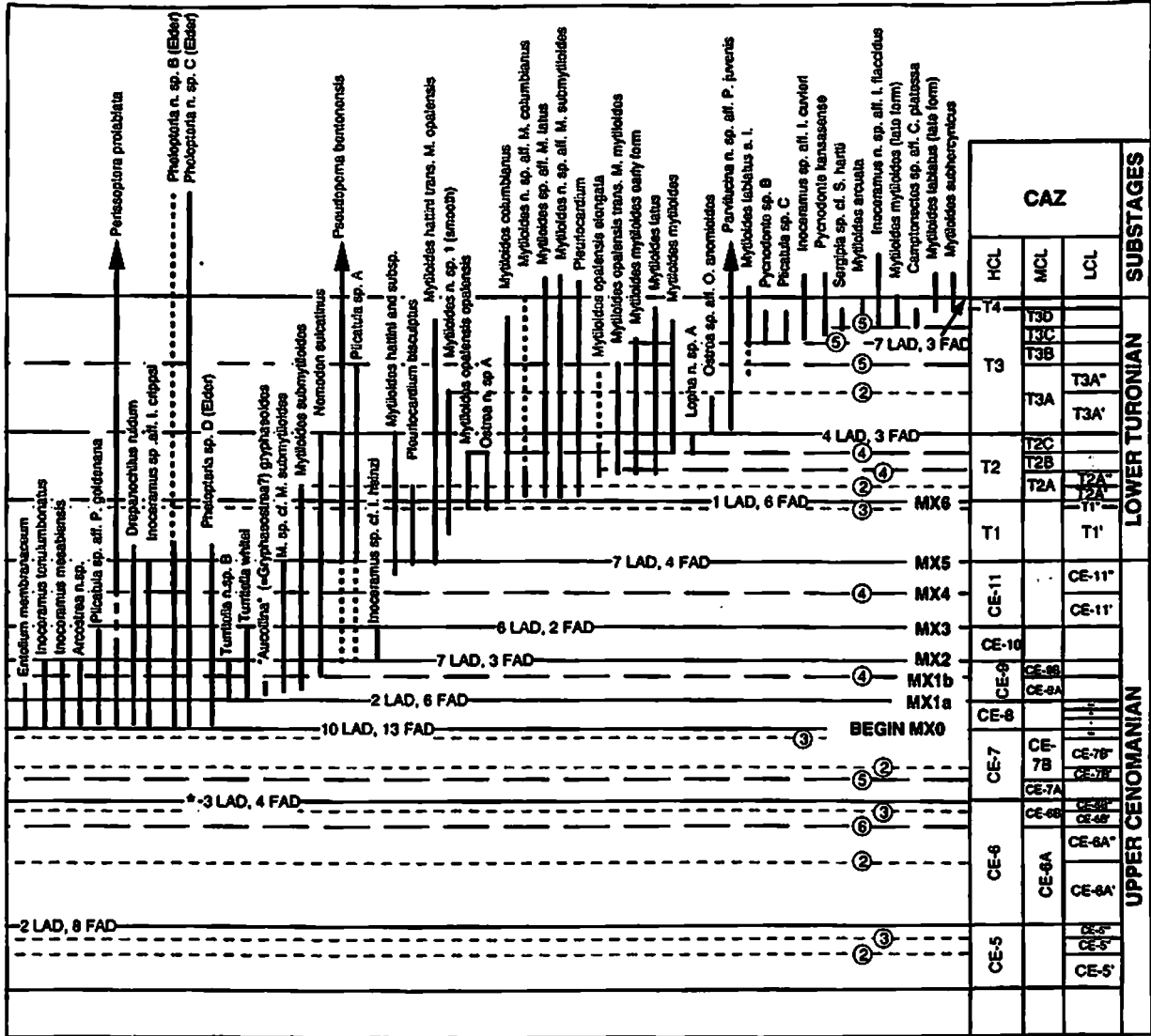
| MYBP | Stage | Substage | Northern Western Interior Basin | | Tethyan/Southernmost Western Interior Basin and Gulf Coast | | Composite Assemblage Zones: CAZ |
|---|---|---|---|---|---|---|---|
| 124 | HAUTERIVIAN | UPPER | Craspedodiscus sp.cf. C. discofalcatus | Acroteuthis sp. aff. A. conoides s. l. | Pseudothurmannia angulicostatus | | H-6 |
| 126 | | | | | Subsaynella subsayni | | H-5 |
| | | MIDDLE | Simberskites sp.cf. S. kleini S. (S.) ex. gr. S. (S.) progredicus | | Crioceras duvali | | H-4 |
| 128 | | | Acroteuthis sp.aff. A . conoides s. s. | | | | H-3 |
| | | LOWER | UNKNOWN | | Acanthodiscus radiatus | | H-2 |
| 130 | | | | | Lyticoceras s.l. sp. | | H-1 |
| | VALANGINIAN | UPPER | Homolsomites ? sp. cf. and aff. H. quatsinoensis | Buchia inflata Buchia n.sp. aff. B. inflata Buchia bulloides | Saynoceras verrucosum | Saynoceras callidiscus | V-8 |
| 132 | | | | | | Himantoceras trinodosum | V-7 / V-6 |
| | | MIDDLE | Homolsomites sp. cf. H. giganteus Euryptychites stubbendorfi | | | Saynoceras verrucosum | V-5 / V-4 |
| 134 | | | Thorsteinssonoceras ellesmerensis Polyptychites sp. cf. P. keyserlingi | | Kilianella roubaudi | Kilianella compylotoxus | V-3 |
| | | LOWER | Tollia sp. cf. T. tolli Temnoptychites novosemelicus Buchia keyserlingi, s.s. | | | Kilianella roubaudi | V-2 |
| 136 | | | | | | Kilianella pertransiens | V-1 |
| * 137 | BERRIASIAN | UPPER | Buchia volgensis | S. sp.cf. S. payeri | Berriasella boissieri | | BE-5 |
| 138 | | | Buchia uncitoides | | | | BE-4 |
| | | MIDDLE | Buchia okensis | Subcraspedites sp. aff. S. suprasubdites | | | BE-3 |
| 139.5 | | | | | Berriasella grandis | | BE-2 |
| | | LOWER | UNKNOWN | | | | BE-1 |
| 141 | | | | | | | |

**Figure 4.** *Chart showing ammonite-bivalve biozones and their component taxa for Berriasian-Hauterivian time in both the northern (left) and southern arms of the Cretaceous Western Interior Basin. Tentative composite assemblage zones are shown to right. Radiometric age (\*) from Obradovich (pers. comm., 1992); younger ages interpolated between dated upper Berriasian and upper Aptian levels, based on assigning equal time durations to substages above the Berriasian stage.*

| MYBP | Stage | Substage | Northern Western Interior Basin | Southern Western Interior Basin and Western Gulf Coastal Plain | Composite Assemblage Zones; CAZ HCL* | MCL* |
|---|---|---|---|---|---|---|
| 103.4 103.9 | | | | | | |
| 105.0 | ALBIAN | MIDDLE | Stelckiceras liardense | Manuaniceras carbonarium | AL-6 | AL-6 |
| 106.0 | | | Gastroplites sp. cf. G. cantianus | Oxytropidoceras salasi | AL-5 | AL-5C |
| **107.1 | | | Gastroplites canadensis | | | AL-5B |
| 107.8 | | | Pseudopulchellia pattoni | Metengonoceras hilli | | AL-5A |
| 108.1 | | | UNNAMED | Metengonoceras sp. | AL-4 | AL-4 |
| 108.4 109.1 | | LOWER | Arcthoplites mcconnelli | Hypacanthoplites comaliensis | AL-3 | AL-3B |
| | | | Arcthoplites irenense | | | AL-3A |
| 109.7 | | | Arcthoplites belli | Douvilleiceras mammilatum, s.l. | AL-2 | AL-2B |
| 110.4 | | | Lemuroceras sp. cf. L. indicum | | | AL-2A |
| 111.0 | | | Cleoniceras sp. cf. C. subbaylei | Hypacanthoplites cragini | AL-1 | AL-1B |
| 111.7 112 | | | Sonneratia sp. cf. S. kitchini | | | AL-1A |
| # 113 | APTIAN | UPPER | Protelliptio biornatus, P. hamili, P. douglassi, Viviparus murrayenasis, Lioplacoides bituminis, Eupera onestae, Tritigonia natosini | Kazanskyella spathi | AP-4 | AP-4C |
| | | | | Dufrenoyia justinae | | AP-4B |
| 114 | | | | Dufrenoyia rebeccae | | AP-4A |
| | | MIDDLE | ?——————? Tropaeum australe T. n.sp. aff. T. arcticum "Inoceramus" sp. cf. "I." labiatiformis | | | AP-3 |
| 116 | | | Tropaeum sp. cf. T.hillsi | | | AP-2 |
| 118 | | LOWER | UNZONED | | | UNZONED |
| | BARREMIAN | UPPER | Acroteuthis kernensis Acroteuthis? sp. cf. A. mitchelli | NONMARINE | | BA-4 |
| 120 | | MIDDLE | Hoplocrioceras n.sp. aff. H. laeviusculum Acrioceras sp. aff. A. starkingi Shasticrioceras sp. | | | BA-3 |
| 122 | | LOWER | Crioceratites emerici Crioceratites sp. cf. C. lardi | | | BA-2 |
| 124 | | | Crioceratites sp. cf. C. latum Oxyteuthis sp. cf. O. jasikowi | | | BA-1 |

*(Vertical annotations between Northern and Southern columns: "Beudanticeras sp.aff.B. glabrum"; "Aucellina spp. ex.gr. A. aptiensis - A. caucasica")*

**Figure 5.** *Chart showing ammonite-bivalve biozones and their component taxa for Barremian to middle Albian time in both the northern (left) and southern (right) arms of the Cretaceous Western Interior Seaway. Tentative composite assemblage biozones are shown to right.*

*Radiometric age (#) from Obradovich (pers. comm., 1992); radiometric age (**) from Obradovich (this volume); remaining ages interpolated between dated upper Aptian and upper Berriasian levels based on assignment of equal time durations to substages below the base of the Albian, and assignment of equal time durations to biozones between upper Aptian and upper Albian dated levels (*, **).*

*HCL*, MCL* = high- and medium-confidence level composite assemblage zones; for lower Barremian-middle Albian, confidence levels are assumed to be medium to high because zones are largely ammonite-based, and associated molluscan faunas are as yet unstudied. Offset of northern versus southern zonal boundaries in middle Albian based only on comparison of published range data.*
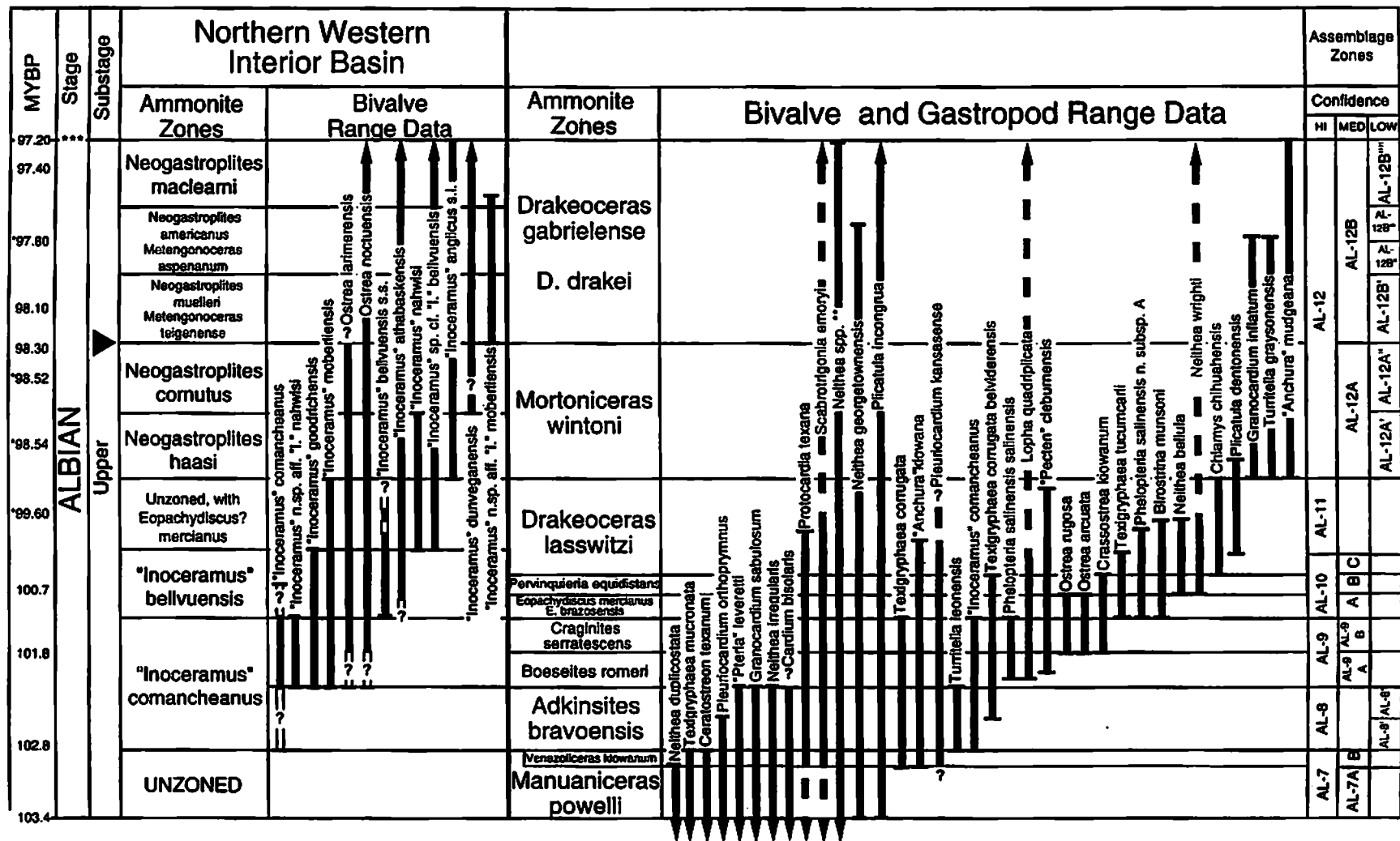
**Figure 6.** *Late Albian ammonite-inoceramid biostratigraphy, molluscan taxa range zones from the northern (left) and southern arms (right) of the Western Interior Seaway, their dated and calculated ages (left), and composite assemblage biozones based on them (right). High, med. and low refer to confidence levels based on number of coincident, or nearly so, first and last appearance points of taxa range zones (see text for further explanation). New radiometric ages (\*) from Obradovich (this volume); all other ages interpolated by assigning equal time durations to mollusc-based range biozones between dated levels.*

*\*\* = This includes the following species of* Neithea *with similar ranges:* N. subalpinus, N. subalpinus linki, N. texana, N. texana elongata, N. altana, N. theodori.

*\*\*\* = Traditional Albian-Cenomanian boundary.*

▶ *New Albian-Cenomanian boundary proposed by Cobban and Kennedy (1989). Cobban (pers. comm., 1992) suggests that the A-C boundary may be as low as the base of the* Neogastroplites *zones.*

ated zonal ammonites (*Baculites* and Scaphitidae). He established seven species and ten subspecies of *Thyasira*, and a biostratigraphy based on them, with average species and subspecies range zone durations of 0.8 m.y. Rare new species from higher and lower stratigraphic levels have now been found, but not yet described; the thyasirid biostratigraphy will eventually be refined by future systematic studies.

The Lucinidae, however, are stratigraphically and paleobiogeographically more pervasive than *Thyasira* in the Western Interior Basin, extending from the Gulf Coast well into Canada in Albian-Maastrichtian strata. Several species have been described, and their known ranges are plotted in Figures 6 to 12. Kauffman (1978) calculated evolutionary rates for Cretaceous Lucinidae of the Western Interior as one to four new taxa per million years. But undescribed Lucinidae are now known from over 100 stratigraphic levels in the Western Interior Cretaceous and, in particular, small species are common in organic-rich black shale and calcareous shale facies. E.G. Kauffman and B.B. Sageman are currently studying this family, and have already identified and plotted the ranges of several new Cenomanian species with an average species duration of 0.1-0.5 m.y. We have assigned informal taxonomic code names to these new taxa (A,B, *etc.*) pending systematic treatment. Their distributions, shown in Figures 6 to 12, demonstrate the potential biostratigraphic utility of the Lucinidae in the Western Interior, with known species durations tentatively calculated as 1 to 2.5 m.y. per lucinid biozone; this is longer than the figures obtained from the Thyasiridae, but strongly suggests that the Lucinidae might eventually be important components of assemblage biozones in oxygen-restricted Cretaceous facies.

## Pectinidae

The Pectinidae have wide application as biostratigraphic tools in the Tertiary of North America (*e.g.,* Addicott, 1974; Ward and Blackwelder, 1975) because of their rapid evolutionary rates and the ease with which species can be determined from complex surface sculpture and shell form. But only Lower Cretaceous *Neithea* of the Gulf Coastal Plain have been studied in sufficient detail to be useful in North American biostratigraphy (*e.g.,* Knicker, 1918), and these did not spread significantly into the Western Interior Basin beyond its southern connection with the Gulf Coast. Two groups of pectinid bivalves do have great promise in Western Interior biostratigraphy, however, although they are currently known only from a few described and many undescribed species and subspecies. These are the genus *Camptonectes* from both nearshore and basinal facies, and various "paper pectens" (*e.g., Syncyclonema, Entolium,* and various Amusiidae) from basinal shale and calcareous shale/laminated chalk facies, including those suggesting dysoxic benthic conditions. Kauffman (1978) noted that described North Ameri-

can Cretaceous *Camptonectes* produced between one and three species per million years within lineages, a moderately rapid rate of evolution. The biostratigraphic ranges of described Pectinidae, and some informally designated new species for which ranges have been established, are shown in Figures 6 to 12. Average species durations are 0.78 m.y. for *Camptonectes* spp., 0.1 m.y. for *Syncyclonema* spp., and 1.38 m.y. for *Entolium* spp. The benefits of applying these small, thin-shelled pectinids to Cretaceous biostratigraphy are as follows: (a) they are relatively common and easily identified; (b) they have strong calcitic shell layers that preserve well in carbonate facies where aragonitic molluscs are normally poorly preserved; and (c) they occur most commonly as scattered individuals and pectinid-dominated event communities in widespread dysoxic litho- and biofacies that characterize much of the depositional history of the Western Interior Basin. A systematic study of the Pectinidae, leading to more refined ranges and greater biostratigraphic potential, is in progress by the authors.

## Plicatulidae

The genus *Plicatula* has been documented recently at a surprising number of localities, considering their published record, and from nearshore oxic to offshore dysoxic facies in the Cretaceous Western Interior Basin. The genus occurs most commonly in proximal offshore and lower shoreface facies, and may dominate low diversity communities in silty clay shales. *Plicatula,* like the Pectinidae, has a relatively complex shell sculpture that makes species easy to identify, and a commonly preserved calcitic shell. Until recently, only scattered species were known from rare specimens in the Cretaceous Western Interior. However, detailed paleontological investigations in New Mexico (*e.g.,* Cobban and Hook, 1989) and Arizona (Kirkland, 1990) have yielded abundant specimens belonging to at least three species from the Cenomanian-Turonian sequence alone. Several undescribed species have been collected as well, so that a Cretaceous plicatulid biostratigraphy now seems possible. Known and new species are plotted in Figures 6 to 12. Detailed systematic study of the Plicatulidae is underway by the authors.

## Turritellidae

Infaunal suspension-feeding Turritellidae are the gastropods with the highest biostratigraphic potential in the Western Interior Cretaceous sequence because of their relatively rapid evolutionary rates and complex surface sculpture, making species easy to differentiate. The Turritellidae have proven biostratigraphic potential both in the Atlantic and Pacific coastal Tertiary sequences (Merriam, 1941; Allison and Adegoke, 1969) and in the Cretaceous of the Gulf and Atlantic Coastal Plain (Sohl, 1977). In the Western Interior Cretaceous sequence, the Tur-

411
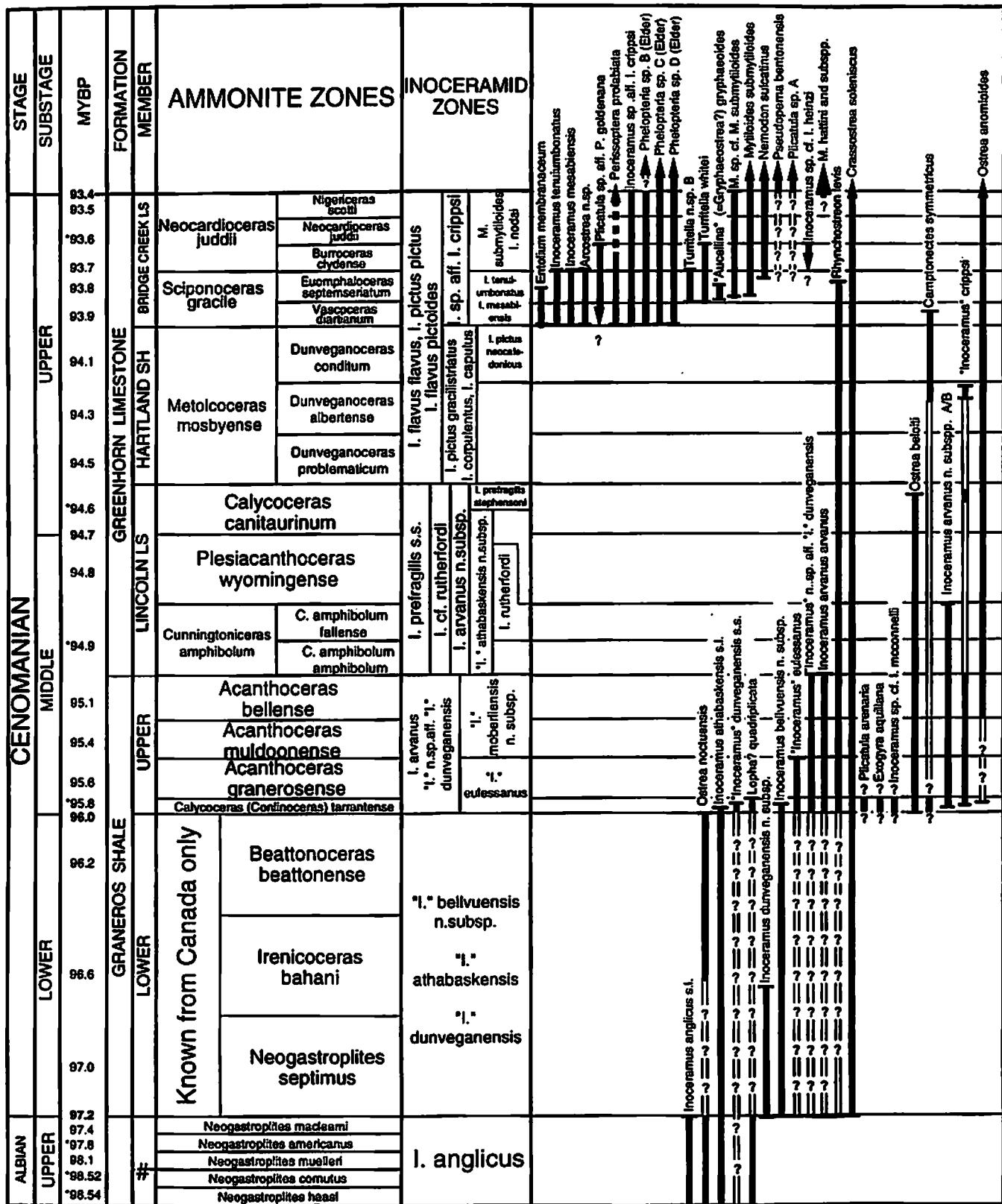
**Figure 7.** *Standard Cenomanian ammonite-inoceramid biostratigraphic zones (left) matched to radiometric data (left) and the composite range zones of these and other biostratigraphically useful taxa (centre) from the Cretaceous Western Interior Basin. Composite assemblage biozones based on these data are shown to right. Radiometric ages (\*) from Obradovich (this volume); remaining ages interpolated based on assignment of equal time durations*
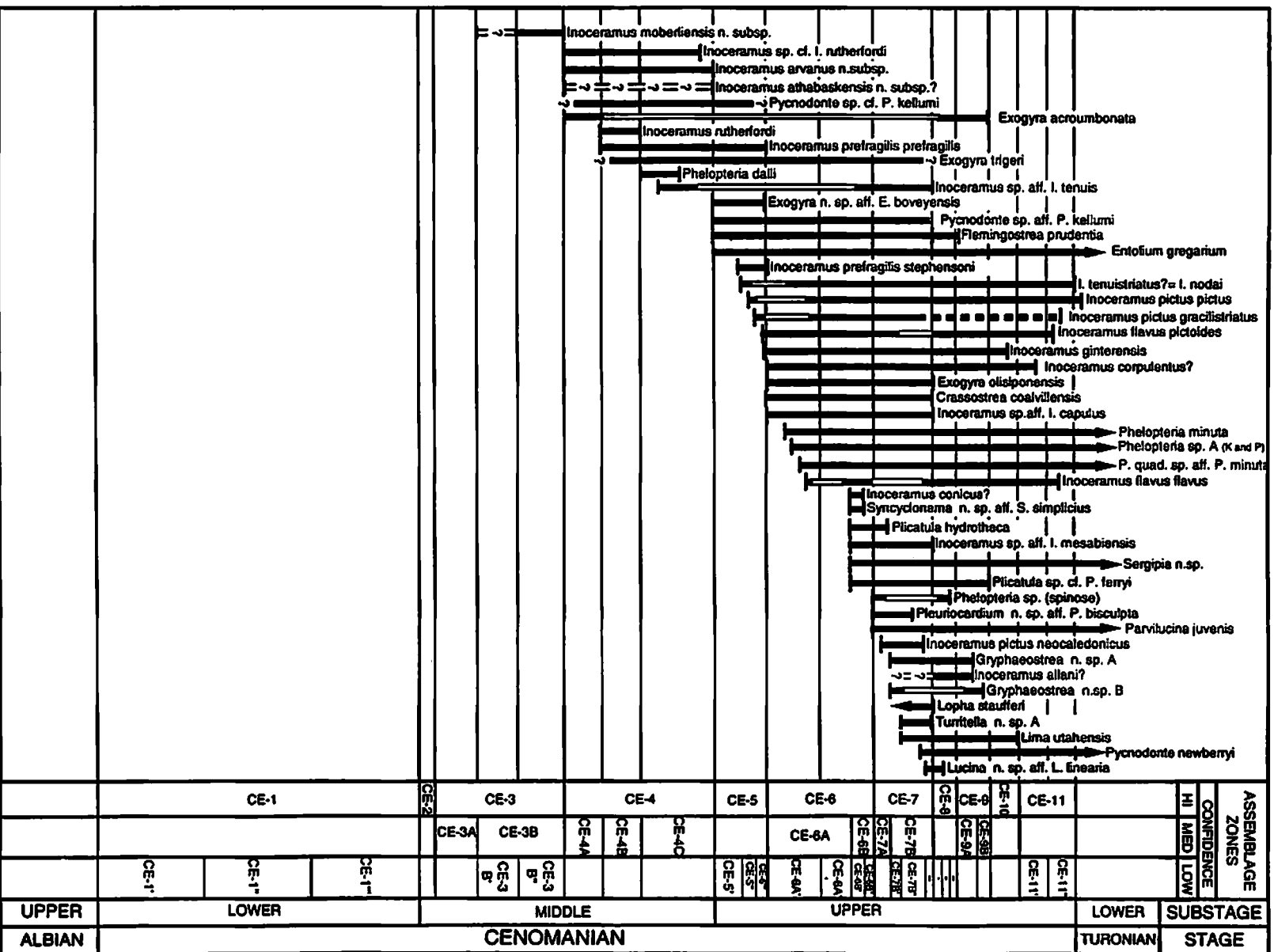
to biozones between dated levels. New Albian-Cenomanian boundary (#) proposed by Cobban and Kennedy (1989); traditional Albian-Cenomanian boundary as shown, at top of Neogastroplites maclearni Zone. High (HI), medium (MED) and low (LO) as explained in Figure 6.

Inoceramus mobertiensis n. subsp.
Inoceramus sp. cf. I. rutherfordi
Inoceramus arvanus n.subsp.
Inoceramus athabaskensis n. subsp.?
Pycnodonte sp. cf. P. kellumi
Exogyra acroumbonata
Inoceramus rutherfordi
Inoceramus prefragilis prefragilis
Exogyra trigeri
Phelopteria dalli
Inoceramus sp. aff. I. tenuis
Exogyra n. sp. aff. E. boveyensis
Pycnodonte sp. aff. P. kellumi
Flemingostrea prudentia
Entolium gregarium
Inoceramus prefragilis stephensoni
I. tenuistriatus? = I. nodai
Inoceramus pictus pictus
Inoceramus pictus gracilistriatus
Inoceramus flavus pictoides
Inoceramus ginterensis
Inoceramus corpulentus?
Exogyra olisiponensis
Crassostrea coalvillensis
Inoceramus sp. aff. I. caputus
Phelopteria minuta
Phelopteria sp. A (K and P)
P. quad. sp. aff. P. minuta
Inoceramus flavus flavus
Inoceramus conicus?
Syncyclonema n. sp. aff. S. simplicius
Plicatula hydrotheca
Inoceramus sp. aff. I. mesabiensis
Sergipia n.sp.
Plicatula sp. cf. P. ferryi
Phelopteria sp. (spinose)
Pleuriocardium n. sp. aff. P. bisculpta
Parvilucina juvenis
Inoceramus pictus neocaledonicus
Gryphaeostrea n. sp. A
Inoceramus allani?
Gryphaeostrea n.sp. B
Lopha staufferi
Turritella n. sp. A
Lima utahensis
Pycnodonte newberryi
Lucina n. sp. aff. L. linearia

| | | | | | | | | | | | | | ASSEMBLAGE ZONES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CE-1 | | CE-2 | CE-3 | | CE-4 | | CE-5 | CE-6 | CE-7 | CE-8 | CE-9 | CE-10 | CE-11 | HI / MED / LOW CONFIDENCE |
| | | | CE-3A | CE-3B | CE-4A | CE-4B | CE-4C | | CE-6A | CE-6B | CE-7A CE-7B | CE-9A | CE-9B | |
| CE-1' | CE-1'' | CE-1''' | CE-3 B' | CE-3 B'' | | | | CE-5' | CE-6A' | CE-6A'' | | CE-11' | CE-11'' | MED LOW |
| UPPER | LOWER | | | MIDDLE | | | | UPPER | | | | LOWER | | SUBSTAGE |
| ALBIAN | CENOMANIAN | | | | | | | | | | | TURONIAN | | STAGE |

ritellidae occur in late Albian to middle Maastrichtian strata, mainly in proximal offshore to middle shoreface silty/sandy facies, and less commonly in basinal facies. Whereas most described species have been broadly defined and have relatively long biostratigraphic ranges (> 1 m.y.), detailed study of the Cenomanian and Turonian species from the United States (Kauffman, 1961; Kirkland, 1990) have shown rapid evolution within the *Turritella whitei* lineage, and a number of new taxa are now described (Kauffman, in manuscript). Average durations for these Cenomanian-Turonian species including new forms listed on Figures 7 and 8 as species A, B, *etc.*, are 0.44 m.y., suggesting high biostratigraphic potential for the Cretaceous Turritellidae once lineages are studied in detail.

## Aporrhaidae

Sohl (1967a, 1977) studied Campanian-Maastrichtian *Drepanochilus* from the Western Interior Basin and established a biozonation based on four species with an average duration of 2.3 m.y. This genus, and other Aporrhaidae are among the most common
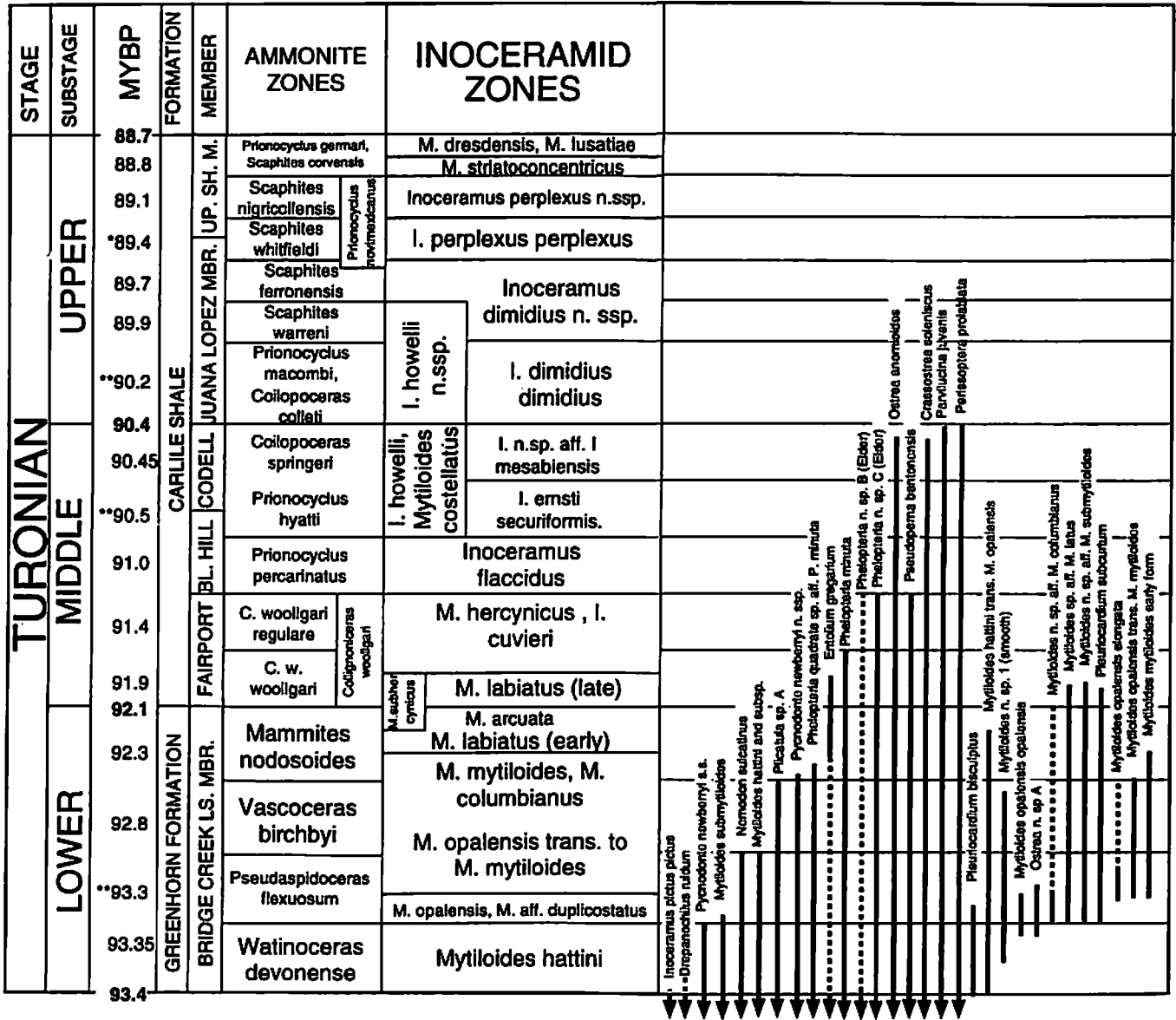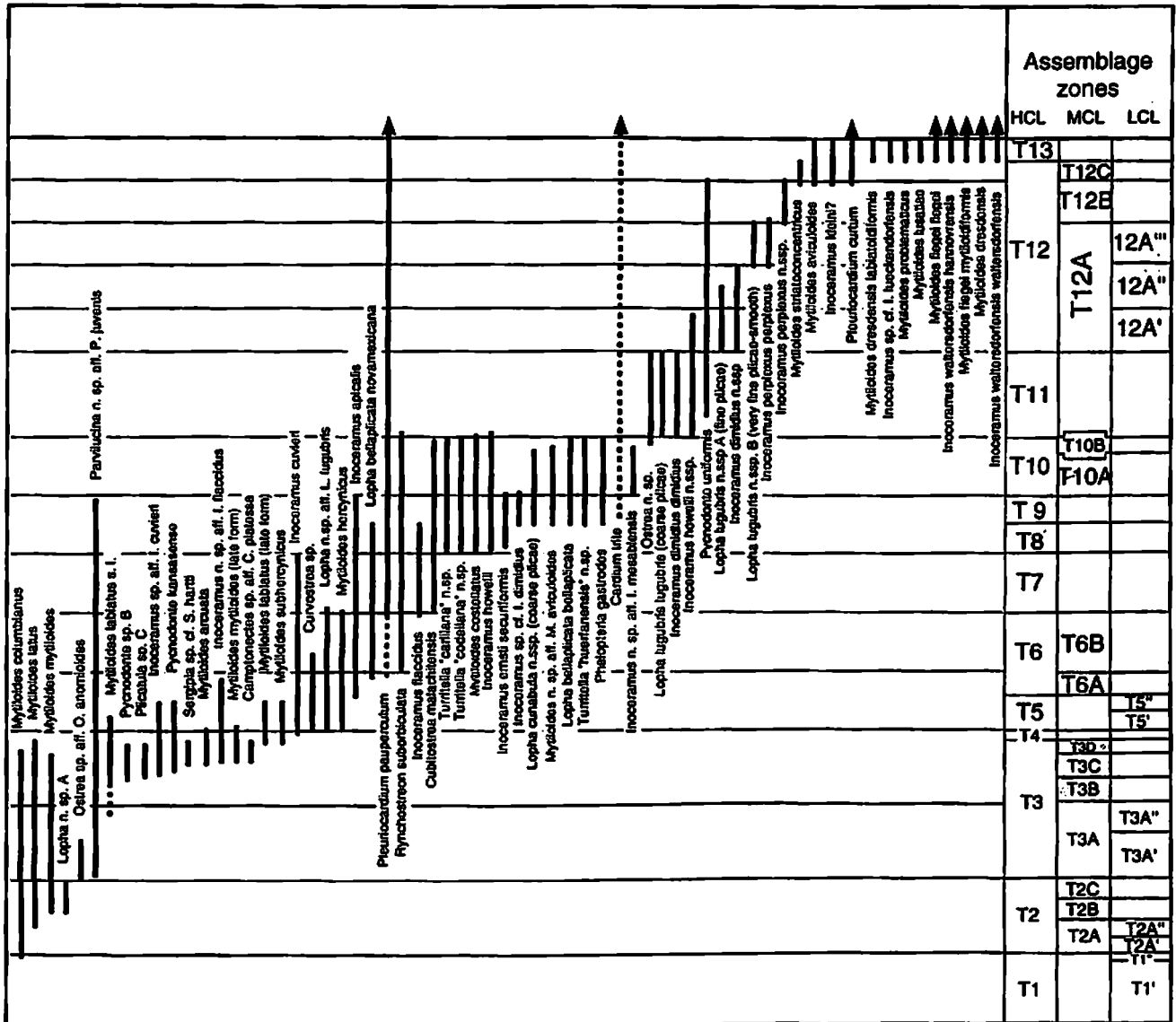


**Figure 8.** *Standard Turonian ammonite-inoceramid bivalve biostratigraphic zones (left) matched to radiometric data (left), and the composite range zones of these and other biostratigraphically useful taxa (centre) from the Cretaceous Western Interior Basin. Composite assemblage biozones derived from these data are shown to right. Radiometric ages from (\*) Kauffman (1977c, corrected) and (\*\*) Obradovich (this volume); remaining ages interpolated between dated levels based on assignment of equal time durations to ammonite-based biozones. Formations and members from Pueblo, Colorado reference section. HCL, MCL and LCL as explained in Figure 6 (for high, medium and low confidence level biozones).*

gastropods in widespread basinal facies, including dysoxic, black shale facies (e.g., Sohl, 1967a; Elder, 1987; Kirkland, 1990). Some species have been described from scattered stratigraphic levels other than those studied by Sohl (1967a, 1977) and their ranges are summarized in Figures 7 to 12. But many additional species have come to light in high-resolution stratigraphic sampling and, when described, will enhance the utility of aporrhaid gastropods in Western Interior Cretaceous biostratigraphy. Currently known average species durations for *Anchura* are 2.5 m.y., for *Perissoptera* are 3.6 m.y., and

for *Drepanochilus* — the major representative of the family — are 1.94 m.y.

The taxonomic groups specifically cited above are among those that have received recent study, as lineages, and which are now becoming important new components of Western Interior composite assemblage zone biostratigraphy. For groups of bivalves which are already important components of the regional biostratigraphic system, e.g., Ostreidae, Gryphaeinae, and Inoceramidae, much new species/subspecies data have been added since the biostratigraphic compilations of Kauffman (1975, 1979)

**Figure 9.** *Standard Coniacian ammonite-inoceramid bivalve biostratigraphic zones (left) matched to radiometric data (left), and the composite range zones for these and other biostratigraphically useful molluscan taxa (centre) from the Cretaceous Western Interior Basin. Composite assemblage biozones derived from these data are shown to the right. Radiometric ages (\*) from Obradovich (this volume); remaining ages interpolated between dated levels based on assignment of equal time durations to ammonite-based biozones. Formations and members from Pueblo, Colorado reference section. High, med. and low as explained in Figure 6.*

and Kauffman *et al.* (1976). These data, and revised ranges for previously used bivalve taxa, are presented in Figures 4 to 12.

## BIOSTRATIGRAPHIC REVISION FOR THE CRETACEOUS OF THE WESTERN INTERIOR BASIN

Figures 4 to 12 show the most recent composite Cretaceous molluscan assemblage biostratigraphy for the Western Interior Basin of North America; the stratigraphically restricted taxa (zonal indices) and range zone boundaries (FADs and LADs) upon which these are based are described in detail in Appendix A. Composite range zones are revised for previously used zonal taxa such as ammonites and Inoceramidae, and are supplemented with new data from other groups with high biostratigraphic potential. Most new data come from high-resolution stratigraphic studies of Albian-Santonian, and to a lesser extent, Campanian-Maastrichtian sequences. The earlier Cretaceous biostratigraphic systems proposed for Canada and Alaska remain essentially unchanged since the compilations of Jeletzky (1968, 1970), Imlay (1959, 1961) and Jones and Gryc (1960), as summarized in Kauffman (1979). It is here that future work needs to be focussed. Composite assemblage zones are constructed wherever detailed species range zone data are sufficient to allow this. Ultimately, when data from the entire Cretaceous are robust, we hope to standardize and code these assemblage zones for easy reference, and as part of a formal Western Interior Cretaceous chronology for the WIK-working group of the Global Sedimentary Geology Program (GSGP), under whose auspices this research was done. Whereas informal letter and number codes are provided for assemblage zones/subzones, respectively, in Figures 4 to 12, these form only a preliminary frame of reference and are not meant to be used as a standard zonal code.

For the great majority of the Western Interior Cretaceous composite assemblage zones described in Appendix A, taxa restricted to all or most of a biozone are listed first under the coding RRZ (Restricted Range Zone); those which have their first appearance at or near the base of the assemblage zone are listed next under the coding FAD (First Appearance Datum), and those with their last appearances at or near the top of the assemblage zone are listed last under the coding LAD (Last Appearance Datum). Those taxa restricted to the Gulf Coast-Caribbean Tethys and southernmost Western Interior Basin prior to the north-south connection of the Western Interior Seaway are indicated by (S). Those of the northern arm of the Western Interior Seaway, and derived from the Circumboreal Sea pri-
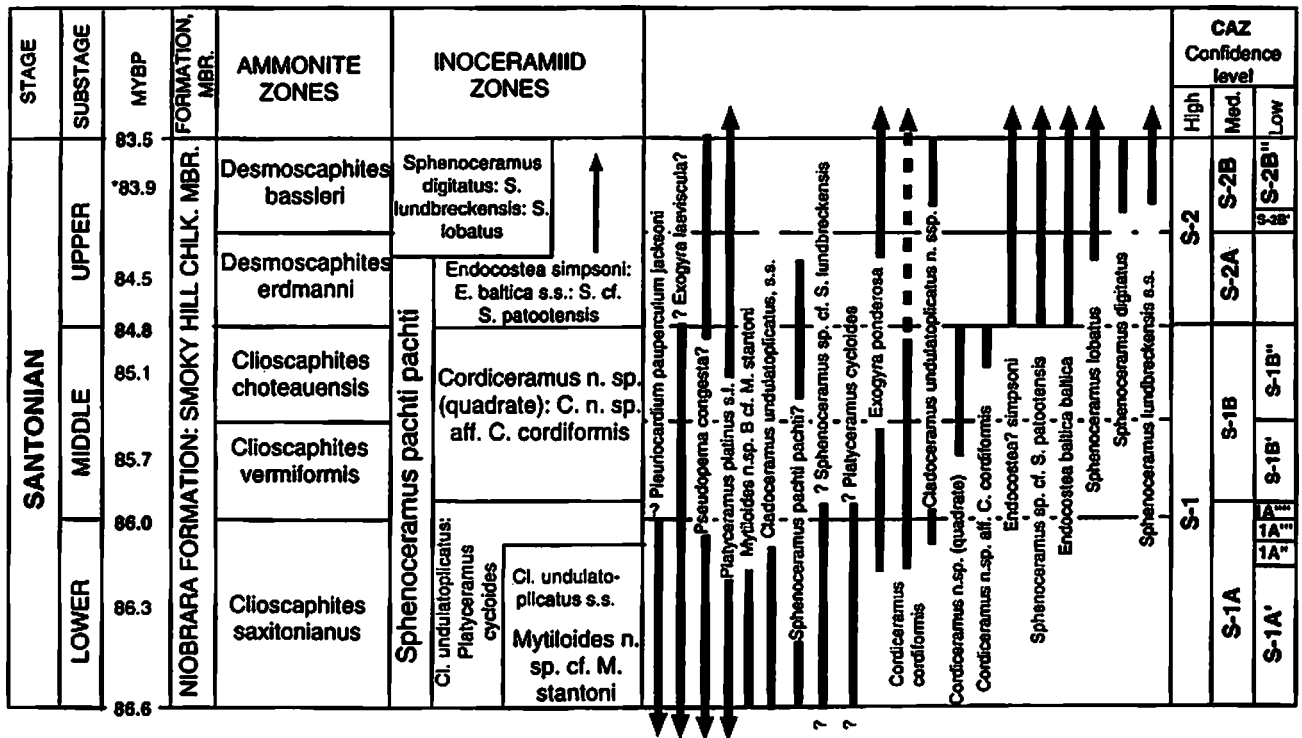


**Figure 10.** *Standard Santonian ammonite-inoceramid bivalve biozones (left), matched to radiometric data (left), and the composite range zones of these and other this biostratigraphically useful molluscan taxa from the Cretaceous Western Interior Basin. Composite assemblage biozones derived from these data are shown to the right. Radiometric ages (\*) from Obradovich (this volume); remaining ages interpolated between dated levels based on assignment of equal time durations to ammonite-based biozones. High, med. and low as explained in Figure 6.*

or to its north-south connection with the southern seaway are indicated by (N). The range zones and stratigraphic position of preliminary composite assemblage zones are shown in Figures 4 to 12, presented in stratigraphic order. On these figures, the range zones are plotted (to the left) against stage and substage designations, as currently-used in the basin, and a calculated time scale based on the new $^{40}Ar/^{39}Ar$ ages of Obradovich (this volume), and, on the right, against the preliminary composite assemblage zone designations. Both published and informal taxonomic names are used in these charts; informal names (e.g., "sp. A,B,C" or as "n. sp.?, n. subsp., aff. or cf. a known taxon") are employed here only where species decisions have already been made and stratigraphic ranges are well defined in ongoing taxonomic studies awaiting review and publication. We emphasize that this biostratigraphic system represents only the state-of-the-science as of 1992, and will continue to be modified until all taxa are described, important new

groups added, and zones can be formalized. Fortunately, most of these composite assemblage zones can be identified by the restricted or partial ranges of well-described ammonites and inoceramid bivalves.

## CONCLUSIONS

The biostratigraphic system proposed herein is a progress report on attempts to improve the resolution of zonation through (a) the addition of new taxonomic groups, many still under study, to the existing, dominantly ammonite-inoceramid bivalve based zonation, and (b) by the use of composite assemblage biozones to take advantage of the varying evolutionary responses of coeval lineages during the evolution of the Cretaceous Western Interior Basin of North America. In Figures 4 to 12 and Appendix A, we describe 89 high confidence level (HCL) composite assemblage zones (CAZs), 136 moderate confidence level (MCL) CAZs, and 169 low
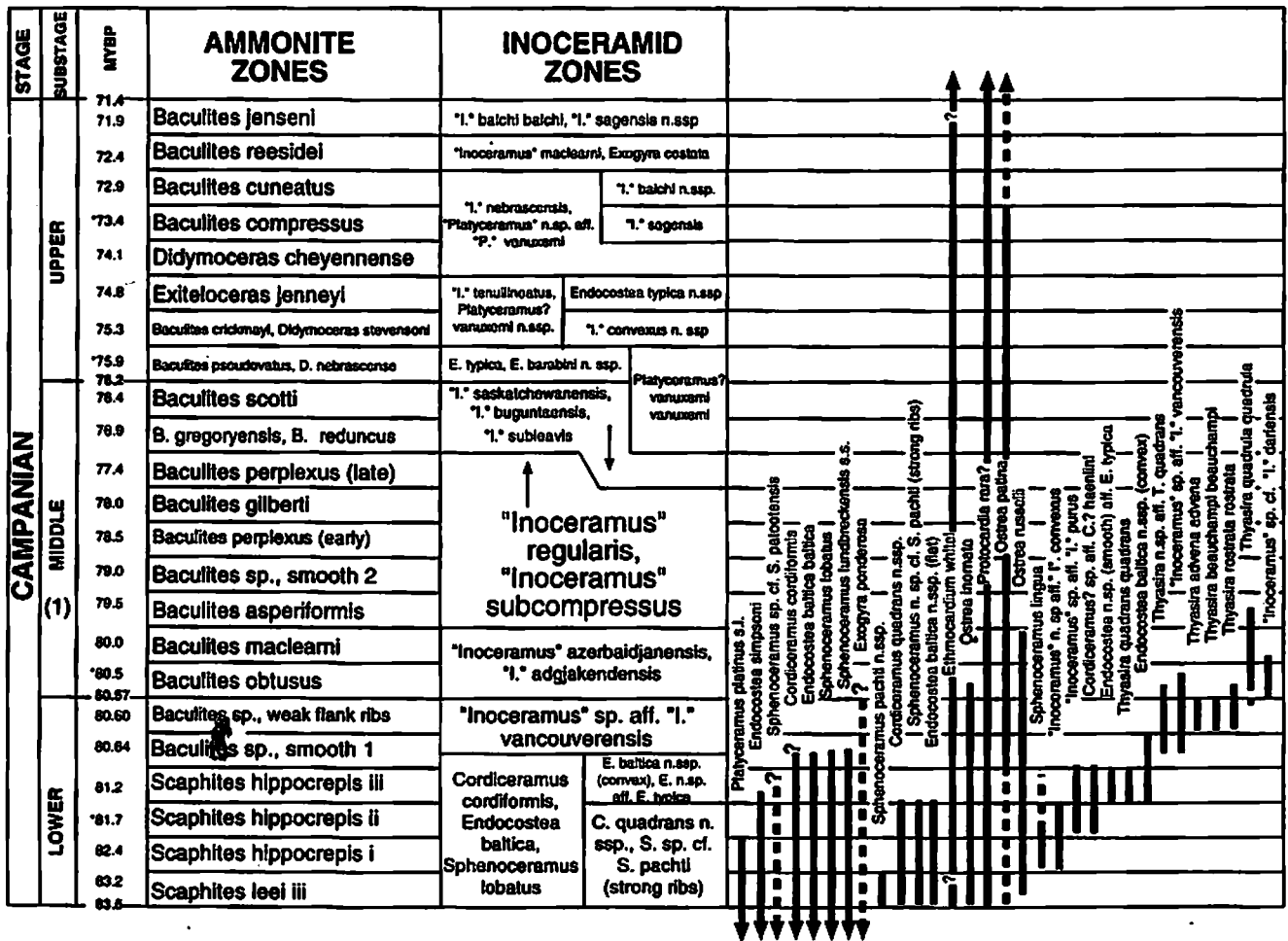
| STAGE | SUBSTAGE | MYBP | AMMONITE ZONES | INOCERAMID ZONES | |
|---|---|---|---|---|---|
| | | 71.4 | | | |
| | UPPER | 71.9 | Baculites jenseni | "I." balchi balchi, "I." sagensis n.ssp | |
| | | 72.4 | Baculites reesidei | "Inoceramus" macleami, Exogyra costata | |
| | | 72.9 | Baculites cuneatus | "I." nebrascensis, "Platyceramus" n.sp. aff. "P." vanuxemi | "I." balchi n.ssp. |
| | | *73.4 | Baculites compressus | | "I." sagensis |
| | | 74.1 | Didymoceras cheyennense | | |
| | | 74.8 | Exiteloceras jenneyi | "I." tenuilineatus, Platyceramus? vanuxemi n.ssp. | Endocostea typica n.ssp. |
| | | 75.3 | Baculites crickmayi, Didymoceras stevensoni | | "I." convexus n. ssp |
| | | *75.9 | Baculites pseudovatus, D. nebrascense | E. typica, E. barabini n. ssp. | Platyceramus? vanuxemi vanuxemi |
| | | 76.2 | | | |
| | | 76.4 | Baculites scotti | "I." saskatchewanensis, "I." buguntaensis, | |
| CAMPANIAN | MIDDLE | 76.9 | B. gregoryensis, B. reduncus | "I." subleavis | |
| | | 77.4 | Baculites perplexus (late) | | |
| | | 78.0 | Baculites gilberti | "Inoceramus" regularis, "Inoceramus" subcompressus | |
| | | 78.5 | Baculites perplexus (early) | | |
| | | 79.0 | Baculites sp., smooth 2 | | |
| | | 79.5 | Baculites asperiformis | | |
| | | 80.0 | Baculites macleami | "Inoceramus" azerbaidjanensis, "I." adgjakendensis | |
| | (1) | *80.5 | Baculites obtusus | | |
| | | 80.57 | | | |
| | | 80.60 | Baculites sp., weak flank ribs | "Inoceramus" sp. aff. "I." vancouverensis | |
| | | 80.64 | Baculites sp., smooth 1 | | |
| | LOWER | 81.2 | Scaphites hippocrepis iii | Cordiceramus cordiformis, Endocostea baltica, Sphenoceramus lobatus | E. baltica n.ssp. (convex), E. n.sp. aff. E. typica |
| | | *81.7 | Scaphites hippocrepis ii | | C. quadrans n. ssp., S. sp. cf. S. pachti (strong ribs) |
| | | 82.4 | Scaphites hippocrepis i | | |
| | | 83.2 | Scaphites leei iii | | |
| | | 83.5 | | | |

**Figure 11.** *Standard Campanian ammonite-inoceramid bivalve biozones (left) matched to radiometric data (left), and the composite range zones of these and other biostratigraphically useful molluscan taxa (centre) from the Cretaceous Western Interior Basin of North America. Composite assemblage biozones derived from these data are shown to the right. (1)* = *Three-fold division of Campanian after Cobban (in press). Radiometric ages (\*) from Obradovich (this volume); remaining ages interpolated between dated levels based on assignment of equal time durations to ammonite-based biozones. High, med. and low as explained in Figure 6.*

confidence level (LCL) CAZs, with average durations of these biozones being 0.85 m.y., 0.56 m.y. and 0.45 m.y., respectively, for the entire Cretaceous. The resolution of these biozones varies tremendously, between intervals which have received only general study (Berriasian to Aptian), and those submitted to high-resolution stratigraphic analysis, commonly at the centimetre-scale of data collection (Albian-Maastrichtian) (Kauffman, 1988a; Kauffman *et al.*, 1991). Thus, for the Upper Cretaceous, 51 HCL CAZs have an average zonal duration of 0.62 m.y., 86 MCL CAZs have an average duration of 0.37 m.y., and 114 LCL CAZs have an average duration of 0.28 m.y. per biozone. Table I compares these average levels of biostratigraphic resolution for Cretaceous substages in the Western Interior Basin. Note that middle Cretaceous resolution, the highest yet achieved (reflecting the interval of most detailed stratigraphic study), reaches 0.04 m.y./biozone; this is the level we hope to achieve ultimately for the entire Cretaceous sequence. These data point out the

great advantages of high-resolution stratigraphic work in biostratigraphy. It not only expands the population and species data base, allowing greater refinement of ranges among tested biostratigraphic indices, but it also increases the discovery rate of new and previously unreported taxa with high biostratigraphic potential. Clearly, high-resolution stratigraphic analysis of the Canadian Lower Cretaceous remains a first priority for future work, as does a more refined treatment of the Campanian and Maastrichtian throughout North America.

The duration of Western Interior composite assemblage biozones depends upon many factors. Primary among them are the following: (1) the amount and diversity of biostratigraphically useful range data, and (2) the evolutionary rates among component taxa utilized in the biozonation. Ammonites, inoceramid, ostreid and certain other bivalve families, and both turritellid and aporrhaid gastropods have the highest evolutionary rates among common Western Interior Mollusca (Kauffman, 1972, 1977a,
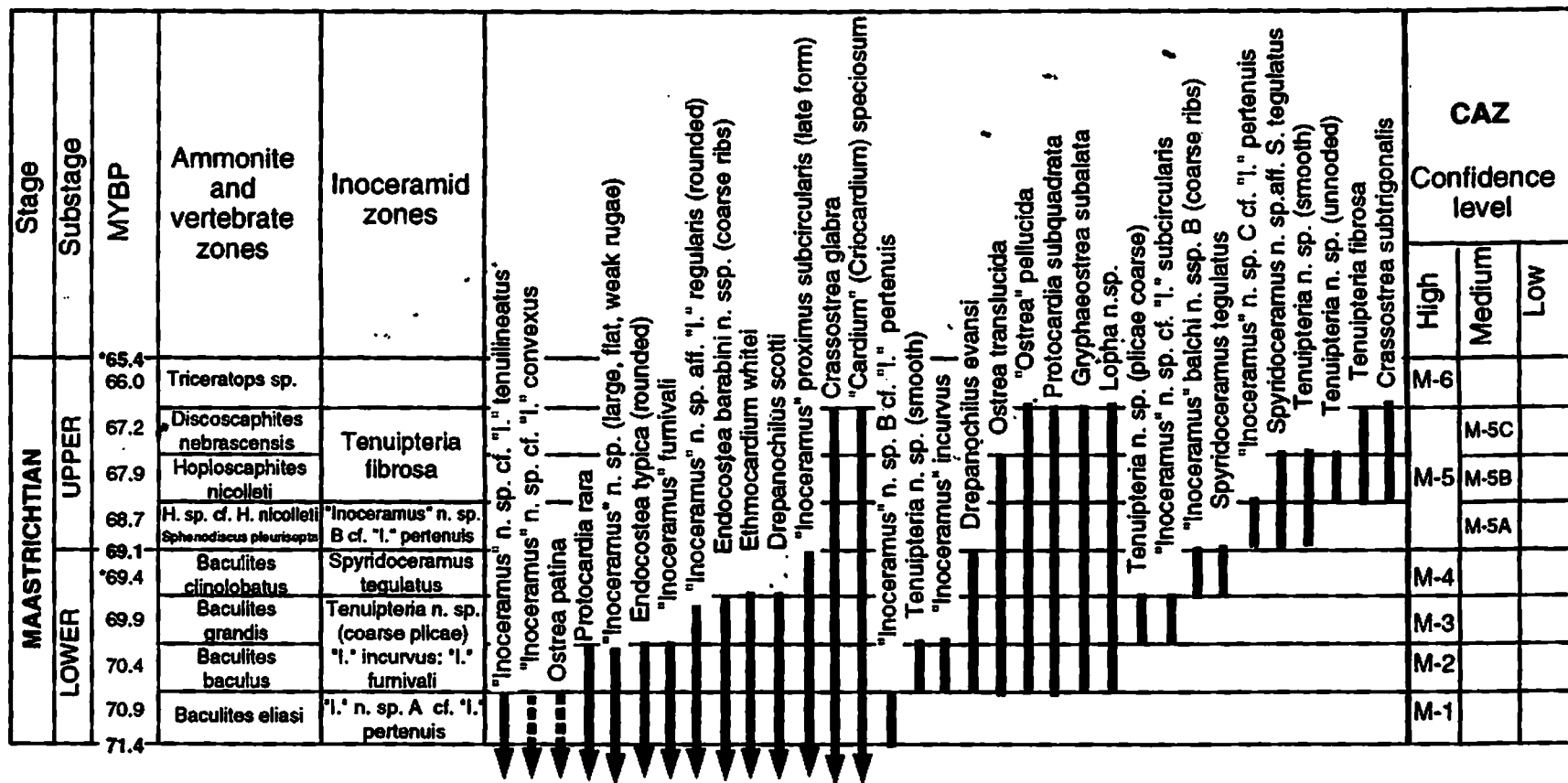


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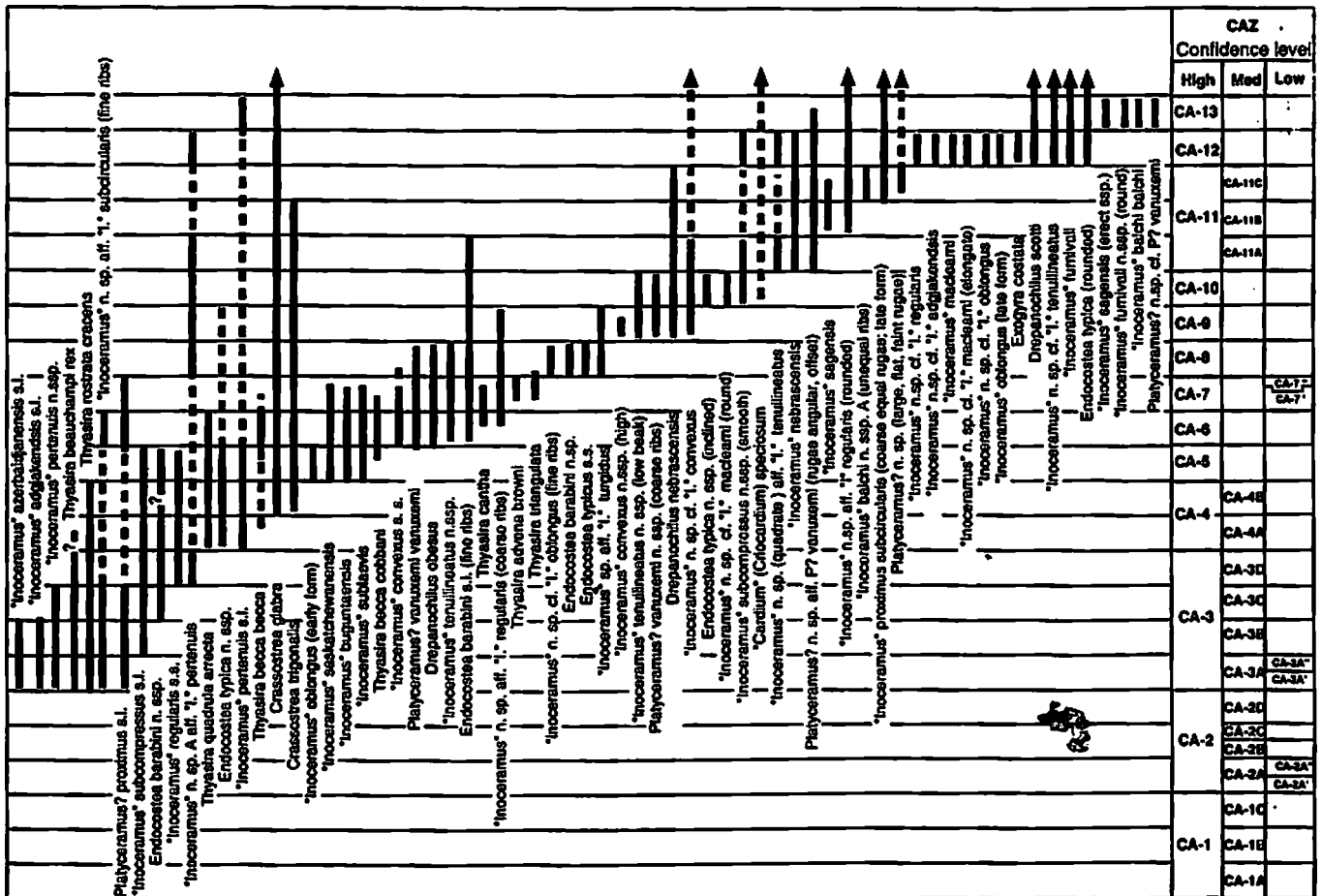
**Figure 12.** *Standard Maastrichtian ammonite-inoceramid bivalve biozones (left), matched to radiometric data (left), and the composite ranges of these and other biostratigraphically useful molluscan taxa (centre) in the Cretaceous Western Interior Basin. Composite assemblage biozones derived from these data are shown to the right. Radiometric ages (\*) from Obradovich (this volume); remaining ages interpolated between dated levels based on assignment of equal time durations to ammonite-based biozones. High, medium and low as explained in Figure 6. Two-fold division of Maastrichtian after Cobban (pers. comm., 1991). Upper Maastrichtian biozone ages interpolated on the basis of Cretaceous-Tertiary boundary (at 65.4 Ma).*

1978, 1984), attaining durations of 0.1-0.5 m.y./ species within continuously evolving lineages; calcareous and other microplankton species are consistently much longer ranging (1-3 m.y. average species durations). Rates of evolution of biostratigraphically useful taxa are also enhanced among regionally endemic taxa, especially those evolving within paleobiogeographic ecotones (Kauffman, 1984). Finally, evolutionary rates among biostratigraphically useful taxa seem to be highest in association with increasing regional environmental stress (Kauffman, 1972, 1977a, 1978); i.e., (a) as during regional eustatically generated marine regressions and shoaling of the Western Interior Seaway, (b) as associated with intervals of rapid and/or large-scale chemical perturbations in the water column (e.g., anoxic/dysoxic events, trace element and stable isotope fluctuations), and/or (c) as associated with mass extinction intervals.

The regional application of the Western Interior Cretaceous biostratigraphic system presented here is greatly enhanced by: (1) the interregional or cosmopolitan biogeographic distribution of many taxa used in the biozonation (e.g., many warm-water ammonites, the Inoceramidae, calcareous plankton); (2) the apparently long-lived planktotrophic larvae of many Cretaceous Mollusca in warm epicontinental seas, and their rapid wide dispersion on currents within and marginal to the Western Interior Seaway (Kauffman, 1975); (3) the typically broad nature of paleobiogeographic ecotones in the Western Interior Basin (Kauffman, 1984; Sohl, 1967b), which allowed blending of northern and southern biotas (and thus biostratigraphic systems based on them) over hundreds of kilometres in the seaway; and (4) the dynamic nature of Cretaceous climate zones, watermasses and paleobiogeographic subprovinces (Kauffman, 1984; Eicher and Diner, 1985, 1989), which showed rapid, frequent northward (predominantly) and southward migrations across the Western Interior Seaway, broadly blending biotas from different climate zones.

Weaknesses that still exist in the system presented here include: (a) incomplete taxonomic documentation of what are now known to be biostratigraphically important molluscs from high-resolution stratigraphic analysis; (b) the lack of evolutionary studies of many lineages employing population systematic methods, which better stabilize and refine taxonomic concepts; (c) the relatively poor knowledge of the pre-Albian Lower Cretaceous bivalve and gastropod faunas, especially in Canada; and (d) the evolving nature of the radiometric time scale used to evaluate evolutionary rates; more high-quality $^{40}Ar/^{39}Ar$ ages are needed between currently dated levels, especially in the Lower Cretaceous, and each tied to biozonal indices, so that the intervals in which ages have to be calculated, based on the tenuous assumption of equal zonal durations, can be reduced.

The Cretaceous Western Interior Basin of North America presents unique opportunities for the development of a complex, integrated biostratigraphic system based on composite assemblage zonation. The resultant system is one of the most refined in the world, and combined with an even more refined high-resolution event chronostratigraphy (Kauffman, 1986b, 1988a; Kauffman et al., 1991) and an expanding geochronology based on new single crystal $^{40}Ar/^{39}Ar$ dating methods (Obradovich, this volume), offers an unprecedented opportunity to develop an even more detailed Cretaceous chronology that will be broadly applicable to geological problem-solving and basin analysis.

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# Appendix A

## Description of Cretaceous Composite Assemblage Biozones

## from the Western Interior Basin of North America

Figures 4 to 12 show the range zone data for non-ammonite Cretaceous mollusca from the Western Interior Basin of North America, plotted against standard ammonite zones (Cobban, this volume) and a calculated radiometric scale (Kauffman, herein) based on new $^{40}Ar/^{39}Ar$ ages of Obradovich (this volume). These assemblage zones are defined below by the taxa which are restricted to them (RRZ), or whose first appearance datums (FADs) or last appearance datums (LADs) are coincident, or nearly so, with the assemblage zone boundaries. Normally, RRZ taxa are listed first, taxa FADs and/or LADs which define the basal boundary of the zone are listed next, and taxa LADs or FADs which define the top of the zone are listed last. Where the northern and southern arms of the Seaway contained separate, isolated biotas prior to late Albian marine connections, those taxa restricted to the northern sea are designated (N) and those restricted to the southern arm of the sea are designated (S). Construction of the composite assemblage zones is discussed in text. All zones proposed here and in Figures 4 to 12 are preliminary, inasmuch as there is still much systematic work to do, some areas and ages that are still poorly known, and many north to south correlations between separate arms of the Western Interior Seaway that remain to be tested, especially in pre-late Albian strata. Other abbreviations used: HCL, high confidence level; MCL, medium confidence level; LCL, low confidence level; CAZ, composite assemblage zone.

## LOWER BERRIASIAN

### BIOZONE BE-1
Composite Concurrent Range Zone including (at base) FADs of *Berriasella grandis* (S) and *Subcraspedites* sp. aff. *S. suprasubdites* (N) below the FAD of *Buchia okensis* (N) (top of zone).

## MIDDLE BERRIASIAN

### BIOZONE BE-2
Base defined by FAD of *Buchia okensis* and middle part of *Subcraspedites* sp. aff. *S. suprasubdites* range to north (N); top defined by LAD of *Berriasella grandis* (S).

### BIOZONE BE-3
Base defined by FAD of *Berriasella boissieri* (S); top defined by LADs of *Subcraspedites* sp. aff. *S. suprasubdites* and *Buchia okensis* (N).

## UPPER BERRIASIAN

### BIOZONE BE-4
RRZ of *Buchia uncitoides (N)*; base defined by FADs of *Subcraspedites* sp. cf. *S. payeri* (N); middle part of *Berriasella boissieri* range (S).

### BIOZONE BE-5
RRZ of *Buchia volgensis* (N) associated with (at top) LADs of *Subcraspedites* sp. cf. *S. payeri* (N) and *Berriasella boissieri* (S).

## LOWER VALANGINIAN

### BIOZONE V-1
RRZ of *Kilianella pertransiens* (S) associated with (at base) FAD of *K. roubaudi* s.l. (S) and, to the north (N), FADs of *Buchia keyserlingi* s.s., *Temnoptychites novosemelicus* and *Tollia* sp. cf. *T. tolli.*

### BIOZONE V-2
RRZ of *Kilianella roubaudi* s.s. (S) and (at top) LADs of *Tollia* sp. cf. *T. tolli, Temnoptychites novosemelicus* and *Buchia keyserlingi* s.s. (N).

## MIDDLE VALANGINIAN

### BIOZONE V-3
RRZ of *Kilianella complyotoxus* (S) associated (at top) with LAD of *K. roubaudi* s.l. (S) and (at base) FADs of *Thorsteinssonoceras ellesmerensis, Polyptychites* sp. cf. *P. keyserlingi, Buchia inflata, B.* n. sp. aff. *B. inflata* and *B. bulloides* (N).

### BIOZONE V-4
At base, FAD of *Saynoceras verrucosum* (S); at top, LADs of *Thorsteinssonoceras ellesmerensis* and *Polyptychites* sp. cf. *P. keyserlingi* (N).

### BIOZONE V-5
At base, FAD of *Homolsomites* sp. cf. *H. giganteus* (N) and *Euryptychites stubbendorfi* (N); at top, LAD of *Saynoceras verrucosum* s.s. (S).

### BIOZONE V-6
At base, FAD of *Himantoceras trinodosum* (S); at top, LADs of *Homolsomites* sp. cf. *H. giganteus* (N) and *Euryptychites stubbendorfi* (N).

## UPPER VALANGINIAN

### BIOZONE V-7
At base, FAD of *Homolsomites* sp. cf./aff. *H. quatsinoensis* (N); at top, LAD of *Himantoceras trinodosum* (S).

### BIOZONE V-8
RRZ of *Saynoceras callidiscus* (S); at top, LADs of *S. verrucosum* s.l. (S), *Homolsomites* sp. cf./aff. *H. quatsinoensis* (N), *Buchia inflata* (N), *B.* n. sp. aff. *B. inflata* (N) and *B. bulloides* (N).

## LOWER HAUTERIVIAN

### BIOZONE H-1
RRZ of *Lyticoceras* s.l. spp. (S); no northern taxa known.

**BIOZONE H-2**
RRZ of *Acanthodiscus radiatus* (S); no northern taxa known.

## MIDDLE HAUTERIVIAN

**BIOZONE H-3**
RRZ of *Acroteuthis* sp. aff. *A. conoides* (N); base defined by FAD of *A.* sp. aff. *A. conoides* s.l. (N); and FAD of *Crioceras duvali* (S).

**BIOZONE H-4**
RRZ of *Simberskites* sp. cf. *S. kleini* (N) and *S.* (S.) sp. ex. gr. *S.* (S.) *progredicus* (N); top defined by LAD of *Crioceras duvali* (S).

## UPPER HAUTERIVIAN

**BIOZONE H-5**
RRZ of *Subsaynella subsayni* (S); base defined by FAD of *Craspedodiscus* sp. cf. *C. discofalcatus* (N).

**BIOZONE H-6**
RRZ of *Pseudothurmannia angulicostatus* (S); top defined by LADs of *Craspedodiscus* sp. cf. *C. discofalcatus* (N) and *Acroteuthis* sp. aff. *A. conoides* s.l. (N).

## LOWER BARREMIAN

**BIOZONE BA-1**
RRZs of *Crioceratites* sp. cf. *C. latum* (N) and *Oxyteuthis* sp. cf. *O. jasikowi* (N); no southern taxa known.

**BIOZONE BA-2**
RRZs of *Crioceratites emerici* (N) and *C.* sp. cf. *C. lardi* (N); no southern taxa known.

## MIDDLE BARREMIAN

**BIOZONE BA-3**
RRZs of *Hoplocrioceras* n. sp. aff. *H. laeviusculum* (N), *Acrioceras* sp. aff. *A. starkingi* (N) and *Shasticrioceras* sp. (N); base defined by FADs of *Aucella* spp. ex. gr. *A. aptiensis-A. caucasica* (N); no southern taxa known.

## UPPER BARREMIAN

**BIOZONE BA-4**
RRZs of *Acroteuthis kernensis* (N) and *A.?* sp. cf. *A. mitchelli*; no southern taxa known.

## LOWER APTIAN

**UNZONED**
(The Biozone number AP-1 is reserved for this interval pending biostratigraphic definition.)

## MIDDLE APTIAN

**BIOZONE AP-2**
RRZ of *Tropaeum* sp. cf. *T. hillsi* (N); no southern taxa known.

**BIOZONE AP-3**
RRZs of *Tropaeum australe* (N), *T.* n. sp. aff. *T. arcticum* (N) and "*Inoceramus*" sp. cf. "*I.*" *labiatiformis* (N); no southern taxa known.

## UPPER APTIAN

**BIOZONE AP-4 (North)**
This biozone consists of RRZs of a freshwater assemblage of *Protelliptio biornatus, P. hamili, P. douglassi, Viviparus murrayensis, Lioplacoides bituminis; Eupera onestae* and *Tritigonia natosini;* top defined by LADs of marine *Aucellina* spp. ex. gr. *A. aptiensis-A. caucasica* (N). In the south, base defined by FAD of *Dufrenoyia rebeccae,* and top by LAD of *Kazanskyella spathi.* Three ammonite-based biozones characterize southern late Aptian faunas:

**Biozone AP-4A**    RRZ of *Dufrenoyia rebeccae* (S).

**Biozone AP-4B**    RRZ of *Dufrenoyia justinae* (S).

**Biozone AP-4C**    RRZ of *Kazanskyella cragini* (S).

## LOWER ALBIAN

**BIOZONE AL-1**
RRZ of *Hypacanthoplites cragini* (S); base defined by FADs of *Sonneratia* sp. cf. *S. kitchini* and *Beudanticeras* sp. aff. *B. glabrum* (N) and top by LAD of *Cleoniceras* sp. cf. *C. subbaylei* (N). This biozone is divisible in the north into two MCL biozones:

**Biozone AL-1A**    RRZ of *Sonneratia* sp. cf. *S. kitchini* (N) with FAD of *Beudanticeras* sp. aff. *B. glabrum* (N) at base.

**Biozone AL-1B**    RRZ of *Cleoniceras* sp. cf. *C. subbaylei* (N).

**BIOZONE AL-2**
RRZ of *Douvilleiceras mammilatum* s.l. to south; FAD of *Lemuroceras* sp. cf. *L. indicum* (N) at base, LAD of *Arcthoplites belli* (N) at top. Biozone is divisible to the north into two MCL biozones:

**Biozone AL-2A**    RRZ of *Lemuroceras* sp. cf. *L. indicum* (N); FAD of *Douvilleiceras mammilatum* s.l. (S) at base.

**Biozone AL-2B**    RRZ of *Arcthoplites belli* (N), LAD of *Douvilleiceras mammilatum* s.l. at top (S).

**BIOZONE AL-3**
RRZ of *Hypacanthoplites comaliensis* (S); to north, base is defined by FAD of *Arcthoplites irenense* and top by LADs of *A. mcconnelli* and *Beudanticeras* sp. aff. *B. glabrum.* This biozone is divisible to the north into two MCL biozones:

**Biozone AL-3A**    RRZ of *Arcthoplites irenense* (N).

**Biozone AL-3B**    RRZ of *Arcthoplites mcconnelli* (N); LAD of *Beudanticeras* sp. aff. *B. glabrum* (N) at top.

## MIDDLE ALBIAN

**BIOZONE AL-4**
RRZ of *Metengonoceras* sp. (S); northern strata unzoned.

**BIOZONE AL-5**
At base, FADs of *Metengonoceras hilli* (S) and *Pseudopulchella pattoni* (N) (ranges slightly offset); at top, LADs of *Oxytropidoceras salasi* (S) and *Gastroplites* sp. cf. *G. cantianus* (N) (ranges slightly offset). Three MCL biozones characterize the northern expression of Biozone AL-5, whereas two characterize it to the south; these offset ranges tentatively allow the following composite assemblage zone divisions within Biozone AL-5, although these taxa are not yet known to co-occur in the field.

**Biozone AL-5A**    At base, FAD of *Metengonoceras hilli* (S); top defined by LAD of *Pseudopulchella pattoni* (N).

**Biozone AL-5B**    RRZ of *Gastroplites canadensis* (N).

**Biozone AL-5C**    Base defined by FAD of *Gastroplites* sp. cf. *G. cantianus* (N); top defined by LAD of *Oxytropidoceras salasi* (S).

**BIOZONE AL-6**
RRZs of *Manuaniceras carbonarium* (S) and *Stelckiceras liardensis* (N); bases slightly offset N to S.

## UPPER ALBIAN

**BIOZONE AL-7**
RRZ of *Manuaniceras powelli* (S). At base, FADs of *Neithea georgetownensis, N. subalpinus, N. subalpinus linki, N. texana, N. texana elongata, N. altana, N. theodori* and *Plicatula incongrua* (all S); at top, LADs of *Ceratostreon texanum* (S) and *Texigryphaea mucronata* (S). This biozone is divisible into two MCL assemblage biozone:

**Biozone AL-7A**   Base defined by FADs as for Biozone AL-7; at top, LAD of *Neithea duplicostata* (S).

**Biozone AL-7B**   RRZ of *Venezoliceras kiowanum* (S); base defined by FADs of *Pleuriocardium kansasense, "Anchura" kiowanum* and *Texigryphaea corrugata* (all S); top defined by LADs of *T. mucronata* (S) and *Ceratostreon texanum* (S).

## BIOZONE AL-8
RRZs of *Adkinsites bravoensis* (S) and *Turritella leonensis* (S); base defined by possible FAD of *"Inoceramus" comancheanus* (N,S); top defined by LADs of southern *"Pteria" leveretti, Cardium bisolaris,* and *Granocardium sabulosum*. This biozone is divisible into two LCL biozones:

> **Biozone AL-8'**   Base defined by FADs as in Biozone AL-8 plus *Adkinsites bravoensis* (S); top of biozone marked by the FAD of *Texigryphaea corrugata belviderensis* (S) and (slightly offset) top marked by the LAD of *Pleuriocardium orthoprymnus* (S).

> **Biozone AL-8"**   Base marked by FAD of *Texigryphaea corrugata belviderensis* (S); top at LADs of *Turritella leonensis, Neithea irregularis, Granocardium sabulosum, Cardium bisolaris* and *"Pteria" leveretti.*

## BIOZONE AL-9
A HCL assemblage zone that spans the ammonite biozones of (ascending) *Boeseites romeri* and *Craginites serratescens*. RRZ of *Phelopteria salinensis salinensis* (both S) and *"Inoceramus"* n. sp. aff. *"I." nahwisi* (N); base defined by FADs of *Lopha quadriplicata* (S) and, to the north, *"I." goodrichensis, "I." moberliensis,* and possibly *Ostrea larimerensis* and *O. noctuensis* (N); top defined by LADs of *Texigryphaea corrugata* (S) and *"I." comancheanus* (N,S). This biozone is divisible into two MCL biozones:

**Biozone AL-9A**   RRZ of *Boeseites romeri*; base defined by FADs as for Biozone AL-9.

**Biozone AL-9B**   RRZ of *Craginites serratescens*; base defined by FADs of *Ostrea rugosa, O. arcuata* and *Crassostrea kiowanum* to south. Top defined by LADs of *Phelopteria salinensis salinensis* (S) *"Inoceramus" comancheanus* (S,N), and *"I."* n. sp. aff. *"I." nahwisi* (N).

## BIOZONE AL-10
A HCL CAZ spanning the ammonite biozones of (ascending) *Eopachydiscus mercianus-E. brazosensis, Pervinquieria equidistans,* and the lower part of the *Drakeoceras lasswitzi* Zone to the south, and the main documented range of *"Inoceramus" bellvuensis* to the north. RRZ *Texigryphaea tucumcarii* (S); base defined by FADs of *"I." bellvuensis* (N), *Phelopteria salinensis* n. subsp. A (S), *Birostrina munsoni* (S), and *"I." athabaskensis* (N); top defined by LAD of *Anchura kiowana* (S) and (slightly higher) LADs of *Pleuriocardium kansasense,* and *Protocardia texana* to south. This biozone is divisible into three MCL biozones:

**Biozone AL-10A**   RRZs of *Eopachydiscus mercianus* and *E. brazosensis* (S); base defined by FADs as in Biozone AL-10; top defined by LADs of *Ostrea rugosa* and *O. arcuata* to south.

**Biozone AL-10B**   RRZ of *Pervinquieria equidistans* (S); base defined by FADs of *Neithea wrighti* and *N. bellula* to south; top defined by LAD of *Crassostrea kiowanum* (S) and possibly rare specimens related to *"Inoceramus" comancheanus* (N).

**Biozone AL-10C**   Base defined by FADs of *Chlamys chihuahensis* and *Drakeoceras lasswitzi* (S); top defined by LADs of *Texigryphaea tucumcarii,* and slightly higher, *Protocardia texana, "Anchura" kiowana,* and probably *Pleuriocardium kansasense* to south as well as *"Inoceramus" goodrichensis* to north.

## BIOZONE AL-11
RRZ of *Eopachydiscus? mercianus* (N); base defined by FADs of *"Inoceramus"* sp. aff. *"I." bellvuensis* (n. sp.?) (N), *"I." nahwisi* (N), and *Plicatula dentonensis* (S); top defined by LADs of *Chlamys chihuahensis* and *Drakeoceras lasswitzi* (S), and *"I." moberliensis* (N), as well as several FADs of typical zone AL-12 taxa.

## BIOZONE AL-12
A HCL biozone that spans the ammonite range zones of (ascending) *Mortoniceras wintoni* and *Drakeoceras drakei-D. gabrielense* to the south and, to the north, the ammonite zones of (ascending) *Neogastroplites haasi, N. cornutus, N. muelleri-Metengonoceras teigenense, N. americanus-M. asperanum,* and *N. maclearni.* RRZs of *"Anchura" mudgeana* and *Camptonectes inconspicuus* to the south, and of *"Inoceramus" anglicus* (N); base defined by FADs of *Turritella graysonensis* and *Granocardium inflatum* to south, FAD of *N. haasi* (N); top defined by LADs of *Neithea subalpinus subalpinus, S. subalpinus linki, N. texana texana, N. texana elongata, N. altana* and *N. theodori* (S), and *Neogastroplites maclearni* (N).

Note that Cobban and Kennedy (1989) have proposed the possibility that the Albian-Cenomanian boundary may lie between the biozones of *Neogastroplites cornutus* and *N. muelleri-Metengonoceras teigenense,* based on the affinities of the *Metengonoceras* to those of the Gulf Coast. Cobban (pers. comm. 1992) has further expressed the view that the base of the Cenomanian may even lie as low as the base of the *N. haasi* Zone. This still needs to be demonstrated by the study of other groups, and is seemingly contradicted by the range of *"Inoceramus" anglicus* (a typical European Albian species) to the top of the *N. maclearni* Zone, and the Albian nature of the foraminifer assemblage in these rocks. We have therefore used the more widely accepted Albian-Cenomanian boundary at the top of *N. maclearni* in this paper, pending further study.

Biozone AL-12 is divisible into two MCL assemblage zones, and six LCL assemblage zones:

**Biozone AL-12A**   RRZ of *Mortoniceras wintoni* (S); base defined by FADs of *"Anchura" mudgeana, Turritella graysonensis, Camptonectes inconspicuus,* and *Granocardium inflatum* to the south, and *"Inoceramus" anglicus* and *Neogastroplites haasi* to the north; top defined by LADs of *Ostrea larimerensis* and *N. cornutus* (N). This biozone is divisible into two LCL biozones:

> **Biozone AL-12A'**   RRZ of *Neogastroplites haasi* (N); base defined by FADs as in Biozones AL-12 and AL-12A; top defined by LAD of *"Inoceramus" nahwisi* (N).

> **Biozone AL-12A"**   RRZ of *Neogastoplites cornutus* (N); base is FAD of *"Inoceramus" dunveganensis* s.l. (N); top is LAD of *Ostrea larimerensis* (N).

**Biozone AL-12B**   RRZs of *Drakeoceras gabrielense* and *D. drakei* (S); base defined by FADs of *"Inoceramus"* n. sp. aff. *I. moberliensis, Metengonoceras teigenense* and *Neogastroplites muelleri* (N); top defined by LADs of *"Anchura" mudgeana, Neithea subalpinus subalpinus, N. subalpinus linki, N. texana texana, N. texana elongata, N. altana* and *N. theodori* (S), and *"I." anglicus* and *N. maclearni* (N). This biozone is divisible into four LCL biozones:

> **Biozone AL-12B'**   RRZs of *Neogastroplites muelleri* and *Metengonoceras teigenense* (N); base defined by FAD of *"Inoceramus"* n. sp. aff. *"I." moberliensis* (N).

> **Biozone AL-12B"**   Base defined by FADs of *Neogastroplites americanus* and *Metengonoceras aspenanum* (N); top defined by LADs of *Turritella graysonensis, Granocardium inflatum* and, somewhat higher, *Neithea georgetownensis* (S).

**Biozone AL-12B'''** Base defined by the LADs of Biozone AL-12B''; top defined by the LADs of *Neogastroplites americanus, Metengonoceras asperanum* and, slightly higher, *"Inoceramus"* n. sp. aff. *I. moberliensis* (all N).

**Biozone AL-12B''''** RRZ of *Neogastroplites maclearni* (N); top defined by LADs of *"Inoceramus" anglicus* (N), and all LADs defining the top of Biozone AL-12 to south.

## LOWER CENOMANIAN

### BIOZONE CE-1
This HCL assemblage zone spans (to N, ascending) the ammonite biozones of *Neogastroplites septimus, Irenicoceras bahani* and *Beattonoceras beattonense.* RRZ of *"Inoceramus" dunveganensis* n. subsp. (lower half of zone only); base defined by the FADs of *N. septimus* (N), *"I." bellvuensis* n. subsp. and *Crassostrea soleniscus* (N,S), and possibly the lowest ranges of *"I." eulessanus* (N), *"I."* n. sp. aff. *"I." dunveganensis, I. arvanus* and *Rhynchostreon levis* (N,S); top defined by the LADs of *Ostrea noctuensis* (N), and (slightly higher) *"I." athabaskensis* (N). This biozone is divisible into three possibly low-confidence level biozones, which will obviously achieve higher order of confidence when Canadian faunas are better studied, as follows:

**Biozone CE-1'** RRZ of *Neogastroplites septimus* (N); base defined by FADs as in Biozone CE-1.

**Biozone CE-1''** RRZ of *Irenicoceras bahani* (N).

**Biozone CE-1'''** RRZ of *Beattonoceras beattonense* (N); top defined by LADs as in Biozone CE-1.

## MIDDLE CENOMANIAN

### BIOZONE CE-2
RRZs of *Calycoceras (Conlinoceras) tarrantense, Plicatula arenaria* and *Exogyra aquillana* to south, and *Inoceramus* sp. cf. *I. mcconnelli* to north; base defined by FADs of *I. crippsi* s.l., *I. arvanus* (n. subspp. A and B), *Camptonectes symmetricus, Ostrea beloiti,* and the first well-defined occurrences of *"I." eulessanus* and *"I."* n. sp. aff. *"I." dunveganensis*; top defined by LADs of *Lopha quadriplicata, "I." bellvuensis* n. subsp. and *"I." dunveganensis* s.s.

### BIOZONE CE-3
A HCL composite assemblage zone spanning the ammonite zones of (ascending) *Acanthoceras granerosense, A. muldoonense* and *A. bellense.* Possible RRZs of *Inoceramus arvanus* s.s. and *"I."* n. sp. aff. *"I." dunvenganensis,* although rare specimens related to these species are reported from the lower Cenomanian; base defined by FADs of *Acanthoceras granerosense, Ostrea anomioides*; top defined by the LADs of *Acanthoceras bellense, "I."* n. sp. aff. *"I." dunveganensis, "I." moberliensis* n. subsp. and *I. arvanus arvanus.* Biozone CE-3 is divisible into two MCL biozones:

**Biozone CE-3A** RRZ of *Acanthoceras granerosense*; base defined by FAD of *Ostrea anomioides*; top defined by LAD of *"Inoceramus" eulessanus.*

**Biozone CE-3B** RRZ of *"Inoceramus" moberliensis* n. subsp.; base defined by FAD of *Acanthoceras muldoonense*; top defined by LADs of *A. bellense, "I."* n. sp. aff. *"I." dunveganensis* and *I. arvanus arvanus.* Biozone CE-3B is divisible into two LCL biozones:

**Biozone CE-3B'** RRZ of *Acanthoceras muldoonense.*

**Biozone CE-3B''** RRZ of *Acanthoceras bellense*; top defined by LADs as for Biozone CE-3.

## BIOZONE CE-4
A HCL composite assemblage biozone spanning the ammonite range zones of *Cunningtoniceras amphibolum* and *Plesiacanthoceras wyomingense*; RRZs of *Inoceramus* sp. cf. *I. rutherfordi, I. arvanus* n. subsp. and *"I." athabaskensis* n. subsp.; base defined by FADs of *Cunningtoniceras amphibolum* and subsp. *C. a. amphibolum, Exogyra acroumbonata* and *Pycnodonte* sp. cf. *P. kellumi.* Biozone CE-4 contains three MCL biozones:

**Biozone CE-4A** RRZ of *Cunningtoniceras amphibolum amphibolum*; base defined by same FADs as for Biozone CE-4.

**Biozone CE-4B** RRZs of *Cunningtoniceras amphibolum fallense* and *Inoceramus rutherfordi rutherfordi*; base marked by FADs of *I. prefragilis prefragilis* and *Exogyra trigeri*; top marked by LAD of *I. arvanus* n. subspp. A and B.

**Biozone CE-4C** RRZ of *Plesiacanthoceras wyomingense*; *Phelopteria dalli* (early form) is restricted to the lower half of the biozone; top marked by LADs of *Inoceramus* sp. cf. *I. rutherfordi, I. arvanus* n. subsp. and *"I." athabaskensis* n. subsp.

## UPPER CENOMANIAN

### BIOZONE CE-5
RRZs of *Calycoceras canitaurinum, Exogyra* n. sp. aff. *E. boveyensis* and (in upper half of zone) *Inoceramus prefragilis stephensoni*; base marked by FADs of *Entolium gregarium, Pycnodonte* sp. aff. *P. kellumi* and *Flemingostrea prudentia*; top marked by LADs of *I. prefragilis prefragilis* and *Exogyra* n. sp. aff. *E. boveyensis.* This biozone is divisible into three LCL biozones:

**Biozone CE-5'** Base marked by FADs of *Exogyra* sp. aff. *E. boveyensis, Entolium gregarium, Flemingostrea prudentia* and *Pycnodonte* sp. aff. *P. kellumi*; bounded at top by the FAD of *Inoceramus prefragilis stephensoni.*

**Biozone CE-5''** Base marked by FADs of *Inoceramus prefragilis stephensoni* and *I. tenuistriatus? (? = I. nodai)*; top marked by LADs of *Pycnodonte* sp. (new?) cf. *P. kellumi* and *Ostrea beloiti.*

**Biozone CE-5'''** Base marked by FADs of *Inoceramus pictus pictus* and *I. pictus gracilistriatus*; top marked by LADs of *I. prefragilis stephensoni, I. prefragilis prefragilis* and *Exogyra* n. sp. aff. *E. boveyensis.*

### BIOZONE CE-6
A HCL CAZ spanning the ammonite biozones of (ascending) *Dunveganoceras problematicum* and *D. albertense*; base is defined by FADs of Biozone CE-6A (below); top is defined by FADs of Biozone CE-6B, defined below. This biozone contains two MCL biozones, each of which is divisible into two LCL biozones:

**Biozone CE-6A** RRZ of *Dunveganoceras problematicum* in lower two-thirds of biozone; base defined by FADs of *Metoicoceras mosbyense, Inoceramus flavus pictoides, I. ginterensis, I. corpulentus?, I.* sp. aff. *I. capulus, Exogyra olisiponensis* and *Crassostrea coalvillensis.* Biozone CE-6A is bounded at top by the FADs of Biozone CE-6B, and is divisible into two LCL biozones:

**Biozone CE-6A'** RRZ of *Dunveganoceras problematicum*; FADs same as in Biozone CE-6A.

**Biozone CE-6A''** Base defined by the FAD of *Dunveganoceras albertense*; top defined by six FADs of taxa characterizing Biozone CE-6B, defined below.

**Biozone CE-6B** RRZ of *Inoceramus conicus?* and *Syn-cyclonema* n. sp. aff. *S. simplicius*, both in lower two-thirds of biozone; base defined by FADs of *Plicatula hydrotheca, P.* sp. cf. *P. ferryi, I.* sp. aff. *I. mesabiensis* and *Sergipia* n. sp.; top defined by LAD of *Dunveganoceras albertense* and *I. crippsi.* This biozone is divisible into two LCL biozones:

*Biozone CE-6B'* RRZs of *Inoceramus conicus?* and *Syn-cyclonema* n. sp. aff. *S. simplicius*; base defined by FADs that also define Biozone CE-6B.

*Biozone CE-6B"* Base defined by the LADs of *Inoceramus conicus?* and *Syncyclonema* n. sp. aff. *S. simplicius*; top defined by the LAD of *"I." crippsi.*

## BIOZONE CE-7
RRZs of *Dunveganoceras conditum* and *Inoceramus pictus neo-caledonicus*; base defined by the FADs of *Phelopteria* n. sp. (spinose), *Pleuriocardium* n. sp. aff. *P. bisculpta* and *Parvilucina juvenis*; top defined by the LADs of *Exogyra trigeri, I.* sp. aff. *I. tenuis, I.* sp. aff. *I. capulus, I.* sp. aff. *I. mesabiensis, Pycnodonte* sp. aff. *P. kellumi, E. olisiponensis, Crassostrea coalvillensis, Lopha staufferi* and *Turritella* n. sp. A. This biozone is divisible into two MCL and three LCL biozones:

**Biozone CE-7A** Base defined by the FADs of *Dunveganoceras conditum, Phelopteria* n. sp. (spinose), *Pleuriocardium* n. sp. aff. *P. bisculpta* and *Parvilucina juvenis*; top of the biozone is marked by the FAD of *Plicatula hydrotheca.*

**Biozone CE-7B** RRZs of *Lopha staufferi* and *Turritella* n. sp. A (just above base of biozone); base marked by the FADs of *Gryphaeostrea* n. spp. A,B, and possibly *Inoceramus allani*; top marked by the LADs of *I.* n. sp. aff. *I. mesabiensis, I.* sp. aff. *I. ca-pulus, I. pictus neocaledonicus, I.* sp. aff. *I. tenuis, Exogyra trigeri, E. olisiponensis, Pycnodonte* sp. aff. *P. kellumi* and *Crassostrea coalvillensis.* Biozone CE-7B is divisible into three LCL biozones as follows:

*Biozone CE-7B'* FADs as in Biozone CE-7B. Bounded at top by FADs of *Turritella* n. sp. A and *Lima utahensis.*

*Biozone CE-7B"* Base marked by FADs of *Turritella* n. sp. A and *Lima utahensis*; top marked by LADs of *Inoceramus pictus neocaledonicus* and (lower) *Pleuriocardium* n. sp. aff. *P. bisculpta.*

*Biozone CE-7B"'* Base marked by FADs of *Pycnodonte new-berryi* and *Lucina* n. sp. aff. *L. linearia*; top marked by LADs of *Metoicoceras mosbyense, Dunveganoceras conditum, Ex-ogyra trigeri, P.* sp. aff. *P. kellumi, Inoceramus* sp. aff. *I. tenuis, I.* sp. aff. *I. capulus, I.* sp. aff. *I. mesabiensis, Turritella* n. sp. A, *Lopha staufferi, E. olisiponensis* and *Crassostrea coalvillensis.*

## BIOZONE CE-8
RRZ of *Vascoceras diartianum*; base marked by FADs of *Scipono-ceras gracile, Inoceramus tenuiumbonatus, I. mesabiensis, "I."* sp. aff. *"I." crippsi, Entolium membranaceum, Arctostrea* n. sp., *Plicatula* n. sp. aff. *P. goldenana, Perissoptera prolabiata* and *Phe-lopteria* n. sp. B,C, and D of Elder (in prep., pers. comm.; top of zone marked by LAD of *Flemingostrea prudentia.* Biozone CE-8 is divisible into three LCL biozones:

*Biozone CE-8'* Base marked by same FADs as for Biozone CE-8; top marked by LAD of *Lucina* n. sp. aff. *L. linearia.*

*Biozone CE-8"* Base is defined by the LADs of Biozone CE-8', and top by the LADs of *Phelopteria* n. sp. (spinose) and *Camptonectes symmetricus.*

*Biozone CE-8"'* Base is defined by the LADs at the top of Biozone CE-8', and the top by the LADs of *Flemingostrea pru-dentia* and *Vascoceras diartianum.*

## BIOZONE CE-9
RRZs of *Euomphaloceras septumseriatum, Turritella* n. sp. B, and *"Aucellina" gryphaeoides* (lower half only); base defined by the FADs of *T. whitei, "Aucellina" gryphaeoides, Mytiloides sub-mytiloides* s.l. and *M.* sp. (new?) cf. *M. submytiloides*; top defined by the LADs of *Inoceramus tenuiumbonatus, I. mesabiensis, Arctostrea* n. sp., *Exogyra acroumbonata, Plicatula* sp. cf. *P. ferryi* and *Gryphaeostrea* n. sp. B. This biozone is divisible into two MCL biozones:

**Biozone CE-9A** Base marked by the same FADs as for Bio-zone CE-9; top marked by the LADs of *Inoceramus allani?, Gry-phaeostrea* n. sp. A, *Rhynchostreon levis, "Aucellina" gryphaeoi-des* and *Entolium membranaceum.*

**Biozone CE-9B** Base marked by the FADs of *Nemodon sul-catinus*, and possibly *Pseudoperna bentonensis* and *Plicatula* n. sp. A; top marked by the same LADs as for the top of Biozone CE-9.

## BIOZONE CE-10
RRZs of *Burroceras clydense* and *Inoceramus* sp. cf. *I. heinzi*; top marked by the LADs of *Lima utahensis, I. ginterensis, Turritella whitei* and *Plicatula* sp. aff. *P. goldenana.*

## BIOZONE CE-11
Includes (ascending) the ammonite zones of *Neocardioceras jud-dii* and *Nigericeras scotti*; base marked by the FAD of *Neocar-dioceras juddii*; top marked by the LADs of *Nigericeras scotti, Mytiloides* sp. (new?) cf. *M. mytiloides, Inoceramus tenuistriatus* (? = *I. nodai*), and by *"I."* sp. aff. *"I." crippsi.* Biozone CE-11 is divisible into two LCL biozones:

*Biozone CE-11'* RRZ of *Neocardioceras juddii* s.s.; top marked by the LADs (some slightly higher) of *Inoceramus pictus gracilistriatus, I. flavus flavus* and *I. flavus pictoides.*

*Biozone CE-11"* RRZ of *Nigericeras scotti*; top marked by the LADs of *"Inoceramus"* sp. aff. *"I." crippsi, Mytiloides* n. sp. cf. *M. submytiloides* and *I. tenuistriatus? (? = I. nodai).*

## LOWER TURONIAN

### BIOZONE T-1
RRZs of *Watinoceras devonense* and *Pleuriocardium bisculptus*; base defined by the FADs of *Mytiloides hattini* trans. to *M. kossmati* (= *M. opalensis* sensu Seitz); top defined by the LADs of *M. submytiloides* and *Pycnodonte newberryi.* This biozone is divisible into two LCL biozones:

*Biozone T-1'* Base defined by the FADs of Biozone T-1; top defined by the FADs of *Mytiloides kossmati* s.s. (= *M. opal-ensis* sensu Seitz) and *Ostrea* n. sp. A.

*Biozone T-1"* Base defined by the FADs of *Mytiloides kossmati* s.s. (= *M. opalensis* sensu Seitz) and *Ostrea* n. sp. A; top defined by the LADs of *Watinoceras devonense, Pycno-donte newberryi* and *M. submytiloides.*

### BIOZONE T-2
A HCL biozone divided into two MCL biozones. Zone defined by RRZ of *Pseudaspidoceras flexuosum*; base characterized by FADs of *Mytiloides* n. sp. aff. *M. columbianus* (= aff. *M. du-plicostatus* of Kauffman and Powell, 1977), *M.* sp. aff. *M. latus, M.* n. sp. aff. *M. submytiloides, M. columbianus* and *Pleuriocardium subcurtum*; top defined by the LADs of *Nemodon sulcatinus, M. hattini* and subspp. and *Lopha* n. sp. A. This zone is divisible into three MCL biozones:

**Biozone T-2A**    Base defined by the same FADs as for Biozone T-2; top defined by LADs of *Mytiloides kossmati* (= *M. opalensis* sensu Seitz) and *Ostrea* n. sp. A. Two LCL biozones can be identified within this zone:

> **Biozone T-2A'**    Base of biozone defined by same FADs as for Biozone T-2; top defined by LADs of *Pleuriocardium bisculptus* and, slightly below it, *Mytiloides submytiloides.*

> **Biozone T-2A"**    Base defined by LADs of Biozone T-2A'; top defined by LADs of *Mytiloides kossmati* (= *M. opalensis* sensu Seitz) and *Ostrea* n. sp. A.

**Biozone T-2B**    Base defined by FADs of *Mytiloides kossmati elongata, M. kossmati* trans. *M. mytiloides, M. latus* and *M. mytiloides* (early form, n. subsp.); top defined by the FADs of *M. mytiloides* and *Lopha* n. sp. A.

**Biozone T-2C**    RRZ of *Lopha* n. sp. A; base defined by the FADs of *Mytiloides mytiloides;* top defined by the LADs of *Nemodon sulcatinus, M. hattini* and subspp., and *Pseudaspidoceras flexuosom.*

**BIOZONE T-3**
HCL biozone spanning (ascending) the ammonite biozones of *Vascoceras birchbyi,* and all but the uppermost part of *Mammites nodosoides;* base defined by FADs of *V. birchbyi* and *Ostrea* sp. aff. *O. anomioides;* top defined by LADs of *Mytiloides columbianus* (just below top), *M. latus, Pycnodonte* sp. B, *Plicatula* sp. C, *Sergipia* sp. cf. *S. harti* and *Camptonectes* sp. cf. *C. platessa.* Zone T-3 is divisible into four MCL biozones:

**Biozone T-3A**    RRZ of *Vascoceras birchbyi;* base defined by FADs of *Ostrea* sp. aff. *O. anomioides* and *Parvilucina* n. sp. aff. *P. juvenis;* top defined by the LADs of *Plicatula* sp. A, *Pycnodonte newberryi* n. subsp., *Mytiloides kossmati* trans. to *M. mytiloides* and *M. kossmati elongata* (= *M. opalensis elongata* of Seitz). Two LCL divisions are possible:

> **Biozone T-3A'**    Base defined on FADs described for Biozone 3-A; top defined on LAD of *Ostrea* sp. aff. *O. anomioides.*

> **Biozone T-3A"**    Base defined on LAD of *Ostrea* sp. aff. *O. anomioides; top defined on LADs of Plicatula, Pycnodonte and Mytiloides spp. described for top of Biozone T-3A.*

**Biozone T-3B**    Base defined on the FADs of *Mammites nodosoides, Mytiloides labiatus* s.l., and LADs at the top of Biozone T-3A; top defined on the LADs of *M. mytiloides* (early form; n. subsp.) and *Phelopteria quadrate* sp. aff. *P. minuta.*

**Biozone T-3C**    Base defined on FADs of *Pycnodonte* sp. B, *Plicatula* sp. C, *Inoceramus* sp. aff. *I. cuvieri* and *Pycnodonte kansasense;* top defined on the LADs of *Mytiloides mytiloides, M. columbianus* and *M. hattini* trans. to *M. opalensis.*

**Biozone T-3D**    RRZ of *Camptonectes* sp. aff. *C. platessa;* base defined by FADs of *Inoceramus* n. sp. aff. *I. flaccidus, Mytiloides arcuata* and *M. mytiloides* (late form, n. subsp.).

**BIOZONE T-4**
Base defined by the FADs of *Mytiloides labiatus* (late form, n. subsp.), and *M. subhercynicus;* top defined by the LADs of *Mytiloides arcuata, M. mytiloides* (late form, n. subsp.) and *Mammites nodosoides.*

**MIDDLE TURONIAN**
**BIOZONE T-5**
Incorporates the lower half of the range of *Collignoniceras woolgari woolgari;* base is defined by the FADs of *C. woolgari woolgari, Inoceramus cuvieri, Curvostrea* sp., *Lopha* n. sp. aff. *L. lugubris* and *Mytiloides hercynicus;* top is defined by the LADs of *M. subhercynicus, M. labiatus* (late form, n. subsp.), *Pycnodonte kansasense, Inoceramus* sp. aff. *I. cuvieri, Entolium gregarium, M.* sp. aff. *M. latus* and *M.* n. sp. aff. *M. submytiloides.* This zone is divisible into two LCL biozones:

> **Biozone T-5'**    Base defined by FADs cited for Biozone T-5; top defined by LADs of *Mytiloides labiatus* s.l. and *Pleuriocardium subcurtum.*

> **Biozone T-5"**    Base defined by the FAD of *Inoceramus apicalis;* top defined as for Biozone T-5.

**BIOZONE T-6**
This biozone spans the ammonite range zones of *Collignoniceras woolgari woolgari* (upper half) and *C. woolgari regulare;* base defined by the FADs of *Inoceramus apicalis;* top defined by the LADs of *Mytiloides hercynicus, Lopha* n. sp. aff. *L. lugubris, Pseudoperna bentonensis* and *Phelopteria* n. spp. B and C of Elder (in prep., pers. comm.). This biozone is divisible into two MCL biozones:

**Biozone T-6A**    Base is defined by the FAD of *Inoceramus apicalis;* top is defined by the LADs of *Collignoniceras woolgari woolgari, I.* n. sp. aff. *I. flaccidus* and *Phelopteria minuta.*

**Biozone T-6B**    RRZ of *Collignoniceras woolgari regulare;* base is defined by the FAD of *Lopha bellaplicata novamexicana, Pleuriocardium pauperculum* and *Rynchostreon suborbiculata;* top is defined on LADs defining Biozone T-6.

**BIOZONE T-7**
RRZ of *Prionocyclus percarinatus;* base defined by FADs of *Inoceramus flaccidus* and *Cubitostrea malachitensis;* top defined by LAD of *I. cuvieri.*

**BIOZONE T-8**
Base defined by the FADs of *Prionocyclus hyatti, Collopoceras springeri, Inoceramus ernsti securiformis, I. howelli, Lucina juvenis, Turritella "carlilana"* n. sp. (Kauffman manuscript name), *T. "codellana"* n. sp. (Kauffman manuscript name), and *Mytiloides costellatus;* top defined by LADs of *I. flaccidus* and *Lopha bellaplicata novamexicana.*

**BIOZONE T-9**
RRZ of *Inoceramus* sp. cf. *I. dimidius;* upper half of the RRZs of *Prionocyclus hyatti* and *I. ernsti securiformis;* base defined on the FADs of *Lopha bellaplicata bellaplicata, L. cunabula* n. subsp. (coarse plicae), *Mytiloides* n. sp. aff. *M. aviculoides, Turritella "huerfanensis"* n. sp. (Kauffman manuscript name), *Phelopteria gastrodes,* and possibly *Cardium trite;* top defined by LADs of *I. apicalis* and *I. ernsti securiformis.*

**BIOZONE T-10**
RRZ of *Inoceramus* n. sp. aff. *I. mesabiensis;* top defined by the LADs of *Rynchostreon suborbiculata, Cubitostrea malachitensis, Mytiloides costellatus, I. howelli, Lopha bellaplicata bellaplicata, Parvilucina juvenis, Turritella "carlilana"* n. sp., *T. "codellana"* n. sp., *T. "huerfanensis"* n. sp. (all Kauffman manuscript names), *Perissoptera prolabiata* and *Phelopteria gastrodes.* This biozone is divisible into two MCL biozones:

**Biozone T-10A** RRZ of *Inoceramus* n. sp. aff. *I. mesabiensis*; top defined by LADs of *Lopha cunabula* n. subsp. (coarse plicae), *Mytiloides* n. sp. aff. *M. aviculoides*, *Crassostrea soleniscus* and *Ostrea anomioides*.

**Biozone T-10B** Base defined by FAD of *Ostrea* n. sp.; top defined by LADs of *Coilopoceras springeri*, *Rynchostreon suborbiculata*, *Cubitostrea malachitensis*, *Mytiloides costellatus*, *Inoceramus howelli*, *Lopha bellaplicata bellaplicata*, *Parvilucina juvenis*, *Turritella "carlilana"* n. sp., *T. "codellana"* n. sp., *T. "huerfanensis"* n. sp. (Kauffman manuscript names), *Perissoptera prolabiata* and *Phelopteria gastrodes*.

## UPPER TURONIAN

### BIOZONE T-11

RRZs of *Coilopoceras colleti*, *Prionocyclus macombi*, *Lopha lugubris lugubris*, and *Inoceramus dimidius dimidius*. Base defined by the FAD of *I. howelli* n. subsp. The FAD of *Pycnodonte uniformis* lies near the base. Top defined by the LAD of *Ostrea* n. sp.

### BIOZONE T-12

A HCL biozone which contains the RRZs (ascending) of *Scaphites warreni*, *S. ferronensis*, *S. whitfieldi*, *S. nigricollensis* and *Mytiloides striatoconcentricus*; base is characterized by FADs of *S. warreni*, *Lopha lugubris* n. subsp. A (fine plicae) and *Inoceramus dimidius* n. subsp.; top defined by the LAD of *M. striatoconcentricus* and numerous FADs at the base of Biozone T-13. Biozone T-12 is divisible into three MCL biozones:

**Biozone T-12A** Successive RRZs of *Scaphites warreni*, *S. ferronensis*, *and S. whitfieldi*; base defined by FADs of *Lopha lugubris* n. subsp. (fine plicae) and *Inoceramus dimidius* n. subsp.; top defined by LADs of *L. lugubris* n. subsp. B (very fine plicae to smooth) and *I. perplexus perplexus*. Biozone T-12A is divisible into three LCL biozones:

    *Biozone T-12A'* RRZ of *Scaphites warreni*; base defined by FADs of *Lopha lugubris* n. subsp. A (fine plicae) and *Inoceramus dimidius* n. subsp.; top defined by LAD of *I. howelli* n. subsp.

    *Biozone T-12A"* RRZ of *Scaphites ferronensis*; top defined by LAD of *Inoceramus dimidius* n. subsp.

    *Biozone T-12A'"* RRZs of *Scaphites whitfieldi*, *Lopha lugubris* n. subsp. B (very fine plicae to smooth) and *Inoceramus perplexus perplexus*; FAD of *Prionocyclus novimexicanus* at base.

**Biozone T-12B** RRZs of *Scaphites nigricollensis* and *Inoceramus perplexus* n. subsp.; top defined by LADs of *Prionocyclus novimexicanus* and *Pycnodonte uniformis*.

**Biozone T-12C** RRZ of *Mytiloides striatoconcentricus*; base defined by FADs of *Prionocyclus germari*, *Scaphites corvensis*, *M. aviculoides*, *Inoceramus kleini?* and *Pleuriocardium curtum*; top defined by numerous FADs of taxa characterizing Biozone T-13.

### BIOZONE T-13

RRZs of *Mytiloides lusatiae*, *M. problematicus*, *M. dresdensis labiatoidiformis* and *Inoceramus* sp. cf. *I. lueckendorfensis*; base defined by the FADs of *I. waltersdorfensis waltersdorfensis*, *I. waltersdorfensis hannovrensis*, *M. flegei flegei*, *M. flegei mytiloidiformis* and *M. dresdensis*; top defined by LADs of *Pleuriocardium pauperculum*, *Prionocyclus germari* and *Scaphites corvensis*.

## LOWER CONIACIAN

### BIOZONE CO-1

This high-resolution assemblage biozone spans the RRZs of, in ascending order, *Cremnoceramus? rotundatus*, *Cr.? erectus* trans. to *Cr.? rotundatus* and *Cr. erectus erectus*; base is characterized by the FADs of *Scaphites impendicostatus*, *S. mariasensis*, *S. frontierensis*, *Forresteria biancoi*, *F. peruana*, *F. hobsoni*, *Cr.? rotundatus* and *Cr.? n.* sp. cf. *Cr.? erectus*, and possibly *Pycnodonte aucella*; top is characterized by LADs of *Durania austinensis*, *Cremnoceramus erectus erectus* and *Inoceramus percostatus*. This biozone is divisible into three MCL biozones:

**Biozone CO-1A** RRZs of *Cremnoceramus? rotundatus* and *Cr.* n. sp. cf. *Cr. erectus*; top is defined by the LADs of *Mytiloides flegei mytiloidiformis*, *M. dresdensis dresdensis*, *M. flegei flegei* and *Inoceramus waltersdorfensis waltersdorfensis*.

**Biozone CO-1B** RRZ of *Cremnoceramus? erectus* trans. to *Cr.? rotundatus*; top defined by the LAD of *Inoceramus* sp. cf. *I. lueckendorfensis*.

**Biozone CO-1C** RRZs of *Cremnoceramus? erectus erectus*, *Inoceramus percostatus* and *Durania austinensis*.

### BIOZONE CO-2

This HCL biozone spans the RRZs of, in ascending order, *Cremnoceramus? erectus* n. subsp. (late form), *Cr. deformis deformis* and *Cr. deformis* (late form); base is defined by the FADs of *Cr.? erectus* n. subsp. (late form), *Cr.* n. sp. cf. *Cr. deformis*, *Didymotis* n. sp. and *Pseudoperna congesta*; top is defined by LADs of *Cr. deformis* n. subsp. (late form), *Forresteria peruana*, *F. hobsoni*, *Scaphites mariasensis* and *S. frontierensis*. This HCL biozone is divisible into three MCL biozones:

**Biozone CO-2A** RRZs of *Cremnoceramus? erectus* n. subsp. (late form) and *Cr.?* n. sp. cf. *Cr. deformis*; base defined by FADs of *Didymotis* n. sp., *Pseudoperna congesta* and (within the biozone) *Baculites mariasensis*; top defined by LAD of *Inoceramus waltersdorfensis hannovrensis*.

**Biozone CO-2B** RRZ of *Cremnoceramus deformis deformis*; base defined by FAD of *Lopha sannionis*; top defined by LAD of *Pycnodonte aucella* and *Didymotis* n. sp.

**Biozone CO-2C** RRZ of *Cremnoceramus deformis* n. subsp. (late form; Kauffman, 1977); base defined by FAD of *Cr. inconstans inconstans*; top defined by LADs of *Forresteria peruana*, *F. hobsoni*, *Scaphites mariasensis* and *S. frontierensis*.

## MIDDLE CONIACIAN

### BIOZONE CO-3

RRZs of *Scaphites preventricosus*, *Forresteria aluaudi*, *Cremnoceramus brownii* and *Cr.* sp. trans. between *Cr. deformis* and *Cr. schloenbachi*; base defined by FAD of *Lopha* n. sp. aff. *L. lugubris*; top defined by LADs of *F. biancoi*, *S. impendicostatus*, *Baculites mariasensis*, *Mytiloides problematicus* n. subsp., *L. sannionis* and *Cr. inconstans inconstans*.

### BIOZONE CO-4

RRZs of *Cremnoceramus schloenbachi schloenbachi*, *Cr. schloenbachi woodsi* (upper part of biozone) and *Volviceramus involutus* n. subsp. (early form); base defined by FADs of *Scaphites ventricosus*, *Peroniceras trinodosum*, *Baculites codyensis*, *B. asper*, *Gauthericeras* sp., *V. koeneni*, *Platyceramus* n. sp. aff. *P. platinus* (smooth form) and *Exogyra laeviscula*.

## BIOZONE CO-5

RRZs of *Cremnoceramus wandereri* and *Cr. inconstans* n. subsp. (late form); base defined by FADs of *Volviceramus involutus involutus, Platyceramus platinus* and *Pleuriocardium pauperculum jacksoni;* top defined by LADs of *Scaphites ventricosus, Peroniceras trinodosum, Gauthericeras* sp., *V. koeneni, Platyceramus* n. sp. aff. *P. platinus* (smooth form) and *V. undabundus.* This HCL biozone is divisible into two LCL biozones:

*Biozone CO-5'* At base, FADs as for Biozone CO-5; top of biozone marked by the FAD of *Mytiloides stantoni* and possibly *Volviceramus undabundus.*

*Biozone CO-5"* RRZ of *Volviceramus undabundus;* base marked by FAD of *Mytiloides stantoni;* top marked by LADs of *Scaphites ventricosus, Peroniceras trinodosum, Gauthericeras* sp., *Cremnoceramus wandereri, Cr. inconstans* n. subsp. (late form), *V. koeneni, Platyceramus* n. sp. aff. *P. platinus* (smooth form) and *Cr. inconstans* n. subsp.

## UPPER CONIACIAN

### BIOZONE CO-6

RRZs of *Scaphites depressus, Peroniceras* sp., *Phlyctricrioceras oregonense, Magadiceramus subquadratus subquadratus* and *M. austinensis;* base defined by FAD of *Mytiloides* n. sp. aff. *M. stantoni;* top defined by LADs of *Baculites codyensis, B. asper, Magadiceramus soukupi, M. subquadratus crenelatus, M.* sp. cf. *M. austinensis, M. subquadratus complicatus, M. subquadratus crenelatus* trans. to *M. subquadratus complicatus, Pleuriocardium curtum, P. pauperculum, Cardium trite, Lopha* n. sp. aff. *L. lugubris* and *Volviceramus involutus involutus.* This HCL biozone is divisible into two MCL biozones:

**Biozone CO-6A** RRZ of *Mytiloides* n. sp. A aff. *M. stantoni;* base defined by FADs as in Biozone CO-6; top defined by LAD of *M. stantoni* (near top of biozone).

**Biozone CO-6B** RRZs of *Magadiceramus soukupi, M. subquadratus crenelatus, M.* sp. aff. *M. austinensis* and *M. subquadratus crenelatus* trans. to *M. subquadratus complicatus;* top of biozone is defined by LADs of *M. subquadratus complicatus, Volviceramus involutus involutus, Lopha* n. sp. aff. *L. lugubris, Scaphites depressus, Baculites codyensis, B. asper, Peroniceras* sp. and *Phlyctricrioceras oregonense.* This biozone is divisible into two LCL biozones:

*Biozone CO-6B'* Base defined by the FADs of taxa used to define Biozone CO-6B; top defined on the FAD of *Magadiceramus subquadratus complicatus.*

*Biozone CO-6B"* Base defined on the FAD of *Magadiceramus subquadratus complicatus;* top defined on the LADs of taxa used to define top of Biozone CO-6.

## LOWER TO MIDDLE SANTONIAN

### BIOZONE S-1

A HCL biozone spanning (ascending) the ammonite RRZs of *Scaphites saxitonianus, Clioscaphites vermiformis* and *C. choteauensis;* base defined on the FADs of *C. saxitonianus, Cladoceramus undulatoplicatus, Sphenoceramus pachti pachti, S.* sp. cf. *S. lundbreckensis, Mytiloides* n. sp. B cf. *M. stantoni* and *Platyceramus cycloides;* top defined on LADs of *Clioscaphites choteauensis, Cordiceramus* n. sp. (quadrate), *C.* n. sp. aff. *C. cordiformis* and *Exogyra laeviscula.* This biozone is divisible into two MCL and six LCL biozones:

## LOWER TO LOWER MIDDLE SANTONIAN

**BIOZONE S-1A** RRZs of *Clioscaphites saxitonianus, Platyceramus cycloides, Cladoceramus undulatoplicatus* s.l. and *Sphenoceramus* sp. cf. *S. lundbreckensis;* base defined by FADs of *S. pachti pachti, Mytiloides* n. sp. B cf. *M. stantoni* and *C. undulatoplicatus undulatoplicatus;* top defined by LAD of *Pleuriocardium pauperculum jacksoni.* Biozone S-1A is divisible into four LCL biozones:

*Biozone S-1A'* RRZ of *Mytiloides* n. sp. B cf. *M. stantoni.* FADs as in Biozone S-1A define base; top is marked by the FADs of *Exogyra ponderosa* and *Cordiceramus cordiformis.*

*Biozone S-1A"* Base defined by FADs of *Exogyra ponderosa* and *Cordiceramus cordiformis;* top defined by LAD of *Cladoceramus undulatoplicatus undulatoplicatus.*

*Biozone S-1A'''* Base defined by FAD of *Cladoceramus undulatoplicatus* n. subsp.; top defined by LADs of *Clioscaphites saxitonianus* and *Pleuriocardium pauperculum jacksoni.* Top of the lower Santonian.

*Biozone S-1A''''* Basal middle Santonian; base defined by FAD of *Clioscaphites vermiformis;* top defined by LADs of *Sphenoceramus* sp. cf. *S. lundbreckensis* and *Platyceramus cycloides.*

## MIDDLE SANTONIAN

**BIOZONE S-1B** A MCL biozone which spans, in ascending order, the ammonite RRZs of *Clioscaphites vermiformis* (except earliest part) and *C. choteauensis;* RRZ of *Cordiceramus* n. sp. (quadrate); base defined by LADs of Biozone S-1A; top defined by LADs of *Clioscaphites choteauensis, Exogyra laeviscula?* and *Cordiceramus* n. sp. aff. *C. cordiformis.* This biozone is divisible into two LCL biozones:

*Biozone S-1B'* Most of RRZ of *Clioscaphites vermiformis;* base defined as in Biozone S-1B; FAD of *Cordiceramus* n. sp. (quadrate).

*Biozone S-1B"* RRZ of *Clioscaphites choteauensis* and, in upper half, RRZ of *Cordiceramus* n. sp. aff. *C. cordiformis;* top defined by LADs of *Cordiceramus* n. sp. (quadrate) and *Exogyra laeviscula?.*

## UPPER SANTONIAN

### BIOZONE S-2

A HCL biozone spanning, in ascending order, the RRZs of *Desmoscaphites erdmanni* and *D. bassleri;* base defined by FADs of *D. erdmanni, Endocostea? simpsoni, Sphenoceramus* sp. cf. *S. patootensis* and *E. baltica baltica;* top defined by the LADs of *D. bassleri, Pseudoperna congesta* and *S. digitatus.* This biozone is divisible into two MCL and two LCL biozones:

**Biozone S-2A** RRZ of *Desmoscaphites erdmanni;* base defined by FADs of *Endocostea simpsoni, Sphenoceramus* sp. cf. *S. patootensis* and *E. baltica baltica;* approximate LAD of *S. pachti pachti* near top.

**Biozone S-2B** RRZ of *Desmoscaphites bassleri;* top defined by LADs of *Pseudoperna congesta, Cladoceramus undulatoplicatus* n. subsp. and *Sphenoceramus digitatus.* Biozone S-2B is divisible into two LCL biozones:

*Biozone S-2B'* Base defined by FAD of *Desmoscaphites bassleri;* top of zone is defined by the FADs of *Sphenoceramus digitatus* and *S. lundbreckensis lundbreckensis.*

*Biozone S-2B"* RRZ of *Sphenoceramus digitatus*; base defined by FAD of *S. lundbreckensis lundbreckensis*; top defined by LADs of *Desmoscaphites bassleri, Pseudoperna congesta* and *Cladoceramus undulatoplicatus* n. subsp.

## LOWER CAMPANIAN
### BIOZONE CA-1
A HCL biozone spanning, in ascending order, the RRZs of *Scaphites leei* III, *S. hippocrepis* I and *S. hippocrepis* II of Cobban (this volume). RRZs of *Cordiceramus quadrans* n. subsp., *Sphenoceramus* n. sp. cf. *S. pachti* (with coarse ribs) and *Endocostea baltica* n. subsp. (flat form); base defined by FADs of *Scaphites leei* III, *Sphenoceramus pachti* n. subsp., *Ethmocardium whitei, Protocardia rara, Ostrea inornata* and *O. patina*; top defined by LAD of *"Inoceramus'* n. sp. aff. *"I." convexus*. This biozone is divisible into three MCL biozones:

**Biozone CA-1A** RRZ of *Scaphites leei* III and *Sphenoceramus pachti* n. subsp.; base defined by same FADs as for Biozone CA-1.

**Biozone CA-1B** RRZ of *Scaphites hippocrepis* I; base defined by FADs of *Sphenoceramus lingua* and *"Inoceramus"* n. sp. aff. *"I." convexus*; top defined by LAD of *Platyceramus platinus* s.l.

**Biozone CA-1C** RRZ of *Scaphites hippocrepis* II; base defined by FADs of *"Inoceramus"* sp. aff. *"I." purus* and *Cordiceramus?* sp. aff. *C.? haenlini*; top defined by LADs of *C. quadrans* n. subsp., *Sphenoceramus* n. sp. cf. *S. pachti* (strong ribs), *Endocostea baltica* n. subsp. (flat form) and *"I."* n. sp. aff *"I." convexus*.

### BIOZONE CA-2
A HCL biozone spanning, in ascending order, the RRZs of *Scaphites hippocrepis* III, *Baculites* sp. (smooth 1) and *Baculites* sp. (weak flank ribs) (in Cobban, this volume); base defined by the FADs of *S. hippocrepis* III, *Endocostea* n. sp. (smooth) aff. *E. typica, E. baltica* n. subsp. (highly convex) and *Thyasira quadrans quadrans*; top defined by LADs of *Baculites* sp. (weak flank ribs), *Thyasira advena advena, T. beauchampi beauchampi* and *Exogyra ponderosa*. This biozone is divisible into four MCL biozones:

**Biozone CA-2A** RRZs of *Scaphites hippocrepis* III, *Endocostea* n. sp. (smooth form) aff. *E. typica* and *Thyasira quadrans quadrans*; base defined by FADs as for Biozone CA-2; top defined by LADs of *Sphenoceramus lingua, "Inoceramus"* sp. aff. *"I." purus* and *Cordiceramus?* sp. aff. *C.? haenlini*. This biozone is divisible into two LCL biozones:

*Biozone CA-2A'* Base defined by FADs of *Scaphites hippocrepis* III, *Thyasira quadrans quadrans, Endocostea baltica* n. subsp. (convex) and *E.* n. sp. (smooth) aff. *E. typica*; top defined by LADs of *E. simpsoni* and *Sphenoceramus* sp. cf. *S. patootensis*.

*Biozone CA-2A"* The base is marked by the LADs of Biozone CA-2A'; top is marked by the LADs of *Scaphites hippocrepis* III, *Sphenoceramus lingua, "Inoceramus"* sp. aff. *"I." purus, Cordiceramus?* sp. aff. *C.? haenlini, Endocostea* n. sp. (smooth) aff. *E. typica* and *Thyasira quadrans quadrans*.

**Biozone CA-2B** Base is at FAD of *Baculites* sp. (smooth 1); top is at the LADs of *Cordiceramus cordiformis, Endocostea baltica baltica, Sphenoceramus lobatus* and *S. lundbreckensis lundbreckensis*.

**Biozone CA-2C** Base is at FADs of *Thyasira* n. sp. aff. *T. quadrans* and *"Inoceramus"* sp. aff. *"I." vancouverensis*; top is defined by LADs of *Baculites* sp. (smooth 1) and *Endocostea baltica* n. subsp. (convex).

**Biozone CA-2D** RRZs of *Baculites* sp. (weak flank ribs), *Thyasira advena advena* and *T. beauchampi beauchampi*; base is at FAD of *T. rostrata rostrata*; top is at LAD of *Exogyra ponderosa*.

## MIDDLE CAMPANIAN
### BIOZONE CA-3
This HCL biozone spans the RRZs of, in ascending order, the zonal ammonites *Baculites obtusus, B. maclearni, B. asperiformis* and *Baculites* sp. (smooth 2) (Cobban, 1962b); RRZ of *Thyasira beauchampi rex*; base defined by FADs of *B. obtusus, "Inoceramus" azerbaidjanensis* s.l., *"I." adgjakendsis* s.l., *"I." pertenuis* n. subsp., *"I."* n. sp. aff. *"I." subcircularis* (fine ribs), *"I."* sp. cf. *"I." dariensis, Platyceramus? proximus, T. rostrata cracens* and *T. quadrula quadrula*; top defined by the LAD of *Baculites* sp. (smooth 2). Biozone CA-3 is divisible into four MCL biozones:

**Biozone CA-3A** RRZs of *Baculites obtusus* and *"Inoceramus"* sp. cf. *"I." dariensis*; base defined by FADs as in Biozone CA-3. Biozone CA-3A is divisible into two LCL biozones:

*Biozone CA-3A'* FADs as in Biozone CA-3; top marked by LADs of *Ostrea inornata, Thyasira* n. sp. aff. *T. quadrans* and *T. rostrata rostrata*.

*Biozone CA-3A"* Base defined by LADs of Biozone CA-3A'; top defined by LADs of *Baculites obtusus* and *"Inoceramus"* sp. cf. *"I." dariensis*.

**Biozone CA-3B** RRZ of *Baculites maclearni*; base defined by FAD of *"Inoceramus" subcompressus* s.l.; top defined by LADs of *Ostrea russelli, "I." azerbaidjanensis* s.l. and *"I." adgjakendsis* s.l.

**Biozone CA-3C** RRZ of *Baculites asperiformis*; base defined by FAD of *Endocostea barabini* n. subsp.; top defined by LAD of *"Inoceramus" pertenuis* n. subsp.

**Biozone CA-3D** RRZ of *Baculites* sp. (smooth 2); base defined by FADs of *"Inoceramus"* n. sp. aff. *"I." pertenuis* and *"I." regularis* s.s.; top defined by LAD of *Thyasira beauchampi rex*.

### BIOZONE CA-4
A HCL biozone spanning, in ascending order, and ammonite RRZs of *Baculites perplexus* (early form; Cobban, 1962b) and *B. gilberti*; base defined by FADs of *Thyasira quadrula arrecta, Endocostea typica* n. subsp. and *"Inoceramus" pertenuis* s.l.; top defined by LADs of *B. gilberti* and *T. rostrata cracens*. Biozone CA-4 is divisible into two MCL biozones:

**Biozone CA-4A** RRZ of *Baculites perplexus* (early form); base defined by FADs as for Biozone CA-4.

**Biozone CA-4B** RRZ of *Baculites gilberti*; base defined by FADs of *Crassostrea glabra* and *C. trigonalis*. LAD of *Thyasira rostrata cracens*.

### BIOZONE CA-5
RRZs of *Baculites perplexus* (late form) and *"Inoceramus" oblongus* (early form); base defined by FADs of *"I." saskatchewanensis, "I." buguntaensis* and *"I." sublaevis*; top defined by LADs of *"I." subcompressus* s.l., *"I." regularis* s.s. and *Endocostea barabini* n. subsp.

### BIOZONE CA-6
RRZ of *Baculites gregoryensis* and *B. reduncus*; base defined by FADs of *"Inoceramus" convexus* s.s., *"I." tenuilineatus* n. subsp., *Endocostea barabini* s.l. (fine ribs), *Platyceramus? vanuxemi vanuxemi* and *Drepanochilus obesus*; top defined by LADs of *"I."* n. sp. aff. *"I." subcircularis* (fine ribs) and *Thyasira quadrula arrecta*.

## BIOZONE CA-7

RRZ of *Baculites scotti*; base defined by LAD of *"Inoceramus"* n. sp. aff. *"I." subcircularis* and *Thyasira becca becca*; top defined by LADs of *T. advena browni*, *T. triangulata* (slightly above top), *I. convexus* s.s. and *Platyceramus? proximus* s.l. This biozone is divisible into two LCL biozones:

> **Biozone CA-7'** Base defined by same FADs as Biozone CA-7; top defined by LADs of *Thyasira cantha*, *"Inoceramus" saskatchewanensis*, *"I." buguntaensis*, *"I." sublaevis* and possibly *T. becca becca*.

> **Biozone CA-7"** RRZs of *Thyasira advena browni* and *T. triangulata*; top defined by LADs of *Platyceramus? proximus* s.l. and *"Inoceramus" convexus* s.s.

## UPPER CAMPANIAN

### BIOZONE CA-8

RRZs of *Baculites pseudovatus*, *Didymoceras nebrascense*, *Endocostea typica* s.s., *E. barabini* n. subsp. and *"Inoceramus"* n. sp. aff. *"I." oblongus* (fine ribs); base defined by FADs of *"I." sp. aff. "I." turgidus*; top defined by LADs of *Platyceramus? vanuxemi vanuxemi*, *"I." tenuilineatus* n. subsp. and *Drepanochilus obesus*.

### BIOZONE CA-9

RRZs of *Baculites crickmayi*, *Didymoceras stevensoni* and (within zone) *"Inoceramus" convexus* n. subsp. (high shell); base defined by FADs of *"I." tenuilineatus* n. subsp. (low beak, umbo), *"I."* n. sp. cf. *"I." convexus*, *Platyceramus? vanuxemi* n. subsp. (coarse ribs) and *Drepanochilus nebrascensis*; top defined by the LADs of *Endocostea typica* n. subsp., *"I."* n. sp. aff. *"I." regularis* (coarse ribs) and *"I." sp. aff. "I." turgidus*.

### BIOZONE CA-10

RRZs of *Exiteloceras jenneyi*, *Endocostea typica* n. subsp. (inclined), and *"Inoceramus"* n. sp. cf. *"I." maclearni* (rounded); base marked by FADs of *"I." subcompressus* n. subsp. (smooth form) and *Cardium (Criocardium) speciosum*; top marked by LADs of *"I." tenuilineatus* n. subsp. (low beak) and *Platyceramus? vanuxemi* n. subsp. (coarse ribs).

### BIOZONE CA-11

A HCL biozone spanning, in ascending order, the ammonite RRZs of *Didymoceras cheyennense*, *Baculites compressus* and *B. cuneatus*; base marked by the FADs of *D. cheyennense*, *"Inoceramus"* n. sp. (quadrate) aff. *"I." tenuilineatus*, *"I." nebrascensis* and *Platyceramus?* n. sp. aff. *P.? vanuxemi* (rugae angular, offset); top marked by the LADs of *B. cuneatus*, *Drepanochilus nebrascensis* and *"I." balchi* n. subsp. (unequal rugae). Biozone CA-11 is divisible into three MCL biozones:

**Biozone CA-11A** RRZ of *Didymoceras cheyennense*; base marked by FADs as in Biozone CA-11. Top marked by LAD of *Endocostea barabini* s.l. (fine ribs).

**Biozone CA-11B** RRZ of *Baculites compressus*; base marked by FADs of *"Inoceramus" sagensis* and *"I."* n. sp. aff. *"I." regularis* (rounded); top marked by LAD of *Crassostrea trigonalis*.

**Biozone CA-11C** RRZs of *Baculites cuneatus* and *"Inoceramus" balchi* n. subsp. A (unequal ribs); base marked by FADs of *"I." proximus subcircularis* (variant with coarse equal rugae) and *Platyceramus?* n. sp. (large, flat, faint rugae); top marked by LAD of *Drepanochilus nebrascensis*.

### BIOZONE CA-12

RRZs of *Baculites reesidei*, *"Inoceramus"* n. sp. cf. *"I." regularis*, *"I."* n. sp. cf. *"I." adgjakendsis*, *"I." maclearni*, *"I."* n. sp. aff. *"I." pertenuis*, *"I."* n. sp. aff. *"I." maclearni*, *"I."* n. sp. cf. *"I." oblongus*, *"I." oblongus* (late form) and *Exogyra costata*; base marked by the FADs of *"I."* n. sp. cf. *"I." tenuilineatus*, *"I." furnivali*, *Endocostea typica* (rounded form) and *Drepanochilus scotti*; top

marked by the LADs of *"I." subcompressus* n. subsp. (smooth), *"I."* n. sp. A aff. *"I." pertenuis*, *"I."* n. sp. (quadrate) aff. *"I." tenuilineatus* and *"I." nebrascensis*.

### BIOZONE CA-13

RRZs of *Baculites jenseni*, *"Inoceramus" sagensis* n. subsp. (erect), *"I." furnivali* n. subsp. (rounded), *"I." balchi balchi* and *Platyceramus?* n. sp. cf. *P.? vanuxemi*; top marked by the LAD of *"I." pertenuis* s.l.

## LOWER MAASTRICHTIAN

### BIOZONE M-1

RRZs of *Baculites eliasi* and *"Inoceramus"* n. sp. B cf. *"I." pertenuis*; top is marked by LADs of *"I."* n. sp. cf. *"I." tenuilineatus*, *"I."* n. sp. cf. *"I." convexus* and *Ostrea patina*.

### BIOZONE M-2

RRZs of *Baculites baculus*, *Tenuipteria* n. sp. (smooth) and *"Inoceramus" incurvus*; base marked by FADs of *Drepanochilus evansi*, *Ostrea translucida*, *"O." pellucida*, *Protocardia subquadrata*, *Gryphaeostrea subalata* and *Lopha* n. sp.; top marked by LADs of *P. rara*, *"Inoceramus"* n. sp. (large, flat rugae), *Endocostea typica* (rounded form) and *"I." furnivali*.

### BIOZONE M-3

RRZs of *Baculites grandis*, *Tenuipteria* n. sp. (coarse plicae) and *"Inoceramus"* n. sp. cf. *"I." subcircularis*; top marked by LADs of *"I."* n. sp. aff. *"I." regularis*, *Endocostea barabini* n. subsp. (coarse ribs), *Drepanochilus scotti* and *Ethmocardium whitei*.

### BIOZONE M-4

RRZs of *Baculites clinolobatus*, *"Inoceramus" balchi* n. subsp. and *Spyridoceramus tegulatus*; top defined by the LADs of *"I." proximus subcircularis* (late form) and *Drepanochilus evansi*.

## UPPER MAASTRICHTIAN

### BIOZONE M-5

This HCL biozone spans the ammonite RRZs of, in ascending order, *Sphenodiscus pleurisepta-Hoploscaphites* sp. cf. *H. nicolleti*, *H. nicolleti* and *Discoscaphites nebrascensis*; base defined by FADs of *S. pleurisepta*, *H.* sp. cf. *H. nicolleti*, *"Inoceramus"* n. sp. B aff. *"I." pertenuis*, *Spyridoceramus* sp. aff. *S. tegulatus* and *Tenuipteria* n. sp. (smooth); top defined by LADs of *D. nebrascensis*, *Crassostrea glabra*, *Cardium (Criocardium) speciosum*, *"Ostrea" pellucida*, *Protocardia subquadrata*, *Gryphaeostrea subalata*, *Lopha* n. sp., *T. fibrosa* and *Crassostrea subtrigonalis*. Biozone M-5 can be subdivided into three MCL biozones:

**Biozone M-5A** RRZs of *Sphenodiscus pleurisepta*, *Hoploscaphites* sp. cf. *H. nicolleti* and *"Inoceramus"* n. sp. B cf. *"I." pertenuis*; base defined by the FADs of *Spyridoceramus* n. sp. aff. *S. tegulatus* and *Tenuipteria* n. sp. (smooth).

**Biozone M-5B** RRZs of *Hoploscaphites nicolleti* and *Tenuipteria* n. sp. (unnoded); base defined by the FADs of *T. fibrosa* and *Crassostrea subtrigonalis*; top defined by the LADs of *Spyridoceramus* n. sp. aff. *S. tegulatus*, *Ostrea translucida* and *Tenuipteria* n. sp. (smooth).

**Biozone M-5C** RRZ of *Discoscaphites nebrascensis*; top defined by eight LADs as listed for the top of Biozone M-5.

### BIOZONE M-6

Characterized by *Triceratops* and associated terrestrial biotas.