Non-marine Cretaceous biostratigraphy and biochronology

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The Cretaceous saw fundamental changes in the nonmarine ecosystem with the origin and/or rise of major clades, including flowering plants, social insects, derived dinosaurs (hadrosaurids, ceratopsids, tyrannosaurids), birds and therian mammals. The rocks that yield this fossil record are widespread and occur on every continent and often contain significant economic resources, notably coal and gas. There is a long and voluminous literature on the correlation of the non-marine Cretaceous that utilizes many taxonomic groups, from pollen to dinosaurs. However, the diverging continents produced provincialization of non-marine biotas that makes global correlations challenging.

Sha Jin-geng of the Nanjing Institute of Geology and Palaeontology and Spencer G. Lucas of the New Mexico Museum of Natural History and Science have edited an important new volume that addresses diverse issues in Cretaceous non-marine biostratigraphy and biochronology. This volume is an issue of the Chinese *Journal of Stratigraphy* (*Dicengxue Zazhi*) which is available from the China International Book Trading Company, PO Box 399, Beijing 100044, China.

The volume includes 22 contributed articles and a detailed introductory essay by the editors. The introduction is a very useful contribution that contains a concise but elegant synopsis of the Cretaceous world and its timescale. Sha and Lucas conclude the introduction by identifying six ways to further multidisciplinary approaches to resolve problems of non-marine Cretaceous chronology and correlation: (1) identify marine and non-marine fossils in marine, alternating marine and non-marine Cretaceous strata; (2) utilize the high-resolution of microfossil assemblages/zonations to precisely subdivide, correlate and date non-marine Cretaceous strata; (3) precisely and successively measure radioisotopic ages of interbedded datable

volcanic and volcanoclastic rocks to constrain the age of the associated sedimentary rocks/fossils; (4) develop more magnetostratigraphy in direct relationship to non-marine biostratigraphy; (5) concentrate more on the recognition of depositional systems and subsystems and their fluctuation in space and time to facilitate a high-resolution sequence stratigraphic analysis of marginal and continental deposits; and (6) increase use of chemostratigraphy and isotopes for correlation of Cretaceous non-marine deposits. The remaining papers in the volume address nonmarine Cretaceous biostratigraphy, biochronology and correlation using spore-pollen, megafossil plants, ostracods, conchostracans, non-marine molluscs and vertebrates.

The first six papers are concerned with spore-pollen. Vajda and Berocovici and Berocovici, Vajda and Sweet provide two papers that review pollen and spore stratigraphy of the Cretaceous-Palaeogene mass-extinction interval in the Southern and the Northern hemispheres, respectively. Each paper is less than a dozen pages long but provides a good overview of the fossil record in the hemisphere and identifies areas that need additional study. The best studied palynological record is in North America, only 2000 to 5400 km from the Chicxulub impact crater, and in general there is a need to better understand the consequences of this event in more distant locations.

Two contributions address the palynostratigraphy of West Siberia. Pestchevitskaya, Smokotina and Baykalova review the early Valanginian palaeoenvironments and vegetation of coastal and continental areas in southeastern West Siberia and note that the palynomorphs exhibit typical features of both the Indo-European and the Siberian-Canadian palaeofloristic provinces. Lebedeva and Pestchevitskaya provide a broader context and establish a reference succession of Cretaceous pollen and spores in western Siberia using palynomorphs from marine sections to calibrate to ammonite zones.

Prámparo evaluates the palynostratigraphy of the important Cretaceous non-marine basins of Argentina and evaluates palynozones. There is obviously a need for additional work, notably in the Late Cretaceous, but this paper provides a good overview of the current state of knowledge.

Dinoflagellates have been recognized in non-marine Cretaceous strata in the past 30 years but principally only in England, China and Australia. Chen and He focus on non-

marine dinoflagellate assemblages from China and also review the fossil record in southern England and southwestern Australia. Dinoflagellates clearly have potential importance in biostratigraphy and paleo-environmental reconstruction (notably paleosalinity).

There is only one contribution on megafossil plants, but it is a very useful review of Cretaceous floras of China by Deng, Lu, Fan, Li, Fang and Liu. The extensive early Cretaceous record and its biostratigraphy are discussed in detail, and the sparse Late Cretaceous floras are also reviewed.

Two very different papers in the volume address ostracods and their potential in biostratigraphy and biochronology. Sames and Horne's stimulating contribution is entitled "Latest Jurassic to Cretaceous non-marine ostracod biostratigraphy: unde venis, quo vadis?" Essentially, ostracods have acknowledged utility in regional correlations but their use in supraregional biostratigraphy has been doubted. Sames and Horne enthusiastically argue that global correlations using non-marine ostracods are feasible given both a more conservative approach to taxonomy and an awareness of paleoenvironmental factors. Essential to this goal is an appreciation of the fact that many non-marine ostracod groups are not restricted to individual water bodies or small geographical regions. Sames and Horne acknowledge that there is much work to be done but they foresee "the dawn of a new late Jurassic to Cretaceous non-marine ostracod biostratigraphy." There is an extensive record of Cretaceous non-marine ostracods in China, and Wang, Sha, Pan, Zhang and Rao provide a good preliminary review of the assemblages and their correlation. This is a very useful review of a voluminous literature.

Chen reviews the Cretaceous conchostracan record in China. The extensive faunas undoubtedly require some taxonomic revision as Chen notes (e.g., the *Eosestheria* and *Euestherites* faunas each have more than 100 species!) but they provide an apparently significant biostratigraphy.

It is gratifying to see that non-marine molluscs receive significant recognition in this volume, with five papers. The diverse European record is almost entirely from the Early Cretaceous and is reviewed by Munt, Delvene and Sha. They describe how a distinctive European freshwater mollusc community had developed by the Barremian. Japan has an extensive record of Early Cretaceous non-marine molluscs that is

reviewed by Kozai, Ishida and Hirsch. Marine intertongues provide accurate age constraints and allow for the recognition of four successive faunas. This paper is notable in the volume for having five photographic plates.

Pan examines Cretaceous non-marine gastropod assemblages from China and distinguishes four principal assemblages. Two of these assemblages may be divisible on the basis of geography or stratigraphy. Sha, Pan, Wang, Zhang and Rao utilize molluscs and radiometric dating to correlate Lower Cretaceous non-marine and marine units in northeastern China, southeastern Korea and southwestern Japan. They date the Longzhaogou, Jixi and Jehol groups and overlying Huashan Group and Sunjiawan Formation of northeastern China, Sindong Group and lower Hayang Group of southeastern Korea, and Tetori and Monobegawa groups of southwestern Japan as Hauterivian–Albian. This conclusion is based on the work of Sha (2007) who correlated the non-marine and marine Cretaceous strata in northeast China and Inner Mongolia. Sha, Pan, Wang, Zhang and Rao conclude that the three areas (northeastern China, southeastern Korea and southwestern Japan) were connected in the Hauterivian–Albian and formed part of the same fluvial system. Cretaceous sedimentary rocks in Thailand, Laos and Vietnam are almost entirely non-marine in origin. Sha, Meesook and Nguyen utilize molluscs (and palynomorphs and dinosaurs) to correlate the Barremian–Maastrichtian of this region.

The volume contains six papers with impressive geographic spread on vertebrate fossils, three on osseous faunas, one on footprints and two on eggs. LeLoueff, Lang, Cavin and Buffetaut provide a useful review of the Early Cretaceous dinosaur-dominated faunas of Africa and identify four successive assemblages: (1) Late Jurassic (Kimmeridgian–Tithonian) to earliest Cretaceous (Valanginian) assemblage with stegosaurids, brachiosaurids and diplodocids; (2) Hauterivian–Barremian? assemblage with baryonychine spinosaurids, the pholidosaurid crocodile *Sarcosuchus*, large iguanodontids and the shark *Priohybodus arambourgi*; (3) Aptian? to early Albian assemblage that

still includes iguanodontids but in which spinosaurine spinosaurids replace baryonychines; and (4) an early Cenomanian assemblage characterized by the association of dinosaurs (*Spinosaurus*, *Carcharodontosaurus*), sharks (*Onchopristis numidus*) and crocodyles (libycosuchids, stomatosuchids).

The non-marine vertebrate faunas of Central Asia (Gobi of Mongolia, Inner Mongolia of China) are relatively well known but those of Middle Asia (Uzbekistan, Kazakstan, Kyrgyzstan) are much less studied. Averianov and Sues assess the relative stratigraphic positions and ages of the Late Cretaceous assemblages from these areas by means of parsimony analysis of 26 proposed biostratigraphic marker taxa.

The development of the Cretaceous vertebrate biochronology of the Western Interior of North America began in the 1890s. Lucas, Sullivan and Spielmann review and revise the vertebrate biochronology of the Cretaceous of this region by redefining and defining (new Fencelakean) 10 land-vertebrate “ages” to encompass all of Cretaceous time in the Western Interior, which are (from oldest to youngest) – Comobluffian (~Tithonian–Hauterivian), Buffalogapian (~Barremian–early Aptian), Cashenranchian (~early Aptian–late Albian), Mussentuchian (~late Albian–Cenomanian), Fencelakean (~Turonian–late Santonian), Aquilan (~late Santonian–early Campanian), Judithian (~middle Campanian), Kirtlandian (~late Campanian), Edmontonian (~latest Campanian–early Maastrichtian) and Lancian (~late Maastrichtian). This important paper thus represents the culmination of the refinement of a vertebrate-based non-marine biochronology for a region that includes significant dinosaur (and other vertebrate) faunas.

Lockley, Lucas, Matsukawa and Harris examine the global record of Cretaceous tetrapod footprints in detail and their article includes an immense bibliography. They confirm the earlier hypothesis of Lucas (2007) that there are essentially only two global Cretaceous footprint biochrons: (1) Early Cretaceous characterized by sauropod and ornithomimid tracks; (2) Late Cretaceous that has fewer sauropod tracks and tracks of hadrosaurs, tyrannosaurids and ceratopsians.

However, they also suggest that the Cretaceous footprint record of Asia may allow for the recognition of three or four Cretaceous footprint provincial biochrons.

Dinosaur eggs are notably abundant and widely distributed in China. Wang, Wang, Jiang, Cheng, Zhang, Zhao and Jiang provide a very useful overview of the record of Cretaceous eggs in China. They review the ages of the main egg-producing basins in China and also provide a useful synopsis of dinosaur egg assemblages from other countries. Lucas, Bray, Emry and Hirsch use dinosaur eggs on a more local scale, in combination with plant-based biostratigraphy, to place the Cretaceous–Tertiary boundary in the Zaysan Basin of eastern Kazakstan. They document a stratigraphic succession of Late Cretaceous (Maastrichtian?) dinosaur eggshell overlain by late? Paleocene paleoflora capped by middle Eocene mammals.

Overall Sha and Lucas have produced a very important volume. Even though this is a Chinese publication there is an impressive geographic spread in the articles, covering every continent. The diversity of taxonomic coverage is also laudable, representing the majority of important Cretaceous non-marine taxa, from pollen to dinosaurs. Furthermore, the majority of the articles are high level reviews and thus this volume represents a synopsis of an enormous amount of primary literature. This volume is a landmark contribution to global non-marine Cretaceous chronology and is a must read for all students of the Cretaceous.

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