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High-resolution calcareous nannofossil biostratigraphy of the Santonian/Campanian Stage boundary, Western Interior Basin, USA

Zachary A. Kita [a, *], David K. Watkins [a], Bradley B. Sageman [b]

[a] Department of Earth and Atmospheric Sciences, University of Nebraska, Lincoln, NE 68588, USA
[b] Department of Earth and Planetary Sciences, Northwestern University, Evanston, IL 60208, USA

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ABSTRACT

The base of the Campanian Stage does not have a ratified Global Stratotype Section and Point (GSSP); however, several potential boundary markers have been proposed including the base of the *Scaphites leei* III ammonite Zone and the base of the paleomagnetic Chron C33r. Calcareous nannofossil assemblages from the Smoky Hill Member of the Niobrara Formation in the central Western Interior Seaway, USA were analyzed from two localities to determine relevant biohorizons and their relationships to these potential boundary markers. In a previous study, the Aristocrat Angus 12-8 core (Colorado) was astrochronologically dated and constrained using macrofossil zonations and radiometric ages. The Smoky Hill Member type area (Kansas) provides an expanded interval with good to excellent nannofossil preservation.

Five biohorizons are useful for recognition of the Santonian/Campanian transition within the Smoky Hill Member type area, and three are useful in the Aristocrat Angus 12-8 core. The first occurrences (FOs) of *Aspidolithus parcus parcus* and *Aspidolithus parcus constrictus*, as well as the last occurrences (LOs) of *Zeugrhabdotus moulladei*, *Helicolithus trabeculatus* specimens larger than 7 μm, and *Zeugrhabdotus biperforatus* are in close stratigraphic proximity to the base of the *Scaphites leei* III Zone and the base of Chron C33r.

1. Introduction

Since the naming of the Campanian Stage by Coquan in 1857, the definition of its base has been debated. There is currently no ratified marker or Global Boundary Stratotype Section and Point (GSSP) for the base of the Campanian Stage (Ogg and Hinnov, 2012). Several markers have been proposed including paleomagnetic chrons, ammonite zones, isotope excursions, calcareous nannofossils bioevents, and other macrofossil events. The authors of this study follow the definition of the Santonian/Campanian Stage boundary used by Ogg and Hinnov (2012), which is the base of the paleomagnetic Chron C33r.

The Upper Cretaceous Niobrara Formation of the North American Western Interior Basin contains diverse and well-preserved calcareous nannofossil assemblages. Two Niobrara Formation sections were utilized for biostratigraphic analyses (Fig. 1). The Aristocrat Angus 12-8 core from Weld County, Colorado was previously examined for stable isotopes (Joo and Sageman, 2014) and placed within a chronostratigraphic framework using cyclostratigraphy, macrofossils, and radiometric ages (Locklair and Sageman, 2008; Sageman et al., 2014). Paleomagnetic data are not available from this core, so the base of the *Scaphites leei* III ammonite zone has been used as the base of the Campanian (Joo and Sageman, 2014; Sageman et al., 2014). Preservation of nannofossils in this core is poor and chalk intervals directly above the base of the Campanian were not recovered. The Smoky Hill Member of the Niobrara Formation in its type area in northwestern Kansas was also sampled. The study interval spans the upper Santonian to lower Campanian and contains well-preserved calcareous nannofossils. Biostratigraphic data collected from the Smoky Hill Member type area and the Aristocrat Angus 12-8 core samples were used to create a new, high-resolution biostratigraphic framework for the Santonian/Campanian Stage boundary (Fig. 2).

2. Materials and methods

Localities 20, 24, 25, and 21 of the Smoky Hill Member type area (Hattin, 1982; Fig. 3) in Kansas were collected at 10 cm intervals in

* Corresponding author.
E-mail address: zkita@huskers.unl.edu (Z.A. Kita).

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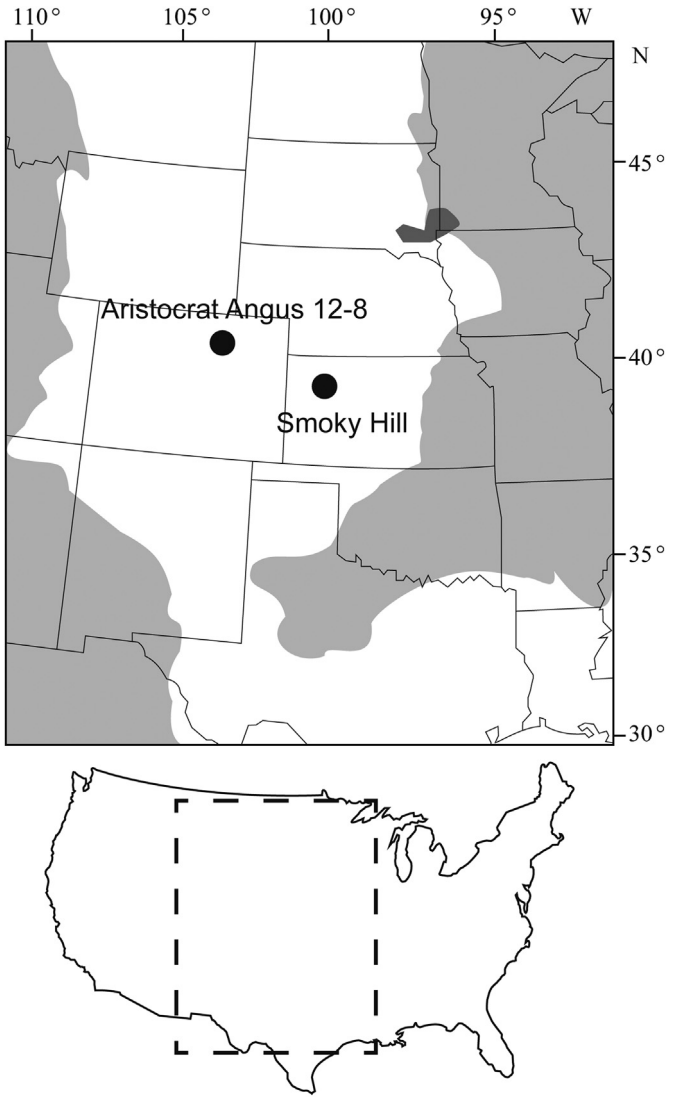

Fig. 1. Study section area for the Santonian/Campanian boundary. Extent of Western Interior Seaway (white) and land (gray) modified from Blakey (2015).

2000. Samples for this study were prepared at approximately 1.0 m intervals, while the Aristocrat Angus 12-8 core was sampled at 60 cm intervals, yielding a total of 53 and 17 samples, respectively.

Smear slides were prepared from outcrop and core sediments using the double slurry method detailed by Watkins and Bergen (2003). Calcareous nannofossils were observed using an Olympus BX 51 microscope at total magnification of 1250× using cross-polarized light, plane polarized light, phase contrast, and a one-quarter λ gypsum plate. Photomicrographs were taken using an Olympus DP71 camera. Whole coccoliths and fragments greater than half the original size were counted. The cascading counting technique of Styzen (1997) was used to collect assemblage data for the Smoky Hill Member type area. Total counts of relevant taxa were then converted to percent relative abundances to limit the bias of sample thickness and for comparison with previously published data. Only presence/absence data were collected from the Aristocrat Angus 12-8 core due to poor preservation and low nannofossil abundance.

3. Santonian/Campanian Stage boundary

3.1. Definition of the Santonian/Campanian Stage boundary

The Campanian Stage was named by Coquand (1857) after the hillside exposures of Grande Champagne near Aubeterresur-Dronne (northern Aquitaine province, France), but due to changes in stratigraphic definitions, the bulk of the type "Campanian" at Aubeterre is currently classified as Maastrichtian (van Hinte, 1965; Séronie-Vivien, 1972). No clear base was documented in the lower portion of the Aubeterre section, therefore preventing designation of a lower Campanian boundary.

The base of the Campanian was placed at the first occurrence (FO) of the ammonoid *Placenticeras bidorsatum* by de Grossouvre (1901); however, due to its rarity and geographic limitation to northwest Europe, the FO of *P. bidorsatum* was later deemed impractical for use as a boundary marker event (Hancock and Gale, 1996). The extinction of the crinoid *Marsupites testudinarius* is synchronous with the FO of *Placenticeras bidorsatum*, which has led to the use of the extinction of *M. testudinarius* as a provisional boundary marker for the base of the Campanian (Hancock and Gale, 1996; Gale et al., 2008). *Marsupites testudinarius* appears to be restricted to shelf environments and thus should not be used as a global marker. In the Western Interior Seaway, the base of the Campanian has been correlated to the base of the *Scaphites leei* III ammonite Zone (e.g., Cobban et al., 2006). Unfortunately, several of the ammonites used in the Western Interior Seaway zonal scheme are not distributed worldwide. Therefore, the Campanian Working Group of the International Commission on Stratigraphy is considering using the base of the paleomagnetic Chron C33r as the primary criterion for the base of the Campanian, thereby enabling global recognition in pelagic, continental, and other non-shallow-marine settings (Ogg and Hinnov, 2012) when magnetostratigraphy is available.

While no boundary stratotype has been ratified for the Santonian/Campanian boundary, two have been proposed. The Waxahachie dam spillway section (north central Texas) could be a candidate if the extinction of *M. testudinarius* is selected for the boundary based on the multidisciplinary study by Gale et al. (2008). If the base of Chron C33r is chosen as the boundary marker, the Gubbio section in Italy could be selected as the stratotype because of its compilation of biostratigraphy and magnetostratigraphy (e.g., Lowrie and Alvarez, 1977; Tremolada, 2002; Gardin et al., 2001).

3.2. Calcareous nannofossil proxies for the Santonian/Campanian Boundary

Calcareous nannofossil biohorizons have been utilized as proxies for stage boundaries due to the cosmopolitan distribution and high abundance of nannofossils in marine sediments. Currently, published nannofossil zonation schemes exhibit uncertainty in markers for the Santonian/Campanian Stage boundary (Fig. 2).

In 1977, Sissingh first published a cosmopolitan calcareous nannofossil zonation scheme for the Cretaceous with 26 zones based largely on low-to middle-latitude outcrop sections. Perch-Nielsen (1985) revised Sissingh's zonation scheme and increased resolution through the addition of subzones. She determined that the FO of *Aspidolithus parcus parcus* (base of Zone CC18) marked the base of the Campanian (Fig. 2).

Shortly after Sissingh published his cosmopolitan zonation based on outcrop, Roth (1978) published a cosmopolitan zonation scheme created from deep-sea sections. In this scheme, the