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Calcareous nannofossils from the Niobrara Formation (Upper Cretaceous) and paleoenvironments of the North American Western Interior Basin

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CALCAREOUS NANNOFOSSILS FROM THE NIOBRARA FORMATION (UPPER CRETACEOUS) AND PALEOENVIRONMENTS OF THE NORTH AMERICAN WESTERN INTERIOR BASIN

by

Huaibao Liu

A DISSERTATION

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DISSERTATION TITLE

The Calcareous Nannofossils from the Niobrara Formation (Upper Cretaceous)

and the Paleoenvironments of the North American Western Interior Basin

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I. INTRODUCTION

1. The Western Interior Basin

The Late Cretaceous Western Interior Basin was a huge foreland basin east of the Rocky Mountains in North America. It was flooded from the Aptian to the Maastrichtian and formed a broad interior seaway. During its maximum development, the interior basin extended from Arctic Canada down to the Gulf of Mexico, a distance about 5,000 km. The width (west to east) of the interior basin is more than 1,600 km, that is from southwestern Utah and northeastern Nevada as far as to Iowa and southwestern Minnesota (Kauffman, 1977; Fig. 1). The Western Interior Basin accumulated up to 6,000 m of marine sediments (Einsele, 1992).

The lithology and thickness of these sediments vary markedly as a result of differing tectonic regimes and water depths (King, 1959; Kauffman, 1977). The interior seaway filled a west to east asymmetrical basin as shown in Figure 2. Four zones were named by Kauffman (1977), based upon structures and depositional environments: (1) the maximum subsidence zone; (2) high subsidence zone; (3) "hinge zone"; and (4) stable eastern platform zone.

The western margin of the basin was tectonically active along the Sevier orogenic belt during the Late Cretaceous. More than 3,000 m of coarse-grained sediments were deposited in these shallow marine environments. Toward the east, the sediment grain size became finer, and the strata correspondingly thinner.

The Western Interior Basin experienced five major and numerous minor transgressive-regressive cycles. Hays and Pitman (1973) suggested that the Upper Cretaceous in the Western Interior Basin was deposited in a single large Late Cretaceous transgression with lesser fluctuations. Kauffman (1973, 1977) reported that the major Late Cretaceous transgression consisted of several subordinate transgressive-

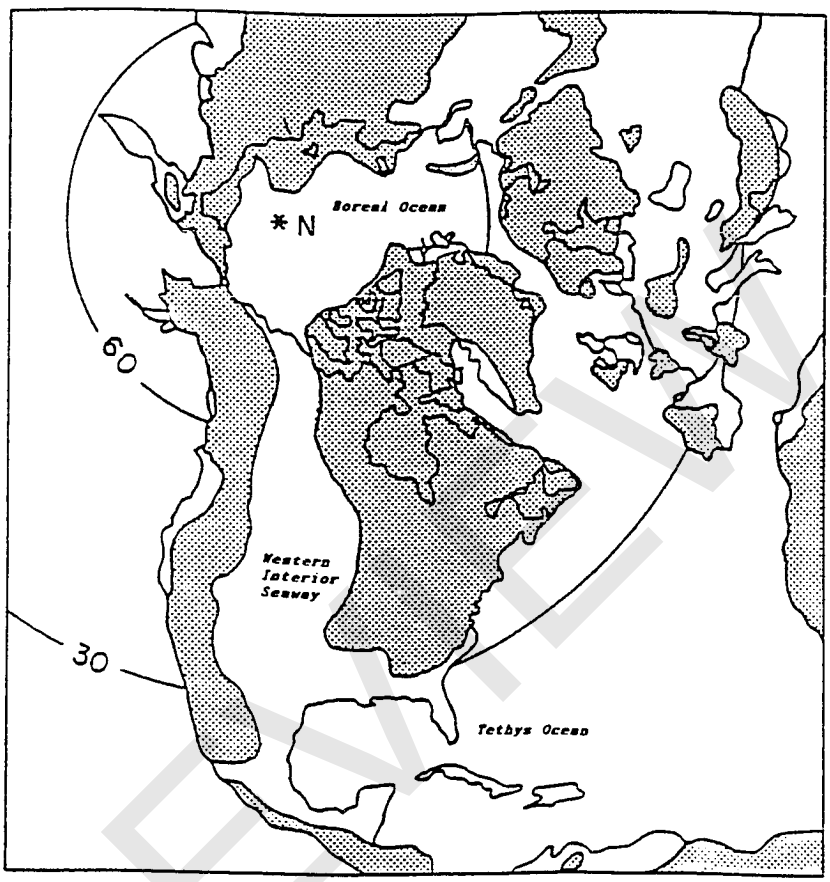

Fig. 1: Geographic distribution of the North American Western Interior Basin near peak transgression in the Late Cretaceous. (from Eicher & Diner, 1989)

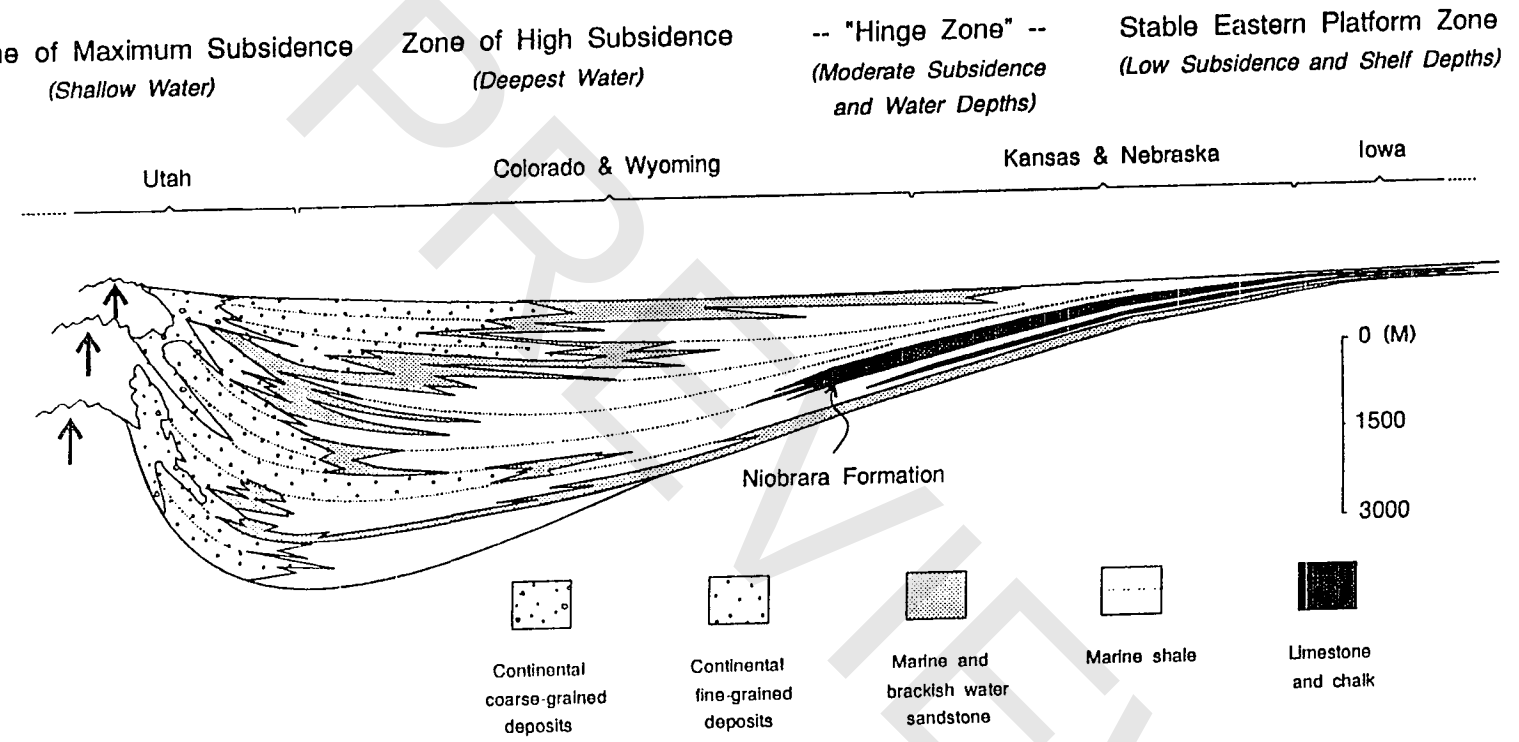

Fig. 2: Generalized cross section through the Cretaceous Western Interior Basin and sedimentary sequence between Utah and Iowa (adapted from Kauffman, 1977).

regressive cycles (Fig. 3). As a result of the two largest marine transgressions, two carbonate beds (theGreenhorn Limestone and the Niobrara Formation) were deposited along the eastern side of the interior basin. This dissertation is on the Niobrara Formation, particularly on calcareous nannofossils, nannofossil biostratigraphy, and depositional environments within the Western Interior Basin.

The Niobrara Formation has attracted geologists' attention for more than 100 years because it is rich in well-preserved vertebrate and invertebrate fossils. Since the middle of last century, several hundred articles about the Niobrara Formation and its fossils have been published. Recently, it has been shown that these chalk beds serve as a source rock for both oil and fractured reservoirs (e.g. Hinds & Berg, 1990). The history of the interior basin is also an important indicator for Cretaceous tectonic evolution, history of eustatic and epeirogenic motion, and global paleoclimate change. This dissertation focuses on Late Cretaceous paleoenvironments of the Western Interior Basin based on data provided by calcareous nannofossils from the Niobrara Formation.

2. Calcareous Nannofossils

Calcareous nannofossils are a group of low-magnesium calcite fossils, known only in marine environments. The majority of these objects contain diagnostic skeletal features that allow them to be classified with the planktonic Coccolithophyceae, a class of the algal Division Haptophyta. The individual circular to oval skeletal elements (coccoliths) articulate by means of a tongue and groove arrangement to form a complete hollow sphere (coccosphere). When they are preserved as fossils, coccospheres are usually disaggregated into coccoliths. The size of a single coccolith ranges from approximately 2-20 μm.

Calcareous nannoplankton occur in significant numbers of individuals in certain marine environments. As one of the most important primary producers in oceanic food

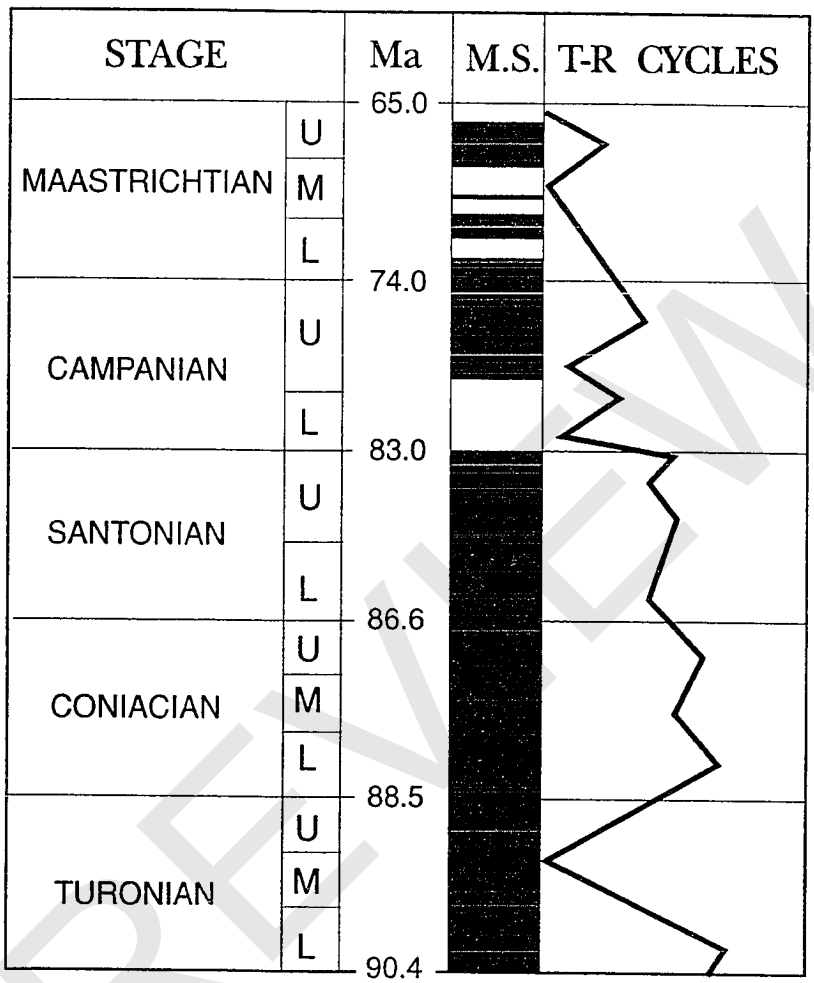

Fig. 3: The transgression-regression pattern in the Late Cretaceous (Turonian through Maastrichtian).

The age (Ma) and magnetic polarity (M.S.) data are from Harland and others (1990). The transgression-regression pattern (T-R Cycles) is from Kauffman (1977).

chain, nannoplankton are eaten by zooplankton, and then transported to the ocean bottom in fecal pellets (Honjo, 1976). Since they are covered by an organic pellicle with which the zooplankton (such as copepods) encase their fecal pellets, the coccoliths are protected from chemical attack and are easily preserved as fossils.

These tiny nannofossils are valuable for biostratigraphic study because of their rapid evolution. They also yield information about marine paleoenvironments because they are sensitive to changing environmental conditions, such as water temperature, nutrient, and salinity variations. Based upon the fossil data from Deep Sea Drilling Project (DSDP) and European continental sections, 59 standard Cenozoic nannofossil zones (and subzones) (Okada & Bukry, 1980) and 36 standard Cretaceous coccolith zones (CC zones) (Sissingh, 1977) are employed in nannofossil biostratigraphy. Several nannofossil species are also known from particularly restricted environments.

Calcareous nannofossils have been known from the Western Interior Basin for more than a century. Dawson (1874) first reported calcareous nannofossils in the Boyne Formation of the Manitoba Escarpment. Subsequent reports of calcareous nannofossils from the Upper Cretaceous chalks in Kansas (Bunn, in Patrick 1883; Williston, 1890; McClung, 1898) and Minnesota (Woodward & Thomas, 1895) indicated their widespread distribution in the chalk facies in the eastern part of the basin. More recently, it has been found that the Niobrara Formation consists mostly of calcareous nannofossils, including some unusually well preserved coccospheres and "coccocylinders" (Fig. 4) termed by Covington (1985).

Calcareous nannofossils were first used for biostratigraphy purpose in the Western Interior Basin by Trexler (1967) from the Greenhorn and Niobrara cyclothems of central Colorado and the Black Hills (Wyoming and South Dakota). Although Trexler's (1967) work demonstrated the general stratigraphic distribution of calcareous nannofossils in the Niobrara Formation, the taxonomy cannot be reconciled with

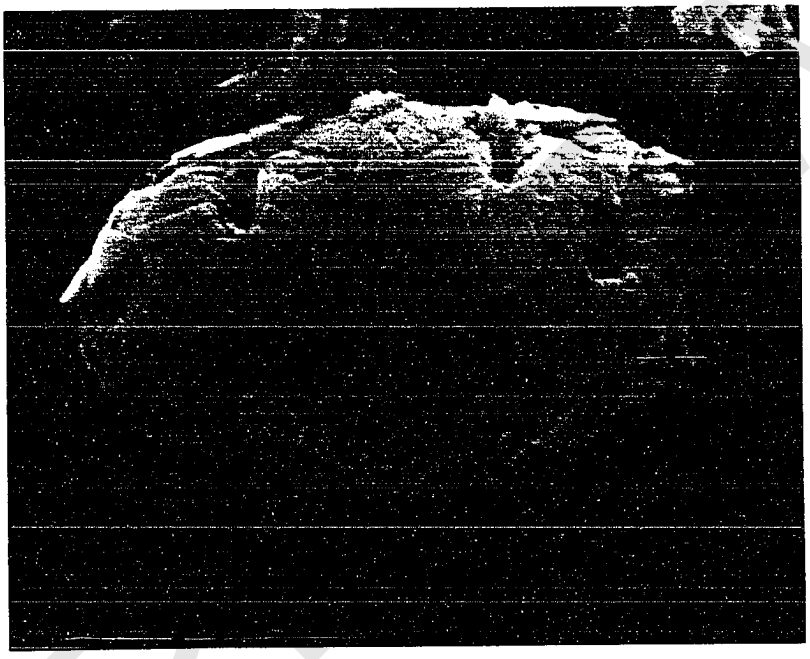

Fig. 4: SEM photograph of a well-preserved "Coccocylinder" from the Niobrara Formation, western Kansas (X10,000).

modern taxonomic concepts. Bukry (1969) described some nannofossil species from the Upper Cretaceous chalks in Texas, but the stratigraphic placement of these samples is impossible to ascertain. Covington (1985, 1986) first investigated the nannofossils from the type area of the Smoky Hill Chalk Member (western Kansas), with extensive scanning electron microscopy. Since the sample spacing varied widely (between 1 and more than 14 meters), his studies are useful only to indicate the general biostratigraphic succession.

3. The Purpose of this Study

Detailed documentation of calcareous nannofossil assemblages, biostratigraphic zonation, correlation with invertebrate fossil zones and with the standard Cretaceous coccolith zones (CC zones) in the Western Interior Basin warranted further study. The present research fills this gap by providing detailed nannofossil systematic treatment and paleoecological analysis.

The following goals are included in this study:

1. document the Upper Cretaceous calcareous nannofossil assemblages and their biostratigraphic distributions in the Niobrara Formation;

2. correlate nannofossil assemblages of the interior basin with the standard Cretaceous coccolith zones and (where possible) invertebrate zones;

3. examine the latitudinal variation of nannofossil assemblages within the basin, and investigate possible sources for the variation; and

4. examine and reconstruct paleoenvironments of the Western Interior Basin based upon nannofossil data from the Niobrara Formation.

II. LOCALITIES AND SAMPLES

In order to examine the latitudinal variation of sediment and calcareous nannofossil assemblages through the Western Interior Basin, four sections were chosen for this study: the Smoky Hills area of western Kansas, and the Miner, Iroquois, and Sisseton sections in eastern South Dakota (Fig. 5).

The study area in western Kansas is the Smoky Hill Member type area. The Niobrara Formation in this area is not a continuous section but was measured at 12 outcrops by Hattin (1982). Correlation between adjacent sections was facilitated by marker units. The localities of the 12 sections in the Smoky Hills area of Kansas are shown in Figure 6 and the locality of each section is shown in Table 1.

Samples from the Smoky Hills area were collected by Drs. D. K. Watkins and M. A. Holmes in the early 1980's, following the section measured by Hattin (1982). The samples for nannofossil study were collected with sample interval of 1 meter. A total of more than 200 samples were collected from the 12 sections in western Kansas.

The three locations in eastern South Dakota (Fig. 5) are stratigraphic core samples collected by the South Dakota Geological Survey. Since the Niobrara Formation is much thinner in South Dakota than in western Kansas, the sampling interval varies between 10 and 60 cm, depending on the lithology and thickness of the Niobrara Formation. A total of 71 samples were examined from the Miner County core, 74 from the Iroquois core, and 24 from the Sisseton core.