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Internationally recognised index macro- and microfossils used to define the Upper Cretaceous stages boundary

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Abstract

The Cretaceous system (145-66 Ma) in the history of the Earth can be divided into two series, which are the Lower Cretaceous and the Upper Cretaceous. The Upper Cretaceous can be divided into six stages (Cenomanian, Turonian, Coniacian, Santonian, Campanian and Maastrichtian). The boundaries between some of the Upper Cretaceous stages are now well defined in different localities in the world especially in Europe. The Upper Cretaceous stages boundaries were primarily defined by ammonites, inoceramid bivalves, belemnites, crinoids and in some cases planktonic foraminifera as well. At the moment four out of the six Upper Cretaceous stages boundaries are now formally ratified as the Global Boundary Stratotype Section and Point (GSSP). The formally ratified GSSP boundaries which are approved by the International Union of Geological Sciences are (Cenomanian, Turonian, Santonian and Maastrichtian).

Due to relatively rare of ammonoid groups in the Cenomanian, therefore, the base of the Cenomanian Stage can be defined by the lowest occurrence of the planktonic foraminifera *Thalmanninella globotruncanoides.* After considering several potential placements, the Turonian Working Group placed the base of the ammonite *Watinoceras devonense* for the base of the Turonian Stage. The sudden turnover from *Magadiceramus* inoceramid bivalves to the lowest occurrence of the widespread inoceramid *Platyceramus undulatoplicatus* has been selected as the marker for the base of the Santonian. The Maastrichtian Working Group recommended the base of the Maastrichtian to be assigned as the lowest occurrence of ammonoid *Pachydiscus neubergicus* that has a much wider geographic distribution than belemnite *Belemnella lanceolata*.

Introduction

The Cretaceous System is divided into two rock series, Lower and Upper, which correspond to units of time known as the Early Cretaceous Epoch (145 to 100.5 million years ago) and the Late Cretaceous Epoch (100.5 to 66 million years ago) [1].

Both the Early and the Late Cretaceous epochs are divided into six ages of variable length. Their definition was originated during the mid- to late 1800s, when geologists working in France, Belgium, Netherlands, and Switzerland documented and named the 12 consistent rock stages [2]. Each of the stages is defined by rocks, sediments, and fossils found at a specific locality called the type area. For instance, d'Orbigny defined the Cenomanian Stage in Le Mans, northern France in 1847, based on some 847 fossil species distinguishing the strata [2]. For the Lower Cretaceous series the stages are the Berriasian, Valanginian, Hauterivian, Barremian, Aptian, and Albian [1], (Figure. 1). For the Upper Cretaceous they are

the Cenomanian, Turonian, Coniacian, Santonian, Campanian, and Maastrichtian [1], (Figure. 1). The longest is the Aptian, lasting more than 12 million years; the Santonian is the shortest at just under 3 million years [1], (Figure. 1).

Since the origination of the 12 Cretaceous stages (Figure. 1), geologists have worked to solve problems caused by incompleteness of the stratigraphic record and fossils in type areas. Researchers meet periodically to discuss problems of stage boundaries and to suggest solutions. In 1983 a group of geologists from around the world met in Copenhagen, Denmark, and recommended that alternative type areas be elected for all the stage boundaries mentioned above. They agreed that the most practical way to define a stage is by the base of the earliest biozone at a boundary type area. Conventionally, ammonites have been used to define biozones within the type area of Cretaceous stages, but other organisms, such as inoceramid bivalves, belemnites, crinoids, and even planktonic foraminifera are sometimes used [3-15]. The objectives of this study are: 1) to collect and present all previous published data that define the Upper Cretaceous stages boundary all over the world that is formally ratified or still in the ratification process; 2) to follow the most recent standardization that is internationally approved for defining any stages in Late Cretaceous Epoch in Kurdistan and Iraq; and 3) to do an extensive research in Kurdistan region at least for formally defining some stages in the Early Cretaceous Epoch that are still have no any candidate boundary stratotypes in the world.

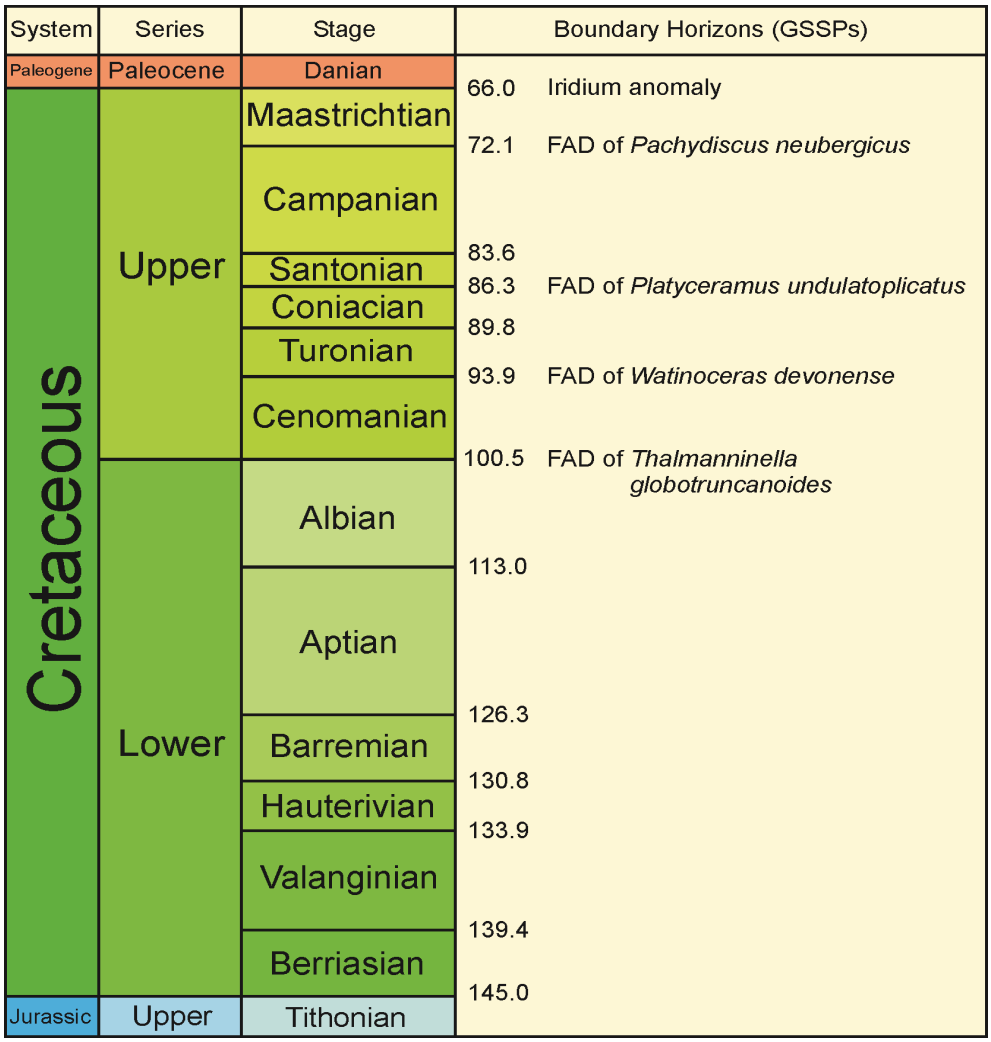

Figure-1: Stages with ratified Global Boundary Stratotype Section and Point (GSSP) are indicated by the first appearance datum (FAD) of the main correlation marker (planktonic foraminifer, ammonite, and inoceramid bivalve) or other correlation level. Numbers are in (Ma) adapted from [1].

Subdivisions of the Upper Cretaceous

The original Turonian and Senonian stages of [16] were increasingly subdivided into the present six stages which are (Cenomanian, Turonian, Coniacian, Santonian, Campanian and Maastrichtian).

Diverse collections of primary markers are used for defining stage and substage boundaries, including ammonoids, inoceramid bivalves, planktonic foraminifers, pelagic crinoids and magnetic polarity chrons [1].

1. Cenomanian

Author: d'Orbigny, 1847.

Type area: Le Mans (Sarthe region, northern France).

In Le Mans, the ammonoid markers for the base of the Cenomanian were the lowest occurrence of the genus *Mantelliceras*, or the lowest occurrence of the genus *Neostlingoceras* [1].

Because these ammonoid groups are comparatively rare in many regions [4]; therefore the Cenomanian Working Group selected the lowest occurrence of the planktonic foraminifer, *Rotalipora brotzeni* (of some studies and now classified as *Thalmanninella globotruncanoides*) (Fig. 2.1) as the basal boundary criterion for the Cenomanian Stage. This foraminifer level is somewhat lower than the lowest occurrence of the Cenomanian ammonoid marker *Mantelliceras mantelli*.

The Mont Risou section in southeast France was chosen as the GSSP [8,17] and formally ratified by the International Union of Geological Sciences in 2002 [13].

Substages of the Cenomanian

The base of the Middle Cenomanian is currently placed at the lowest occurrence of the ammonite *Cunningtoniceras inerme* at the Southerham Gray Quarry in the Sussex province of the England [17].

The replacement of *Acanthoceras* ammonites by the *Calycoceras* genus is commonly used to mark the base of the Upper Cenomanian [4].

2. Turonian

Author: d'Orbigny, 1847.

Type area: Tours or Touraine region of France.

[18] clarified his definition by selecting a type region lying between Saumur and Montrichard. In this region, the lowest Turonian formation contains the ammonite *Mammites nodosoides*, therefore its lowest occurrence was considered the marker for the base of the Turonian Stage [19].

After considering several possible placements, the Turonian Working Group placed the base of the ammonite *Watinoceras devonense* (Figure. 2.2) near the global oceanic anoxic event (OAE2) [5]. The GSSP is at Rock Canyon Anticline, east of Pueblo (Colorado, west-central USA) [5, 12, 14, 20] and was formally ratified by the International Union of Geological Sciences in 2003.

Substages of the Turonian

The base of the Middle Turonian is marked by the lowest occurrence of ammonite *Collignoniceras woollgari* [5] and [12].

The base of the Upper Turonian is not yet formalized, but potential datums are the lowest occurrences of the ammonite *Romaniceras deverianum* in the Tethys realm or an inoceramid bivalve, *Inoceramus perplexus* [5].

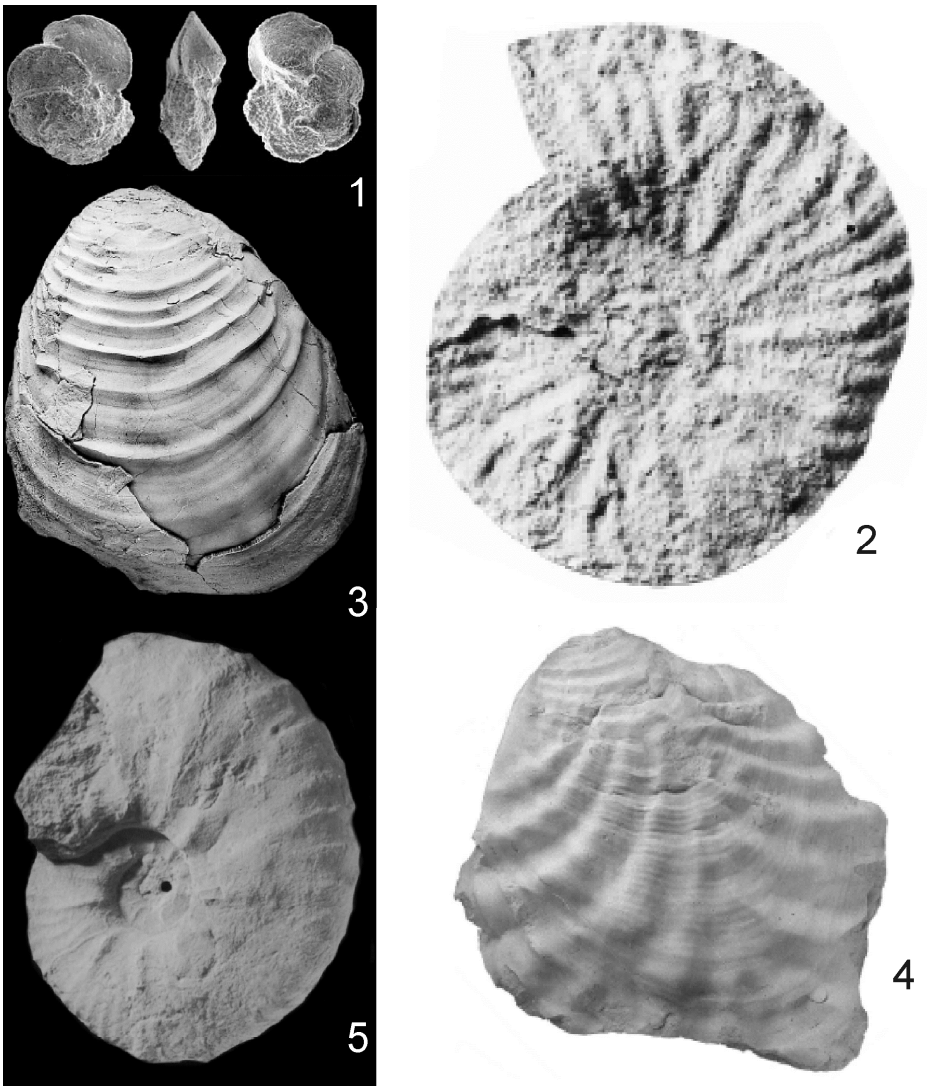

Figure-2: Basal boundary criterion for defining the GSSPs around the world. 1. Planktonic foraminifera *Thalmanninella globotruncanoides* from the Mont Risou section in southeast France [13]; 2. Ammonite *Watinoceras devonense* from the Rock Canyon Anticline, east of Pueblo, Colorado, west-central USA [14]; 3. Inoceramid bivalve *Cremnoceramus deformis erectus* from the Salzgitter-Salder Quarry, southwest of Hannover, Lower Saxony province, northern Germany [21]; 4. Inoceramid bivalve *Platyceramus undulatoplicatus* from the Cantera de Margas quarry; Olazagutia, Navarra region, northern Spain [11]; 5. Ammonite *Pachydiscus neubergicus* from the Tercis les Basin in southwest France [22]. Note that all images are without scale.

3. Coniacian

Author: Coquand, 1857a, b.

Type area: Richemont Seminary near Cognac (Charente province, northern part of the Aquitaine Basin, western France).

At Richemont Seminary, the entry of ammonoid *Harleites petrocoriensis* was used to mark the base of the Coniacian Stage [23] and [24]. However, there can be problems in identifying this species, and ammonoids can be rare or absent [4] and [7]. Therefore, the Coniacian Working Group redefined the Coniacian Stage and its substage boundaries using lowest occurrences of widespread inoceramid bivalves.

The proposed marker for the base of the Coniacian is the lowest occurrence of inoceramid bivalve *Cremnoceramus deformis erectus* (Fig. 2.3). This inoceramid is present throughout the Europe-American biogeographic province and in the Tethyan realm, and can be easily correlated to the North Pacific and southern hemisphere [25].

A candidate boundary stratotype is the Salzgitter-Salder Quarry, southwest of Hannover (Lower Saxony province, northern Germany) [7]; [21] and [25].

Substages of the Coniacian

The base of the Middle Coniacian is placed at the lowest occurrence of the inoceramid bivalve genus Volviceramus [7].

The base of the Upper Coniacian is placed at the lowest occurrence of the inoceramid bivalve *Magadiceramus* subquadratus [7].

4. Santonian

Author: Coquand, 1857b.

Type area: Saintes (Cognac, southwest France).

The boundary in Saintes was drawn on a hardground between glauconitic, nodular limestone, with many *Exogyra* of the Coniacian below, and soft micaceous chalk of the Santonian above [24].

In the Santonian Working Group report to the second Symposium on Cretaceous Stage Boundaries [10]; the lowest occurrence of inoceramid bivalve *Platyceramus undulatoplicatus* was confirmed as the primary marker for the base of the Santonian Stage (Figure. 2.4).

The first occurrence of the planktonic foraminifer *Sigalia carpatica* is the secondary marker of the base of the Santonian [11]. It is widespread in the Mediterranean region of the Tethys, is associated with *Inoceramus siccensis* and *Texanites* in Tunisia, and in northern Spain (Navarra) its lowest occurrence is very close to the lowest occurrence of *Platyceramus undulatoplicatus*.

The GSSP is at Cantera de Margas quarry; Olazagutia, Navarra region, northern Spain [11] and was formally ratified by the International Union of Geological Sciences in 2013.

Substages of the Santonian

A possible datum for the base of the Middle Santonian is the extinction of the same *Platyceramus undulatoplicatus* inoceramid bivalve that marks the Coniacian-Santonian boundary [10].

The lowest occurrence of crinoid *Uintacrinus socialis* is commonly used to place the base of the Upper Santonian [10].

5. Campanian

Author: Coquand, 1857b.

Type area: Grande Champagne (northern Aquitaine province, France).

In Grande Champagne, the base of the Campanian was placed at the lowest occurrence of ammonoid *Placenticeras bidorsatum* [24], but this very rare species is not an applied marker [6]. Therefore, the extinction of the crinoid *Marsupites testudinarius* has been a provisional boundary marker for the base of the Campanian Stage [6], although the occurrence of this taxon is restricted to certain environments. Therefore, the Campanian Working Group is considering using the beginning of Chron C33r as the primary boundary definition [26].

Potential boundary stratotypes might be the Waxahachie dam spillway section (north central Texas) if the crinoid marker is selected [9], or, if the base of C33r is chosen, perhaps the Gubbio section in Italy [27] and [28].

Substages of the Campanian

The Campanian is generally subdivided into Lower, Middle and Upper substages of approximately equal duration, but there are not yet formal recommendations for primary markers or boundary stratotypes for substages [1].

6. Maastrichtian

Author: Demont, 1849.

Type area: Maastricht (southern Netherlands, near the border of Belgium).

The base of the stage was assigned to the lowest occurrence of belemnite *Belemnella lanceolata* [3, 29] and [30]. However, the belemnite *Belemnella lanceolata* is not a useful marker into the Tethyan realm, whereas the ammonoid *Pachydiscus neubergicus* (Figure. 2.5) has a much wider geographic distribution [4]. Therefore, the Maastrichtian Working Group recommended the base of the Maastrichtian to be assigned as the lowest occurrence of ammonoid *Pachydiscus neubergicus* [31], (Figure. 2.5).

The ratified GSSP boundary approved by the International Union of Geological Sciences is in quarry near the village of Tercis les Basin in southwest France [15] and [31].

Substages of the Maastrichtian

The Maastrichtian is commonly divided into two substages, although there is no agreement on the boundary criterion for the base of the Upper Maastrichtian [31]. One potential marker is the lowest occurrence of ammonoid *Pachydiscus fresvillensis* [31]. Alternative criteria include a magnetic polarity reversal (base of C31n), the extinction of rudistid reefs, or the extinction of the majority of inoceramid bivalves.

Conclusions

Different types of macro- and microfossils are widely used in entire world to formally define the base of Cretaceous stages and substages. The base of the Cenomanian Stage can be defined by the lowest occurrence of the planktonic foraminifer *Thalmanninella globotruncanoides*. The lowest occurrence of the ammonite *Watinoceras devonense* can be used for defining the base of the Turonian Stage. The lowest occurrence of the widespread inoceramid *Platyceramus undulatoplicatus* has been selected as the marker for the base of the Santonian. The Maastrichtian Working Group recommended the base of the Maastrichtian to be assigned as the lowest occurrence of ammonoid *Pachydiscus neubergicus.*

The present author reached to a point that ammonites, inoceramid bivalves, and to some extent planktonic foraminifera play major roles in defining the base of the Upper Cretaceous stages and substages.

Recommendations

As the boundary of most of the Upper Cretaceous stages are formally ratified by the International Union of Geological Sciences, and some of them such as Coniacian and Campanian stages have candidate boundary stratotypes; therefore, the author suggests doing an extensive research in Kurdistan region at least for formally defining some stages in the Lower Cretaceous that are still have no any candidate boundary stratotypes in the world such as (Berriasian Stage) or the end of the Upper Jurassic (Tithonian Stage). There are quite good exposures for Lower Cretaceous strata in Kurdistan that are rich by different types of macro- and microfossils such as ammonites and planktonic foraminifera which can be used as the primary marker for defining the base of some stages in the Lower Cretaceous.

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