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TOPIC

Paleodiversity and Paleoenvironmental Conditions of the Coniacian-Santonian Strata in the Southwestern Aures (Batna- Algeria)

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ملخص تهدف هذه الدراسة إلى تحليل البيئة القديمة والتركيب الأحفوري لتكوينات جيولوجية في منطقة باتنة، الواقعة شمال شرق الجزائر، والتي تنتمي جيولوجيًا إلى جبال الأوراس ضمن الأطلس الصحراوي الشرقي. تم الاعتماد على تحليل توزيع المستحاثات الدقيقة والكبيرة لتحديد طبيعة البيئات الرسوبية التي سادت خلال الفترة الكريتاسية. أظهرت النتائج وجود ثلاثة أنماط رئيسية للبيئات البحرية: بيئات ضحلة دافئة غنية بالكربونات، مناطق رصيفية عميقة قليلة الأكسجين، وأخرى مفتوحة ذات طابع محيطي وتيار تيثياني. تعكس هذه البيئات تأثيرات دورية لارتفاع مستوى سطح البحر وتغيرات مناخية مدارية. وتبرز الدراسة أهمية المنطقة كممر جيولوجي بين شمال إفريقيا ومجال التيثيس، ما يساهم في تعزيز الإطار الطباقي الإقليمي وفهم الديناميكيات القديمة.

الكلمات المفتاحية: الأوراس، البيئة القديمة، المستحاثات، الكريتاسي، الأطلس الصحراوي، تيثيس،

Résumé : Cette etude présente une analyse paléoenvironnementale et paléontologique des formations géologiques de la région de Batna, située dans le nord-est de l'Algérie, au sein des montagnes des Aurès, qui font partie de l'Atlas saharien oriental. L'étude repose sur l'analyse de la distribution des microfossiles et macrofossiles afin de reconstruire les environnements marins du Crétacé. Les résultats révèlent trois milieux principaux : des plateformes carbonatées peu profondes à climat chaud, des zones de plateforme externe appauvries en oxygène, et des environnements marins ouverts influencés par les courants téthysiens. Ces contextes traduisent des transgressions marines répétées liées aux variations eustatiques et aux conditions tropicales. L'étude met en évidence le rôle paléogéographique stratégique des Aurès comme lien entre l'Afrique du Nord et le domaine téthysien.

Mots-clés : Aurès, paléoenvironnement, paléontologie, Crétacé, Atlas Saharien, Téthys.

Abstract : This study presents a paleoenvironmental and paleontological assessment of the geological formations in the Batna region, northeastern Algeria, geologically part of the Aurès Mountains in the eastern Saharan Atlas. By analyzing the spatial distribution of both microfossils and macrofossils, the study reconstructs the marine depositional environments that prevailed during the Cretaceous. The results reveal three major paleoenvironmental settings: warm, shallow carbonate platforms, oxygen-depleted outer shelf zones, and nutrient-rich open marine environments associated with Tethyan circulation. These patterns reflect eustatic sea-level changes and tropical climatic conditions. The study underscores the paleogeographic importance of the Aurès as a transitional corridor between North Africa and the broader Tethyan realm, offering valuable insights into regional stratigraphy and global Cretaceous paleoceanography.

Keywords: Aurès, paleoenvironment, paleontology, Cretaceous, Saharan Atlas, Tethys.

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أهدي واشكر هذا العمل من أعماق قلبي، محمّلًا بحبٍ خالص وامتنانٍ لا ينضب، إلى:

أستاذي العزيز بن خدة عبد الحكيم، منارة دربي الأكاديمي، الذي آمن بي حين خفتُ أن أضلّ الطريق. كنتَ لي المرشد والسند، تشاركني علمك الغزير وخبرتك الثمينة، وتقودني بحكمةٍ في رحلة البحث هذه. لن أنسى أبدًا دعمك الذي أضاء سنوات تعليمي، وستبقى ذكراك محفورة في قلبي.

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الأستاذ العويني حمزة، رئيس القسم، الذي جعل مسيرتنا الأكاديمية دربًا ميسّرًا. قلبك الكبير وجهودك جعلت كل تحدٍ أخف .وطأة، فشكرًا من القلب

وإلى أساتذة قسم علوم الأرض والكون، وخاصة أولئك الذين تركوا بصمةً لا تُمحى في سنواتي الثلاث الأخيرة. لقد .غرستم فيّ العلم والشغف،وستظلون نجومًا تضيء ذكرياتي التعليمية.

ربما لاتروى الحكايات بأكملها ... ولا تقال النهايات كما عشناها .ولكن ما بين البداية والخاتمة ثمة الكثير

Dedication

لطالما آمنتُ أن في القلب بذوراً لا تثمر إلا إذا سُقيت بالدمع والصبر. وها أنا اليوم أكتب هذه الكلمات بعدما عبرتُ فصولًا من الشدة، ووقفتُ في وجه العاصفة بعزيمة وإيمان بأن الحلم، مهما تأخر، لا يضل طريقه إلى من أصرَّ عليه. تعثرتُ، تألمتُ، وبكيتُ وحدي، لكنني نهضتُ. فالنور ليس من حولنا، بل منا نحن. نحن الذين آمنَّا دائماً أن في الصبر جمالًا، وفي الضعف قوة، وفي الألم ميلادٌ جديد، حتى وإن طال الانتظار... ولو بعد حين!

إلى أمي، اليد التي امتدت إليَّ في العتمة فأضاءت طريقي، والأنيسة التي احتضنتني دائماً فاشتدَّ بها عزمي. كنتِ السند حين وهن الجسد، والصوت حين خفت الأمل، والوهج الذي غمر أيامي لطفاً وحناناً. فلولاكِ ما كنتُ لأدرك أن في داخلي امرأة لا يُهزم طموحها ولا يعوقها المستحيل أبداً.

إلى أبي، الجبل الراسخ الذي استندتُ إليه حين ضاقت بي السبل، والنور الذي أرشدني في ليالي الحيرة. كنتَ الظهر الذي يقويني، والحكمة التي تهديني، والصبر الذي يعلمني أن أقاوم الصعاب بقلبٍ ثابت. يداكَ الخشنتان من العمل كانتا دائماً ملاذي الآمن، وعيناكَ تحملان لي فخراً يرفعني إلى السماء. فلولاكَ، ما كنتُ لأعرف معنى القوة الحقيقية، ولا لأؤمن بأن الحب الصامت قد يكون أعمق من الكلمات وأبقى.

إلى أخي، الرفيق الذي سار معي دروب الحياة، والسند الذي لم يتخلَّ عني يوماً. كنتَ الضحكة في أيامي الحزينة، والقوة حين خارت خطواتي. يدكَ التي امتدت لترفعني، ونصيحتكَ التي أضاءت لي الطريق، جعلتا منكَ أكثر من أخٍ، بل روحاً تسكنني. بدونك ما عرفتُ أن الصداقة الحقيقية قد تولد من رحم العائلة، وأن الأخوة درعٌ يحمي وجناح يرفع

إلى أختاي، الزهرتان اللتان أنارتا حديقة عمري، واللتان كانتا لي مرآةً تعكس أحلامي وقلباً يحمل همومي. كنتما الهمسة الدافئة في ليالي البرد، والابتسامة التي تمحو أحزاني. حنانكما غمرني، وتشجيعكما رفعني، فصرتم لي ملاذاً وسط العواصف. فلولاكما، ما كنتُ لأدرك أن الحب قد يكون رقةً وإلهاماً، وأن الأختين كنزٌ لا يُضاهى يزداد قيمةً مع الأيام.

إلى خالاتي وجدتي وخوالي، أنتم نعمةٌ في حياتي. خالاتي، كنتنَّ أمهاتٍ ثانيات بحنانكنَّ ونصائحكنَّ الثمينة. جدتي، دعواتكِ وحكاياتكِ علمتني الصبر والإيمان. خوالي، كنتم سندي وضحكتي في كل محنة.

إلى قطتي، الرفيقة الصغيرة التي ملأت أيامي بهجةً ودفئاً. كنتِ النسمة الرقيقة التي تهبُ على قلبي، ونظرة عينيكِ البريئة كانت كفيلة بمحو همومي. خطواتكِ الخفيفة ولهوكِ الطفولي كانا لي مصدر إلهامٍ وسعادة، فكأنكِ تعلمينني أنالحياة قد تكون بسيطة وجميلة في لحظات الصمت.

وإلى أي أحد غريبا ام صديقا كان. كل من أسهم بكلمة.بدعوة .بموقف ربما حتى كان عابرا لكنه بروحي لا يزال محفوظا لا تكفيني الكلمات لرد جميلكم ولا العبارات لإحتواء قدركم .انتم وطني الذي وإن غادرته ..... فدعوه لا يغادرنيأبدا

إلى كل من ذكرته أهدي هذه الكلمات التي تفيض حبا وإمتنان

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Introduction

The Late Cretaceous, particularly the Coniacian-Santonian stages, represents a pivotal period of environmental and biotic evolution marked by significant marine transgressions and climatic fluctuations across the Tethyan region. During this interval, a global rise in sea level, coupled with a relatively warm climate, facilitated the deposition of marly-limestone series characterized by high faunal diversity (Herkat, 1999). The Aurès Massif, located in the core of the Atlasic domain in northeastern Algeria, serves as a critical geological archive for studying these dynamics. Spanning from the Hodna Mountains in the west to the Nememcha-Ain Beïda Mountains in the east, the massif is bounded to the south by the South Atlasic Fault near Biskra and includes Miocene marine detrital deposits in the northern Timgad Basin, extending northeast of Khenchela. The southwestern Aurès, encompassing rugged terrains and sedimentary basins along the northern margin of the Saharan platform, preserves a rich record of Upper Cretaceous deposits shaped by tectonic activity and marine incursions. This thesis focuses on the paleodiversity and paleoenvironmental conditions of the Coniacian-Santonian strata in the southwest Aurès region of Batna, Algeria, aiming to reconstruct the sedimentological, climatic, and ecological factors that defined its ancient landscapes. By integrating stratigraphic, paleontological, and geochemical approaches, this study investigates the taxonomic composition, adaptations, and ecological interactions of macro- and microfaunal assemblages, elucidating their role within Late Cretaceous ecosystems. The research positions the southwestern Aurès as a key paleobiogeographic corridor linking North African and Tethyan realms, contributing to a deeper understanding of global Cretaceous biodiversity and environmental transitions. Through this work, the interplay between geological processes and biological evolution during a transformative chapter of Earth's history is illuminated, highlighting the region's significance as a vital repository for deciphering past climatic and ecological dynamics.

1. Objectiv :

The present work objectiv is to investigate and reconstruct the paleodiversity and paleoenvironmental conditions of the Coniacian-Santonian in the southwestern Aures by analyzing fossil assemblages, sedimentological features, and stratigraphic data. This study aims to identify the taxonomic composition and ecological associations of macrofossils and microfossils, assess their implications for biodiversity during this interval of the Late Cretaceous, and interpret the depositional environments and paleoceanographic conditions that prevailed in this part of the southern Tethyan margin, contributing to a broader understanding of regional and global environmental changes during the Coniacian-Santonian stages.

2. Materials and methods :

In order to achieve the objectives mentioned above, the southwestren Aurés section was selected, where the Coniacian-Santonian deposits are fully exposed and accessible. The study of this area required multiple approaches, which, while different, were complementary-particularly in terms of lithology and macropaleontology. A total of 10 samples were collected for analysis.

The work conducted so far has focused on three main aspects:

- A systematic review and data collection, gathering as much information as possible regarding the sedimentological, stratigraphic, and paleontological characteristics of the study area. This research was based on previous studies and supported by geological, topographic, and structural maps.
- A detailed lithological description, including panoramic photographs to document key features
- A systematic sampling was carried out on various groups of gastropods, bivalves, sea urchins, and ammonites, with each collected fossil assigned a unique identification number.
- In the laboratory, the macrofossils underwent a thorough washing and cleaning process to facilitate the identification of different taxa.

  The best-preserved specimens were photographed using a high-resolution digital camera

CHAPTRE I

GEOGRAPHICAL AND GEOLOGICAL CONTEXT

I .Geographical and stratigraphic framework:

I-1. Location

The study area is located in Batna Province, northeastern Algeria, within the Aurès region of the Saharan Atlas Mountains. Geologically, it occupies the foreland of the Atlas system, forming a transitional zone between the Tell Atlas to the north and the Saharan Atlas to the south (Fig. 1).

The province is bordered by

- Sétif and Mila to the north
- Biskra to the south
- Khenchela and Tébessa to the east
- Oum El Bouaghi and M'Sila to the west

The study concentrated on the eastern sector of this domain, specifically in the Aurès region, with a sharp focus on the terminal Cretaceous (Coniacian–Santonian) strata in the southwestern Aurès

The geographical coordinates of the specified location , are precisely determined as 35.291615° N latitude and 5.800298° E longitude

Fig1.A : Geological map showing the position of Batna within North Africa and its proximity to the Mediterranean Sea

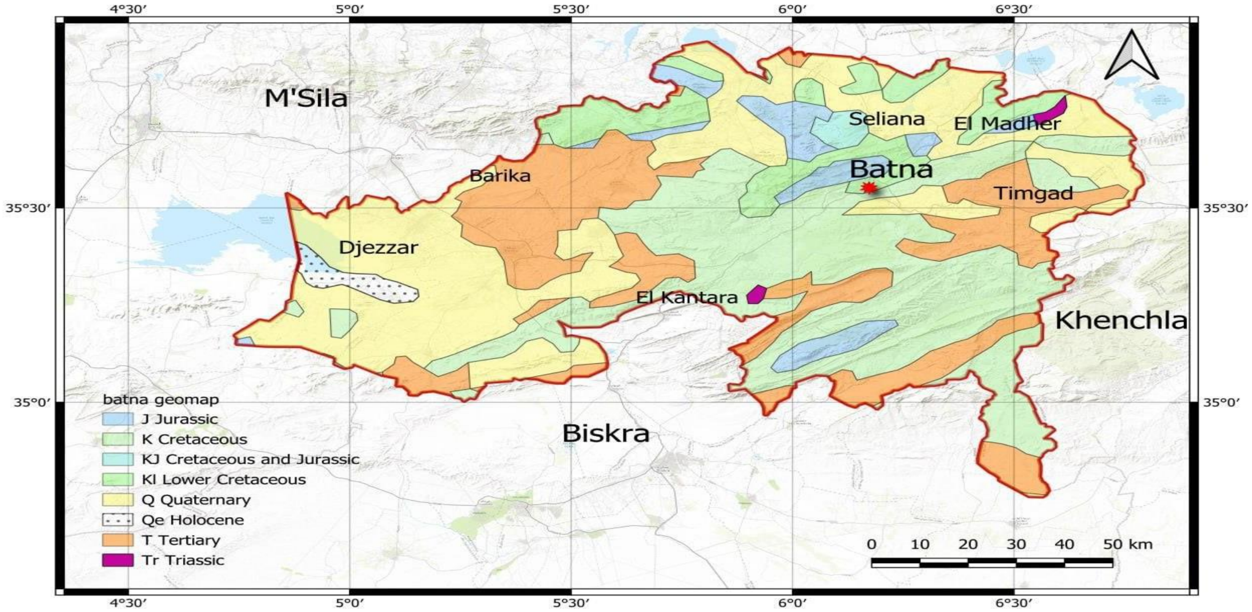

Fig . 1B: Geological map of Batna region and its surrounding areas

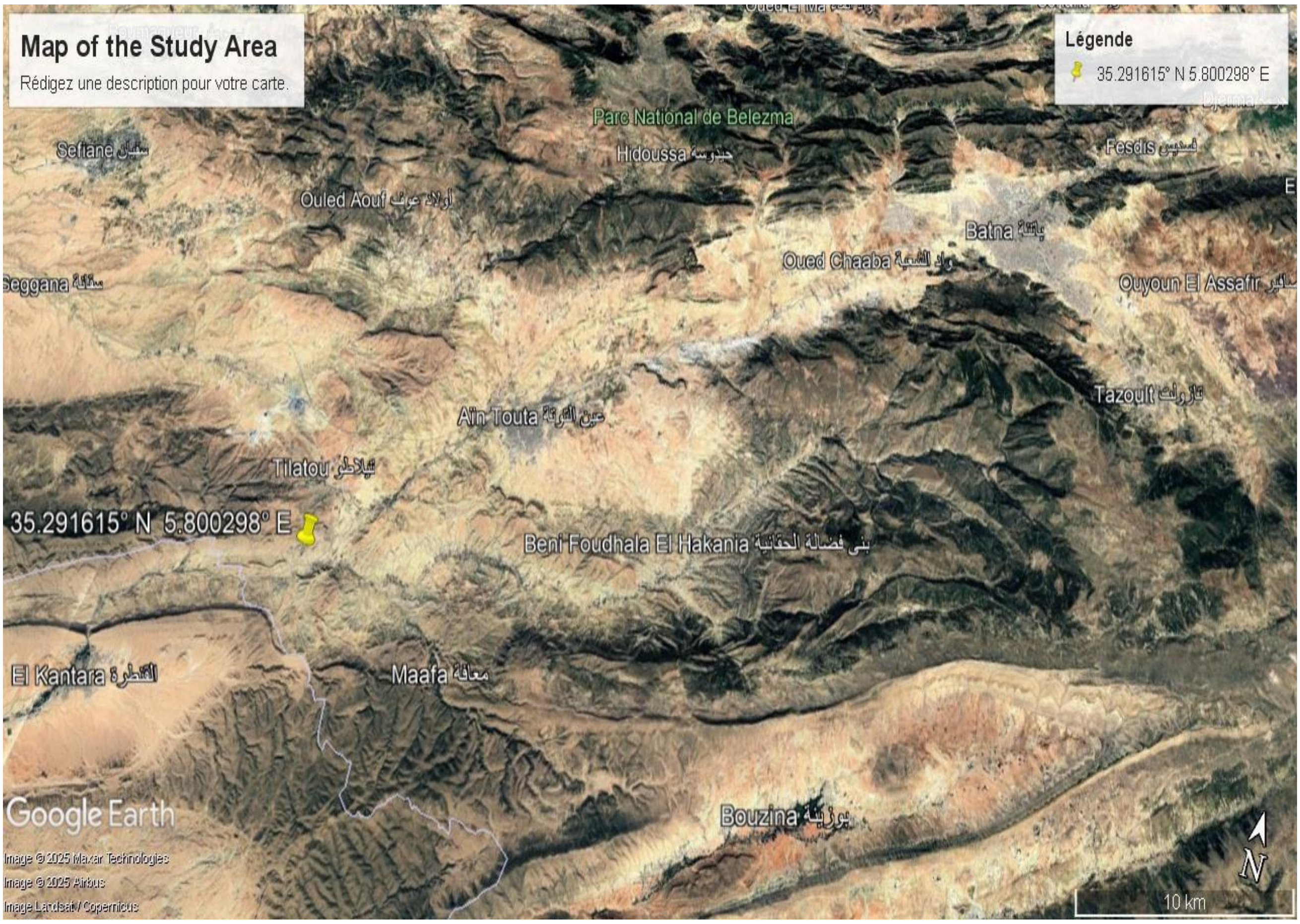

Fig 02: A satellite image showing the location of the study area within Batna Province

I. Geological framework :

To better grasp the geological history of the study area, it appears essential to position it within its broader geological context.

Northern Algeria, encompassing the Maghrebides, forms a critical segment of the peri-Mediterranean Alpine orogenic belt, shaped during the Tertiary period (Durand-Delga, 1969). This extensive orogen spans approximately 2,000 km, stretching from southern Spain to the Calabro-Sicilian arc and incorporating the Rif, Tell, North Sicilian, and Calabrian domains (Durand-Delga & Fontboté, 1980). Structurally, the region is delineated into internal and external zones, molded by Alpine tectonic processes that profoundly influenced the evolution of the Maghrebian Basin (Bouillin, 1992).

The geological framework of Northern Algeria, is delineated based on tectonic, stratigraphic, sedimentological, and paleogeographic criteria. These subdivisions reflect the region's complex evolution within the peri-Mediterranean Alpine orogeny, characterized by tectonic processes such as thrusting and folding, distinct stratigraphic sequences, and its paleogeographic position along the southern Tethyan margin. This classification framework was developed through comprehensive geological investigations by scholars including Bouillin (1982, 1983, 1986, 1992), Durand-Delga (1969, 1980), Vila (1980),

1. Internal Domain

This domain consists of basement massifs overlain by Paleozoic rocks with low-grade metamorphism (Bouillin, 1986). The coastal massifs of northern Algeria, remants of the "Meso-Mediterranean microplate" fragmented during the Early Miocene (Durand-Delga, 1980), are bordered by the Kabyle Ridge or "Limestone"

II.1.1. The Flysch Domain:

Situated between the internal zones (Peloritano–Kabylo–Rif) and external domains, the Flysch domain constitutes a transitional tectonic unit within the Maghrebides (Bouillin, 1982). The placement of the flysch sequences remains contentious, with two primary series identified: the Massylian and Mauritanian flyschs (Gélard, 1969; Raoult, 1969–1972). Durand-Delga et al. (1980) propose a southern position relative to the Kabyle basement, whereas Bouillin (1983, 1992) contends that these flyschs were thrust over the external zones, followed by back-thrusting onto the Kabyle basement. Distinct from these, the Numidian flysch, dated to the Oligo–Miocene, typically overlies younger Burdigalian deposits (Durand-Delga, 1980).

II.1.1. The External Domain

The Tell-Rif external domain corresponds to the African Tethyan margin, exhibiting large south-verging nappes in the Rif (Morocco), Tell (Algeria), and Kroumirie (Tunisia) (Wildi, 1983).

A. The Foreland of the Maghrebides

The Alpine structures in Algeria include the Tellian Atlas, High Plateaus, Constantine Massif, Saharan Atlas, Aurès, and Bellezma Mountains, separated from the Saharan platform by the Atlasic fault.

The Northern Foreland:

Research by Vila (1980) and others describes this region as consisting of allochthonous units, such as the Setifian Units and Constantine Neritic Massif. However, later studies (Chadi, 1991; Coiffait, 1992) questioned the allochthonous nature of the neritic massif and its southern boundaries, suggesting a marly cover lies conformably over the underlying neritic limestones of the Constantine Massif

The TheSouthern (Atlasic) Foreland:

This domain is divided into three main regions in Algeria: the Western Saharan Atlas, the Central Saharan Atlas, and the Eastern Saharan Atlas (the focus of our study).

1. The Western Saharan Atlas

Ksour Mountains, primarily Jurassic, trending NE-SW.

2. The Central Saharan Atlas

Amour Mountains and Ouled Naile range, mainly Jurassic and Cretaceous.

3. The Eastern Saharan Atlas

This region has been the subject of numerous investigations, with notable contributions from Fournel (1849), Coquand (1862), Péron (1883), Ficheur (1896), Savornin (1920), Laffitte (1939), Dubordieu (1956), Guiraud (1973, 1990), and Donze (1973-1974).

More recent research on the Eastern Saharan Atlas has been conducted by Vila (1980), Aïssaoui (1984), Bureau (1986), Kazi-Tani (1986), Yahiaoui (1990), Ghandriche (1991), and Marmi (1995), contributing to a deeper understanding of this region.

3.1. The Aurès Region

The Aurès extends from the Hodna Mountains in the west to the Nememcha-Aïn Beïda Mountains in the east.

It is bordered southward by the South Atlasic fault, where Miocene deposits unconformably overlie Cretaceous formations. The northern region is characterized by Cretaceous anticlines such as Djebel Bou Arif, Fedjoudj, and Tarf (Laffitte, 1939).

The Aurès Massif is characterized by folds trending N 50° to N 60° E, formed during the Atlasic tectonic phase, and intersected by three principal fault systems oriented NE–SW, NW–SE, and E–W. Within these folds, Triassic outcrops are overlain by reef formations (Guiraud, 1973; Guellal & Megartsi, 1972).

Geologically, the Aurès is part of the Maghrebides chain and the Atlasic foreland, with a complete sedimentary sequence from the Triassic to the Quaternary. It exhibits diverse tectonic influences, marked by significant folds and faults (Laffitte, 1939; Guiraud, 1973; Kazi-Tani, 1986).

Lithostratigraphic Description of the Studied Formations:

.1. *Secondary Formations*

These formations are defined by the combination of two distinct facies types: marl-carbonate deposits and sandstone deposits. The former are widely exposed in the massifs surrounding the Timgad basin, such as Djebel Bou Arif, Djebel Amrane, and the Chélia Massif, where they are unconformably overlain by Miocene sandstone**.**

❖ ***Triassic***

The Triassic formations in the Aurès represent the oldest rocks in the external Alpine chain, occurring in localized outcrops along fold flanks and faults. These evaporitic deposits, mainly gypsiferous and saline clays, are often found in diapiric structures and injected layers. Due to their fossil-free nature, stratigraphic correlations are challenging, but their resemblance to the Germanic Triassic facies supports their attribution to this period. Key outcrops include Djebel Melah, Menâa, L'Arbaâ, Narah, Medina, Khenchela, and Maâfa-Arba, characterized by combinations of gypsum, variegated marls, dolomite, and bipyramidal quartz. The depositional environment was an evaporative lagoon, leading to the accumulation of clays, gypsum, and salt (Laffitte, 1939 Ghandriche, 1991 Herkat, 1992 Bachu et al., 1995; Tucker, 2001)

❖ ***.Jurassic***

The Jurassic formations are primarily confined to the cores of major anticlines in the Saharan Atlas, forming the oldest continuous stratigraphic sequences in the Aurès. Between Oued Abdi and Oued El Abiod, these formations create an inlier approximately 20 to 25 km long, dominated by Kimmeridgian, Portlandian, and Berriasian deposits.

Kimmeridgian and Portlandian

Lower Kimmeridgian: Marked by shallow marine conditions, where oysters and corals thrived on submarine highs, with cephalopods such as Phylloceras, Lissoceras, Simoceras, and Streblites recorded (Laffitte, 1939).

Upper Kimmeridgian: Characterized by reef developments and dolomitization, which obliterated most fossils. However, belemnites, Natica sp., Exogyra coulouni, Terebratula carterouni, and Terebratula campichei are preserved in.

Lower Jurassic :

The Lower Jurassic sequence consists ofDolomites, micritic limestones, and algal limestones, dated by Involutina liassica and ostracods (Vila, 1980). Overlain by Ammonitico Rosso facies (nodular limestones and marly limestones) containing Lillia byani (Ficheur, 1896).

Dolomitic formations observed in Messaouda and Djebel Mestaoua, dated to the Toarcian (Lias) by Pseudogrammoceras aff. quadratum and Caeloceras (Glaçon, 1955).

West of the Aurès, yellow and blue limestones with belemnites and foraminifera characterize the Lower Toarcian (Flandrin, 1952).

Middle and Upper Jurassic Deposits :

Middle Jurassic: Predominantly dolomitic, with limestone beds containing chert and filamentous fossils.

Upper Jurassic (Portlandian): Found in the Djebel Azreg anticline and Djebel Toumbait (Aïn Yagout region), consisting of Fine-grained siliceous limestones (whitish-purple) rich in radiolarians, corals, and sponges. Marly and barren dolomites overlying these limestones.

The Jurassic paleogeography suggests a subsiding pelagic zone, with thick detrital sedimentation originating from the Saharan platform, allowing the deposition of neritic and pelagic sediments (Laffitte, 1935; Hallam, 1981).

- ***Cretaceous***

This period is represented by a thick, conformable sedimentary succession extending from the Berriasian to the Danian, which can be divided into two principal units: (1) a sandstone-dominated Lower Cretaceous sequence interbedded with limestones and marls up to the Albian, and (2) a marly-limestone Upper Cretaceous succession (Laffitte, 1935). The Lower Cretaceous deposits were first identified by Fournel (1849) in El Kantara and further refined by Coquand (1862) in the Batna region.

Lower Cretaceous

Berriasian: Brachiopod-bearing limestones overlie reefal deposits, while Calpionella-bearing limestones and occasional cephalopods appear in other areas.

Valanginian: Marine sediments interbedded with detrital deposits, restricted to the Djebel El Azereg anticline, contain fossil-rich pyritic layers (Kilianella roubaudi Zone).

Hauterivian: Sandstones and pisolitic limestones host corals, foraminifera, and algae, indicating shallow marine conditions (Bureau, 1975).

Barremian: Coarse-grained sandstones dominate, with gypsum deposits suggesting lagoonal conditions in the southwest, while marine carbonate sedimentation persisted in the northeast (Laffitte, 1935).

Aptian: Well exposed in major anticlines, characterized by marly layers containing Heteraster tissoti.

Albian: Lagoonal conditions dominated the southwest, transitioning into marl-quartzite alternations in the northeast. Fossiliferous limestone beds are infrequent except in the uppermost sequences.

Upper Cretaceous

Cenomanian: Marls rich in cephalopods are prevalent, with localized limestone deposits near Biskra and El Kantara. Shallow marine indicators include foraminifera (Thomasinella, Orbitolina) and rudists.

Turonian: The most extensive Cretaceous outcrop, characterized by rudist reefs (Radiolites, Hippurites) along the massif's periphery and marly limestones containing echinoids (Hemiaster) in central areas.

Senonian: Comprising up to 2,000 meters of fossil-rich marls and limestones, with rudist-bearing limestones in the Coniacian (Durania) and abundant ceratites (Tissotia) (Kieken, 1962). The significant deposit thickness suggests active subsidence.

Campanian: Predominantly marly deposits, interbedded with chalky limestone beds rich in ammonites and echinoids in the west, while foraminiferal limestones dominate in the east (Laffitte, 1939)

Maastrichtian: Marked by extensive calcareous sedimentation, including massive lithothamnion-rich limestones in the west. The Djebel Metlili section (400 m thick) features bioclastic and gravelly limestones with gastropods (Kazi-Tani, 1986). Thickness decreases eastward, with reduced sequences at Bouzina (230 m) and Tafrint (190 m).

ETAGES	FACIES	AMMONITES
MAASTRICHTIEN	- Calcaires massifs à Laffitéines, algues lithotammniées et bryozoaires 300-400 m. - Marnes noires à intercalations calcaires à huîtres et oursins 200-300 m.	*Libycoceras chargense* *Pachydiscus neubergicus*
CAMPANIEN	- Calcaires crayeux à *Ostrea dichotoma O. vesicularis* et marnes à oursins. - Marnes à intercalations de gypse, calcaires marneux à ammonites et inocérames.	*Mortoniceras delawarense* *Heterotissotia Sphenodiscus*
SANTONIEN	- Calcaires à *Inoceramus reguliaris*, parfois à rudistes. - Marnes à *Hemipneustes*.	*Placenticeras syrtale* *Mortoniceras texanum*
CONIACIEN	- Alternance de marnes et calcaires décimétriques lumachelliques à bryozoaires et à oursins. - Marnes dominantes à intercalations calcaires décimétriques (gastropodes, Ostrea) trés riches en ammonites et oursins à la base.	*Tissotia* sp. *Barroisiceras haberfellneri*
TURONIEN	- Calcaire dominant en bancs métriques pouvant former une barre (10-15 m) à rudistes, oursins, gastropodes. - Alternance marno-calcaire fossilifère (oursins, lamellibranches, gastropodes) riche en ammonites dans la partie supérieure. - Calcaires en gros bancs à intercalations de niveaux marneux à oursins.	*Hoplitoides* cf. *ingens Pseudotissotia* *Mammites* sp. aff. *nodosoides*
CENOMANIEN	- Calcaires, marnes à *Ostrea*, gastropodes, polypiers, orbitolines. *Heterodiadema libycum* et *Radiolites*. - Marnes à intercalations de passées calcaires lumachelliques et de gypse très fossilifères.	*Acanthoceras* cf.*rothomagense* *Acanthoceras* cf. *mantelli*

Fig. 14: The Upper Cretaceous according to the bibliography in the Aurès mountains and the Batna mountains (A. Yahiaoui, 1990).

.2. *Tertiary Formations*

❖ *Paleogene*

Tertiary outcrops in the foreland of the eastern Algerian Alpine chain are relatively limited compared to Secondary formations, with younger deposits often incorporating reworked microfaunal assemblages (Marmi, 1995). In the Belezma-Batna Mountains, post-Cretaceous deposits overlie the Cretaceous in angular unconformity, similar to the Aurès, where Tertiary formations are primarily found in synclinal basins or morphological depressions (Bureau, 1975c).

❖ **Paleogene (Nummulitic)**

The Paleogene formations in the Aurès are divided into two main units (Laffitte, 1939):

Marine Unit (Danian – Upper Lutetian): Found in large synclines (e.g., Ouled Rechaïch, Khanguet Sidi Nadji), it consists of white marls, limestones, gypsum, and phosphatic beds, with flint-bearing layers in the Eocene.

Continental Unit (Upper Eocene – Oligocene): Comprising red marls, coarse sandstones, and conglomerates, it is mainly located in the western Aurès (El Kantara) and southern flanks of the massif (Rhassira, Bouzina), often resting unconformably over older formations (Chebbah, 2007).

❖ **Neogene**

Neogene deposits occur at basin margins and centers, often covered by Quaternary sediments. These deposits unconformably overlie formations of different ages (Oligocene, Eocene, Upper Cretaceous) and include (Chebbah, 2007; Djaiz, 2011):

Aquitanian-Burdigalian: Green or brown clays and limestones.

Langhian-Serravallian: Brown clays with gypsum beds.

Tortonian: Gypsiferous red clays.

Messinian: Brown-red sandstones.

Pliocene: Red conglomerates (puddingstones).

II .Tectonic Evolution and Its Impact on Sedimentation :

The Aurès is located within the Saharan Atlas, a region forming part of the African plate margin. This anticline is primarily shaped by Atlasic and Alpine tectonics due to its position in an active zone at the convergence of the allochthonous domain to the north and the para-autochthonous domain to the south.

Its structural development is tied to a series of tectonic events unfolding over time, from the end of the Paleozoic to the present day. This development fits into the geodynamic framework of the Arabo-African Tethyan margin, as outlined by Guiraud (1997).
Here in this resarch , we will attempt to review the main faults that influenced the sedimentation of the Upper Cretaceous in the Aurès, considering all available data.

II.2.1. The Aurès and Batna Mountains

We will sequentially examine the WNW-ESE and NW-SE faults, followed by the NE-SW faults, and finally the south-meridian NNE-SSW faults.

II.2.1.1. WNW-ESE and NW-SE Faults

-..Faults of Djebel Azreg, Toubount Massif, Ich Moul, Chelia, Ich Ali, and Igguedlene..

These are faults trending N 110°-N 140° (e.g., the Argoub El Baguelet fault and the Menaa-Tighanimine fault), which define blocks tilted toward the south. They are highlighted on the framework of synsedimentary faults by Bureau (1983),

though the tilt direction indicated is opposite to the actual configuration. These faults primarily manifest through flexural activity influencing sedimentation.

- ..Relay Faults of Djebel Bou Tlarmine, Ich Moul, and Bou Hmama - Oued Mellaguou..

In addition to their activity contemporaneous with sedimentation, these faults exhibit reactivation during the Atlasic tectogenesis, expressed as faults affecting the Upper Cretaceous series terms (Herkat, 2000).

II.2.1. ***The Zibans and Bellezma Mountains***

The primary faults trend WNW-ESE to E-W, NW-SE, and NNE-SSW.

II.2.1.1. WNW-ESE to E-W Faults

A) South Zibans Fault

This fault is expressed as a series of relay faults trending N 110°-N 120°, well-documented in Bureau’s (1973) structural diagrams, extending from Djebel Ksoum in the west to Djebel Bou Rhezal. It delineates the southern boundary of the Zibans massif, separating it from the North Saharan Naama-Tolga basin.

B) Djebel Moddiane - El Outaya Fault and Djebel Metlili (Djebel Melah) - El Kantara Fault

According to Bureau’s structural diagrams, these faults, trending N 80° to N 90°, are reflected in the Upper Cretaceous series by blocks tilted southward with varying throw. Thickness variations across the first fault are minimal, whereas they are significantly greater across the second fault.

C) North Zibans Fault

This corresponds to a fault zone trending roughly E-W (N 80° to N 100° E), passing north of Djebel Fozna and beneath the Hodna plain. Their uplift of the pre-Atlasic zone is clearly visible in electrical survey profiles (in Guiraud, 1973). The absence of Upper Cretaceous series in the Hodna pre-Atlasic zone prevents confirmation of the fault’s activity during that period, though it is likely to have been similar if we judging by the differential subsidence that is evident along the northern Atlasic fault of the Ouled Naïl Mountains, of which the North Zibans fault forms an extension.

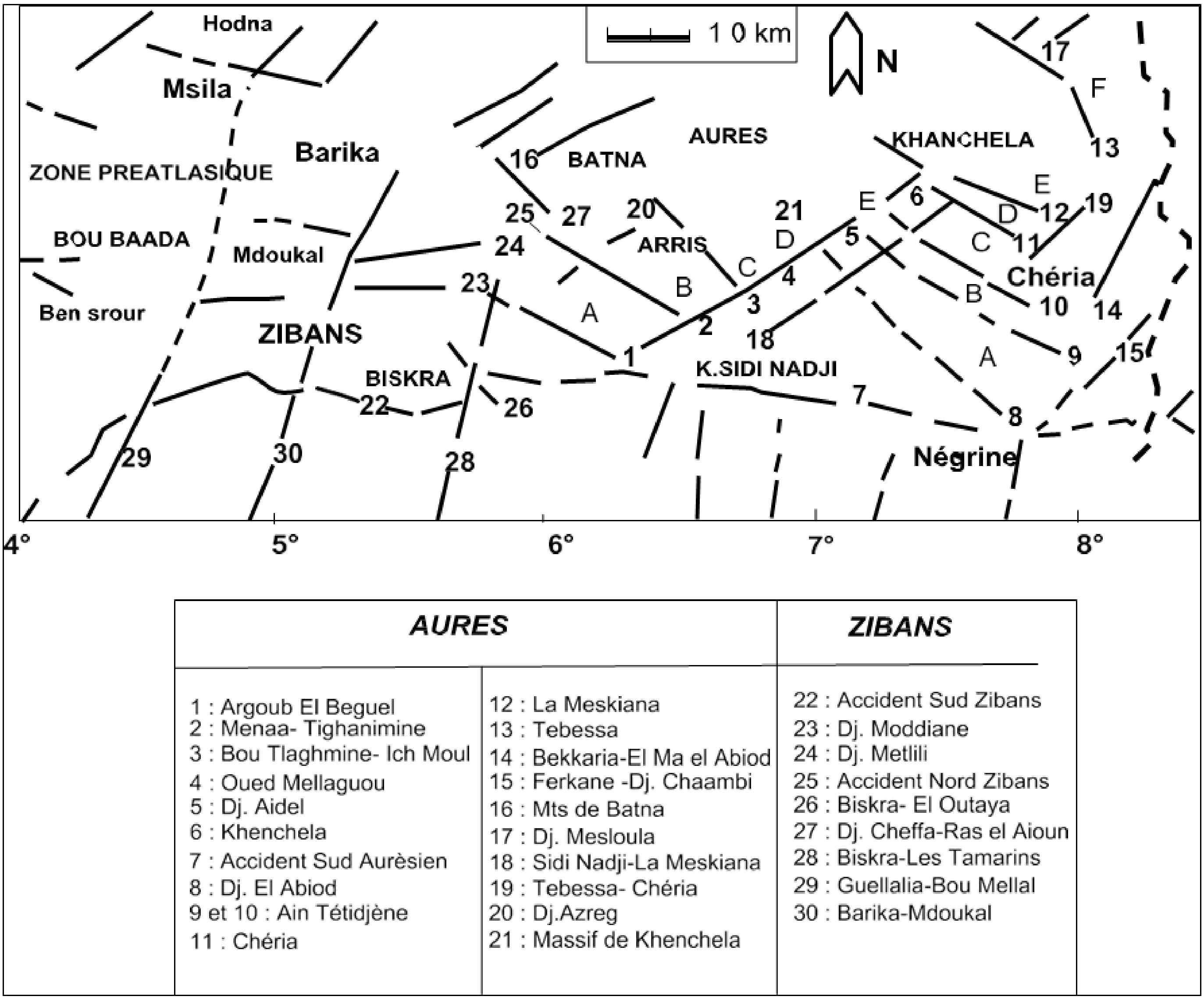

Fig.09 : le canevas des accidents synsédimentaires des Aurès (Herkat, 2000).

II.2.1.1.NW-SE Faults :

A) Biskra - El Outaya "Fault"

This is an N 130° fault depicted by Bureau in his structural sketches of the eastern Zibans region. Its activity during the Upper Cretaceous has not been established.

B) Djebel Cheffa - Rass El Aïoun "Fault"

This fault is inferred from paleogeographic reconstructions, which indicate a boundary at this level between the subsiding basin of the Upper Senonian (ElKantara - Oued Berriche) and the Batna Mountains zone, characterized by reduced sedimentation.

II.2.1.1. South-Meridian NNE-SSW Faults

A) Biskra - Les Tamarins "Fault"

In the Biskra region, this fault is manifested by the Djebel Bou Rhezal fault, trending N 10° E. To the north, it corresponds to a sedimentary flexure separating the less subsident, predominantly carbonate series of the Zibans from the more subsident marly-limestone series of the Aurès basin. This fault aligns with an extension of a branch of the Mouydir massif, a major basement fracture feature that induced differential subsidence during the Mesozoic. Additionally, the fault is evidenced by geophysical data, particularly the gravimetric map of Lagrula (1957).

B) Guelalia - Bou Mellal "Fault"

This fault marks the boundary between the Zibans massif and the Ouled Naïl basin. It represents another significant basement fault of the Saharan platform

(Mouydir massif) that appears to extend northward. It corresponds to the Colbert transverse (Aïn Oulmene) of Guiraud (1973), likely encompassing a fault corridor trending N 15° to N 20°, stretching from Djebel Mimouna in the south to the Hodna. It is also reflected in gravimetric and aeromagnetic maps.

C) Barika - Mdoukal Fault

Highlighted on Guiraud’s (1973) structural maps, this fault separates the pre-Atlasic zone of the Chott el Hodna from the northeastern part of the Zibans (Djebel Metlili) and the Bellezma Mountains, where the series exhibit greater subsidence.

The entirety of these sub-meridian faults appears to correspond to the network of African basement faults from the Tuareg Shield, extending beneath the Saharan platform.

PREVIOUS GEOLOGICAL AND GEOGRAPHICAL RESEARCHS :

The Paleontological studies conducted in the study region during the Upper Cretaceous began in the 19th century by French geologists:

1974 – Donze: Introduced micropaleontology in the southwestern Constantine region, using ostracods as biostratigraphic markers.

1990 – Yahiaoui: Conducted litho-biostratigraphic and sedimentological studies from the Upper Cenomanian to the Lower Coniacian, proposing six new formations applicable to the Belezma-Batna Mountains and the Aurès.

2014 – Slami: Investigated lithology, stratigraphy, and paleoenvironment around the Cenomanian-Turonian boundary in the Belezma-Batna Mountains based on micropaleontological analysis.

2015 – Benmansour et al: Identified 109 ostracod species from the Campanian-Maastrichtian in the Aurès. The study revealed mixed assemblages and two paleobiogeographic provinces influenced by Late Cretaceous ocean currents.

2016 – Benyoucef et al: Studied the Cenomanian-Turonian boundary in the western Saharan Atlas. Their work highlighted major transgressive events and global stratigraphic correlations.

2017 – Benmansour et al: Refined Late Cretaceous stratigraphy in the Aurès using foraminifera. They established three members (Haraoua, Akhdar, Ncham) and recognized 141 foraminiferal species.

2018 – Ferré et al: Analyzed foraminifera, ostracods, and geochemistry in the Théniėt El Manchar section, revealing Cenomanian-Turonian paleoenvironmental changes and bathymetric shifts.

2018 – Aouissi et al.: Provided a systematic list of 49 macrofossil species (corals, bivalves, gastropods, echinoids) from Djebel Metrassi, supporting biostratigraphic subdivisions of the Cenomanian.

2019 – Salmi et al: Documented the occurrence of the coral Aspidiscus cristatus in Cenomanian marls in Batna, marking the Middle Cenomanian.

2020 – Aouissi et al.: Subdivided the Cenomanian Smail Marl Formation in the Belezma and Aurès into detailed ammonite and coral biozones. This includes zones like Mantelliceras, Cunningtoniceras, and Acanthoceras.

2022 – Salmi et al: Identified 73 ostracod species from Djebel Sabaoune, suggesting a shift from deep marine to reefal environments during the Cenomanian.

2022 – Aouissi & Salmi: Described Crassatella baudeti from the lower Cenomanian, highlighting its paleoecological implications in cold, calm, shallow environments.

2022 – Aouissi et al: Studied 35 bivalve species from the Smail Formation, including five newly reported taxa. Results support a marine paleoenvironment linked to the Tethys Realm.

2023 – Benmansour:

(1) Identified nine bivalve species, including first records of rudists such as Vaccinites and Sauvagesia from the Cenomanian-Turonian of the Belezma-Batna Mountains. A biogeographic map was established.

(2) Investigated foraminifera from Djebel Azeb showing opportunistic species responding to paleo-oxygenation and salinity fluctuations.

(3) Reported anatomical anomalies in echinoids (Macraster and Mecaster), a first in Algerian paleontology, suggesting genetic or environmental causes.

2024 – SLalmi et al: Detailed the upper Cenomanian–lower Coniacian succession in the Northern Aurès, emphasizing sea-level changes and tectonic controls on depositional environments.

2024 – Aouissi et al: Analyzed the Cenomanian-Turonian boundary near Batna using ammonites and microfossils to reconstruct environmental and biostratigraphic changes.

2024 – Aouissi et al.: Focused on refining the Cenomanian–Turonian stratigraphy in the Batna Mountains using ammonite and microfossil records to correlate with the southern Tethyan margin

2024 – Aouissi et al: Linked biostratigraphy and environmental reconstructions of the Upper Cenomanian to Lower Turonian interval in Batna to global oceanic events.

2024 – Kherchouche et al.: Discovered a new brachiopod species, Orbirhynchia mantilliana, in the Upper Campanian marly limestones at Djebel Gueroun, within the Globotruncana calcarata Zone.

2024 – Aouissi: Identified 16 echinoid species (including Pygaulus subaequalis, a first for Algeria) from 700 specimens in Batna's Cenomanian strata. Biozones were correlated with sea-level variations

CHAPTER 2 :

SYSTEMATIC

Introduction

This chapter examines the lithostratigraphic and paleontological features of the Coniacian–Santonian sequence in the southwestern Aurès region, a geologically important succession approximately 80 meters thick. The strata consist of alternating marl and limestone layers, showing varied colors, grain sizes, and sedimentary structures that indicate changing depositional environments during the Late Cretaceous. These layers contain a diverse fossil assemblage, providing key insights into the paleoenvironments and ecological relationships of the period. The study carefully analyzes microfossils, such as ostracods and foraminifera, which are abundant and well-preserved, offering valuable data for biostratigraphy and paleoecology. The macrofossil record, including gastropods, bivalves, echinoids, and ammonites, is systematically described with accurate taxonomic classifications, improving our understanding of faunal diversity and evolutionary patterns. By combining lithostratigraphic and paleontological data, this chapter reconstructs the depositional history and ecological significance of the Coniacian–Santonian interval in the southwestern Aurès, supporting regional and global comparisons of Late Cretaceous sedimentary and biological records.

Lithostratigraphic description :

This section provides a descriptive study of the lithostratigraphic succession of Coniacian-Santonian strata in the Southwestern Aures. We were able to document only one detailed lithostratigraphic section (bed by bed).

The "Southwestern Aures Formation" has a thickness of 80 meters and consists of three units characterized by alternating marl and limestone layers.(figure 08)

- **Member I (20 m) figure 08**

This sequence is defined by an alternation of greenish marl and friable limestone layers, with thicknesses ranging from centimeters to meters. The section comprises bioclastic limestone beds, varying from centimeter- to meter-scale, exhibiting a weathered grayish to beige hue and coarse texture, interbedded with intervals of greenish marl.

- **Member II (40 m)**

The basal part of this sequence is characterized by alternating layers of greenish marl and friable bioclastic limestone, with thicknesses ranging from centimeters to meters. These limestone beds, exhibiting a weathered grayish-beige color and coarse-grained texture, vary in scale from thin laminations to meter-thick units, interbedded with greenish marl intervals

The middle portion of the Coniacian–Santonian sequence in the southwestern Aurès region is characterized by alternating micritic limestone layers, including lumachellic and clayey varieties, alongside limestone beds that transition from fine-grained micrite at the base to coarser-grained textures at the top, interbedded with greenish to grayish marl layers.

The uppermost part of the sequence consists of alternating hard bioclastic limestone and friable clayey limestone, both exhibiting medium-grained textures, interspersed with fossiliferous marl layers. These lithological variations reflect diverse depositional environments during the Late Cretaceous, providing a foundation for paleoenvironmental analysis.

- **Member III (20m):**

The sequence primarily consists of alternations of hard, grayish bioclastic limestone with a medium texture, hard brownish limestone, and fossiliferous marl layers.

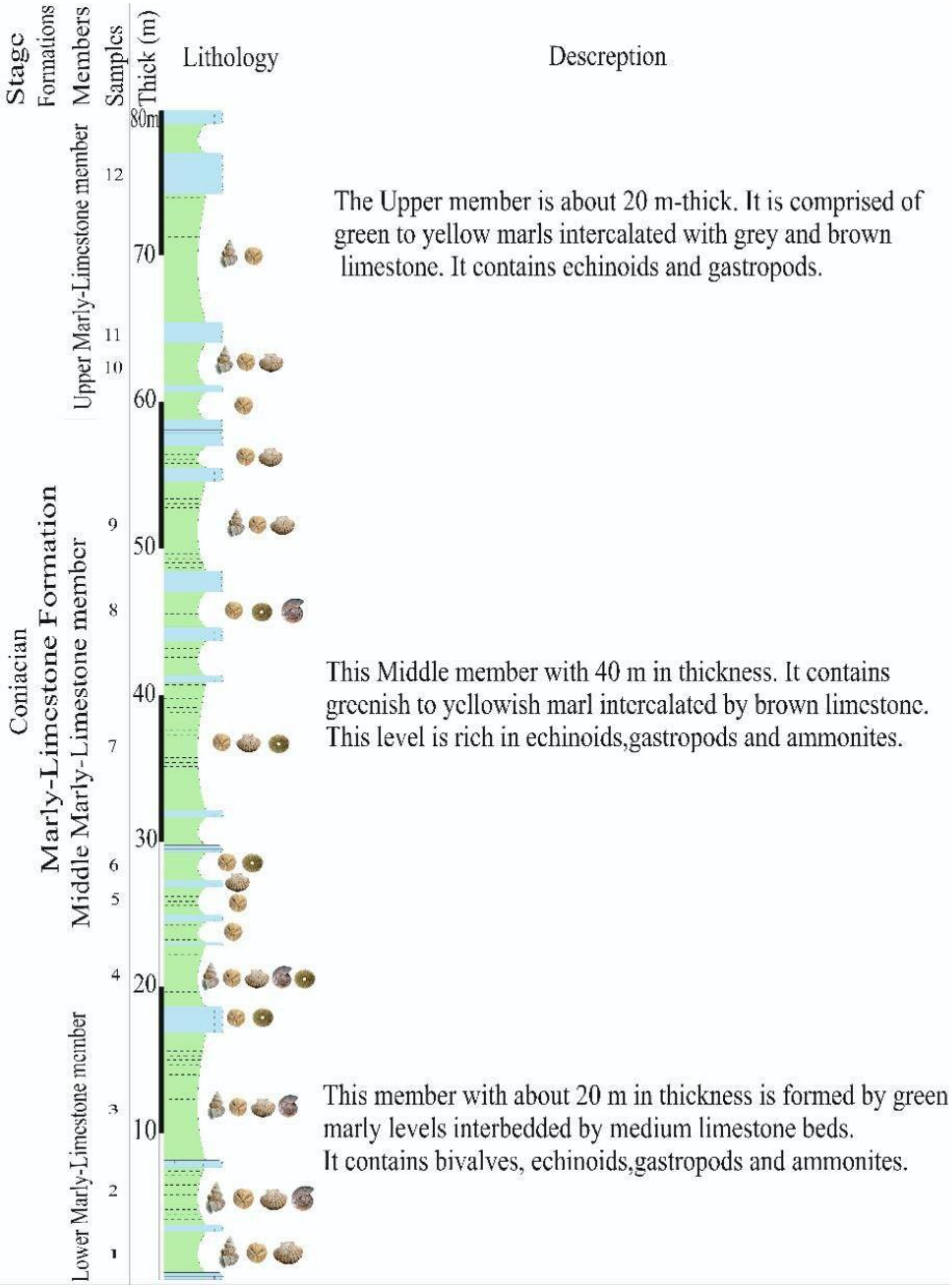

Figure08 : Lithostratigraphic column of the Coniacian-Santonian Strata in the Southwestern Aures

Paleobiodiversity :

- **Macrofauna:**

Macrofauna serves as a valuable paleoenvironmental indicator, frequently utilized in analyzing environmental conditions and reconstructing paleoenvironments during the Holocene. Analysis of samples collected along the formation section was conducted on 09 samples, revealing the presence of

The mollusk fauna comprises three gastropod genera (*Gyrodes*, *Nerinea*, *Tylostoma*) and five bivalve genera (*Protocardia*, *Aphrodina*, *Amphidonte*, *Oscillopha*, *Plicatula*), with representative species including *Protocardia hillana*, *Aphrodina dutrugei*, *Oscillopha dichotoma*, and *Plicatula ferryi*. The echinoid fauna includes two identified genera (*Mecaster*, with species *Mecaster fourneli* and *Mecaster africanus*), alongside a potential third genus pending further identification. Additionally, a single unidentified ammonite genus is recorded. This taxonomic classification based on the classification by Germain (**1969a, b**).

Gastropods

Systematic position:

Phylum: Mollusca, **Linnaeus, 1758**

Class: Gastropoda **,Cuvier, 1795**

Order: Neritimorpha, **Koken, 1896**

Family: Naticidae, **Guilding, 1834**

Genus: *Gyrodes* **,Conrad, 1860**

Gyrodes sp

- **Description:**

Low-spired, globose shell; smooth surface; large aperture; often with umbilicus; thin outer lip.

- **Paleoenvironment**:

Infaunal predators/scavengers in sandy shallow marine substrates. Sohl, N. F. (1987).

- **Remarks:**

Cosmopolitan genus in Late Cretaceous; found across Tethyan and Atlantic platforms.

Kollmann, H. A. (2005).

Order: Heterobranchia**, Burmeister, 1837**

Family: Nerineidae**, Zittel, 1895**

Genus: *Nerinea***, Defrance, 1825**

Nerinea

- **Description:**

High-spired, turreted shells with internal folds (columellar plaits); often large.

- **Paleoenvironment:**

Warm shallow carbonate platforms; reef and lagoon settings. Pchelintsev, V. F. (1965).

- **Remarks:**

Index fossil for Cretaceous carbonate platforms; common in Tethyan regions. Kollmann, H. A. (2005).

Order: Caenogastropoda**, Cox, 1960**

Family: Aporrhaidae**, Gray, 1850**

Genus: *Tylostoma***, Sharpe, 1849**

Tylostoma

- **Description:**

Turreted shell with wide flaring outer lip and distinctive ornamental spines.

- **Paleoenvironment:**

Shallow marine, warm epicontinental seas; epifaunal lifestyle. Abdel-Gawad, G. I. (1986).

- **Remarks:**

Found in North African Cretaceous strata, especially in carbonate-dominated facies. El Qot, G. M. (2006).

▪ Bivalves

Systematic position:

Phylum: Mollusca**, Linnaeus, 1758**

Class: Bivalvia**, Linnaeus, 1758**

Order: Cardiida**, Férussac, 1822**

Family: Cardiidae**, Lamarck, 1809**

Genus: *Protocardia***, Beyrich, 1845**

Protocardia hillana, **(Sowerby, 1813)**

➢ **Description:**

Medium-sized, equivalve to slightly inequivalve, subtrigonal shell; prominent radial ribs and concentric growth lines; robust umbo; posterior margin often truncated.

➢ **Paleoenvironment:**

Inhabited shallow marine environments with sandy or muddy substrates. Likely infaunal(burrowing), adapted to well-oxygenated soft sediments (Jaitly et al., 2000).

➢ **Remark:**

Recorded from Late Cretaceous deposits in Algeria, Tunisia, and parts of West Africa. Its presence is indicative of nearshore environments. Jaitly, and al. (2000).

Order: Hippuritida**, Newell, 1965**

Family: Radiolitidae**, d'Orbigny, 1847**

Genus: Aphrodina**, Bayle, 1878**

Aphrodina dutrugei, **(Coquand, 1862)**

Aphrodina

➢ **Description:**

Inequivalve; left valve generally convex with radial ribs, right valve flatter; often shows concentric lamellae and thickened shells.

- **Paleoenvironment:**

Shallow warm marine carbonate platforms. Aphrodina is considered an indicator of stable inner shelf conditions with moderate energy. Steuber, T. (1999).

- **Remarks:**

Well distributed in Coniacian-Santonian carbonate shelves in North Africa, often associated with rudist biostromes. El Qot, G. M. (2006).

Order: Ostreida, **Férussac, 1822**

Family: Gryphaeidae**, Vyalov, 1936**

Genus: *Amphidonte,* **Fischer, 1887**

Amphidonte

- **Description:**

Small-sized, inequivalve oysters with convex left valve and flatter right valve; often cemented to hard substrates; shell with radial striae.

- **Paleoenvironment:**

Lived attached to firm substrates in shallow marine waters with moderate turbulence, common on carbonate ramps. Dhondt, A. V. (1992).

- **Remarks:**

Their abundance is associated with stable high-energy platforms, often used as paleoenvironmental indicators. Abdelhady, A. A., & Elewa, A. M. T. (2010).

Family: Ostreidae, **Rafinesque, 1815**

Genus: *Oscillopha*, **Malchus, 1990**

Oscillopha dichotoma, **(Bayle, 1849)**

- **Description:**

Small to medium bivalve, features not well documented, likely thin-shelled with radial ornamentation.

- **Paleoenvironment:**

Assumed to live in lagoonal or inner shelf settings with brackish water tolerance. Dhondt, A. V. (1992).

- **Remarks:**

Its stratigraphic and taxonomic position needs better resolution; regionally rare.
El Qot, G. M. (2006).

Order: Pectinida, **Gray, 1854**

Family: Plicatulidae**, Gray, 1854**

Genus: *Plicatula*, **Lamarck, 1801**

Plicatula ferryi, **(Coquand, 1862)**

- **Description:**

Small, strongly ribbed bivalve with irregular outline; often attached to hard substrates; both valves ornamented.

- **Paleoenvironment:**

Shallow marine, reef-associated or hardground-dwelling; common in transgressive deposits. Coquand, H. (1862)

- **Remarks:**

Described by Coquand from Algerian Cretaceous; marker for shallow marine carbonate environments. Coquand, H. (1862).

▪ Echinodermata

Systematic position:

Phylum: Echinodermata**, Klein,1754**

Class: Echinoidea, **Leske, 1778**

Order: Spatangoida**, Claus, 1876**

Family: Toxasteridae**, Lambert,1920**

Genus: *Mecaster*, **Pomel, 1883**

Mecaster fourneli, **(Agassiz, 1847)**

- **Description:**

Heart-shaped test, large and bilaterally symmetrical; well-developed anterior groove; petaloid ambulacra; peristome anterior.

- **Paleoenvironment:**

Lived in soft muddy substrates in outer shelf settings; adapted to low-energy, deeper marine conditions. Néraudeau, D., & Courville, P. (1997).

- **Remarks:**

Common in Upper Cretaceous marls in North Africa; used in stratigraphic correlation.
Smith, A. B., & Bengtson, P. (1991).

Mecaster africanus, , **(Coquand, 1862)**

- **Description:**

Similar to M. fourneli but often smaller and with more defined ambitus. May show regional morphological adaptation.

- **Paleoenvironment:**

Slightly deeper shelf, similar depositional setting. Néraudeau, D., & Courville, P. (1997).

- **Remarks:**

Found across Algeria, Libya, and Tunisia. Considered part of the "African echinoid assemblage" of the Upper Cretaceous. Smith, A. B., & Bengtson, P. (1991).

Mecaster,*. **Pome, 1883***

- **Remarks:**

General attribution to the genus; indicates similar environmental preference as above species possibly with local variation . Smith, A. B., & Bengtson, P. (1991).

Ammonites

Indeterminate ammonite genus.

Microfossils

The study of benthic microfossils (Foraminifera and Ostracods) is an essential tool for reconstructing paleo-environments

Ostracods

Systematics position:

Phylum: Arthropoda**, von Siebold, 1848**
Class: Ostracoda**, Latreille, 1802**
Order: Platycopida, **Sars, 1866**
Family: Cytherellidae**, Sars, 1866**
Genus: *Cytherella***, Jones, 1849**
Cytherella gambiensis, **Apostolescu, 1961**

- **Description:**

Small, smooth-shelled carapace with a subovoid outline; very fine punctation, no strong ornamentation or ridges.

- **Paleoenvironment:**

Typically occurs in low-energy, mid- to outer-shelf marine environments with reduced oxygen levels, often associated with transgressive systems. Gebhardt, H. (1999).

- **Remarks**:

Reported from the Tarfaya Basin (Morocco) and Gafsa Basin (Tunisia), supporting the extension of low-oxygen environments along the southern Tethyan margin during the Late Cretaceous. Bassiouni, M. A., & Luger, P. (1990).

Cytherella ovata, ***(Roemer, 1841)***

- **Description:**

Ovate, smooth valves with a subtle central depression and symmetrical shape; less robust than C. gambiensis.

- **Paleoenvironment:**

Outer shelf to upper slope settings; tolerant of low-oxygen conditions and typically associated with deeper marine facies. Gebhardt, H. (1999).

- **Remarks:**

Documented in Coniacian sequences of southern Tunisia and northern Egypt, indicating similar depositional settings. Bassiouni, M. A., & Luger, P. (1990).

Cytherella **. Jones, 1849**

- **Description:**

Undetermined species; generally smooth, thin-shelled, and possibly juvenile forms; lacking significant ornamentation

- **Paleoenvironment:**

Reflects quiet, stable marine environments, possibly associated with outer ramp conditions. Gebhardt, H. (1999).

Order: Podocopida**, Müller, 1894**

Family: Cyprididae**, Baird, 1845**

Genus: *Paracypris, Sars***, 1866**

Paracypris mdaouerensis, **Andreu, 1991**

- **Description:**

Slightly elongated carapace, robust in structure with occasional fine ridges or tubercles,species described from Algeria.

- **Paleoenvironment:**

Interpreted as marine to marginal marine, possibly euryhaline, with tolerance to salinity fluctuations in lagoonal to deltaic environments. Bassiouni, M. A., & Luger, P. (1990)

- **Remarks:**

Apparently endemic to southeastern Algeria (Mdaouer), suggesting local paleoecological specialization or restricted environments during the Coniacian. Andreu, B. (1991)

Paracypris ***. Sars, 1866***

- **Description:**

Small, oval to sub-rectangular valves, lacking surface ornamentation,thin-shelled.

- **Paleoenvironment:**

Shallow marine to brackish water environments, often found near paleocoastlines or in protected inner shelf settings. Bassiouni, M. A., & Luger, P. (1990)

Order: Podocopida, Müller**, 1894**

Genus: *Amphicytherura***, Butler & Jones, 1957**

Amphicytherura sp

- **Description:**

Subquadrate carapace with distinct reticulate (net-like) ornamentation and a well-defined marginal ridge,moderately robust valves.

- **Paleoenvironment:**

Shallow, warm, open marine environments with moderate energy,often linked to inner to mid-shelf carbonate platforms. Andreu, B. (1991)

- **Remarks:**

Comparable taxa found in the Cretaceous of Morocco (High Atlas) and northern Tunisia,especially in neritic limestone facies. Bassiouni, M. A., & Luger, P. (1990)

- **Foraminifera**

Systematic position:

Class: Foraminifera**, d'Orbigny, 1826**

Order: Globuligerinida, **Loeblich & Tappan, 1984**

Family: Heterohelicidae**, Cushman, 1927**

Genus: *Heterohelix***, Ehrenberg, 1843**

*Heterohelix reussi***, Cushman, 1938**

- **Description:**

Biserial arrangement with elongate chambers and slightly twisted tests;thin walls, sometimes finely ornamented.

- **Paleoenvironment:**

Deep neritic to outer shelf settings; tolerant of oxygen-poor environments, often use as indicators of transgressive or anoxic events. Robaszynski, F., & Caron, M. (1995)

- **Remarks:**

Present in the Coniacian–Santonian of Tunisia (Gafsa) and Morocco; considered widesprea in low-oxygen marine conditions during the Late Cretaceous. Premoli Silva, I., & Verga, D. (2004)

Order: Rotaliida, **Delage & Hérouard, 1896**

Family: Heterohelicidae, **Cushman, 1927**

Genus: *Whiteinella*, Premoli **Silva & Boersma, 1973**

Whiteinella

- **Description:**

Globular test with planispiral to trochospiral coiling; chambers increase in size gradually;finely perforated surface.

- **Paleoenvironment:**

Open marine planktonic forms; often associated with normal salinity and warm water masses. Premoli Silva, I., & Verga, D. (2004)

- **Remarks:**

Found in the Coniacian deposits of Egypt and Tunisia, linked to stable open marine carbonate platforms. Robaszynski, F., & Caron, M. (1995)

Family: Hedbergellidae, **Loeblich & Tappan, 1961**

Genus: *Muricohedbergella*, **Banner & Blow, 1959**

Muricohedbergella flandrini, **Masters, 1977**

- **Description:**

Trochospiral test, rounded chambers, surface covered with fine pores, periphery slightly keeled.

- **Paleoenvironment:**

Warm surface waters in open marine settings; indicator of transgressive episodes in tropical shallow basins. Premoli Silva, I., & Verga, D. (2004)

- **Remarks:**

Widespread in the Late Cretaceous deposits of the Tethys, notably reported in the Saharan Atlas and Northern Egypt. Robaszynski, F., & Caron, M. (1995)

Family: Globotruncanidae, **Reiss, 1957**

Genus: *Marginotruncana*, **Pessagno, 1967**

Marginotruncana sigali, **Reiss, 1957**

- **Description:**

Biconvex trochospiral test with peripheral keel and inflated chambers; umbilicus is wide.

- **Paleoenvironment**:

Upper photic zone planktonic form, indicative of open oceanic conditions during peak transgression. Caron, M. (1985)

- **Remarks:**

Present in Coniacian–Santonian sections in Tunisia and western Libya, showing consistency of pelagic conditions in North Africa. Robaszynski, F., & Caron, M. (1995)

Family: Globotruncanidae, **Reiss, 1957**

Genus: Globotruncana, **Cushman, 1927**

Globotruncana bulloides, **Vogler, 1941**

- **Description:**

Strongly trochospiral test with inflated chambers, well-developed keel; deep sutures.

- **Paleoenvironment:**

Occupies surface to mid-water column; typical of open marine Tethyan environments with relatively high nutrient availability. Caron, M. (1985)

- **Remarks:**

Found in equivalent strata of the Saharan basins and in Moroccan shelf sections,commonly used in regional biostratigraphy. Robaszynski, F., & Caron, M. (1995)

Family: Globotruncanidae, **Reiss, 1957**

Genus: *Globotruncana*, **Cushman, 1927**

Globotruncana

- **Description:**

Indeterminate species; globular to angular chambers, keeled margin; moderate size.

- **Paleoenvironment:**

Oceanic planktonic foraminifer; indicates relatively stable open sea conditions in tropical to subtropical zones. Caron, M. (1985)

- **Remarks:**

Occurs across the North African Tethyan margin from Algeria to Libya. Robaszynski, F., & Caron, M. (1995)

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Family: Globigerinidae, **Carpenter, Parker & Jones, 1862**

Genus: *Archaeoglobigerina*, **Pessagno, 1967**

Archaeoglobigerina

- **Description:**

Rounded test with a low trochospiral coil and globular chambers; surface finely perforate,often smooth.

- **Paleoenvironment:**

Epipelagic form, common in warm shallow seas during transgressive intervals. Premoli Silva, I., & Verga, D. (2004)

- **Remarks:**

Frequently found in the Coniacian to Santonian sediments of Tunisia, Egypt, and the Western Sahara margin. Robaszynski, F., & Caron, M. (1995)

Family: Globotruncanidae, **Reiss, 1957**

Genus: *Dicarinella*, **Blowi, 1959**

Dicarinella

- **Description:**

Planoconvex test with double keel; flat umbilical side, well-developed peripheral margin.

- **Paleoenvironment:**

Outer shelf to upper slope, associated with nutrient-rich pelagic settings. Caron, M. (1985)

- **Remarks:**

Found in the Tethyan realm from Algeria to Jordan; excellent index fossils for upper Coniacian to Santonian sequences. Robaszynski, F., & Caron, M. (1995)

Conclusion

This chapter presents a detailed taxonomic classification of the fossil assemblages from the Coniacian–Santonian strata in the southwestern Aurès region, Batna, northeastern Algeria, highlighting their remarkable diversity. The assemblages include abundant microfossils, such as foraminifera and ostracods, and diverse macrofossils, including gastropods (*Gyrodes*, *Nerinea*, *Tylostoma*), bivalves (*Protocardia*, *Aphrodina*, *Amphidonte*, *Oscillopha*, *Plicatula*), echinoids (*Mecaster fourneli*, *Mecaster africanus*), and a single indeterminate ammonite genus. This faunal diversity reflects the varied marine environments of the Late Cretaceous Tethyan margin, ranging from shallow carbonate platforms to deeper shelf settings. The established taxonomic framework provides a robust foundation for subsequent paleoenvironmental analyses, enabling regional and global correlations of Cretaceous biotic and sedimentary records.

CHAPTER 3 : PALEOENVIRONEMENT AND PALEOGEOGRAPHY

Paleoenvironmental Evolution, and Paleogeographic Reconstruction

1. Introduction

The fossil assemblage collected from the studied section offers an exceptionally richand varied record of Late Cretaceous marine environments. The fossil taxa span multiple invertebrate groups, including ostracods, foraminifera, bivalves, echinoids,gastropods, and ammonites. Each group contributes distinct ecological signals that,when combined, allow for the reconstruction of a dynamic marine ecosystem shapedby episodic sea-level fluctuations, sedimentological changes, and long-term paleogeographic evolution. Rather than classifying these fossils solely by taxonomy,this chapter identifies mixed ecological assemblages based on co-occurrence and inferred environmental affinities. These assemblages are then used to interpret thedepositional settings and paleogeographic context of the area (e.g., BouDagher-Fadel,2008; Whatley & Stephens, 1977).

2- Paleoecological Assemblages:

These assemblages reveal:

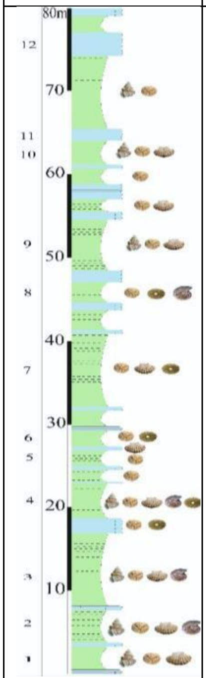
- The vertical and lateral variation of depositional environments across a marineplatform.

- The influence of global sea-level changes on sedimentation patterns.

-The importance of biotic indicators for paleogeographic positioning within the

Tethyan realm.

Tabel01 : Stratigraphic distribution of macrofaune

Lithology	Bivalves					Gasteropods			Sea urchins			Ammonite
	Protocardia hillana	*Aphrodina dutrugei*	*Amphidonte sp*	*Oscillopha dichotoma*	*Plicatula ferryi*	*Gyrodes sp*	*Nerinea sp*	*Tylostoma sp*	*Mecaster fourneli*	*Mecaster africanus*	*Mecaster sp.*	
						+	+	+	+	+	+	+
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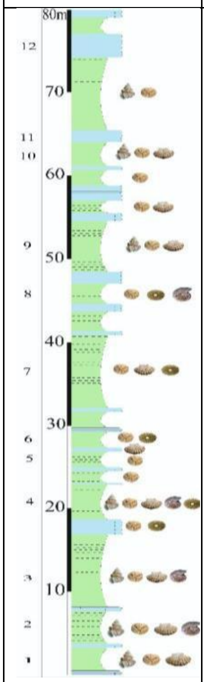
Tabel02 : Stratigraphic distribution of microfaune

Lithology	Ostracod					Foraminifera					
	Cytherella gambiensis	*Cytherella ovata*	*Paracypris mdaouerensis*	*Paracypris sp*	*Amphicytherura sp*	*Heterohelix reussi*	*Whiteinella sp*	*Muricohedbergella flandrini*	*Marginotruncana sigali*	*Globotruncana bulloides*	*Dicarinella sp*
	+		+	+	+	+	+	+	+		
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2.1 Assemblage I: Deep-Marine Benthic to Outer Shelf Assemblage

Fossil Taxa:

A- **Ostracoda:** *Cytherella gambiensis, Cytherella ovata, Cytherella sp., Paracypris mdaouerensis, Paracypris sp., Amphicytherura sp.*

B- Echinoidea: *Mecaster fourneli, Mecaster africanus, Mecaster sp.*

C- Foraminifera: *Heterohelix reussi, Whiteinella sp., Muricohedbergella flandrini, Marginotruncana cf. sigali, Globotruncana bulloides, Globotruncana sp., Archaeoglobigerina sp., Dicarinella sp.*

This assemblage is characteristic of outer shelf to upper bathyal settings, reflectingcalm, low-energy conditions. The combination of benthic ostracods, deposit-feedingechinoids, and planktonic foraminifera suggests sedimentation in a deeper marinezone with a well-oxygenated water column and normal salinity. The microfaunaldominance implies a relatively low sedimentation rate, allowing for continuousaccumulation of pelagic material (Van Morkhoven, 1963; Reboulet et al., 2018).

Interpretation:

The presence of Cytherella and Paracypris, which prefer quiet, deeper environments,combined with planktonic foraminifera such as Globotruncana and Dicarinella,highlights a basin influenced by open-ocean circulation (Robaszynski & Caron,1979). Mecaster, an irregular echinoid adapted to soft muddy substrates, confirms thelow-energy conditions typical of distal shelf environments. This assemblage supportsa scenario of stable marine transgression, possibly part of a regional deepening trend linked to global eustatic sea-level rise (Haq et al., 1987).

2.1 Assemblage II: Shallow Neritic to Inner Shelf Assemblage

Fossil Taxa:

A- Bivalvia: *Protocardia hillana, Aphrodina dutrugei, Aphrodina sp., Amphidonte sp., Oscillopha dichotoma, Plicatula ferryi* (Coquand, 1862)

B- Gastropoda: *Gyrodes sp., Nerinea sp., Tylostoma sp.*

C- Ostracoda: *Paracypris sp., Amphicytherura sp.*

This assemblage reflects a shallow marine setting, most likely from the inner to middle shelf, with a mix of carbonate and siliciclastic sedimentation. Substrates ranged from soft, muddy bottoms to more consolidated carbonate platforms. The fossil taxa suggest a moderate to low-energy regime, possibly influenced by periodic storms or lagoonal isolation (Aberhan, 1999).

Interpretation:

The combination of Aphrodina, Plicatula, and Amphidonte indicates life on and within soft substrats, often in calm water with stable salinity (Seilacher, 1982).Nerinea and Tylostoma, genera typically associated with conditions of platforms and reefal margins, suggest intervals of reef development or nearby carbonate sources(Fürsich & Wendt, 1977). Gyrodes, a generalist gastropod, and ostracods like Amphicytherura imply tolerance to a range of salinities and substrates. Overall, this assemblage reveals a transitional setting between open marine and nearshore, possibly with lagoonal or deltaic influence during regressive events.

2.2 Assemblage III: Open Marine Pelagic and Nektonic Assemblage

Fossil Taxa:

Ammonite: *Volutomorpha sp.*
Foraminifera *(Planktonic): Globotruncana spp., Marginotruncana cf.sigali,*
Dicarinella sp., Muricohedbergella flandrini

Paleoenvironment:

This assemblage is indicative of fully marine, pelagic settings within the outer shelf to upper bathyal zones. The dominance of planktonic foraminifera and the presence of ammonites suggest a deep-water environment with strong water-column stratification and high nutrient productivity (Premoli Silva & Sliter, 1999).

Interpretation:

The combination of nektonic (Volutomorpha) and planktonic (Globotruncana,Marginotruncana) components indicates open ocean influence, with a fully marine connection to the Tethyan seaway. These taxa are excellent biostratigraphic markers, placing the age of deposition in the Turonian to Coniacian stages (Caron, 1985). The absence of benthic faunas may reflect deeper water or oxygen-restricted bottom conditions.

Table of Mixed Assemblages :

Assemblage Type	MainFossilTaxa	Interpreted
Deep-Marine to Outer Shelf	*Cytherella,* *Paracypris,* *Mecaster,* *Globotruncana,* *Dicarinella.*	Outer shelf, low-energy, well-oxygenated
Shallow Neritic to Inner Shelf	*Aphrodina* *Plicatula* *Oscillopha* *Gyrodes* *Nerinea* *Amphidonte*	Inner shelf, carbonate-siliciclastic transition
Open Marine Pelagic & Nektonic	*Volutomorpha* *Globotruncana* *Muricohedbergella* *Dicarinella*	Pelagic zone, open marine connection

Table03: Mixed Assemblages

4. Paleogeographic Implications

The studied fossil assemblages indicates that the studied region was located on the southern margin of the Tethys Ocean during the Late Cretaceous (Stampfli & Borel, 2002). It formed part of a wide epicontinental shelf system, subjected to episodic transgressions and regressions.

- ✓ Assemblage I support a distal shelf to upper slope environment, likely representing the deepest setting preserved in the section. Assemblage II, mixed faunal content shallow marine indicators, corresponds to nearshore platforms and embayments, influenced by coastal currents and sediment influx from terrestrial sources. Assemblage III represents oceanic incursions into the platform interior, highlighting the region's paleobiogeographic connectivity to the broader Tethyan marine corridor (Scotese, 2014).

- ✓ wide paleogeographic distributions of taxa such as *Globotruncana*, *Nerinea*, and *Mecaster*, regional connections with Europe, the Middle East, and North Africa. This distribution aligns with reconstructions of the Tethys as a vast, equatorial marine passage during the Late Cretaceous (Ziegler, 1988).

Conclusion

The taxonomic classification of fossil assemblages into ecologically mixed groups enables a robust reconstruction of the paleoenvironmental evolution in the Aurès region. Each assemblage corresponds to a distinct marine habitat, spanning sheltered inner shelf settings to expansive open pelagic zones.

In conclusion, the fossil record from this region reveals a dynamic marine ecosystem shaped by transgressive–regressive cycles and biogeographic interactions. These findings provide critical insights into the development of Cretaceous marine ecosystems in North Africa, enhancing our understanding of regional and global paleoceanographic dynamics.

GENERAL CONCLUSION

Conclusion :

This study of the Coniacian–Santonian (~89–83 Ma) strata in the southwestern Aurès, Algeria, has better understanding of Late Cretaceous paleobiodiversity and paleoenvironmental conditions along the southern Tethyan margin.

The fossil recorded reveals significant biodiversity, gastropods (Gyrodes *sp.*, *Nerinea sp.*, *Tylostoma sp.*), bivalves (*Protocardia hillana*, *Aphrodina dutrugei*, *Amphidonte sp.*, *Oscillopha dichotoma*, *Plicatula ferryi*), echinoids (*Mecaster fourneli*, *Mecaster africanus*), and an ammonite genus, alongside ostracods (*Cytherella gambiensis, Cytherella ovata, Paracypris mdaouerensis, Amphicytherura sp*.) and foraminifera (Heterohelix reussi, Whiteinella sp., Muricohedbergella flandrini, Marginotruncana sigali, Globotruncana bulloides, Archaeoglobigerina, Dicarinella). These taxa collectively demonstrate a vibrant marine ecosystem with adaptations to diverse habitats..

These taxa paint three distinct paleoenvironments shaped by global sea-level swings: (1) sunlit, shallow neritic platforms of carbonate and siliciclastic sediments, where *Nerinea*, *Aphrodina*, and *Plicatula* formed reef-like communities under tropical warmth; (2) deeper, oxygen-starved outer shelf zones, home to *Mecaster*, *Cytherella*, and *Heterohelix* during transgressive highs; and (3) nutrient-rich pelagic waters hosting *Volutomorpha* and *Globotruncana*, tied to open Tethyan currents. Cyclic shifts between marly-limestones and siliciclastics, driven by eustatic sea-level rises in a balmy climate, sculpted these diverse habitats, from tranquil coastal lagoons to oxygen-poor shelves. Paleogeographically, the Aurès stood as a vital corridor within the Tethyan epicontinental shelf, bridging North African, Mediterranean, and Middle Eastern ecosystems, as shown by cosmopolitan taxa like *Globotruncana* and *Mecaster*. This work sharpens regional stratigraphic frameworks and enriches global Cretaceous paleoceanography, revealing how climate, sea-level dynamics, and biotic evolution intertwined to shape the Tethyn

These findings strengthen regional stratigraphic frameworks and enhance global perspectives on Cretaceous paleoceanography, particularly regarding transgression-driven environmental shifts. This research provides a robust platform for future studies, which could employ advanced methodologies to further explore the paleoecological and paleoenvironmental evolution of the Tethyan margin.

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