People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University of Oum El Bouaghi
Faculty of Earth Sciences and Architecture

Thesis

Presented to ob[1]tain

3rd Cycle Doctorate

Branch: Geology
Specialty: Applied Dynamic Geology

Title:

Geodynamical frame and cretaceous anoxic events: study area Tebessa

---

Presented by:
BEKHOUCH Garmia

Publicly defended on ../../2023 in front of the following committee members:

N°	first and last name	Grade	University	Quality
01	BOUMEZBER Abdrahman	Prof.	University of Oum El Bouaghi	President
02	KHIARI Abdelkader	Prof.	University of Oum El Bouaghi	Supervisor
03	DJERRAB Abderazak	Prof.	University of Guelma	Examiner
04	CHOUAI Said	MCA	University of Oum El Bouaghi	Examiner
05	MANCHAR Nabil	MCA	University of Oum El Bouaghi	Examiner

1

Acknowledgments

I would like to seize this moment to extend my heartfelt appreciation to all those who have been instrumental in the fulfillment of my Ph.D. thesis. Foremost, I extend my deepest gratitude to my dedicated thesis mentor, Professor Mr. KHIARI Abdelkader. His unwavering support, guidance, and wealth of expertise have significantly influenced the direction and quality of this research. I wish to convey my sincere thanks to the jury president, Pr BOUMEZBER Abdahman , and my thesis examiners, Pr DJERRAB Abderazak, Pr Chouai Said, Dr Menchar Nabil Their meticulous assessments and valuable feedback have greatly elevated the academic excellence of this thesis.

I'm particularly appreciative of Professor Markham Puckett from the University of Southern Mississippi, USA, for affording me the opportunity to undertake an internship at USM. Their support, mentorship, and knowledge sharing during the internship have enriched my research experience and broadened my horizons. Acknowledgment is also due to the faculty and staff of the Department of Geology at Larbi Ben M'Hidi University. Their unwavering support, availability of resources, and collaborative environment have significantly eased the progression of my research.

I extend my sincere appreciation for Dr Ruault-Djerrab Muriel exceptional guidance and support throughout our collaboration. Our expertise and kindness have significantly contributed to the success. I am truly grateful for the invaluable mentorship you have provided.

I'm profoundly indebted to my colleagues and fellow researchers for their enlightening discussions, valuable insights, and technical assistance. Their scholarly contributions and camaraderie have been invaluable. I extend my appreciation to my friends and family for their unwavering encouragement, understanding, and steadfast support during the highs and lows of this academic journey. Their love, unwavering faith in my abilities, and uplifting words have been a constant wellspring of motivation.

Lastly, I wish to express my deep gratitude to the funding organizations and scholarships that have generously provided financial support for my research (University of L’Arbi Beni M’Hidi Oum El Bouaghi & University of Southern Mississippi). Their generosity has made it possible for me to undertake this study and pursue my academic aspirations.

In conclusion, my immense gratitude goes out to all individuals and institutions who have played a pivotal role in the successful completion of my Ph.D. thesis on the subject of "Geodynamical frame and cretaceous anoxic events: study area Tebessa." The contributions, guidance, and support have been indispensable in achieving this significant milestone in my academic voyage.

Abstract

The Middle Cretaceous period, spanning from approximately 100 to 89 million years ago, represents a pivotal era in Earth's geological history. Characterized by a notably warm climate and the absence of polar ice caps, this epoch is defined by a remarkable global transgression culminating at the Cenomanian-Turonian boundary approximately 93.5 million years ago. This transgressive event, lasting 2 to 3 million years, coincided with a profound global anoxic crisis, known as Oceanic Anoxic Event 2 (OAE2). The impacts of OAE2 are imprinted lithologically, biologically, and chemio-stratigraphically across sedimentary basins in Africa, Europe, and America.

Algeria's northern margin, particularly the Tebessa region, was no exception to this transformative geological episode. The transgression reached into the Saharan Atlas, extending its influence even to the distant Sahara lands north of the Hoggar Mountains. The result was the deposition of fossiliferous marl-limestone sediments overlying Albian detrital deposits.

The eastern Saharan Atlas, located at the eastern extremity of the extensive Atlasian system, assumed the form of a subsiding basin during the Cretaceous. Here, thick sedimentary sequences accumulated, presenting an excellent opportunity for geological investigation. This research focuses on four key sections: Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana, and Djebel Boulhaf Dir in Tebessa.

The primary aim of this thesis is twofold. Firstly, it strives to establish a highly precise stratigraphic framework for the Middle Cretaceous in the region, building upon prior research in the Atlasian domain. The identification of planktonic foraminiferal zones and stage and sub-stage boundaries is a key part of this endeavor. Secondly, this research seeks to reconstruct paleoenvironments using a combination of lithostratigraphy and quantitative micropaleontology, with a focus on the distribution of benthic and planktonic foraminifera and ostracods.

The microscopic realms of foraminifera and ostracods serve as the lenses through which we explore the enigmatic geological history of Tebessa during the Cretaceous. Through them, we aim to unveil the silent testimonies of Earth's ancient environments and unlock the secrets of this intriguing epoch.

In conclusion, our study of the geodynamical frame and Cretaceous anoxic events in the Tebessa region provides valuable insights into the ever-changing paleoenvironments, intricately linked to geological processes. These findings underscore the dynamic nature of the region's geological history, shedding light on the complex interplay of tectonics, sea level changes, sedimentary basin evolution, climate, and local geological structures. This knowledge enhances our understanding of Earth's geological patterns and processes, contributing significantly to the broader field of geology and paleontology.

Keywords: *Late Cretaceous, Geodynamic Frame, Paleoenvironments, Foraminifera, Ostracods, Sedimentary Basins, Tebessa.*

Résumé

La période du Crétacé moyen, s'étendant d'environ 100 à 89 millions d'années en arrière, représente une ère cruciale de l'histoire géologique de la Terre. Caractérisée par un climat nettement chaud et l'absence de calottes glaciaires polaires, cette époque est définie par une remarquable transgression mondiale culminant à la limite Cénomanien-Turonien, il y a environ 93,5 millions d'années. Cet événement de transgression, d'une durée de 2 à 3 millions d'années, a coïncidé avec une profonde crise anoxique mondiale, connue sous le nom d'Événement Anoxique Océanique 2 (OAE2). Les impacts d'OAE2 sont imprimés lithologiquement, biologiquement et chemio-stratigraphiquement dans les bassins sédimentaires en Afrique, en Europe et en Amérique.

La marge nord de l'Algérie, en particulier la région de Tébessa, n'a pas fait exception à cet épisode géologique de transformation. La transgression a atteint l'Atlas saharien, étendant son influence jusqu'aux terres lointaines du Sahara au nord des montagnes du Hoggar. Il en est résulté le dépôt de sédiments marno-calcaires fossilifères recouvrant des dépôts détritiques albien.

L'Atlas saharien oriental, situé à l'extrémité orientale du vaste système atlasique, a pris la forme d'un bassin en subsidence au cours du Crétacé. Ici, d'épaisses séquences sédimentaires se sont accumulées, offrant une excellente opportunité pour des investigations géologiques. Cette recherche se concentre sur quatre sections clés : Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana et Djebel Boulhaf Dir à Tébessa.

L'objectif principal de cette thèse est double. Premièrement, elle s'efforce d'établir un cadre stratigraphique très précis pour le Crétacé moyen dans la région, en s'appuyant sur des recherches antérieures dans le domaine atlasique. L'identification des zones de foraminifères planctoniques et des limites de stades et de sous-étages en est une partie essentielle. Deuxièmement, cette recherche cherche à reconstruire les paléoenvironnements en utilisant une combinaison de lithostratigraphie et de micropaléontologie quantitative, en mettant l'accent sur la distribution des foraminifères benthiques et planctoniques et des ostracodes.

Les mondes microscopiques des foraminifères et des ostracodes servent de lentilles à travers lesquelles nous explorons l'histoire géologique énigmatique de Tébessa pendant le Crétacé. À travers eux, nous visons à dévoiler les témoignages silencieux des anciens environnements de la Terre et à percer les secrets de cette époque intrigante.

En conclusion, notre étude du cadre géodynamique et des événements anoxiques du Crétacé dans la région de Tébessa fournit des informations précieuses sur les paléoenvironnements en constante évolution, étroitement liés aux processus géologiques. Ces résultats soulignent la nature dynamique de l'histoire géologique de la région, éclairant la complexité des interactions de la tectonique, des changements du niveau de la mer, de l'évolution des bassins sédimentaires, du climat et des structures géologiques locales. Cette connaissance renforce notre compréhension des schémas et des processus géologiques de la Terre, contribuant de manière significative au domaine plus vaste de la géologie et de la paléontologie.

Mots-clés : *Crétacé supérieur, cadre géodynamique, paléoenvironnements, foraminifères, ostracodes, bassins sédimentaires, histoire géologique.*

الملخص

فترة الكريتاسي الوسطى، التي تمتد تقريبًا من 100 إلى 89 مليون سنة مضت، تمثل فترة مهمة في تاريخ الجيولوجيا الأرضية. تتميز بمناخ دافئ بشكل ملحوظ وغياب أغطية جليدية قطبية باردة، ويتميز هذا العصر بتصاعد عالمي رائع تطور للذروة عند الحدود بين السينوماني والتيرونيان تقريبًا قبل 93.5 مليون سنة. هذا الحدث التصاعدي، الذي استمر لمدة 2 إلى 3 مليون سنة، تزامن بشكل كبير مع أزمة أوكسينية عالمية عميقة، تعرف باسم حدث عدم الأكسجين الأوقياني 2 .(OAE2) تظهر تأثيرات OAE2 بشكل ليثولوجي وبيولوجي وكيميائي تكتسبه حوضيات رسوبية في أفريقيا وأوروبا وأمريكا.

لم يكن الحافة الشمالية للجزائر، ولا سيما منطقة تبسة، استثناءًا من هذا الحدث الجيولوجي التحولي. بل وصلت الزيادة في البحر إلى الأطلس الصحراوي، ممتدة تأثيرها حتى أراضي الصحراء البعيدة شمال جبال هوغار. ونتيجة لذلك، تم ترسيب رواسب طينية كلسية تحتوي على أحافير في هذه المنطقة تغطي رواسب ألبية نتجت عنها.

الأطلس الصحراوي الشرقي، الموجود في الطرف الشرقي للنظام الأطلسي الشاسع، اكتسب شكلاً حوض انضباطيًا خلال العصر الكريتاسي. هنا، تراكمت سلاسل رسوبية سميكة، مما يوفر فرصة ممتازة للتحقيق الجيولوجي. تتركز هذه البحث على أربعة أقسام رئيسية: جبل زيتونة، وجبل بكاريا، وبلالة وادي مسكيانا، وجبل دير في تبسة.

الهدف الرئيسي لهذه الرسالة هو مزدوج. أولاً، يسعى إلى إنشاء إطار تصريفي دقيق جدا للكريتاسي الوسطى في هذه المنطقة، استنادًا إلى أبحاث سابقة في ميدان الأطلس. إن تحديد مناطق الفورامينفرات الطفيلية وتحديد حدود المراحل والأقسام الفرعية هو جزء رئيسي من هذا الجهد. ثانيا، تسعى هذه الأبحاث إلى إعادة بناء البيئات القديمة باستخدام مزيج من الليثوستراتيجرافيا والميكروباليونتولوجيا الكمية، مع التركيز على توزيع الفورامينفرات القاعية والطفيلية والقواقع.

عوالم الفورامينفرات والقواقع تخدم بمثابة العدسات من خلالها نستكشف التاريخ الجيولوجي الغامض لتبسة خلال العصر الكريتاسي. من خلالها، نهدف إلى كشف الشهادات الصامتة لبيئات الأرض القديمة وكشف أسرار هذا العصر المثير.

في الختام، تقدم دراستنا للإطار الجيوديناميك الجيولوجي وأحداث الفقدان الأوكسجيني في منطقة تبسة إلى رؤى قيمة حول البيئات القديمة القائمة بالتغير المرتبطة بعمليات جيولوجية. تسلط هذه النتائج الضوء على الطبيعة الديناميكية لتاريخ المنطقة، ملقيةً بذلك الضوء على التفاعل المعقد لعوامل محلية مثل الاصطفاف وتغير مستوى سطح البحر وتطور حوض الرسوب والمناخ والهياكل الجيولوجية المحلية. يزيد هذا المعرفة من فهمنا لأنماط وعمليات الجيولوجيا الأرضية، مما يسهم بشكل كبير في مجال الجيولوجيا وعلم الأحفوريات عمومًا.

الكلمات الرئيسية: الكريتاسي العلوي، الإطار الجيوديناميكي، البيئات القديمة، الفورامينفرات، القواقع، حوض الرسوبات، تاريخ جيولوجي.

Thesis structure

Chapter I: Generality

- Introduction

- Setting the stage for the study

- Highlighting the significance of the Middle Cretaceous period

- Discussing the great transgression and global anoxic event (OAE2)

- Introduction to the study area: Tebessa in Algeria

Chapter II: Materials and Methods

- Introduction

- Discussing the importance of comprehensive materials and methods

- Providing an overview of fieldwork and laboratory procedures

- Fieldwork

- Detailed description of field trips to Tebessa's sections

- Collection and labeling of marl samples, ammonites, and bivalves

- Laboratory Techniques

- Overview of sample treatment processes

- Detailed description of sample preparation techniques

- Introduction of new laboratory methods and their significance

- Thin section analysis and its applications

- Application of calcimetry and Total Organic Carbon (TOC) analysis

Chapter III: Introduction to Ostracods: Microscopic Shells, Macroscopic Insights

- Introduction

- Establishing the importance of ostracods

- Their significance as paleoenvironmental indicators

- Overview of the diversity and fossil record of ostracods

- Historical developments in ostracod research

Chapter IV: Constraint Optimization

- ➢ Introduction

- Highlighting the significance of the Middle Cretaceous Age

- Emphasizing the role of foraminifera and ostracods

- Introduction to constraint optimization as a research concept

- ➢ Constraint Optimization

- Detailed explanation of the concept and its application in the study

- Linking various species of foraminifera and ostracods

- Integration of data from different sources to create a coherent timeline

Chapter V: Biostratigraphy and Paleoenvironment

- ➢ Introduction

- Emphasizing the role of geology in understanding Earth's history

- Introduction to the study area and its geological significance

- ➢ Biostratigraphy and Paleoenvironment

- Exploration of the geological history in four Tébessa sections: Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana, and Djebel Boulhaf Dir

- Detailed paleoenvironmental reconstructions using microfossil data

- Insights into changes in water depth, proximity to the shore, and environmental dynamics

- Application of biostratigraphy to date rocks and understand changing paleoenvironmental conditions

General Conclusion

- Summarizing the key findings of the study

- Revisiting the objectives and contributions of the research

- Reflecting on the significance of the geodynamical frame and Cretaceous anoxic events in Tébessa

- Discussing the broader implications of the study for the field of geology and paleontology

Recommendation

LIST OF FIGURES

LIST OF PHOTOS

LIST OF TABLES

LIST OF ABBREVIATION

N	North
S	South
W	West
E	Est
DJ	Djebel
Fig	Figure
m	Meter

SRTM	Shuttle Radar Topography Mission
DEM	Digital Elevation Model
USGS	United States Geological Survey
GPS	Global Positioning System
OAE	Oceanic Anoxic Event
CONOP	Constrained Optimization
LOC	Line of Correlation
TOC	Total Organic Carbon
H2O2	Hydrogen Peroxide
Na2SO4· H2O	Sodium Sulfate Dihydrate
HCl	Hydrochloric Acid
CO2	Carbon Dioxide
CaCO3	Calcium Carbonate
C	Carbon (element)
Na2SO4	Sodium Sulfate
FADs	First Appearance Datums
LADs	Last Appearance Datums
Kd+	Kitchinites darwini
Dc+	Diplomoceras cylindraceum
Al	Aluminum
TSP	Traveling Salesman Problems
Ph. D	Doctor of Philosophy

Contents

General Introduction

The Middle Cretaceous period, spanning approximately from 100 to 89 million years ago, represents a remarkable chapter in Earth's geological history. It is characterized by a distinctly warm climate and the conspicuous absence of polar ice caps. The defining feature of this period is the profound global transgression that reached its zenith at the Cenomanian-Turonian boundary around 93.5 million years ago. This transgressive episode, extending over 2 to 3 million years, culminated in a moment when global sea levels soared to their maximum height of around 250 meters above present-day levels, as evidenced in the works of Arthur et al. (1987) and Busson et al. (1999). This dynamic geological event was closely accompanied by a worldwide anoxic crisis, denoted as OAE2 (Oceanic Anoxic Event 2) by Schlenger and Jenkyns (1976) and Arthur et al. (1987).

The effects of OAE2 are manifest lithologically, biologically, and chemio-stratigraphically. Sedimentary basins across the continents of Africa, Europe, and America bear the enduring imprint of these transformations. On the northern margin of Africa, and particularly in Algeria, the transgression permeated the Saharan Atlas, influencing even the distant Sahara lands to the north of the Hoggar Mountains. Fossiliferous marl-limestone sediments emerged, overlaying Albian detrital deposits in this region, as observed by Laffitte (1939), Fabre (1976), and Amard et al. (1981).

Nestled at the eastern extremity of the formidable Atlasian system, the eastern Saharan Atlas assumed the form of a subsiding basin during the Cretaceous, as delineated by Laffitte (1939), Herkat (1999, 2002, 2004, 2006, 2007). This period bore witness to the accumulation of extensive sedimentary sequences. The continuity and fossil richness of these deposits render them exceptional cross-sections for geological investigation. The chosen study sections, namely Zitouna, Bekkaria, Blala, and Dir in Tebessa, serve as the epicenter of our research endeavors.

This thesis brings together the fruits of meticulous micropaleontological examinations of foraminifera and ostracods within these four sections, which collectively encompass the Cenomanian to Turonian stages. Employing a multifaceted approach that incorporates micropaleontology and sedimentology, the primary objectives of this research are twofold. First, it seeks to construct a highly precise stratigraphic framework for the Middle Cretaceous in this region, complementing prior work conducted by esteemed predecessors in the Atlasian domain

(Laffite, 1939; Benkherouf, 1987, 1988; Chikhi, 1998). This task involves the identification of planktonic foraminiferal zones and the definition of stage and sub-stage boundaries.

Secondly, this thesis endeavors to reconstruct paleoenvironments through a comprehensive analysis of lithostratigraphy and quantitative micropaleontology, focusing on the distribution of benthic and planktonic foraminifera and ostracods. By unraveling the enigmatic geological history and environmental conditions of the Tebessa region during the Cretaceous period, this research seeks to contribute significantly to the broader understanding of geodynamic processes and anoxic events that shaped our planet's past. Through the microscopic worlds of foraminifera and ostracods, we aim to decipher the silent testimonies of Earth's ancient environments and unlock the secrets of this intriguing epoch.

CHAPTER 01:

GENERALITIES

1. Introduction

The study area is located in the northeast region of Algeria, in the province of Tebessa, bordering Tunisia. It is chosen for its rich geological features, ideal for paleontological studies.

The research methodology employed a systematic sampling approach, focusing on four distinct sections to represent the region's paleontological and geological features. These sections cover a variety of sedimentary and geological conditions, crucial for understanding Earth's history and paleoenvironments.

The Tebessa area is part of Algeria's Saharan Atlas Mountains, extending from the western to the eastern border. It contains Quaternary deposits and intrusive Triassic sequences, disrupting host rock layers and causing structural features observed in various locations.

Several geological studies, including those by Burollet in 1956, Dubourdieu in 1956 and 1959, and Vila in 1980 and 1996, have contributed to understanding the region's geology.

2. Geographical Framework

The dissertation's study area is located in the northeast region of Algeria, in the province of Tebessa. This region shares a border with the neighboring country Tunisia. As a result, it is a suitable location for various paleontological studies.

The dissertation's research methodology utilized a systematic sampling approach, which involved four distinct sections. These four distinct sections were selected for the research. Each of these sections was carefully chosen to exhibit a sample of the regions to represent the various paleontological and geological features that can be found in this region.

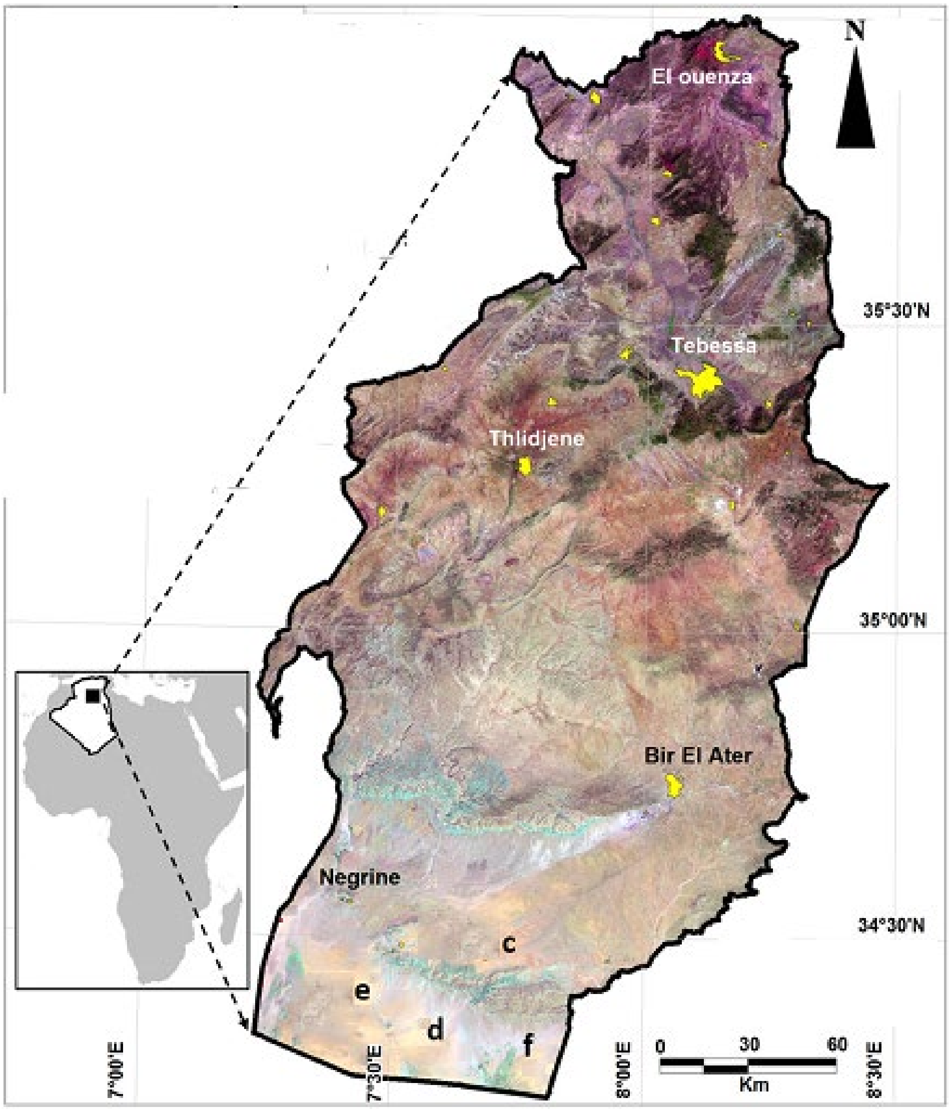


Figure.1: study area location

The sections were selected to cover a similarity of sedimentary and geological conditions, which are important in comprehending the Earth's history and the region's paleoenvironments. This feature also helps visualize the locations of the samples collected. (Figure. 1)

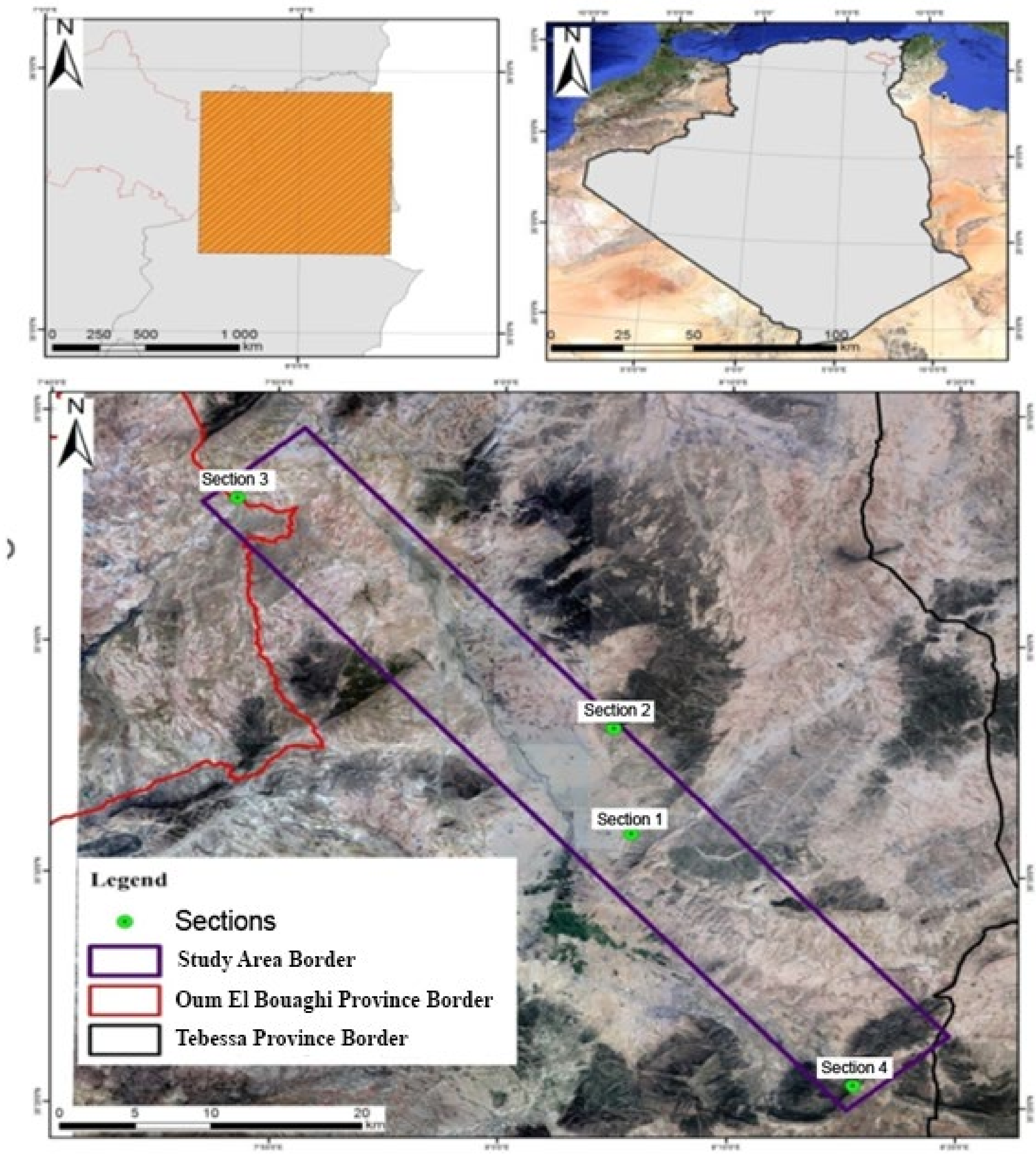


Figure. 2: Studied sections localities google earth

The map is a valuable reference tool that allows readers and researchers to gain a deeper understanding of the region's geographical features. The chosen sections and the fieldwork carried out within the study area are crucial to the dissertation's research objectives. They provide valuable information on the region's paleontological and geological history, which can help us better understand the Earth's past and its environmental changes over time. (Figure. 2)

3. Geological Setting:

The Tebessa area, which is located in Algeria's northeast province, is an important constituent of the nation's Saharan Atlas Mountains (Figure. 2). Those mountains range, encompassing Algeria from its western border to its eastern frontier, is a prominent linear anomaly.

Extending beyond Algeria's borders, those mountain ranges are known as the "Tunisia Atlas," (Ghomsi et al. 2020), and its importance as a geological feature is acknowledged by its name. Its varied geological characteristics are crucial to comprehending the Earth’s past and its complex history (Frodeman. 1995).

Numerous Quaternary deposits are also commonly found in the sedimentary sequences of this region, especially in the flat plains. These archives are regarded as significant geological repositories and can provide researchers with valuable data on the area's geological history (Muhs. 2013).

The Tébessa region's sedimentary cover is also characterized by the presence of intrusive Triassic sequences (Figure. 2). These occurrences disrupt the host rock layers, causing structural features (Bencharef. 2022). These disturbances can cause various changes, such as the reduction in the thickness of sediment and the inversion of dip angles. They are commonly observed in the Ouasta, Djebels Djebissa, and Ouenza (Bencharef. 2022). These locations are ideal for conducting in-depth studies on this topic.

Different geological studies have helped researchers gain a deeper understanding of the area's geology. Some of the prominent studies that were carried out include those of Burollet in 1956, Dubourdieu in 1956 and 1959, and Vila in 1980 and 1996. (Figure. 3)

Their contributions have helped expand the knowledge base of the region's geology and provided additional details to the dissertation's research.

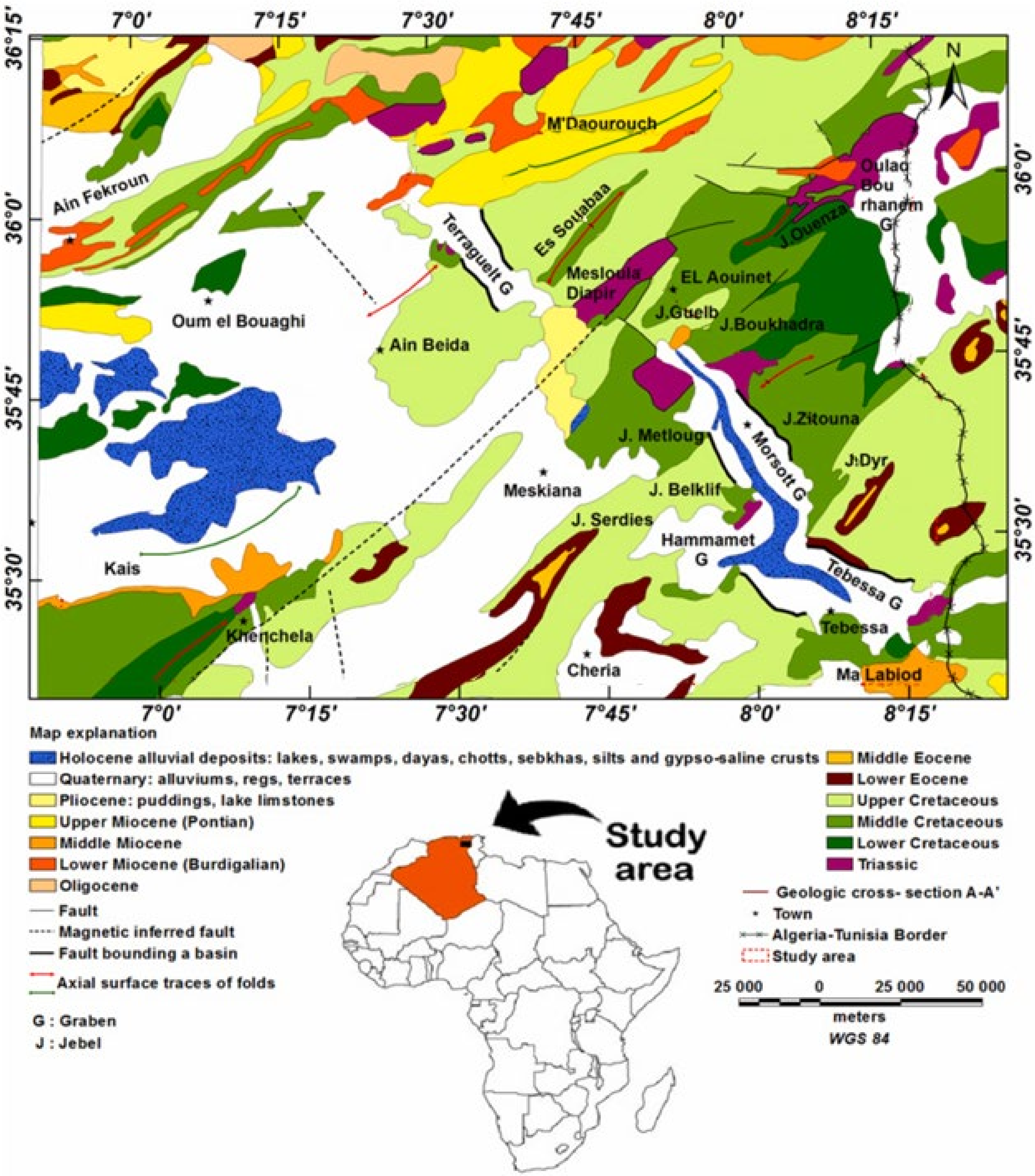


Figure. 3: Geological map of the study area

4. Geodynamic Framework

The northern part of Algeria, which is located within the Maghreb region's broader area, exhibits a layered structure that dates back to the Cenozoic period. This region is also classified into two structural units: the Saharian Atlas and the Tellian Atlas (Figure. 3). The dissertation's research focuses on the Atlas region, which encompasses the foreland portion of the Tell-Riif system and extends north from the Saharan belt.

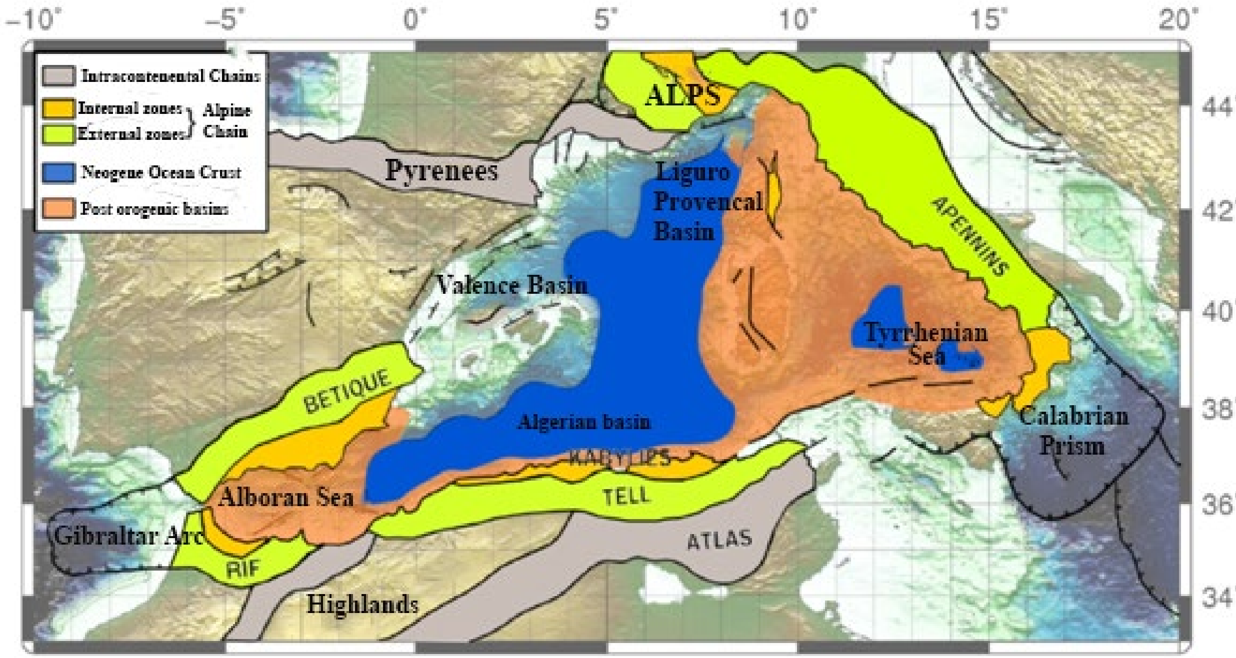


Figure. 4: Main Structural Domains of the Western Mediterranean (modified from D. Frizon deLamotte et al., 2000 and Billi et al., 2011 in Leprêtre 2012)

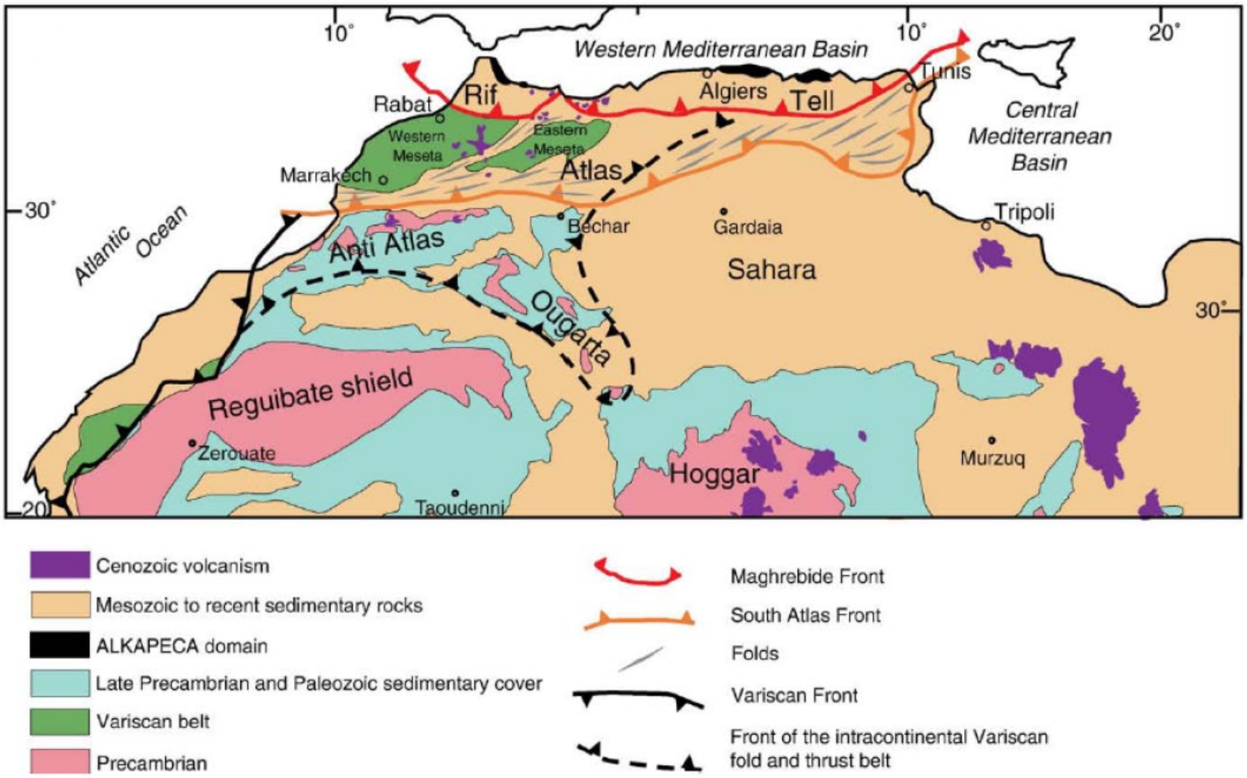


Figure. 5 : Main structural domains (after Michard et al., 2008). The geological "Maghreb" corresponds essentially to the Rif-Tell and Atlas orogenic domains (Frizon de Lamotte, 2009)

The Atlas domain's geodynamic evolution can be traced back to the early Jurassic period and the Triassic when a rifting event occurred. This occurrence triggered the development of graben systems, which eventually evolved into areas of weak geology. (Frizon de Lamotte et al., 2006). It's important to note that this event occurred at the same time that the Atlantic Ocean started to open, a process that commenced approximately 180 million years ago in the North Atlantic region.

The geology of Northern Algeria has been characterized by rift-related structures and tectonic activities, which have played a significant role in shaping its landscape. Due to these dynamics, the region's sedimentary deposits, rock formations, and overall geological structure have remained imprinted, making it an ideal location for further study. (Figure. 05)

The tectonic activities that occurred within the Eastern Atlas region, including areas such Tebessa, have been particularly noticeable. The tilted blocks that were defined by the faults are located in an area that's characterized by a network of faults that's trending toward the WNW-ESE direction. According to Delfaud and Herkat 2000, the activity of these faults started during the Albian phase.

In 1981, Bismuth reported that a similar structure with tilted blocks was found in central Tunisia. The region's geology is also characterized by an extensive corridor that's flanked by NE-SW faults. One of these includes the Kasserine Mole and North-Atlas faults (Figure. 5).

The region's geology features various phases of subsidence during the Cretaceous period, which is characterized by notable eustatic rises. The beginning of the Turonian phase and the Albian's end also contributed to the development of the basin's deepening.

The variations exhibited by eustatic cycles can be linked to the outlines of the Haq et al. curve, which is a well-known reference material in paleogeography. These processes led to the rapid and substantial deepening of the basins.

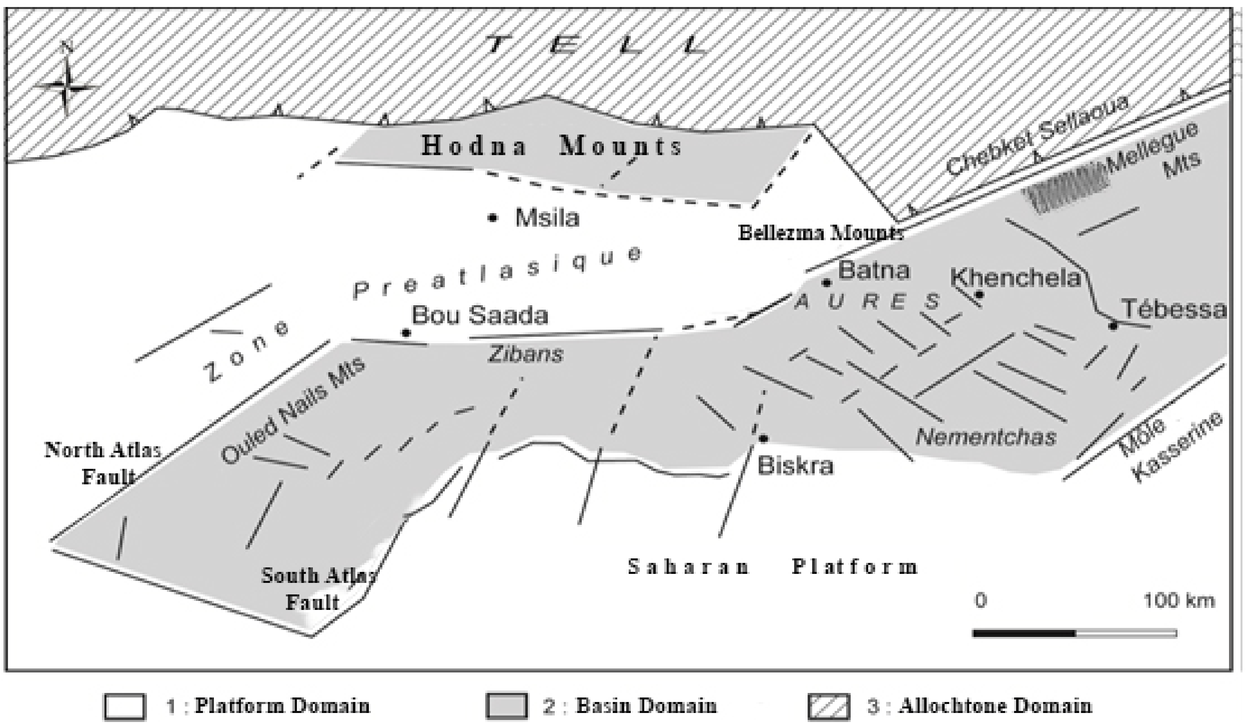


Figure 06: Main Structural Units of the Maghreb (according to Caire, 1970, In Herkat, 1999, modified by Ruault-Djerrab Muriel, 2008). The area studied in this thesis is outlined.

The observed eustatic variations are related to the outlines of Haq et al' 1987 curve, which is an established standard for paleogeography. The resulting processes led to the swift and substantial deepening of these basins.

During the Late Cretaceous period, the various subsidence-related processes decreased significantly. This change was triggered by the beginning of compressive forces in the margins of the basin.(Guiraud 1973 and Herkat 1992).

Tectonic transformations and the emergence of diapirism were significant factors that contributed to the development of the region's geology during the Cretaceous period. This phenomenon is already apparent during the Saharan Atlas' transition from the Jurassic era to the Cretaceous. In 1979, Masse and Thieuloy reported the Ouenza incident during the Aptian stage. (Figure. 6)

Algeria's geodynamic history during the Eocene epoch was subjected to a significant compression during the Cenozoic era. This event eventually led to the Saharan Atlas' formation. The ongoing convergence of the Eurasian and African tectonic plates resulted in this phenomenon.

The rate at which the convergence process continues to evolve has been estimated to be around 5 millimeters a year. In 2006, Yelles-Chaouche and colleagues reported that the region has been experiencing the emergence of north-south, east-west, and NW-SE compressive forces. The continuous movement of these tectonic plates has a lasting impact on the region's geology. (Figure. 7)

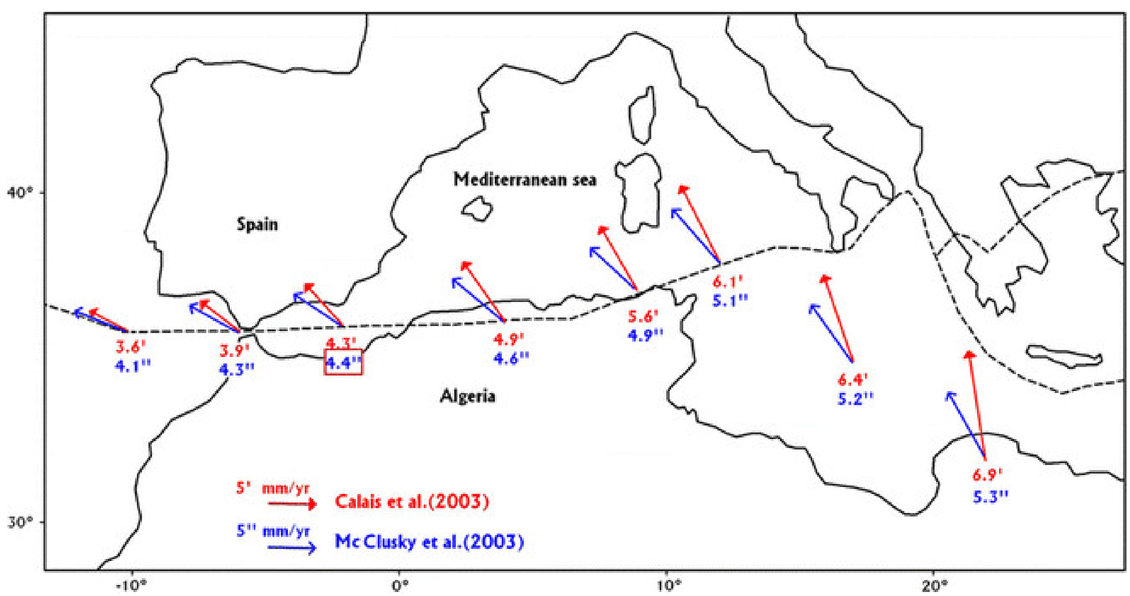


Figure. 7: Convergent movements occurring between the African and Eurasian tectonic plates, adapted from Calais et al. (2003) and McClusky et al. (2003). The displacements are depicted in millimeters per year, relative to the Eurasian plate.

5. Literature review on the study area:

- In 1956, Dubourdieu conducted significant geological work in the Ouenza region, focusing on specific sections like Boukhedra, Haoud-esghir, and Ain-Chenia, where Middle Cretaceous rock formations are exposed. In his study, he meticulously documented the diverse fauna he encountered, including ammonites, sea urchins, bivalves, rudists, and gastropods. This faunal inventory provides valuable insights into the paleobiology and paleoecology of the area during the Middle Cretaceous. Additionally, Dubourdieu's work extended beyond paleontology to encompass the broader geological context. He offered an overview of the tectonic processes that shaped this part of the eastern Saharan Atlas. This tectonic perspective likely contributed to a more comprehensive understanding of the region's geological history, providing a crucial framework for future studies in the area. Overall, Dubourdieu's work is pivotal for both the paleontological and geological understanding of the Ouenza region during the Middle Cretaceous period. Vila. J.M., (1980) created geological and paleogeographical maps which are presented in his study dedicated to the Alpine chain of eastern Algeria and and the Algerian-Tunisian confines.
- In 1985, Viviere conducted a study on the Upper Cretaceous in Tébessa. His research focused on the ostracod fauna, which were small aquatic crustaceans. The study provided him with valuable information on the region's paleoenvironnementand biostratigraphy. By evaluating the assemblages and distribution of ostracods, Viviere was able to provide valuable data that will help scientists understand the environmental and chronological features of the Upper Cretaceous period in Tébessa. This study also provided insight into the region's geological history.
- Benkherouf research in 1988 focused on the study of planktonic and benthic foraminifera that lived in the area of Djebel Boulhaf Dir during the Cenomanian Period. The goal of this study was to provide a comprehensive understanding of the environmental conditions of the region. Benkherouf also performed a comparative analysis of the sedimentary sequences in the Maritime Alps. This study provided a better understanding of the environmental and geological conditions of the region during the Cenomanian.
- Herkat conducted a study in 1999 on the Upper Cretaceous rock deposits in the eastern Atlas. The research utilized quantitative and qualitative analysis methods to gain a deeper understanding of the region's ecological and sedimentary features. The study also revealed how tectonic forces and structural changes affected the sediment deposition in the

eastern Atlas. This work is believed to have contributed to a better understanding of the region's environmental and geological history.

- Jati.M., (2007), by focusing on the Cenomanian-Turonian interval, conducted a sequence analysis complemented by a geochemical study of the series of sections, taken in Algeria, Tunisia, and Morocco, on a platform/basin profile. The results of this work revealed the existence of a geochemical anomaly in δ 13C, characteristic of the global anoxic event OAE2. Paleogeographical patterns for this episode and correlations with the stratotype section of Pueblo and Tunisia were proposed.

- In 2008, a study was carried out by Djerrab Ruault in Djebel Chemla . The project focused on analyzing the history of the area's geology and paleoenvironmental conditions. It used microfossils to create a chronological record of the past. The information collected from this study will help improve our knowledge of past ecological factors and climates.

- Maandi Nabila 2011. This study investigates Cretaceous microfauna in five sections along the northern margin of the Aurès and Southeast Constantine basins in the Eastern Saharan Atlas. It identifies nearly 100 foraminifera taxa, including the first report of Rotalipora planoconvexa in Algeria. New biostratigraphic data refines the biozonation, enhancing stratigraphic resolution. Analyses reveal varying paleodepths, substrate types, and an Oceanic Anoxic Event 2 (OAE2) geochemical anomaly. These findings indicate diverse ancient marine environments and hint at connections with the eastern Aurès and the southern Tethyan margin.

- Salmi-Laouar Sihem. The author discusses the presence of Oceanic Anoxic Event 2 (OAE2) near the southern Tethys margin in the Es Souabaa area. This event is marked by distinct features in sedimentary records, reflecting transgressive drowning and hypoxic conditions. The findings indicate a climax of OAE2 around the Cenomanian-Turonian boundary. Isotopic data suggest significant changes in marine productivity and increasing temperatures. Comparisons with a nearby section in Tunisia reveal similarities, but OAE2 is more pronounced in Algeria.

- Chaaban Koudair 2015 . In the El Guelb massif (Tébessa), discusses lithological and microfaunal variations associated with Oceanic Anoxic Event 2 (OAE-2) during the transition from the Cenomanian to the Turonian. The Cenomanian-Turonian passage is marked by dark, laminated limestones, abundant planktonic microfauna, and glauconium, indicative of a deep, oxygen-depleted environment. Notably, the presence of "filaments" en masse and *Whiteinella archaeocretacea* suggests significant biological changes. The Turonian facies, identified by the presence of *Helvetoglobotruncana helvetica*, includes siliceous levels with Radiolaria, and a shift from Nassellaria to Spumellaria. These bio-events reflect environmental modifications, particularly a decline in oxygen levels in the Upper Cenomanian and Lower Turonian.

6. Research Objectives:

6.1. Stratigraphy:

- The first objective is to establish the stratigraphic position of the studied deposits, focusing on the Middle Cretaceous period, encompassing the Cenomanian to Turonian stages. This time frame is particularly notable for its significant geological events and the presence of various fossil organisms, which serve as invaluable indicators for stratigraphic analysis. Among these organisms, ammonites, ostracods, bivalves, and planktonic foraminifera are highly sought-after. (Figure. 8)
- Ammonites, while being prominent stratigraphic markers, present certain challenges due to their rarity and often poor preservation. As a result, their inclusion in this study would necessitate more extensive fieldwork, which remains a potential avenue for future research.
- However, despite the limitations related to ammonites, it is ostracods, and planktonic foraminifera that have emerged as essential stratigraphic markers for this investigation. Several biozones are established based on these microfossils, with variations arising from different authors and geographical regions. These biozones play a crucial role in the stratigraphic analysis.
- Notably, significant contributions in this field have been made by various researchers. Robaszynski and Caron (1979, 1995) have provided substantial work in this area, which is exemplified in Figure 5. Caron (1985) is another noteworthy contributor to the field. Additionally, the study by Amédro and Robaszynski (2008) stands out for its proposal of a correlation between ammonite and planktonic foraminifera zonations. This correlation extends to both the Tethys domain, represented by Tunisia, and the Boreal domain in Western Europe, illustrating the widespread importance of these microfossils in establishing zonations. (Figure. 9)
- Beyond these key studies, research on stratigraphy in Algeria and neighboring Tunisia is extensive, with a historical foundation. When it comes to planktonic foraminifera

and, to a lesser extent, ostracods, significant contributions have been made by Sigal (1949, 1954, 1956, 1967, 1977, 1987), Dalbiez (1955), Glintzboekel and Magné (1960), Fleury (1969), Salaj (1980, 1987), Bismuth et al. (1981), and Bellier (1983). These researchers have collectively advanced the understanding of microfossils' role in stratigraphy and the unique characteristics of the Cenomanian to Turonian period.

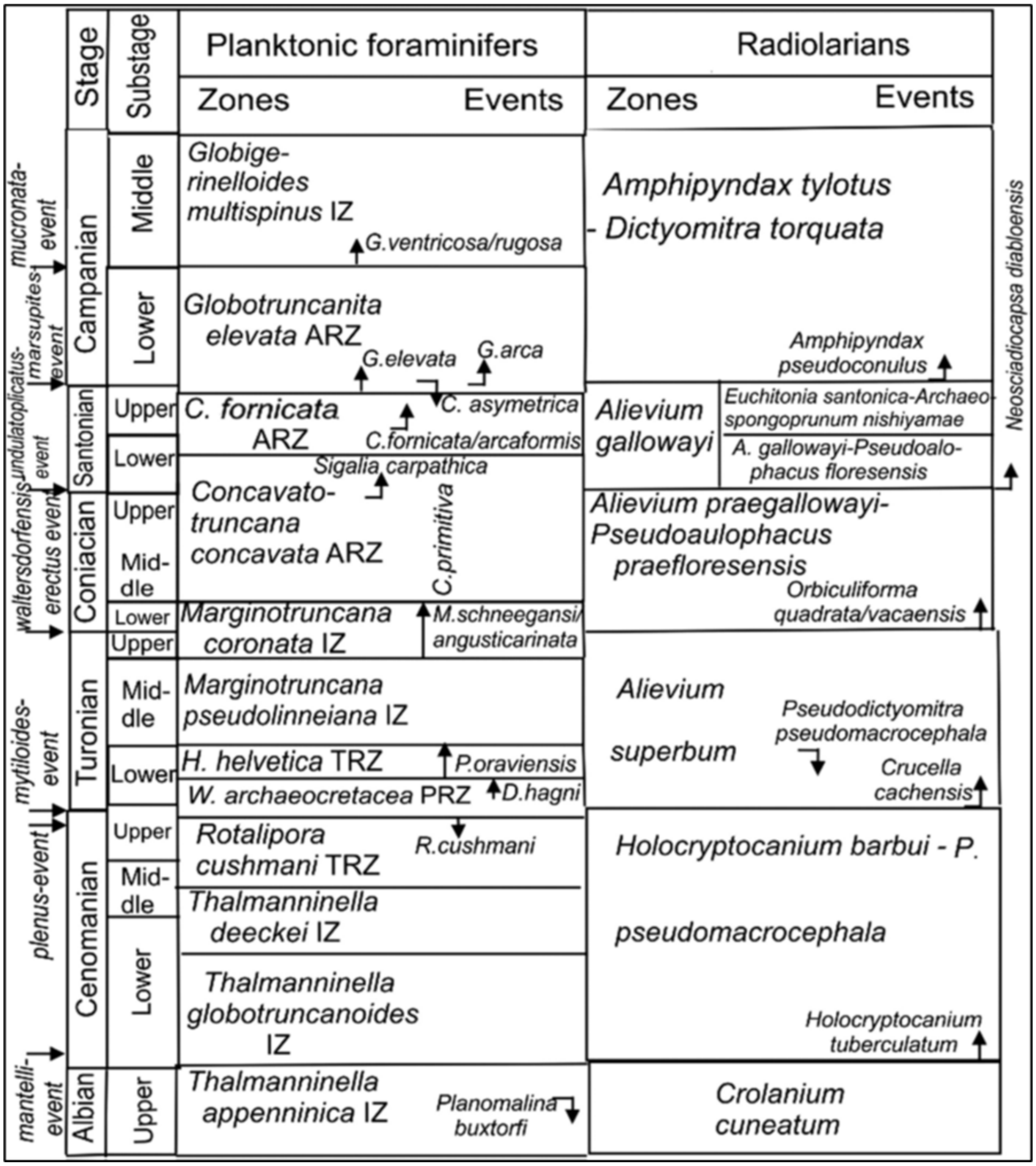


Figure. 8: Biozonation of the Cretaceous by planktonic foraminifera and radiolarians (figure slightly modified from Robaszynski & Caron, 1995).

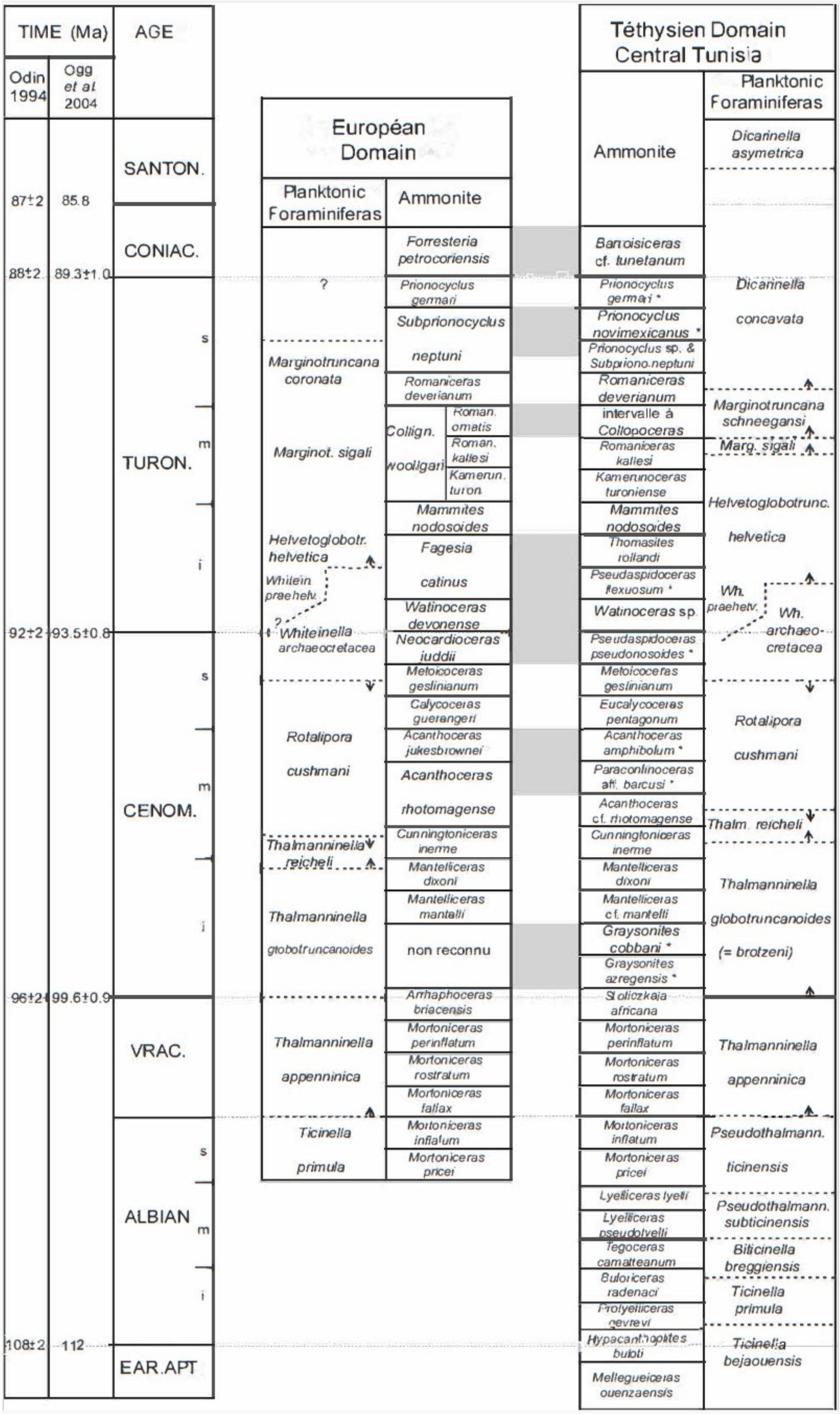


Figure. 9: Biozonation of the Middle to Upper Cretaceous using ammonites and planktonic foraminifera (from Amedro & Robaszynski, 2008; Latil, 2011).

6.2. Paleoenvironment:

The second focus of this research is the paleoenvironmental study. It involves analyzing various fossils, their abundance ratios, and microfacies to estimate paleo-depths and the seabed's oxygenation state.

Additionally, this study examines the Cenomanian/Turonian boundary, which is characterized by a significant oceanic anoxia crisis.

The first to define this event, along with several others of a similar nature, were Schlanger & Jenkyns (1976). According to these authors, these oceanic anoxic events (OAE), exceptional in the Earth's history, are characterized by the development of dysoxic to anoxic conditions in most of the oceans, resulting in the deposition of carbon-enriched layers and modifications in the global cycle of this element. The mechanisms responsible for the occurrence of these OAEs are still poorly understood (Westermann et al., 2010). Among the numerous possible causes, are increased primary productivity, expansion of oxygen minimum zones, and more. and intensification of water column stratification (Schlanger & Jenkyns, 1976; Arthur & Schlanger, 1979; Jenkyns, 1980; Scholle & Arthur, 1980; Bralower & Thierstein, 1984; Pederson & Calvert, 1990; Jenkyns, 2003; Pancost et al., 2004; Hardas & Mutterlose, 2007; Pearce et al., 2009).

The end-Cenomanian event, OAE2.1, is one of the most well-studied of all (Schlanger & Jenkyns, 1976; Jenkyns, 1980; Schlanger et al., 1987; Jenkyns et al., 1994; Strasser et al., 2001; Leckie et al., 2002; Sageman et al., 2006; Caron et al., 2006; Mort et al., 2007; Voigt et al., 2007; Montoya-Pino et al., 2010). It is associated with major climate and paleogeographic changes (Jenkyns et al., 1994; Huber et al., 2002; Norris et al., 2002; Forster et al., 2007) and is notably characterized by a biological crisis (extinction), which led to significant changes in planktonic foraminifera, radiolaria, and nannofossil assemblages (Caron & Homewood, 1982; Hart & Ball, 1986; Lamolda et al., 1997; Grosheny & Malartre, 1997; Keller et al., 2001; Leckie et al., 2002; Erba, 2004; Caron et al., 2006; Grosheny et al., 2006). OAE2 is also marked by a global sea-level rise (Haq et al., 1987), a positive $\delta13C$ geochemical anomaly (Schlanger & Jenkyns, 1976; Jenkyns, 1980; Schlanger et al., 1987; Gale et al., 1993; Erbacher et al., 1996; Jarvis et al., 2006; Voigt et al., 2006), and a general increase in phosphorus accumulation rates, which could be related to a widespread increase in surface productivity (Mort et al., 2007).

In recent years, many authors have made significant efforts to characterize this event in the best possible way, from both a geochemical and micropaleontological perspective, in North Africa and other continents (see Fig. I-3). This is the case, for example, in Morocco (e.g., Ettachfini et al., 2005; Nzoussi-Mbassani et al., 2005; Mort et al., 2008; Jati et al., 2010...) and in Tunisia (e.g., Accarie et al., 1996, 2000; Maamouri et al., 1994; Caron et al., 1999; 2006; Nederbragt & Fiorentino, 1999; Monnet, 2009; Robaszynski et al., 2010...), countries with abundant available literature. Recent studies in Algeria are notably fewer (Naili et al., 1995; Lüning et al., 2004; Groshény et al., 2007, 2008; Chikhi-Aouimeur et al., 2010), but the geographical proximity of these regions easily allows for the comparison of the obtained results.

Conclusion

In conclusion, Chapter 01 has laid the foundational understanding for our comprehensive investigation into the geodynamical and paleoenvironmental aspects of the Middle Cretaceous period in the Tebessa region of Algeria. We have delved into the significance of this geological epoch, marked by its distinct climate, global transgression, and the enigmatic Oceanic Anoxic Event 2 (OAE2). This chapter has provided insights into the lithological, biological, and chemiostratigraphic changes that occurred as a result of this transgressive episode, emphasizing the impact on sedimentary basins across the globe.

The Tebessa region, nestled within the Saharan Atlas, stands as our chosen geological canvas for this research, offering a wealth of sedimentary sequences and stratigraphic treasures. We introduced our primary research objectives, which encompass the development of a precise stratigraphic framework, identification of planktonic foraminiferal zones, and the definition of stage and sub-stage boundaries. Additionally, our goal to reconstruct paleoenvironments through lithostratigraphy and quantitative micropaleontology promises a comprehensive understanding of ecological and environmental dynamics during the Middle Cretaceous.

This chapter also framed our study within the geographical context, highlighting the significance of Tebessa's location within Algeria's Saharan Atlas. Moreover, the geodynamic framework was addressed, shedding light on the geological structure and the northern part of Algeria within the Maghreb region.

The rich literature review on the study area provided a historical backdrop for the significant geological work conducted in the region, which paved the way for our research. Dubourdieu's extensive documentation of Middle Cretaceous formations and the diverse fauna found within them is of particular note.

Our research objectives are clear: to construct a detailed stratigraphic framework, understand the paleoenvironmental conditions, and investigate the geodynamical and anoxic events in the Tebessa region during the Cretaceous period. The knowledge we gain from this study will not only deepen our understanding of Earth's past but will also contribute to the broader fields of geology and paleontology.

Chapter 01 has set the stage for the subsequent chapters that will delve deeper into the geological and paleoenvironmental history of this region, unveiling the secrets of the Middle Cretaceous period through the microscopic worlds of foraminifera and ostracods.

CHAPTER II

MATERIALS AND METHODS

1. Introduction

In this study, the exploration of Tébessa's geological, paleontological, and stratigraphic history during the Cretaceous period, employing a combination of meticulous field and laboratory techniques. Our fieldwork involved extensive field trips to four distinct sections, namely Bekkaria, Blala, Zitouna, and Dir, where we systematically collected and labeled 123 samples varied marl, limestone and marly limestone in addition to a valuable collection of ammonites and bivalves for paleontological investigations. The laboratory phase encompassed a multi-step treatment process based on sample hardness, including thermal shock for highly indurated marl, hydrogen peroxide for less indurated samples, and sieving/washing to prepare specimens for detailed analysis. The introduction of a new laboratory method, inspired by Puckett's work, provided an efficient means of dissolving organic matter and extracting microscopic fossils. We also investigated the Glauber's Salt Method, demonstrating its superiority to hydrogen peroxide in breaking down sediment samples with fewer microfossil damages. Thin section analysis was essential for texture, mineralogical, proportion, and microfacies studies, yielding valuable insights into the sedimentary deposits. Furthermore, we applied additional methods such as Calcimetry for calcium carbonate measurement and Total Organic Carbon (TOC) analysis to comprehend organic carbon composition in soil and geological samples, facilitating critical insights into sedimentary rock characterization, paleoenvironmental reconstruction, hydrocarbon potential assessment, and carbon sequestration studies.

2. Methods used in this study:

Field Methods

The field techniques utilized for the research in Tébessa helped to carry out accurate measurements and sampling. These also ensured that the geological data and samples were documented properly.

- Field Trips:

Through the field techniques, we were able to identify four distinct sections in Tébessa, which were selected for detailed study. These areas, namely Bekkaria, Blala, Zitouna, and Boulhaf Dir, were regarded as significant for this research.

- Sampling Process:

A systematic approach was used to collect samples along the chosen sections. The goal of the sampling process was to ensure that the data collected from the selected areas were collected consistently. Usually, the samples were collected from the marl layers within about 50 centimeters to 1 meter. In cases where the changes in the ground's facies were observed, close intervals were used to accurately record these occurrences.

Dir Section: A total of 34 samples were collected from the Dir section. Zitouna Section: The Zitouna section yielded 32 samples. Bekkaria Section: In the Bekkaria section, 34 samples were acquired. Blala Section: Approximately 23 samples were collected from the Blala section.

- Sample Labeling:

To ensure that the samples were properly organized and documented, each sample was placed inside a plastic bag. It was then labeled with a unique number and its origin was traced back to its specific location.

- Fauna Collection:

A fauna collection was also carried out, which included various types of ammonites and bivalves. These specimens are important for studies related to stratigraphic and paleontological investigations.

By using the proper field techniques, we were able to obtain crucial information and samples for the study of the geology, paleontological, and stratigraphic characteristics of Tébeessa during the Cretaceous period.

Laboratory methods

The laboratory work performed on the project mainly concerned with the treatment of the marl specimens that were gathered throughout the study. The following steps provide an overview of the different procedures utilized in the facility.

- Weighing the Samples:

The weight of the marl samples was initially measured. Each sample was weighed with an estimate of 200 grams.

- Treatment Based on Hardness:

Different treatments were then carried out on the marl samples depending on their hardness level (induration). The methodology for this process was based on the thesis presented by Benkherouf in 1988.

- Thermal Shock for Indurated Samples:

The most indurated marl specimens were subjected to a thermal shock treatment that involved repeated freeze-thaw cycles. This process helped in breaking down the marl samples' hardened structures.

Following the thermal shock process, the samples were then subjected to sodium sulfate. Less indurated marl samples were then treated with hydrogen peroxide.

For those with lower induration levels, the treatment involved adding hydrogen peroxide to the marl specimens for 48 hours. This process is believed to have helped in breaking down and softening the less indurated ones.

- Sieving and Washing:

The sediment collected from the different treatments was then subjected to further sieves with different mesh sizes. The sizes used were 40µ , 0.063, and 0.250 millimeters.

The sediment was then submerged in a stream of water, where it would be collected and separated from particulate matter or residues.

- Fraction Sorting:

After the washing and sieving process, the three different fractions were sorted by a binocular microscope. For each sample 300 specimens have been sorted.

The various laboratory procedures utilized during the treatment and preparation of marl specimens served a vital role in the study. They enabled the subsequent examination and analysis of the structures and microorganisms in the study area and the extraction of vital information about the sedimentary deposits.

3. New Laboratory Method:

A new laboratory technique that involves using peroxide with heat has also been developed to treat sediment samples. This method was adapted from Puckett's work in 1992, 2005. It is useful in the dissolution of organic matter and the extraction of microscopic fossils. This step-by-step guide is designed to help to understand how this process works. (Puckett, 1992)

- Sample Preparation:

After collecting the sediment samples, break them into pieces that are about 1/2 centimeter in diameter.

- Heating in Drying Oven:

To prepare the sediment samples, place them inside a drying oven that's at 60 degrees Celsius (140°F). They should be allowed to rise in temperature for around two hours, as this helps in the drying process.

- Hydrogen Peroxide Solution:

After heating the sediment pieces, submerge them in a hydrogen peroxide-based solution with a 3% concentration of H_2O_2.

- Ultrasonic Cleaner Treatment:

Some samples can be placed inside an ultrasonic cleaner to enhance the cleaning and dissolution of microscopic fossils. To prevent the vibrations from damaging the specimens, fill the top reservoir of the cleaning machine. This process usually lasts for around an hour.

- Wet-Sieving:

After the samples have been treated with hydrogen peroxide, they should be wet-sieved. To separate organic matter and other particles, a 75-micron mesh should be used.

- Oven Drying:

After wet-sieving, oven-dry the samples to remove excess moisture and prepare them for further analysis.

- Repeat Processing (if necessary):

Some samples may require multiple processing steps to thoroughly separate microscopic fossils and dissolve organic matter.

Pyroxide-based methods are particularly advantageous when it comes to cleaning and extracting microscopic fossils from sediment deposits. These results offer valuable information for sedimentological and paleontological studies.

***Glauber's Salt Method* (Slipper, 2019)**

As an experiment, Slipper (2019) utilized Glauber's Salt Method to determine if it was more effective than hydrogen peroxide when it came to breaking down sediment samples. This method involves using a supersaturated solution of Glauber's salt (mirabilite: $Na2SO4 \cdot H2O$) to promote the disintegration of the sample.

- Sample Preparation:

Break the sediment pieces into smaller pieces to make them easier to handle during the processing stage.

- Oven dry

For about two to three days, the samples should be subjected to a temperature of around 70 degrees Celsius. This will help remove any excess moisture.

- Preparation of Supersaturated Glauber's Salt Solution:

A supersaturated solution incorporating a large amount of salt can be created by adding it to boiling water until its dissolution can't be completed. This will cause the salt to settle at the bottom.

- Sample Treatment:

After placing the warm and dried samples inside a glass beaker, add the Glauber's Salt solution and cover it with plastic to prevent the evaporation of the liquid.

- Soaking and Nucleation:

Cover the beaker with the Glauber's Salt solution and place it inside an oven for an hour to allow the substance to seep into the sample's pores.

- Cooling and Freezing:

After cooling it for around 30 minutes, submerge the beaker in an ice bath. Transfer it to a freezer and store it overnight. Rapid chilling can cause small crystals to form inside the sample, which can then break apart and separate it with minimal damage to the microscopic fossils.

- Boiling and Sieving:

After removing it from the freezer, fill the beaker with water and place it inside a microwave oven. Once it turns into a soupy consistency, it's ready to be sieved.

According to a study conducted (Slipper, 2019), the Salt Method employed by the Glauber is more efficient at breaking down sediment samples than the hydrogen peroxide technique, resulting in fewer microfossils with damaged components. This method can be utilized to extract and prepare such specimens for further study in the fields of sedimentology and paleontology. (Slipper, 2019)

The processing of indurated marl-limestone and limestone samples included the creation of thin sections, which were mainly utilized for microscopic analysis. This process also served other objectives, such as studying the sedimentary features.

- Texture Analysis: Following the concept of Dunham (1962), thin sections of rock provide an opportunity to study and describe its texture. This involves sorting and characterizing the different components and grains within the rock.
- Mineralogical Identification: The creation of thin sections of rock is essential in the process of mineralogical analysis, which determines the constituents of the object's mineral composition. This helps in gaining a deeper understanding of its origins and the evolution of its diagenetic traits.
- Proportion and Distribution: The thin sections allowed researchers to determine the relative proportions of various constituents within the rock. They also helped them understand the matrix's distribution.
- Microfacies Analysis: A crucial part of thin section studies is the microfacies analysis, which allows for the detailed study of sedimentary features and grains within a rock. Through this process, the observations made from field samples can be compared with those obtained from marl samples.

60 thin sections from various parts of the sample were analyzed for different purposes, which allowed for a detailed analysis of the mineral composition, microfacies, and the limestones and the marl-limestone's textural characteristics. The findings from these segments can help improve our knowledge of how the sedimentary features are transported and deposited.

These 60 thin sections were made in the Laboratory of Geology in University Farhat Abbas Setif.

4. *Other Methods:*

- Calcimetry:

A Bernard calcimeter was utilized for the measurement of calcium carbonate in a sample. This type of instrument provides a simple and accurate method for determining the amount of CaCO3 (calcium carbonate) in the sample.

I conducted the calcimetry experiment at the National Laboratory of Housing and Construction.

The measurement process involves the following steps:

Sample Preparation: A single gram of the material is prepared during the sample preparation process.

- Chemical Reaction:

A 1 milliliter of hydrochloric acid (HCl) was added to the sample to trigger a chemical reaction. The reaction then resulted in the release of CO2.

Calcium Carbonate Comparison: The CO2 gas produced by the sample was then measured to compare its volume with that of pure calcium carbonate.

Calculation: By comparing the two volumes, the CaCO3 level can be calculated in the sample.

Although the use of a Bernard calcimeter is convenient in calculating carbonate content, it must be noted that this method comes with some limitations. Its precision might vary, with an average error of around 5%-10%. This means that even though it offers an estimate, it might not be precise.

- TOC (Total Organic carbon)

The total organic carbon or TOC, which is a crucial analytical parameter, is a representation of the concentration of the organic carbon in a sample.

I conducted the COT experiment at the Laboratory of the Algerian Water Company.

The TOC analysis is performed in soil and geological studies to gain a deeper understanding of the organic carbon composition of different materials, such as rocks and soils. This information can provide insight into their past composition and how they might store carbon.

- Importance in Geological and Soil Studies:

Sedimentary Rock Characterization: The TOC analysis can be used by sedimentologists and geologists to determine the organic carbon content within sedimentary rocks. This data can be used to gain a deeper comprehension of the sedimentary environment and its history.

Paleoenvironmental Reconstruction: The data collected from the TOC can be used to reconstruct the paleoenvironnementof a region, allowing us to identify the changes that occurred in the past. For instance, the variations in the organic productivity or oxygen levels could suggest that the conditions in ancient lakes or oceans changed.

Hydrocarbon Source Rock Evaluation: The evaluation of the source rock's hydrocarbon potential is carried out using the TOC analysis. High TOC values are often detected in sedimentary rocks that have a strong potential to produce hydrocarbons.

Carbon Sequestration Studies: TOC analysis is utilized in the study of carbon storage and sequestration CSS. It helps in identifying the subsurface reservoirs that can accommodate storing large amounts of carbon.

- TOC Analysis Protocol for Geological and Soil Samples:

1. Sample Collection: Collect soil or rock samples from the site, ensuring that the specimens represent the stratigraphic or depth interval of interest. Since the TOC values of different depths can vary, it's important to gather an adequate quantity for the analysis.

2. Sample Preparation: Prepare a homogenous subsample by crushing or milling the sample. Make sure that it doesn't have foreign materials or contaminants.

3. Drying: The subsample should be placed in an oven at a temperature of around 70 to 110 degrees Celsius to eliminate the organic and moisture constituents.

4. Sample Combustion: The dried subsample is then subjected to high temperatures and combustion in the TOC analyzer at high temperatures (typically >900°C) in the presence of oxygen. This process converts the organic carbon in the sample into a type of greenhouse gas known as carbon dioxide.

5. CO_2 Detection: The amount of CO_2 generated by +-+a combustion process is quantified by an instrument that's commonly an infrared analyzer. The organic carbon content of a sample dictates the concentration of CO_2.

6. Calibration: Standard reference materials, such as those used in calibration, are utilized to ensure the accuracy of TOC measurements.

7. Data Interpretation: The data interpretation process involves showing the percentage of TOC that was reported because of the study. This represents the organic carbon's mass relative to that of the sample.

8. Data Correlation: The correlation of TOC data with data from stratigraphy and lithological studies can help create a comprehensive picture of the site's environmental and geological history.

9. Additional Analysis: A combination of TOC analysis with other analytical methods, like carbon isotope analysis, can lead to discoveries about the organic carbon's origin and nature in soil and geological samples.

The use of TOC analysis in soil and geological studies allows scientists to gain a deeper understanding of the environmental conditions that affect the development of sedimentary rocks. This protocol provides a general overview of the procedures involved in the study. However, the exact procedures might vary depending on the equipment and methods used by different research facilities and laboratories.

- SEM

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons.

I took the SEM images of differnts specimens during my short term abroad, at Southern Mississippi University in the Chemistry Laboratory.

To take pictures of microfossils using a Scanning Electron Microscope (SEM), I followed these steps:

1. Sample Preparation: Prepare your microfossil samples for SEM imaging. This may include mounting the microfossils on a conductive substrate and coating them with a thin layer of conductive material such as gold or carbon to prevent charging.

2. Instrument Setup: Turn on the SEM and allow it to warm up. Set the appropriate parameters such as accelerating voltage, probe current, and working distance for imaging microfossils.

3. Sample Loading: Place the prepared sample on the SEM stage using tweezers or a sample holder. Ensure that the sample is securely mounted and positioned for imaging.

4. Initial Imaging : Use the SEM's low-magnification mode to locate the microfossils on the sample. Adjust focus, brightness, and contrast as needed to locate the microfossils.

5. High-Magnification Imaging : Once the microfossils are located, switch to higher magnifications for detailed imaging. Adjust imaging parameters to achieve the desired image quality.

6. Image Capture : Capture images of the microfossils at different magnifications and orientations. Save the images for further analysis and documentation.

7. Analysis : Use the SEM's software or external software to analyze the images, measure features, and gather data about the microfossils' morphology and composition.

8. Shutdown: When finished, turn off the SEM, vent the chamber if necessary, and clean the sample chamber and stage.

It's important to follow the specific instructions and guidelines provided by the SEM manufacturer for imaging microfossils to ensure the best results and the safety of both the operator and the instrument.

Conclusion

In this detailed chapter, the investigation is supported by a meticulous combination of field and laboratory techniques.

Fieldwork played a crucial role in the study, with carefully planned trips to four distinct sections of the Tébessa region: Bekkaria, Blala, Zitouna, and Dir. A total of 123 marl, limestone, and marly limestone samples were systematically collected during these trips, each labeled for precise tracking and reference. Additionally, a collection of some ammonites and bivalves was assembled for paleontological investigations. These field techniques ensured accurate documentation of geological data and sample collection, forming the basis of the research.

In the laboratory phase, a variety of methods were employed for the treatment and analysis of marl specimens. The procedures were tailored based on the hardness of the samples, with highly indurated specimens undergoing a thermal shock treatment involving freeze-thaw cycles. Other treatments included the use of sodium sulfate and hydrogen peroxide to soften specimens. Sieving and washing processes were then used to separate sediment from particulate matter, followed by fraction sorting under a binocular microscope for detailed analysis of structures and microorganisms.

A novel technique inspired by Puckett's work involved using peroxide with heat to dissolve organic matter and extract microscopic fossils from sediment samples. The Glauber's Salt Method, experimented by Slipper, was also explored for breaking down sediment samples effectively. Thin section analysis was conducted for texture, mineralogical identification, and microfacies analysis, providing insights into sedimentary features and grains within the rock.

Additional techniques included calcimetry for measuring calcium carbonate and Total Organic Carbon (TOC) analysis for organic carbon concentration. TOC analysis proved invaluable in sedimentary rock characterization and environmental reconstruction.

In conclusion, this chapter demonstrates the extensive and carefully executed methods used in the research on Tébessa's geological, paleontological, and stratigraphic history during the Cretaceous period. These techniques were instrumental in uncovering the region's ancient past, highlighting geodynamical processes and anoxic events. The combination of fieldwork and advanced laboratory methods, including innovative approaches, showcases the multidisciplinary nature and significant contribution of this research to broader understanding.

CHAPTER III

INTRODUCTION TO OSTRACODS: MICROSCOPIC SHELLS, MACROSCOPIC INSIGHTS

CHAPTER III. INTRODUCTION TO OSTRACODS: MICROSCOPIC SHELLS, MACROSCOPIC INSIGHTS

1. Introduction

Ostracods are among the few kinds of crustaceans that are known to be ecologically significant both in the non-marine and marine domains. Their fossil record makes them an ideal bioclimatic, stratigraphy, and paleoenvironmental indicator.

Besides being used for the analysis of fossil and geological data, the studies of ostracods are also carried out in other fields such as limnology and molecular biology. These studies are often integrated with those of oceanography and evolutionary biology.

Although it is not clear exactly how many Ostracoda species are known to exist, the data gathered through the various database programs has led to the identification of more than 65,000 living and fossil species that are below the Kempf level. (Kempf 1996, 1997, and updates) includes subspecies and related synonyms (Ikeya et al., 2005).

Besides being utilized for the analysis of fossil records, ostracods studies can also be performed in other disciplines, such as molecular biology, zoology, and limnology, and these can be integrated with other areas of paleoclimatic research.

About half of the approximately 10,000 known Ostracod species have been officially described. Most of them are from marine and transitional waters, while around 2,000 are from non-marine regions.

The fossil record of arthropods, including ostracods, spans more than 450 million years. It is regarded as the most comprehensive of its kind, and it serves as a great resource for studying the evolution of metazoans. (Siveter et al., 2003) The group is also a model for the metazoans' sexual development. One of the oldest known records of males from the Silurian region dates to more than 200 million years. (Martens, 1998; Martens et al., 2003; Martens, 2008)

The establishment of the community of metazoan communities during the late 18th century largely depended on the work of two individuals: Linnaeus and Baker. In 1746, Linnaeus first described an ostracod, while Baker presented the first illustration for a Cypris in 1753. (Oertli, 1982) The proposal by Muller for the creation of a taxonomy for metazoans in 1776 was the most significant contribution made during that period. (Müller, 1776, in Oertli, 1982; Neale, 1988)

CHAPTER III. INTRODUCTION TO OSTRACODS: MICROSCOPIC SHELLS, MACROSCOPIC INSIGHTS

Pierre Latreille presented the Ostracoda to his class in 1802. He then used the term "Ostrachoda" before changing it to "Ostracoda" in 1806. (Oertli, 1982)

Different works published during the 19th century introduced a classification system that was designed to better categorize the main groups of metazoan species.

Following the discovery of sea animals during oceanic cruises, several studies on these organisms were carried out in inland and coastal waters in Britain. These studies provided researchers with valuable information on the ecology and biogeography of these organisms. (Brady, 1868, 1880; Brady and Norman, 1889, 1896; Müller, 1894), as well as the first major study of British Pleistocene ostracods (Brady et al., 1874).

The first major studies about the taxonomy of ostracods (Sars, 1923–1928), which focused on the functional morphology and ecology of the organisms (Skogsberg, 1920; Cannon, 1925, 1933) were published during the 20th century.

The joint efforts of several studies on the ostracod community during the 20th century were affected by geochemistry and the advancement of radioactive dating.

The traits of various living organisms have been described according to their environmental conditions. (McKenzie and Jones, 1993) This has allowed the recent discoveries to be considered modern examples of fossil materials, as indicated by De Deckker and colleagues in 1988.

2. Ostracod definition:

To respond to the question What ostracods are? (Horne et al. 2005) the researchers discussed the criteria used to define the Ostracoda. They concluded that these organisms are bivalved arthropods that have 8 pairs of limbs each. They also have a furca and copulatory limbs, and these can completely enclose themselves with a bivalved carapace.

The members of the Ostracoda belong to a diverse group of aquatic crustaceans. These organisms commonly live in various types of aquatic ecosystems, such as freshwater, brackish water, and marine waters. Their bivalve shells are made of chitin. These organisms, which have intricate ornamentation, come in different shapes and sizes. (Rossetti et al 2006; Martens et al 2008; Külköylüoğlu, 2013)

An adult ostracod typically has a trunk that measures about 0.5 to 2.0 millimeters in length. (Scholle et al 2003; Vannier 2020) It also has five to eight pairs of legs that extend from its body. In freshwater species such as South Africa's Megalocypris, the body length of these organisms can grow to over 8 millimeters. (Turpen et al 1971; Angel et al 1987, Smith 2010)

These organisms play a vital role in the dynamics of aquatic ecosystems by participating in diverse ecological niches. Their diverse feeding habits, which include detritivory and herbivory, make them an important part of the web of life. Because of their ecological significance, ostracods have a significant impact on the health of aquatic ecosystems. (Holmez et al 2002 ; Boomer et al 2008 ; Rodriguez Lazaro et al 2012 ; Ruiz et al 2013)

Exceptional is the fact that ostracods can serve as environmental indicators. By studying both living and fossil ones, (De deckker et al 1988; Karanovic 2012; Zuschin et al 2003; Danielopol et al 2002; Zwair 2023) scientists can gain a profound understanding of the past and current state of aquatic ecosystems, providing a unique perspective on Earth's history as well as the changes that have unfolded over time. (Scharm et al 1982; Rodriguez-Lazaro et al 2012; Willis, K. 2010, Harvey et al 2012; Bekhouch, G. 2023)

Through the study of ostracods, which is interdisciplinary, researchers from different scientific fields, such as ecology, paleontology, and evolutionary biology, have been able to gain a deeper understanding of the Earth's history and the evolution of life.(Danielopol, 1989; Palumbi, 1994; Mezquita, 2005; Cristescu, et al 2010; Lau, S 2021; Harmon, et al 2019) Their ability to provide information on the environmental responses of aquatic communities has been instrumental in making them a focus of various studies that seek to examine the interactions between aquatic ecosystems.(Ruiz,.2013; Mezquita, et al 2005; Chivas, 1987, Bekhouch, et al 2023)

The remarkable thing about ostracods is their ability to serve as ecological indicators.(Delorme, 1969; De Deckker, et al 1988; Sames, 2010) By studying both fossil and living ones, scientists can gain a profound insight into the past and present state of aquatic ecosystems, which can provide a unique perspective on Earth's history.(Zeppilli, et al 2015; Boomer, 2005, Hunt, et al., 2006; Rodriguez-Lazaro, & Ruiz-Muñoz, F.2012). Their fossil record is particularly valuable as it allows researchers to gain a unique historical perspective.

Interdisciplinary studies on ostracods transcend the boundaries of scientific disciplines, such as paleontology, ecology, and evolutionary biology. (Milli, S et al 2013) They have been utilized by researchers to investigate topics related to the evolution of life, the history of Earth, and the current state of the planet's ecosystems (Bennett, 1997; Burge, et al 2018; Love, 2022). Their interconnectedness is evidenced by their ability to shed light on the environmental responses. As a result, their diverse nature has made them a central focus of numerous studies that seek to untangle the complicated interactions within aquatic ecosystems. (Humphreys, 2006)

3. Ostracod Morphology:

According to Horne et al 2005, the characteristics of ostracods serve as a basis for describing their broader category within the world of crustaceans (Oakley, 2013; Rodriguez-Lazaro, 2012) These traits enable researchers to distinguish them from other bivalved arthropods. (Figure. 10)

- A bivalved carapace is the protective shell of an ostracod. It encloses the entire body and acts as a shelter for the animal.
- Limbs: Adult ostracods typically have up to eight pairs of limbs, including a furca and copulatory limbs. These are important for a wide range of functions, such as feeding and locomotion.
- Ostracods evolve by moulting, which involves periodically removing their old exoskeleton and constructing a new one. The moulting process is different from the continuous growth cycle of the organisms and serves as the life cycle's main mechanism.

- Juveniles, Not Larvae: Unlike many other crustaceans, ostracods do not go through a larval stage in their life cycle. Instead, they have juveniles that resemble miniature versions of adults and grow through moulting.
- The absence of growth lines: Ostracods don't have growth lines on their bivalved carapace, which is a notable trait. This characteristic distinguishes them from other such creatures that use calcified exoskeletons.

Although ostracods are categorized as a class within the crustacean category Crustacea, their monophyletic nature is under debate due to the distinguishing characteristics of their two main subgroups. The Podocopa and Mydocopa show distinct limb structures, which could indicate that the two groups evolved differently.

The classification of ostracods as a group within the Crustacea highlights their important contribution to the evolution of the crustacean world. (Horne, al 2000; Butlin, et al 2000) Debate surrounds their monophyletic origins. The Mydocopa and Podocopa, which show distinct structures on their limbs, suggest that the two groups have diverged potential evolutionary differences. (Figure. 10)

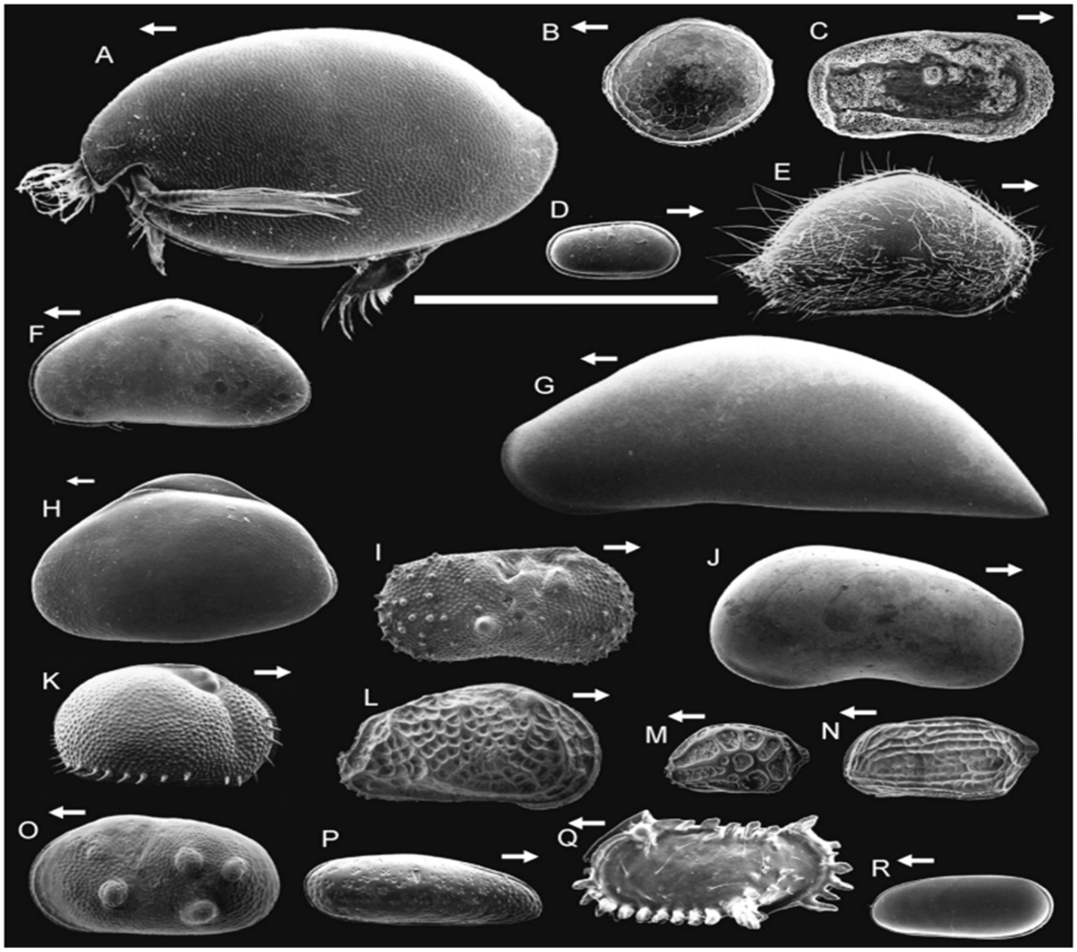


Figure.10: Examples of genera of the major living groups of Ostracoda, all external lateral views. (A) *Vargula* (Myodocopida, Cypridinoidea), car. with appendages, left side; (B) *Polycope* (Halocyprida, Cladocopoidea), LV; (C) *Cytherelloidea* (Platycopida, Cytherelloidea), RV; (D–R) Podocopida: (D) *Saipanetta* (Sigillioidea), car., right side; (E) *Neonesidea* (Bairdioidea), car., right side; (F) *Propontocypris* (Pontocypridoidea), car., left side; (G) *Macrocypris* (Macrocypridoidea), LV; (H) *Cyprinotus* (Cypridoidea), car., left side; (I) *Ilyocypris* (Cypridoidea), RV; (J) *Candona* (Cypridoidea), RV; (K) *Centrocypris* (Cypridoidea), RV; (L) *Baffinicythere* (Cytheroidea), RV; (M) *Hemicytherura* (Cytheroidea), LV; (N) *Semicytherura* (Cytheroidea),LV; (O) *Cyprideis* (Cytheroidea), LV; (P) *Sahnicythere* (Cytheroidea), car., right side; (Q) *Pterygocythereis* (Cytheroidea), LV; (R) *Darwinula* (Darwinuloidea), car., left side. Scale bar1.0 mm; arrows point anteriorly. RV, right valve; LV, left valve; car., carapace. A–G, L–M and P–Q are marine, N–O are brackish water; H–K and R are non-marine (fresh water). Modified after Horne et al. (2002).

The structures on the limbs of Podocopans and Myodocopans suggest that they have evolved to closely resemble stem-group members. (Broodbakker, 1982; Rodriguez-Lazaro, 2012; Meisch, 2007; Horne, 1998; Horne et al 2005, 2012) This suggests that the lineage of ostracods has undergone a complex evolutionary history. The detailed information about the evolution of these bivalved organisms' limbs provides valuable clues about the origins of the whole group. (Schram, 1982; Selden, 2012; Schram, 2013)

The various characteristics of ostracods, such as their structures and growth mechanisms, make them an interesting and unique group within the crustacean category. (Martin, et al 2001 ; Thorp, et al 2009 ; Cole, et al 2015). Their evolutionary history can help us understand the evolution of other features within the family tree of arthropods (Oakley, 2013). (Figure. 12)

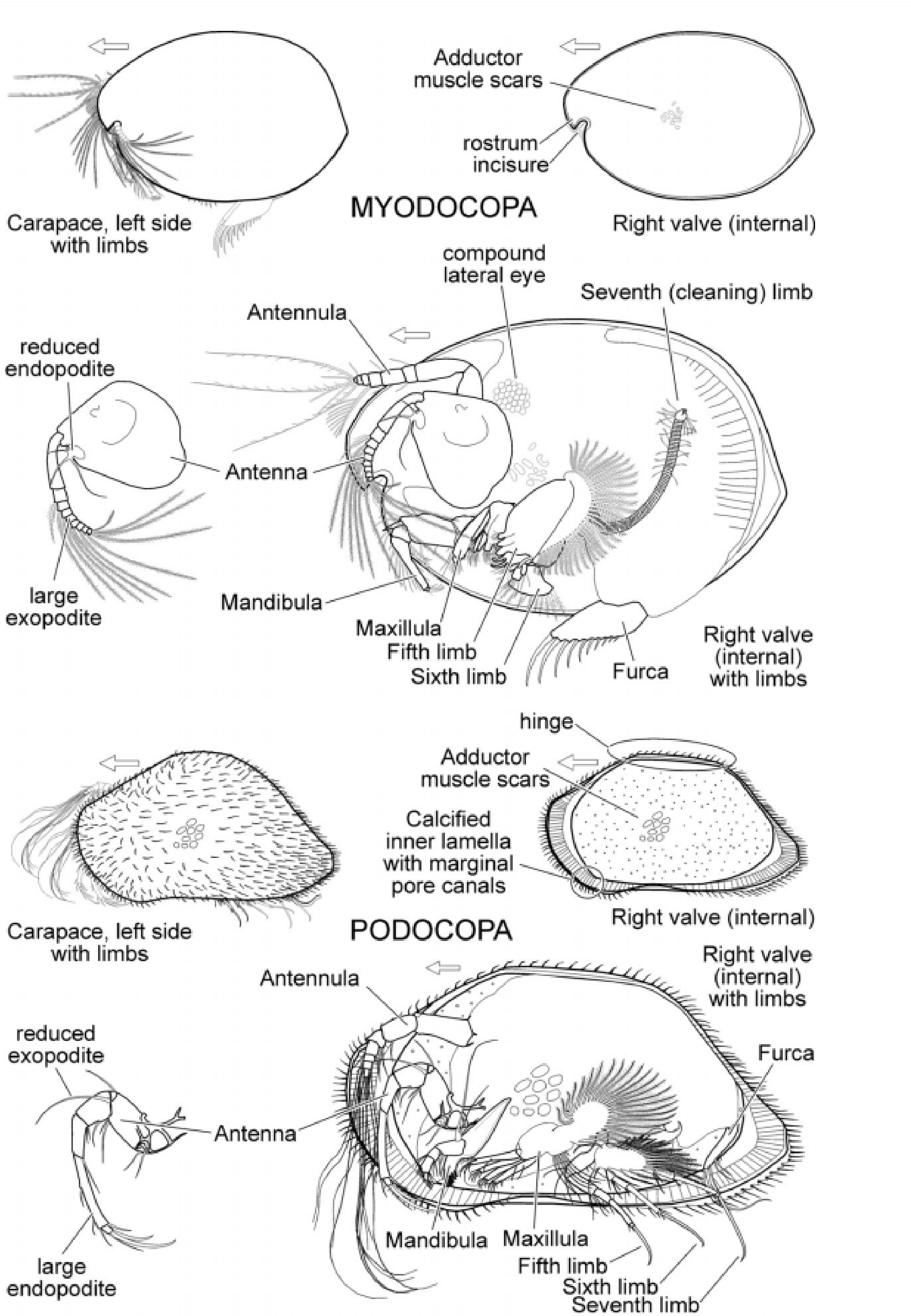


Figure.11: Main morphologic characteristics of the carapace and limbs of a marine nekto-benthonic myodocopan (Cypridinoidea) and a marine benthonic podocopan (Bairdioidea). Arrows point anteriorly. (Horne, 2005).

CHAPTER III. INTRODUCTION TO OSTRACODS: MICROSCOPIC SHELLS, MACROSCOPIC INSIGHTS

Despite being categorized as a group within the crustacean category Crustacea, Ostracoda's evolutionary history and classification are in some difficulties due to the distinct limbs of its two main subgroups. (Oakley, 2013; Cohen, et al 2003) Myodocopa and Podocopa have raised questions regarding the monophyletic nature of the group.

The two main groups of Ostracods, known as Podocopa and Myodocopa, have unique features and structures on their limbs. (Horne, 2005; Park, et al 2003). This makes them an interesting and unique group within the crustacean category. Members of monophyletic families share similar evolutionary ancestors. (Figure. 10,11)

The structures and characteristics exhibited by the two main groups of ostracods suggest affinities with stem-group crustaceans that lived during the Cambrian period. (Horne, 2005, Ikeya, 2005, Henze, 2015). This implies that certain traits of ostracods could have originated from ancient crustacean ancestors and could provide valuable information regarding the evolution of the group's traits. (Horne, et al 2000; Mesquita-Joanes, F 2012)

Evolutionary timeline: The history of the ostracod family is a subject of debate and scientific investigation. Although some of its characteristics suggest that it evolved from ancient crustacean relatives, the exact timeline of their evolution remains unclear. It has been theorized that this process might have started during the Palaeozoic Era, which experienced biological and geological changes during this period. (Tinn, et al, 2008; Horne, 2003; Regier, 2010)

The structures of ostracod limbs, including the post-mandibular, pre-anal, and branchial plates, offer critical insights into their evolutionary affinities and relationships with other crustaceans. These morphological features have led scientists to question the evolutionary origins of ostracods and their place within the broader context of crustacean diversity. (Horne, et al 2005, Martin, et al 2001 ; Giribet, al 2019)

Due to the complexity of the ostracod's evolution and its potential such as its relationships with other groups and the possible link it has with ancient crustacean relatives, are being studied by paleontology and evolutionary biology researchers. (Wheat, et al 2013 ; Oakley, et al 2013; Schram, et al 1982)

CHAPTER III. INTRODUCTION TO OSTRACODS: MICROSCOPIC SHELLS, MACROSCOPIC INSIGHTS

The evolution of the ostracods has been the subject of scientific inquiries into the category Crustacea.

4. Ostracod Classification:

The classification system used by scientists to categorize the members of the ostracod family is highly organized. It consists of 10 suborders and 16 superfamilies. (Zwair, 2023; Wang, et al 2020), This system's objective is to provide a comprehensive view of the diversity within the group. The classification criteria used are based on the soft and hard parts of the animal's body. These include the limbs and appendages (Yamaguchi, et al 2003; Smith,. 2000; Yin, 1999).

The soft parts of the ostracods, such as their limbs and appendages, serve a vital role in helping scientists understand their evolutionary relationships and ecological adaptations. The morphological characteristics of the group vary between benthic and planktonic genera. (Hessler, 1982; Helmdach, 2005) This indicates that they have distinct ecological specializations belonging to the Podocopa and myodocopa families. (Figure .12)

4.1. Myodocopa group:

The main characteristics of the Myodocopa group are that they are exclusively marine. Their morphological attributes are adapted to the lifestyle of open water.

- The thin carapaces of the Myodocopa ostracods are designed to have minimal valve overlap and a weak hinge. This makes their design ideal for living in open water.
- Anterior Beak: The beak of some Myodocopa ostracods features an anterior notch, which can serve a specific ecological function.
- The lateral compound eyes: various Myodocopa ostracods allow them to perceive and navigate in their environment.
- Limb morphology: The Myodocopa ostracods swim well with their well-adapted morphology, which allows them to move efficiently. They typically have several pairs of flexible appendages designed to allow them to move efficiently. The antennae are made of exopodite shells with feathery "swimming setae." The other limbs have different adaptations, and the seventh limb is an internal cleanser.
- Genital Apparatus: Myodocopa ostracods' eighth limb is dedicated to its genital apparatus, which highlights the importance of this organ in its reproductive journey.

- The furca: is a large structure that's involved in stabilization and swimming. It's located near the anus.

By studying the detailed morphological characteristics of ostracods, scientists can gain a deeper understanding of their evolutionary history and ecological makeup. This classification framework is a valuable resource for further expanding our knowledge of the diverse lifestyles of aquatic crustaceans.

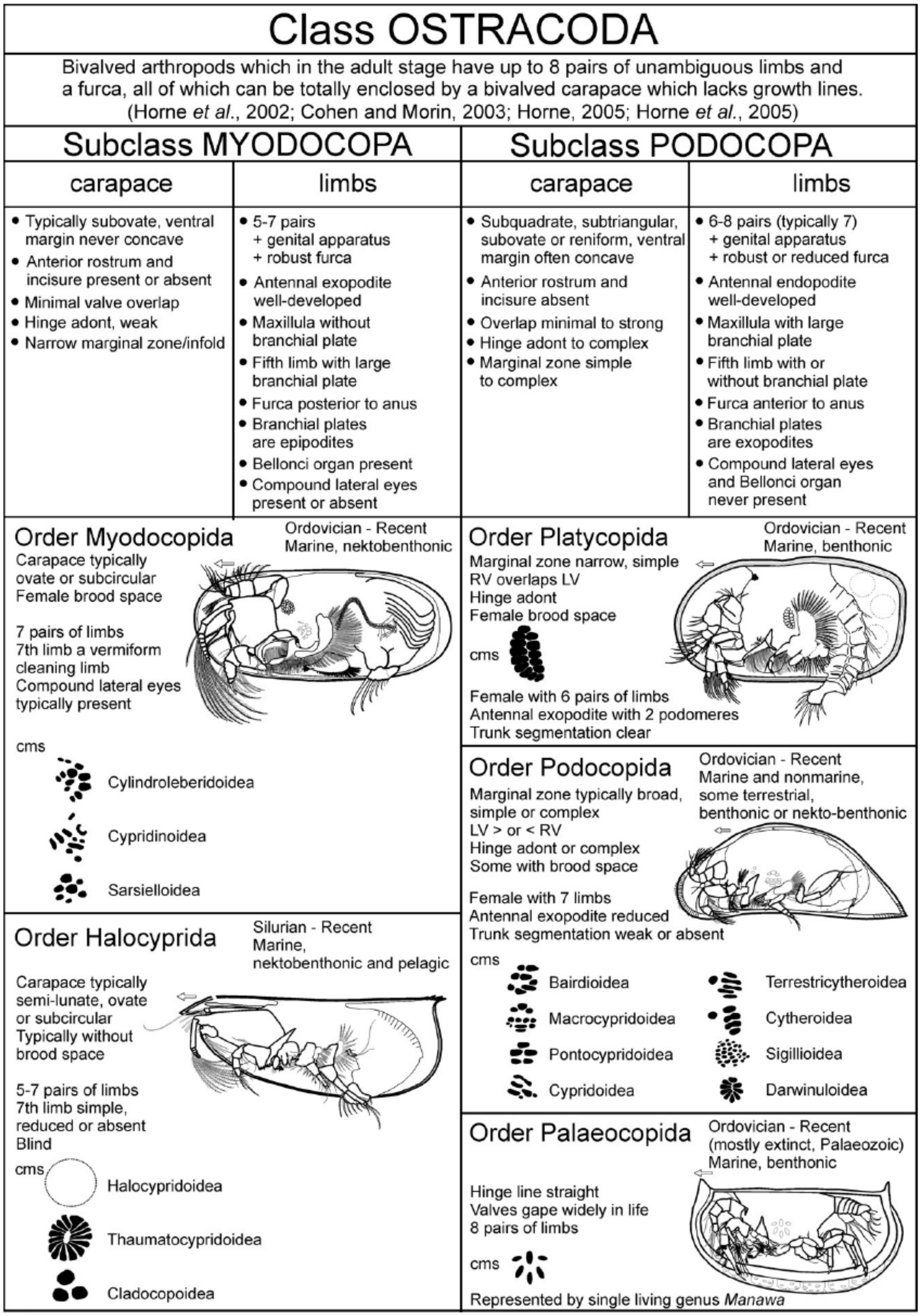


Figure.12: Synoptic characteristics of the two subclasses and five orders of Quaternary and living ostracods. CMS, central muscle scars (characteristic patterns). (Rodriguez-Lazaroet al 2012).

4.2 Podocopa group:

Podocopa ostracods have a low-magnesium epidermis that forms the outer and inner lamellae. It then forms the inner and outer portions of the lamellae through the two valves that enclose its body ;(Karanovic, 2012 ; Olempska, 2012)

These features, which are connected to the inner surface through the valve's dorsal attachment, help protect the soft tissues of the animal. (Kesling, 1949; Kesling, 1951; Boomer, 2003) Their body is enclosed by two valves, which are dorsally articulated. These features protect the soft parts of the body and contribute to the carapace's structural integrity.

The internal surfaces of the Podocopa ostracods' valves have various features including:

➢ The hinge region is an important part of the valve's structure and plays a vital role in its articulation.

The carapace's hinge is a crucial feature that varies among different species, The unique hinge design of the ostracod plays a crucial role in helping differentiate and classify these small aquatic crustaceans. (Pokorný, 1998; Siveter, 2008; Smith, 2010). This region is where the two valves join to maintain its integrity. There are eight different kinds of hinge structures found in these shells. (Figure. 13)

- Adonts have a simple hinge design. It has a chitinous connection connecting its two valves.
- A lophodont hinge features a pair of sockets and teeth at each end. A bar and groove are also located between the sockets and teeth. The teeth and socket independently separate when the carapace is opened.
- Merodont hinge is similar to lophodont hinge, it has crenulated sockets and teeth, which makes it appear serrated or notched in the edge.
- Schizodont: In the schizodont hinge, each tooth and corresponding socket are bifid, meaning they are divided by a deep notch. This division adds complexity to the hinge structure.
- Ampidont: The ampidont hinge is similar to the schizodont hinge, but it only has a bifid (divided) posterior tooth and socket. The anterior tooth and socket are not bifid.

- Gongylodont: In the gongylodont hinge, teeth are present on both valves, and there are corresponding sockets on both valves. This symmetrical structure contributes to the stability of the carapace.
- Visordont: The visordont hinge is a unique type found only in the Terrestricytheroidea group. It consists of two teeth at each end of the hinge on the right valve and two corresponding sockets on the left valve. When the valves open, the teeth and sockets act as pivot points, causing the right valve to override the left along the dorsal margin, resembling the movement of a visor.

The various kinds of hinge structures utilized by ostracods distinguish them from one another, which is why they play such a crucial role in taxonomy and identification (Melik, 1966; Parker, 1997) The diverse array of hinge types demonstrates how ostracods adapt to their specific habitats and ecological niches in aquatic ecosystems (Mesquita-Joanes 2012)

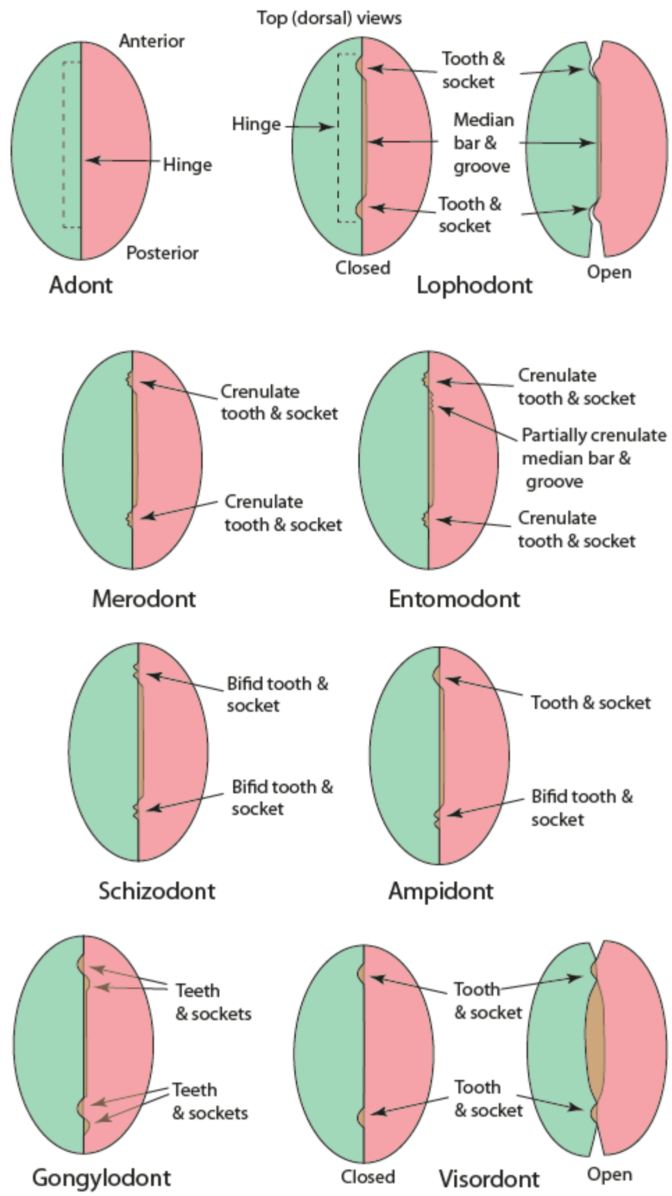


Figure. 13: The figure presents the various types of hinge structure.

➢ The marginal zone is the periphery of the valve, and it may have features or structures.

➢ Muscles imprints can be used to differentiate Podocopa superfamilies. On the internal surfaces of the valves, the imprints create clusters of scars, which serve as valuable clues regarding the functioning of the ostracods.

The way ostracods close and open their carapaces is an interesting aspect of their adaptation to their environment.

The Adductor Muscles play a crucial role in the process of opening and closing the carapace, and they contract when the two valves are pulled together, which seals the creature inside its protective shell. (Parker, 1997). These muscles are connected to the valves, and the points where they are attached are called "adductor muscle scars." (Gabbott, 2013). These marks can be seen on the animal's exterior surface.

This vital action is required to fend off predators and environmental hazards.

- Precise closure: The Ostracod carapace is designed to close with high precision. One of its valves has a slightly larger opening than the other, which overlaps the smaller one. This seals the area to keep the carapace closed.
- opening carapace: The animal can open its carapace by relaxing its adductor muscles and letting its appendages twist and break its valves. It also uses its appendages to push its valves apart. The movements of these appendages allow the ostracod to remove its protective shell and start performing various activities such as reproduction and feeding.

To survive in their aquatic environments, ostracods need to be able to tightly seal and open their carapace using appendages. This allows them to endure threats while also safeguarding themselves from environmental hazards.

In addition to serving as important aspects of the biology of ostracods, the presence and patterns of adductor muscle scars can also serve as distinguishing features in higher-level taxonomic groups (Athersuch, J., 1989; Horne, D. J. et al 2000; Hessler, R. R., et al 1982) This helps researchers gain a deeper understanding of the group's diversity.

Podocopa ostracods possess remarkable structural and morphological traits, which enable scientists to appreciate their adaptability to varying environments and the distinctions among different groups. (Figure. 14)

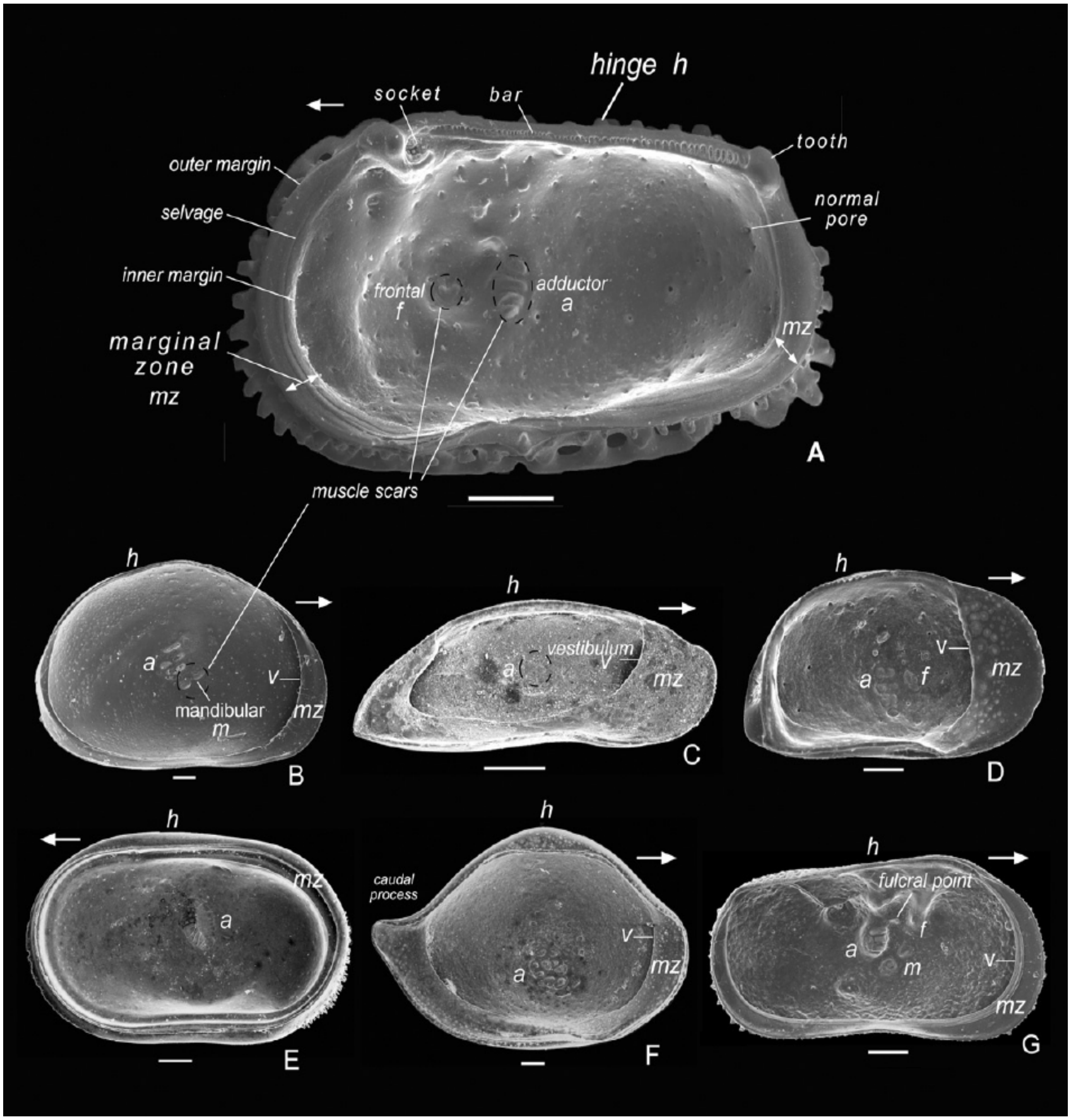


Figure. 14: Characteristic morphologies of the interior of Recent and fossil ostracod valves: (A) *Carinocythereis* (Cytheroidea), RV, Recent. (B) *Heterocypris* (Cypridoidea), LV, Pliocene. (C) *Argilloecia* (Pontocypridoidea), LV, Holocene. (D) *Krithe* (Cytheroidea), LV, Holocene. (E) *Cytherella* (Cytherelloidea), RV, Holocene. (F) *Bairdia* (Bairdioidea), LV, Holocene. (G) *Ilyocypris* (Cypridoidea), female LV, Pleistocene. Scale bar¼100 mm; arrows point anteriorly. RV, right valve; LV, left valve. A and C–F are marine, B and G are non-marine. (Rodriguez-Lazaro, J., et al 2012).

CHAPTER III. INTRODUCTION TO OSTRACODS: MICROSCOPIC SHELLS, MACROSCOPIC INSIGHTS

The appearance of the valves of ostracods is variable, and they can exhibit various characteristics and they may exhibit a wide range of features that are ideal for ecological and taxonomic investigations. (Mesquita-Joanes, F et al 2012 ; Levin, L. A. 1984 ; Athersuch, J., et al 1989)

- The surface texture: the texture of an ostracod's valve can be variable smooth, to pitted. For instance, some species have a punctate or finely textured surface, while others have a more prominent pitting or sculpturing appearance. (Meyer, J et al 2017; Cabral, M. C et al 2008) Their surfaces' distinctiveness can serve as a diagnostic characteristic for distinguishing organisms.
- Reticulated ridges: In some ostracods, the surface of their valves has reticulated ridges, which are characterized by raised lines and grooves. (Bassler, R. S et al 1934; Brady, G. S. 1868; Brady, G. S. 1889) These patterns are unique to a specific species.
- Tubercules and spines: Tubercles are small, round projections that can be found on the surface of a valve. They can also be setae or spines. (Sylvester-Bradley, P. C. 1948; Sylvester-Bradley, P. C 1971; Brady, G. S. 1886; Smith, W. 1817) The distribution and size of these spines can vary, which makes the animal's morphological diversity even more remarkable.

Although the general shape and size of a valve are important for identifying generic and distinct species, sexual dimorphism and development variations can also affect its morphological characteristics. (Hunt, G. 2017; Martens, K. 2000) For instance, the sexual dimorphism of male and female valves may involve their size and shape. On the other hand, the evolution of the valve's morphology can be affected by the changes that occur as an ostracod's body grows and through their various instars and morphology. (Kesling, R. V. 1949; Zwair, H. 2023; Von Grafenstein, U., 1999)

In order to accurately identify and classify ostracods, it is important to study their external features, such as the appendage morphology and the hinge structure. Furthermore, valve variations can provide insight into the strategies and ecological adaptations of different taxa. (McCormack, J., 2019; Horne, D. J., 200). These factors are valuable in the fields of systematics, paleontology, and ecology. (Figure. 15)

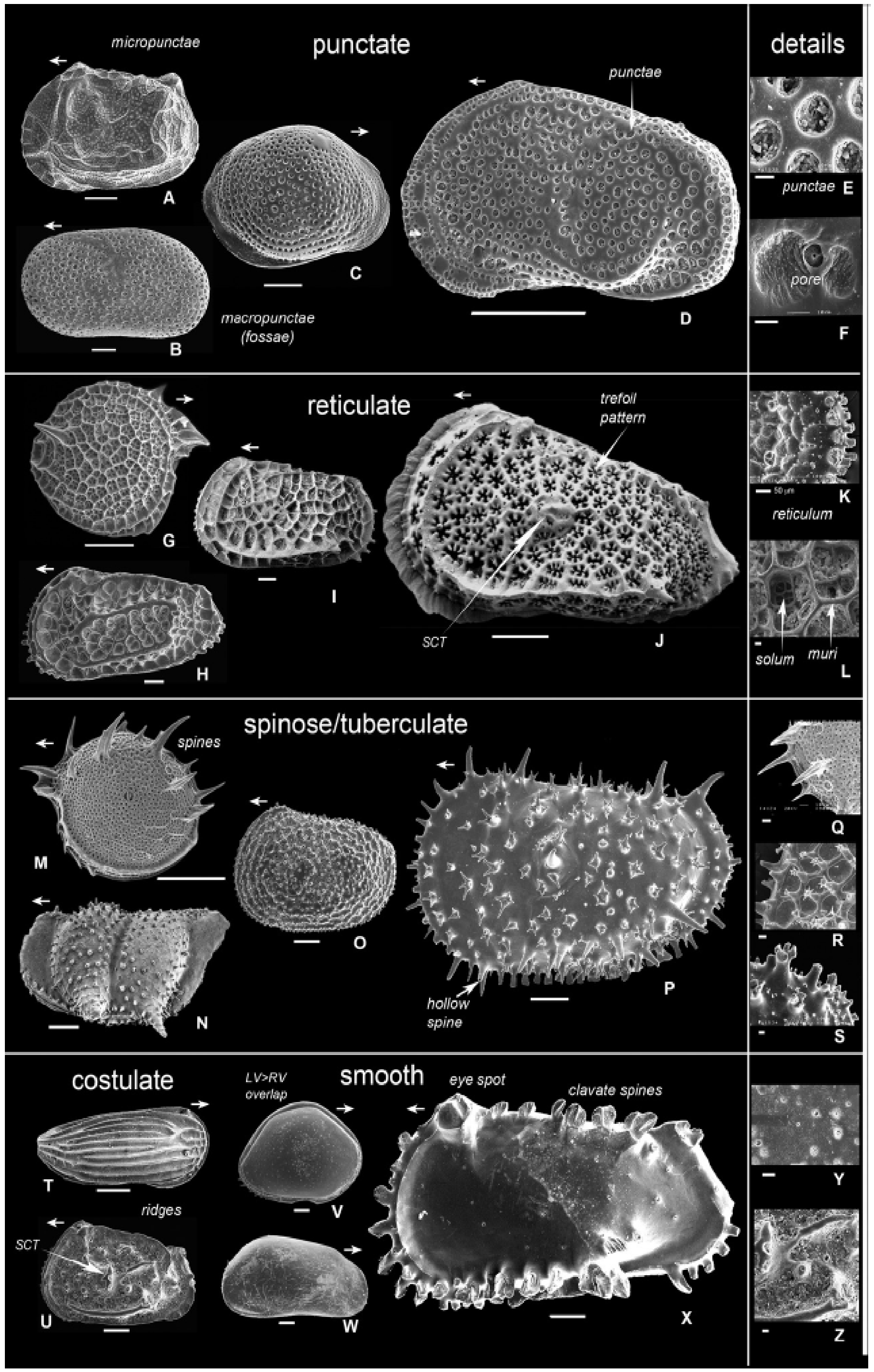


Figure. 15: Characteristic external morphologies (ornamentation) of living and fossil ostracod valves. (A) Palmenella (Cytheroidea), LV, Recent. (B) Cytherella (Cytherelloidea), LV, Holocene. (C) Loxoconcha (Cytheroidea), RV, Recent. (D) Cluthia (Cytheroidea), LV, Recent. (E, F) Details of punctae and sieve-type pore. (G) Polycope (Cladocopoidea), RV, Recent. (H) Costa (Cytheroidea), LV, Recent. (I) Bradleya (Cytheroidea), LV, Holocene. (J) Trachyleberidea (Cytheroidea), LV, Holocene. (K, L) Details of reticulum structure. (M) Polycope (Cladocopoidea), LV, Recent. (N) Bythoceratina (Cytheroidea), LV, Holocene. (O) Henryhowella (Cytheroidea), LV, Holocene. (P) Actinocythereis (Cytheroidea), LV, Recent. (Q, R, S) Details of spines and tubercles. (T) Ruggieriella (Cytheroidea), RV, Holocene. (U) Thaerocythere (Cytheroidea), LV, Recent. (V) Bairdia (Bairdioidea), car., right side, Recent. (W) Candona (Cypridoidea), RV, Recent. (X) Pterygocythereis (Cytheroidea), LV, Pleistocene. (Y) Detail of smooth surface with normal pores. (Z) Detail of costulate surface. Scale bar¼100 mm (10 mm for the details in right column); arrows point anteriorly. RV, right valve; LV, left valve; car., carapace; SCT, sub-central tubercle. All marine except W which is non-marine. (Rodriguez-Lazaro, J., et al 2012).

5. Distribution:

The distribution of Ostracods, varies depending on the type of habitat they live in. (Martens, K., 2008; Külköylüoğlu, O. 2004; Kiss, A. 2007) Their ability to adapt to different environmental factors and their preference for feeding and reproductive strategies are the reasons why their ecological condition is remarkable (Boomer, I., 2003; Dole-Olivier, M. J., 2000, Horne, D. J. 2003).

Ostracods can be found in various types of environments, such as ranging from the deep ocean abyss to temporary water bodies, terrestrial habitats, and soils covered with leaf litter. (Danielopol, D. L. 2002; Smith, A. J., et al 2015).

The study of Horne, in 2003 which was carried out, investigated the ecological diversity of various seabird species. It provided valuable information about the distribution and environmental preference of the Podocopan superfamilies, as well as the findings of a similar investigation conducted.

Ostracods' ability to survive and grow in marine habitats is due to their lack of a larval stage, which allows them to live in ecosystems defined by water mass, sediment, and the water-sediment interface. (Claassen, C. 1998; Copper, P. 1992; Giere, O. 2008)

Non-marine ostracods prefer to lay eggs at resting sites or in environments with anti-desiccation features. (Gray, J., et al 1977) This strategy allows them to distribute eggs across various organisms, such as insects and birds (Martens and Horne, 2009)

The temporal and physical characteristics of an area or region influence the distribution and abundance of ostracods. (Mezquita, F. et al 1999 ; Nagorskaya, L., et al 2005 ; Allen, P. E., et al 2011). In 2002, Horne and Smith demonstrated the importance of studying the diverse groups of these animals to gain a deeper understanding of their distribution.

Their diverse assemblages can be studied to learn more about the environment's influence on their distribution (Poquet, J. M., et al 2011, Boomer, I., et al 2003)

The ecological traits of Ostracoda can serve as a valuable resource for studying past environmental conditions. (Boomer, I., et al 2003; Mezquita, F.,et al 2005; De Deckker, P., et al 1988; Rodriguez-Lazaro, J., et al 2012) Nevertheless, more precise data on present ecosystems is urgently required to broaden our comprehension and enable the creation of comprehensive databases.

The ecological traits of Ostracods can provide us with a better understanding of environmental conditions. (Boomer, I., et al 2003; Mezquita, F.,et al 2005; Ruiz, F., et al 2013) But, more precise information on present ecosystems is required in order to gain a deeper comprehension of the world's ecosystems.(Mesquita-Joanes et al., 2012)

The exact number of modern species of Ostracods is still unclear due to the varying research intensity across different biogeographical regions. (Griffiths, H. I. 2001; Boomer, I., et al 2003) Out of the 20,000 known species, about half are non-marine, while the others are parasites or free-living. (Rodriguez-Lazaro, J., et al 2012 ; Costello, M. J., et al 2017)

In 2009, Horne and Martens reported that there were about 400 non-marine species in the African and Palaearctic regions, while around 250 were in South America. The exact number of extant ostracods is not known due to the ongoing assessments in different biogeographic areas.

6. Reproduction and ontogeny

The reproductive options of Ostracods are varied. They utilize three primary reproductive strategies. (Horne, D. J., et al 1998 ; Tran Van, P., et al 2021 ; Schön, I.,et al 2000, Pokorný, 1978; Hao & Mao, 1993; Hinz-Schallreuter & Schallreuter, 1999; Ikeya & Kato, 2000; Holmes & Chivas, 2002)

- ***Gamogenic Reproduction****:* this is a sexual reproduction mode, males and females mutually acquire eggs and sperm to produce offspring. This strategy is commonly used by marine ostracods.
- ***Parthenogenetic Reproduction:*** asexual reproduction, females are capable of producing offspring without intercourse with males. Certain non-marine ostracods are believed to reproduce through this process, possibly because the absence of males.
- ***Mixed Reproduction:*** In some cases, an Ostracod exhibits a mixed approach to reproduction, with both asexual and sexual options. The choice between these two strategies can be

influenced by the environment's conditions. This phenomenon, which is referred to as geographical parthenogenesis, occurs when an organism chooses between reproducing both ways. In favorable conditions, they may reproduce sexually, while in unfavorable conditions, they can opt for asexual reproduction.

7. Life Cycle:

The life cycle of ostracods involves distinct developmental stages. (Heip, C. 1976 ; Mesquita-Joanes, F., et al 2012 ; Kesling, R. V. 1949 ; Smith, A. J., et al 2010 ; Dole-Olivier, M. J., et al 2000) (Figure. 16)

- Egg Stage: Ostracods lay eggs, which can hatch either within the expanded posterior brood space of the adult female carapace or be laid directly into the water.
- Nauplius Stage: The larva hatched from the egg is called a nauplius, representing the first instar (A-8). During this stage, the nauplius is already enclosed by a bivalve carapace and possesses three pairs of appendages.
- Instar Transitions: Ostracods go through multiple instar transitions before reaching adulthood. These transitions involve molting, where the old carapace is shed, and a new, larger one is secreted. The number of instars varies among ostracod taxa, with some having eight instars (Podocopida) and others having four to seven instars (Myodocopida).
- Adult Stage: The larva goes through instar transitions, with the final stage resulting in the development of the adult ostracod.
- Shell Structure: Ostracod shells have a unique double-layered structure, consisting of an outer lamella and an inner lamella. The outer lamella is composed of calcite, while the inner lamella is partially calcified and partially chitinous. The calcified inner lamella, known as the duplicature, appears only when the ostracod becomes an adult.

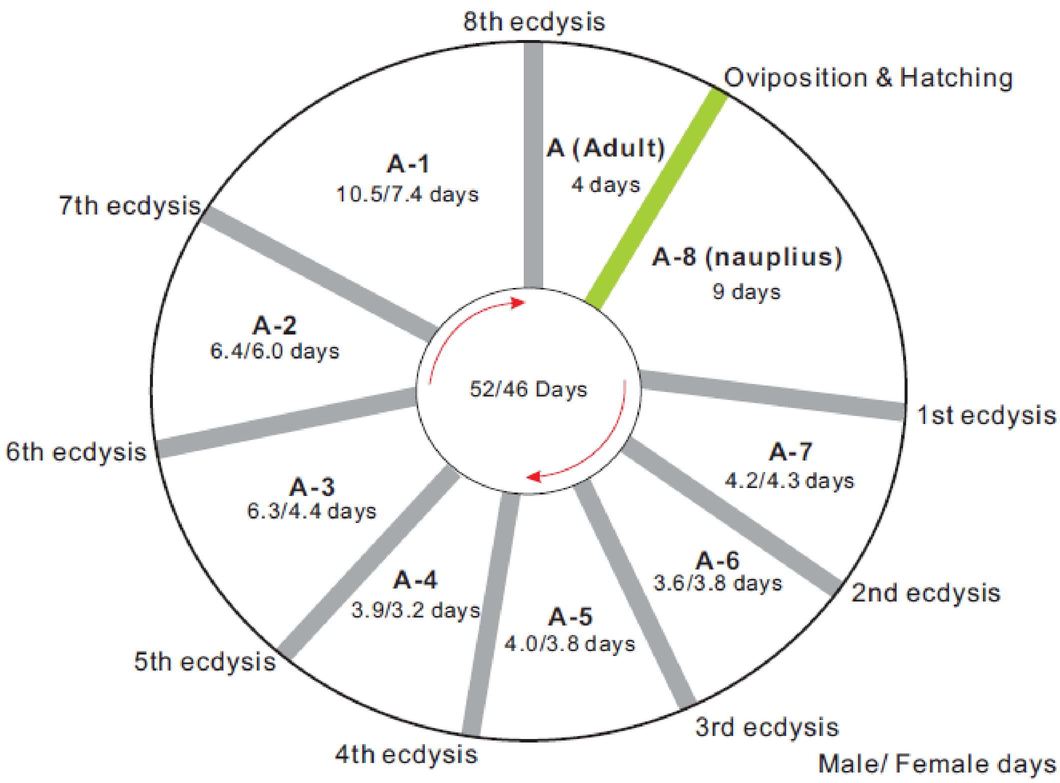


Figure. 16: life cycle of Ostracods. (Yuan, 2008)

8. Fossil records:

Fossil records of ostracods provide us with valuable information on the history of this tiny aquatic crustacean. (Schram, F. R., et al 1982; Karanovic, I. 2012; Oakley, T. H., 2013)

- The calcitic carapace of Ostracods is made up of two valves. This carapace shield protects the animal from the potential dangers of aquatic ecosystems. (Karanovic, I. 2012; Oakley, T. H., 2013)
- Encapsulation of Signatures: the ostracod carapace has a unique ability to encapsulate the water's chemical signatures. This allows us to study the various processes that occurred in the water where these organisms resided. (Morse, J. W., et al 2007 ; Tunnicliffe, V., et al 1998 ; Gould, S. J. 1989).
- Preservation in Sediments: ostracod carapace highly preserved in sedimentary deposits is attributed to their durability and resistance to decay (Matzke-Karasz, R.,et al 2013, Danielopol, D. L., et al 2002).

CHAPTER III. INTRODUCTION TO OSTRACODS: MICROSCOPIC SHELLS, MACROSCOPIC INSIGHTS

The fossil record of the ostracods is regarded as one of the longest among all known arthropods, standing at around 450 million years (Karanovic, I. 2012; Schram, F. R., et al 1982) Its long history allows scientists to study the evolution of these ancient creatures and Earth's past.

Highly adaptable to different ecological niches, the Ostracods have evolved to adapt to survive and proliferate in diverse environments (Horne, D. J., et al 2000; Vogt, G. 2017) With numerous lineages emerging during the Ordovician period, their ecological adaptability has resulted in a long-term persistence and proliferation.

Besides providing insight into the evolution of the ostracods, also the fossil records provide information on past climate and environmental conditions (Rodriguez-Lazaro, J., et al 2012; Marco-Barba, J., 2013; Börner, N., et al 2013; Mesquita-Joanes, F., et 2013; Bekhouch, G. 2023)

The durability of the carapaces and the adaptable nature of the Ostracods have contributed to their success. (Figure. 17)

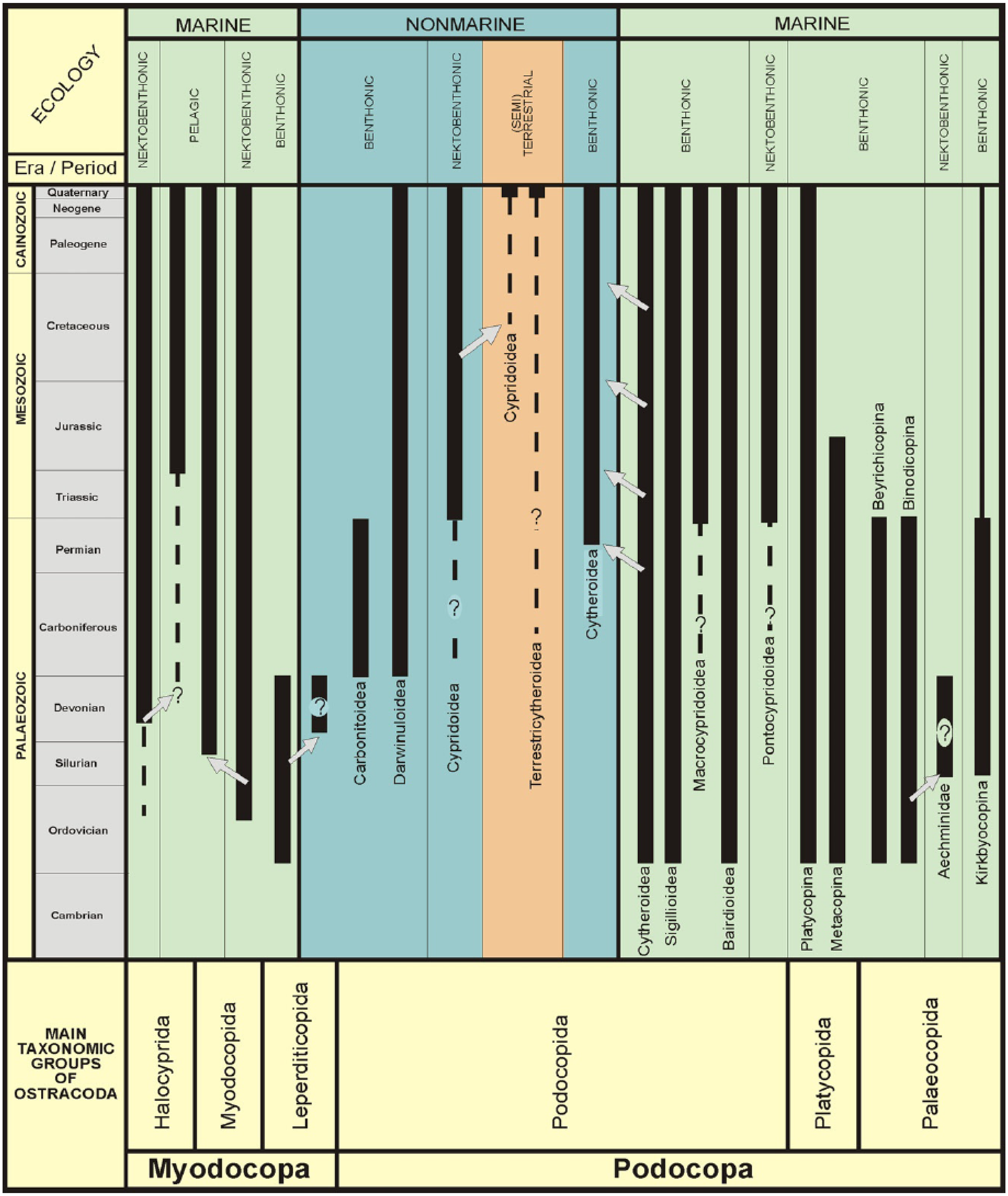


Figure. 17: Stratigraphical timelines of the major ecological radiations of the Ostracoda, (modified after Horne. 2003, 2005).

Application:

In the geological field, the ostracods fossil records can be utilized for a wide range of applications, such as biostratigraphy and paleoclimatic studies.

In addition to being used for scientific studies, the fossil records can also be utilized as environmental indicators and bioclimatic markers. Despite their lesser-known use compared to other organisms, such as the planktonic foramenifera, they have been extensively utilized in this domain. (Colin and Lethiers, 1988; Whittaker and Hart, 2009; Bekhouch, G. 2023).

Due to their diverse in terms of their habitat, the ostracod can be considered an ideal candidate for environmental and climate studies as they can be found in marine, transitional, or non-marine environments. (Ferreira, V. G. 2023 ; Czajkowska, M. et al 2022 ; Mischke, S.,et al 2012)

In addition to being used for scientific studies, the fossil records of the ostracods can also be utilized for age analyses in various fields, such as oceanography, biostatistics, and archaeology. (Kidwell, S. M.,et al 2002; Balasubramanian, A. 2017).

Researchers can use the data collected from the fossil records of the ostracods to reconstruct the past conditions of their present location. (Verschuren, D. 2003; Birks, H. J. B., et al 2010) By performing detailed analyses of the organisms' traits, such as their ecological characteristics, they can gain a deeper understanding of the past climate in their current environment. (Boomer, I., et al 2003; Mesquita-Joanes, F.,et al 2012; Rodriguez-Lazaro, J., et 2012)The study also involves taking into account the different aspects of the aquatic organisms, such as oxygenation, salinity, temperature, and productivity.(De Deckker, P., r, P., et al 1998; Frenzel, P.,et al 2005 ; McCormack, J.,et al 2019)

Different methods are used in these studies depending on the data that is gathered from different sources, such as shells, assemblages, and species. The data collected from the fossil records of the ostracods are used in various studies. These include analyses of the organisms' traits, their ecological characteristics, and species and assemblages. (De Deckker, P., r, P., et al 1998 ; Mezquita, F., Roca, J. R., et al 2005 ; Ruiz, F., et al 2013)

The evaluation of an assemblage is carried out to define its diversity, composition, and overall richness. The composition of ostracod groups is different from that of marine or non-marine waters due to the varying water chemistry and salinity levels in certain regions (Horne, D. J., et al 2012; Boomer, I., et al 2003; Ruiz, F., et al 2013; Bekhouch, G. 2023)

The abundance and diversity of pelagic and benthic ostracods are highest within the marine environment due to their distribution across massive water masses. (Correge, T. 1993; Benson, R. H. 1975). The varying assemblages of these organisms can be attributed to the effects (palaeo)oceanographic and hence, climatic changes. (Bassetti, M. A.,et al 2010; Marchegiano, M., et 2022; Boomer, I., et al 2003)

The abundance of benthic podocopian ostracod communities in oceans with fossil records of a distinct species belonging to a marine metazoan group is considered as an ideal representation of its diversity. (Jellinek et al., 2006)

The collected data from the ostracod communities could be used to predict the future climate of deep-sea regions. (Cronin, T. M., et al 1999; Zeppilli, D., et al 2015; Levin, L. A., et al 2001) They also utilized the results of their geochemical analysis to forecast the changes in the environment. (Croninet al, 1997; Cronin et al., 1999, 2000; Rodriguez-Lazaroet al, 1999; Didie´ and Bauch, 2000; Dwyer et al., 2000).

The signals of diversity and geochemistry can be used to identify environmental changes in coastal regions. (Frenzel, P., et al 2005; Anadón, P., et al 2002; Ruiz, F., et al 2013; Boomer, I., et al 2003) They can be used to determine the effects of sea level elevation on benthic communities. However, due to their unique properties, their precise interpretations can be challenging at times. (Verschuren, D.,et al 2000; Matsuda, J. T.,ety al 2015; Yavuzatmaca, M., et al 2017)

The ostracods are known to provide an ideal assessment of the current state of aquatic ecosystems. They can be found residing in ponds, lakes, and other types of water bodies. (Külköylüoğlu, O. 2004 ; Ruiz, F., et al 2013 ; Mesquita-Joanes, F., et al 2012)

The data collected from non-marine geological archives can be used to determine global climate patterns. (Leng, M. J., et al 2004; Yavuzatmaca, M., et al 2017; Bekhouch, G. 2023) The combination of these signals from continental and marine settlements allows scientists to identify changes in the atmosphere.

In shallow lakes and wetlands, the presence of ostracods can aid in understanding how climate affects water flow in these areas. (Ruiz, F., et al 2013 ; Boomer, I., et al 2003 ; (De Deckker, P., r, P., et al 1998)

In semi-arid regions, the presence of populations of ostracods that are representative of dilute or saline water can help predict the evaporation and precipitation balance.

Although certain types of water ostracods benefit from seasonal changes, it is still important to conduct long-term studies on the history of the environment in order to gain valuable information about past environmental events. (Ito, 2002; Henderson, A. C.,2009; Leng, M. J., 2004; Lowe, J. J., 2014)

Conversely, deep-water lakes that are geologically active can provide paleoclimatic data on long-term climate changes. (Cronin, T. M. (1999); Saltzman, B. (2002); Frogley et al., 2002) By studying the diversity of benthic communities and the isotopic variations in the lake's water, researchers can get a better understanding of the past climate of a region. (Mourguiart et al, 2002; von Grafenstein, 2002).

The data collected from non-marine communities can be utilized to reconstruct the climate that occurred during the evolution of the paleoclimatic framework (von Grafenstein et al., 1999).

According to Schmereve and colleagues, the data collected by the communities of ostracods during the Holocene and Pleistocene periods can be utilized in studies about the environment.Schreve et al., 2002).

A study conducted by Mezquita in 1999 revealed the importance of ostracod communities in identifying environmental changes.

In 2005, another study by Ruiz examined how human activities affected marine environments. The data collected during these studies were analyzed to determine how human activities affected the populations of ostracods and their diversities. The researchers were able to conclude that the animals decreased in numbers near their sources of pollution.

The researchers were able to determine the toxicity of various substances found in sewage, aquatic systems, and soils. They were also able to observe the reactions of specific animals to the chemicals (Khangarot and Das, 2009).

Conclusion

In conclusion, ostracods, often referred to as nature's tiny time capsules, have a fascinating role in various scientific disciplines. These minute crustaceans, both in marine and non-marine environments, serve as invaluable bioclimatic, stratigraphic, and paleoenvironmental indicators. Beyond paleontology, their study extends into fields such as limnology and molecular biology, often integrating with oceanography and evolutionary biology.

The extensive diversity of ostracods, with over 65,000 known living and fossil species, provides a wealth of data for researchers. While around half of these species have been officially described, the group's fossil record, spanning over 450 million years, is a rich source for studying metazoan evolution. Additionally, ostracods play a pivotal role in understanding metazoans' sexual development, with some of the earliest records dating back over 200 million years.

The taxonomy and classification of ostracods have evolved over the centuries, with contributions from pioneers such as Linnaeus, Baker, and Latreille. Significant works throughout the 19th and 20th centuries brought a deeper understanding of ostracod functional morphology, ecology, and taxonomy.

Advancements in geochemistry and radioactive dating during the 20th century have further enriched our knowledge of ostracods, allowing researchers to consider them modern examples of ancient organisms.

This chapter sets the stage for a more detailed exploration of ostracods in the following sections, covering their morphology, classification, distribution, life cycle, fossil records, and various applications in scientific research. Ostracods, with their intricate history and diverse applications, continue to be a subject of great interest and significance in the world of paleontology and beyond.

CHAPTER IV

CONSTRAINT OPTIMIZATION

1. Introduction:

In chapter three, we will discuss the importance of connecting the various species of foraminifer and ostracods to create a cohesive environmental narrative for the region. This project will involve merging multiple datasets, which represent distinct aspects of the paleoenvironment, into a single timeline. The integration of data from different sources will help illuminate the biogeographical data of our study area, revealing the geodynamic framework's enigmatic anoxic event and the story of the Cretaceous age.

The goal of this project is to provide a deeper understanding of the ancient marine life by piecing together the various constraints that bind these organisms to their environment and temporal context.

This chapter will introduce the concept of constraint optimization, which will help us improve our knowledge of the region's paleoenvironnementand our ability to recognize the intricate details of ancient marine life.

Through our study of the microcosmic world of foraminifera and ostracods, we will be able to gain a deeper understanding of their silent testimonies and the secrets of the Cretaceous age.

The end of this chapter will help us gain a better understanding of the link between the various species of foraminifera and ostracods. It will also help us understand the history of Earth as a whole.

2. Biostratigraphy and Biozones:

Summary of the origins, development, and techniques employed in biostratigraphy.

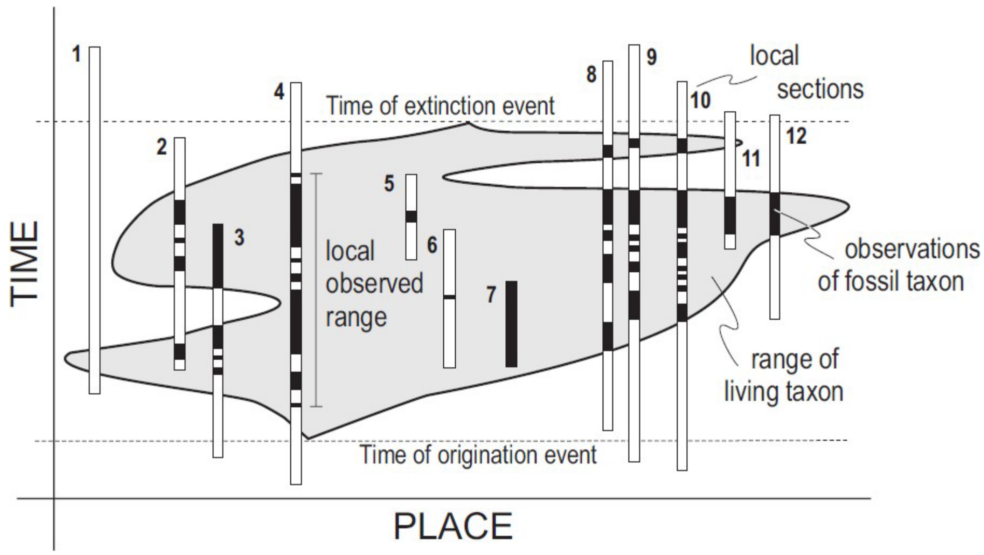


Figure. 18: The chart shows the range of a fossil taxon in life (gray), the fossil taxon (black), and in stratigraphic sections (rectangles), as well as the timelines that define its extinction and origin. (Sadler, 2013).

2.1. A Brief History:

Researchers in biostratigraphy examine how sedimentary layers are made up of fossils. They're primarily focused on reconstructing the past of life and developing a standard time scale for other studies related to geology.

About 200 years ago, before evolution theory was formulated (Darwin 1859), it was clear that the general evolution of animals had similar characteristics in the rocks. For instance, dinosaurs appeared before mammals, and trilobites became abundant before ammonites.

These observations led to the establishment and division of the time scale for the three periods: the Mesozoic, the Paleozoic, and the Cenozoic. They also enabled researchers to resolve finer subdivisions by studying fossil species. The subdivisions developed by (Oppel, 1858) and (D'Orbigny, 1851) helped in time correlation by allowing them to identify strata in varying locations.

By using fossil materials, (Smith, 1799) was able to pinpoint the locations of various strata in England. He was able to do so by complementing the similarities between topographic expression and rock type (Lauden, 1976).

In the Paris Basin, (Brongniart and Cuvier, 1808) focused on various faunal assemblages that they believed were separated by disastrous events.

By using fossil materials, (Phillips, 1829) was able to pinpoint the locations of various faunal assemblages in England. He was also able to introduce new species into the faunal succession in the region (Sedgwick and Murchison, 1939).

Rather than referring to the presence of new species in nearby strata, the researchers used the intermediate attributes of the new fauna to identify them.

The duration of a zone or stage of fossil materials depends on the ranges of individual taxa and fossil materials. Biochronologists started using qualitative methods a hundred years ago, and numerical methods were not used.

Petroleum companies started incorporating sequences of fossil species into their studies, which significantly improved the correlation's resolution.

(Alan Shaw, 1964) a petroleum geologist came up with the concept of economy-of-fit as a way to analyze the differences between the species found in different areas of the same age.

At Shell Oil Company, the recognition of the differences in the fossil species led to concerns about their validity (Shaw, 1995). Some people preferred to look at the fossil species' disappearance and appearance as if it occurred at the same time in different locations.

The results of his correlation graphs revealed that the uncertainty of the two effects and the sequence of all the taxa at hand was underdetermined. However, the practical value of carrying out a good approximation led him to use a biostratigraphic approach.

The use of Shaw's method by Amoco benefited from the company's decision to take advantage of the rich fossil record. The data collected by the company increased the volume of information stored in biostratigraphic databases (Carney and Pierce, 1995; McGowran, 2005).

Through the Deep-Sea Drilling Project, the resolution of the subdivisions was standardized using the collected microfossils. A computer scientist discovered that natural selection could be used to solve optimization problems. It was a trial-and-error procedure that could be replicated in algorithms.

During the 1980s, paleontologists started using various numerical methods to study biochronology (Tipper, 1988). They also started using evolutionary heuristics to solve engineering and scheduling problems.

With the help of computers, individual paleontologists were able to create detailed timelines of the faunal assemblages (Guex, 1991) and species' first appearances (Alroy, 1992).

The methods used for correlation were also adapted to the changing conditions of the world, such as the availability of radioisotope dates. This led to a shift in the focus of biochronology from the definition of biozones to the age calibration of fossil species appearances. This allowed indirect dating to be performed.

The gap between the time horizons and the biostratigraphic horizons is the challenge that biostratigraphy's various approaches face when trying to date (Figure. 19).

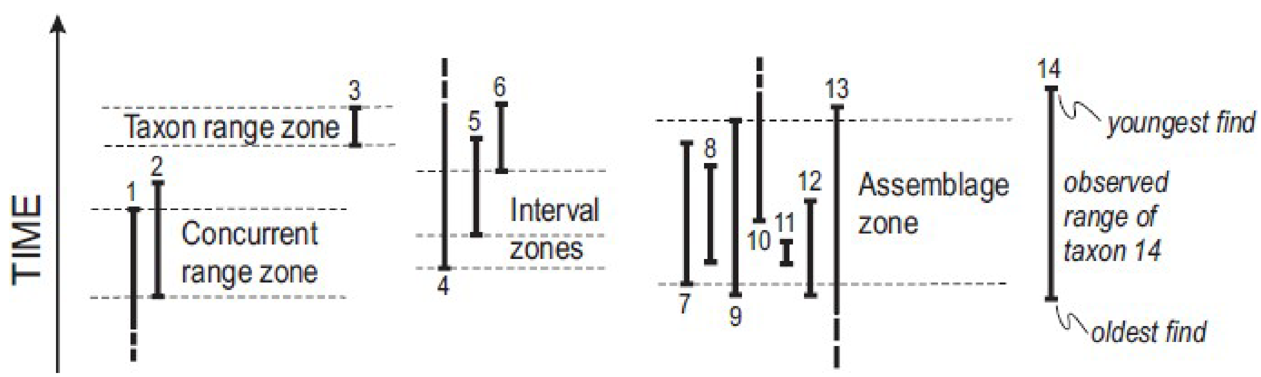


Figure. 19: Biozones defined by subdivision of a range chart. (Sadler, 2009).

To properly describe the time of the disappearance and appearance of fossil species, it is essential to compensate for the various factors that can affect their time of appearance. For instance, the local discrepancies in information can be caused by the preservation and collection processes.

Despite the various arguments about how to solve this issue, it is still evident that the most cost-effective and feasible method for addressing it is by studying the fossil correlates of rock layers (Ludvigsen et al., 1986).

2.2. Terms and Basic Data:

Salvador states that biozones are bodies of rock that are characterized by fossils (Salvador, 1994). The bounding surfaces of these units are often diachronous, which means that the age when the most and least fossils of a particular species were found varies in various places.

New species tend to evolve at different places and times. Their distribution and range expand to varying degrees over time. Also, as the species is lost and replaced by others, the geographic range decreases. Incomplete preservation of fossils results in a patchwork of patches.

Even in deep marine regions, the accumulation of sedimentary strata does not always occur continuously (Aubry, 1995). This means that some ranges will end up artificially at gaps in their distribution.

A biozone's bounding surface is characterized by the presence of biohorizons, which are stratigraphic surfaces that are characterized by significant faunal changes. (Figure. 20)

Due to the failure of collections and fossil preservation, the biozones of living species will be smaller than their living counterparts. The chronozone, which spans beyond the living range, would encompass the deposits of the organisms during their lifetime.

Despite the diachronous nature of biozones, they are still used to estimate the positions of datum surfaces, which are generally located at the time when a taxon originated or died out.

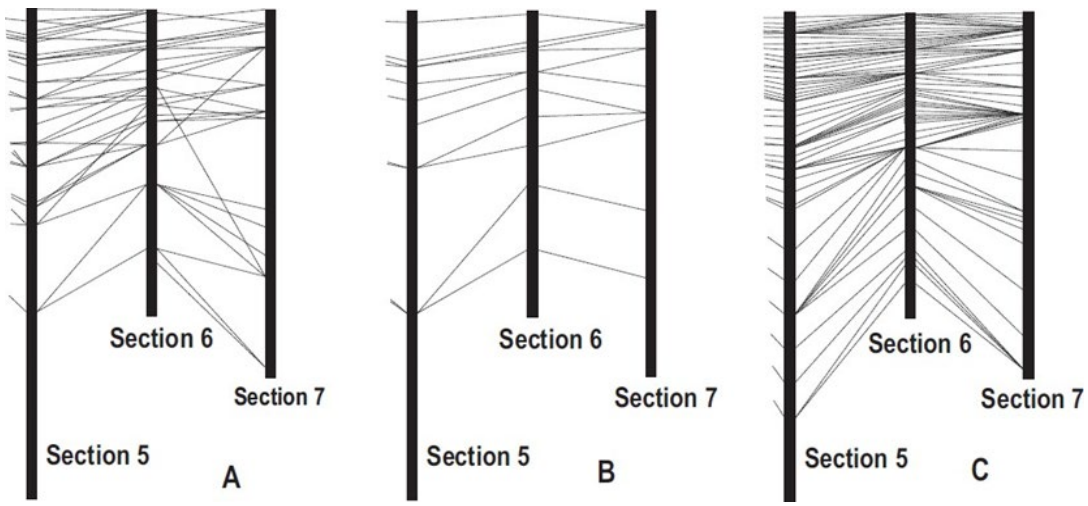


Figure. 20: Biostratigraphic correlation as a fence diagram: part of a 7-section project. A) Literal correlation of observed range ends. B) Range ends culled to those found in the same sequence in all 7 sections. C) Adjustment of all range ends to the sequence that best fits all local observations.

The data collected by biostratigraphy are mainly comprised of faunal lists, which are inventories of the fossil taxa that can be found in the same area. Ideally, these lists should be placed in sequence, so that the spans of the various types can be depicted in local range charts (Figure. 20).

The local finds of a taxon are classified into the highest and lowest ones based on their estimated first appearance and last appearance datums (FADs and LADs).

The distinguishing characteristic of biohorizons is their diachronous nature. The boundary lines connecting the highest and lowest finds in a biohorizon are drawn through the stratigraphic sections, forming a fence diagram (Fig.3). Unfortunately, many of these correlation lines cross each other, which makes it impossible to consider them to be timelines.

2.3.FADs and LADs (biohorizons):

Modern biostratigraphy avoids using only a few bio-horizons to define zones and aims to retain as many as possible. This method also requires the adjustment of the local bio-horizons (Figure. 20).

The elimination of bio-horizons does not eliminate the possibility of diachronism. However, it does not eliminate the correlation lines' isochronous nature.

Three different methods are used to correct diachronism. One of these is the use of gaps in the ranges to add confidence intervals (Marshall, 1990). This method only corrects the difference between time and biostratigraphy.

The other method combines the use of radioisotope dates and paleomagnetic reversals. It is ideal for determining the age of ranges at various locations in the cores of LADs and FADs from the sea floor.

The third method combines the observed sequences and coexistences in different locations. It then searches for a composite set of events that can be used to fit the minimum range adjustments.

If the ranges are shorter than their true counterparts, then they should be extended to fit the global sequence. This method was first proposed as a graphical representation of regression (Shaw, 1960).

With the help of algorithms and data sets, computer programs can now perform a sequence optimization search in large numbers of records (Sadler, 2004). If there are known age horizons, such as the dates of paleomagnetic reversals or ash falls, then they can also be used to find the best sequence.

In certain cases, such as over short distances, ecological factors can be used to improve the correlation between the observed sequences and the data. For instance, if the ocean currents and global temperature changes cause a shift in the relative abundance of foraminiferans and pollen, then these can be used to improve the relationship between the data and the environment.

The variations in the stratigraphic trends concerning the relative abundance of taxa can be used to identify the type of strata in a given area.

2.4.Resolving power:

A zonation based on the characteristics of marine organisms can be used to resolve intervals of less than a million years.

These sets of zones are usually based on a single biological clade and can resolve intervals of around 0.5 to 0.75 million years. In the Mesozoic, the conventional ammonite subzones and foraminifera can resolve up to 3 million years.

The average duration of chronometer-based subzones and zones for the same types of microfossils ranges from 0.75 to 1.0 million years during the Cretaceous period. It is necessary to establish distinct sets of chronometer-based structures for different climate regions. (Figure. 21)

In the Cenozoic era, there were 32 low-latitude and 11 mid-latitude chronometer-based structures. The conodonts of the Ordovician era support the North Atlantic and the Midcontinent with resolutions of up to 4 million years. The finer resolution of the Silurian and Ordovician chronometer-based structures is provided by the more cosmopolitan areas.

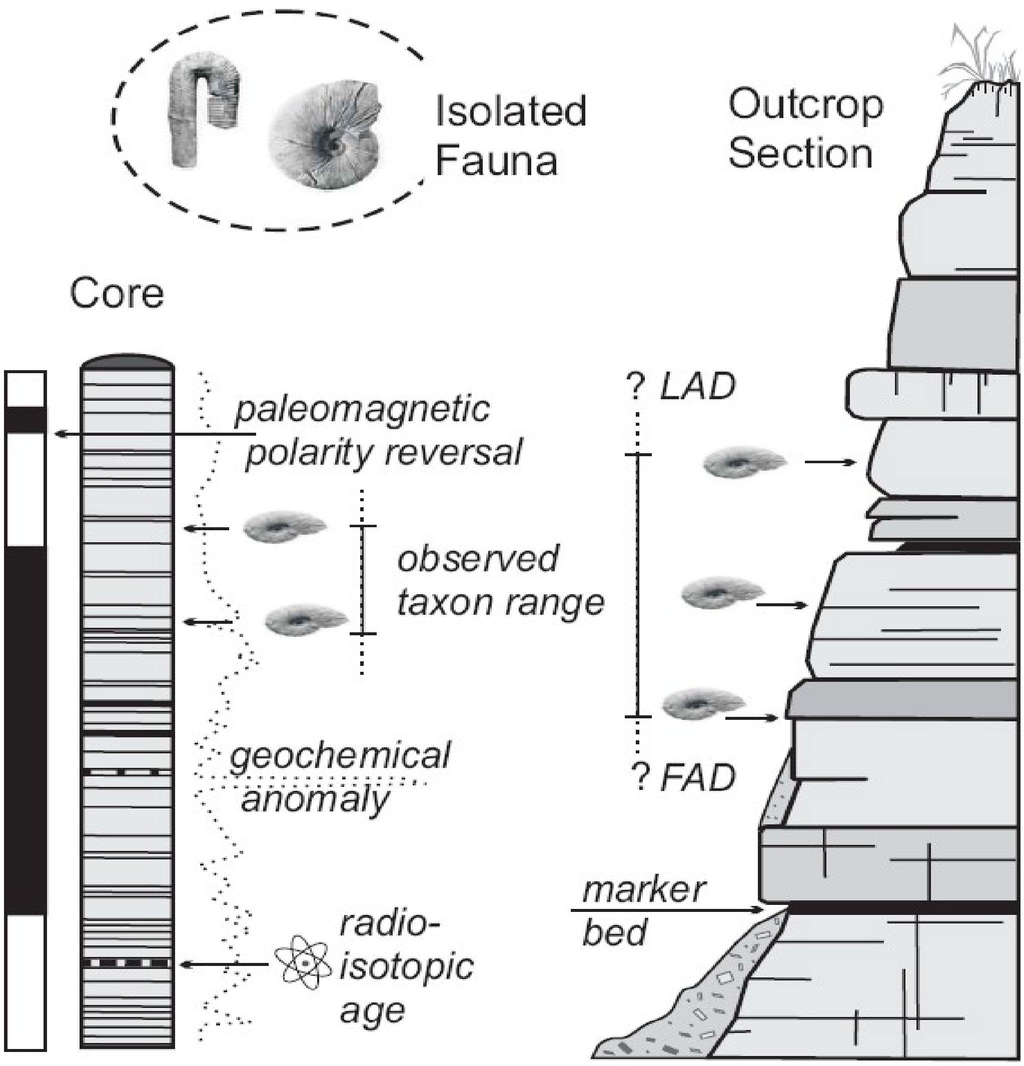


Figure. 21: Figure presents the various sources of information about the coexistence and taxon ranges, as well as other types of stratigraphic data that can be used for inclusion and correlation in timelines. (Sadler, 2013).

The ability to resolve more complex time sequences through the use of biohorizons is a promising prospect. For instance, for the Silurian and Ordovician periods, over 3,000 events of extinction and graptolite appearance have been identified.

In the Cenozoic, there were around 100 calibrated biohorizons for calcareous nannofossils and foraminifera. It is believed that the power to resolve a period of 0.25 million years or more can be achieved by utilizing biohorizons from multiple fossil sources.

Although computer optimization or radioisotopic calibration can be used to resolve complex time sequences, the relative age of the biohorizons that are located in the range-end zone can still be considered irresolvable. Nevertheless, resolvable clusters and events can increase the power of biohorizons to a significant degree (5- to 10-fold over traditional biozones).

It has been estimated that the time scales based on biohorizons could resolve intervals of 500,000 to 1 million years through the Phanerozoic period. This is equivalent to the size of errors that are quoted for the dates of the ash falls from the Paleozoic. It is also likely shorter than what the taxa took to spread the biohorizons from their original point of origin. This is a contributing factor to the global correlation between timelines and biohorizons.

The reduction in the distance of correlation leads to an increase in the number of biohorizons and strata that can approximate timelines. However, the actual resolution of the given correlation will be affected by the strata's fossil content.

2.5. Too Much Information:

Getting too much information can make it harder to carry out simple procedures. Also, the growing number of facts can overwhelm the capabilities of qualitative analysts. This can expose them to errors in their assumptions.

The initial use of fossil successions to determine sedimentary strata dates began immediately, even though there was a limited amount of information available regarding the various aspects of paleontologic research. Nowadays, with the availability of large open-access databases, paleontologists have the necessary information to resolve complex time sequences.

The sheer number of facts can also overwhelm the capabilities of qualitative analysts. For instance, it is sometimes necessary to combine the data from multiple locations to get a complete picture of the fossil record.

The expanding geographic scope can also lead to the development of new problems, such as provinciality and faunal migration issues. New locations can result in the discovery of new taxa, and the time-line task becomes less determined.

For instance, the amount of information required to resolve a timeline based on the extinct graptolite cladé is immense. This type of clade supports the traditional biostratological studies of the Silurian and Ordovician.

To resolve the timeline issue, the reserhers have collected a database containing 506 sections with over 20,000 events and 28,000 pairwise constraints. In addition, I have found a total of 261,126 first-appearance cases that need to be resolved before a final appearance. This database was created by Alroy (1992, 1994).

Despite the immense amount of data that has been collected by the computer, there are still many unknowns when it comes to solving the timeline problem.

In addition to the use of computers, the solution should also involve applying uncertainty intervals to the position of the first and last events in the timelines.

3. Chronostratigraphy and Time-lines:

paleobiologic timelines and their applications in the study of macroevolution, time stratigraphy, and paleobiogeography.

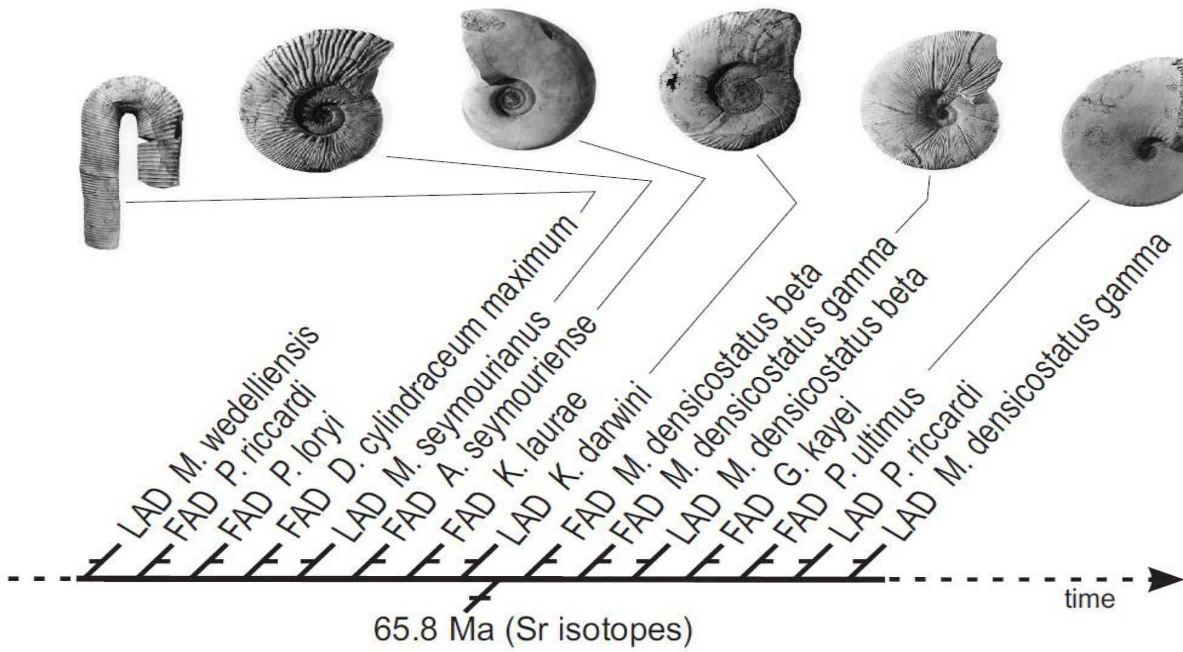


Figure. 22: A part of the timeline that is built from eight stratigraphic sections located on Seymour Island in Antarctica. It consists of dated events and ammonite ranges-end events. The events are ordered but the spacing is arbitrary. The term LAD and FAD are abbreviations used for the global extinction and origination times of fossil deposits. These periods are distinguished from the biostratigraphic ones by the unique features of their time-stratigraphy. (Sadler, 2013).

3.1. Timelines and Time Scales:

Geological knowledge can be expressed as a set of past occurrences that were placed in chronological order (Figure. 22).

The timeline is made possible through the contributions of various stratigraphic sections. These include the sequences of superposed strata, which provide the local order of events (Figure. 21). Also, the presence of isolated flora and faunas helps prove the existence of taxa that have overlapping ranges.

Fossil species extinction and origin events are typical occurrences in geologic timelines. The number of LADs and FADs, which are first-appearance events, outnumbers the significance of other noteworthy occurrences such as volcanic ash falls and paleomagnetic reversals.

The number of first-appearance event occurrences in geologic timelines exceeds that of radioisotopic dates. This means that the sequence of biostratigraphic events can easily be established using the contributions of stratigraphic superposition.

The relative spacing of events within a given period can also be estimated by taking into account the average rock thicknesses at the ends of the species ranges. For instance, if a particular occurrence is included in the sequencing program, its spacing can be used as a test of its success.

Traditional time scales for biostratigraphic occurrences present events in zones and only show the ones that have defined their boundaries. For most periods during the Mesozoic and the Paleozoic, the intervals between the zone boundaries are shorter.

The practical resolution of geochronometry is affected by the small number of events that can be dated. Also, the uncertainty in the most recent radioisotopic dates is shorter than in the biozones of the Paleozoic. On the other hand, the timelines of biostratigraphic events provide a better chance of keeping up with modern geochronological precision.

The power of an ordered timeline's correlation and resolving power increases as the number of occurrences on it increases. The analytic precision and number of events added to the timeline also improve its resolution. Unfortunately, estimating the sequence of the first and last-appearance events can be challenging due to the high number of occurrences.

Together, geochronometry and biostratigraphy can provide a better understanding of the sequence of first-appearance events in the biostratigraphic timelines. In practice, there are still clusters of events that can't be resolved due to the relative positions of the timelines. These are usually drawn with an overlap in the uncertainty interval, which provides a rigor comparable to the error bars in radioisotopic dates.

Compared to the number of occurrences in biozones, the number of irresolvable clusters tends to be smaller. The use of uncertain intervals provides a degree of rigor comparable to that of error bars in numerical age dates. While radioisotopic laboratories continue to develop new methods for reducing analytical uncertainties, biostratigraphic experts are developing new approaches for estimating the sequence of first appearance events in the bioregions.

New methods for performing biostratigraphy sequencing can improve the speed and accuracy of the process by using optimization algorithms and computer memories.

The use of simple logical rules in the sequencing algorithms is not only beneficial for improving the accuracy of the process, but it also ensures that the statements are expressed in precise and logical terms. To understand the need for computational algorithms, we should first review two fundamental geological problems.

The unsteady process problem is a major issue with the stratigraphic record because it can contain hiatuses at various scales. This means that the long-term relationship between the rock thickness and the elapsed time is not reliable. In practice, we must avoid using linear clusters to estimate age and construct composite sections to fill in the gaps.

The complexity of identifying and quantifying numerous sections in a single timeline is caused by the biostratigraphic sequencing issue. Although the range ends at each site do not accurately represent the true sequence of occurrences or FADs, the algorithms are attempting to solve this challenge when creating composite time frames.

3.2. The Unsteady Process Problem:

A single radiocarbon date can be used to estimate the age of a fossil from the Holocene or the Pleistocene era. However, the host rocks and the fossils from the older record are not suitable for dating. Due to the lack of suitable datable layers and the irregular distribution of fossils, paleobiologists usually require two radioisotopic dates to establish a fossil's age.

By using an interpolation procedure between two dated ash fall intervals, one can estimate the other layers' age and determine the average rate of change across the given period (Sadler, 1999). Unfortunately, this method can introduce an error due to the presence of hiatuses in the stratigraphic record.

One of the most common mistakes made by linear interpolation is assuming that the sediment will continue to accumulate steadily. This assumption is not accurate since the time between two intervals will most likely be randomly apportioned between the intervening rock layers. To minimize the uncertainties introduced by this method, it is recommended that the intervals between the dates be brief.

The unsteady process problem is also related to the sedimentary record's net accumulation rate (Reineck, 1960; Sadler, 1981). It shows variations in organic evolution and the rates of change in the environment (Gingerich, 1983, 2001; Reznick et al., 1997). Rapid changes can characterize short-term activities, but they can't be sustained for a long time (Gardner et al., 1987).

Even at short time scales, the changes in the level of sea and sand can be observed in our daily lives. Long-term fluctuations can also be detected in the paleontologic and historical records.

The average rates of change over long periods are generally decreased as we consider the different dates that are farther apart. The reduction in average rates is related to the dependence of the mean rate on averaging time (Sadler, 1993). For instance, the logarithm of the mean rate decreases steeply as the averaging time increases.

The rolling motion of rates affects the time scales of stratigraphy, paleontology, and sedimentology. Only the combined knowledge of these disciplines can provide a comprehensive picture.

The effects of short-term changes, such as tsunamis and hurricanes, can have significant consequences for human activities. They can also influence Earth's history. For instance, mass extinctions and the rapid evolution of climate patterns can be observed through short-term pulse changes.

For the past few decades, the abundance of radioisotopic dates has allowed scientists to easily assess short-term extremes. To gain a deeper understanding of Earth's history, it is important to extend the sampling interval to the older periods of geologic time.

Unfortunately, the ability to accurately observe long-term changes is not as good as it used to be due to the interval between the successive dates in the stratigraphic sequence. This is because the accuracy of the individual dates is not as good as the precision of the intermediaries.

3.3. The Need for Composite Sections:

It is also important to have closely spaced events in the same section of the stratigraphic record to gain a better understanding of the organic evolution and the sudden changes in the environment. Ideally, the intervals between the dates should be shorter than the analytical uncertainty.

Unfortunately, the ideal condition for accurate stratigraphic dates is not yet realized in the older periods of geologic time, such as the Paleozoic and Mesozoic. Even global compilations of records show that few radioisotopic dates have robust and high-precision contexts (e.g., Gradstein et al., 2004); summarized in Figure. 23.

The fossil record of the Ordovician period and the Silurian period has produced hundreds of sections with ranges for more than 2,000 species of graptolite and over 1,000 conodont species.

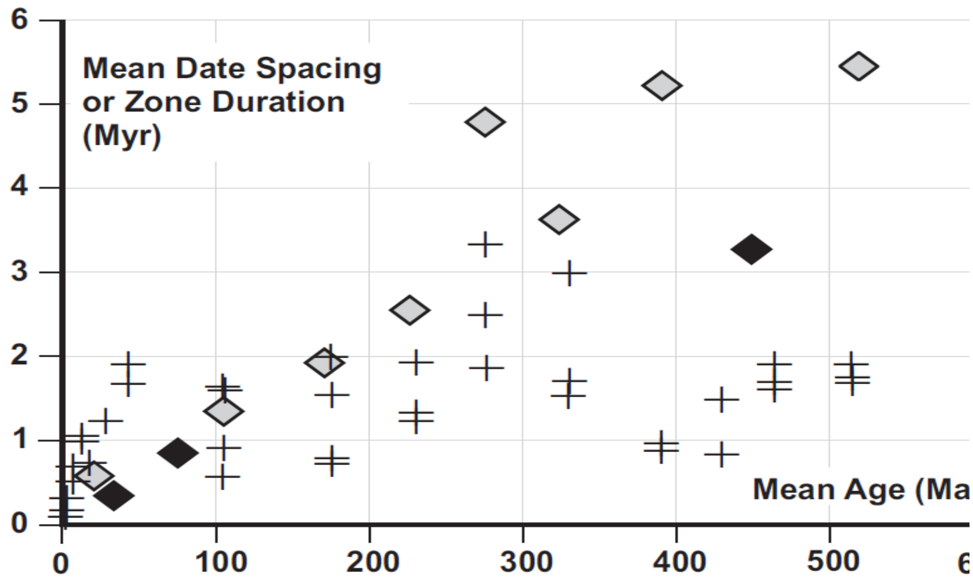


Figure. 23: The average time spans between radioisotopic dates, represented by diamonds, and the boundaries of biostratigraphic zones, marked as crosses. The open diamonds correspond to radioisotopic dates used for calibration, while the filled diamonds denote radioisotopic dates linked to specific mammal, ammonite, and graptolite examples mentioned in the text. The crosses on the graph signify the typical durations of biostratigraphic zones within each geological period for the clades with the most robust discriminating capabilities, as presented in Gradstein et al. (2004).

In total, there are over 6,000 species that have first- or last-appearance events. These events were recorded by more than 28,000 local range ends (Sadler and Cooper, 2003; Cooper and Sadler, 2004; Melchin et al., 2004). For the same period, only around 20 to 25 radioisotopic dates are linked to the association between a graptolite or conodont fauna.

Less than ten of these sections have yielded well-defined conodont or graptolite ranges. In contrast, only one section has more than one dated event.

The average number of years between the useful events in a given section is over three million. This means that there are only four known dated bentonites in a 5-million-year interval.

Young clades seem to be improving. For instance, the number of species from the Maastrichtian and Campanian ammonites has increased significantly. In total, there have been over 600 species from over 200 sections worldwide. For the 18-million-year interval, 21 significant events have been linked to ammonite fauna. Alroy's report shows that there have been over three thousand species from 4978 collections Alroy (1992, 1994, 2000).

The average spacing of the calibrated and dated events that have been produced in single sections of the fossiliferous marine limestones is shown in Figure III. These areas are known to have the best possible calibrated boundaries. In addition to direct beds, these sections also have the calibrated limits of units defined by stable isotope composition, paleomagnetic polarity, and biostratigraphy.

The average spacing of the control points for the generation of single dates in the Mesozoic and Paleozoic periods is shown in Figure II. It also approaches the duration of the biostratigraphic zones.

To ensure that the dated events presented in Figure 23 are preserved, a global composite section has to be correlated with the local stratigraphy. If the correlation is successful, a time scale with units that can resolve only within the standard biozones will be generated.

Although this approximation is better than current averages (Figure. 24), it is coarser than what is considered optimal for analytical uncertainty. Biostratigraphy's potential to resolve power can be matched by precisely sequencing the end ranges of all known species into a composite timeline.

The advantage of having radioisotopically calibrated events is that they can be shown without superposition in one section. If the uncertainties in the two local radioisotopic dates don't coincide, the order of their dates can be in doubt.

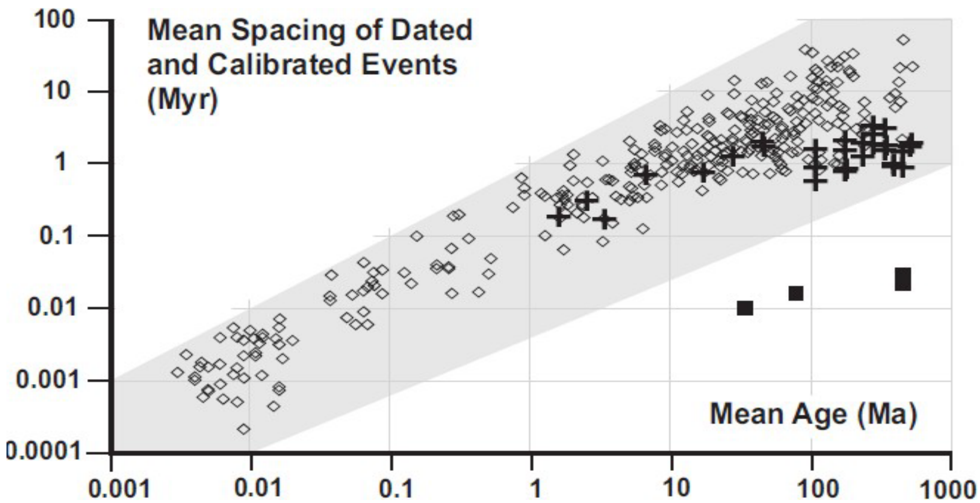


Figure. 24: The average time intervals between events that are both dated and calibrated, represented by open diamonds. This data is derived from examples of the most meticulously calibrated individual stratigraphic sections, specifically from calcareous ooze and carbonate platform databases, as detailed in Sadler's work (1993, 1999). This information is then contrasted with the resolving capabilities of biostratigraphic zones, marked by crosses on the graph. The gray-shaded region indicates the uncertainty intervals (+/- 2 sigma) associated with typical published radioisotopic dates in stratigraphic research. Additionally, the black squares depict the potential resolving power of extended sequences of biostratigraphic events, with examples taken from mammals, ammonites, and graptolites. (Sadler, 2013).

The advantages of having a composite timeline are that it can bring more dated occurrences into a single sequence, which can reduce the time needed to perform interpolation. Another disadvantage of having a timeline is that the locations of observed range ends in different biogeographic regions are not aligned exactly with the ages of the actual extinction events and evolutionary origins. This issue is the main reason why the sequencing problems are related to the local chronologies.

3.4. The Biostratigraphic Sequencing Problem:

A biostratigraphic zone is a type of strategy used to address the issue of the distribution of living species. It is because, for various reasons, the observed range ends are not always the same age. Also, the limits of a species' habitat can change over time, and the effects of preserving and fossil collecting are not always well known.

It is widely expected that the observed ranges of various species will be shorter compared to their true global or regional counterparts. This is due to various factors, such as biogeographic fact and the fiction introduced by collecting and preserving. However, these factors can make the local range ends unreliable for time scales and correlations.

The exact sequence of the observed range ends is also not always the same. This is because, for various reasons, the range ends of different species are not always the same age. It is therefore not possible to treat the local range ends as if they were FADs or LADs.

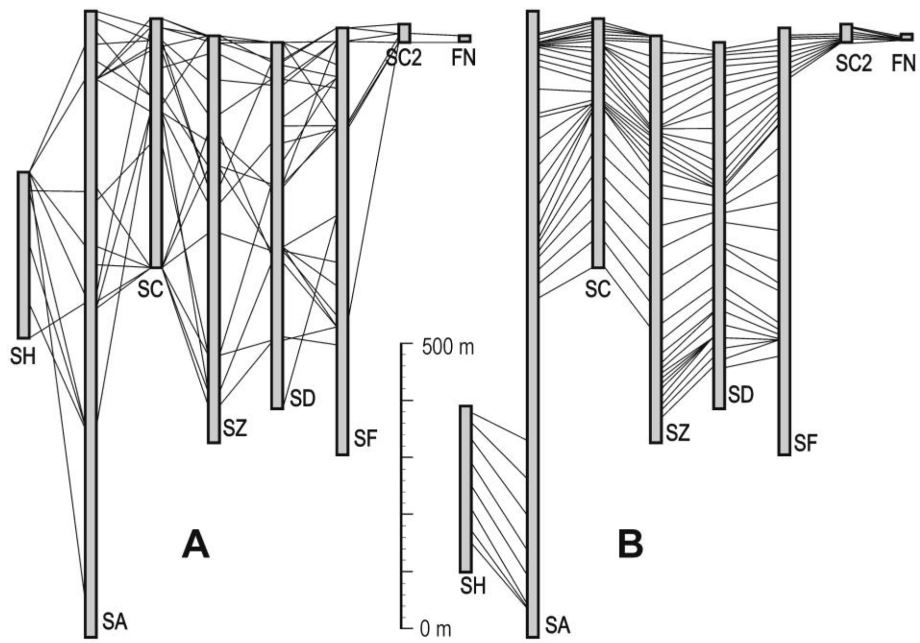


Figure. 25: fence diagrams that illustrate the correlation of 8 stratigraphic sections located on Seymour Island in the Antarctic Peninsula. These correlations are based on the presence of ammonite and nautiloid species. Part A of the figure represents the direct connections between the observed range ends of these species. In Part B, you'll see the same data after applying a parsimonious range extension technique. This method involves extending the observed ranges of species to ensure that all sections align with the same chronological sequence and inserting missing events as necessary. The optimal solution was determined through constrained optimization using CONOP software. Furthermore, to reduce any irregular spikes in the data occurring at sample horizons, the resulting range end positions were smoothed with a 7-point smoothing process, as detailed in the accompanying text for a more comprehensive explanation.

Despite the current difficulties associated with the sequencing of living species, the long-term evolution of the world's fauna is still expected to continue. This is because, despite the current problems with the identification of new species, the quality of the data remains intact.

To identify the extent of the issue, try drawing a fence diagram with a direct link between the various species' range ends (Figure. 25). Unfortunately, this method usually leads to a tangle of overlapping lines.

To understand the scope of the problem, consider how we can disprove an unpalatable suggestion that all species have never gone extinct. Due to the length of the actual ranges of living species, it is not possible to directly conclude that this notion is not possible. Instead, we would reject it due to the massive failures of observation and preservation.

Let us consider a sequence of events that suggests the least amount of failures in the preservation and observation of living species. Before we start looking for ways to solve the sequencing problem, let us first examine how biozones have been able to solve this issue.

3.5. Traditional Biozones as a Solution to the Sequencing Problem:

The traditional biostratigraphy approach to solving the range end issue involves selectively culling the correlation lines from the fence diagram (Figure .25). The remaining lines become the boundary events that define the various cluster events within the interval zones.

The culling process can solve the range end issue by minimizing the power of the resolving agent. Unfortunately, it does not eliminate the possibility that the events that survived the cull will not be preserved at the same age in all the timelines. In 2009, a study conducted by Sadler et al. showed that biozones can be recognized in time sequences that have been created without the use of zonation Sadler et al. (2009).

A traditional biostratigraphy approach can also solve the range end issue by establishing an assemblage zone boundary, which is defined according to the appearance of various taxa. This type of boundary can help maintain the consistency of the events in the region.

It is also possible that the first appearance of a particular subset of taxa is more stable than that of individual first appearances. In the development of the "Unitary Association" method by Guex in 1977, he proposed using computer-assisted recognition to address the diachronism issue in interval zone boundary definitions.

One disadvantage of using time-lines is that they determine the expected co-occurrence among any taxa. Although naming and defining boundaries are useful, they are not necessary for relative dating or correlation.

The uncertainty interval associated with biozones is often ignored and regarded as the tacit duration of their existence. Unfortunately, many biostratigraphers report the age of faunas as biozones to non-experts.

After receiving the collected information, the recipients of this information often combine it with the purported zone boundaries in their publications. Unfortunately, this method limits the scope of the timelines that can be built based on the raw data.

4. Graphic Correlation:

Alan Shaw's graphs serve as a valuable tool for visualizing the paleobiologic sequencing problem.

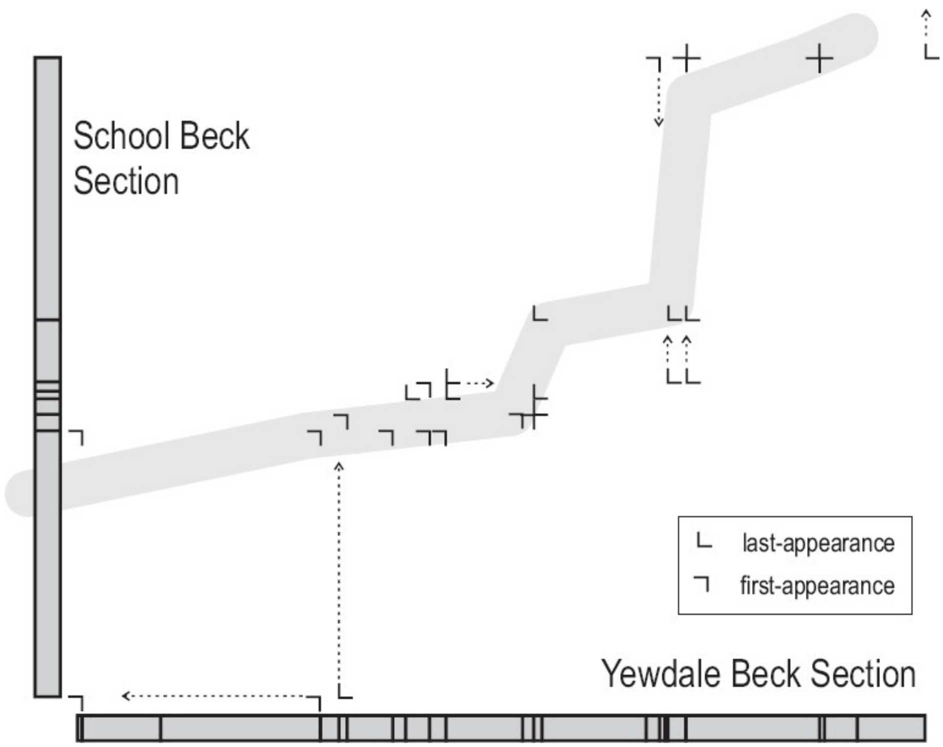


Figure. 26: we present a graphic cross-plot of two early Llandovery (Silurian) sections, utilizing data sourced from Hutt's work in 1975. This plot illustrates the range-end coordinates for all graptolite species identified in both sections. A prominent gray line, known as the Line of Correlation (LOC), is not solely based on the taxa presented in this chart. It takes into account information from a comprehensive graptolite dataset encompassing 506 sections and 2090 taxa. It's worth noting that the symbols denoting the first- and last-appearance events are designed to signify that they define the corners of larger boxes, and the Line of Correlation must traverse through these boxes, as articulated by Kemple and colleagues in 1995. The presence of thin dashed arrows highlights instances of implied range-end adjustments, which consistently extend from one of the open ends of the event symbol, signifying an expansion of the observed range within one of the two sections. (Sadler, 2013).

4.1. Graphic Correlation: a Better Solution:

The graphic correlation method pioneered by Shaw in 1964 solved the issue of correlation by applying the observed range's smallest net adjustments to align all ranges with the sequence of events (Mann and Lane, 1995).

Although some events may occur in different positions and with different species associations, they are not suitable for correlation due to the large adjustments required. On the other hand, the number of events that require only small adjustments is usually more than enough to overcome the traditional zone boundaries. The concept of graphic correlation is to solve the real problem of correlation, which is that none of the ranges end up being aligned with the LAD or FAD.

When using graphic correlation, the assumption is that the observed ranges are shorter than their true ranges. It limits the range adjustments to the extensions specified by the method (Edwards, 1982). This means that it can only search for extreme events, such as the earliest and the last appearances, and it is susceptible to bias caused by taxonomy.

The ability to recognize anomalies and outliers is very important when using graphic correlation. It allows the simultaneous control of quality and correlation. The simple rules that can be used in graphic correlation are also useful in automating the sequencing of large data sets.

The two sections of a graph are drawn up as the Y- and X- axes. The events that are seen in these sections are plotted as points in the range-end events. These events are then set as the levels at which the events are observed. The symbols that are used in this process are the corners of the error boxes. Adjustments can be made in the direction of the symbols' open ends.

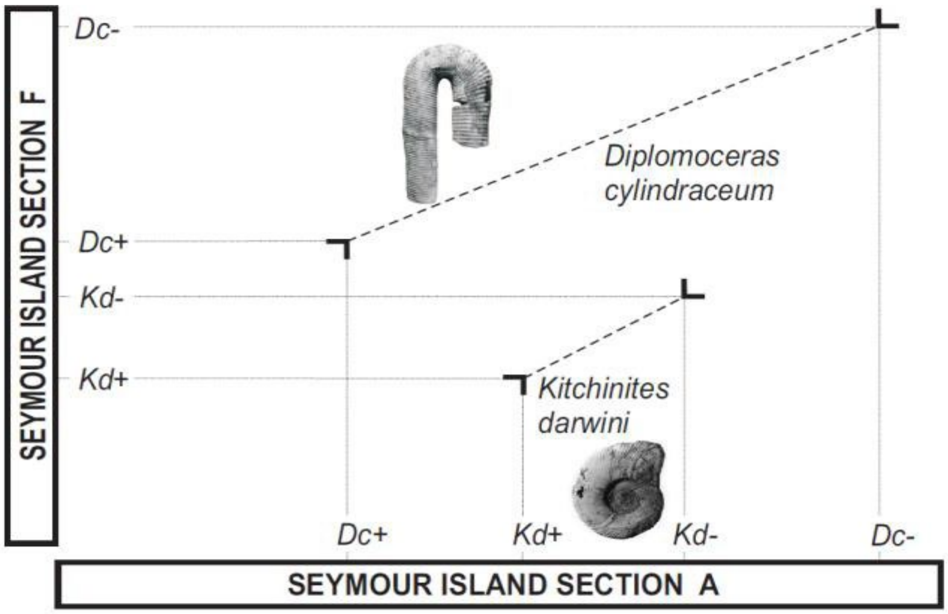


Figure. 27: presents a graphic cross-plot featuring the ranges of two ammonite taxa, as derived from two of the stratigraphic sections located on Seymour Island, Antarctica. (Macellari in 1985).

The first appearance coordinates of the graph can be adjusted to the left or downward. For instance, they can be set to extend the range of an event in one section or to stratigraphically reflect its downward position.

Adjusting the points will bring them all to the same line of correlation. The LOC will show the points that were deposited in each section at the same time.

The LOC can be piecewise linear. A horizontal and vertical segment can be introduced in the LOC by introducing multiple horizons that collapse into one. On the other hand, no segment can have a negative slope unless one of the sections is upside-down.

Figure. 27 shows the limitations of the LOC that prevent it from traversing the points on the graph. It can be fitted to the most reliable range ends and adjusted onto the line to represent the range extensions in one section. FAD events can also be adjusted downward to align them with the levels at which they occur.

LAD events are only adjusted upward unless it's suspected that they are being changed. In cases where the correlation problem is well-behaved, the LOC has a narrow band that dictates its position. Outliers can also be identified by the position of the points in the graph.

In Figure .27, the LOC can only intercept one more range-end coordinate if it passes through Dc+ without a negative sloping segment. On the other hand, if it passes through Kd+, it can acquire two more range-ends and leave Dc+ with a revised downward position in section F.

In the future, we will learn that coexistence serves as significant constraints on timelines and LOCs. As a result, the data in Section A is better than the information in Section F. Compatibility between the two sets of observations can be established due to how they assume that the true ranges are underestimated.

4.2.. Incorporating Other Events:

Significant time correlation gains can be made possible through events that can't be adjusted in stratigraphic regions. These include paleomagnetic reversals, marker beds, and isotopic excursions. They have to occur in the regions where they are observed.

These events must be shared with the LOC so that it can pass through them. Ideally, all of these LOCs should be determined by these events, but in practice, they're not readily available.

The appearance of a magnetic reversal in Figure. 27 demonstrates the constraints of having conflicting range end information. Since the LOC must go through the center of the chart, it can't teach the Al+ range end. A negative slope is required for this.

The cluster of first-appearance events, such as the Hc+, Pn+, and Dc+), can attract the LOC away from Al-. This demonstrates the importance of having a good LOC based on the data collected at the end of the range.

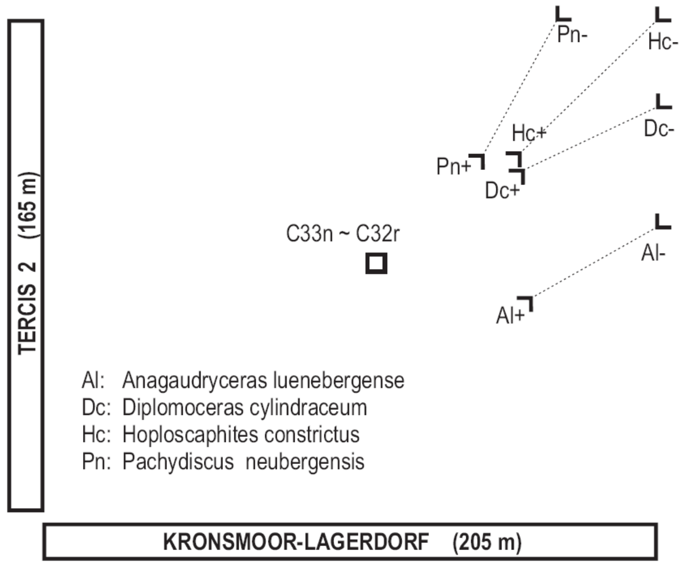


Figure. 28: Graphic correlation of two European late Cretaceous sections that share a paleomagnetic reversal (open box) and four ammonite taxa. (Sadler, 2013).

Paleomagnetic reversals and marker beds can be useful, as they can help the LOC identify the relative ages of the regions in the graph. Older events, which are numerically dated, are more powerful. In Figure 28, dated events block the path of the LOC as it approaches certain parts of the graph.

A pair of dates divides the graph into quadrants. Each of these dates has an out-of-bounds boundary since its coordinates indicate that it's older than the younger one. With two sets of dates, a blocked zone can generate a "pass" or agate through the path of LOC.

In Figure 29 the ideal LOC will have a vertical segment that goes through the gate's left-hand limit. This segment indicates a hiatus, which can be seen in the Redbird region.

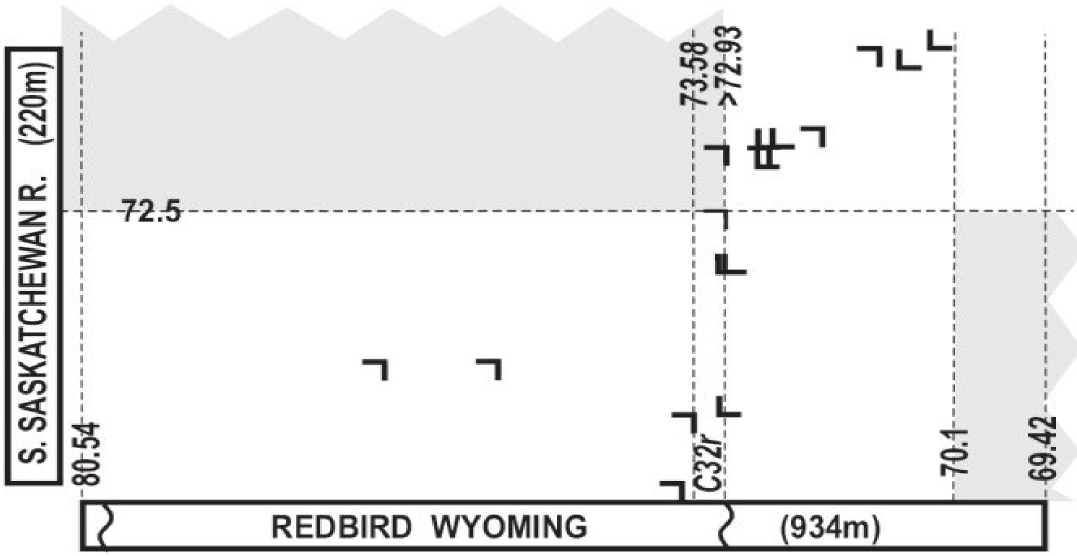


Figure. 29: Graphical correlation depicting the late Cretaceous Redbird section in North America and the South Saskatchewan River section. This correlation is established by utilizing ammonite range ends and incorporating four radio-isotopically dated ash fall tuffs along with two calibrated paleomagnetic reversals. (Sadler, 2013).

4.3. Shortcomings of Graphic Correlation:

In 1995, Kemple and colleagues reviewed the strengths and disadvantages of graphic correlation. One of its main strengths is its ability to see the consequences of decisions. However, all of its weaknesses can be caused by the procedure's limited scope.

The first section is made up of the data from the second and the added sections, and the LOCs are used to project these into it. The ranges in the first section can be extended as needed, and missing taxa can also be projected into it. As the first section evolves into a composite time-line, its thickness scale is augmented and corrected until it becomes a standard time-line.

The increasing number of sections and taxa in a graph can make it more time-consuming and cumbersome to perform graphical correlation. With more taxa, it also increases the number of LOCs that are possible. The optimal one becomes harder to recognize.

The addition of new sections can also make it harder to perform graphical correlation. To minimize this effect, the process is repeated through several rounds. This method is used to remove the bias, and it can only produce diminishing returns. Some practitioners do only one round of correlation, which is a fine way to evaluate the quality of the data. However, it doesn't provide a rigorous method for identifying conflicts.

To optimize the processing of global data sets with minimal effort, we often use computers. They can be equipped with several dimensions, which allows all of the sections to be considered at the same time. Multidimensional graphic correlation is a good description of this process. Various computational methods can be used to find the optimal LOC.

The guidelines for choosing LOCs follow the same basic stratigraphic logic that Shaw pioneered. The constraints that geochronometry provides can also be accommodated by enhancing the basic rules.

They can be modified to mimic other correlation techniques. For instance, the range extension sizes can be measured by taking into account the event levels instead of rock thickness. This approach was developed by Edwards in 1982. If the rules are well-written, they can provide the best possible solutions for addressing the sequencing problem of biostratigraphic graphs.

In addition, they can be modified to follow other correlation strategies. For instance, measuring the range extension sizes using event levels can be done instead of rock thickness, which can help avoid bias if the thick sections are at the center of the range. If the rules follow the correct path, these techniques can provide the best solution for addressing the sequencing issue.

5. Constrained Optimization illustrates one approach for expanding graphic correlation into multiple dimensions:

5.1. The Simplest Case:

The concept of graphic correlation is inverted, which means that instead of working from the data collected in the field, possible solutions are evaluated to find them that fit the data. This method can be used by Computers that have enough speed to solve problems by trial and error in this fashion (Kemple et al. 1995).

The use of this method allows scientists to take advantage of the time's brute force to find solutions to complex problems. It should come as no surprise then that some of the techniques that are used in this field have been referred to as evolutionary programming.

To learn more about the computer scientists' approach to solving the sequencing problem, consider the simplest case presented in Figure 27 by comparing the two taxa and two sections in the diagram shown in Figure. 30. This method can be used to analyze the complete set of possible sequences.

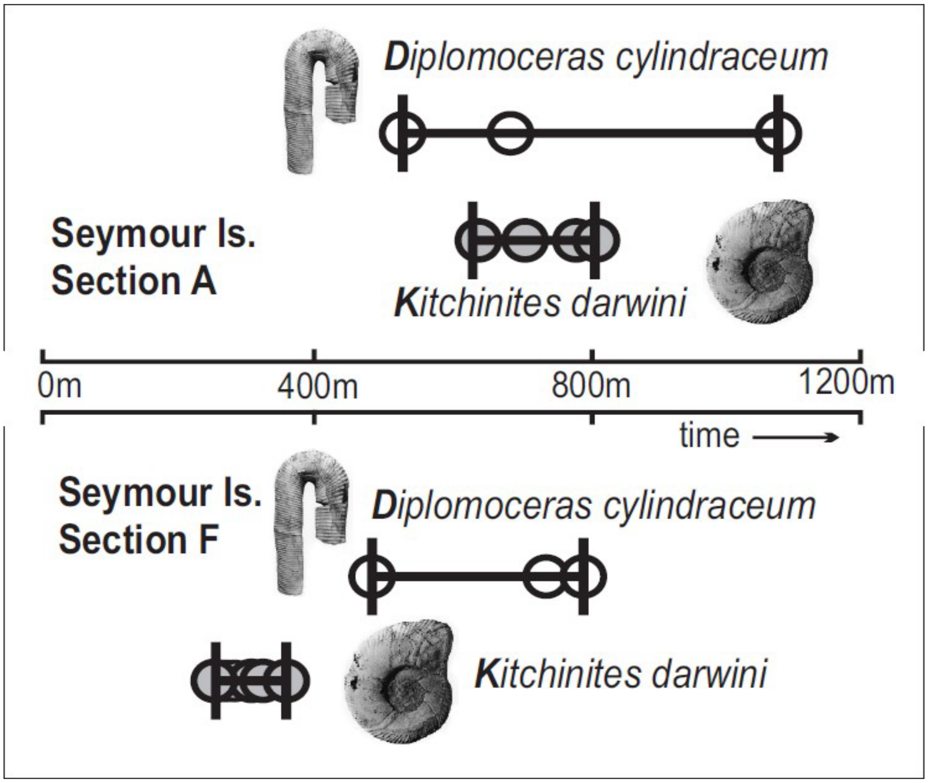


Figure. 30: Range charts for two commonly found ammonite taxa within two sections from Seymour Island, Antarctica. (Macellari in 1985).

Four range-end events can be arranged in six distinct sequences using two taxon ranges. Each taxon has to appear before the events can be eliminated (Figure. 31).

There are many reasons why ties shouldn't be an issue. One of these is that they can disappear with precise timekeeping.

Another reason why ties shouldn't be a problem is that they can be used to reserve events until a later task, which will recognize intervals between zero-length events. In addition, several well-fitting sequences can be found in the sequence where the events cannot be resolved.

Figure 31 presents the six possible sequences. One of the taxon ranges may overlap the ends of the other range, and it may also be completely different from the other range.

Instead of drawing range charts, we can use the solutions as event codes, which can be presented in a variety of ways. For instance, the taxon's genus and species initials can be used to identify it. Furthermore, disappearance and appearance events can have minus and plus suffixes. For instance, solution 6b can be represented as Kd+, DC+, and Kd-.

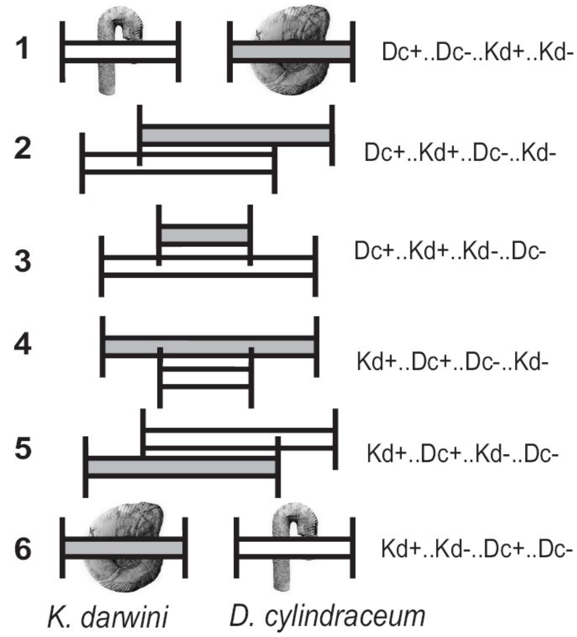


Figure. 31: Six possible ways to order the range end events of two taxa, disregarding the possibility of ties.A single pointer array or spreadsheet column can be used to store the various possible solutions for a massive data set. Each event can either be assigned to a specific location or physically sorted. It's important to note that there are many ways that computers can store solutions for large sets of data. (Sadler, 2013).

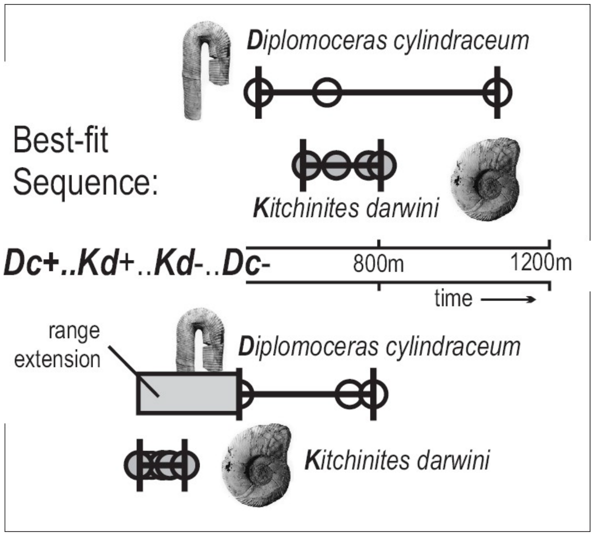


Figure. 32: The sequence of events that requires the smallest net extension of the four locally observed ranges. (Sadler, 2013).

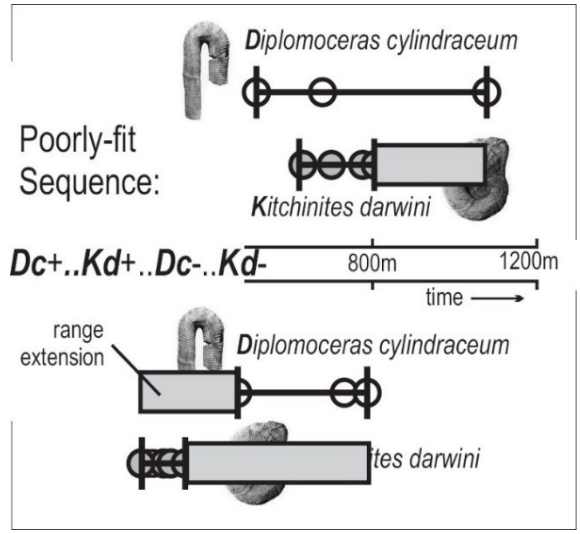


Figure. 33: The sequence of events that requires a large net extension of the four locally observed ranges. (Sadler, 2013

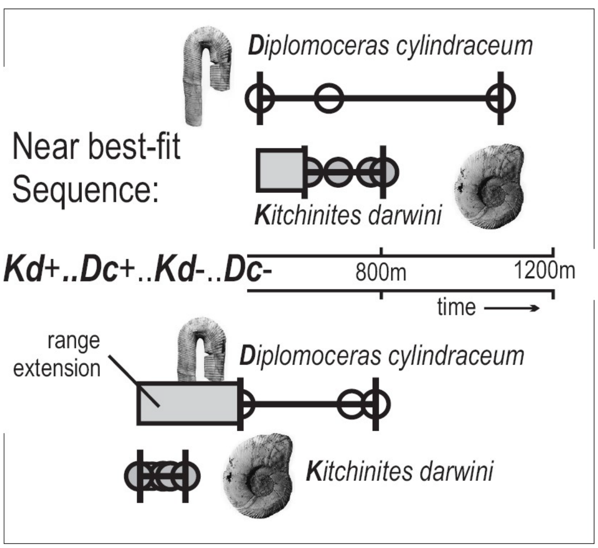


Figure. 34: A sequence of events that requires a small net extension of the four locally observed ranges. (Sadler, 2013

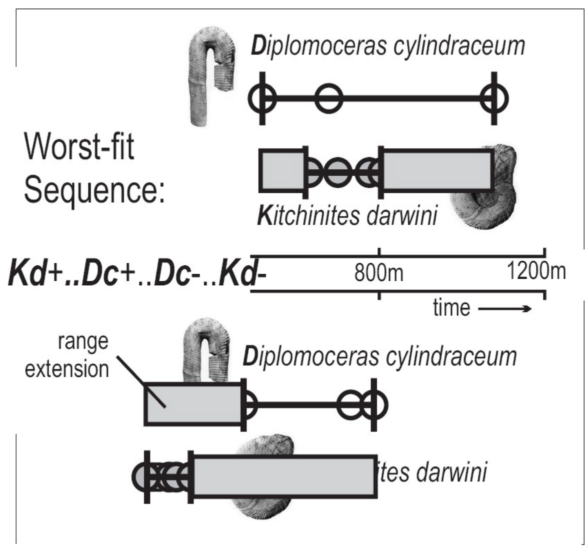


Figure. 35: The sequence of events that requires the greatest net extension of the four locally observed ranges. (Sadler, 2013

The easiest solution for the simple case presented in Figure 32 is to use inversion. Since there's evidence suggesting that K. darwini and D. cylindraceum share a common ancestor, we'll eliminate cases 6e and 6f. For the remaining solutions, we can determine how much of the observed ranges should be extended to fit the sequence of events.

The minimum misfit computed by solution 6a is shown in Figure 33. It is the best-fit choice, or even the optimal one.

We've used a constrained optimization approach to solve the problem. We'll eliminate all the impossible solutions and look for the one that fits the data with the least variance (Sadler, 2003-6). It is implemented using the CONOP9 framework.

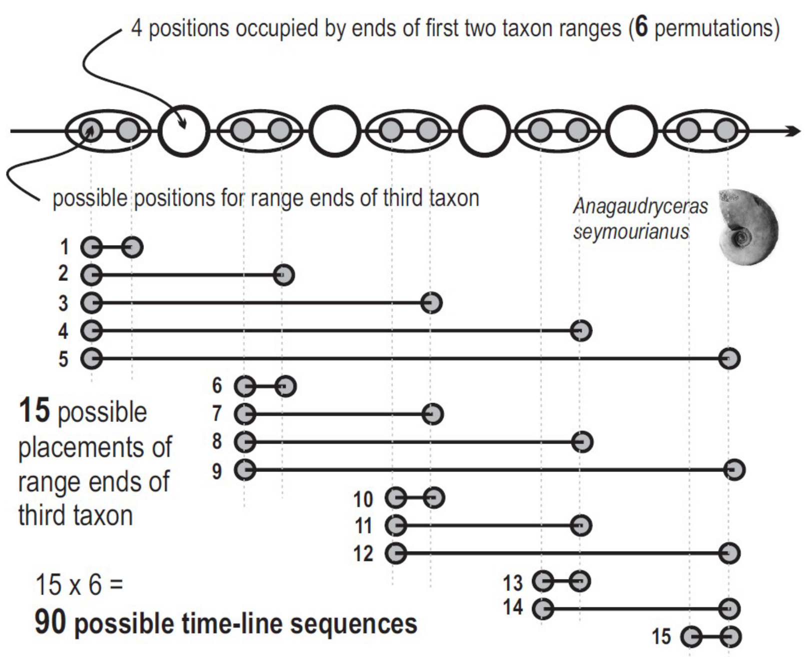


Figure. 36: Ninety possible timelines after the introduction of a third taxon. (Sadler, 2009)

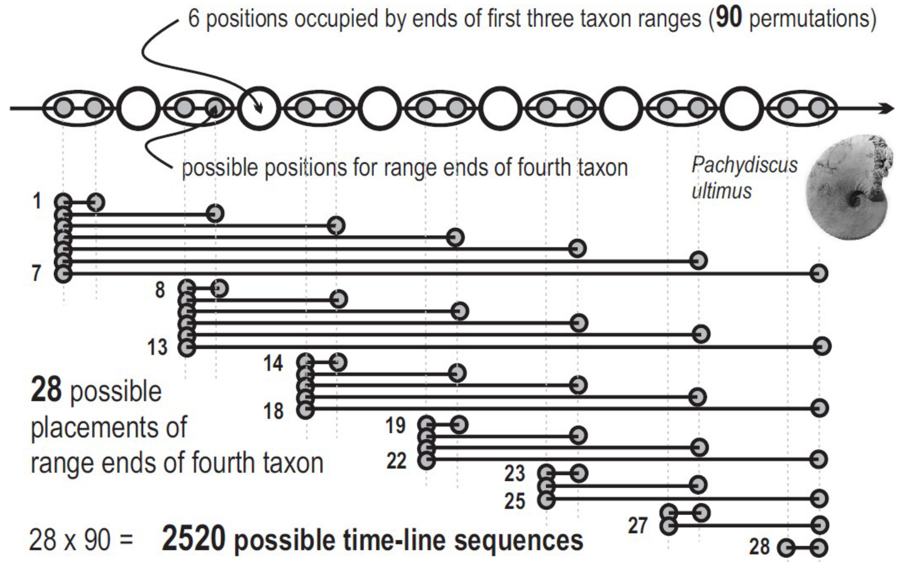


Figure. 37: Over twenty-five thousand possible timelines after the addition of a fourth taxon. (Sadler, 2009)

A range extension can be measured by taking into account the number of occurrences within a particular fossiliferous horizon or event within it. These types of measures favor a sequence of events that are preserved in the most heavily sampled and fossiliferous regions.

The different measures of misfit that are used to calculate range extensions should be expected to lead to various solutions. For instance, in 1978, Edward's "no-space graphs" showed the event horizons in the extension range. With the help of a computer, we can quickly determine the optimal sequences for each fit.

Table 01: Rapid increase in the number of possible sequences as the taxon count climbs to seven.

Number of taxa	1	2	3	4
Number of Possible Time-line possible	1	6	90	2520
Number of taxa	5	6	7	8
Number of Possible Time-line possible	113400	7484400	681080400	748080400113

The choice of the best measure should be made to accommodate the problem. The robustness of the solution should also be evaluated based on its sensitivity to the misfit.

Although it's easier to solve this problem with fewer sections and taxa than it is with a trivial example, it's still more challenging to perform calculations due to the complexity of the data.

5.2. Adding More Taxa

One of the main challenges when it comes to handling large sets of data is the number of sequences that can be considered. For instance, if we have a set of 90 possible sequences for each taxon (Figures. 36; 37) adding a third taxon can increase our possibilities to over half a billion (Table 1).

The number of sequences that can be considered in a given data set is often greater than the number of milliseconds in geologic time. For instance, if we have a set of 90 possible sequences for each taxa, the number of events that can be considered exceeds the count capacity of a popular spreadsheet program.

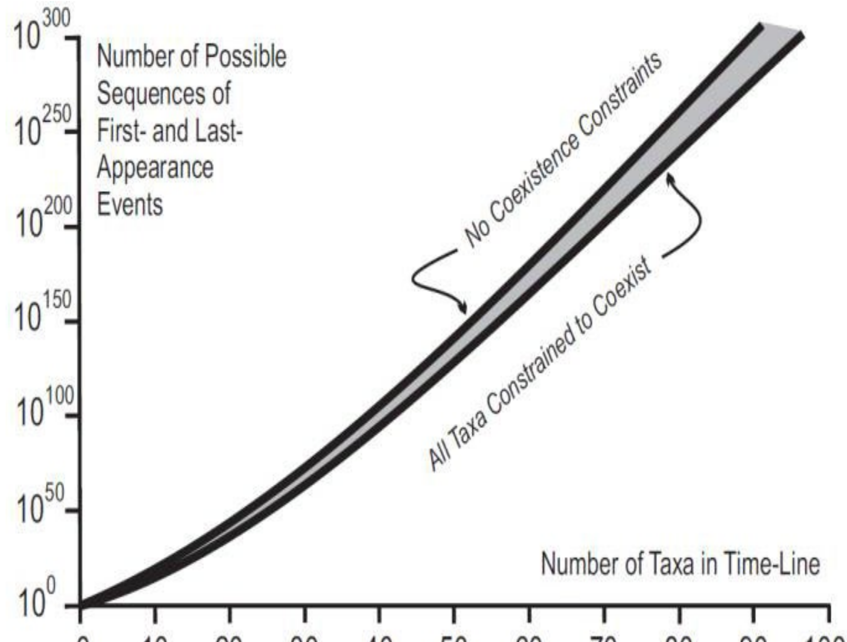


Figure. 38: As the number of taxa approaches practical values, an exhaustive search of all possible sequences is out of the question. (Sadler, 2013)

In general, it's not feasible to perform an exhaustive search on a set of sequences. Fortunately, computer scientists have developed a variety of heuristic search methods that can identify good solutions to these types of problems.

One of the most important factors that computer scientists consider when it comes to developing a good solution is the resolving power of the events. By taking into account the various positions in the sequence, they can determine the event's range of positions (Sadler and Cooper, 2003).

5.3. Which Information is Trustworthy?

Due to the lack of reliable information about local biostratigraphic data, scientists usually use constrained optimization techniques. This method eliminates false identifications and other errors.

The data collected from the first and last appearances can provide valuable information. Three properties can be useful: the spacing and order of the events within the range-end, the overlap of the taxon ranges, and the reliability of the observations.

Some of these properties can be incorporated into a measure of misfit. These are also referred to as objective functions or penalty functions that are designed to be minimized.

Differing expert perspectives on the scope of the reliable information about stratigraphic data can affect the results. For instance, if the objective functions and constraints are justified, the results might not be unique (Sadler et al, 2008).

This value represents the degree to which incomplete information contributes to an issue being overlooked.

5.4. Observed Stratigraphic Spacing and Order

The graphic correlation method used by Shaw utilizes the stratigraphic and order spacing of the events within a range-end. In 1986, the Graphcor program was used by Hood to automate the process. The equivalent approach in Conop9 utilizes the INTERVAL measure to take into account the local thicknesses of the range-end adjustments.

The preservation and migration processes can affect the order and spacing of the events. The thickness of the stratigraphic data can also be affected by the inconsistent accumulation rates.

It's generally better to use a different scale or to eliminate the information about the spacing. In 1978, Edwards introduced the no-space graphs, which were characterized by uniform event spacing.

The range extension function known as the "LEVEL" in Conop9 counts the number of events that occur within a given range-end. On the other hand, the "EVENTUAL" function takes into account the number of events at a given level and scores them according to their count.

The three Conop9 penalty functions that are used in calculating the cost of adjusting the local successions are also utilized to determine the trial timelines' minimum value. The other functions, which are similar to graphic correlation, merely compare the events' order spacing and data from the field.

5.5. Observed Stratigraphic Overlap

According to Guex (1991), the order and local spacing of events within a range-end are not reliable indicators of biochronology. Instead of fitting solutions to the range ends, he developed a method that only takes into account the observed overlap.

These programs are mainly used for analyzing the data collected from isolated fossil sites and collections that do not have the necessary superpositional information to produce no-space and graphic correlation graphs. Extended ranges can create new coexistences, but they can't falsify the observed ones. As a measure of the misfit in optimization, observed coexistence can be used as a corrective measure.

When using the constrained optimization approach to mimic the no-space or graphic correlation graphs, the resulting coexistences are considered powerful constraints that the composite sequences have to honor. Usually, the best-fit sequences include the observed coexistence.

This is especially true for data with separate biotic provinces and coeval regions. The number of observed coexistences is a measure of the misfit with the data's local information. They can be used as the objective factor to reduce the overall coexistence.

Although the rules for extending the range can be used to create new coexistences, they can also force more constraints than the ones derived from the observed ones.

In 1994, Alroy realized that the constraints related to the appearance event partition could be used to reduce the overall coexistence. He presented a method that allows users to achieve more power than the coexistences derived from the observed ones.

The approach is similar to the SEQUEL function in Conop9. It takes into account the excess first-to-last pairs in timelines that aren't required by local sections.

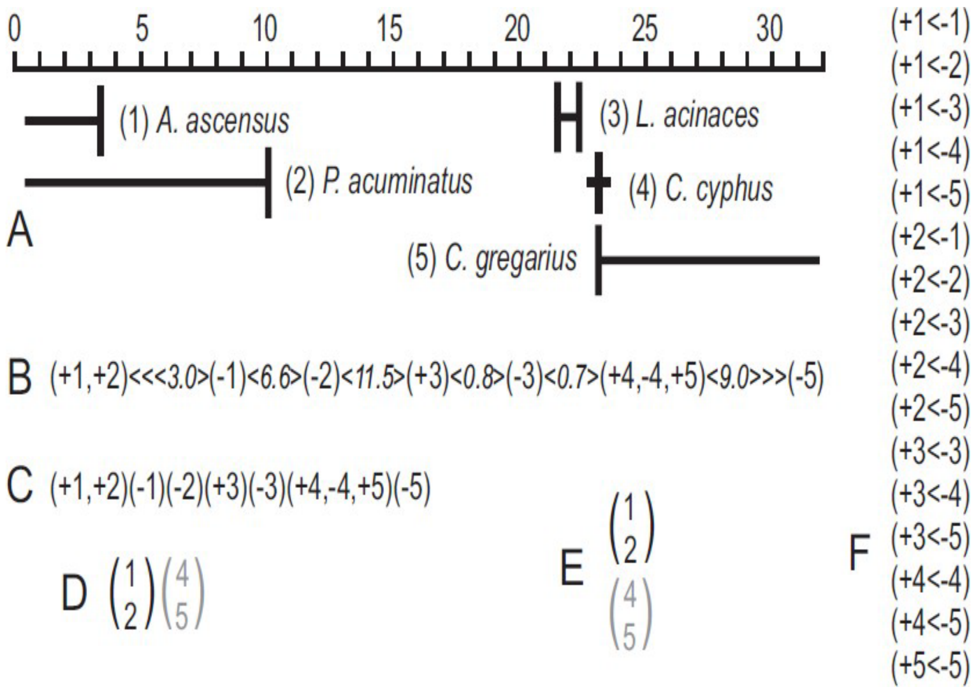


Figure. 39: Varying levels of biostratigraphic data for 5 out of the 56 observed taxa within the Llandoverian (Silurian) Yewdale Beck section, as documented by Hutt in 1975.

A: The range chart, which is the most commonly published graphical representation of biostratigraphic data. Here, range ends are plotted against a thickness scale and connected by continuous lines.

B-E: These panels show a stepwise reduction of information to its potentially more reliable core. It's important to note that the notation used here is introduced for this presentation and does not represent a standardized practice.

B: Range-end order and spacing, with numbers corresponding to taxa in the range chart. Positive numbers within parentheses indicate first-appearance range ends, while negative numbers represent last-appearances. Events occurring at the same level are grouped within the same parentheses, and relative spacing is depicted in italic numbers.

C: Displaying range-end order only.

D: Depicting overlap and order, with coexisting taxa sharing vertical parentheses. Black parentheses indicate certain overlap (evidence of coexistence in the strictest sense), while gray parentheses signify coexistence at a single level only (evidence of coexistence in a broader sense).

E: Providing information solely about overlap.

F: Focusing on first-before-last ordering information.

For reference, the genus abbreviations used in this context are A. for Akidograptus, P. for Parakidograptus, L. for Lagarograptus, and C. for Coronograptus.

For long timelines, the data will have pairs of sections that don't overlap in age. The SEQUEL and ROYAL objectives will minimize the likelihood of overlapping taxa to avoid generating excess coexistence.

The two functions are not focused on minimizing the likelihood of overlapping taxa. Instead, they assume that differences in age are more likely to cause faunal dissimilarity than differences in coeval regions.

For instance, the economy-of-fits approach doesn't add a penalty for interleaving dissimilar biotas. Instead, graphic correlation prefers to attribute biotas to their provincial nature. The decision to use sequence evidence or only those sequences that can't be falsified should be based on the data set's biogeographic and temporal scope.

5.6. Reworked Fossils

There are several reasons why the observed range might be too long or completely out of place. For instance, sedimentary fossils can endure cycles of erosion and re-positioning.

Sometimes, the re-positioning can create a last appearance or a completely out-of-place range. Also, benthic mixing can lower a first appearance. In well-cuttings, the collapse of the walls might lead to anomalously old occurrences.

Quality control is a regular issue when it comes to taxonomy, and bad taxonomy can ruin a time-line. One way to avoid this is by only using last occurrences, which can prevent bore-hole caving. On the other hand, reworking and downward mixing can cause significant issues.

RASC algorithms were developed to fit the sequence of events in the range-end events to the most commonly ordered pairwise ordering. In Conop9, the different objective functions are similar. However, they differ depending on the number of events and the spacing between them.

Other functions assume that the data has no reworked occurrences. However, these functions overstate the true range by treating it as if it has been underestimated. This method is not ideal, and it can be hard to develop efficient computer programs that can recognize reworked fossils.

Sometimes, this method is easy for humans to perform due to the presence of worn specimens or the taxa being out of context. However, it can be hard to teach a computer how to interpret the data without knowing the signs of a well-functioning range.

5.7. Assemblage Zones and Interval Zones

The decision to use only sequence evidence or all of the information can be influenced by the difference between using taxa and range-end events.

The former offers fewer permutation possibilities. Taxa may have two ordering outcomes, which means that if one of them overlaps with the other, it may be considered the older one. This treatment can be used to establish timelines for taxon assemblages, which can be utilized to define biogeographic assemblage zones (Guex, 1991).

As shown in graphic correlation, a pair of taxa may be grouped together into four range-end events with 26 possible sequences (Figure. 40).

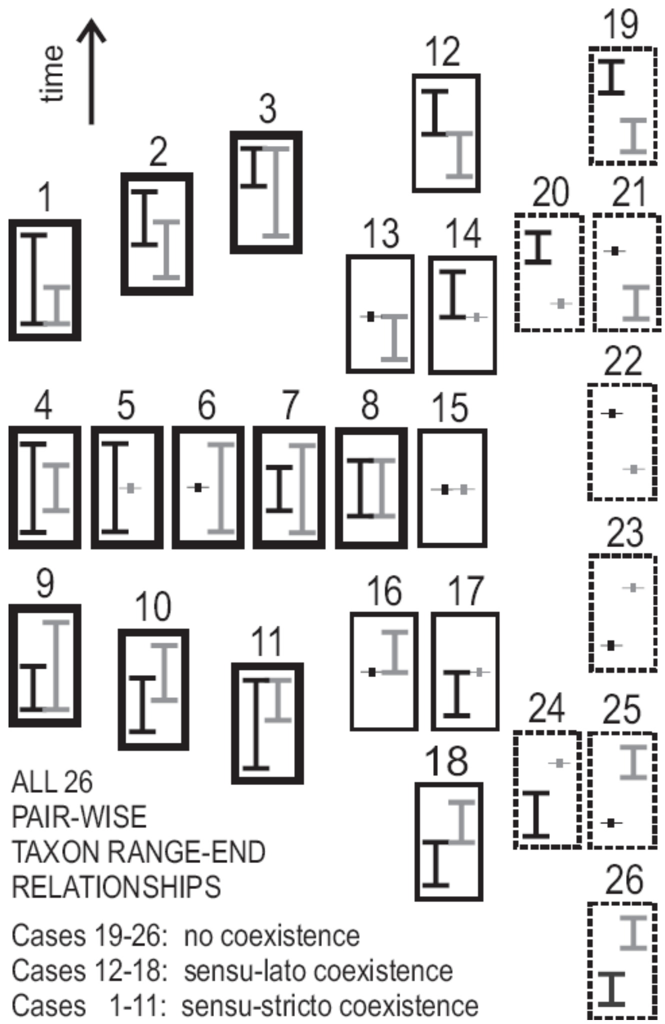


Figure. 40: Twenty-six possible arrangements of the four range ends of two taxa when "ties" are considered (from a standard CONMAN screen analysis). (Sadler, 2009)

A timeline of events is a more accurate estimate of paleologic history than interval zones. It can be used to select various events for the creation of biostratigraphic interval regions.

The boundaries of the range-end events are only used to avoid getting stuck with events that can be recorded in the wrong order. This practice is necessary because the events in the local first and last-appearance events can be diachronous.

The constraints of graphic correlation are used to estimate the range extensions that would provide the best approximation of the age of true extinction and origin.

5.8.Constraints from Non-Paleobiologic Events

Other chronostratigraphic events can also be added to the timelines with the help of trial-and-error procedures. These procedures require that the events have specific rules that can determine their possible positions.

The concept of correlational horizons refers to layers that can be traced back to the same locality. For example, ash-fall tuffs with finger-printed traces can be traced back to the same location. Unlike taxon range ends, these layers' positions are not affected.

The positions of these layers in the timeline are considered to be relative to the events that can't be adjusted toward them. First-appearances below them must be older than those found above them, while last-appearances above them must be younger.

The concept of correlational intervals refers to the events that can be traced back to a specific section but whose location is restricted by a finite uncertainty interval. For instance, seismic reflectors can't be located to better than a few meters.

Although a correlational horizon can exist in a section within a specified timeline, it can't be assumed that it actually runs through every section. Instead, it shrinks to fit into a slot instead of stretching. These intervals serve as a guide in the early stages of the study of chronostratigraphic history to find the best-fit timelines.

The order in which events have been dated by radioisotopic techniques is determined without regard to superposition. This is the most powerful constraint on timelines (Sadler, 2006).

From the beginning, the positions of the time-lines and uncertainty intervals must be obtained with the help of associated faunas. This allows the time-calibration process to be performed without using biostratigraphic tools (Sadler et al., 2009).

Table. 02: Properties and Information Content of Time-Stratigraphic Events. (Sadler, 2013)

	Uniqueness of Event		Freedom to adjust stratigraphic pition				Nature of change			May occur at surface of hiatus	Reliable ordering information
	Unique	Binary	Up only	Up or down	Down only	None	Present-absent	Present-absent	Alternation		
TAXON RANGE-ENDS:											"stretch-to-fit"
Reworked last app.	X			X			X			Y/N	above FAD
Last appearance	X		X				X			Y/N	super-position only [2]
First appearance	X				X		X			Y/N	sub-position only [1]
Caved first app.	X			X			X			Y/N	below LAD
REVERSALS: **Paleomag reversal Isotope cycle boundary**	X		X	X			X			Y/N	position[3]
RESETTINGS: **Sequence boundary Flooding surface**	X		X	X			X			Y/Y	position[3]
SPIKES: **Marker bed Isotopic transient**	?		X	X			X	X		NN	position[3]
TAXON ACMES	X		X				X			N	between FAD and LAD
DATES (in age-scaled section!)	X										"shrink-to-fit"
Mean – 2-sigma					X						sub-position only 1
Mean + 2-sigma			X								super-position only 2
SAMPLED ASH FALLS	?		X				X			N	position[3] and age value4 [5]

1. Event type 1 should be older than event types 2 and 3, which occur higher in the stratigraphic section, but it may still exhibit some shifting concerning events below it.

2. Event type 2 needs to be younger than event types 1 and 3, which are situated lower in the section, but it too may display some shifting concerning events above it.

3. Event type 3 should be younger than event types 1 and 3, which occur lower in the section, while also being older than event types 1 and 3, which are located higher in the section.

4. The relative age of event type 4 concerning other type 4 events is determined by its placement on a numerical age scale. It does not necessitate its occurrence within the same section.

5. A dated ash fall event may be presented as a 2-sigma interval within an age-scaled section, accompanied by other dates. This interval is placed at a single sampled point within a stratigraphic section based on real thickness scaling.

To describe the relationships between events:

- "Stretch-to-fit" refers to paired events whose spacing may be increased, analogous to using "jacks" mechanically.

- "Shrink-to-fit" characterizes paired events where their separation can be reduced, similar to using "clamps" in a mechanical context.

- For events that should not be adjusted, the mechanical analog is "nails."

6. The Traveling Salesman's Solution

Explains how to solve the biochronological sequencing problem by analogy.

6.1. Traveling Salesman Problems

The TSP (Traveling salesman) is a straightforward optimization problem that seeks to find the shortest route to each city. It is one of the more difficult problems in the NP-complete series. The running time for this problem increases exponentially if it is searched for all possible sequences.

CHAPTER IV. CONSTRAINT OPTIMIZATION

In the previous chapter, it was revealed that the timeline problem encountered in paleobiologic studies was caused by the NP-complete class (Dell et al., 1999). These problems have been studied for decades and are widely used in various applications.

The time-line problem in paleobiologic studies can be solved by implementing the same methods used in the other problems in the series. This method is very simple: the taxon range-end events are the cities, and the net range adjustment is the travel distance. The shortest route is the one with the lowest adjustment (Kemple et al., 1995).

Compared to the number of ranges end, the number of stratigraphy sections adds to the computation time. It lengthens the range adjustment calculation, though the increase is linear.

The exact methods for calculating the time-line solution of the TSP become impractical if the number of range ends exceeds a certain value. There are various heuristic techniques that can be used to solve this problem in a more reasonable running time. Heuristics refer to methods that are similar to physical or biological systems, and they are often simpler to implement than mathematical methods.

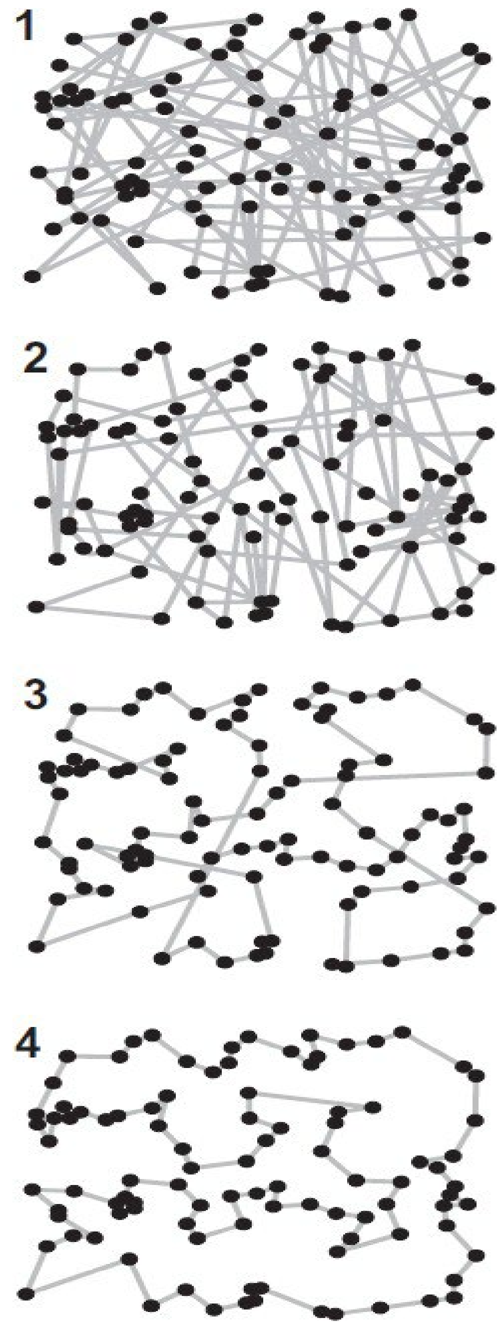


Figure. 41: Four snapshots from a trial and error solution of a traveling sales man problem from a random starting tour (1) through numerous random path changes (. . 3 . . 4 . .) to the shortest tour (4). (Sadler, 2013)

A well-fitting timeline can be obtained with the use of a trial-and-error strategy. It can be done while only looking at a fraction of the sequences that are possible.

The initial solution to the TSP is to choose a feasible tour and measure its length (Figure .41). Then, randomly choose four cities and rearrange their links. Determine the tour's length and make another change if it's too long or too short. Repeat the process until the route no longer gets shortened.

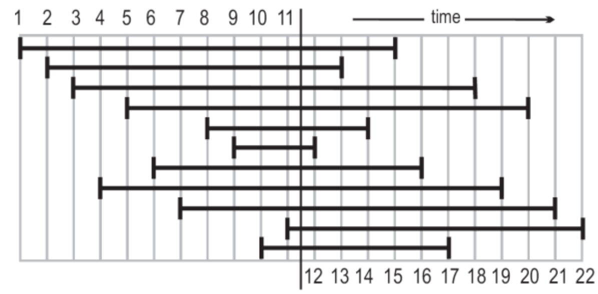


Figure. 42a: In this simple and sufficient initial sequence all taxa coexist. (Sadler, 2013)

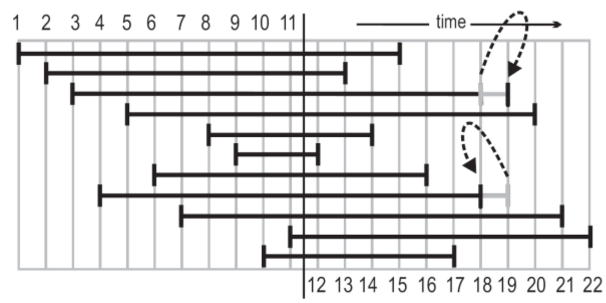


Figure. 42b: The smallest mutation option. (Sadler, 2013)

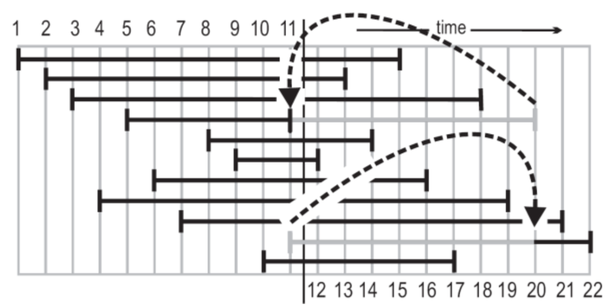


Figure. 42c: The most efficient mutation option moves a randomly chosen event to a random position. (Sadler, 2013)

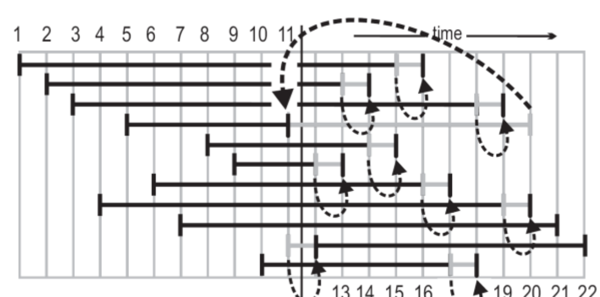


Figure. 42d: A more radical mutation protocol switches two events chosen at random. (Sadler, 2013)

The operational definitions of the time-line problem must be provided for both the salesman and the biostratigrapher. Different heuristics are created to solve this problem. In this chapter, we will look at how CONOP implements a simulation of the annealing heuristic. Before we can start implementing the simulated annealing method, we need a definition of the biochronological system (Figure. 42 a.d).

The events in a timeline that are bound to the constraints of the first appearance event must also satisfy the constraint that the taxon will not disappear before the last appearance. A biostratigrapher can also preserve every first appearance event and every observation of coexistence before the last appearance. The initial guess (Figure. 42 a) suggests that these constraints can be satisfied by randomly assigning all first-appearance occurrences to the first half of a sequence and then by randomly assigning all the last-appearance events.

Non-biological events, such as ash fall deposits, are placed in the middle portion of the timeline. The order of their dated events is constrained so that it matches their numerical ages. On the other hand, the superposition constraints on these markers prevent adjustment down and up sections.

CONOP offers three different ways to mutate the sequence. The simplest strategy involves randomly selecting an event in the sequence and then replacing it with the next one (Figure. 42 b). This method can simplify the calculation of fitness after a mutation, but it becomes more inefficient as the complexity of the problem increases.

The most practical and efficient way to mutate the sequence is by moving an event at random into a new position in the sequence (Figure. 42 c). All of the events that are moved by this mutation then move one place in the other direction (Figure. 42 d). A more extreme variant of this strategy changes two events at random in the sequence, but this method is not ideal for making adjustments.

6.2. Heuristic Search Strategies

A heuristic search is generated by placing each point in a landscape on a timeline that is different from the field data and its elevation. The best-fit sequence is at the lowest point since the neighboring sequences are marked by single mutations. The measure of misfit and the type of mutation that is allowed vary depending on the topology.

The search strategies employ a string of steps across the landscape to trail random starting points to the lowest point. Due to the vastness of the landscape, even small datasets cannot be exhaustive surveys (Sadler and Cooper, 1993).

The goal of the search is to find the most suitable sequence with the least number of errors and to generate a map that shows the previous steps taken. At every step, the algorithms perform various simple operations, such as picking the next trial mutation. They also analyze the fit caused by the mutation and compare it with the threshold that determines if it should be removed or retained.

The threshold is used to determine which mutations are worth keeping or removing. It only requires the coordinates of the current and lowest position. It's optional to keep a complete map of the previous steps. Memory management can slow down the search path depending on the complexity of the task.

The complexity of the landscape is considered to be a "lunar" because it features numerous closed depressions that aren't the best-fit points. The search engine has to devise a strategy to find and avoid such minima.

The strategy can be described as a raindrop. The first step is to start at a random starting point and follow the path of the elevation changes over time. At each subsequent position, the algorithm can map the changes in the fitness for a single step. It can also take a steeper downhill step and adopt the mutation with the greatest fit improvement.

The strategy is most likely to search for the nearest local minimum, which is a sequence with no chance of improving due to the lack of fit caused by any single mutation. It avoids neighborhood mapping and blindly follows the first downhill step.

After a few rain-drop searches, the algorithms start with the fittest of them and then periodically update their hybrid state. In 2001, Zhang and Plotnick developed a genetic algorithm that can fit the LOC in correlation with the graphic correlation. However, implementing viable hybrids is time-consuming. In 1995, Kemple and colleagues suggested using a simulation-based strategy known as simulated annealing (Kirkpatrick et al., 1983).

6.3. Simulated Annealing

The simulated annealing uses a single landscape searcher. It learns to accept gentle uphill steps instead of steep ones, gradually losing its tolerance for such paths as the search progresses.

It starts at the beginning and becomes more finely tuned as the task progresses. The algorithm takes into account the cooling curve effect of the landscape as it accepts gentle uphill steps (Kemple et al., 1995). The calculation used in the algorithm is based on the Boltzmann equation and the analogy of building a perfect crystal by cooling and annealing.

A few constraints must be set to ensure that the search will reach the lowest point. These are similar to the cooling rate and the starting temperature. The CONOP software can handle most of these. More important decisions are also taken regarding the field data collected after each mutation

The advantage of the simulated annealing strategy is that it doesn't have to follow specific mathematical limitations when it comes to the selection of fitness formulations (Ingber, 1993). This allows the algorithm to perform comprehensive biostratigraphical analyses.

Good mutations are also usually found in clusters in random searches. However, in complex environments, such as multi-dimensional landscapes, the searcher might wander into winding and steep paths while looking for clues (Glover, 1989).

The concept of a dynamic first-in-first-out shortlisting strategy is to find good mutations that should be repeated only once and bad ones that should be kept as long as possible. In 1992, Dell and colleagues were not able to develop a tabu list that could improve the efficiency of the search. Instead, they used the time saved by trying more mutations.

Various simple strategies can be used to increase the number of beneficial mutations, but these tend to get the searcher caught in the cooling rate. Increasing the number of temporary deleterious mutations is very important to improve the fitness of the searcher (Moore and al, 1997)

Conclusion

In the realm of Chapter IV, we've embarked on a journey through the intricate world of constraint optimization, unveiling its significance in the pursuit of deeper insights into the ancient marine life and the Cretaceous Age. As the Middle Cretaceous period unfolded, remarkable environmental shifts left their mark on Earth's geological history, presenting a unique opportunity to study the silent testimonies within the shells of ancient marine organisms.

Our explorations in biostratigraphy and biozones revealed the origins, development, and techniques employed in this field. Biostratigraphy, with its focus on sedimentary layers and the reconstruction of life's past, is a pivotal cornerstone of geology. The introduction of terms like biozones and the concepts of FADs (First Appearance Datums) and LADs (Last Appearance Datums) added depth to our understanding, as we grappled with the diachronous nature of these units. The power of biostratigraphy to resolve intervals of less than a million years and the cautionary note about information overload equipped us with essential tools and awareness.

Moving into chronostratigraphy and time-lines, we navigated the challenges posed by the unsteady process of dating fossils from different eras. The need for composite sections, the biostratigraphic sequencing problem, and the role of traditional biozones provided us with valuable insights into unraveling the mysteries of Earth's past.

As we progressed into graphic correlation, we acknowledged its role as a better solution, emphasizing the incorporation of other events to gain a more holistic understanding of the stratigraphic record. Yet, we were also mindful of its limitations.

The heart of this chapter, constraint optimization, unveiled a world of complexities and strategies. From the simplest cases to adding more taxa and weighing the trustworthiness of information, we explored the intricacies of observed stratigraphic spacing, order, and overlap. The idea of reworked fossils and the differentiation between assemblage zones and interval zones shed light on the multifaceted nature of the fossil record.

Finally, the concept of the Traveling Salesman's Solution, with heuristic search strategies and simulated annealing, demonstrated the importance of optimizing our understanding of the past's temporal and spatial puzzles.

CHAPTER V

BIOSTRATIGRAPHY AND PALEOENVIRONNEMENT

Introduction

The study of geology takes us on a journey through time, allowing us to unravel the mysteries of Earth's ancient environments and the remarkable changes that have shaped our planet. In this fifth chapter, we delve into the biostratigraphy and paleoenvironnementof four distinct sections, each providing a unique window into the geological history of Algeria's Tebessa Province. These sections, Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana, and Djebel Boulhaf Dir, offer invaluable insights into the Cenomanian to Turonian stages of the Cretaceous period. (Figure. 43)

Djebel Zitouna:

Our exploration begins at Djebel Zitouna, a prominent mountain located in the eastern reaches of Algeria, close to the Tunisian border. This section boasts a rich geological tapestry characterized by sedimentary deposits, including marl, and limestone reminiscent of a shallow marine environment. Notably, limestone formations dominate the upper part of this section, revealing various lithofacies, such as marly limestones and bioclastic limestones, teeming with marine fossils. These fossils provide a crucial glimpse into the persisting shallow marine environment.

The study of microscopic organisms offers a deeper understanding of the ancient environments in Djebel Zitouna. With detailed investigations into planktonic foraminifera, keeled foraminifera, and ostracods from the samples, we discern variations in paleoenvironmental conditions. This region, in particular, showcases a diversity of paleoenvironments, ranging from nearshore to deep marine settings, reflecting changes in water depth and proximity to the shore. The varying degrees of marine depth hint at the intricate tapestry of influences that shaped this landscape over time.

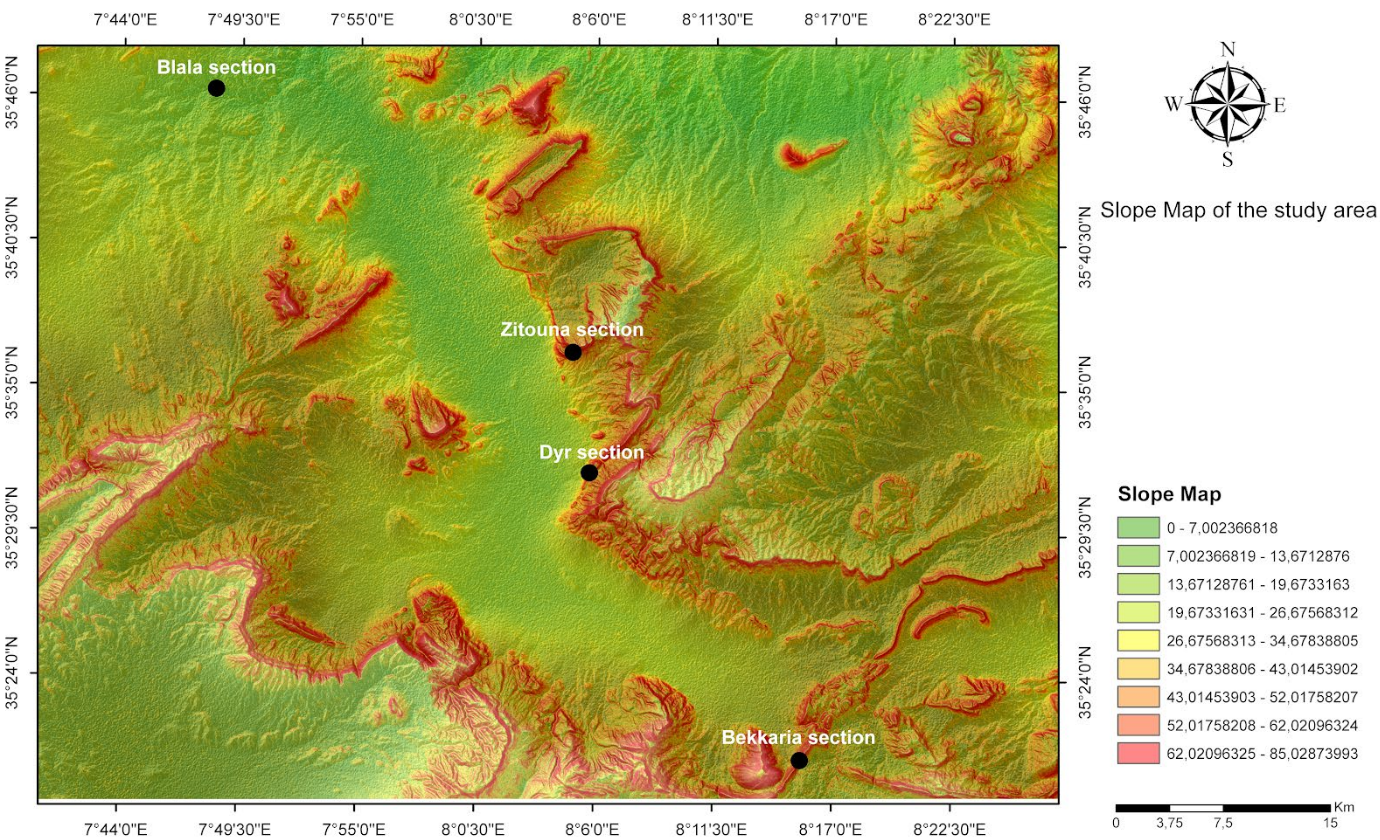


Figure. 43: Slope map presents the study area with the four sections

Djebel Bekkaria:

Djebel Bekkaria, a mountain range situated approximately 15 kilometers southwest of the city of Tebessa. This locale reveals a similar lithological composition characterized by sedimentary deposits, including marl, and limestone, attesting to a shallow marine environment. However, Djebel Bekkaria can be divided into three distinct parts, each representing different ages and paleoenvironmental conditions. Notably, the presence of specific ostracods and foraminifera species offers glimpses into the changing environmental dynamics that unfolded within this region.

Blala Oued Meskiana:

Next, we venture to Oued Meskiana, a district within the city of Blala in Tebessa, where the lithology primarily comprises marine sediments like limestone, marl, and marly limestone . These sediments bear witness to a shallow sea environment, where marine organisms such as foraminifera and rudist bivalves found their final resting places. The presence of fine-grained clay and silt deposits points to deeper marine conditions.

Our investigation of samples from the Blala section underscores a predominantly open marine environment, with planktonic foraminifera dominating the microfossil assemblages. Variations in Keeled foraminifera percentages shed light on subtle environmental changes, contributing to our understanding of the regional paleoenvironment.

Djebel Boulhaf Dir:

Finally, we arrive at Djebel Boulhaf Dir, another mountain range in Tebessa, Algeria, where the lithology consists of limestone beds intercalated with shale and clay layers, indicative of a predominantly carbonate sedimentary environment. The consistently high percentages of planktonic foraminifera in the samples hint at a stable marine environment conducive to the proliferation of planktonic microorganisms.

In summary, our journey through Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana, and Djebel Boulhaf Dir unveils significant variations in paleoenvironments, showcasing the role of geodynamic factors in shaping these landscapes. The distinct paleoenvironmental conditions found in close geographic proximity provide a unique opportunity to explore the influence of tectonics, sea level changes, sedimentary basin evolution, climate, and local geological structures on the region's diverse landscapes and water depths throughout the Cenomanian to Turonian stages.

Biostratigraphy serves as our guiding light throughout this chapter, enabling us to pinpoint specific geological boundaries and understand the paleoenvironnementof these geological sequences. Different species of microfossils found within each section act as valuable biostratigraphic tools, offering precise markers for dating rocks and providing insights into the changing paleoenvironmental conditions that unfolded over time. As we delve deeper into these sections, our understanding of Earth's ancient past becomes increasingly enriched, illuminating the intricate tapestry of life that once flourished in these ancient landscapes.

Djebel Zitouna

1. *Geographic location :*

Location: Djebel Zitouna, also known as Jebel Zitouna, is a mountain located in the Tebessa Province of Algeria. It is situated in the eastern part of the country, not far from the border with Tunisia. (Photo. 01)

Coordinates: The geographic coordinates of Djebel Zitouna are approximately 35.385°N latitude and 7.310°E longitude.

Description: Djebel Zitouna is a significant geographic feature in the Tebessa Province, offering scenic beauty and playing a role in the local ecology. It may be of interest to geologists, ecologists. (Figure. 44)

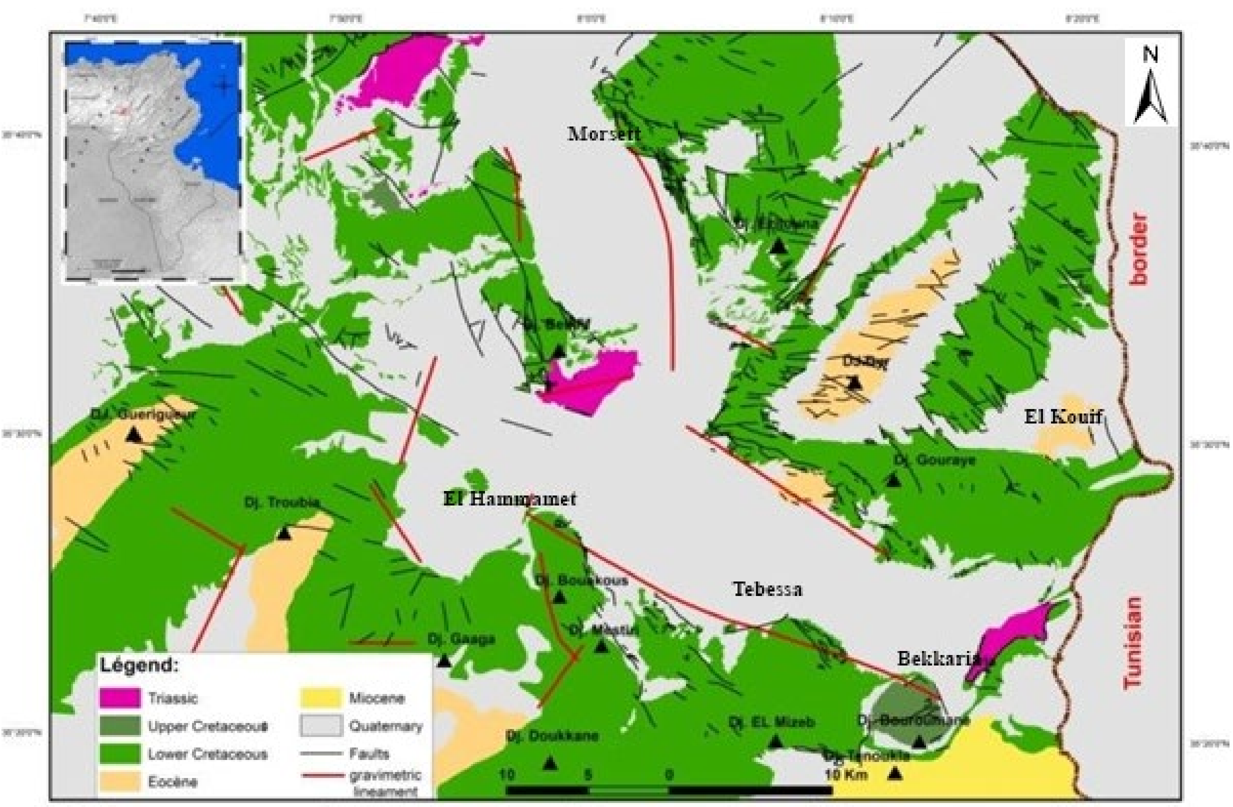


Figure. 44: Location of Zitouna section in geological map. (Morssot Geological Map)

Photo. 01: Panoramic vision of Zitouna section.

2. Lithologic description

Djebel Zitouna featured sedimentary deposits consisting of marl, limestone, and marly limestone . These sediments were primarily deposited in a shallow marine environment.

The region saw the dominance of limestone formations in the upper part of the section. These limestones often exhibit various lithofacies, including marly limestones and bioclastic limestones. The presence of abundant marine fossils in the limestones indicates the persistence of a shallow marine environment.

The lithologic description of Djebel Zitouna during the Cenomanian to Turonian highlights the sedimentary nature of the region, emphasizing the influence of a shallow marine environment in the deposition of limestone and associated sediments. Understanding the tectonic history is crucial for interpreting the geological evolution of the Tebessa region and Djebel Zitouna during this time frame. Further research and field studies are essential to provide more detailed insights into the geologic history of this area.

3. Paleoenvironnement

Through the study of the distribution and composition of microscopic organisms, it is possible to gain a deeper understanding of the ancient environments that existed in the sediment deposition processes. This study focuses on the samples from the Zitouna section. Figure

By reviewing the indices of the different kinds of marine and non-marine fossils, such as the percentage of planktonic foraminifera, keeled foraminifera, and ostracods, it can categorize these specimens into paleoenvironmental groups. This comprehensive analysis, which will also explore the past settings of these organisms, will help to understand the different episodes and section's history, which provide us with valuable information on the ancient water and landscapes. (Figure. 45

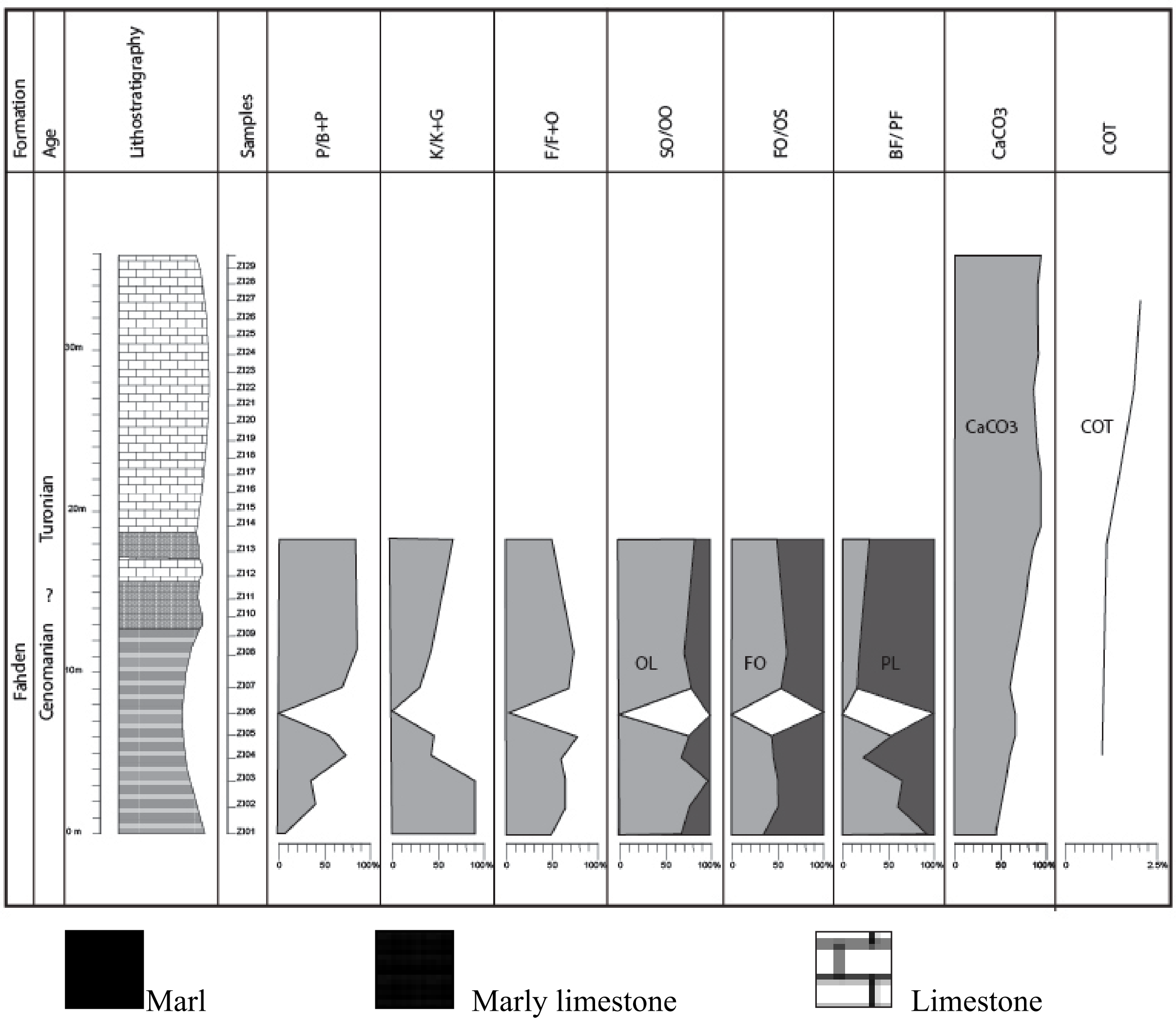


Figure. 45: Paleoenvironmental indexes of Zitouna section.

Interpretations for each subdivision of the paleoenvironmental changes based on the samples:

- Sample N°=01 reveals distinct features indicative of paleoenvironmental changes. The low percentage of planktonic foraminifera suggests proximity to the shore, where these microorganisms are less abundant. High percentages of keeled foraminifera support this interpretation and imply a relatively shallow, nearshore environment. The balanced percentage of foraminifera and ostracods signifies a dynamic, mixed environment. The equal distribution of benthos and planktonic foraminifera further confirms the relatively shallow water depth, suitable for both groups. The presence of smooth ostracod reflects the nearshore setting. Altogether, this sample points to a shallow to nearshore environment.

- Sample N°=02 presents a different paleoenvironmental scenario. High percentages of planktonic foraminifera suggest a deeper marine setting where these microorganisms thrive. Similarly, high percentages of keeled foraminifera indicate marine conditions. The balanced percentage of foraminifera and ostracods implies a stable marine environment. The dominance of foraminifera, particularly planktonic foraminifera, and the high presence of smooth ostracod further suggest a deeper marine environment. This sample is suggestive of a deeper marine environment.
- Sample N°=03 is unique, reflecting a paleoenvironnementwith mixed influences. The low percentage of planktonic foraminifera suggests some distance from the open sea. High percentages of keeled foraminifera imply marine influences. The balanced percentage of foraminifera and ostracods signifies a complex, dynamic environment. The dominance of foraminifera, particularly planktonic foraminifera, indicates relatively stable, but not necessarily deep, marine conditions. The high presence of smooth ostracod supports these interpretations. Sample N°=03 presents a unique ecological niche with a combination of marine and non-marine influences.
- Samples N°=04 N°=05 provides insights into a different paleoenvironmental context. High percentages of planktonic foraminifera are indicative of deeper marine waters where these microorganisms are abundant. In contrast, the low percentage of keeled foraminifera suggests a more specialized environment. The balanced percentage of foraminifera and ostracods indicates stable marine conditions. The dominance of foraminifera, especially planktonic foraminifera, underlines the prevalence of a deep marine environment. The presence of smooth ostracod further supports this interpretation, suggesting a relatively deep marine setting.

➢ Sample N°=06 is characterized by the absence of typical marine microorganisms and suggests a unique, potentially freshwater or very shallow-water environment. This interpretation aligns with the provided indexes of 0% for all categories, highlighting the absence of marine microorganisms and the potential presence of non-marine or very specific ecological conditions.

The absence of marine microorganisms in Sample N°=06 can be attributed to several potential factors and environmental conditions:

1. Shallow or Non-Marine Setting: The most likely explanation for the absence of marine microorganisms is that Sample N°=06 represents an environment with very shallow water or non-marine conditions. Shallow, stagnant water bodies like lagoons, swamps, or even temporary freshwater pools may not support the typical marine microorganisms found in other samples.

2. Salinity: Changes in salinity can significantly impact the distribution of microorganisms. The low or variable salinity in the water could deter marine foraminifera and ostracods from thriving, favoring the development of non-marine microorganisms or causing their absence.

3. Nutrient Levels: Nutrient availability can also play a crucial role. High nutrient levels in the water may promote the growth of specific microorganisms, while low nutrient levels can limit their presence. Sample N°=06 might have experienced nutrient conditions unsuitable for marine microorganisms.

4. Environmental Isolation: The specific location of Sample N°=06 could have isolated it from the marine environment. It may be situated in an isolated, landlocked area where it does not have easy access to marine water and the associated microorganisms.

5. Paleoclimate Changes: Long-term climatic changes could have led to shifts in the local environment, including alterations in temperature, rainfall, and humidity. Such changes might have made the environment unsuitable for marine microorganisms.

6. Depositional History: The sedimentary history of the area, such as sediment influx, subsidence, or tectonic activity, could have influenced the preservation and distribution of microorganisms in this particular sample.

7. Ecological Niche: Sample N°=06 might represent a highly specialized ecological niche where only specific microorganisms adapted to those conditions can survive, leading to the absence of others.

Samples N°=07 N°=08: presents features associated with a deep marine environment. High percentages of planktonic foraminifera indicate deeper marine conditions. Low percentages of keeled foraminifera imply specific marine influences. The balanced percentage of foraminifera and ostracods suggests relatively stable marine conditions. The dominance of foraminifera, particularly planktonic foraminifera, confirms a deep marine environment. The presence of smooth ostracod supports this interpretation.These interpretations collectively provide a comprehensive understanding of the diverse paleoenvironments recorded in the Zitouna section, reflecting changes in water depth, proximity to the shore, and the influence of marine and non-marine factors over time.

4. Biostratigraphy:

Based on the characteristics of the section and the presence or absence of specific species, the section can indeed be divided into three distinct parts, each representing different ages and paleoenvironmental conditions.

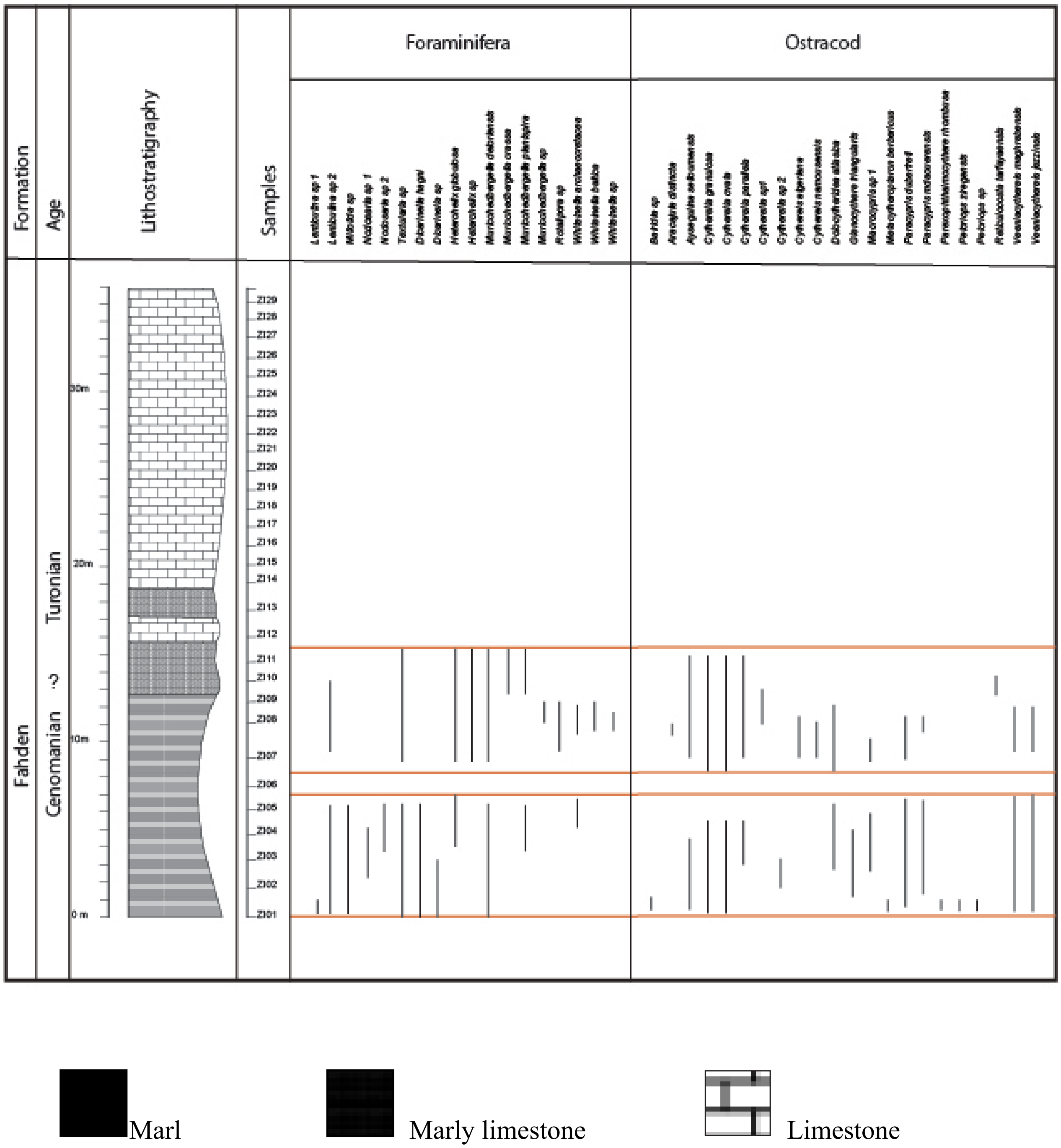


Figure. 46: Zitouna section range chart.

4.1. Part 1: Dominance of Ostracods (Late Cenomanian to Early Turonian):

In this part, where ostracods dominate, their relatively large size (around 0.35mm) suggests favorable conditions for their development. Ostracods are often more tolerant of variable salinity and water depth, and their presence, combined with diverse species, indicates a shallow marine environment. The larger ostracods may have been well-adapted to this environment, where they could find sufficient resources and ecological niches to thrive. (Figure. 46)

In this part of the section, characterized by limestones and marls, several distinct ostracod species have been identified, providing valuable insights into the Cenomanian-Turonian age. The diverse ostracod assemblage includes species such as *Cytherella parallela*, *Cytherella ovata*, *Macrocypris sp 1*, *Macrocypris sp 2*, *Metacetherapteron berburecus*, *Peloriops zirgensis*, *Reticulocosta tarfayaensis*, *Paracypris dubertreti*, *Paracypris mdaouerensis*, *Dolocytheridea atlasica*, *Aysegulina selloumensis, Glenocythere triangularis, Parexophthalmocythere rhombusa*, *Veeniacythereis Jezzineensis*, and *Veeniacythereis maghrebensis*.

The presence of these ostracod species is indicative of a Cenomanian-Turonian age, a conclusion reinforced by the co-occurrence of small planktonic foraminifera within the same strata. Notable foraminifera species in this context include *Heteherolix globulosa*, *Whiteinella archaeocretacea*, *Muricohedbergella planispira*, and *Whiteinella baltica*. These microfossils are invaluable for biostratigraphy and provide a robust basis for dating the rock layers in Djebel Zitouna, Tebessa, during this specific geological interval. Together, the ostracods and planktonic foraminifera offer a comprehensive picture of the Cenomanian-Turonian paleoenvironnementand age in this region, aiding in the reconstruction of past marine conditions and evolution.

The presence of relatively small foraminifera (approximately 63 micrometers) in this part suggests that these tiny microorganisms coexisted with the ostracods. This may indicate a stable and well-oxygenated water column, typical of shallow marine settings. The foraminifera could have been adapted to these conditions, coexisting with the larger ostracods.

4.2. Part 2: Absence of Species:

The complete absence of both ostracods and foraminifera in this part might be linked to specific environmental conditions. It's possible that this interval experienced unfavorable conditions for the preservation of microfossils. This could include changes in sediment type, water chemistry, or even a significant temporal gap in deposition. The absence of any size-specific data in this section leaves the reasons for this gap open to interpretation.

4.3. Part 3: Rich in Ostracods but Less Diverse with presence of planktonic foraminifera (Late Cenomanian to Early Turonian):

Part 3 of the section displays some interesting variations in the micropaleontological record. While ostracods are still present and relatively abundant, the reduced diversity of ostracod species suggests a shift in the local environment. Notably, the presence of specific ostracod species like *Aracajuia distincta*, *Aysegulina selloumensis*, *Cythereis algeriana*, *Cythereis namousensis*, and

Reticulucosta tarfayensis, which are relatively larger in size (approximately 0.35mm), might indicate ecological preferences or adaptations to distinct niches within the Late Cenomanian Early Turonian environment.

The continuity of relatively small foraminifera (approximately 63 micrometers) such as *Heteherolix globulosa*, *Whiteinella archaeocretacea*, *Muricohedbergella planispira*, *Whiteinella baltica* and *Rotalipora sp* in this part supports the interpretation of a late Cenomanian to Early Turonian age. It is intriguing to note that these microorganisms were able to coexist with the ostracods despite the changes in the ostracod community. This could imply that the environmental conditions remained suitable for these smaller foraminifera.

In summary, the variations in ostracod and foraminifera sizes closely mirror changes in the paleoenvironnementwithin different parts of the section. The dominance of larger ostracods in the first and third parts suggests a shallow marine environment with relatively stable conditions. The presence of relatively small foraminifera in these sections indicates the coexistence of various microorganisms well-adapted to these environmental conditions. However, the second part's lack of species may be linked to environmental changes that hindered the preservation of microfossils during this time frame. These findings contribute significantly to our understanding of the paleoenvironmental dynamics in Djebel Zitouna , Tebessa, during the Cenomanian-Turonian age.

Djebel Bekkaria

1. Geographic location :

- Location: Djebel Bekkaria is a mountain range located in the Tebessa province of Algeria. It is approximately 15 kilometers southwest of the city of Tebessa. (photo. 02)

- Coordinates: The geographic coordinates of Djebel Bekkaria are approximately 35.372°N latitude and 7.054°E longitude. (Figure. 47)

- Description: Djebel Bekkaria is a prominent natural feature in the Tebessa province, offering scenic beauty and potentially serving as a destination for outdoor activities and exploration. It is known for its unique geological and ecological characteristics.

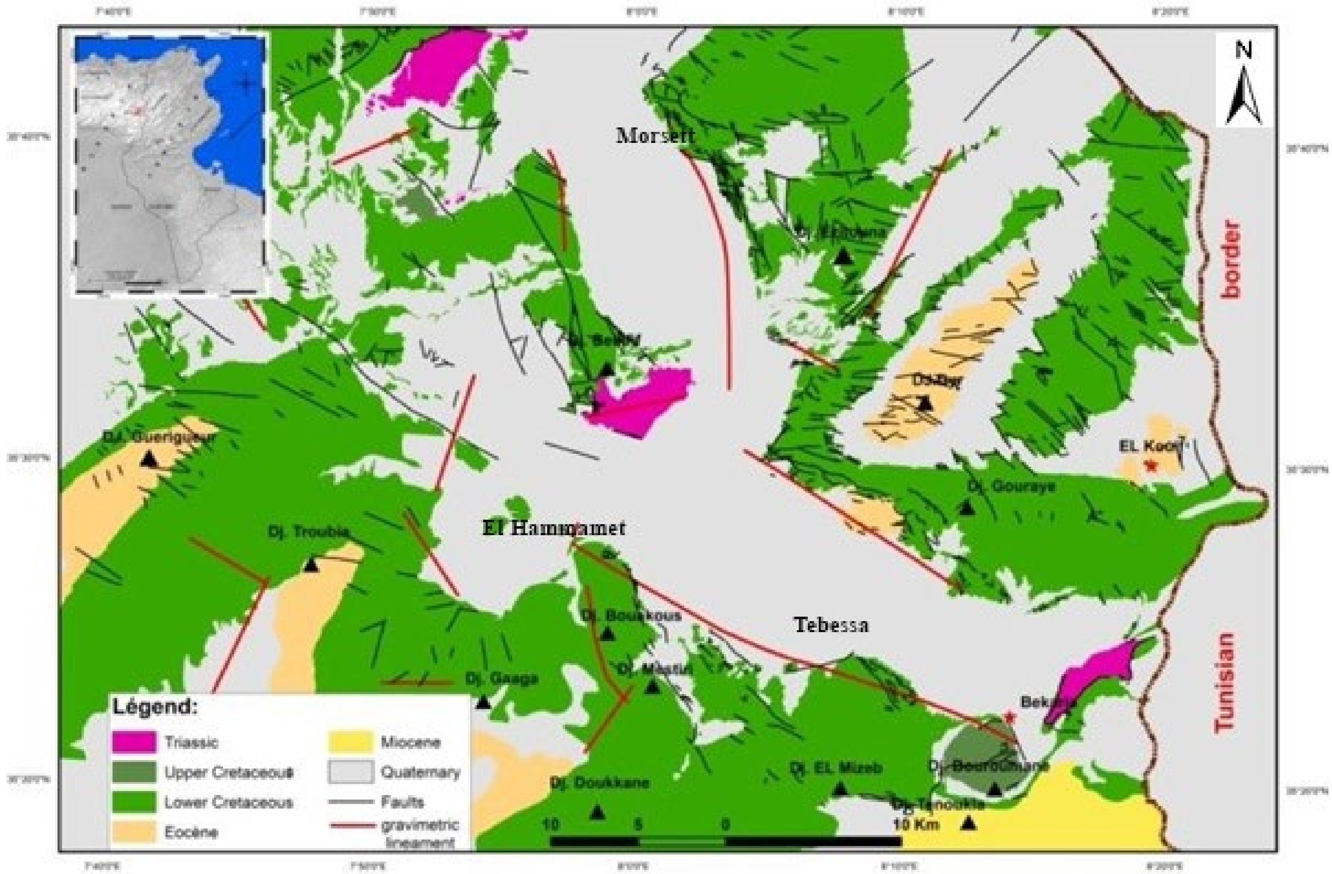


Figure. 47: Location of Djebel Bekkaria in geological map. (Tebessa Geological Map)

Photo. 02: Panoramic vision of Djebel Bekkaria

2. Lithologic description

Lithologic Description of Djebel Bekkaria (Cenomanian to Turonian)

Djebel Bekkaria was characterized by sedimentary deposits. These included marl, limestone, and marlylimestone.

Limestone Dominance: In the Turonian period, the region saw a transition to predominantly limestone formations. These limestones exhibited various lithofacies, including marly limestones and bioclastic limestones. Abundant marine fossils found within these limestones suggest the persistence of a shallow marine environment.

3. Paleoenvironment:

- Samples N°=01 N°=02: These samples suggest a shallow to nearshore environment. Sample N°=01 shows a balanced distribution of planktonic and benthic foraminifera, indicating proximity to the shore but not in very shallow waters. The high percentage of keeled foraminifera hints at some nearshore influence, possibly a coastal environment While both samples share some characteristics of nearshore influence, the planktonic foraminifera percentages hint at different degrees of marine depth. Sample N°=01 may represent a relatively shallower nearshore environment, while Sample N°=02 could correspond to a slightly deeper marine setting. It's essential to consider these subtle differences when interpreting the paleoenvironment. (Figure. 48)
- Sample10: suggests a very deep marine environment. The high percentage of planktonic foraminifera and a low percentage of keeled foraminifera indicate deep water conditions. The high percentage of smooth ostracod suggests high paleo-salinity, typical of deep marine settings.
- Sample 13: indicates a moderately deep marine environment with a balanced distribution of foraminifera and ostracods. The presence of both planktonic and benthos foraminifera suggests marine conditions with some influence from shallow waters.
- Samples N°=16, N°=17, N°=19, N°=22 and N°=26: These samples represent very deep marine environments. They display an extremely high percentage of planktonic foraminifera and a minimal presence of keeled foraminifera and ostracods. These conditions are typical of very deep marine settings, suggesting open ocean conditions.

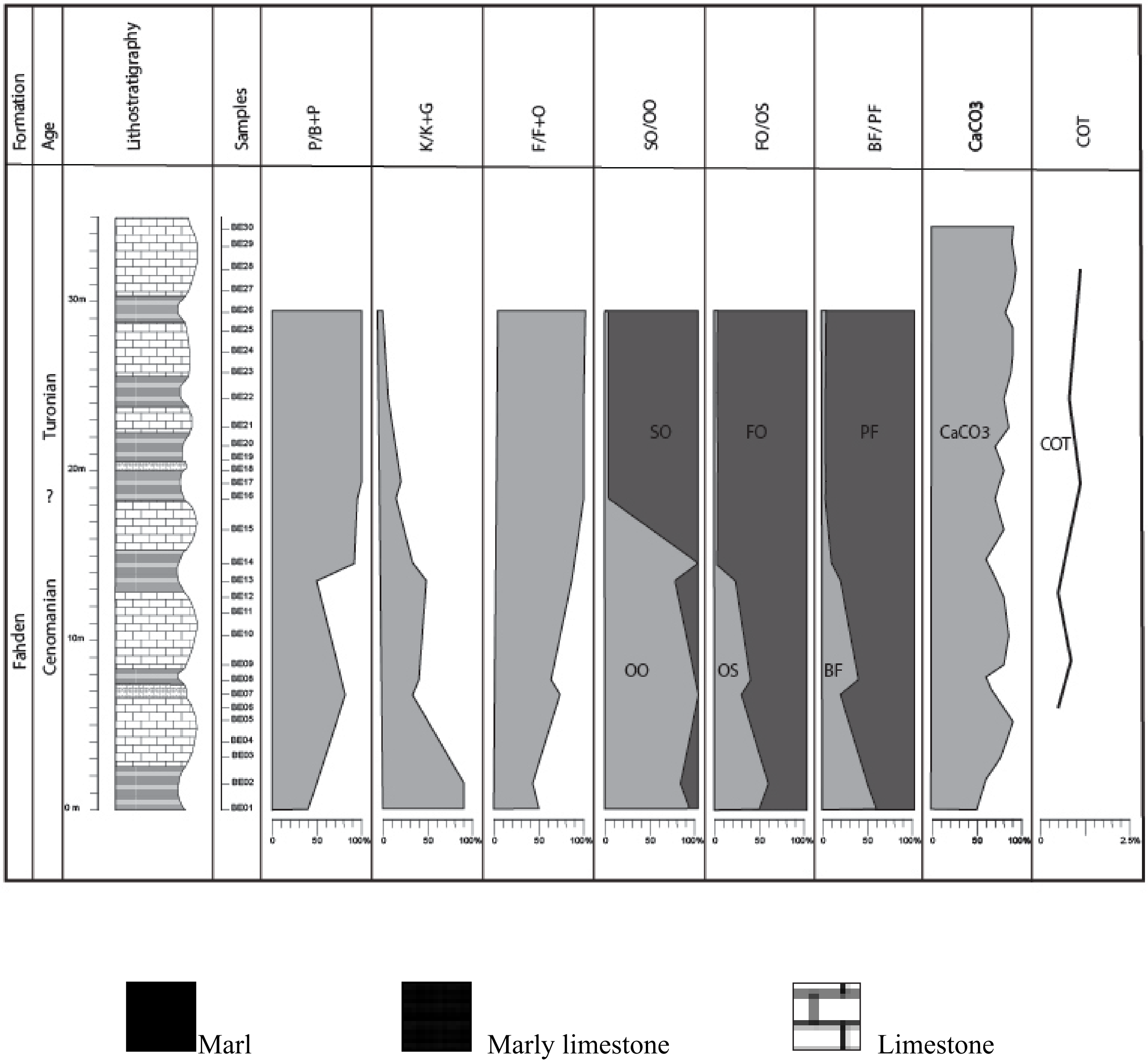


Figure. 48: Paleoenvironmental indexes of Djebel Bekkaria section.

4. Biostratigraphy

The Bekkaria Section, with its rich and diverse fossil assemblage, provides valuable insights into the paleoenvironnementduring the late Cenomanian and early Turonian stages of the Cretaceous period. Based on the species found in the section, the biostratigraphy of Bekkaria can be divided into four distinct parts, each indicative of different environmental conditions and ages.(Figure. 49)

4.1. Part 01: Late Cenomanian Ostracod and Keeled Foraminifera Assemblage:

This part of the section presents a remarkable assemblage featuring a diverse range of ostracod species, including *Bythoceratina tamarae*, *Cythereis Algeriana*, *Cythereis namousensis*, *Paracypris dubertreti*, *Paracypris mdaouerensis*, *Dolocytheridea atlasica*, *Metacytheropteron berbericus*, *Veeniacythereis Jezzineensis*, and *Veeniacythereis maghrebensis*. Additionally, some Keeled foraminifera, like *Muricohedbergella planispira* and *Dicarinella hagni*, are also present. These species collectively point to a late Cenomanian age. The abundance of ostracods, along with the specific foraminiferal indicators, signifies a unique paleoenvironnementassociated with this section.

4.2. Part 02: Late Cenomanian to Early Turonian Environment:

In this segment, it observes an assemblage characterized by the coexistence of benthic foraminifera, particularly *lenticulina sabalata*, and Keeled foraminifera such as *Dicarinella hagni* and *Muricohedbergella planispira*. Additionally, there is the presence of some ostracods similar to those found in the first part (*Cythereis algeriana*, *Cythereis namousensis*, *Paracypris dubertreti*, *Paracypris mdaouerensis*, *Dolocytheridea atlasica*, *Metacytheropteron berbericus*, *Veeniacythereis jezzineensis*, *Veeniacythereis maghrebensis*, and *Reticulicosta tarfayensis*).

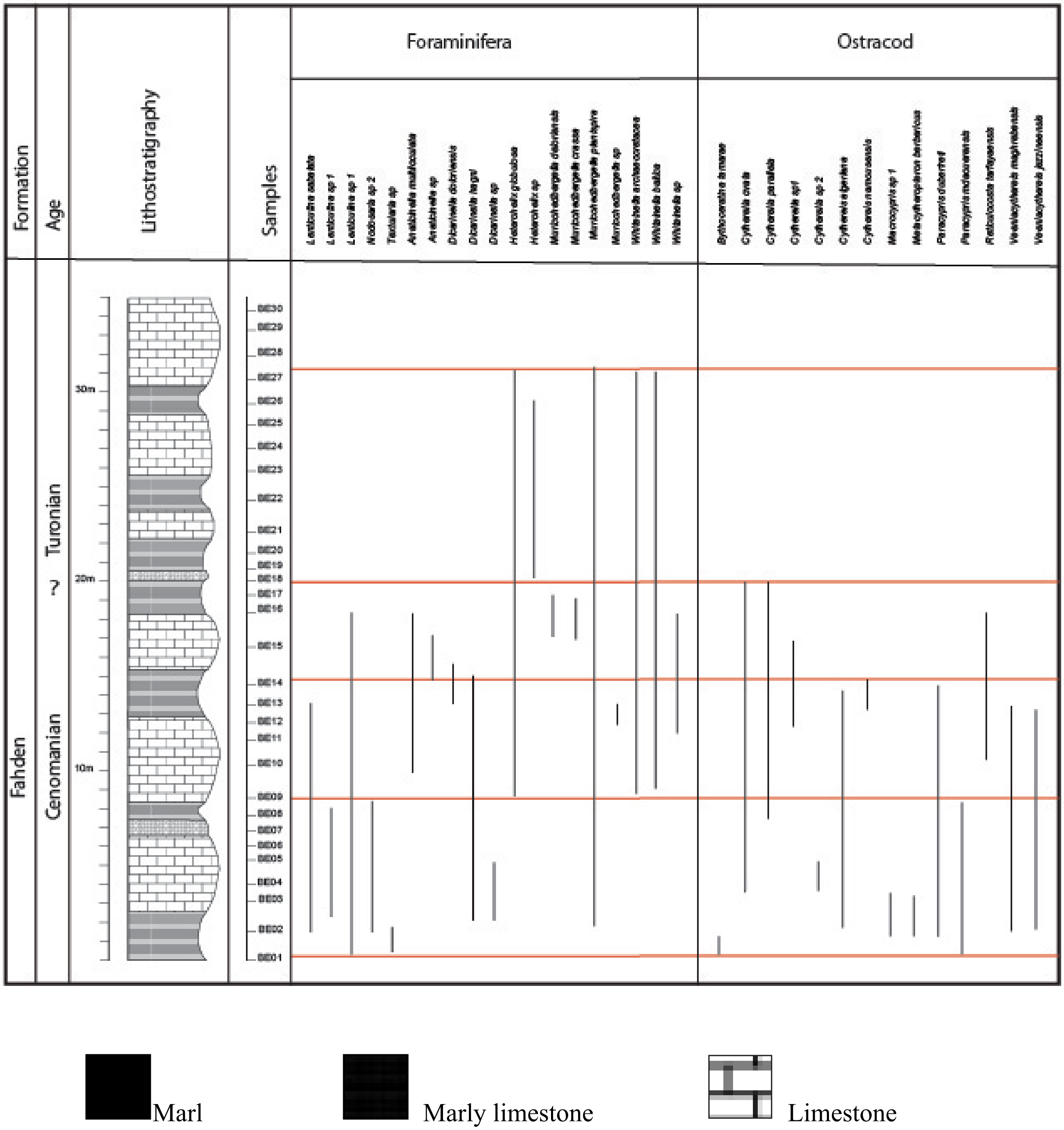


Figure. 49: Djebel Bekkaria section range chart.

This part aligns with the Late Cenomanian to Early Turonian age. The significant representation of both benthic and Keeled foraminifera within this section indicates specific paleoenvironmental conditions.

4.3. Part 03: Late Cenomanian to Early Turonian Transition:

The third part exhibits an intriguing assemblage with the presence of benthic foraminifera, Keeled foraminifera (such as *Dicarinella hagni* and *Muricohedbergella planispira*), and planktonic foraminifera like *Heteherolix Heterohelix globulosa*, *Whiteinella archaeocretacea*, *Muricohedbergella planispira*, and *Whiteinella baltica*. Although the numbers of ostracods, such as *Cytherella sp* and *Paracypris sp*, are relatively smaller and their preservation is suboptimal, the fossil assemblage still points to the late Cenomanian age. The presence of all three foraminiferal groups suggests complex and dynamic paleoenvironmental conditions during this transitional period.

4.4. Part 04: Early Turonian Environment:

The fourth part is characterized by the abundance of foraminifera including *Heteherolix Heterohelix globulosa*, *Whiteinella archaeocretacea*, *Muricohedbergella planispira*, and *Whiteinella baltica*. Notably, these foraminifera are exceptionally well-preserved and relatively large, indicating highly favorable environmental conditions. The species encountered in this part provide strong evidence of an Early Turonian age, signifying a significant change in the paleoenvironnementthat favored the proliferation of these larger microorganisms.

The biostratigraphy of Bekkaria section, as revealed by the species distribution in these four parts, not only provides valuable information for dating rocks within the late Cenomanian and early Turonian intervals but also highlights the changing paleoenvironmental conditions and ecological dynamics that occurred during this period. The presence and abundance of different species within each part offer a glimpse into the complex history of this region.

Blala Section (Oued Meskiana)

1. Geographic location :

Location: Oued Meskiana is a district within the city of Blala in the Tebessa Province of Algeria. Coordinates: The geographic coordinates for Oued Meskiana in Blala, Tebessa, are approximately 35.414°N latitude and 7.401°E longitude. (Photo. 03)

Description: Oued Meskiana, as a district within Blala, contributes to the cultural and residential aspects of this region. It is strategically located near Blala city of the Oum El Boighi Province. (Figure. 50)

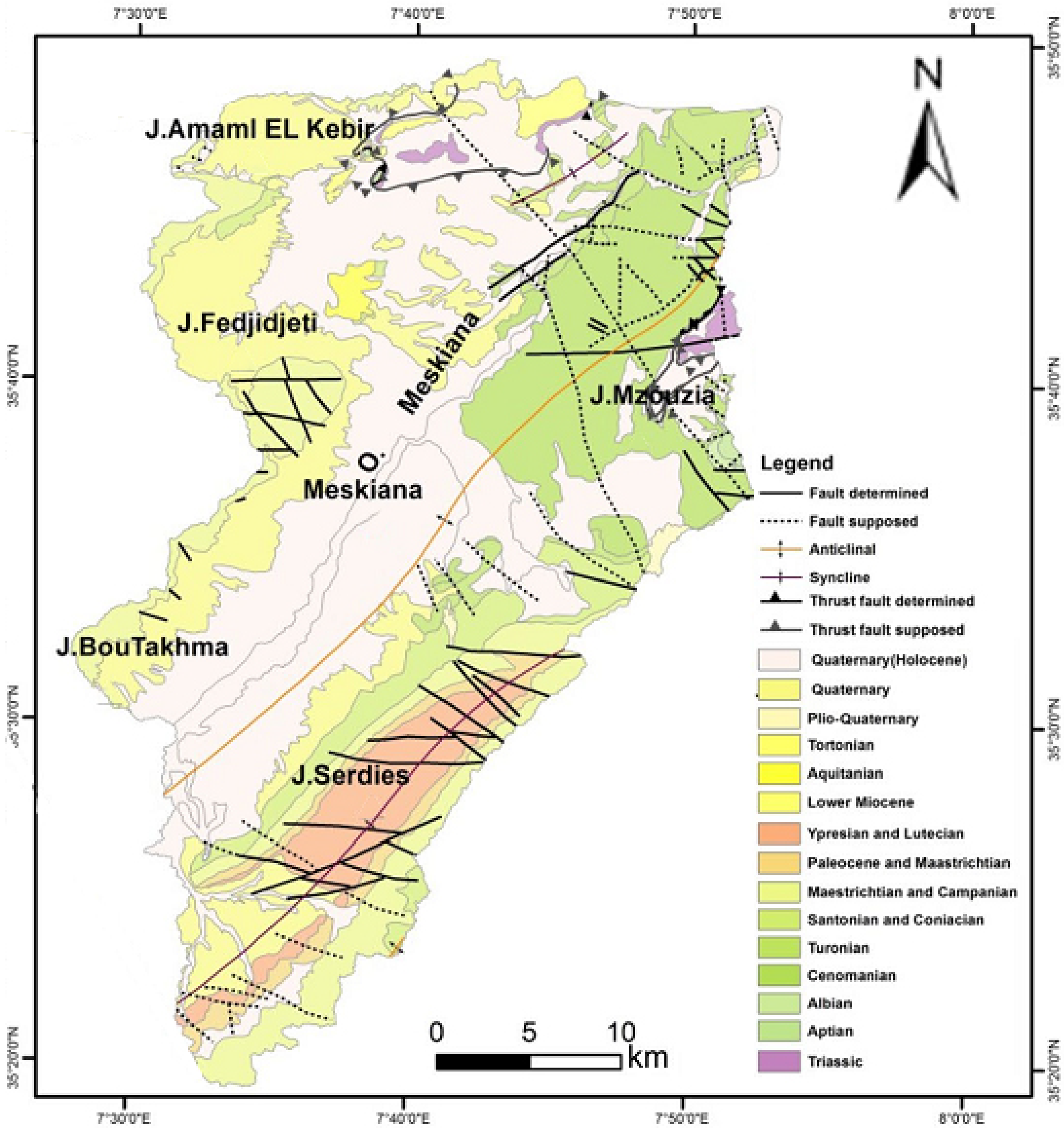


Figure. 50: Location map of Oued Mekiana section in the geological map.(Meskiana Goelogical Map)

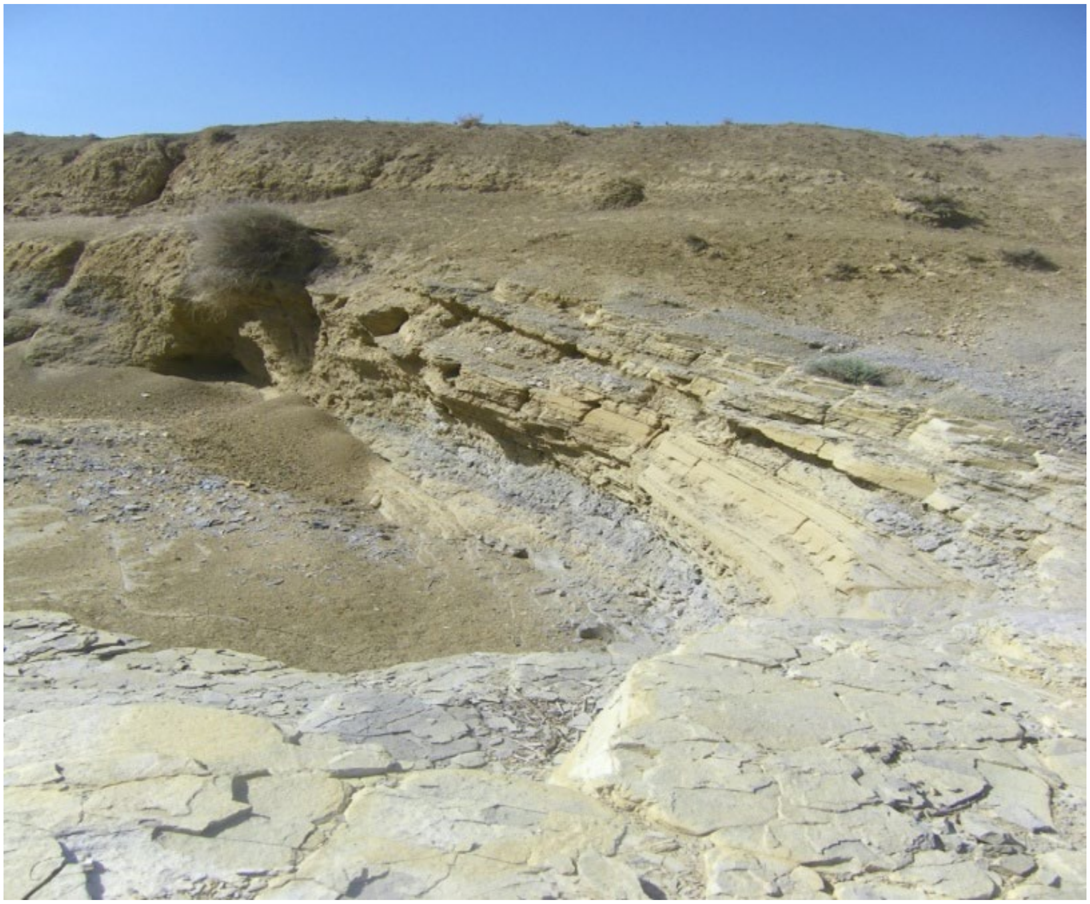


Photo. 03: Panoramic view of the Oued Meskiana Section in the study area

2. Lithologic description:

The Oued Meskiana region's, lithology primarily consists of marine sediments. These sediments include limestone, marl, and marly limestone , reflecting the influence of a shallow sea. Fossilized marine organisms such as foraminifera and rudist bivalves are commonly preserved in these rocks.

Paleoenvironment:

The collected data from the samples suggests that the Blala section represents a predominantly open marine environment with a significant presence of planktonic foraminifera. The dominance of foraminifera over ostracods in most samples indicates favorable conditions for foraminiferal growth. The varying percentages of Keeled foraminifera may reflect changing environmental conditions or ecological preferences of different foraminiferal groups. Overall, these indexes provide valuable information about the paleoenvironnementof the Blala section, characterized by a predominance of planktonic foraminifera in a marine setting. This suggests a consistent marine environment with potential variations or subtle influences that need further investigation for a comprehensive understanding of the paleoenvironnementin this region. (Figure. 51)

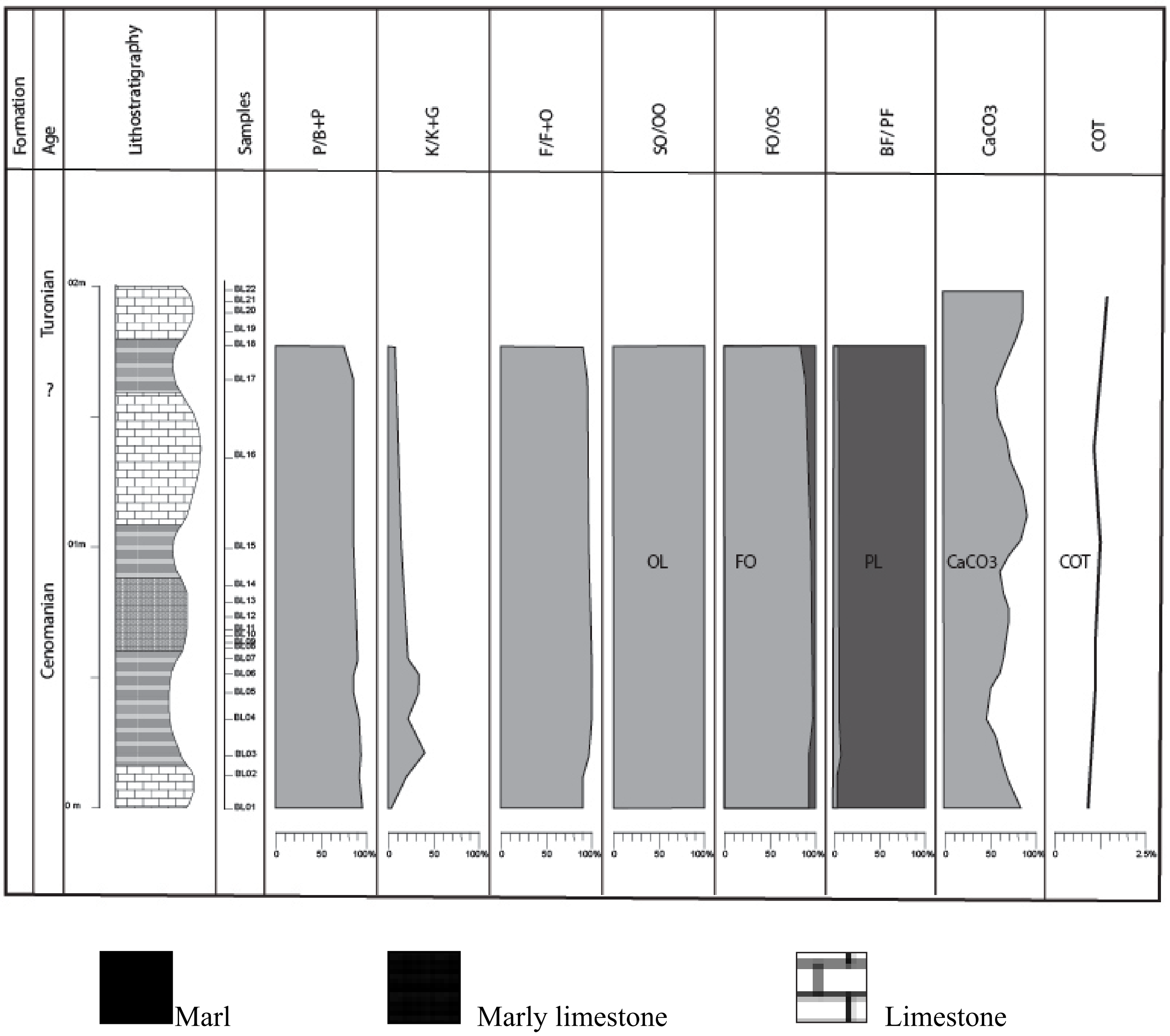


Figure. 51: Paleoenvironmentalindexes of Oued Meskiana section

3. Biostratigraphy:

The presence of these species, such as Anaticinella multiloculata, Dicarinella hagni, *Heteherolix globulosa, Muricohedbergella planispira, Whiteinella baltica, and Whiteinella arceocretacea*, in the Blala section confirms the late Cenomanian to early Turonian age of the rock sequence. These species have a relatively narrow temporal range and are excellent biostratigraphic markers for dating rocks within this interval.

The consistent presence of these species across multiple samples suggests a relatively stable and well-oxygenated marine environment during this time period, which is consistent with the characteristics of the late Cenomanian and early Turonian stages. (Figure. 52)

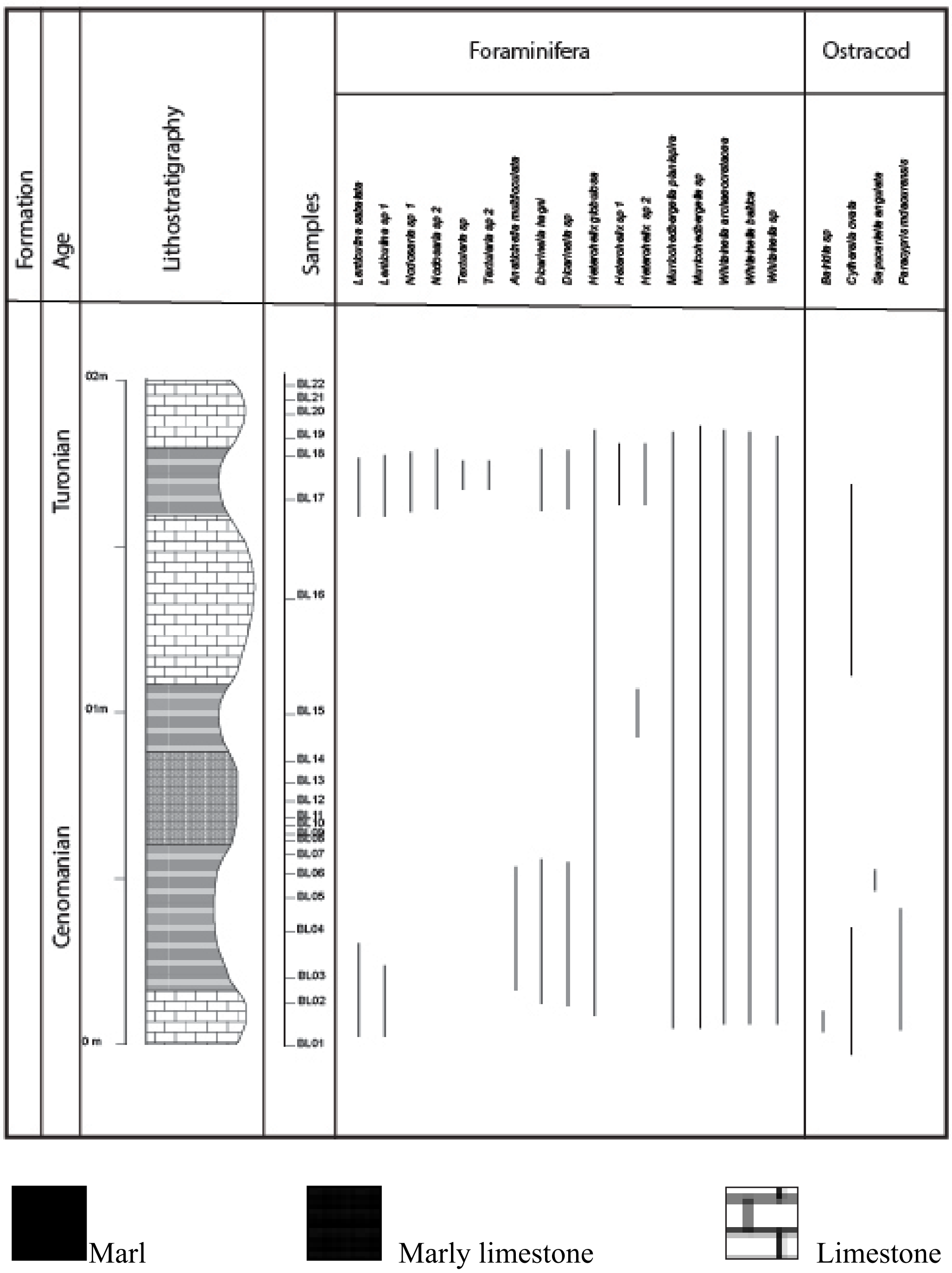


Figure. 52: Oued meskiana section range chart

In summary, the presence of these species in the Blala section provides robust biostratigraphic evidence for the late Cenomanian to early Turonian stages of the Cretaceous period. These species are valuable tools for dating rocks within this interval and are used to refine age determinations with high precision. The consistent presence of these well-documented index fossils across multiple samples in the section strengthens the reliability of the biostratigraphic assessment and contributes to a better understanding of the geological history of the area during this time period.

Djebel Boulhaf Dir

1. Geographic location:

Location: Djebel Boulhaf Dir is another mountain range located in the Tebessa province of Algeria. The exact geographical coordinates can vary depending on specific points within this mountain range. (Photo. 04)

Coordinates: Generally, Djebel Boulhaf Dir can be located around 35.4046°N latitude and 7.7376°E longitude.Description: Djebel Boulhaf Dir Tebessa is an extensive mountain range, known for its diverse landscapes, including rocky terrain and lush valleys. (Figure. 53)

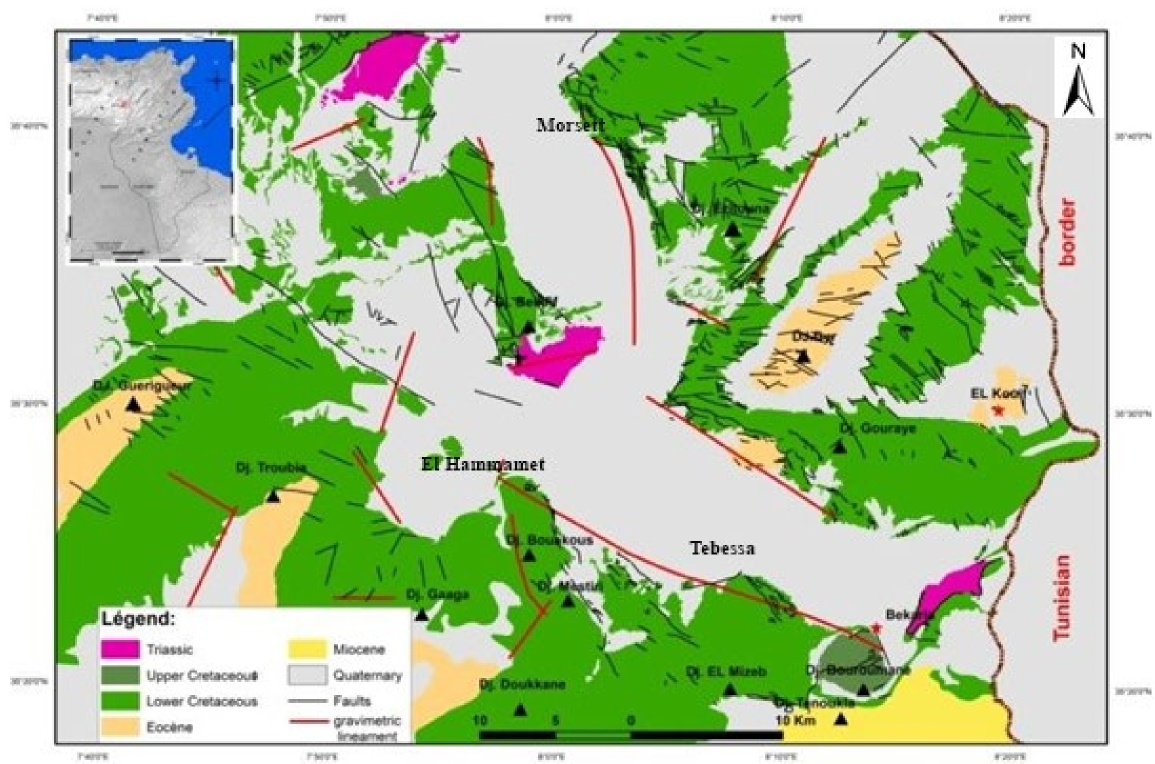


Figure. 53: Location map of Djebel Boulhaf Dir in the geological map (Morsott geological Map)

Photo. 04: Picture of Djebel Boulhaf Dir section in field

2. Lithologic description:

The lithology of Djebel Boulhaf Dir in Tebessa, Algeria, reflects a sedimentary sequence primarily composed of limestone beds intercalated with shale and clay layers, indicative of a predominantly carbonate sedimentary environment occasionally influenced by fine-grained sediment input. The sedimentary rocks contain an abundance of well-preserved microfossils, including foraminifera, ostracods, and planktonic microorganisms, which serve as valuable biostratigraphic markers and provide insights into the paleoenvironmental conditions of the ancient marine setting. The presence of various bedding structures and occasional chert nodules hints at dynamic depositional conditions and possible fluctuations in water energy. This lithological diversity and exceptional fossil preservation contribute to our understanding of the geological history and environmental dynamics during the Cenomanian-Turonian age in this region.

3. Paleoenvironment:

The consistently high percentages of planktonic foraminifera in all samples (ranging from 94% to 99%) suggest a marine environment with stable conditions conducive to the proliferation of planktonic microorganisms. This marine setting is further substantiated by the low Keeled foraminifera percentages (ranging from 12% to 23%), indicating minimal influence from shallow-water or nearshore conditions. (Figure. 54)

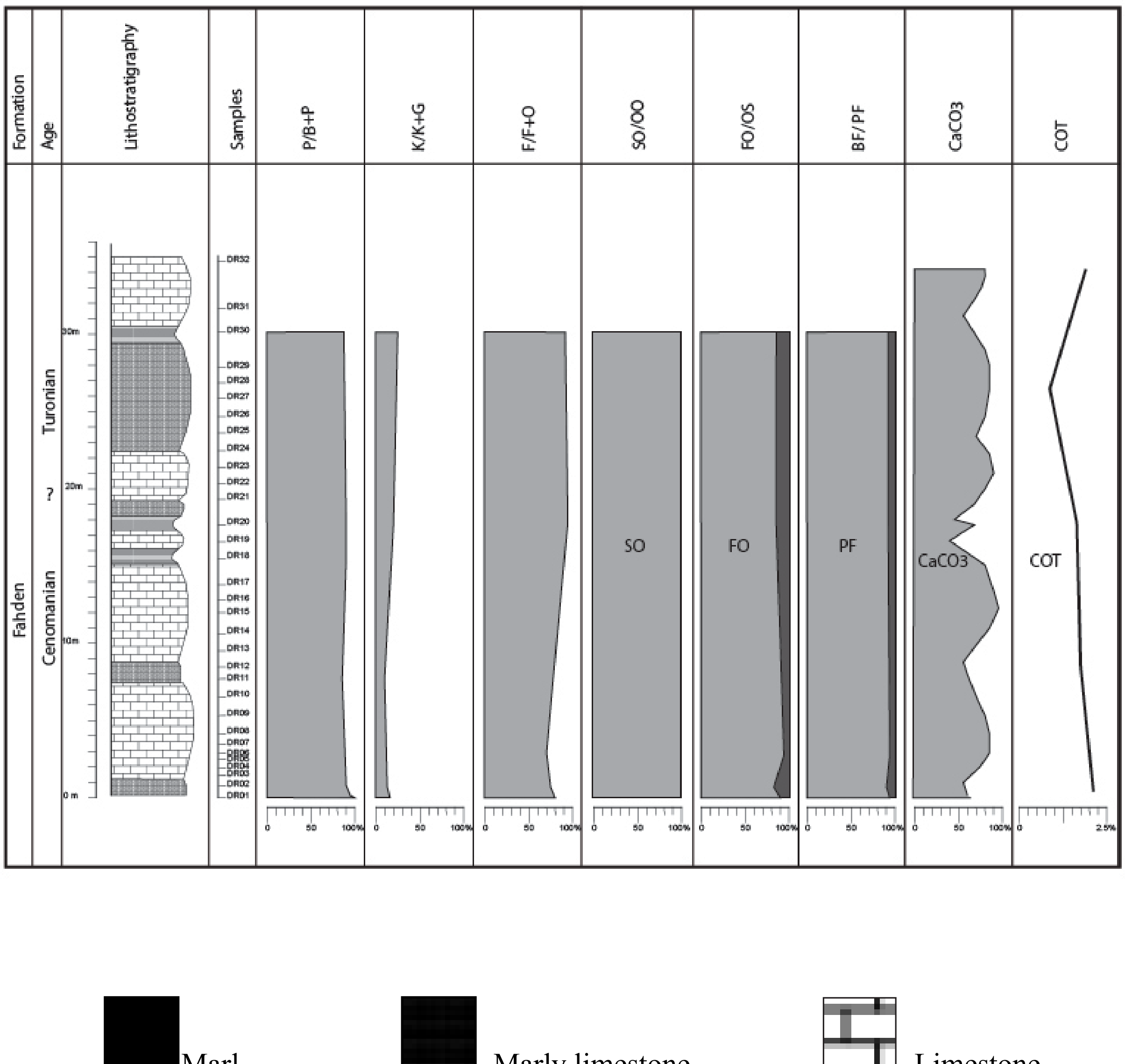


Figure. 54: Paleoenvirmental indexes of Djebel Boulhaf Dir section.

Moreover, the high percentages of foraminifera (ranging from 82% to 98%) in these samples highlight the dominance of foraminiferal assemblages in this deep marine environment. The abundance of foraminifera is consistent with a well-oxygenated marine setting, which is typically associated with deep waters. The limited presence of ostracods (ranging from 2% to 18%) and their absence in some samples indicate that these microorganisms may not have been favored in this particular paleoenvironment. Additionally, the complete absence of smooth ostracod and orlemented ostracods confirms the relatively pristine marine conditions, with minimal terrestrial influence.

In summary, the Djebel Boulhaf Dir section reflects a consistently deep marine paleoenvironnementduring the Cenomanian-Turonian period, characterized by stable marine conditions, well-oxygenated waters, and limited influence from terrestrial or nearshore factors.

4. Biostratigraphy:

The microfossil assemblages found in all the studied samples from the Dyr section are remarkably consistent, implying both a uniform paleoenvironnementand temporal range. These samples exhibit common microfossil constituents, notably featuring ostracods such as *Cytherella* and *Paracypris*, as well as planktonic foraminifera including *Dicarinella hagni*, *Dicarinella sp*, *Heterohelix globulosa*, *Heterohelix sp1*, *Muricohedbergella planispira*, *Mericohedbergella doloriensis*, *Whiteinella baltica*, and *Whiteinella archaeocretacea*. Collectively, these microfossils point to a chronological span encompassing the late Cenomanian to the early Turonian stages of the Cretaceous period. The consistent microfossil content reaffirms the reliability of the biostratigraphic data, shedding light on the stable paleoenvironmental conditions that persisted throughout this time frame in the Djebel Boulhaf Dir section. This shared microfossil inventory enhances the precision of dating and understanding the geological record within this specific interval. (Figure. 55)

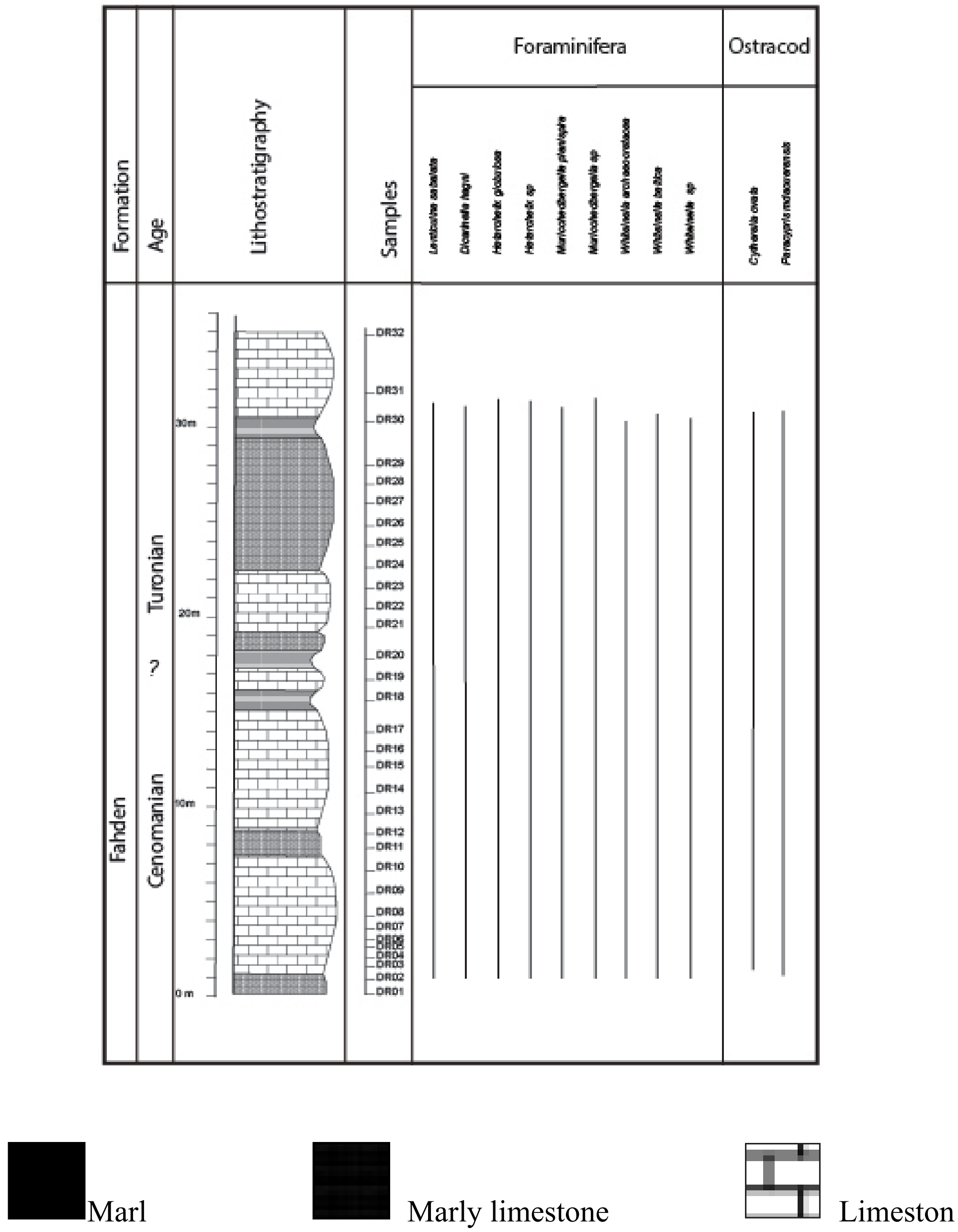


Figure. 55: Djebel Boulhaf Dir section range chart.

Paleoenvironment:

In the study of four sections (Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana, and Djebel Boulhaf Dir), significant variations in paleoenvironments become evident. The presence of ostracods in the Zitouna and Bekkaria sections suggests that these areas represent shallow-water environments. In contrast, the Blala and Dir sections reflect open marine environments. These sections, located in close proximity to each other and characterized by similar rock types, reveal distinct paleoenvironments.

Djebel Zitouna:

The study of the Zitouna section highlights the utility of microscopic organisms in understanding ancient environments. Examination of planktonic foraminifera, Keeled foraminifera, and ostracods in the samples allows the categorization of paleoenvironmental groups. Sample N°=01 indicates a relatively shallow nearshore environment with a dynamic mix of microorganisms. Sample N°=02 suggests a deeper marine environment with planktonic foraminifera dominance. Sample N°=03 presents a unique, mixed environment with both marine and non-marine influences. Samples N°=04 and N°=05 point to a deep marine environment. Sample N°=06 reflects potentially freshwater or very shallow-water conditions, while Samples N°=07 and N°=08 indicate deep marine settings. These interpretations collectively provide a comprehensive understanding of the diverse paleoenvironments in the Zitouna section, reflecting changes in water depth, proximity to the shore, and the influence of marine and non-marine factors over time.

Djebel Bekkaria:

Djebel Bekkaria is divided into distinct parts. Part 1, dominated by ostracods, reflects a shallow marine environment. The presence of relatively large ostracods suggests favorable conditions for their development. Part 2, with the absence of some species, might indicate unfavorable environmental conditions for microfossil preservation. Part 3, rich in ostracods but less diverse, suggests a shift in the local environment. Specific ostracod species indicate changes within the Late Cenomanian to Early Turonian setting. The presence of small foraminifera suggests stable, well-oxygenated water conditions despite the changes in the ostracod community. These findings offer insights into the Cenomanian-Turonian paleoenvironnementand the coexistence of different microorganisms.

Blala Oued Meskiana:

The Blala section represents a predominantly open marine environment. The dominance of planktonic foraminifera, indicating favorable conditions for these microorganisms. Variations in Keeled foraminifera percentages may reflect changing environmental conditions or ecological preferences. This section provides valuable insights into a consistent marine environment with subtle variations that warrant further investigation for a comprehensive understanding of the paleoenvironment.

Djebel Boulhaf Dir:

Djebel Boulhaf Dir consistently indicates a deep marine paleoenvironnementduring the Cenomanian-Turonian period. High percentages of planktonic foraminifera and low Keeled foraminifera suggest a stable marine setting with minimal influence from shallow waters. The dominance of foraminifera underscores a well-oxygenated marine environment associated with deep waters. The limited presence of ostracods and their absence in some samples confirm the pristine marine conditions with minimal terrestrial influence.

These findings highlight the influence of different paleoenvironmental conditions within close geographic proximity and underscore the importance of microfossils in deciphering ancient environments. The variations in paleoenvironments may be linked to paleogeodynamic factors, such as tectonics, sea level changes, sedimentary basin evolution, climate, and local geological structures, which collectively shaped the region's diverse landscapes and water depths over time.

Biostratigraphy

In the study of the four sections, Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana, and Djebel Boulhaf Dir, biostratigraphy has played a pivotal role in determining chronological limits and understanding the paleoenvironnementof these geological sequences. Notably, different species of microfossils found in each section have been utilized as biostratigraphic tools to pinpoint specific geological boundaries. In Djebel Zitouna, for instance, the presence of ostracods, such as *Cytherella parallela, Cytherella ovata*, and *Macrocypris sp*, coexisting with planktonic foraminifera like *Heterohelix globulosa*, *Whiteinella archaeocretacea*, and *Whiteinella baltica*, has provided key evidence for identifying the Cenomanian-Turonian limit. Similarly, in Djebel Bekkaria, diverse species, including *Bythoceratina tamarae*, *Cythereis Algeriana*, and *Metacytheropteron berbericus*, in combination with Keeled foraminifera like *Dicarinella hagni* and *Muricohedbergella planispira*, have been crucial in dividing the section into parts, each indicative of different ages and environmental conditions. Furthermore, in Blala Oued Meskiana, species such as *Anaticinella multiloculata*, *Dicarinella hagni*, *Heterohelix globulosa*, and *Whiteinella arceocretacea* have consistently confirmed the late Cenomanian to early Turonian age, serving as precise biostratigraphic markers. Finally, the remarkable consistency in microfossil assemblages across all samples in Djebel Boulhaf Dir, featuring ostracods and planktonic foraminifera like *Dicarinella hagni* and *Whiteinella archaeocretacea*, has further cemented the conclusion of a chronological span encompassing the late Cenomanian to early Turonian stages. Collectively, these different species, strategically employed as biostratigraphic tools, have enabled the delineation of limits and provided valuable insights into the changing paleoenvironmental conditions and ecological dynamics that unfolded within each section, contributing to a comprehensive understanding of the geological history in this region. (Figure. 56)

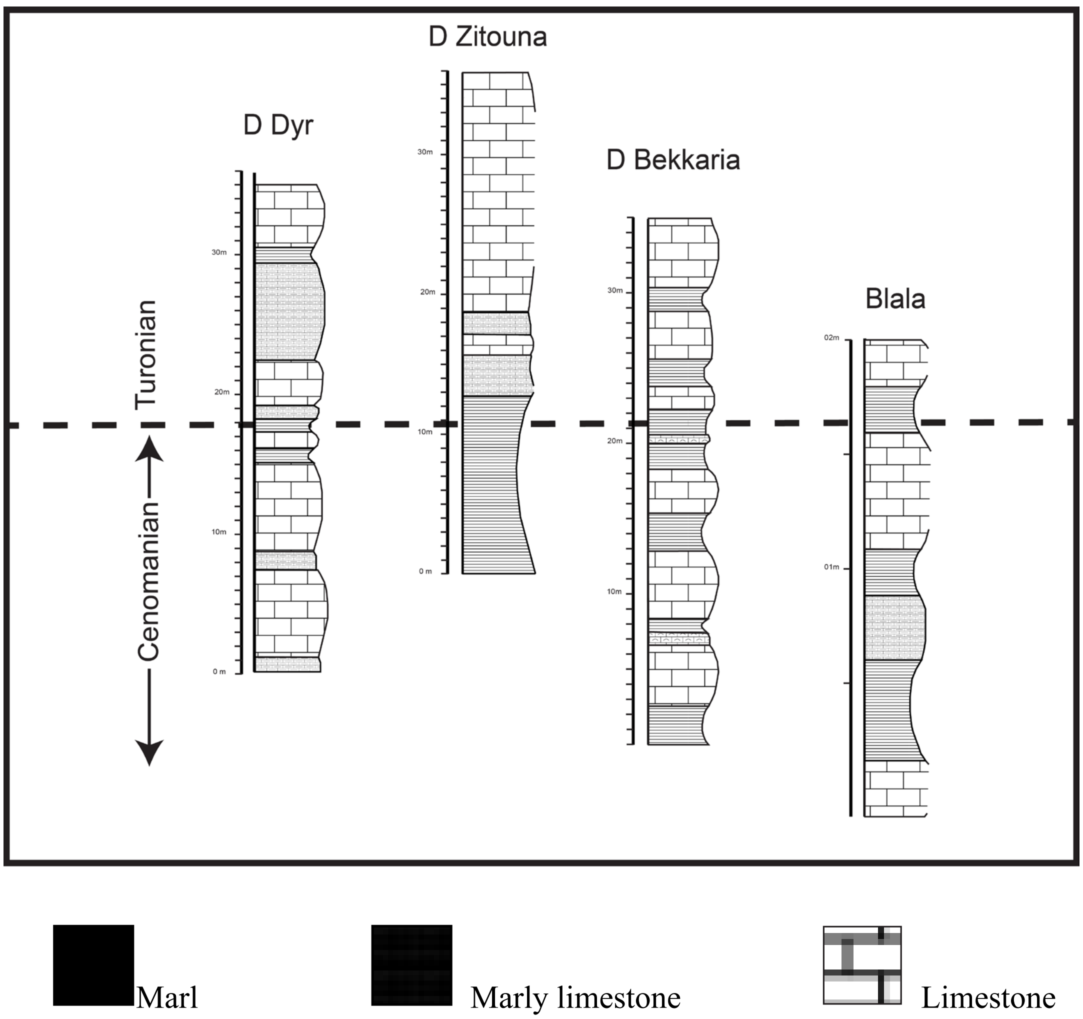


Figure. 56: biostratigraphy Section correlations

Conclusion

Studying the Geodynamical Frame and Cretaceous Anoxic Events in the Tébessa region, the conclusion of this chapter on Biostratigraphy and Paleoenvironnementis of utmost importance. It provides a pivotal summary of the findings and their implications for understanding the geological history and environmental dynamics in this critical area.

In the pursuit of our study, we ventured into the heart of the Cretaceous period, exploring four distinct sections: Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana, and Djebel Boulhaf Dir. These sections, each bearing a unique geological fingerprint, have unveiled invaluable insights into the past paleoenvironments and their transformation over time.

Djebel Zitouna, a mountain located near the Tunisian border, unveiled the presence of a diverse range of paleoenvironments, varying from nearshore to deep marine settings. Microscopic organisms, such as planktonic foraminifera, Keeled foraminifera, and ostracods, played a critical role in categorizing these paleoenvironmental groups. This dynamic range underscores the complex interplay of local factors, such as tectonics and sea level fluctuations, that have shaped this landscape.

Our journey then led us to Djebel Bekkaria, revealing distinct parts reflecting different ages and environmental conditions. The presence of specific ostracods and foraminifera species provided key evidence of changes within the Late Cenomanian to Early Turonian setting. The richness of microfossils allowed us to decipher the complex puzzle of coexisting microorganisms in this region.

Blala Oued Meskiana, located in the district of Blala, gifted us with a predominantly open marine environment. The dominance of planktonic foraminifera in the microfossil assemblages was indicative of a consistent marine environment, while variations in Keeled foraminifera percentages offered glimpses into subtle environmental changes.

Finally, our exploration reached Djebel Boulhaf Dir, characterized by its deep marine paleoenvironnementduring the Cenomanian-Turonian period. Planktonic foraminifera dominated, underscoring a well-oxygenated marine setting, free from the influence of shallow waters. The consistent microfossil content across all samples reaffirmed a chronological span, providing a consistent snapshot of the past.

As we weave these findings together, it is evident that the Tébessa region has played host to a diverse array of paleoenvironments, each carefully documented through biostratigraphy. This microfossil-based approach has enabled us to pinpoint specific geological boundaries, confirm the ages of rock sequences, and gain a comprehensive understanding of the changing environmental conditions and ecological dynamics that unfolded within these sections.

In conclusion, this chapter underscores the dynamic nature of the Cretaceous paleoenvironments in the Tébessa region, intricately linked to the geodynamical frame. The variations in paleoenvironments are a testament to the ever-changing landscape of Earth, influenced by factors such as tectonics, sea level changes, sedimentary basin evolution, climate, and local geological structures. These findings illuminate the complex geological history of the Tébessa region and provide a solid foundation for our overarching thesis on Geodynamical Frame and Cretaceous Anoxic Events. They highlight the importance of understanding past environmental changes, which, in turn, inform our knowledge of Earth's geological processes and patterns.

General Conclusion

The journey through the comprehensive study titled "Geodynamical Frame and Cretaceous Anoxic Events: Study Area Tébessa" has taken us deep into the heart of Earth's geological history and the enigmatic Middle Cretaceous period. This thesis comprises multiple chapters, each contributing essential pieces to the puzzle of the past.

In Chapter 01, the foundation was set for our investigation into the geodynamic and paleoenvironmental aspects of the Middle Cretaceous in Algeria's Tebessa region. The significance of this geological epoch, marked by its unique climate and the enigmatic Oceanic Anoxic Event 2 (OAE2), was highlighted. Insights into lithological, biological, and chemostratigraphic changes resulting from the global transgression were offered. The Tebessa region, nestled within the Saharan Atlas, was introduced as our geological canvas. The chapter framed our research within the geographical context and shed light on the northern part of Algeria within the Maghreb region. The rich literature review on the study area provided a historical backdrop for our research. Chapter 01 set the stage for further exploration of the geological and paleoenvironmental history of this region, unveiling the secrets of the Middle Cretaceous through the microscopic worlds of foraminifera and ostracods.

In Chapter II, an exhaustive exploration of geological, paleontological, and stratigraphic history was conducted through meticulous fieldwork and advanced laboratory methods. Field methods played a pivotal role in our study, systematically collecting marl samples and assembling a valuable collection of ammonites and bivalves. Laboratory methods included innovative approaches for the treatment and analysis of marl specimens, revolutionizing our understanding of sedimentary deposits. The chapter showcased the multi-disciplinary nature of our research and its significant contribution to the broader understanding.

Chapter III delved into the microscopic world of ostracods, tiny time capsules that hold a key to the Earth's past. These crustaceans, found in both marine and non-marine environments, serve as valuable indicators in various scientific disciplines, including paleontology, limnology, and molecular biology. With over 65,000 known living and fossil species, their diversity provides a wealth of data for researchers. The chapter illuminated the significance of ostracods in understanding metazoan evolution, sexual development, and their application in modern scientific research.

In Chapter IV, we navigated the intricacies of constraint optimization, a vital tool for gaining deeper insights into the ancient marine life and the Cretaceous Age. Our explorations in biostratigraphy and biozones revealed the origins and techniques in this field. We ventured into chronostratigraphy and time-lines, exploring the challenges of dating fossils from different eras. Graphic correlation was examined as a better solution, and the complexities of constraint optimization were unveiled, offering a powerful method for understanding the past's temporal and spatial puzzles.

Chapter V, focusing on biostratigraphy and paleoenvironment, provided an essential summary of our journey through the Cretaceous period in the Tébessa region. The unique paleoenvironments of Djebel Zitouna, Djebel Bekkaria, Blala Oued Meskiana, and Djebel Boulhaf Dir were explored through microfossils, offering insights into the dynamic interplay of local factors that shaped this landscape. The chapter underscored the importance of biostratigraphy in pinpointing geological boundaries, confirming rock sequence ages, and comprehending changing environmental conditions and ecological dynamics.

In conclusion, this multi-chaptered thesis has unveiled the secrets of the Middle Cretaceous period, taking us on a journey through time, from the microscopic worlds of ancient marine life to the intricacies of geological processes. These chapters collectively contribute to our understanding of Earth's geological history, the impact of environmental changes, and the significance of regions like Tébessa within the broader context of our planet's evolution. This comprehensive study serves as a testament to the importance of interdisciplinary research, where geology, paleontology, and various scientific disciplines converge to paint a vivid portrait of Earth's past, enriching our understanding of the world we inhabit today.

Recommendations

1. Continued Research: Encourage further research into the Tebessa region's geological and paleoenvironmental history. Suggest that future studies build upon the foundation you've laid to gain a more comprehensive understanding of this area's past.

2. Cross-Disciplinary Collaboration: Promote collaboration among researchers from diverse fields, including geology, paleontology, microbiology, and geochemistry. The multidisciplinary approach has been valuable in the research and can continue to yield meaningful insights.

3. Advanced Analytical Techniques: Recommend the incorporation of cutting-edge laboratory techniques and methodologies to enhance the precision and scope of research. Stay updated on innovations in sedimentological analysis, fossil extraction, and mineralogical identification.

4. Regional and Global Context: Encourage researchers to place their findings within the broader context of regional and global geological and paleoenvironmental histories. This will help identify connections and patterns across different areas.

5. Data Sharing and Repositories: Suggest the creation of centralized data repositories to store research findings and data for future reference. Open-access data sharing can foster collaboration and accelerate scientific progress.

6. Outreach and Education: Promote the dissemination of research findings to the public and within educational institutions. Raise awareness about the importance of geological and paleontological studies, and inspire the next generation of scientists.

7. Environmental Conservation: Recognize the need to assess how current environmental changes may mirror or differ from those in the past. Advocate for the application of historical data to inform modern conservation efforts and sustainable practices.

8. Conservation of Fossil Sites: Stress the significance of preserving fossil-rich sites in the Tebessa region and the need for local and national authorities to protect these areas from potential destruction due to urbanization or resource extraction.

9. International Collaboration: Highlight the potential benefits of international collaboration in studying regions with shared geological and paleoenvironmental histories. Collaboration with neighboring countries can provide a broader understanding of the geological past.

10. Societal Impact: Emphasize the practical implications of this research on society, such as understanding geological processes, predicting environmental changes, and making informed decisions regarding land use and resource management.

11. Address Limitations: Acknowledge any limitations or challenges encountered during this research and encourage future researchers to find innovative solutions to overcome these obstacles.

12. Continuous Monitoring: Suggest the importance of continuous monitoring of geological and environmental changes in the Tebessa region. This ongoing research can provide valuable insights into the area's dynamic history.

13. Document Indigenous Knowledge: Explore the possibility of collaborating with local communities to document indigenous knowledge about the geological and environmental history of the Tebessa region, which could complement scientific research.

14. Interdisciplinary Training: Advocate for the inclusion of interdisciplinary training in geology and paleontology programs, enabling future researchers to engage effectively in cross-disciplinary research.

15. Policy Impact: Encourage engagement with policymakers and government authorities to ensure that the findings from my research inform policies related to land use, environmental conservation, and geological heritage protection.

These recommendations will help guide future research and ensure that the knowledge gained from the thesis continues to contribute to our understanding of Earth's geological history and environmental dynamics.

Plates

PLATES

Plate 01

1. *Paracypris mdaouerensis,* Left Valve, Zitouna, Bekkaria Sections
2. *Dolocytheridea atlasica,* Left Valve, Zitouna, Bekkaria Sections
3. *Cytherella granulosa*, Right Valve, Zitouna Section
4. *Bythoceratina tamare*, Left Valve, Zitouna Section
5. *Bythoceratina tamare*, Dorsal View, Zitouna Section
6. *Metacytheropteron berbericus*, Dorsal View, Zitouna Section, Bekkaria sections
7. *Aracajuia distincta*, Left Valve, Zitouna Section
8. *Cytherella sp*, Right Valve, Zitouna section
9. *Metacytheropteron berbericus*, Right Valve , Zitouna Section, Bekkaria sections
10. *Sapucariella adunca*, Left Valve, Blala Section

12\. *Bairidia sp* , Left Valve, Zitouna Section

13\. *Metacytheropteron berbericus*, Left Valve , Zitouna, Bekkaria Sections

14\. *Cytherella ovata*, Right Valave, all Sections

15\. *Bythocypris sp*, Dorsal View, Zitouna Section

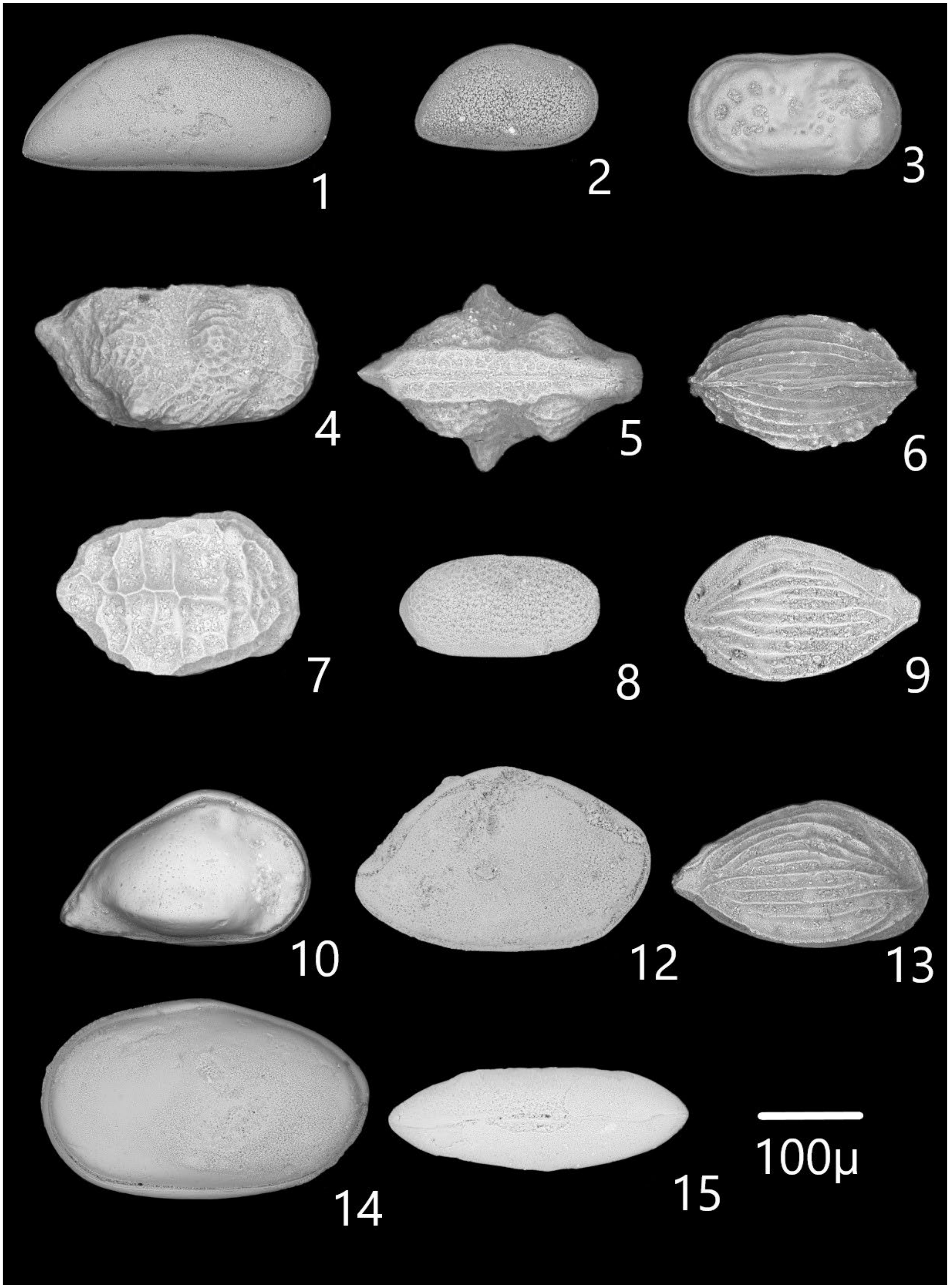

1
2
3
4
5
6
7
8
9
10
12
13
14
15
100µ

Plate 02

01 *Cythereis sp* , Right Valve, Zitouna section

02. *Parexophthalmocythere rhombusa*, Right Valve, Zitouna section

03. *Veeniacythereis maghrebensis,* Ventral View, Zitouna, Bekkaria Sections

04. *Cythereis algeriana,* Right Valve, Zitouna, Bekkaria sections

05. *Cythereis namousensis,* Left Valve, Zitouna Section.

06. *Reticulocosta tarfayansis,* Left Valve, Zitouna, Bekkaria Sections

07. *Veeniacythereis maghrebensis,* Right Valve, , Zitouna, Bekkaria Sections

08. *Veeniacythereis jezzineensis*, Interior Right Valve

09. *Veeniacythereis jezzineensis*, Ventral View, Zitouna, Bekkaria Sections

10. *Reticulocosta tarfayansis,* Left Valve, Bekkaria, Zitouna Sections

11. *Glenocythere triangularis*, Left Valve, Bekkaria

12. *Pelpriops sp,* Left Valve, Zitouna Section

13. *Pelpriops sp,* Left Valve, Zitouna Section

14. *Pelpriops sp*, Right Valve, Zitouna Section

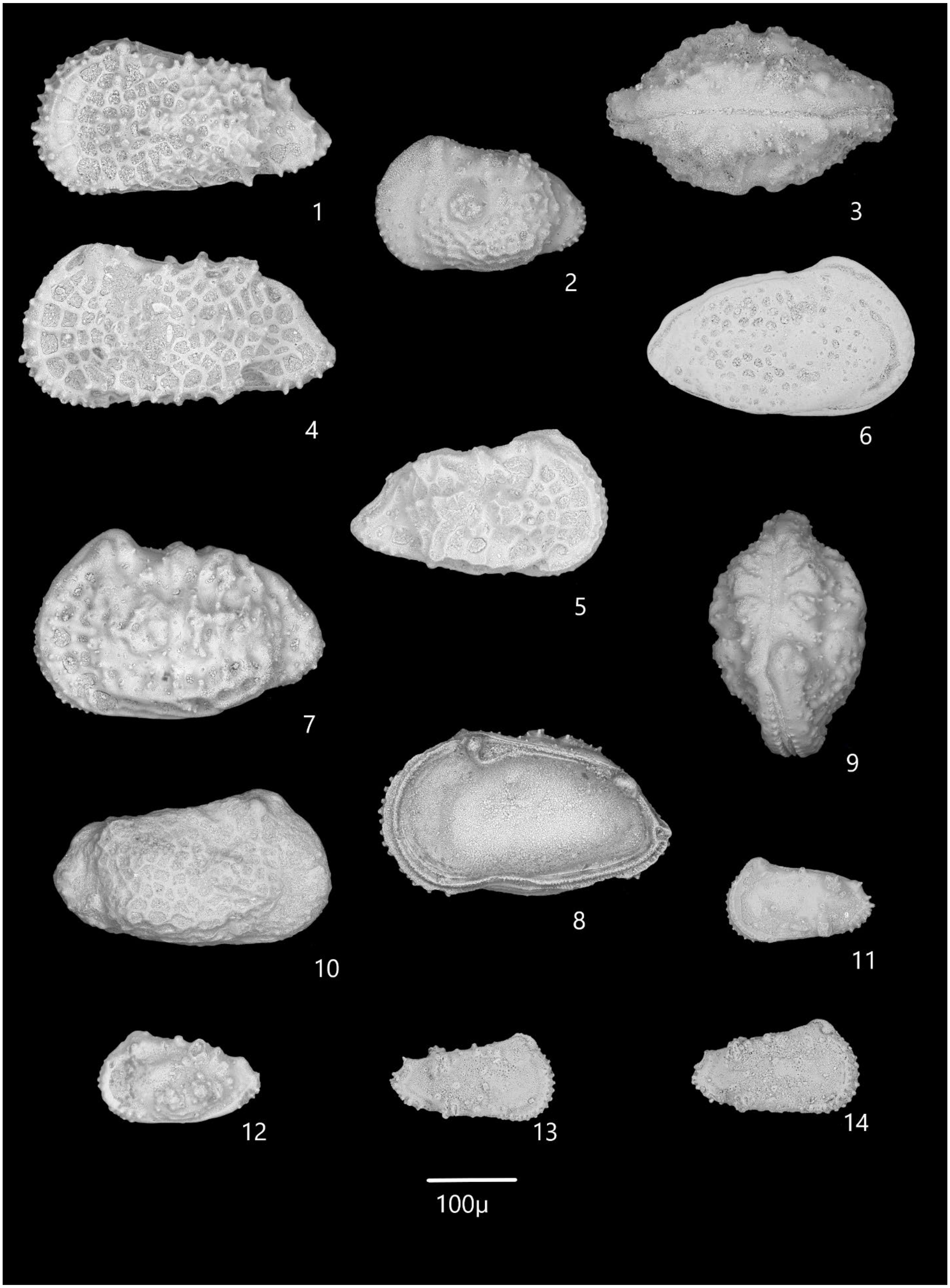

1
3
2
4
6
5
7
9
8
10
11
12
13
14
100µ

Plate 03:

01. *Rotalipora cushmani*, Spiral View, Zitouna Section
02. *Rotalipora Cushmani ,* umbilical view, Zitouna Section
03. *Heterohelix Heterohelix globulosa,* Spiral View, All Sections.
04. *Whiteinella archaeocretacea,* Spiral View, All sections.
05. *Whiteinella archaeocretacea,* Spiral View, All sections.
06. *Heterohelix sp,* , All Sections.
07. *Muricohedbergella sp*, Spiral View, All sections.
08. *Whiteinella baltica,* Spiral View, All Sections
09. *Dicarinella sp,* Spiral View, All Sections
10. *Anaticinella multiloculate,* Spiral View, All Sections.
11. *Whiteinella sp,* Spiral View,Blala Section.
12. *Whiteinella baltica,* Spiral View, All Sections
13. *Heterohelix globulosa,* , All Sections.

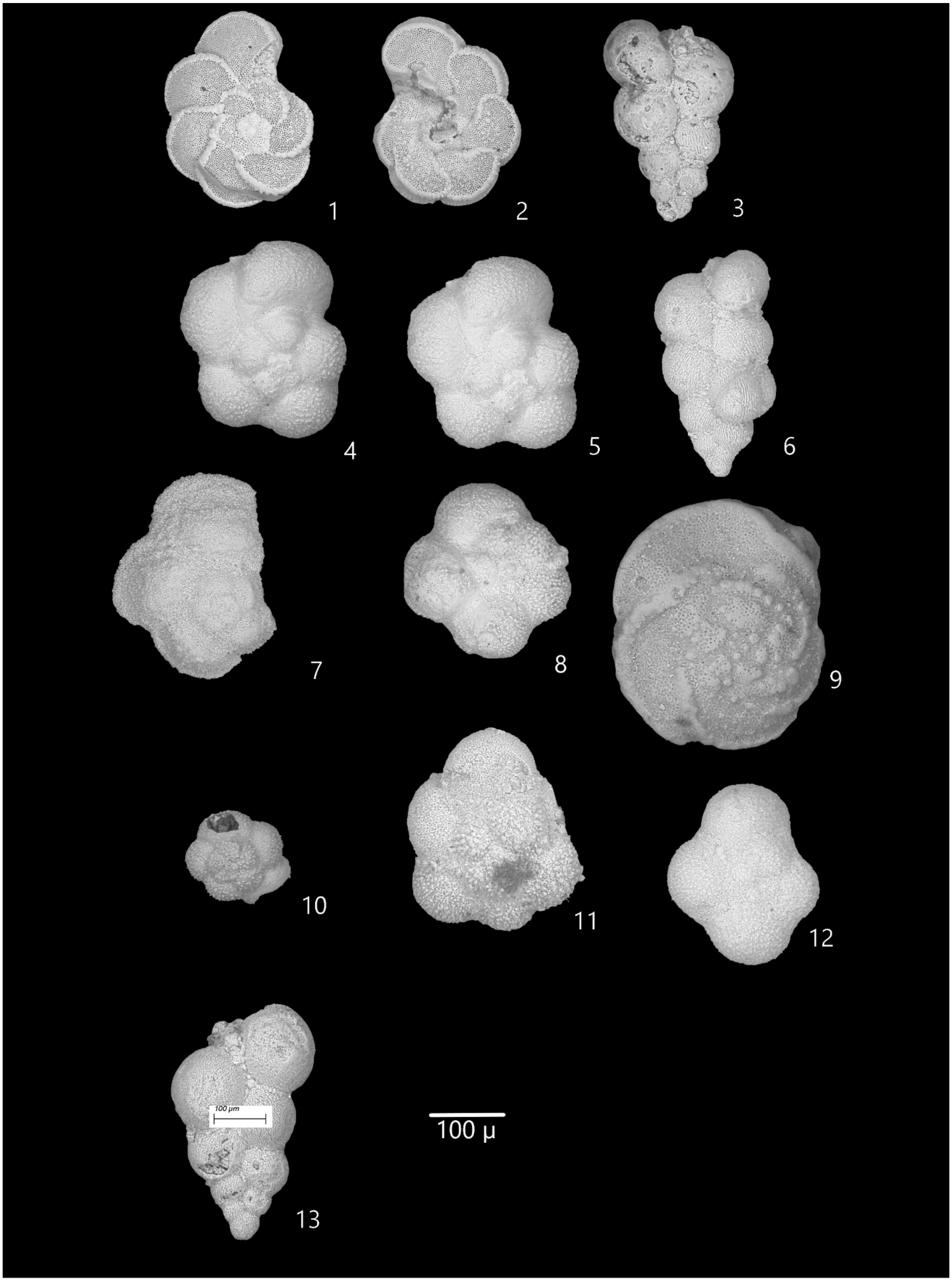

1
2
3
4
5
6
7
8
9
10
11
12
13
100 µm
100 µ

Plate 03

01 Mudstone

02 Wakestone with foraminifera

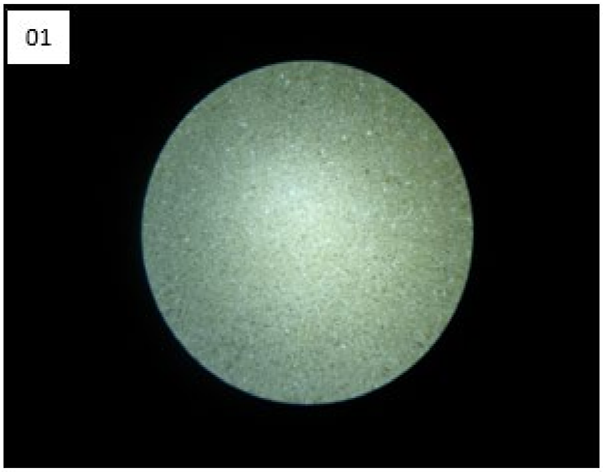
03 Wakestone with foraminifera

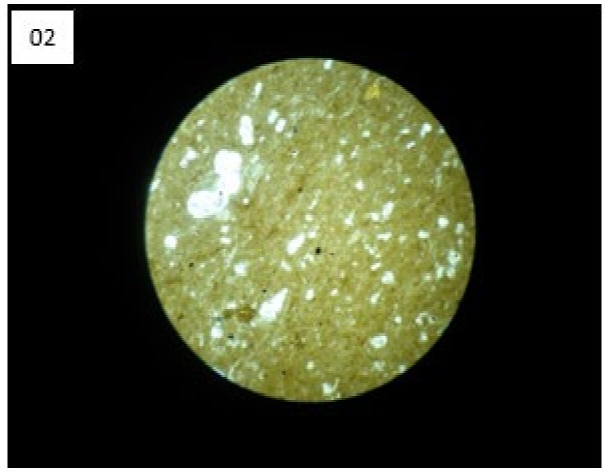
04 Wakstone with foraminifera

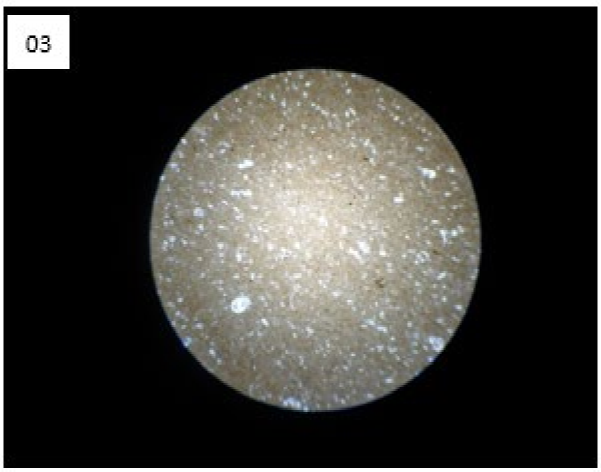
05 Mudstone a wakestone with oxidation

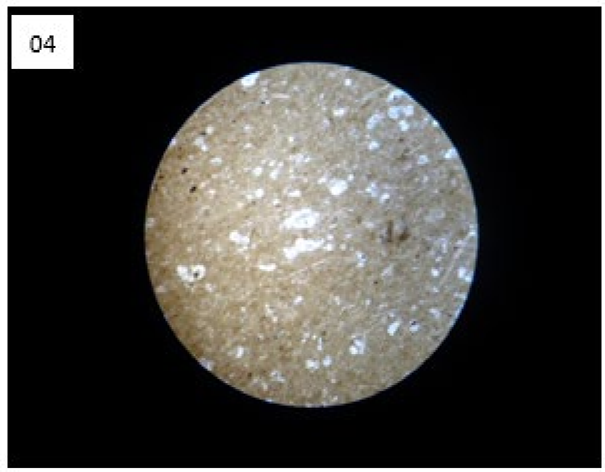
06 Wakestone with foraminifera

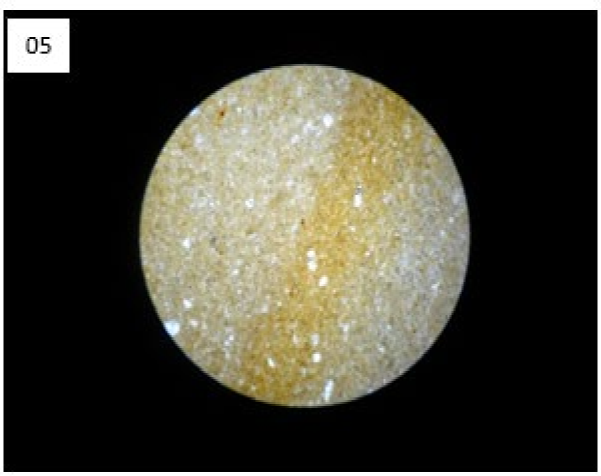
PLATES

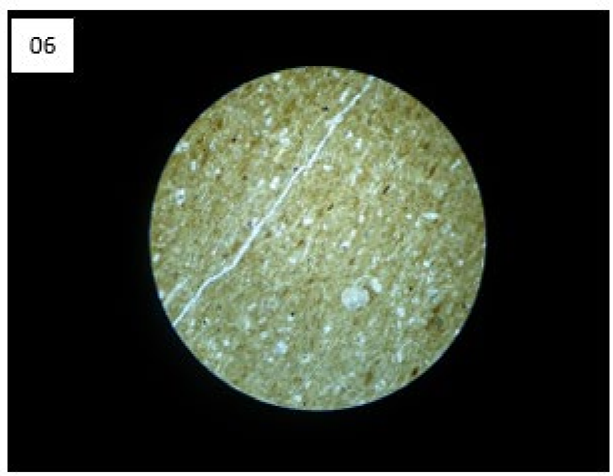












PLATES

Plate 05

07 Wakestone with foraminifera

08 Wakestone with foraminifera

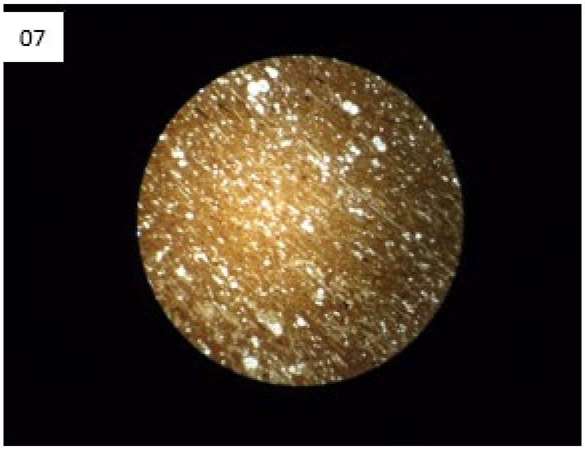
09 Grainstone

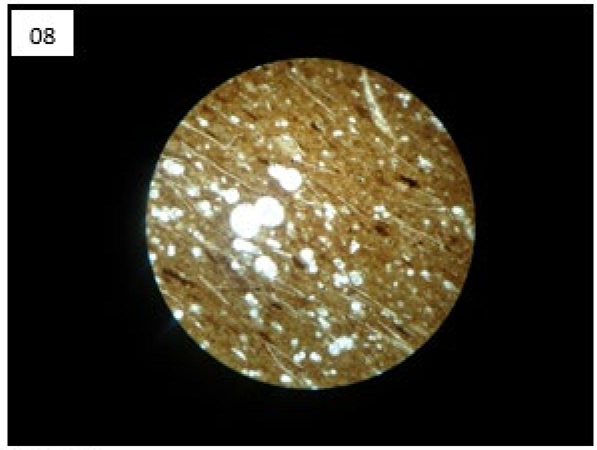
10 Grainstone with microfossil

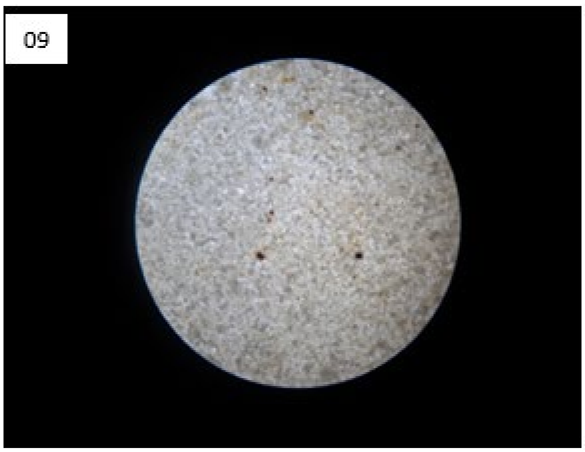
11 Wackestone with foraminifera

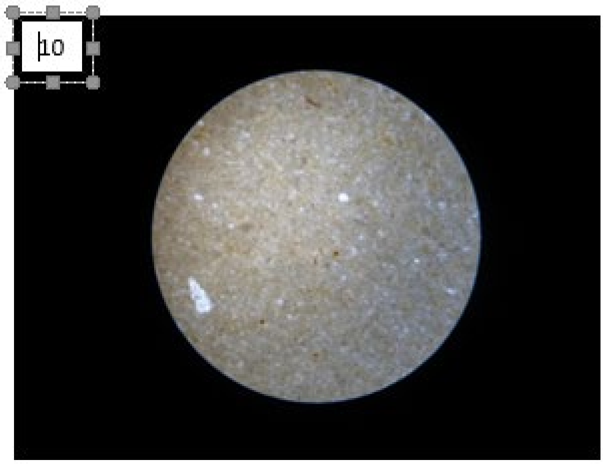
12 Wakestone with foraminifera

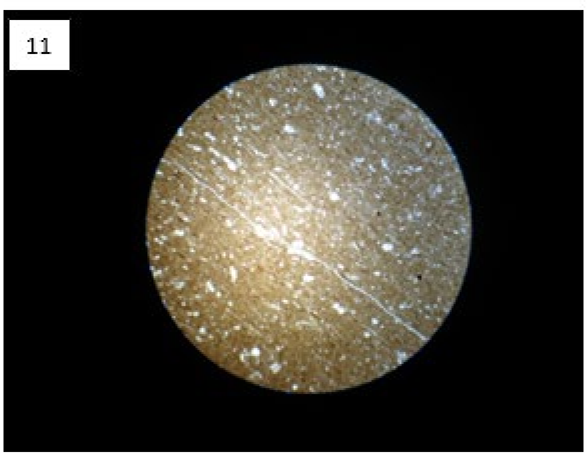
PLATES

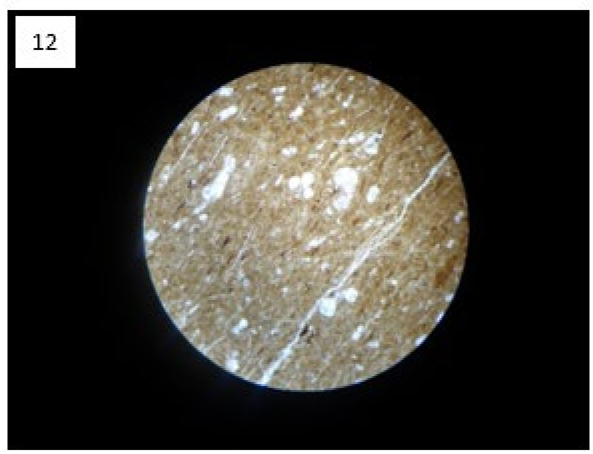












References

REFERENCES

Accarie H., Emmanuel L., Robaszynski F., Baudin F., Amedro F., Caron M. & Deconinck J.F., 1996 - La Géochimie Isotopique Du Carbone (Δ13c) Comme Outil Stratigraphique. Application A La Limite Cénomanien–Turonien En Tunisie Centrale. Comptes Rendus De L'académie Des Sciences De Paris (2a) 322, P.579–586.

Accarie H., Robaszynski F., Amedro F., Caron M. & Zagrarni M.F., 2000 - Stratigraphie Evénementielle Au Passage Cénomanien–Turonien Dans Le Secteur Occidental De La Plate-Forme De Tunisie Centrale (Formation Bahloul, Région De Kalaat Senan). Annales Des Mines Et De La Géologie, Tunisie 40, P.63–80.

Agterberg, F. P. 1990. Automated Stratigraphic Correlation. Developments In Palaeontology And Stratigraphy, 13:1-424.

Agterberg, F. P., And Gradstein, F. M. 1999. The Rasc Method For Ranking And Scaling Of Biostratigraphic Events. Earth Science Reviews, 46:1-25.

Agterberg, F. P., And Nel, L. D. 1982. Algorithms For The Ranking Of Stratigraphic Events. Computers And Geosciences, 8:69-90.

Allen, P. E., & Dodson, S. I. (2011). Land Use And Ostracod Community Structure. Hydrobiologia, 668(1), 203-219.

Alroy, J. 1992. Conjunction Among Taxonomic Distributions And The Miocene Mammalian Biochronology Of The Great Plains, Paleobiology, 18:326-43.

Alroy, J. 1994. Appearance Event Ordination: A New Biochronological Method. Paleobiology, 20:191-207.

Alroy, J. 2000. New Methods For Quantifying Macroevolutionary Patterns And Processes. Paleobiology, 26:707-33.

Amard.B., Collignon.M. Et Roman.J., 1981. Etude Stratigraphique Et Paléontologique Du Crétacé Supérieur Et Paléocène Du Tinrhert-W Et Tadmaït-E (Sahara Algérien).Doc. Lab. Géol. Lyon, H.S. 6, P.15-173, 19 Fig., 8 Tabl., 17pl.

Amedro F. & Robaszynski F., 2008 - Zones D'ammonites Et De Foraminifères Du Vraconnien Au Turonien : Une Comparaison Entre Les Domaines Boréal Et Téthysien (Nw Europe /

Tunisie Centrale). Carnets De Géologie / Notebooks On Geology, Brest, Note Brève 2008/02-Fr (Cg2008_L02 (Fr)).

Anado´N, P., Gliozzi, E. & Mazzini, I., 2002. Paleoenvironmental Reconstruction Of Marginal Marine Environments From Combined Paleoecological And Geochemical Analyses On Ostracods. In: Holmes, J.A. & Chivas, A.R. (Eds), The Ostracoda: Applications In Quaternary Research, Agu Geophysical Monograph 131, 227–247.

Angel, M. V., & Iliffe, T. M. (1987). Spelaeoecia Bermudensis, New Genus, New Species, A Halocyprid Ostracod From Marine Caves In Bermuda. *Journal Of Crustacean Biology*, *7*(3), 541-553.

Arthur M.A. & Schlanger S.O., 1979 - Cretaceous Oceanic Anoxic Events As Causal Factors In Development Of Reef-Reservoired Giant Oil Fields. American Association Of Petroleum Geologists Bulletin 63, P.870-885.

Arthur M.A., Dean W.E. & Pratt L.M., 1988 - Geochemical And Climatic Effects Of Increased Marine Organic Carbon Burial At The Cenomanian/Turonian Boundary. Nature 335, P.714–717.

Arthur.M.A., Schlanger.S.O And Jenkyns.H.C., 1987. The Cénomanian-Turonian Oceanic Event, Ii. Palaeoceanographic Controls On Organic-Matter Production And Preservation: In Brooks, J. Fleet, A.J (Eds) 1987, Marine Petroleum Source Rocks Geological Society Special Publication. N. 26, Pp. 401-420.

Athersuch, J., Horne, D. J., & Whittaker, J. E. (1989). Marine And Brackish Water Ostracods (Superfamilies Cypridacea And Cytheracea): Keys And Notes For The Identification Of The Species (Vol. 43). Brill Archive.

Aubry, M.-P., 1995. From Chronology To Stratigraphy: Interpreting The Lower And Middle Eocene Stratigraphic Record In The Atlantic Ocean, Sepm Special Publication, 54, 213-274.

Baadsgaard, H., Lerbekmo, J. F., Wijbrans, J. R., Swisher, C. C., And Fanning, M. 1993. Multi-Method Radiometric Age For A Bentonite Near The Top Of The Baculites Reesidei Zone Of Southwestern Saskatchewan (Campanian-Maastrichtian Stage Boundary?), Canadian Journal Of Earth Science, 30:769- 775.

REFERENCES

Baird, W., 1850. The Natural History Of The British Entomostraca. I–Viii, 1–364. The Ray Society, London Balasubramanian, A. (2017). 150 Branches Of Geology (Earth Science). Department Of Studies In Earth Science, University Of Mysore, Mysore-6, 1-47.

Bassetti, M. A., Carbonel, P., Sierro, F. J., Perez-Folgado, M., Jouët, G., & Berné, S. (2010). Response Of Ostracods To Abrupt Climate Changes In The Western Mediterranean (Gulf Of Lions) During The Last 30 Kyr. Marine Micropaleontology, 77(1-2), 1-14.

Bassler, R. S., & Kellett, B. (1934). Bibliographic Index Of Paleozoic Ostracoda (Vol. 1). Geological Society Of America.

Bekhouch, G., Puckett, T. M., Khiari, A., Djerrab, M. R., Meguelatti, A., & Dinar, H. (2023). Optimized Event Stratigraphy Of Cenomanian-Turonian Ostracods Of North Africa And The Middle East. Journal Of African Earth Sciences, 105061.

Bellier J.P., 1983 – Foraminifères Planctoniques Du Crétacé De Tunisie Septentrionale : Systématique, Biozonation, Utilisation Stratigraphique De L'albien Au Maastrichtien. Mem. Sc. Terre Univ. Curie, Paris, 250 P.

Bencharef, M. H., Boubaya, D., Aboud, E., & Ayfer, S. (2022). Role Of An Advanced Gravity Data Analysis In Improving The Geologic Understanding Of The Northern Tebessa Region, Northeastern Algeria. Journal Of African Earth Sciences, 196, 104693.

Benkherouf. F., 1987. Microbiostratigraphie Et Paléoenvironnement Ds Marnes Cénomaniennes Du Dj. Dyr (Tébessa, Algérie). Rev. Micropaléontologie, Vol. 30, N°2, Pp.69-78.

Benkherouf. F., 1988. Les Foraminifères Cénomaniens Des Alpes-Maritimes (Sud-Est) Et Du Djebel Boulhaf Dir (Ne Algérie) : Biostratigraphie Et Paléo-Environnements. Thèse Doct. Univ. Nice .N°9. Pp173.

Bennett, K. D. (1997). Evolution And Ecology: The Pace Of Life. Cambridge University Press.

Benson, R. H. (1975). The Origin Of The Psychrosphere As Recorded In Changes Of Deep-Sea Ostracode Assemblages. Lethaia, 8(1), 69-83.

Birks, H. H., & Birks, H. J. B. (2006). Multi-Proxy Studies In Palaeolimnology. Vegetation History And Archaeobotany, 15, 235-251.

REFERENCES

Birks, H. J. B., Heiri, O., Seppä, H., & Bjune, A. E. (2010). Strengths And Weaknesses Of Quantitative Climate Reconstructions Based On Late-Quaternary. The Open Ecology Journal, 3(1).

Bismuth H., Boltenhagen C., Donze P., Le Fevre J. & Saint-Marc P., 1981 – Le Crétacé Moyen Et Supérieur Du Djebel Semmama (Tunisie Du Centre-Nord) : Microstratigraphie Et Évolution Sédimentologique. Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine, 5, 2, P.193-267.

Blackham, M. 1998. The Unitary Association Method Of Relative Dating And Its Application To Archaeological Data. Journal Of Archaeological Method And Theory, 5:165-207.

Boomer, I. & Eisenhauer, G., 2002. Ostracod Faunas As Palaeoenvironmental Indicators In Marginal Marine Environments. In: Holmes, J. A. & Chivas, A.R. (Eds), The Ostracoda: Applications In Quaternary Research, Agu Geophysical Monograph 131, 135–149

Boomer, I., Horne, D. J., & Slipper, I. J. (2003). The Use Of Ostracods In Palaeoenvironmental Studies, Or What Can You Do With An Ostracod Shell?. The Paleontological Society Papers, 9, 153-180.

Börner, N., De Baere, B., Yang, Q., Jochum, K. P., Frenzel, P., Andreae, M. O., & Schwalb, A. (2013). Ostracod Shell Chemistry As Proxy For Paleoenvironmental Change. Quaternary International, 313, 17-37.

Brady, G. S. (1868). A Monograph Of The Recent British Ostracoda (Vol. 26). Taylor & Francis.

Brady, G. S. (1889). A Monograph Of The Marine And Freshwater Ostracoda Of The North Atlantic And Of North-Western Europe: Podocopa (Vol. 4).

Brady, G.S. & Norman, A.M., 1889. A Monograph Of The Marine And Freshwater Ostracoda Of The North Atlantic And Of North-Western Europe. Section 1. Podocopa. Scientific Transactions Of The Royal Dublin Society 4 (Series Ii), 63–270.

Brady, G.S. & Norman, A.M., 1896. A Monograph Of The Marine And Freshwater Ostracoda Of The North Atlantic And Of North-Western Europe. Part Ii. Sections Ii–Iv, Myodocopa, Cladocopa And Platycopa. Scientific Transactions Of The Royal Dublin Society 5 (Series Ii), 621–746.

REFERENCES

Brady, G.S., 1868. A Monograph Of The Recent British Ostracoda. Transactions Of The Linnean Society Of London 26, 353–495.

Brady, G.S., 1880. Report On The Ostracoda Dredged By H. M. S. Challenger During The Years 1873–1876. Reports Of The Scientific Results Of The Voyage Of H.M.S. Challenger, Zoology 1, Part Iii, 1–184.

Brady, G.S., Crosskey, H.W. & Robertson, D., 1874. A Monograph Of The Post-Tertiary Entomostraca Of Scotland Including Species From England And Ireland. Palaeontological Society, Monographs, 1–274.

Bralower T. J., Cobabe E., Clement B., Sliter W.V., Osburn C.L. & Longoria J., 1999 - The Record Of Global Change In Mid-Cretaceous (Barremian- Albian) Sections From The Sierra Madre, Northeastern Mexico, J. Foraminiferal Res., 29, P.418–437.

Bralower T.J. & Thierstein H.R., 1984 - Low Productivity And Slow Deep-Water Circulation In Mid-Cretaceous Oceans. Geology 12, P.614-618.

Broodbakker, N.W., & Danielopol, D.L. (1982). The Chaetotaxy Of Cypridacea (Crustacea, Ostrocoda) Limbs: Proposals For A Descriptive Model. Bijdragen Tot De Dierkunde , 52 (2), 103-120.

Burge, D. R., Edlund, M. B., & Frisch, D. (2018). Paleolimnology And Resurrection Ecology: The Future Of Reconstructing The Past. Evolutionary Applications, 11(1), 42-59.

Burollet P.F., 1956 – Contribution À L'étude Stratigraphique De La Tunisie Centrale. Thèse Sc. Alger. Ann. Min. Et Géol. Tunis, N°18, 350 P.

Busson.G., Dhondt.A., Amédro.F., Néraudeau.D Et Cornée.A., 1999. La Grande Transgression Du Cénomanien Supérieur-Turonien Inférieur Sur Le Hamada De Tinrhret (Sahara Algérien) : Datations Biostratigraphiques, Environnements De Dépôt Et Comparaison D'un Témoin Épicratonique Avec Les Séries Contemporaines À Matière Organique Du Maghreb. Cretaceous Research. 20, 29-46

Butlin, R. K., & Menozzi, P. (2000). Open Questions In Evolutionary Ecology: Do Ostracods Have The Answers?. In Evolutionary Biology And Ecology Of Ostracoda: Theme 3 Of The 13th International Symposium On Ostracoda (Iso97) (Pp. 1-14). Springer Netherlands.

REFERENCES

Cabral, M. C., Colin, J. P., & Azerêdo, A. C. (2008). Taxonomy And Palaeoecology Of New Brackish Ostracod Species From The Middle Cenomanian Of Lousa, Lisbon Region, Portugal. Palaeogeography, Palaeoclimatology, Palaeoecology, 264(3-4), 250-262.

Cannon, H.G., 1925. On The Segmental Excretory Organs Of Certain Freshwater Ostracods. Philosophical Transactions Of The Royal Society Of London, Series B., 214, 1–27.

Cannon, H.G., 1933. On The Feeding Mechanism Of Certain Marine Ostracods. Transactions Of The Royal Society Of Edinburgh 57, 739–764.

Carney, J. L. And Pierce, R. W. 1995. Graphiccorrelation And Composite Standard Databases As Tools For The Exploration Biostratigraphers, P. 23-43. In K. O. Mann, And H. R. Lane (Eds.), Graphic Correlation. Special Publications Of The Society Of Economic Paleontologists And Mineralogists, 53.

Caron M. & Homewood P. 1982 - Evolution Of Early Planktonic Foraminifers. Marine Micropaleontology,7, P. 453-462.

Caron M., 1985 - Cretaceous Planktic Foraminifera. In Bolli Hm, Saunders Jb, Perch Nielsen K (Eds), Plankton Stratigraphy, Cambridge University Press, P.17-86.

Caron M., Dall’agnolo S., Accarie H., Barrera E., Kauffman E.G., Amédro F. & Robaszynski F., 2006 - High-Resolution Stratigraphy Of The Cenomanian-Turonian Boundary Interval At Pueblo (Usa) And Wadi Balhoul (Tunisia): Stable Isotope And Bio-Events Correlation. Geobios, 39, P.171-200.

Caron M., Robaszynski F., Amedro F., Baudin F., Deconinck J.-F., Hochuli P., Von Salis-Perch Nielsen K. & Tribovillard N., 1999 - Estimation De La Durée De L’événement Anoxique Global Au Passage Cénomanien–Turonien. Approche Cyclostratigraphique Dans La Formation Bahloul En Tunisie Centrale. Bulletin De La Société Géologique De France 170, P.145–160.

Chikhi-Aouimeur F., Grosheny D., Ferry S., Herkat M., Jati M., Atrops F., Redjimi-Bourouiba W. & Benkherouf-Kechid F., 2010 – Lithofaciès, Paléogéographie Et Corrélations Au Passage Cénomanien-Turonien Dans L’atlas Saharien (Ouled Naïl, Zibans, Aurès Et Hodna, Algérie). Mém. Serv. Géol. Nat. Algérie, 17, P.67-83.

REFERENCES

Chikhi-Aouimeur. F., 1998. Les Rudistes Du Crétacé Supérieur De L'algérie. Etude Paléontologique. Données Paléoécologiques Biostratigraphiques Et Paléogéographiques. Thèse Sci. Usthb Alger. 198 P.

Chivas, A.R., De Deckker, P., & Shelley, J.M.G. (1987). Magnesium And Strontium In Non-Marine Ostracod Shells As Indicators Of Palaeosalinity And Palaeotemperature. In Paleolimnology Iv: Proceedings Of The Fourth International Symposium On Paleolimnology, Held At Ossiach, Carinthia, Austria (Pp. 135-142). Springer Netherlands.

Claassen, C. (1998). Shells. Cambridge University Press.

Clark, R. M. 1985. A Fortran Program For Constrained Sequence-Slotting Based On Minimum Combined Path Length. Computers And Geoscience, 11:605-17.

Clark, R. M. 1995. Depth-Matching Using Pcslot Version 1.6. Newsletter Of The Inqua Working Group For Data-Handling Methods 13. Http://Kv.Geo.Uu.Se/Inqua/News12/N13-Mc.Htm

Cody, R. D., Levy, R. H., Harwood, D. M., And Sadler, P. M. 2008. Thinking Outside The Zone: High Resolution Quantitative Diatom Biochronology For The Antarctic Neogene. Palaeogeography, Palaeoclimatology, Palaeoecology, 269(1-2):92-121.

Cohen, A. C., & Morin, J. G. (2003). Sexual Morphology, Reproduction And The Evolution Of Bioluminescence In Ostracoda. The Paleontological Society Papers, 9, 37-70.

Cole, G. A., & Weihe, P. E. (2015). Textbook Of Limnology. Waveland Press.

Colin, J.-P. & Lethiers, F., 1988. The Importance Of Ostracods In Biostratigraphic Analysis. In: De Deckker, P., Colin, J.-P. & Peypouquet, J.-P. (Eds), Ostracoda In The Earth Sciences, Elsevier, 27–45

Cooper, R. A., And Sadler, P. M. 2004. The Ordovician Period, P. 165-187 In F. Gradstein, J. Ogg And A. Smith (Eds.) A Geologic Time Scale 2004.

Cooper, R.A., Crampton, J. S., Raine, J.I., Gradstein, F. M., Morgans, H. E. G., Et Al. 2001. Quantitative Biostratigraphy Of The Taranaki Basin, New Zealand: A Deterministic And Probabilistic Approach. American Association Of Petroleum Geologists Bulletin, 85:1469-98.

REFERENCES

Copper, P. (1992). Paleoscene 14. Organisms And Carbonate Substrates In Marine Environments. Geoscience Canada.

Corrège, T. (1993). The Relationship Between Water Masses And Benthic Ostracod Assemblages In The Western Coral Sea, Southwest Pacific. Palaeogeography, Palaeoclimatology, Palaeoecology, 105(3-4), 245-266.

Costello, M. J., & Chaudhary, C. (2017). Marine Biodiversity, Biogeography, Deep-Sea Gradients, And Conservation. Current Biology, 27(11), R511-R527.

Crame, J. A., Francis, J. E., Cantril, D. J., And Pirrie, D. 2004. Maastrichtian Stratigraphy Of Antarctica. Cretaceous Research, 25:411-423

Cristescu, M. E., Adamowicz, S. J., Vaillant, J. J., & Haffner, D. G. (2010). Ancient Lakes Revisited: From The Ecology To The Genetics Of Speciation. Molecular Ecology, 19(22), 4837-4851.

Cronin, T. M. (1999). Principles Of Paleoclimatology. Columbia University Press.

Cronin, T. M., Demartino, D. M., Dwyer, G. S., & Rodriguez-Lazaro, J. (1999). Deep-Sea Ostracode Species Diversity: Response To Late Quaternary Climate Change. Marine Micropaleontology, 37(3-4), 231-249.

Cronin, T., Dwyer, G., Baker, P.A., Rodriguez Lazaro, J. & Demartino, D.M., 2000. Orbital And Suborbital Variability In North Atlantic Bottom Water Temperature Obtained From Deep-Sea Ostracode Mg/Ca Ratios. Palaeogeography, Palaeoclimatology, Palaeoecology 162, 45–57.

Cronin, T.M. & Raymo, M.E., 1997. Orbital Forcing Of Deep-Sea Benthic Species Diversity. Nature 385, 624–627.

Cuvier, G., And Brongniart, A. 1808. Essai Sur La Géographie Minéralogique Des Environs De Paris. Annales Du Musée Histoire Naturelle De Paris, 11:293- 326.

Czajkowska, M. (2022). High-Resolution Environmental Changes Recorded In Ostracod And Mollusc Fauna From The Holsteinian Palaeolake At Ortel Królewski Ii, Eastern Poland. Boreas, 51(4), 793-809.

REFERENCES

D'orbigny, A. 1851. Cours Elementaires De Paleontologie Et De Geologie Stratigraphiques. Masson, Paris, 382 P.

Danielopol, D. L. (1989). Groundwater Fauna Associated With Riverine Aquifers. Journal Of The North American Benthological Society, 8(1), 18-35.

Danielopol, D. L., Ito, E., Wansard, G., Kamiya, T., Cronin, T. M., & Baltanás, A. (2002). Techniques For Collection And Study Of Ostracoda. Geophysical Monograph-American Geophysical Union, 131, 65-98.

Danielopol, D. L., Ito, E., Wansard, G., Kamiya, T., Cronin, T. M., & Baltanás, A. (2002). Techniques For Collection And Study Of Ostracoda. Geophysical Monograph-American Geophysical Union, 131, 65-98.

Darwin, C. 1859. The Origin Of Species. Murray, London, 490 P.

De Deckker, P., & Forester, R. M. (1988). The Use Of Ostracods To Reconstruct Continental Palaeoenvironmental Records. Ostracoda In The Earth Sciences, 175-199.

De Deckker, P., Colin, J.-P. & Peypouquet, J.-P. (Eds), 1988. Ostracoda In The Earth Sciences. Elsevier Science Publishers, Amsterdam, The Netherlands, 302 Pp.

Dell, R. F., Kemple, W. G., And Tovey, C. A. 1992. Heuristically Solving The Stratigraphic Correlation Problem. Proceedings Of The 1st. Industrial Engineering Research Conference, 1:293-97

Delorme, L.D. & Zoltai, S.C., 1984. Distribution Of An Arctic Fauna In Space And Time. Quaternary Research 21, 65–73.

Delorme, L.D. (1969). Ostracodes As Quaternary Paleoecological Indicators. Canadian Journal Of Earth Sciences , 6 (6), 1471-1476.

Didie´, C. & Bauch, H.A., 2000. Implications Of Upper Quaternary Stable Isotopic Records Of Marine Ostracodes And Benthic Foraminifers For Paleoecological And Paleoceanographical Investigations. In: Holmes, J.A. & Chivas, A.R. (Eds), The Ostracoda: Applications In Quaternary Research, Agu Geophysical Monograph 131, 279–300.

Djerrab-Ruault.M., (2008), Conducted A Biostratigraphic And Paleoenvironmental Study Of The Hammimat, Focusing On The Example Of The Djebel Chemla Section In Tébessa

REFERENCES

Dole-Olivier, M. J., Galassi, D. M. P., Marmonier, P., & Creuzé Des Châtelliers, M. (2000). The Biology And Ecology Of Lotic Microcrustaceans. Freshwater Biology, 44(1), 63-91.

Dubordieu.G., 1956. Etude Géologique De La Région De L'ouenza (Confins Algéro-Tunisiens). Pull. Serv. Carte. Géol.Algérie,N°10.659p.

Dubourdieu G., 1959 – Esquisse Géologique Du Djebel Mesloula. Publications Du Service De La Carte Géologique De L'algérie, Alger, N.S., 21, 162 P.

Dunham R.J., 1962 – Classification In Carbonate Rocks According To Depositional Textures – In : Classification Of Carbonate Rocks – Soc. Econ.Paleont. Mineral., 1, P. 108-121.

Dwyer, G.S., Cronin, T.M., Baker, P.A. & Rodriguez Lazaro, J., 2000. Changes In North Atlantic Deep-Sea Temperature During Climatic Fluctuations Of The Last 25,000 Years Based On Ostracode Mg/Ca Ratios. Geochemistry, Geophysics, Geosystems 1, 17 Pp. 2000gc000046. (Agu Electronic Journal: Http://G-Cubed.Org/).

Edwards, L. E. 1978. Range Charts And No-Space Graphs. Computers And Geosciences, 4:247-255

Edwards, L. E. 1982. Quantitative Biostratigraphy: The Methods Should Suit The Data, P. 45-60. In J. M Cubitt, And R. A. Reyment (Eds.). Quantitative Stratigraphic Correlation, Chichester, Wiley.

Elles, G. L., And Wood, E. M. R. 1907. A Monograph Of British Graptolites. Palaeontographical Society Monograph, 61:1-216.

Elofson, O., 1941. Zur Kenntnis Der Marine Ostracoden Schwedens Mit Besonderer Beru¨Cksichtigung Des Skageraks. Zoologiska Bidrag Fran Uppsala 19, 217–534.

Erba E., 2004 - Calcareous Nannofossils And Mesozoic Oceanic Anoxic Events. Marine Micropaleontology, 52, P.85-106.

Erbacher J., Thurow J. & Littke R., 1996 - Evolution Patterns Of Radiolaria And Organic Matter Variations: A New Approach To Identify Sea-Level Changes In Mid-Cretaceous Pelagic Environments. Geology 24 (6), P. 499–502.

Ettachfini E.M., Souhel A., Andreu B. & Caron M., 2005 – La Limite Cénomanien-Turonien Dans Le Haut Atlas Central, Maroc. Geobios, 38, P.57-68.

REFERENCES

Fabre. J., 1976. Introduction À La Géologie Du Sahara Algérien Et Des Régions Voisines. S.N. E. D'alger, Ed., 422p.

Ferreira, V. G. (2023). Ostracoda (Crustacea) Biodiversity: A Taxonomic And Functional Approach (Doctoral Dissertation, Universidade Estadual De Maringá. Departamento De Biologia. Programa De Pós-Graduação Em Ecologia De Ambientes Aquáticos Continentais.).

Fleury J.J., 1969 – Stratigraphie Du Crétacé Et De L'eocène (Aptien À Lutétien De La Feuille 1/50 000ème Morsott, N°178, Algérie, Constantinois, Atlas Saharien). Bull. Serv. Géol. Algérie, 39, P.145-157.

Forster A., Schouten S., Moriya K., Wilson P.A. & Sinninghe Damsté J.S., 2007 - Tropical Warming And Intermittent Cooling During The Cenomanian/Turonian Oceanic Anoxic Event 2: Sea Surface Temperature Records From The Equatorial Atlantic. Paleoceanography, 22, Pa1219. Doi:10.1029/2006pa001349.

Frenzel, P. & Boomer, I., 2005. The Use Of Ostracods From Marginal Marine, Brackish Waters As Bioindicators Of Modern And Quaternary Environmental Change. Palaeogeography, Palaeoclimatology, Palaeoecology 225, 68–92.

Frizon De Lamotte D., Michard A. & Saddiqi O., 2006 – Quelques Développements Récents Sur La Géodynamique Du Maghreb. C.R. Geosciences 338, P.1-10.

Frodeman, R. (1995). Geological Reasoning: Geology As An Interpretive And Historical Science. Geological Society Of America Bulletin, 107 (8), 960-968.

Frogley, M.R., Griffiths, H.I. & Martens, K., 2002. Modern And Fossil Ostracods From Ancient Lakes. In: Holmes, J.A. & Chivas, A.R. (Eds), The Ostracoda: Applications In Quaternary Research, Agu Geophysical Monograph 131, 167–184

Gabbott, S. E., Siveter, D. J., Aldridge, R. J., & Theron, J. N. (2003). The Earliest Myodocopes: Ostracodes From The Late Ordovician Soom Shale Lagerstätte Of South Africa. Lethaia, 36(3), 151-160.

Gale A.S., Jenkyns H.C., Kennedy W.J. & Corfield R.M., 1993 - Chemostratigraphy Versus Biostratigraphy: Data From Around The Cenomanian-Turonian Boundary. Journal Of The Geological Society Of London, 150, P.29-32.

Gardner, T. W., Jorgensen, D. W., Shuman, C., And Lemieux, C. R. 1987. Geomorphic And Tectonic Process Rates: Effects Of Measured Time Interval, Geology, 15:259-261.

Gargouri-Razgallah S., 1983 – Le Cénomanien De Tunisie Centrale : Étude Paléoécologique, Stratigraphique, Micropaléontologique Et Paléogéographique. Thèse De Doctorat D'etat, Université De Lyon (France), 215p.

Gebhardt H., 2004a – Planktonic Foraminifera Of The Nkalagu Formation Type Locality (Southern Nigeria, Cenomanian-Coniacian): Biostratigraphy And Palaeoenvironmental Interpretation. Cretaceaous Research, 25, P. 191 – 209

Ghomsi, F. E. K., Tenzer, R., Nguiya, S., Mandal, A., & Nouayou, R. (2020). Crustal Thickness Beneath The Atlas Region From Gravity, Topographic, Sediment, And Seismic Data. Geodesy And Geodynamics, 11(1), 18-30.

Giere, O. (2008). Meiobenthology: The Microscopic Motile Fauna Of Aquatic Sediments. Springer Science & Business Media.

Gingerich, P. D. 1983. Rates Of Evolution: Effects Of Time And Temporal Scaling, Science, 222:159-161.

Gingerich, P. D. 2001. Rates Of Evolution On The Time Scale Of The Evolutionary Process, Genetics, 112/113:127-144.

Giraud F., Olivero D., Baudin F., Reboulet S., Pittet B. & Proux O., 2003 - Minor Changes In Surface-Water Fertility Across The Oceanic Anoxic Event 1d (Latest Albian, Se France) Evidenced By Calcareous Nannofossils. International Journal Of Earth Sciences 92, P.267–284.

Giribet, G., & Edgecombe, G. D. (2019). The Phylogeny And Evolutionary History Of Arthropods. Current Biology, 29(12), R592-R602.

Glintzboeckel C. Et Magne J., 1960 – Répartition Des Microfaunes À Plancton Et À Ostracodes Dans Le Crétacé Supérieur De La Tunisie Et De L'est Algérien. Revue De Micropaléontologie, Vol. 2, N°2, P.57-67.

Glover, F. 1989. Tabu Search – Part I. Operations Research Society Of America Journal On Computing, 1:190-206.

REFERENCES

Gordon, A. D., And Reyment, R. A. 1979. Slotting Of Borehole Sequences, Mathematical Geology, 11:309-27.

Gould, S. J. (1989). Wonderful Life: The Burgess Shale And The Nature Of History. Ww Norton & Company.

Gradstein, F. M., And Agterberg, F. P. 1998. Uncertainty In Stratigraphic Correlation, P. 9-29, In F. M. Gradstein And K. O. Sandvik (Eds.), Sequence Stratigraphy: Concepts And Applications, Norwegian Petroleum Society Special Publication 8.

Gradstein, F., Ogg, J., And Smith, A. 2004. A Geologic Time Scale 2004. Cambridge University Press, 589p.

Gray, J., & Boucot, A. J. (1977). Early Vascular Land Plants: Proof And Conjecture. Lethaia, 10(2), 145-174.

Griffiths, H. I. (2001). Ostracod Evolution And Extinction—Its Biostratigraphic Value In The European Quaternary. Quaternary Science Reviews, 20(16-17), 1743-1751.

Griffiths, H.I. & Holmes, J.A., 2000. Non-Marine Ostracods And Quaternary Palaeoenvironments (Qra Technical Guide No. 8). Quaternary Research Association, London. 173 Pp + 3 Pls.

Groshény D. & Malartre F., 1997 - Stratégies Adaptatives Des Foraminifères Benthiques Et Planctoniques À La Limite Cénomanien-Turonien Dans Le Bassin Du Sud-Est De La France : Essai De Compréhension Globale. Geobios, 21, P. 181-193.

Grosheny D., Beaudoin B., Morel L. & Desmares D., 2006 - High-Resolution Biotratigraphy And Chemostratigraphy Of The Cenomanian/Turonian Boundary Event In The Vocontian Basin, Southeast France. Cretaceous Research, 27, P.629-640.

Grosheny D., Chikhi-Aouimeur F., Ferry S., Jati M., Herkat M., Atrops F., Redjimi W. & Benkherouf F., 2007 - The Cenomanian-Turonian Of The Saharan Atlas (Algeria). In: Bulot L.G., Ferry S. & Grosheny D. (Eds.), Relations Entre Les Marges Septentrionale Et Méridionale De La Téthys Au Crétacé [Relations Between The Northern And Southern Margins Of The Tethys Ocean During The Cretaceous Period].- Carnets De Géologie / Notebooks On Geology, Brest, Memoir 2007/02, Abstract 09 (Cg2007_M02/09).

REFERENCES

Guex, J. 1977. Une Nouvelle Méthode D'analyse Biochronologique. Bulletin Laboratoire Géologique Lausanne,224:309-22

Guex, J. 1991. Biochronological Correlations, Springer Verlag, 252 P. Hammer, O And Harper, D. A. T. 2005.

Hancock, J. M. 1977. The Historic Development Of Concepts Of Biostratigraphic Correlation, P. 3-22. In E.G. Kauffman, And J. E. Hazel, (Eds.), Concepts And Methods Of Biostratigraphy. Dowden, Hutchinson And Ross, Stroudsburg, Pennsylvania.

Haq B.U., Hardenbol J. & Vail P.R., 1987 - Chronology Of Fluctuating Sea Levels Since The Triassic. Science 235, P.1156-1166.

Haq.B.U., Hardenbol.J And Vail.P. 1987. Chronology Of Fluctuating Sea Levels Since Triassic. Science, 235, 1159-1167.

Hardas, P. & Mutterlose, J., 2007 - Calcareous Nannofossil Assemblages Of Oceanic Anoxic Event 2 In The Equatorial Atlantic: Evidence Of An Eutrophication Event. Marine Micropaleontology, 66, P.52-69.

Harmon, L. J., Andreazzi, C. S., Débarre, F., Drury, J., Goldberg, E. E., Martins, A. B., ... & Matthews, B. (2019). Detecting The Macroevolutionary Signal Of Species Interactions. Journal Of Evolutionary Biology, 32(8), 769-782.

Harries, P., 2003. High Resolution Approaches In Paleontology, Kluwer Academic Press

Hart M.B. & Ball K.C., 1986 - Late Cretaceous Anoxic Events, Sea-Level Changes And The Evolution Of The Planktonic Foraminifera. In: Summerhayes, C.P., Shackleton, N.J. (Eds.), North Atlantic Palaeoceanography. Geological Society Of America, Special Publication, Vol. 21, P. 67-78.

Harvey, T. H., Vélez, M. I., & Butterfield, N. J. (2012). Exceptionally Preserved Crustaceans From Western Canada Reveal A Cryptic Cambrian Radiation. Proceedings Of The National Academy Of Sciences, 109(5), 1589-1594.

Hay, W. W., And Southam, J. R. 1978. Quantifying Biostratigraphic Correlation. Annual Reviews Of Earth And Planetary Science, 6:353-375.

REFERENCES

Haythem, D., Khiari, A., Zineb, M., Taib, H., Hana, N., & Bilal, B. (2023). Uplifted Marine Terraces By Active Coastal Tectonic Deformation Along The East Of Algiers: Implications For African And European Plate Convergence And Sea-Level Curves. Boletín Geológico Y Minero, 134(2), 57-67.

Heip, C. (1976). The Life-Cycle Of Cyprideis Torosa (Crustacea, Ostracoda). Oecologia, 24(3), 229-245.

Helmdach, F. F. (2005). 15 Th International Symposium On Ostracoda.

Henderson, A. C., & Holmes, J. A. (2009). Palaeolimnological Evidence For Environmental Change Over The Past Millennium From Lake Qinghai Sediments: A Review And Future Research Prospective. Quaternary International, 194(1-2), 134-147.

Henze, M. J., & Oakley, T. H. (2015). The Dynamic Evolutionary History Of Pancrustacean Eyes And Opsins. Integrative And Comparative Biology, 55(5), 830-842.

Herkat .M Et Kechid-Benkherouf.F., 2006. Distribution Of The Foraminifera And Ostracod Assemblages Along Paleogeographic Zones Of The Cretaceous Basins Of The Eastern Algeria. Environemental Micropaleontology, Microbiology And Meiobenthology, Vol. 3, Pp.44-60.

Herkat .M., 1999. La Sédimentation De Haut Niveau Marin Du Crétacé Supérieur De L'atlas Saharien Oriental Et Des Aurès: Stratigraphie Séquentielle, Analyse Quantitative Des Biocénoses, Évolution Paléogéographique Et Contexte Géodynamique .Thèse. Sci. Usthb. Alger, 802p.

Herkat .M., 2002. Analyse Séquentielle Et Révision Stratigraphique De Coupes Du Crétacé Supérieur De L'aurès Occidentale. Mém. Serv. Géol. Alg. N°10, Pp1-27, 7fig.

Herkat .M., 2004. Contrôle Eustatique Paléogéographique De La Sédimentation Du Crétacé Supérieur Du Bassin Des Aurès (Algérie)- Bull. Soc. Géol. France. T.175.N°3.Pp.273-288.

Herkat M. & Delfaud J., 2000 – Genèse Des Séquences Sédimentaires Du Crétacé Supérieur Des Aurès (Algérie). Rôle De L'eustatisme, De La Tectonique, De La Subsidence : Une Mise Au Point. C.R. Acad. Sci. Paris, Sciences De La Terre Et Des Planètes, 330, P.785-792.

Herkat M., 1992 – Manisfestations Diapiriques Du Trias Dans Les Séries Du Crétacé Supérieur De L'atlas Saharien Et Des Aurès. Bull. Serv. Géol. De L'algérie, 3, N°1, P.15-27.

REFERENCES

Herkat. M., 1999. Evolution Des Séquences Et Géométrie Des Dépôts Du Crétacé Supérieur Du Domaine Atlasique Oriental (Algérie). Bull.Du.Serv.Géol.De L'algérie.Vol 10 ;N°1 ;Pp83-94 ;5fig

Herkat. M., 2005. Analyse Quantitative Des Bioassociatios Et Caractérisation Des Cortèges Sédimentaires Et Des Ensembles Paléogéographiques Des Séries Du Cénomano-Turonien Des Aurès Et Du Tell Oriental (Algérie). Bull. Soc. Géol. France. T.176.N°2.Pp.183-190.

Herkat.M And Guiraud.R., 2006. The Relationships Between Tectonics And Sedimentation In The Late Cretaceous Series Of The Eastern Atlasic Domaine (Algeria). Journal Of African Earth Sciences 46, 346-370.

Herkat.M., 2007. Application Of Correspondence Analysis To Palaeobathynetric Reconstruction Of Cenomanian And Turonian (Cretaceous) Rocks Of Eastern Algeria. Palaeo. 254, 583-605.

Hessler, R. R., Marcotte, B. M., Newman, W. A., Maddocks, R. F., & Abele, L. G. (1982). Evolution Within The Crustacea. Biology Of The Crustacea, 1, 149-185.

Hicks, J. F., Obradovich, J. D., And Tauxe, L. 1999. Magnetostratigraphy, Isotopic Age Calibration And Intercontinental Correlation Of The Redbird Section Of The Pierre Shale, Niobrara County, Wyoming, Usa. Cretaceous Research, 20:1-27.

Holmes, J. A., & Chivas, A. R. (2002). The Ostracoda: Applications In Quaternary Research. Washington Dc American Geophysical Union Geophysical Monograph Series, 131.

Holmes, J.A., 1996. Trace-Element And Stable-Isotope Geochemistry Of Non-Marine Ostracod Shells In Quaternary Palaeoenvironmental Reconstruction. Journal Of Paleolimnology 15, 223–235.

Hood, K. C. 1986. Graphcor - Interactive Graphic Correlation Software, Version 2.2: Copyright 1986-1995, Kc Hood.

Horne, D. J. (2003). Key Events In The Ecological Radiation Of The Ostracoda. The Paleontological Society Papers, 9, 181-202.

Horne, D. J. (2003). Key Events In The Ecological Radiation Of The Ostracoda. The Paleontological Society Papers, 9, 181-202.

REFERENCES

Horne, D. J. (2005). Homology And Homoeomorphy In Ostracod Limbs. Hydrobiologia, 538(1-3), 55-80.

Horne, D. J., & Martens, K. (Eds.). (2000). Evolutionary Biology And Ecology Of Ostracoda (Vol. 148). Springer Science & Business Media.

Horne, D. J., Danielopol, D. L., & Martens, K. (1998). Reproductive Behaviour. Sex And Parthenogenesis: Evolutionary Ecology Of Reproductive Modes In Non-Marine Ostracods. Backhuys Publ, Leiden, 157-196.

Horne, D. J., Holmes, J. A., Rodriguez-Lazaro, J., & Viehberg, F. A. (2012). Ostracoda As Proxies For Quaternary Climate Change: Overview And Future Prospects. Developments In Quaternary Sciences, 17, 305-315.

Horne, D. J., Schon, I., Smith, R. J., & Martens, K. (2005). What Are Ostracoda? A Cladistic Analysis Of The Extant Superfamilies Of The Subclasses Myodocopa And Podocopa (Crustacea: Ostracoda). Crustacean Issues, 16, 249.

Horne, D. J., Schon, I., Smith, R. J., & Martens, K. (2005). What Are Ostracoda? A Cladistic Analysis Of The Extant Superfamilies Of The Subclasses Myodocopa And Podocopa (Crustacea: Ostracoda). Crustacean Issues, 16, 249.

Horne, D.J., 1995. A Revised Ostracod Biostratigraphy For The Purbeckwealden Of England. Cretaceous Research 16, 639–663.

Horne, D.J., 2003. Key Events In The Radiation Of The Ostracoda. In: Park, L.E. & Smith, A.J. (Eds): Bridging The Gap: Trends In The Ostracode Biological And Geological Sciences. The Paleontological Society Papers 9, 181–201.

Horne, D.J., 2005. Homology And Homoeomorphy In Ostracod Limbs. Hydrobiologia 538, 55–80.

Horne, D.J., Baltana´S, A. & Paris, G., 1998. Geographical Distribution Of Reproductive Modes In Living Non-Marine Ostracods. In: Martens, K. (Ed.), Sex And Parthenogenesis: Evolutionary Ecology Of Reproductive Modes In Non-Marine Ostracods. Backhuys, Leiden, The Netherlands, 77–99.

REFERENCES

Horne, D.J., Cohen, A. & Martens, K., 2002. Taxonomy, Morphology And Biology Of Quaternary And Living Ostracoda. In: Holmes, J.A. &

Huber B.T., Norris R.D. & Mcleod K.G., 2002 - Deep-Sea Paleotemperature Record Of Extreme Warmth During The Cretaceous. Geology, 30, P.123-126. Doi:10.1130/0091-7613(2002)030\0123:Dsproe\2.0.Co;2.

Humphreys, W. F. (2006). Aquifers: The Ultimate Groundwater-Dependent Ecosystems. Australian Journal Of Botany, 54(2), 115-132.

Hunt, G., & Roy, K. (2006). Climate Change, Body Size Evolution, And Cope's Rule In Deep-Sea Ostracods. Proceedings Of The National Academy Of Sciences , 103 (5), 1347-1352.

Hunt, G., Martins, M. J. F., Puckett, T. M., Lockwood, R., Swaddle, J. P., Hall, C. M., & Stedman, J. (2017). Sexual Dimorphism And Sexual Selection In Cytheroidean Ostracodes From The Late Cretaceous Of The Us Coastal Plain. Paleobiology, 43(4), 620-641.

Hutt, J. E. 1975. The Llandovery Graptolites Of The English Lake District. Palaeontographical Society Monographs, 1-2:1-137.

Ikeya, N., Tsukagoshi, A. & Horne, D.J., 2005. The Phylogeny, Fossil Record And Ecological Diversity Of Ostracod Crustaceans. Hydrobiologia 538, Vii–Xiii.

Ingber, L. 1993. Simulated Annealing: Practice Versus Theory. Mathematical And Computer Modelling, 11:29- 57.

Ito, E., 2002. Mg/Ca, Sr/Ca, D18o And D13c Chemistry Of Quaternary Lacustrine Ostracode Shells From The North American Continental Interior. In:

Jarvis I., Gale A.S., Jenkyns H.C. & Pearce M.A., 2006 - Secular Variation In The Late Cretaceous Carbon Isotopes: A New D13c Carbonate Reference Curve For The Cenomanian-Campanian (99.6-70.6 Ma). Geological Magazine, 143, P.561-608.

Jati M., Grosheny D., Ferry S., Masnour M., Aoutem M., Içame N., Gauthier-Lafaye F. & Desmares D., 2010 – The Cenomanian-Turonian Boundary Event On The Moroccan Atlantic Margin (Agadir Basin) : Stable Isotope And Sequence Stratigraphy. Palaeogeography, Palaeoclimatology, Palaeocology, 296, P.151-164.

REFERENCES

Jati.M., (2007), By Focusing On The Cenomanian-Turonian Interval, Conducted A Sequence Analysis Complemented By A Geochemical Study Of The Series Of Sections, Taken In Algeria, Tunisia, And Morocco, On A Platform/Basin Profile. The Results Of This Work Revealed The Existence Of A Geochemical Anomaly In Δ 13c, Characteristic Of The Global Anoxic Event Oae2. Paleogeographical Patterns For This Episode And Correlations With The Stratotype Section Of Pueblo And Tunisia Were Proposed.

Jellinek, T., Swanson, K. & Mazzini, I., 2006. Is The Cosmopolitan Model Still Valid For Deep-Sea Podocopid Ostracods? With The Discussion Of Two New Species Of The Genus Pseudobosquetina Guernet & Moullade 1994 And Cytheropteron Testudo (Ostracoda) As Case Studies. Senckenbergiana Maritima 36 (1), 29–50, Frankfurt Am Main.

Jenkyns H.C., 1980 - Cretaceous Anoxic Events: From Continents To Oceans. Journal Of The Geological Society Of London, 137, P.171-188.

Jenkyns H.C., 2003 - Evidence For Rapid Climate Change In The Mesozoic-Palaeogene Greenhouse World. Philosophical Transactions Of The Royal Society A: Mathematical, Physical And Engineering Sciences, 361, P. 1885-1916.

Jenkyns H.C., Gale A.S. & Corfield R.M., 1994 - Carbon- And Oxygen-Isotope Stratigraphy Of The English Chalk And Italian Scaglia And Its Palaeoclimatic Significance. Geological Magazine, 131, P.1-34.

Julio Rodriguez-Lazaro, Francisco Ruiz-Muñoz, 2012. Chapter 1 - A General Introduction To Ostracods: Morphology, Distribution, Fossil Record And Applications

Karanovic, I. (2012). Recent Freshwater Ostracods Of The World: Crustacea, Ostracoda, Podocopida . Springer Science & Business Media.

Keller G., Han Q., Adatte T. & Burn S.J., 2001 - Palaeoenvironment Of The Cenomanian-Turonian Transition At Eastbourne, England. Cretaceous Research, 22, P.391-422.

Kempf, E.K., 1996. Index And Bibliography Of Marine Ostracoda, Vols. 1–9. Geologisches Institut Der Universitat Koeln, Sonderveroffentlichungen 50–53, 88, 102, 103. (2002, 2004, 2008, Cd Version).

REFERENCES

Kemple, W. G., Sadler, P. M., And Strauss, D. J.1995. Extending Graphic Correlation To Many Dimensions: Stratigraphic Correlation As Constrained Optimization, P. 65-82, In K. O. Mann , And H. R. Lane (Eds.) Graphic Correlation. Special Publications Of The Society Of Economic Paleontologists And Mineralogists, 53.

Kesling, R. V. (1949). The Morphology Of Ostracod Molt Stages . University Of Illinois At Urbana-Champaign.

Kesling, R. V. (1949). The Morphology Of Ostracod Molt Stages. University Of Illinois At Urbana-Champaign.

Kesling, R. V. (1951). Terminology Of Ostracod Carapaces.

Khangarot, B.S. & Das, S., 2009. Acute Toxicity Of Metals And Reference Toxicants To A Freshwater Ostracod, Cypris Subglobosa Sowerby, 1840 And Correlation To Ec50 Values Of Other Test Models. Journal Of Hazardous Materials 172, 641–649.

Kidwell, S. M., & Holland, S. M. (2002). The Quality Of The Fossil Record: Implications For Evolutionary Analyses. Annual Review Of Ecology And Systematics, 33(1), 561-588.

Kirkpatrick, S., Gelatt, C. D., And Vecchi, M. P. 1983. Optimization By Simulated Annealing. Science, 220:671-680.

Kiss, A. (2007). Factors Affecting Spatial And Temporal Distribution Of Ostracoda Assemblages In Different Macrophyte Habitats Of A Shallow Lake (Lake Fehér, Hungary). In Ostracodology—Linking Bio-And Geosciences: Proceedings Of The 15th International Symposium On Ostracoda, Berlin, 2005 (Pp. 89-98). Springer Netherlands.

Külköylüoğlu, O. (2004). On The Usage Of Ostracods (Crustacea) As Bioindicator Species In Different Aquatic Habitats In The Bolu Region, Turkey. Ecological Indicators, 4(2), 139-147.

Külköylüoğlu, O. (2013). Diversity, Distribution And Ecology Of Nonmarine Ostracoda (Crustacea) In Turkey: Application Of Pseudorichness And Cosmoecious Species Concepts. Recent Research Development In Ecology, 4, 1-18.

Laffitte.R., 1939. Etude Géologique De L'aurès. Bull. Serv. Carte Géologique De L'algérie, 2éme Série, N°15.484p.

REFERENCES

Lamolda M.A., Gorostidi A., Martinez R., Lopez G. & Peryt D., 1997 - Fossil Occurrences In The Upper Cenomanian Lower Turonian At Ganuza, Northern Spain: An Approach To Cenomanian-Turonian Boundary Chronostratigraphy. Cretaceous Research, 18, P.331-353.

Lapworth, C. 1876. On Scottish Monograptidae. Geological Magazine, 2(3):308-321.

Lau, E. S., & Oakley, T. H. (2021). Multi-Level Convergence Of Complex Traits And The Evolution Of Bioluminescence. Biological Reviews, 96(2), 673-691.

Laudan, R., 1976. William Smith. Stratigraphy Without Paleontology. Centaurus, 20(3):210-226.

Leckie R.M., Bralower T.J. & Cashman R., 2002 - Oceanic Anoxic Events And Plankton Evolution: Biotic Response To Tectonic Forcing During The Mid-Cretaceous. Paleoceanography 17, Pa 1041. Doi:10.1029/2001pa000623

Leng, M. J., & Marshall, J. D. (2004). Palaeoclimate Interpretation Of Stable Isotope Data From Lake Sediment Archives. Quaternary Science Reviews, 23(7-8), 811-831.

Levin, L. A. (1984). Life History And Dispersal Patterns In A Dense Infaunal Polychaete Assemblage: Community Structure And Response To Disturbance. Ecology, 65(4), 1185-1200.

Levin, L. A., Etter, R. J., Rex, M. A., Gooday, A. J., Smith, C. R., Pineda, J., ... & Pawson, D. (2001). Environmental Influences On Regional Deep-Sea Species Diversity. Annual Review Of Ecology And Systematics, 32(1), 51-93.

Li, X., Liu, W., Zhang, L., & Sun, Z. (2010). Distribution Of Recent Ostracod Species In The Lake Qinghai Area In Northwestern China And Its Ecological Significance. Ecological Indicators, 10(4), 880-890.

Liow, L. H., Skaug, H. J., Ergon, T., And Schweder, T. 2010. Global Occurrence Trajectories Of Microfossils: Environmental Volatility And The Rise And Fall Of Individual Species. Paleobiology, 36(2):224- 252

Love, A. C., Grabowski, M., Houle, D., Liow, L. H., Porto, A., Tsuboi, M., ... & Hunt, G. (2022). Evolvability In The Fossil Record. Paleobiology, 48(2), 186-209.

Lowe, J. J., & Walker, M. J. (2014). Reconstructing Quaternary Environments. Routledge.

Ludvigsen, R., Westrop, S. R., Pratt, B. C., Tufnell, P. A., And Young, G. A., 1986. Dual Biostratigraphy: Zones And Biofacies. Geoscience Canada, 13: 139-154.

Lüning S., Kolonic S., Belhadj E.M., Belhadj Z., Cota L., Barić G. & Wagner T., 2004 – Integrated Depositional Model For The Cenomanian-Turonian Organic-Rich Strata In North Africa. Earth-Science Reviews, 64, P.51-117.

Maamouri A.I., Zaghbib-Turki D., Matmati M.F., Chikhaoui M. & Salaj J., 1994 - La Formation Bahloul En Tunisie Centro-Septentrionale : Variations Latérales, Nouvelle Datation Et Nouvelle Interprétation En Terme De Stratigraphie Séquentielle. Journal Of African Earth Sciences, 18, P.37–50.

Maandi, N. (2011). Biostratigraphie et paléoenvironnements du crétacé moyen des Aurès et de Morsott (Doctoral dissertation, Alger).

Macellari, C. E. 1984. Late Cretaceous Stratigraphy, Sedimentology, And Macropaleontology Of Seymour Island, Antarctic Peninsula, Phd Thesis, The Ohio State University, 598 P.

Macellari, C. E. 1986. Late Campanian-Maastrichtian Ammonite Fauna From Seymour Island (Antarctic Peninsula). Paleontological Society Memoir 18:1-55.

Macleod N., And Sadler P. M. 1995. Estimating The Line Of Correlation, P. 51-64, In K. O. Mann And H. R. Lane, (Eds.) Graphic Correlation. Special Publications Of The Society Of Economic Paleontologists And Mineralogists, 53.

Mann, K. O., And Lane, H. R. 1995. Graphic Correlation: A Powerful Stratigraphic Technique Comes Of Age. P. 3-13, In K. O. Mann And H. R. Lane (Eds.) Graphic Correlation. Special Publications Of The Society Of Economic Paleontologists And Mineralogists, 53.

Marchegiano, M., & John, C. M. (2022). Disentangling The Impact Of Global And Regional Climate Changes During The Middle Eocene In The Hampshire Basin: New Insights From Carbonate Clumped Isotopes And Ostracod Assemblages. Paleoceanography And Paleoclimatology, 37(2), E2021pa004299.

Marco-Barba, J., Holmes, J. A., Mesquita-Joanes, F., & Miracle, M. R. (2013). The Influence Of Climate And Sea-Level Change On The Holocene Evolution Of A Mediterranean Coastal Lagoon: Evidence From Ostracod Palaeoecology And Geochemistry. Geobios, 46(5), 409-421.

REFERENCES

Marshall, C. R., 1990. Confidence Intervals On Stratigraphic Ranges. Paleobiology, 16:1-10.

Martens, K. & Horne, D.J., 2000. Ostracoda And The Four Pillars Of Evolutionary Wisdom. Hydrobiologia 419, Vii–Xi.

Martens, K. & Horne, D.J., 2009. Ostracoda. In: Likens, G.E. (Ed.), Encyclopedia Of Inland Waters 2, 405–414.

Martens, K. (2000). Factors Affecting The Divergence Of Mate Recognition Systems In The Limnocytherinae (Crustacea, Ostracoda). Hydrobiologia, 419, 83-101.

Martens, K. (Ed.), 1998. Sex And Parthenogenesis. Evolutionary Ecology Of Reproductive Modes In Non-Marine Ostracods. Backhuys, Leiden, Pp. 335.

Martens, K., 2008. Ancient Asexuals: Darwinulids Not Exposed. Nature 453,587.

Martens, K., Schön, I., Meisch, C., & Horne, D. J. (2008). Global Diversity Of Ostracods (Ostracoda, Crustacea) In Freshwater. Freshwater Animal Diversity Assessment, 185-193.

Martin, J. W., & Davis, G. E. (2001). An Updated Classification Of The Recent Crustacea (Vol. 39, P. 129). Los Angeles: Natural History Museum Of Los Angeles County.

Masse J.P. & Thieuloy J.P., 1979 – Précisions Sur L'âge Des Calcaires Et Des Formations Associées De L'aptien Sud Constantinois (Algérie). Conséquences Paléogéographiques. Bull. Soc. Géol. De France, 7, Xxi, P.65-71.

Matsuda, J. T., Lansac-Tôha, F. A., Martens, K., Velho, L. F. M., Mormul, R. P., & Higuti, J. (2015). Association Of Body Size And Behavior Of Freshwater Ostracods (Crustacea, Ostracoda) With Aquatic Macrophytes. Aquatic Ecology, 49, 321-331.

Matzke-Karasz, R., Neil, J. V., Smith, R. J., Godthelp, H., Archer, M., & Hand, S. J. (2013). Ostracods (Crustacea) With Soft Part Preservation From Miocene Cave Deposits Of The Riversleigh World Heritage Area, Nw Queensland, Australia. Journal Of Systematic Palaeontology, 11(7), 789-819.

Mccormack, J., Viehberg, F., Akdemir, D., Immenhauser, A., & Kwiecien, O. (2019). Ostracods As Ecological And Isotopic Indicators Of Lake Water Salinity Changes: The Lake Van Example. Biogeosciences, 16(10), 2095-2114.

REFERENCES

Mcgowran, B., 2005 Biostratigraphy: Microfossils And Geologic Time. Cambridge University Press, 459 P.

Mckenzie, K.G. & Jones, P.J. (Eds), 1993. Ostracoda In The Earth And Life Sciences. Balkema, Rotterdam, P. Xvii 724 Pp.

Mclaren, D. J. 1988. Detection And Significance Of Mass Killings. Canadian Society Of Petroleum Geologists Memoir, 14:1-7.

Meisch, C. (2007). On The Origin Of The Putative Furca Of The Ostracoda (Crustacea). In Ostracodology—Linking Bio-And Geosciences: Proceedings Of The 15th International Symposium On Ostracoda, Berlin, 2005 (Pp. 181-200). Springer Netherlands.

Melchin, M. J., Cooper, R. A., And Sadler, P. M. 2004. The Silurian Period, P. 188-201 In F. Gradstein, J. Ogg And A. Smith (Eds.) A Geologic Time Scale 2004. Cambridge University Press.

Melik, J. C. (1966). Hingement And Contact Margin Structure Of Palaeocopid Ostracodes From Some Middle Devonian Formations Of Michigan, Southwestern Ontario, And Western New York.

Mesquita-Joanes, F., Smith, A. J., & Viehberg, F. A. (2012). The Ecology Of Ostracoda Across Levels Of Biological Organisation From Individual To Ecosystem: A Review Of Recent Developments And Future Potential. Developments In Quaternary Sciences, 17, 15-35.

Meyer, J., Wrozyna, C., Gross, M., Leis, A., & Piller, W. E. (2017). Morphological And Geochemical Variations Of Cyprideis (Ostracoda) From Modern Waters Of The Northern Neotropics. Limnology, 18, 251-273.

Mezquita, F., Herna´Ndez, R. & Rueda, J., 1999. Ecology And Distribution Of Ostracods In A Polluted Mediterrane An River. Palaeogeography, Palaeoclimatology, Palaeoecology 148, 87–103.

Mezquita, F., Roca, J. R., Reed, J. M., & Wansard, G. (2005). Quantifying Species–Environment Relationships In Non-Marine Ostracoda For Ecological And Palaeoecological Studies: Examples Using Iberian Data. Palaeogeography, Palaeoclimatology, Palaeoecology, 225(1-4), 93-117.

REFERENCES

Mezquita, F., Roca, J. R., Reed, J. M., & Wansard, G. (2005). Quantifying Species–Environment Relationships In Non-Marine Ostracoda For Ecological And Palaeoecological Studies: Examples Using Iberian Data. Palaeogeography, Palaeoclimatology,

Milli, S., D'ambrogi, C., Bellotti, P., Calderoni, G., Carboni, Mg, Celant, A., ... & Ricci, V. (2013). The Transition From Wave-Dominated Estuary To Wave-Dominated Delta: The Late Quaternary Stratigraphic Architecture Of Tiber River Deltaic Succession (Italy). Sedimentary Geology , 284 , 159-180.

Mischke, S., Ginat, H., Al-Saqarat, B., & Almogi-Labin, A. (2012). Ostracods From Water Bodies In Hyperarid Israel And Jordan As Habitat And Water Chemistry Indicators. Ecological Indicators, 14(1), 87-99.

Monnet C., 2009 – The Cenomanian-Turonian Boundary Mass Extinction (Late Cretaceous) : New Insights From Ammonoid Biodiversity Patterns Of Europe, Tunisia And The Western Interior (North America). Palaeogeography, Palaeoclimatology, Palaeoecology, 282, P.88-104.

Montoya-Pino C., Weyer S., Anbar A.D., Pross J., Oschmann W., Van De Schootbrugge B. & Arz H.W., 2010 - Global Enhancement Of Ocean Anoxia During Oceanic Anoxic Event 2: A Quantitative Approach Using U Isotopes. Geology, 38, P.315-318.

Moore, J. C., Jin, H. M., Kuchner, O., & Arnold, F. H. (1997). Strategies For The In Vitro Evolution Of Protein Function: Enzyme Evolution By Random Recombination Of Improved Sequences. Journal Of Molecular Biology, 272(3), 336-347.

Morse, J. W., Arvidson, R. S., & Lüttge, A. (2007). Calcium Carbonate Formation And Dissolution. Chemical Reviews, 107(2), 342-381.

Mort H.P., Adatte T., Föllmi K.B., Keller G., Steinmann P., Matera V., Berner Z. & Stüben D., 2007 - Phosphorus And The Roles Of Productivity And Nutrient Recycling During Oceanic Event 2. Geology, 35, P. 483-486.

Mort H.P., Adatte T., Keller G., Bartels D., Föllmi K.B., Steinmann P., Berner Z. & Chellai E.H., 2008 – Organic Carbon Deposition And Phosphorus Accumulation During Oceanic Anoxic Event 2 In Tarfaya, Morocco, Cretaceous Research, 29, P.1008-1023.

REFERENCES

Mourguiart, P. & Montenegro, M.E., 2002. Climate Changes In The Laketiticaca Area: Evidence From Ostracod Ecology. In: Holmes, J.A. & Chivas, A.R. (Eds), The Ostracoda: Applications In Quaternary Research, Agu Geophysical Monograph 131, 151–165.

Muhs, D. R. (2013). The Geologic Records Of Dust In The Quaternary. Aeolian Research, 9, 3-48.

Murphy, M. A., 1994. Fossils As A Basis For Chronostratigraphic Interpretation. Neues Jahrbuch Fuer Geologie Und Palaeontologie Abhandlungen, 192:255- 271.

Nagorskaya, L., & Keyser, D. (2005). Habitat Diversity And Ostracod Distribution Patterns In Belarus. Hydrobiologia, 538(1-3), 167-178.

Naili H., Belhadj Z., Robaszynski F. & Caron M., 1995 – Présence De Roches Mère À Faciès Bahloul Vers La Limite Cénomanien-Turonien Dans La Région De Tébessa (Algérie Orientale), Notes Du Service Géologique De Tunisie, N° 61, P.19-32

Neale, J.W., 1988. Ostracoda-A Historical Perspective. In: Hanai, T., Ikeya, N. & Ishizaki, K. (Eds), Evolutionary Biology Of Ostracoda. Kodansha, Tokyo, 3–15.

Nederbragt A.J. & Fiorentino A., 1999 - Stratigraphy And Palaeoceanography Of The Cenomanian–Turonian Boundary Event In Oued Mellegue, North-Western Tunisia. Cretaceous Research 20, P.47–62.

Norris R.D., Bice K.L., Magno E.A. & Wilson P.A., 2002 - Jiggling The Tropical Thermostat In The Cretaceous Hothouse. Geology, 30, P.299-302.

Nzoussi-Mbassani P., Khamli N., Disnar J.R., Laggoun-Defarge F. & Boussafir M., 2005 – Cenomanian-Turonian Organic Sedimentation In North-West Africa : A Comparison Between The Tarfaya (Morocco) And Senegal Basins. Sedimentary Geology, 177, P.271-295.

Oakley, T. H., Wolfe, J. M., Lindgren, A. R., & Zaharoff, A. K. (2013). Phylotranscriptomics To Bring The Understudied Into The Fold: Monophyletic Ostracoda, Fossil Placement, And Pancrustacean Phylogeny. Molecular Biology And Evolution, 30(1), 215-233.

Obradovich, J. D. 1988. A Different Perspective On Glauconite For Geologic Time Scale Studies. Paleoceanography, 3:757-770.

REFERENCES

Obradovich, J. D., And Cobban, W. A. 1975. A Time Scale For The Late Cretaceous Of The Western Interior Of North America, P. 31-54, In W. G. E. Caldwell, (Ed.), The Cretaceous System In The Western Interior Of North America, Geological Association Of Canada Special Paper 13.

Obradovich, J. D.1993. A Cretaceous Time Scale, P. 379-396, In W. G. E. Caldwell And E. G. Kauffman (Eds.), Evolution Of The Western Interior Basin. Geological Association Of Canada, Special Paper 39.

Oertli, H., 1982. Early Research Of Ostracoda And The French Contribution. In: Bate, R.H., Robinson, E. & Sheppard, L.M. (Eds), Fossil And Recent Ostracods. The British Micropalaeontological Society, Ellis Horwood Limited, Chichester, 454–478.

Olempska, E. (2012). Morphology And Affinities Of Eridostracina: Palaeozoic Ostracods With Moult Retention. Hydrobiologia, 688, 139-165.

Oppel, A. 1856-58. Die Jura Formation Englands, Frankreichs, Und Des Südwestlichen Deutchlands; Nach Ihren Einzelnen Gliedern Eingeteilt Und Verglichen.

Ou, Q., Vannier, J., Yang, X., Chen, A., Mai, H., Shu, D., ... & Mayer, G. (2020). Evolutionary Trade-Off In Reproduction Of Cambrian Arthropods. Science Advances, 6(18), Eaaz3376.

Paleontological Data Analysis. Blackwell, 368 P.

Palumbi, S. R. (1994). Genetic Divergence, Reproductive Isolation, And Marine Speciation. Annual Review Of Ecology And Systematics, 25(1), 547-572.

Pancost R.D., Crawford N., Magness S., Turner A., Jenkyns H.C. & Maxwell J.R., 2004 - Further Evidence For The Development Of Photic-Zone Euxinic Conditions During Mesozoic Oceanic Anoxic Events. Journal Of The Geological Society Of London, 161, P.353-364.

Park, L. E., & Ricketts, R. D. (2003). Evolutionary History Of The Ostracoda And The Origin Of Nonmarine Faunas. The Paleontological Society Papers, 9, 11-36.

Parker, A. R. (1997). Functional Morphology Of The Myodocopine (Ostracoda) Furca And Sclerotized Body Plate. Journal Of Crustacean Biology, 17(4), 632-653.

Pearce C.R., Jarvis I. & Tocher B.A., 2009 - The Cenomanian-Turonian Boundary Event, Oae 2 And Palaeoenvironmental Change In Epicontinental Seas: New Insights From The Dinocyst

And Geochemical Records. Palaeogeography, Palaeoclimatology, Palaeoecology 280 (1-2), P.207-234.

Pederson T.F. & Calvert S.E., 1990 - Anoxia Vs. Productivity: What Controls The Formation Of Organic Carbon-Rich Sediments And Sedimentary Rock? Bulletin Of The American Association Of Petroleum Geologists, 74, P.454-466.

Phillips, J. 1829. Illustrations Of The Geology Of Yorkshire. T. Wilson, York. 192p.

Pirrie, D., Crame, J. A., Lomas, S. A., And Riding, J. B. 1997. Late Cretaceous Stratigraphy Of The Admiralty Sound Region, James Ross Basin, Antarctica. Cretaceous Research, 18:109-137

Pokorný, V. (1998). Ostracodes. In Introduction To Marine Micropaleontology (Pp. 109-149). Elsevier Science Bv.

Poquet, J. M., & Mesquita-Joanes, F. R. A. N. C. E. S. C. (2011). Combined Effects Of Local Environment And Continental Biogeography On The Distribution Of Ostracoda. Freshwater Biology, 56(3), 448-469.

Pribyl, A. 1940. Die Graptolithen Fauna Des Mittleren Ludlows Von Böhmen (Oberes Eß). Věstník Státního Géologického Ustavu Ĉeskoslovenské, 16:63-73.

Regier, J. C., Shultz, J. W., Zwick, A., Hussey, A., Ball, B., Wetzer, R., ... & Cunningham, C. W. (2010). Arthropod Relationships Revealed By Phylogenomic Analysis Of Nuclear Protein-Coding Sequences. Nature, 463(7284), 1079-1083.

Reineck, H.-E. 1960. Über Zeitlücken Im Rezenten Flachsee Sedimenten. Geologische Rundschau, 49:149-161.

Reznick, D. N., Shaw, F. H., Rodd, F. H., And Shaw, R. G. 1997. Evaluation Of The Rate Of Evolution In Natural Populations Of Guppies (Poecilia Reticulata), Science, 275:1934-1937.

Robaszynski F. & Caron M., 1979 - Atlas Des Foraminifères Planctoniques Du Crétacé Moyen (Mer Boréale Et Téthys). Cahiers De Micropaléontologie, 1/2, 185 P., 181 P.

Robaszynski F., Caron M., Dupus C., Amedro F., Gonzàlez Donoso J.-M., Linares D., Hardenbol J., Gartner S., Calandra F. & Deloffre R., 1990 – A Tentative Integrated Stratigraphy

In The Turonian Of Central Tunisia : Formations, Zones And Sequential Stratigraphy In The Kalaat Senan Area. Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine, 14, P.213-384.

Robaszynski F., Faouzi Zagrarni M., Caron M. & Amedro F., 2010 – The Global Bio-Events At The Cenomanian-Turonian Transition In The Reduced Bahloul Formation Of Bou Ghanem (Central Tunisia). Cretaceous Research, 31, P. 1-15.

Rodriguez Lazaro, J. & Cronin, T., 1999. Quaternary Glacial And Deglacial Krithe (Ostracoda) In The Thermocline Of The Little Bahama Bank (Nw Atlantic): Palaeoceanographic Implications. Palaeogeography, Palaeoclimatology, Palaeoecology 152 (3–4), 339–364.

Rodriguez-Lazaro, J., & Ruiz-Muñoz, F. (2012). A General Introduction To Ostracods: Morphology, Distribution, Fossil Record And Applications. In Developments In Quaternary Sciences (Vol. 17, Pp. 1-14). Elsevier.

Rossetti, G., Martens, K., Meisch, C., Tavernelli, S., & Pieri, V. (2006). Small Is Beautiful: Diversity Of Freshwater Ostracods (Crustacea, Ostracoda) In Marginal Habitats Of The Province Of Parma (Northern Italy). Journal Of Limnology, 65(2), 121.

Ruiz, F., Abad, M., Bodergat, A. M., Carbonel, P., Rodríguez-Lázaro, J., González-Regalado, M. L., ... & Prenda, J. (2013). Freshwater Ostracods As Environmental Tracers. International Journal Of Environmental Science And Technology, 10, 1115-1128.

Ruiz, F., Abad, M., Bodergat, A.M., Carbonel, P., Rodriguez-Lazaro, J. & Yasuhara, M., 2005. Marine And Brackish-Water Ostracods As Sentinels Of Anthropogenic Impacts. Earth-Science Reviews 72, 89–111.

Ruiz, F., Abad, M., Bodergat, Am, Carbonel, P., Rodríguez-Lázaro, J., González-Regalado, Ml, ... & Prenda, J. (2013). Freshwater Ostracods As Environmental Tracers. International Journal Of Environmental Science And Technology , 10 , 1115-1128.

Ryan, P. D., Ryan, M. D. C., And Harper, D. A. T. 1999. A New Approach To Seriation , P. 433-49,. In D. A. T. Harper (Ed.) Numerical Palaeobiology: Computer- Based Modeling And Analysis Of Fossils And Their Distributions, Chichester, Uk: Wiley

Sadler, P. M. 1981. Sediment Accumulation Rates And The Completeness Of Stratigraphic Sections, Journal Of Geology, 89:569-584.

REFERENCES

Sadler, P. M. 1993. Time Scale Dependence Of The Rates Of Unsteady Geologic Processes, P. 221-228 In J. M. Armentrout, R. Bloch, H. C. Olsen, And B. F. Perkins (Eds.), Rates Of Geologic Processes, Sepm Gulf Coast Section Annual Research Conference, 14.

Sadler, P. M. 1999. The Influence Of Hiatuses On Sediment Accumulation Rates, P.15-40, In P. Bruns And H. C. Haas (Eds.), On The Determination Of Sediment Accumulation Rates, Trans Tech Publications, 5.

Sadler, P. M. 2004. Quantitative Biostratigraphy - Achieving Finer Resolution In Global Correlation. Annual Reviews Of Earth And Planetary Sciences, V. 32, P. 187-213.

Sadler, P. M. 2006. Composite Time-Lines: A Means To Leverage Resolving Power From Radioisotopic Dates And Biostratigraphy, P. 145-170. In T. D. Olszewski (Ed.) Geochronology: Emerging Opportunities, Paleontological Society Papers, 12:145-170.

Sadler, P. M. 2009, False Coincidences – A Pervasive Characteristic Of The Unevenly Under-Sampled Fossil Record? 9th North American Paleontological Convention Abstracts, Cincinnati Museum Center Scientific Contributions, 3:256-257.

Sadler, P. M. 2010. Constrained Optimization Approaches To The Paleobiologic Correlation And Seriation Problems: A Users' Guide And Reference Manual To The Conop Family Of Programs, Version 7.61, Copyright 1998-2010, P. M. Sadler

Sadler, P. M., And Cooper, R. A. 2003 Best-Fit Intervals And Consensus Sequences: Comparison Of The Resolving Power Of Traditional Biostratigraphy And Computer-Assisted Correlation. In P. Harries (Ed.) High Resolution Stratigraphic Approaches In Paleontology. Kluwer-Academic Press.

Sadler, P. M., And Cooper, R. A., 2004, Calibration Of The Ordovician Time Scale, In Webby, B., Paris, F., Droser, M.L., And. Percival, I. G. (Eds.), The Great Ordovician Biodiversification Event, Columbia University Press (Critical Moments And Perspectives In Earth History And Paleobiology Series) P. 48-51.

Sadler, P. M., And Sabado, J. A., 2009,Automated Correlation, Seriation, And The Treatment Of Biotic Dissimilarity. Museum Of Northern Arizona Bulletin 65:21-35

Sadler. P. M., Cooper, R. A., And Melchin, M. 2009. High-Resolution, Early Paleozoic (Ordovician-Silurian) Time Scales. Geological Society Of America Bulletin, 121:887-906.

REFERENCES

Sageman B.B., Meyers S.R. & Arthur M.A., 2006 - Orbital Time Scale And New C-Isotope Record For Cenomanian-Turonian Boundary Stratotype. Geology, 34, P.125-128.

Sadler, P. M. (2013). Biochronology as a Traveling Salesman Problem: Introduction to the CONOP9 Seriation Programs.

Salaj J., 1980 – Microbiostratigraphie Du Crétacé Et Du Paléogène De La Tunisie Septentrionale Et Orientale (Hypo-Stratotypes Tunisiens). Inst. Géol. Bratislava, 283 P.

Salaj J., 1987 – The Problem Of Planktic Foraminifera Of The Family Globotruncanidae. In : Pokorny V. (Ed.) : Contribution Of Czechoslovak Palaeontology To Evolutionary Science 1945-1985. Univ. Karlova, Praha, P.23-38.

Saltzman, B. (2002). Dynamical Paleoclimatology: Generalized Theory Of Global Climate Change (Vol. 80). Academic Press.

Salvador, A., 1994. International Stratigraphic Guide. Boulder, Usa: Geological Society Of America, 214pp.

Sames, B., Cifelli, Rl, & Schudack, Me (2010). The Nonmarine Lower Cretaceous Of The North American Western Interior Foreland Basin: New Biostratigraphic Results From Ostracod Correlations And Early Mammals, And Their Implications For Paleontology And Geology Of The Basin—An Overview. Earth-Science Reviews , 101 (3-4), 207-224.

Sars, G.O., 1866. Oversigt Af Norges Marine Ostracoder. Forhandlinger I Videnskabs-Selskabet I Christiania 1865, 1–130.

Sars, G.O., 1923–1928. An Account Of The Crustacea Of Norway, Volume 9 - Ostracoda, Parts 3–16, 33–277.

Savary, J., And Guex, J. 1991. Biograph: Un Nouveau Programme De Construction Des Correlations Biochronologique Basées Sur Les Associations Unitaires. Bull. Lab. Géol. Univ. Lausanne 313:317-40.

Savary, J., And Guex, J. 1999. Discrete Biochronological Scales And Unitary Association: Description Of The Biograph Computer Program. Mémoire Géologique Lausanne, 34:1-281.

Schlanger S.O., Arthur M.A., Jenkyns H.C. & Scholle P.A., 1987 - The Cenomanian-Turonian Oceanic Anoxic Event, I. Stratigraphy And Distribution Of Organic Carbon-Rich Beds And

The Marine Δ13c Excursion. Geological Society Of London, Special Publications, 26, P.371-399.

Schlanger, S.O. & Jenkyns H.C., 1976 - Cretaceous Oceanic Anoxic Events, Causes And Consequences. Geologie En Mijnbouw, 55, P. 179–184.

Scholle P.A. & Arthur M.A., 1980 - Carbon Isotope Fluctuations In Cretaceous Pelagic Limestone: Potential Stratigraphic And Petroleum Exploration Tool. American Association Of Petroleum Geologists Bulletin, 64, P.67-87.

Scholle, P. A., & Ulmer-Scholle, D. S. (2003). A Color Guide To The Petrography Of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis, Aapg Memoir 77 (Vol. 77). Aapg.

Schön, I., Gandolfi, A., Di Masso, E., Rossi, V., Griffiths, H. I., Martens, K., & Butlin, R. K. (2000). Persistence Of Asexuality Through Mixed Reproduction In Eucypris Virens (Crustacea, Ostracoda). Heredity, 84(2), 161-169.

Schram, F. R., & Abele, L. G. (1982). The Fossil Record And Evolution Of Crustacea. The Biology Of Crustacea, 1, 93-147.

Schram, F.R. (2013). Comments On Crustacean Biodiversity And Disparity Of Body Planes. The Natural History Of The Crustacea , 1 , 1-33.

Schram, Fr, & Abele, Lg (1982). The Fossil Record And Evolution Of Crustacea. The Biology Of Crustacea , 1 , 93-147.

Schreve, D.C., Bridgland, D.R., Allen, P., Blackford, J.F., Gleed-Owen, C.P., Griffiths, H.I., Keen, D.H. & White, M.J., 2002. Sedimentology, Palaeontology And Archaeology Of Late Middle Pleistocene River Thames Terrace Deposits At Purfleet, Essex, Uk. Quaternary Science Reviews 21, 1423–1464.

Scott, G. H., 1985. Homotaxy And Biostratigraphical Theory. Palaeontology, 28:777-782.

Sedgwick, A., And Murchison, R. I. 1839. Classification Of The Older Stratified Rocks Of Devonshire And Cornwall. Philosophical Magazine And Journal Of Science Series 3, 14:241-260.

Selden, P., & Nudds, J. (2012). Evolution Of Fossil Ecosystems . Elsevier.

Shaw, A. B. 1964. Time In Stratigraphy. New York: Mcgraw Hill. 365 Pp.

REFERENCES

Shaw, A. B. 1995. Early History Of Graphic Correlation. P. 15-19. In K. O. Mann , And H. R. Lane (Eds.) Graphic Correlation. Special Publications Of The Society Of Economic Paleontologists And Mineralogists, 53.

Sigal J., 1949 – Une Date Remarquable Dans L'évolution De La Microfaune Du Cénomanien-Turonien En Algérie. C.R. Soc. Géol. France, P.264-266.

Sigal J., 1952 – Aperçu Stratigraphique Sur La Micropaléontologie Du Crétacé. 19ème Int. Geol. Congr. Monographies Régionales, Alger, Série 1, Algérie, 26, P.1-45.

Sigal J., 1954 – Aperçu Stratigraphique Sur La Micropaléontologie Du Crétacé. 19ème Congr. Géol. Intern., Alger. Monographies Régionales, Alger, Série 1, Algérie, 26, 47 P.

Sigal J., 1956 – Notes Micropaléontologiques Nord-Africaines. 4- Biticinella Breggiensis (Gandolfi) Nouveau Morphogenre. 5- A Propos De Globotruncana Helvetica Bolli. C.R. Soc. Géol. France, P. 35-37.

Sigal J., 1967 – Essai Sur L'état Actuel D'une Zonation Stratigraphique À L'aide Des Principales Espèces De Rosalines (Foraminifères). C.R. Soc. Géol. France, P.48-50.

Sigal J., 1977 - Essai De Zonation Du Crétacé Méditerranéen À L'aide Des Foraminifères Planctoniques. Géologie Méditerranéenne, Marseille, T. 4, N° 2, P. 99-108.

Siveter, D. J. (2008). Ostracods In The Palaeozoic?. Senckenbergiana Lethaea, 88, 1-9.

Siveter, D.J., Sutton, M.D., Briggs, D.E.G. & Siveter, D.J., 2003. An Ostracode Crustacean With Soft Parts From The Lower Silurian. Science 302, 1749–1751.

Skogsberg, T., 1920. Studies On Marine Ostracods. Part I (Cypridinids, Halocyprids And Polycopids). Zoologiska Bidrag Fran Uppsala Suppl.-Bd 1,784 Pp.

Slipper 2019

Slipper, I. J., 2019, Ostracoda From The Turonian Of South-East England: Palaeontographical Society, V. 655, P. 1-45.

Smith, A. J., & Delorme, L. D. (2010). Ostracoda. In Ecology And Classification Of North American Freshwater Invertebrates (Pp. 725-771). Academic Press.

REFERENCES

Smith, A. J., Horne, D. J., Martens, K., & Schön, I. (2015). Class Ostracoda. In Thorp And Covich's Freshwater Invertebrates (Pp. 757-780). Academic Press.

Smith, A.J. & Horne, D.J., 2002. Ecology Of Marine, Marginal Marine And Non-Marine Ostracodes. In: Holmes, J.A. & Chivas, A.R. (Eds), The Ostracoda: Applications In Quaternary Research, Agu Geophysical Monograph 131, 37–64.

Smith, R. J. (2000). Morphology And Ontogeny Of Cretaceous Ostracods With Preserved Appendages From Brazil. Palaeontology, 43(1), 63-98.

Smith, W. (1817). Stratigraphical System Of Organized Fossils (Vol. 1). E. Williams.

Smith, W., 1799, Tabular View Of The Order Of Strata In The Vicinity Of Bath With Their Respective Organic Remains.

Spencer, H. 1864. The Principles Of Biology, Volume 1.

Strasser A., Caron M. & Gjermeni M., 2001 - The Aptian, Albian And Cenomanian Of Roter Sattel, Romandes Prealps, Switzerland: A High-Resolution Record Of Oceanographic Changes. Cretaceous Research, 22, P.173-199.

Stuttgart, Ebner Und Seubert, 875p. (Württembergische Naturwissenschafliche Jahreshefte, 12:121-556, 13:141-396, 14:128-291)

Sylvester-Bradley, P. C. (1948). The Ostracode Genus Cythereis. Journal Of Paleontology, 792-797.

Sylvester-Bradley, P. C., & Benson, R. H. (1971). Terminology For Surface Features In Ornate Ostracodes. Lethaia, 4(3), 249-286.

Thorp, J. H., & Covich, A. P. (Eds.). (2009). Ecology And Classification Of North American Freshwater Invertebrates. Academic Press.

Tinn, O., & Oakley, T. H. (2008). Erratic Rates Of Molecular Evolution And Incongruence Of Fossil And Molecular Divergence Time Estimates In Ostracoda (Crustacea). Molecular Phylogenetics And Evolution, 48(1), 157-167.

Tran Van, P., Anselmetti, Y., Bast, J., Dumas, Z., Galtier, N., Jaron, K. S., ... & Schön, I. (2021). First Annotated Draft Genomes Of Nonmarine Ostracods (Ostracoda, Crustacea) With Different Reproductive Modes. G3, 11(4), Jkab043.

REFERENCES

Tunnicliffe, V., Mcarthur, A. G., & Mchugh, D. (1998). A Biogeographical Perspective Of The Deep-Sea Hydrothermal Vent Fauna. In Advances In Marine Biology (Vol. 34, Pp. 353-442). Academic Press.

Turpen, J. B., & Angell, R. W. (1971). Aspects Of Molting And Calcification In The Ostracod Heterocypris. The Biological Bulletin, 140(2), 331-338.

Verschuren, D. (2003). Lake-Based Climate Reconstruction In Africa: Progress And Challenges. Aquatic Biodiversity: A Celebratory Volume In Honour Of Henri J. Dumont, 315-330.

Verschuren, D., Tibby, J., Sabbe, K., & Roberts, N. (2000). Effects Of Depth, Salinity, And Substrate On The Invertebrate Community Of A Fluctuating Tropical Lake. Ecology, 81(1), 164-182.

Vila J.M., 1980 – La Chaîne Alpine D'algérie Orientale Et Des Confins Algéro-Tunisiens. Thèse De Doctorat, Université Paris Vi, 665 P.

Vila J.M., Ghanmi M. & Kechid-Benkherouf F., 1996 - Données Nouvelles Sur L'anticlinal D'el Ouasta-Sakiet (Frontière Est-Algérienne) Et Interprétation De Son Trias Comme Un « Glacier De Sel » Sous-Marin Albien Le Long D'un Bloc Basculé, Plissé Au Tertiaire. C. R. Acad. Sci. Paris, 323, Ser. Ii, P.1035-1042.

Vivière.J.L., (1985) Conducted A Micropaleontological Study Of The Upper Cretaceous In The Tébessa Region. He Provided Biostratigraphical And Paleoenvironmental Insights Through The Study Of Ostracod Fauna.

Vogt, G. (2017). Facilitation Of Environmental Adaptation And Evolution By Epigenetic Phenotype Variation: Insights From Clonal, Invasive, Polyploid, And Domesticated Animals. Environmental Epigenetics, 3(1), Dvx002.

Voigt S., Aurag A., Leis F. & Kaplan U., 2007 - Late Cenomanian To Middle Turonian High-Resolution Carbon Isotope Stratigraphy: New Data From The Münsterland Cretaceous Basin, Germany. Earth And Planetary Science Letters 235 (1-2), P.196-210. Doi:10.1016/J.Epsl.2006.10.026

REFERENCES

Voigt S., Gale A.S. & Voigt T., 2006 - Sea-Level Change, Carbon Cycling And Palaeoclimate During The Late Cenomanian Of Northwest Europe; An Integrated Palaeoenvironmental Analysis. Cretaceous Research, 27 (6), P.836-858. Doi:10.1016/J.Cretres.2006.04.005.

Von Grafenstein, U., 2002. Oxygen-Isotope Studies Of Ostracods From Deep Lakes. In: Holmes, J.A. & Chivas, A.R. (Eds), The Ostracoda: Applications In Quaternary Research, Agu Geophysical Monograph 131, 249–266

Von Grafenstein, U., Erlernkeuser, H., & Trimborn, P. (1999). Oxygen And Carbon Isotopes In Modern Fresh-Water Ostracod Valves: Assessing Vital Offsets And Autecological Effects Of Interest For Palaeoclimate Studies. Palaeogeography, Palaeoclimatology, Palaeoecology, 148(1-3), 133-152.

Wang, H., Matzke-Karasz, R., Horne, D. J., Zhao, X., Cao, M., Zhang, H., & Wang, B. (2020). Exceptional Preservation Of Reproductive Organs And Giant Sperm In Cretaceous Ostracods. Proceedings Of The Royal Society B, 287(1935), 20201661.

Webster, M., Sadler, P. M., Kooser, M. A., And Fowler, E. 2003. Combining Stratigraphic Sections And Museum Collections To Increase Biostratigraphic Resolution: Application To Lower Cambrian Trilobites From Southern California, In P. Harries (Ed.) High Resolution Stratigraphic Approaches In Paleontology. Kluwer-Academic Press.

Westermann S., Caron M., Fiet N., Fleitmann D., Matera V., Adatte T. & Föllmi K.B., 2010 – Evidence For Oxic Conditions During Oceanic Anoxic Event 2 In The Northern Tethyan Pelagic Realm. Cretaceous Research, 31, P.500 – 514.

Wheat, C. W., & Wahlberg, N. (2013). Phylogenomic Insights Into The Cambrian Explosion, The Colonization Of Land And The Evolution Of Flight In Arthropoda. Systematic Biology, 62(1), 93-109.

Whittaker, J.E. & Hart, M.B. (Eds), 2009. Ostracods In British Stratigraphy. The Micropalaeontological Society, Special Publications. The Geological Society, London, Viii Þ 485 Pp.

Williams And Norgate. London. 492p. Tipper, J. C. 1988. Techniques For Quantitative Stratigraphic Correlations: A Review And Annotated Bibliography. Geological Magazine, 125:475-94

REFERENCES

Willis, K. J., Bailey, R. M., Bhagwat, S. A., & Birks, H. J. B. (2010). Biodiversity Baselines, Thresholds And Resilience: Testing Predictions And Assumptions Using Palaeoecological Data. Trends In Ecology & Evolution, 25(10), 583-591.

Wood, E. M. R. 1900. The Lower Ludlow Formation And Its Graptolite Fauna. Quarterly Journal Of The Geological Society Of London, 56:415-492

Yuan, A. (2008). Latest Permian Deep-Water Ostracod (Crustacea) Fauna from South China (Doctoral dissertation, Université Pierre et Marie Curie-Paris VI).

Yamaguchi, S., & Endo, K. (2003). Molecular Phylogeny Of Ostracoda (Crustacea) Inferred From 18s Ribosomal Dna Sequences: Implication For Its Origin And Diversification. Marine Biology, 143, 23-38.

Yavuzatmaca, M., Külköylüoğlu, O., & Yılmaz, O. (2017). Estimating Distributional Patterns Of Non-Marine Ostracoda (Crustacea) And Habitat Suitability In The Burdur Province (Turkey). Limnologica, 62, 19-33.

Yavuzatmaca, M., Külköylüoğlu, O., Yılmaz, O., & Akdemir, D. (2017). On The Relationship Of Ostracod Species (Crustacea) To Shallow Water Ion And Sediment Phosphate Concentration Across Different Elevational Range (Sinop, Turkey). Turkish Journal Of Fisheries And Aquatic Sciences.

Yelles-Chaouche A., Boudiaf A., Djellit H. & Bracene R., 2006 – La Tectonique Active De La Région Nord-Algérienne. C.R. Geosciences, 338, P.126-139.

Yin, Y., Geiger, W., & Martens, K. (1999). Effects Of Genotype And Environment On Phenotypic Variability In Limnocythere Inopinata (Crustacea: Ostracoda). Hydrobiologia, 400, 85-114.

Zeppilli, D., Sarrazin, J., Leduc, D., Arbizu, P. M., Fontaneto, D., Fontanier, C., ... & Fernandes, D. (2015). Is The Meiofauna A Good Indicator For Climate Change And Anthropogenic Impacts?. Marine Biodiversity, 45, 505-535.

Zeppilli, D., Sarrazin, J., Leduc, D., Arbizu, Pm, Fontaneto, D., Fontanier, C., ... & Fernandes, D. (2015). Is The Meiofauna A Good Indicator For Climate Change And Anthropogenic Impacts?. Marine Biodiversity , 45 , 505-535.

REFERENCES

Zhang, T., And Plotnick, R. E. 2001. Determining The Line Of Correlation Using Genetic Algorithms. Geological Society Of America Abstracts With Programs 33(6):141 (Abstr.).

Zinsmeister, W. J. 2001. Late Maastrichtian Short-Term Biotic Events On Seymour Island, Antarctic Peninsula. Journal Of Geology, 109:213- 229.

Zuschin, M., Stachowitsch, M., & Stanton Jr, Rj (2003). Patterns And Processes Of Shell Fragmentation In Modern And Ancient Marine Environments. Earth-Science Reviews , 63 (1-2), 33-82.

Zwair, H. (2023). Perspective Chapter: Ostracoda.