Republic of Algeria Ministry of Higher Education and Scientific Research

KASDI MERBAH UNIVERSITY – OUARGLA

FACULTY OF HYDROCARBONS, RENEWABLE ENERGIES, AND EARTH AND UNIVERSAL SCIENCES

DEPARTMENT OF EARTH AND UNIVERSAL SCIENCES

Master's Dissertation

Field of Study: Geology

Specialization: Geology of Sedimentary Basins

Micropaleontology of Foraminifera from the Upper Jurassic of the Chellala Mountains

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Academic Year: 2025/2026

Acknowledgments

After praise and gratitude to God, by His grace and guidance this work—represented in this Master's graduation thesis—has been accomplished. It stands as the fruit of twenty years of perseverance and dedication.

It is my honor, at the outset, to extend sincere thanks to all those who contributed to the success of this endeavor:

To ourselves, **Kholoud and my colleague Hanan**, for our commitment and determination.

To our supervising professor, **Ms. Zouit K.**, for her guidance and support.

To **Professor Maazouzi A. M.**, with deep appreciation for his valuable contributions.

To my fellow classmates, whose companionship enriched this journey.

To all those who remembered me in their prayers, asking for my success and the easing of my path.

Finally, all praise is due to God, through Whose grace all good works are completed.

Dedication

I dedicate this work, first and foremost, to myself my khouloud—who has endured much hardship and persevered until joy was finally attained, by the grace of God.

I dedicate it to those who raised me with the finest upbringing and values:

To my beloved mother, Ghalia, whose prayers illuminated my path and eased my journey toward success.

To my father, Mohamed, whose unwavering encouragement and sacrifices enabled me to pursue my academic path and achieve my goals.

I also dedicate this work to my pillars of strength—my dear siblings—whose support has always been a source of comfort.

To the one most cherished in my heart, **A**, and to my dear aunt **S**, may God preserve your honor and grant you success in all aspects of life.

To all of you, I extend my deepest gratitude and appreciation, from the very core of my heart.

First and foremost, I thank Allah for giving me the strength and perseverance to complete this work.

I dedicate this achievement to my beloved mother and dear grandmother, whose love, prayers, and support have always been the source of my success.

To my brothers and sisters, my family, and my friends for their encouragement and support throughout my academic journey.

Finally, I dedicate this work to everyone who contributed, directly or indirectly, to its completion.

Hanane Alioua ✨

Abstract

Based on the geological investigations carried out on the Upper Jurassic succession of the eastern Chellala Mountains, located along the Algerian Atlas margin, significant progress has been achieved in understanding the lithostratigraphic, sedimentological, and micropaleontological evolution of the Djebel Harraza area. The studied Lower Kimmeridgian succession was subdivided into two distinct lithological units, reflecting variations in depositional conditions during sedimentation.

Micropaleontological analysis of the collected samples revealed a diverse foraminiferal assemblage comprising 30 taxa, including both agglutinated and hyaline forms. The vertical distribution of these taxa allowed the recognition of three characteristic foraminiferal assemblages, providing a refined biostratigraphic framework for the Lower Kimmeridgian succession.

From a paleoenvironmental perspective, the integration of foraminiferal assemblages with sedimentological observations indicates that the depositional environment experienced successive variations in water depth. These environmental changes were primarily controlled by eustatic sea-level fluctuations, which influenced the distribution of foraminiferal communities and the evolution of the depositional settings throughout the studied interval.

Keywords: Chellala Mountains, Lower Kimmeridgian, Djebel Harraza, foraminiferal assemblage

الملخص : .

استنادًا إلى الدراسات الجيولوجية المنجزة على تعاقبات الجوراسي الأعلى في الجزء الشرقي من جبال الشلالة الواقعة على هامش الأطلس الجزائري، أحرزت هذه الدراسة تقدمًا مهمًا في فهم التطور الليثوستراتيغرافي والرسوبي والميكروباليونتولوجي لمنطقة جبل الحرازة. وقد أظهرت النتائج أن تعاقبات الكيمريدجي الأسفل يمكن تقسيمها إلى وحدتين ليثولوجيتين متميزتين، تعكسان التغيرات التي شهدتها ظروف الترسيب خلال هذه الفترة.

وأظهرت الدراسة الميكروباليونتولوجية للعينات وجود تجمع غني من المنخربات (Foraminifera) يضم 30 نوعًا تنتمي إلى الأشكال الملتحمة (Agglutinated) والزجاجية .(Hyaline) ومن الناحية البيوستراتيغرافية، مكّن التوزيع الرأسي لهذه المنخربات من التعرف على ثلاثة تجمعات أحفورية مميزة، مما ساهم في تحسين الإطار الطباقي الحيوي لتعاقبات الكيمريدجي الأسفل.

أما من الناحية البيئية القديمة، فقد بينت النتائج، بالاعتماد على توزيع المنخربات والخصائص الرسوبية، أن البيئة الترسيبية شهدت تغيرات متعاقبة في عمق المياه، ويُعزى ذلك أساسًا إلى التذبذبات اليوستاتية (التغيرات العالمية في مستوى سطح البحر)، والتي كان لها تأثير مباشر في توزيع المنخربات وتطور البيئات الترسيبية خلال الفترة المدروسة.

الكلمات المفتاحية :جبال الشلالة، الكيمريدجي الأسفل، جبل الحرازة، تجمعات المنخربات.

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Introduction

The Upper Jurassic in the Tiaret was a period during which depositional conditions and geodynamic history were extensively studied beginning in the 1970s. The lower Kimmeridgian interval has been the subject of several stratigraphic and sedimentological investigations (Caratini, 1970; Guiraud, 1973 ; 1982 ; ATROPS and BENEST, 2016 ; Maazouzi *et al.*, 2023 et Maazouzi 2025), through sedimentological and biostratigraphic analyses in the Chelalla Mountains, have provided new insights that complement earlier lower knowledge.

This work is devoted to the study of microfauna (foraminifera) of Lower Kimmeridgian age in the Chelalla Mountains, based on a geological section measured at Djebel Haraza. The study is organized into four chapters:

- **Chapter One** presents general information, including the geographical setting, general and structural geology of the studied area, as well as a review of the principal works carried out on the “Chelalla Clays Formation.”
- **Chapter Two** focuses on lithostratigraphic analysis, comprising lithological descriptions and stratigraphic subdivisions.
- **Chapter Three** is dedicated to the study of foraminifera, identified The objective is to refine the subdivision of the Kimmeridgian stage through a comprehensive view of its microfaunal content.
- **Chapter Four** aims to establish the characteristic associations of depositional environments, in an attempt to identify the main ecological and sedimentological factors controlling the distribution of these foraminifera.

Finally, the work concludes with a general synthesis summarizing the results of this study.

Chapter 01: General Overview of the Study Area

1- The main structural areas of Algeria

The geology of Algeria is conventionally divided into four major physiographic and structural regions from north to south:

- The Tell Atlas (Tellian Atlas): This northern region is characterized by rugged mountainous relief and fertile coastal plains, including the Mitidja Plain in central Algeria, the Chelif Plain in the west, and the Seybouse Plain in the east.
- The High Plateaus: Located between the Tell Atlas and the Saharan Atlas, this extensive semi-arid steppe region forms a transitional zone marked by broad plains, internal drainage basins, and scattered salt depressions.
- The Saharan Atlas: This region comprises a continuous chain of mountain ranges trending northeast–southwest (NE–SW), extending from the Moroccan border in the west to the Tunisian border in the east. It forms the southern boundary of the High Plateaus and separates them from the Sahara.
- The Algerian Sahara: Occupying the largest part of the country, the Algerian Sahara is a vast desert region that contains most of Algeria's hydrocarbon resources. It is characterized by extensive sand seas (the Great Eastern Erg and the Great Western Erg), broad stony plains (regs), and numerous oases that constitute important urban centers, including El Oued, Ghardaïa, and Djanet (Fig. 1). To the south, the Eglab Massif in the southwest and the Hoggar Massif in the southeast define the geological limits of the Algerian Sahara.

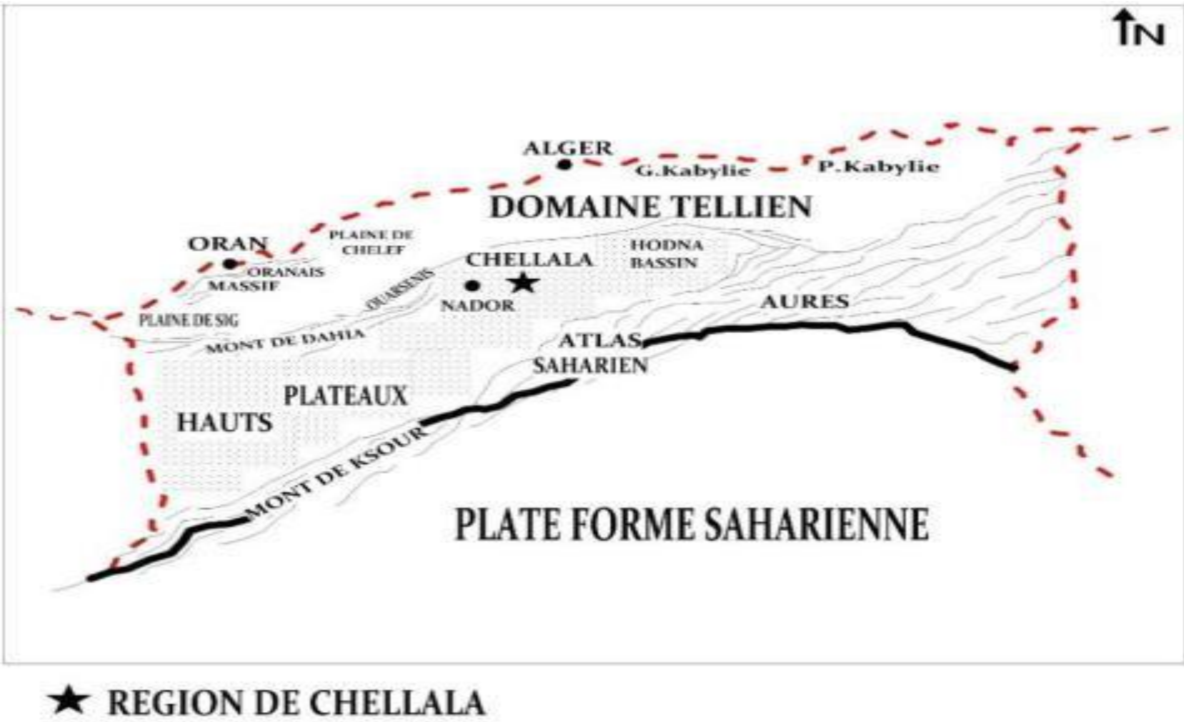


Figure 1: Geographical setting of the study area (adapted from Frizon de Lamotte et al., 2000)

The Chellala Mountains are situated in the northeastern portion of the Western High Plains, representing an intermediate transitional zone between the major geographical systems of Algeria that separates the Tellian geosyncline from the Saharan Atlas domain. Geographically and structurally, the Chellala Mountains are assigned to the Pre-Atlasic domain (Guiraud, 1973), which is integrated into the northern margins of the Atlasic realm. The northern boundaries of the study area correspond to the Tell Atlas, while the Saharan Atlas marks its southern limit. Topographic elevations generally range between 400 and 700 meters, locally reaching up to 1000 meters in certain localities (Fig. 02).

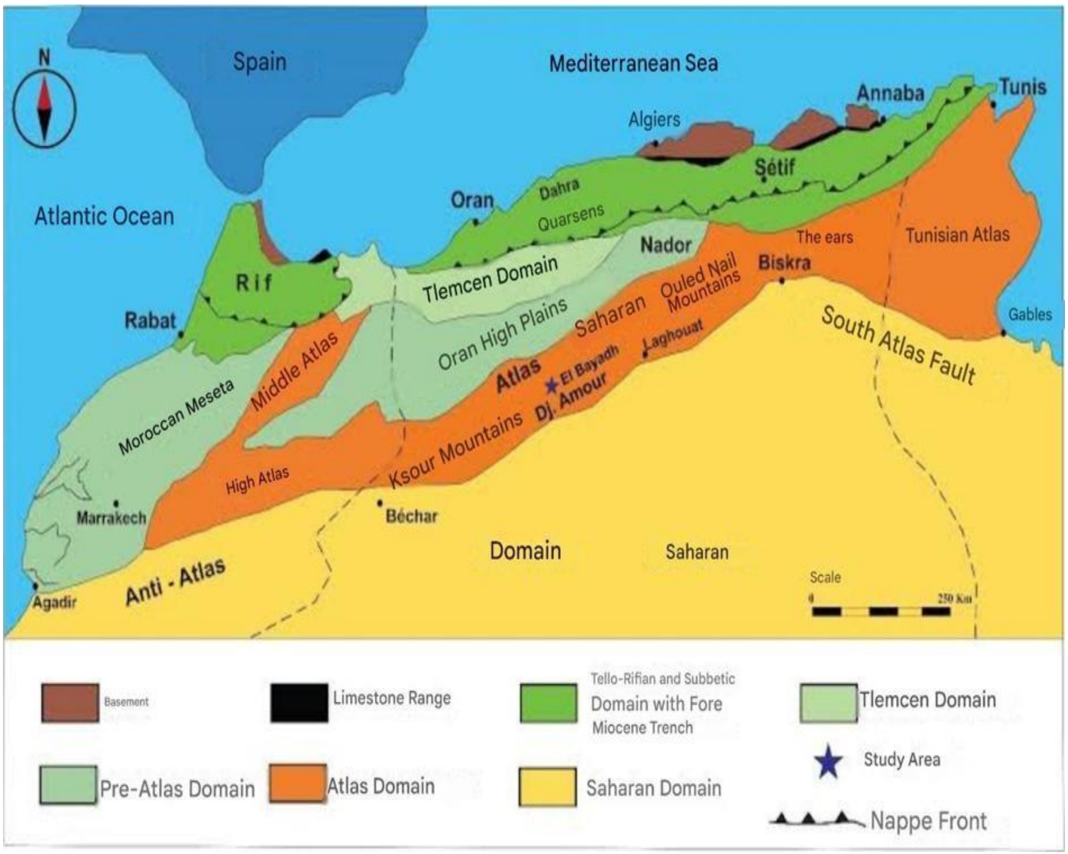


Figure 2: Principal structural domains of Algeria and the Western Mediterranean (adapted from Frizon de Lamotte et al., 2000).

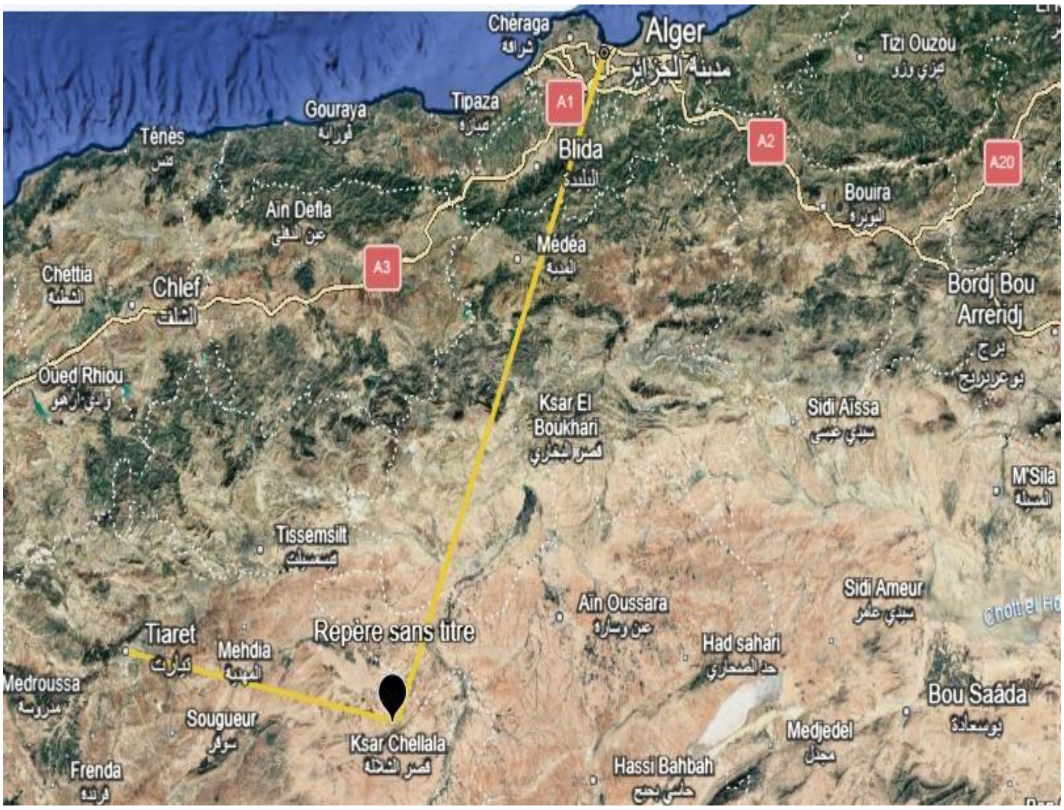


Figure 3: Satellite image showing the location of the Chellala Mountains (prepared by the authors using Google Earth; imagery accessed on June 13, 2026, at 10:00 a.m.)

2- General geological framework

The Chellala complex is generally characterized by a prominent mountain range that exhibits intricate structural details.

This range extends from **Djebel Metales** and the **Zerga diapirs** in the southwest to **Djebel Serguine** in the northeast, traversing Tniet el Hamra, Draa Zidia, the trio of Djebel Keskas, Albiod, and Mendjel, followed by Djebel Ben Hemad and Seba el Hadid, and finally the Djefala region and Djebel Kradou along the entire extent of the main anticline.

The southwestward continuity of the Nador-Chellala alignment is interrupted by a complex zone, whereas its northeastern extremity is characterized by the abrupt disappearance of Jurassic strata (Caratini, 1970).

As established by Caratini (1970), the main anticline corresponds to an elongated massif composed of a cluster of structures that can be subdivided into two distinct sections by the complex region of Djefala:

- **Western Section:** Djebel Ben Hemmad.
- **Eastern Section:** Djebel Serguine.

The sedimentary formations in this region exhibit tabular structures characteristic of nearly all High Plateaus (*Hauts-Plateaux*) formations, owing to the absence of major tectonic or orogenic events throughout the regional geological history.

Within the Mesozoic Era, **Jurassic** and **Cretaceous** deposits are the most predominant. In the Cenozoic, the **Miocene** is marked by marine deposits, which succeeded a period of Paleogene erosion (Caratini, 1970).

Djebel Ben Hemad

The structural architecture of this massif is simple within its central sector (Fig. 03) and is characterized from north to south by the following features (Caratini, 1970):

- A major fault traces nearly the entire length of the main anticline located in **Djebel Keskas**.
- The southern flank is highly regular in its southernmost portion, though it is punctuated by a few fractures in its median zone.
- To the southwest, the massif terminates in a periclinal closure, with a distinct radial fault observed at **Kef Fchima** and **Draa Zidia**.
- To the northeast, the massif plunges gradually, resulting in numerous small-scale irregularities that are difficult to quantify due to the dolomitic nature of the terrain.

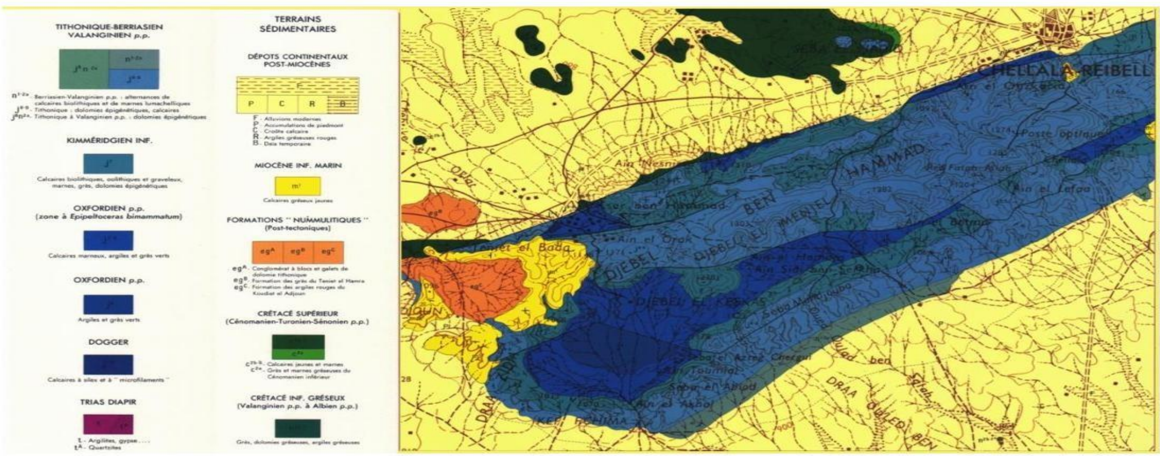


Figure 4 : geological map of the Chellala-Reibell at 1/50 000 scale

Geological Survey of Algeria (ASGA). (2002). Geological map of Algeria (Scale 1:200,000). Ministry of Energy and Mines

3-Lithostratigraphic Overview

According to the pioneering work of Caratini (1970), which remains the foundational reference for the geological study of the Chellala region, the stratigraphic succession is defined as follows:

1-3 :Triassic

The Triassic is generally characterized by diapiric structures outcropping in the southwestern sector of the Chellala Mountains. These diapirs are composed of incompetent, plastic material (gypsum, halite, and argillites) associated with dolomites (Fig. 3) (Regagda, 2016).

2-3 :Jurassic

- **Dogger (Middle Jurassic):** The Dogger outcrops near Ksar Ben Hammad and is characterized by chert-bearing (flint-bearing) limestones.
- **Upper Callovian – Lower to Middle Oxfordian:** This interval is characterized by the deposition of argillaceous marls, sandy marls, and green sandstones. Due to poor exposure and incomplete outcropping, its total thickness cannot be accurately determined (Regagda, 2016).
- **Upper Oxfordian:** This sequence reaches a thickness of approximately 150 m and is subdivided into:
  - A fossiliferous blue-grey marly limestone formation.
  - A fossil-poor, green argillaceous-sandy formation.
- **Lower Kimmeridgian:** interval is represented from base to top by:
  - Dolomitized marly sandstones.
  - Beds of dolomitized limestone.
  - Marly sandstones.

Tithonian – Berriasian – Valanginian Transition: consist of carbonate deposits (limestones and dolomites) marking the transition from the Jurassic to the Cretaceous without any significant variation in sedimentary conditions. This boundary lacks distinct biostratigraphic indicators in the area and is defined on a purely lithological basis.

3-3 : Cretaceous

- **Lower Cretaceous:** Primarily siliciclastic, this interval encompasses formations ranging from the Valanginian to the Albian. It is lithologically characterized by sandstones, dolomitic sandstones, and argillaceous sandstones.

- **Upper Cretaceous:** This sequence initiates with yellow limestones and marls, which progressively transition into sandstones and sandy marls assigned to the Lower Cenomanian.

3-4 : Paleogene (Nummulitic Formations)

From base to top, the following syn-tectonic detrital formations can be distinguished:

- Conglomerates containing clasts of Tithonian dolomite.
- The Tniet El Hamra Sandstone Formation.
- The Koudiat El Aldjoun Red Clay Formation.

Neogene and Quaternary

- **Lower Marine Miocene:** This unit is represented by transgressive and unconformable yellow sandy limestones resting discordantly on the older substratum. The shallow-water depositional environment favored the accumulation of these hybrid sandstone-carbonate sediments (Caratini, 1970).

- **Post-Miocene Continental Deposits:** These consist of Quaternary alluvial deposits, piedmont accumulations, and yellowish calcretes (calcareous and sandy clay crusts).

Structural and Tectonic Framework

The Chellala-Reibell Mountains exhibit a highly complex structural architecture; however, their primary configuration can be schematically defined by the following major structural features:

- **The Reibell Fault Zone:** This major, regional-scale fault zone strikes along a trend (parallel to the Atlasic directional trend). It acts as a major structural boundary separating two distinct tectonic domains:

- **The Southern Domain:** Characterized by the main anticline, which also aligns with the Atlasic trend. It displays a relatively simple structural geometry, except at its lateral extremities.
- **The Northern Domain:** Comprising a significantly less tectonically deformed region, where the primary fold axes exhibit an approximate orientation.

The structural terminations of the main anticline highlight distinct tectonic behaviors at both ends:

- **To the East:** The Serguine region is characterized by the abrupt truncation and disappearance of the Jurassic strata.
- **To the West:** A complex structural zone accommodates the transition and separates the Ben Hammad massif from **Djebel Koudiat** (the easternmost extension of Djebel Nador).

The Main Anticline

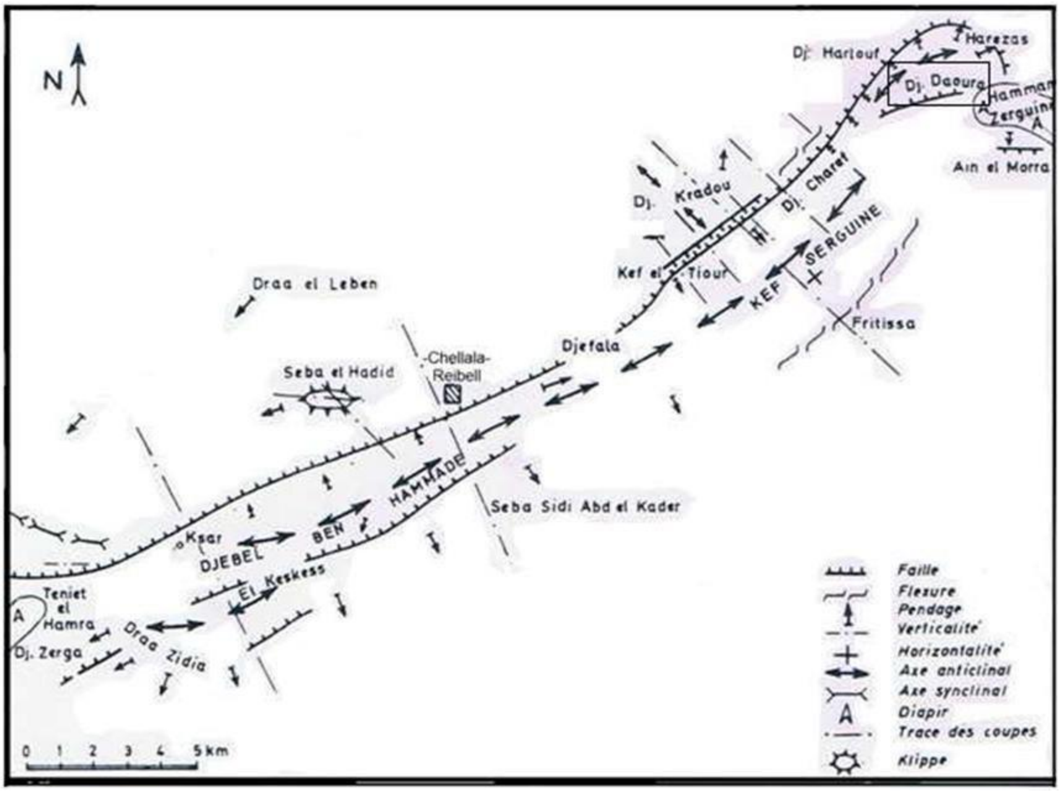
The main anticline can be divided longitudinally into two distinct structural units separated by the topographically depressed region south of Djefala:

- - Djebel Ben Hammade to the west;
- - Djebel Serguine to the east.
- In this section, we will only present the Serguine region.
- - Djebel Serguine

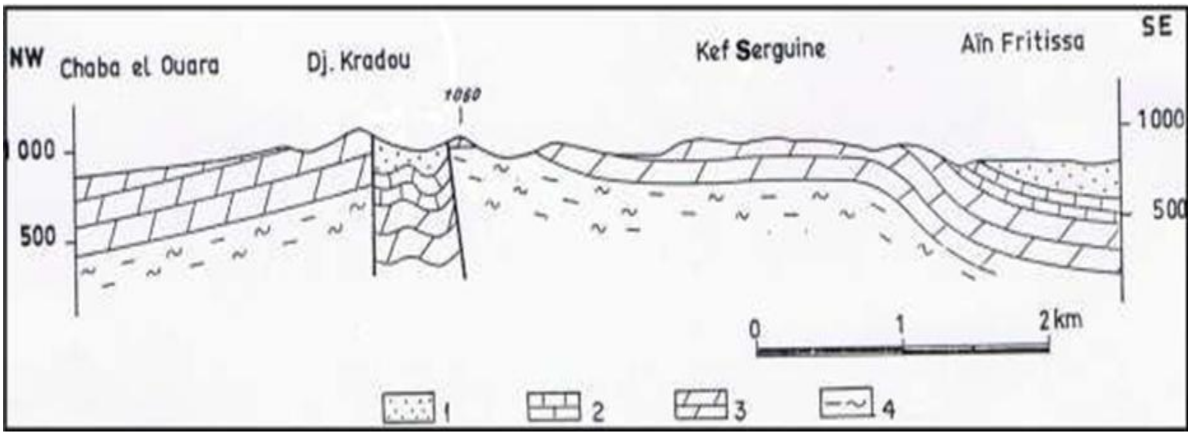
- Rather than representing a true anticlinal fold, Djebel Serguine is interpreted as a plateau situated along the extension of the Ben Hammade anticline. The strata are predominantly subhorizontal but steepen northward adjacent to the major Reibell (Chellala) fault. To the south, a sharp flexure generates dips greater than 45°, whereas a subsequent flexure with reverse curvature farther south reduces the dip, leaving the strata gently inclined southward by only a few degrees

- To the east, the Djebel Serguine is marked by the Khradra-Serguine springs fault. The uppermost Jurassic and the carbonate base of the Cretaceous disappear beneath relatively undeformed Miocene formations before reappearing around the Djebel Daoura.

- Northeast of the town of Chellala, folded terrains appear beneath a layer of Jurassic marl-limestone and dolomite. These formations define an area called Serguine, a region characterized by the presence of thermal springs.
- The Serguine region is structurally complex, with its main peaks being Djebel Harlouf, the Daoura anticline, Djebel Harezas (or Haraza), and Ain El Mora.



: Figure 5 Structural map: Chellala-Reibell mountains (Caratini, 1970).



1. Neocomian, sandstone; 2. Berriasian-Valanginian; 3. Tithonian; 4. Oxfordian – Lower Kimmeridgian:

Figure 6 Structural presentation of the Serguine region (Caratini, 1970).

Previous Research

The first work in the Chellala region dates back to those of Ville (1846) and Renou (1848).

- As early as 1862, Coquand announced the existence of the Corallian and Kimmeridgian stages atDjebel Recheiga, based on fossils collected there by Ville.- Peron (1869-1883) produced the first cross-sections of the Chellala massif, providing asignificant paleontological inventory for the first time.

- It was not until Delau (1948) that the basic stratigraphy and structure of Djebel Nador were established, and Kar poff (1950) delineated the outlines of central Nador and the Chellala-Reibell massif as they appear on the 1952 edition of the 1:500,000 geological map of Algeria. In 1965, AUCLAIR and BIEHLER published the results of the SNR epal study on the Oran High Plains. In the same year, Augier published a report on the High Plateaus.
- In 1970, CARATINI's thesis, entitled "Geological Study of the Chellala-Reibell Region, "was published. In this work, the author details the stratigraphic and tectonic framework of this region. This thesis remains the most important work on this area.

- Guiraud (1973) presented a detailed study on the post-Triassic evolutionof the Alp ine foreland in Algeria.- From the 1980s onward, ATROPS and BENEST, along with other geologists, published several works on the Chellala region.

- In 1982, ATROPS and BENEST discovered ammonites from the Polatynota zone (Lower Kimmiridjian) in the Chellala Mountains for the first time.

- A year later, ATROPS, BENEST, and LE HEGARAT presented a study on the Thitonic deposits of Djebel Recheiga near Chellala.

- In 1985, BENEST presented his doctoral thesis on the Upper Jurassic and Lower Cretaceous platform deposits of western Algeria and eastern Morocco.

- In 1993, MABROUK presented a systematic and biostratigraphic study of the Tertiary period. continental Algeria, citing the Koudiat El Aldjoun deposit in the Chellala region.

- BENEST, ATROPS, andCLAVEL (1994) present a study on the Lower Kimmeridgian echinoids of the Chellala Mountains, adopting the paleoenvironment and eustatic model.

- Starting in 2016, sedimentological studies in the Serguine region on series equivalent to ours,aimed at characterizing the Lower Kimmeridgian Thitonic succession, particularly in the Djebel Harezas, Djebel Harlouf, and Djebel Ain Mora sectors, have been presented in Master's theses (Regagda, 2016; Ammari and Bouggouffa, 2017; and Ammari and Touahar, 2017).

- Methodology

work is a continuation of the study carried out by Caratini in 1970, which remains the sole reference for any geological study focused primarily on stratigraphy.

The objective of this study is to contribute to the sedimentological and stratigraphic analysis of the Chellala Mountains. Therefore, this study is based on a detailed inventory of the facies to determine the depositional environment, as well as a search for microfauna to precisely date our series of samples.

B- Methodology

1- Field

A single geological section was created, including a detailed description of the facies and their fossil content. Precise sampling was carried out, with approximately 500g of sediment collected from each interval. Each sample was then packaged in a plastic bag labeled with its location on the section.

2- Laboratory

In the laboratory, we prepared the samples using the method for soft sediments; the method is sample washing.

- Water Washing

For each bank, a 200 g sediment sample was immersed in water until fully disaggregated. The resulting material was wet-sieved through a series of 250, 125, 90, and 63 µm mesh screens. The dried residues were sorted under a binocular microscope, and the recovered microfossils were picked and mounted on micropaleontological slides for taxonomic identification. Selected specimens were then imaged using a scanning electron microscope (SEMCalcimetry

- *Principle*

Calcimetry was proformed using the Bernard calcimeter method, which is based on measuring the volume of carbon dioxide ($CaCO3$) released when carbonate minerals react with hydrochloric acid (HCl). The amount of CaCO3 produced is directly proportional to the calcium carbonate ($CaCO_3$) content of the sample.

The reaction is expressed as follows:

$$CaCO_3+2HCl \rightarrow CaCl_2+H2O+CO2$$

- *Procedure*

1. A representative sample weighing 0.5 g was finely ground and introduced into the reaction flask of the Bernard calcimeter for carbonate analysis Hydrochloric acid (HCl=10%) was added to the sample.

2. The reaction flask was immediately sealed to ensure an airtight system and prevent the escape of gas.

3. The reaction between $CaCO_3$ and HCl generated CO_2, which displaced water in the graduated tube.

4. The volume of released CO_2 was measured and used to calculate the calcium carbonate content.

- *Calculation*

The volume of carbon dioxide released was calculated using: $V\ CO_2=Vf-Vi$

where:

- VF=19ml (final reading)
- Vi= 0ml (initial reading)

-Therefore: $V\ CO_2=19$Under standard conditions: 1mol CO_2=22400ml

-Since: 100g $CaCO_3 \rightarrow$22400ml CO_2

-the mass of $CaCO_3$ in the sample is: m CaCO$=\frac{19\times100}{2400}$=0.79g

-The percentage of calcium carbonate is then: % $CaCO_3$$==\frac{0.79}{0.5}\times 100 = 7.9\%$

-Result:The analyzed sample contains 7.9% $CaCO_3$.

Sample Washing Stage

Screening Stage under binocular loupe

Stage of dissolving NaOH salt in distilled water

Titration stage

Figure 7: Laboratory Equipment

Chapter 02 : Lithostratigraphy

II- Introduction

Within the framework of a detailed investigation of the Upper Jurassic interval, this part of the study focuses on the detailed lithostratigraphic characterization of the djbele hraza section located in the Chellalla region, northwestern Algeria.

II. Geographical Location of the Studied Section

This section was measured approximately 24 km north of the village of Serguine, near Hammama (Fig. 9).

Figure 8: Photographic presentation of the measured section at Haraza Mountain (A–B: Section trace). Prepared by the Students

III. Lithostratigraphic description

This formation consists of a thick package or a massive succession of marls and carbonate bars belonging to the Marno-Calcaires de Harraza Formation (Lower Kimmeridgian). It is subdivided into two major sub-units (Unit A and Unit B), which are distributed across eight lithological intervals (from E1 to E8):

- **unit 1 (Unit A: from 0 to 34m)**

This unit is characterized by a basal alternating sedimentation that transitions vertically into significant marly masses. It is organized into three distinct intervals: Interval E1 (0 - 15m): The sequence begins with a thick series characterized by regular marl-limestone alternations, reflecting a low-to-medium energy depositional environment. Interval E2 (15 - 19m): This interval starts with a thin horizon of marls, immediately overlain by distinct, well-individualized, and competent limestone beds. Interval E3 (19 - 34m): The top of this sub-unit is materialized by a large package of homogeneous marls (greenish/greyish marls), testifying to a deepening phase and high hydrodynamic stability within the basin.

- **unit 2 (Unit B: from 34 to 93m)**

In this unit, a megacyclic sedimentation dominated by alternations takes place, crowned by key horizons toward the top. It groups five lithological intervals: Intervals E4 and E5 (34 - 74m): They form the major part of the succession, featuring a long, continuous sequence of marl-limestone alternations extending over nearly 40 meters of thickness. Interval E6 (74 - 77m): This is a brief but highly characteristic episode, marked by a bioclastic limestone bed, directly overlain by a metric layer of a marker limestone with bioclastic and dolomitic affinities. This level constitutes an excellent key horizon for regional stratigraphic correlations. Interval E7 (77 - 89m): This interval is marked by the return of a thick package of marls, locally interrupted by a thin limestone intercalation. Interval E8 (89 - 93m): The top of the upper unit concludes with the return of marl-limestone alternations, capped by a final compact limestone bar at the 93m mark.

5.3. Lithological Transitions

Contact analysis shows gradual lithological transitions between most of the intervals (indicated by the progressive shifting of facies), and notes the absence of major unconformities or intermediate erosional surfaces, which attests to continuous and stable sedimentation throughout the deposition

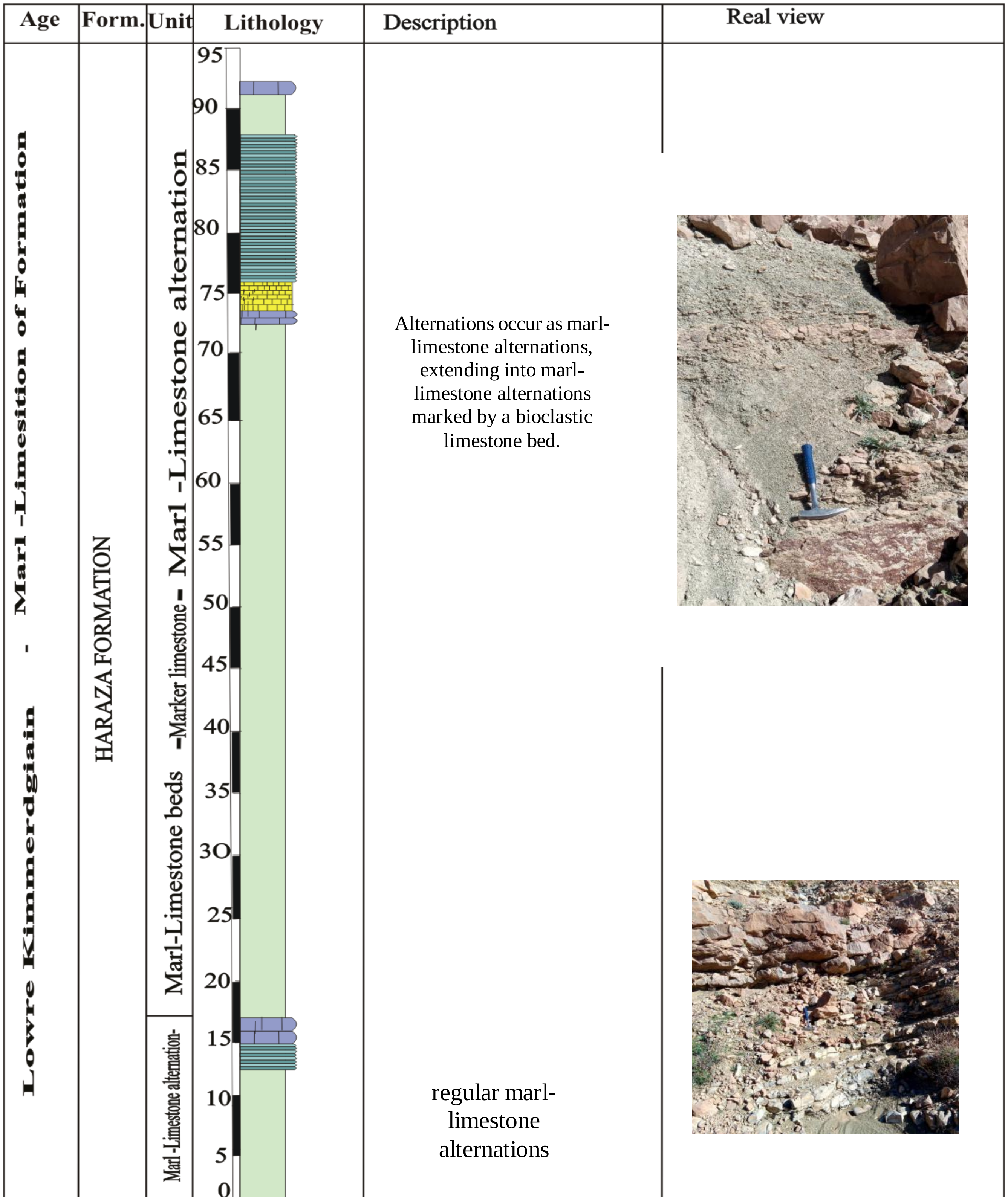


Figure 9 : Lithostratigraphic column of the lower kimmeridgien of djbale Harraza Prepared by the Students

Chapter 03 : Micropaleontology

Introduction

As part of a micropaleontological study of the foraminiferal microfauna from the Haraza section, this part of our research is based on a detailed inventory of the foraminiferal assemblages in order to provide new interpretations, particularly regarding the paleoenvironmental framework.

1- Definition

Foraminifera are protozoans belonging to the class Rhizopoda. They are generally marine organisms, either benthic or planktonic. Their size typically ranges from 38 µm to 1 mm. Their diet consists of bacteria, algae, mollusk larvae, crustaceans, and various organic debris. The abundance of foraminifera in marine sediments allows for reliable biostratigraphic and paleoecological studies. The foraminifera examined in the Haraza section constitute valuable environmental indicators.

2- Classification

The foraminifera collected from the Haraza section were sampled from eight (08) stratigraphic levels within the two units of the section. The extraction was carried out either by the technique of washing and sieving clays under running water or through thin-section analysis.

The systematic study of the foraminiferal assemblages is based on taxonomic determination and classification following the works of **Loeblich and Tappan (1987; 1998)**.

This classification relies primarily on:

- **Nature of the test**: calcareous, chitinous, hyaline, or agglutinated; and the microstructure of the test (porcelaneous or hyaline).
- **Morphological criteria**: following Loeblich and Tappan (1988 and Gupta 1999).
- **Additional classification criteria**: adopted from earlier works, including chamber arrangement (d'Orbigny , 1826), septation of the test (Schultze, 1854), and the shape and position of the aperture (Hofker, 1951).
- Micropaleontological observations in the studied region reveal the existence of two distinct assemblages:

Microfaunal Inventory

Lenticulina münsteri (Römer)

Description

Large, lenticular, biconvex, involute test composed of 10 to 12 chambers that progressively increase in size toward the final chamber. The umbilical area is marked by a well-developed central boss. Sutures are fine, barely visible, and slightly curved toward the peripheral margin. The peripheral margin is rounded to slightly carinate. The aperture is terminal, circular, radiate, and located on a short neck.

Stratigraphic distribution: reported from the Lias to the Malm in the literature.

Distribution in the section : E1, E2, E3, E4, E5, E6, E7, E8

Lenticulina varians (Bornemann)

Description

Calcareous hyaline test, planispirally enrolled and involute. The shell is lenticular and biconvex, composed of numerous chambers that increase progressively in size. Sutures are curved and well marked, and the periphery is rounded to slightly keeled. The aperture is terminal and radiate.

Stratigraphic distribution: Middle Jurassic to Upper Jurassic.

Distribution in the section: Recorded in samples E2,E3,E5,E6,E7.

Lenticulina Kujaviana

Description

Calcareous hyaline test, lenticular and biconvex in shape, with a planispiral involute coiling. The chambers increase gradually in size during growth. Sutures are curved, distinct, and slightly depressed. The periphery is rounded to weakly keeled. The aperture is terminal and radiate.

Stratigraphic distribution: Middle Jurassic to Upper Jurassic,

Distribution in the section: E1

***Paalzowella* sp.**

Description

The test is small, calcareous, and trochospiral, with a low conical to conical shape. The spiral side is convex, whereas the umbilical side is flat to slightly convex. Chambers are inflated and increase gradually in size during growth. Sutures are distinct and slightly depressed. The aperture is interiomarginal, situated at the base of the last chamber.

Stratigraphic distribution: Aalenian to Kimmeridgian**.**

Distribution in the section: E2, E3, E4, E5, E6, E7.

***Dorothia* sp.**

Description

Agglutinated test, elongate and tapering, initially trochospiral and later becoming biserial. Chambers increase gradually in size throughout growth. Sutures are distinct and slightly depressed. The wall is agglutinated, composed of fine sediment particles. The aperture is terminal, located at the end of the last chamber.

Stratigraphic distribution: Middle Jurassic to Upper Jurassic, with a wide distribution in marine environments.

Distribution in the section:E1, E2, E3, E4, E6, E7

***Pseudomorossonella hechti* .**

Description: Test agglutinated, medium-sized, trochospiral in the early stage and becoming more complex during growth. Chambers numerous, arranged in successive whorls and gradually increasing in size. Sutures distinct and slightly depressed. Wall agglutinated, finely perforated and composed of calcareous particles. Aperture multiple (cribrate), situated at the base of the apertural face.

Stratigraphic distribution: Middle Jurassic to Upper Jurassic (Bathonian–Tithonian).

Distribution in the section: E1

Cyclammina concellata

Description : Test agglutinated, large and planispiral, involute to slightly evolute. Chambers numerous, increasing gradually in size as added. Sutures distinct and slightly depressed. Periphery rounded. Wall agglutinated, composed of fine-grained particles. Aperture interiomarginal, situated at the base of the last chamber.

Stratigraphic distribution: Jurassic – Cretaceous.

Distribution in the section: E3

***Glomospira* sp .**

Description: Test agglutinated, small and irregularly coiled, typically forming a streptospiral (irregular spiral) or planispiral early stage. Chambers tubular and undivided, arranged in a continuous coiling tube rather than clearly separated chambers. Wall composed of fine agglutinated particles. Aperture simple, terminal.

Stratigraphic distribution: Jurassic to Recent, commonly found in deep marine to outer shelf environments.

Distribution in the section: E1, E2, E5

***Globigerina* sp.**

Description

Globigerina sp. is a planktonic foraminifera with a calcareous hyaline test. The test is globular and trochospiral with inflated chambers. Sutures are curved and well marked. The aperture is umbilical with a lip.

Stratigraphic distribution: It ranges from the Upper Cretaceous to Recent, and is widely distributed in open marine

Distribution in the section: E1, E5, E8

***Rhizommina* sp.**

Description

Rhizommina sp. is a benthic foraminifera with an agglutinated, tubular to branching test. The test is irregular and thread-like. Apertures are simple and terminal.

Stratigraphic distribution: It is mainly found in the Upper Jurassic and Cretaceous to Recent, especially in deep marine and soft sediment environments.

Distribution in the section: E2, E3, E6, E7, E8.

***Bathysiphon* sp**.

Description:

is an agglutinated benthic foraminifer characterized by a long, tubular test that is straight or slightly curved. The test wall is composed of fine sediment particles cemented together. It is unilocular and possesses a simple aperture located at the end of the tube**.**

Stratigraphic Distribution: Bathysiphon has a long stratigraphic range extending from the Jurassic to the Recent and is commonly found in marine sediments, particularly in deep-water environments.

Distribution in the section :E6, E7, E8

***Ophtalmidium* sp**

Description

The test is calcareous, porcelaneous, free, and planispirally enrolled. It is discoidal to lenticular in shape, with chambers arranged in a quinqueloculine to planispiral mode during growth. Sutures are distinct and slightly depressed. The aperture is terminal, rounded, and provided with a tooth.

Stratigraphic distribution: Triassic to Upper Jurassic,

Distribution in the section: E2, E3

I. Biostratigraphic Distribution of Foraminifera

Analysis of the vertical distribution of foraminifera has improved the stratigraphic characterization of the Harraza Formation. The identified foraminiferal assemblages define three distinct bioassemblages that characterize the Lower Kimmeridgian interval, providing a refined biostratigraphic framework for the studied succession.

Assemblage 1 : This assemblage dominated by rich agglutinated benthic foraminifera, represented by: *Lenticulina munsteri Lenticulina quendesti Lenticulina kujaviana Bolivina sp. Dentalina sp. Pseudomarssonella hetchi Pseudomarssonella jurassica Pseudomarssonella sp. Glomospira sp. Globogerina sp. Reophax sp., Eoguttulina sp., Dorothia* sp1, *Dorothia sp2, Trochammina* sp., *Triplasia* sp. *Paalzowella sp1, Lenticulina varians, Ophtalmidium sp., Rhizammina* sp.

Assemblage 2: This assemblage characterised by increasing in hyaline forms with increased faunal diversity and more stable conditions: *Lenticulina munsteri Bolivina sp. Glomospira sp. Globogerina sp. Reophax sp. Dorothia sp1 Dorothia sp2 Paalzowella sp1 Paalzowella sp2 Lenticulina varians Ophtalmidium sp. Rhizammina sp. Lenticulina sublata Cyclammina concellata Ammodiscus siliceux Lenticulina filosa Quenqueloculina sp. Lenticulina fraasi Spirillina infima.*

Assemblage 3: This assemblage is characterized by a predominance and rich in agglutinated forms. It's characterized by the dominance of this species: *Lenticulina munsteri Bolivina sp. Glomospira sp. Globogerina sp. Reophax sp. Dorothia sp1 Trochammina sp. Paalzowella sp1 Paalzowella sp2 Lenticulina varians Ophtalmidium sp. Rhizammina sp. Lenticulina sublata Quenqueloculina sp. Lenticulina fraasi Spirillina infima Bathysiphon sp. Dentalina gumbeli.*

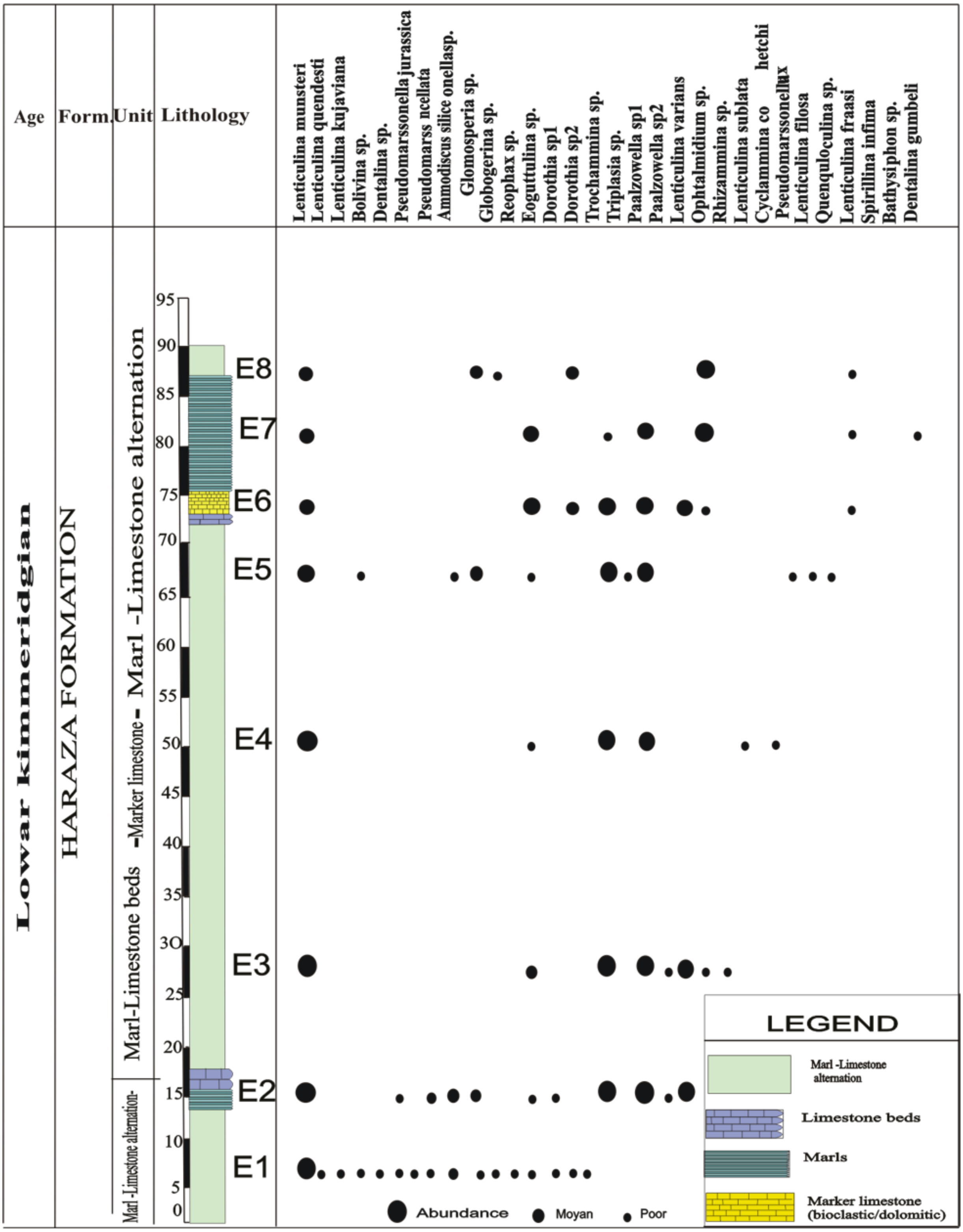


Figure 10: Vertical distribution of foraminifera in the section (Djebel harraza).

Prepared by the Students

Chapter 04 : Paleoenvironmental Interpretation

I- Introduction

The vast majority of foraminifera are marine organisms; approximately 95% of them live a benthic lifestyle. Early ecological studies emphasized the bathymetric distribution of benthic foraminiferal assemblages. However, when bathymetry alone proved insufficient to explain faunal distributions, physicochemical factors emerged as more reliable indicators of spatial variation (Streeter, 1973; Schnitker, 1974, 1980).

More recent research has demonstrated that the abundance and distribution of benthic foraminifera in deep marine environments are predominantly controlled by physicochemical parameters, which govern their spatial distribution:

- **Oxygen**: Oxygen is a fundamental element regulating both survival and biodiversity of benthic foraminifera. In enclosed basins such as ponds, lagoons, or salt marshes, species richness decreases, and only a few stress-tolerant taxa can persist temporarily.
- **Organic matter**: Benthic foraminifera play a crucial role in benthic trophic networks, contributing significantly to the fixation and recycling of carbon, nitrogen, and phosphorus derived from detrital organic matter.
- **pH**: This parameter influences test composition and thus the distribution of agglutinated versus calcareous forms. Agglutinated tests are more resistant to acidic conditions (Murray, 2006). Dissolution of calcareous tests has been observed to begin at a pH of 7.8.
- **Calcium carbonate content ($CaCO_3$)**: The availability of $CaCO_3$ directly determines the formation of calcitic or aragonitic tests.
- **Salinity**: Foraminifera exhibit a wide tolerance range, from freshwater to highly hypersaline environments (0 to ≈70) (Murray, 2006).
- **Temperature**: Benthic foraminifera occur in polar, temperate, tropical, and warm waters. The upper thermal tolerance limit for marine benthic foraminifera is approximately 45 °C (Murray, 2006).
- **Hydrodynamics**: Tidal activity introduces physical energy into marine environments. In coastal settings, diurnal tidal fluctuations often induce significant changes in salinity, although temperature variations remain minimal.

Planktonic Foraminifera differ from benthic foraminifera in that they live floating within the water column, and are therefore controlled by environmental factors associated with the surface and intermediate marine layers rather than the seafloor. The main factors influencing their distribution and abundance can be summarized as follows:

- **Temperature**: Planktonic foraminifera are highly sensitive to thermal variations, and their distribution is closely linked to climatic zones (polar, temperate, tropical). Consequently, they are widely used as climatic indicators in paleoclimatological studies.
- **Salinity**: Salinity directly affects species abundance and distribution. Certain species adapt to the stable salinity of open oceans, while others disappear in environments with fluctuating salinity.
- **Nutrients**: Their abundance depends on primary production (phytoplankton), which provides an indirect food source.
- **Ocean Currents**: Surface and oceanic currents govern their geographic distribution, transporting them over long distances and determining areas of accumulation.
- **Oxygen**: Although less directly influential than in benthic forms, oxygen levels in surface layers still affect diversity and abundance.
- **pH and Carbonate Balance**: These are critical for the formation of their calcareous shells. A decrease in pH (ocean acidification) leads to shell dissolution and threatens their survival. (Hemleben et al., 1989 ; Bijma et al., 1990 ; Kucera, 2007 ; Schiebel & Hemleben, 2017).

II- Paleoecological Interpretation

1. Foraminifera and calcimetric analysis

The detailed analysis of foraminifera collected from the “clayey-sandstone formation of Djebel Harrraza” allows us to distinguish four types of benthic foraminifera and planktonic foraminifera:

- Benthic Foraminifera with hyaline tests *Lenticulina*, *Dentalina.*
- Benthic Foraminifera with agglutinated tests: *Dorothia*, *Glomospira.*
- Benthic foraminifera with porcelaneous tests: *Ophthalmidium*..
- Benthic Foraminifera with aragonitic tests: *Paalzowella* sp.
- Planktonic foraminifera: *Globigerina* sp.

The vertical distribution of the foraminifera reveals changes throughout the studied time interval. To explain these variations, we complemented our observations with a calcimetric analysis carried out on the clayey levels. The aim of this study is to investigate the relationship between the variations in foraminifera and those in calcium carbonate content.

2. Paleoenvironmental Interpretation (lower Kimmeridgian)

We conclude that sedimentation and bathymetry are linked to the disappearance or appearance of a group (or faunal association), which is also due to ecological factors. The influence of the environment is reflected in the specific composition of fossil assemblages.

The vertical distribution of foraminifera in the Djebel Harraza section shows paleoenvironmental changes marked by three assemblages:

- **First assemblage:** This assemblage is characterized by a moderate abundance and diversity of foraminifera. The microfauna is generally rich in agglutinated forms, such as *Dorothia* and *Triplasia*, together with hyaline taxa such as *Lenticulina*, and is associated with a decrease in carbonate ($CaCO_3$) content. This assemblage likely indicates a deep-marine environment influenced by a significant terrigenous input.
- **Second assemblage**: It represents a transitional stage, characterized by low to medium abundance and the appearance of new forms with an improvement in diversity, mainly hyaline types, accompanied by an increase in CO_3, such as, Dentalina sp., Protamina, Spirilina sp., Ephtalinidi, Reopax sp., Paalzowella. These features indicate an advanced open outer marine platform environment, very favorable for life, especially benthic.
- **Final assemblage:** the appearance of new forms with high abundance and wide diversity represents, where taxa are less numerous compared to the previous assemblage. Individuals are characterized by the predominance and richness of agglutinated forms with a variety of species (*Lenticulina munsteri*, Lenticulina, etc.), accompanied by an decrease in CO_3. This assemblage indicates deeper marine environment.

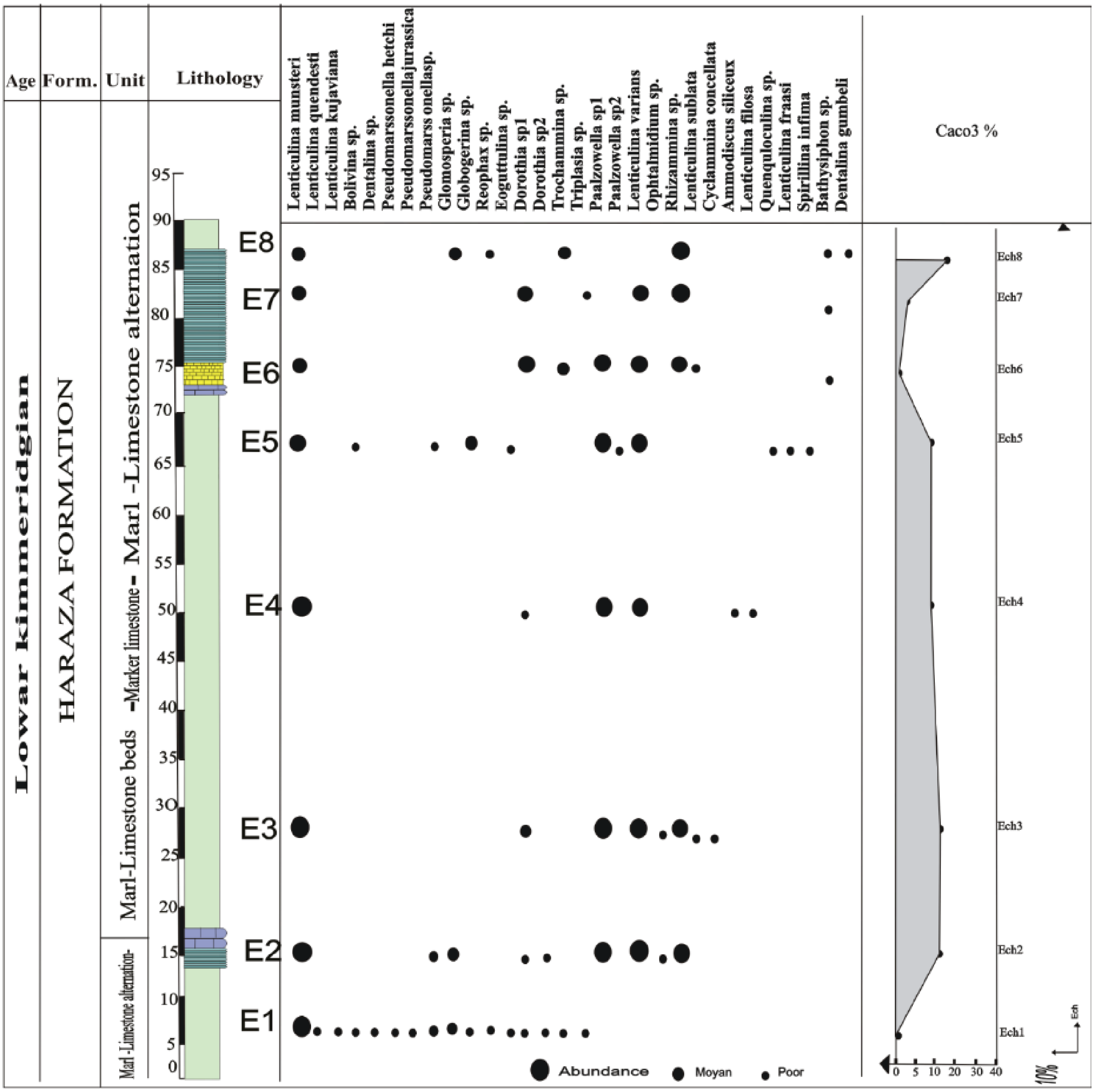


Figure 11: Vertical distribution of foraminifera and the calcium carbonate content in the section (Djebel harraza). Prepared by the Students

Conclusion

The geological investigation of the Djebel Harraza section within the Upper Jurassic (Lower Kimmeridgian) succession of the Chellala Mountains enabled the subdivision of the sedimentary sequence into two lithostratigraphic formations: a regular marl–limestone–carbonate formation and a marl–limestone formation containing an interbedded bioclastic limestone bed.

Micropaleontological analysis of eight sediment samples revealed a rich and diverse assemblage of foraminifera distributed throughout the studied succession. A total of 30 benthic and planktonic foraminiferal species were identified, several of which possess significant biostratigraphic value and contribute to refining the stratigraphic framework of the Harraza Formation.

The integration of the vertical distribution of foraminifera with calcimetric data allowed the recognition of three distinct microfaunal assemblages reflecting successive paleoenvironmental changes. The first assemblage is indicative of a relatively deep marine environment dominated by agglutinated foraminifera, suggesting low-oxygen bottom-water conditions. The second assemblage represents an open outer-shelf to outer-marine setting characterized by an increase in hyaline foraminifera, greater taxonomic diversity, and more stable ecological conditions. The third assemblage records a return to deeper marine conditions, marked by the renewed predominance of agglutinated taxa and more variable environmental conditions.

Overall, these results document a transgressive–regressive environmental evolution during the Lower Kimmeridgian, beginning with relatively deep marine sedimentation, followed by the establishment of a more open and stable marine environment, and finally a return to deeper depositional conditions. This study highlights the importance of integrating micropaleontological and sedimentological data for reconstructing the stratigraphic framework and paleoenvironmental evolution of the Jurassic deposits in the Chellala Mountains.

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