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Petrographical and mineralogical Study Of Quaternary Calcarenites along the Northeastern Algerian Coast: The Annaba Region

Presented by ;
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بسم الله الرحمن الرحيم

وما توفيقي إلا بالله

And my success is only in God

Dedication

Praise be to God, through whose grace good deeds are accomplished, through whose favor wishes are fulfilled, and through whose help steps reach their goals. To Him be thanks, first and last.

To myself, who fought until the very end; to my weary soul, which endured all hardships and overcame all obstacles; to my ambitious self, which has not let me down so far—praise be to God.

To my wonderful father, **Youcef,** who believed in me and taught me that success comes only through determination and patience .

To my great mother, **Salima**, the candle that lit up the dark nights with her prayers, who always hoped to see me succeed on a day like this .

To my sisters, the dear and wonderful **Bouthaina, Hadil, and Khaoula**—the stars who lit my path; to those who did more than prepare me for these moments so they could be proud of me .

To my beloved brother, **Ahmed Nizar**, the apple of my eye and my little support .

To everyone who has been a pillar of support for me on this journey, to my friends and colleagues who have been like siblings to me on this path and companions through the years, and to every unseen hand that has helped me, even with a single word .

Acknowledgments

Praise be to God, who has granted us patience and wisdom, and thanks be to God Almighty, who has enabled us to complete this work. Our success comes only from God; in Him we place our trust, and in Him let those who trust place their trust.

I extend my deepest gratitude to my supervisor, Professor **Remita Abdellatif**, for his invaluable contribution, his tireless efforts in guiding me, and his patience with me, which enabled me to complete this work.

I also extend my gratitude to the distinguished **professors** of the Department of Earth and Space Sciences at **kasdi Marbah University**, each by name, who contributed to our scientific and academic development and did not withhold their knowledge and expertise from us throughout our years of study, supporting us in our academic journey.

I also extend my thanks and appreciation to the professors on the thesis committee and thank them for kindly agreeing to participate in the discussion and evaluation of this research.My gratitude goes to everyone who helped me complete this work, and I pray to God that He may reward them all with the best of rewards.

Abstract

The calcarenite formations of the Edough Massif (east of Annaba, northeastern Algeria) were investigated using an integrated sedimentological, mineralogical, petrographic, morphoscopic, heavy mineral, and micropaleontological approach to reconstruct their depositional environments and sediment sources. The results reveal a progressive transition from quartz-rich continental and coastal deposits to carbonate-rich shallow marine sediments. Heavy mineral assemblages, dominated by tourmaline, zircon, garnet, staurolite, rutile, epidote, and kyanite, indicate significant contributions from the metamorphic rocks of the Edough Massif. Petrographic observations show abundant marine bioclasts and diagenetic features characteristic of shallow marine carbonate environments. Benthic foraminifera and ostracods confirm deposition under calm, well-oxygenated marine conditions. Comparative analysis of the Seraïdi Road, Aïn Bent Soltane, and Cap de Garde sections highlights the influence of both marine and continental processes on sedimentation. The study demonstrates that the Edoughcalcarenites record a paleoenvironmental evolution from high-energy beach settings to shallow marine platform and lagoonal environments during the Quaternary.

Keywords: Edough Massif, Annaba, calcarenites, heavy minerals, petrography, micropaleontology, paleoenvironment, Quaternary.

Résumé (Français)

Les formations calcarenitiques du massif de l'Edough (à l'est d'Annaba, Nord-Est de l'Algérie) ont fait l'objet d'une étude intégrée combinant les approches sédimentologique, minéralogique, pétrographique, morphoscopique, micropaléontologique et l'analyse des minéraux lourds afin de reconstituer leur environnement de dépôt et leur provenance sédimentaire. Les résultats mettent en évidence une évolution progressive d'un milieu continental et côtier dominé par les apports détritiques quartzeux vers un environnement marin peu profond riche en carbonates. L'assemblage des minéraux lourds, dominé par la tourmaline, le zircon, le grenat, la staurolite, le rutile, l'épidote et la cyanite, indique une contribution importante des roches métamorphiques du massif de l'Edough. L'étude pétrographique révèle l'abondance de bioclastes marins et des phénomènes diagénétiques caractéristiques des calcarenites marines peu profondes. Les foraminifères benthiques et les ostracodes témoignent de conditions marines calmes et bien oxygénées. L'analyse comparative des sites de la Route de Seraïdi, d'AïnBentSoltane et du Cap de Garde met en évidence l'interaction entre les processus continentaux et marins. L'ensemble des données indique une évolution paléoenvironnementale allant d'un milieu de plage à haute énergie vers une plateforme marine peu profonde puis lagunaire au cours du Quaternaire.

Mots-clés : Massif de l'Edough, Annaba, calcarenites, minéraux lourds, pétrographie, micropaléontologie, paléoenvironnement, Quaternai.

ملخص

خضعت التكوينات الكلسية الرملية (Calcarenites) المنتشرة في **كتلة الإيدوغ شرق مدينة عنابة (شمال شرق الجزائر)** لدراسة متكاملة اعتمدت على التحاليل الرسوبية والمعدنية والبتروغرافية والمورفوسكوبية ودراسة المعادن الثقيلة والأحياء الدقيقة المتحجرة، بهدف إعادة بناء بيئة الترسيب ومصادر الرواسب. أظهرت النتائج تطورا تدريجيًا من بيئة قارية وساحلية تهيمن عليها الرواسب الكوارتزية إلى بيئة بحرية ضحلة غنية بالكربونات. كما بيّنت دراسة المعادن الثقيلة ،المتمثلة أساسًا في التورمالين والزركون والجارنت والستاوروليت والروتيل والإيبيدوت والكيانيت ،وجود مساهمة مهمة للصخور المتحولة المكونة لكتلة الإيدوغ. وأظهرت الدراسة البتروغرافية وفرة البقايا الحيوية البحرية ووجود مظاهر دياجينية مميزة للرواسب الكربوناتية البحرية الضحلة. كما أكدت المستحاثات الدقيقة ،وخاصة المنخربات القاعية والأوستراكودا ،ترسب هذه الرواسب في ظروف بحرية هادئة وجيدة التهوية. وأبرزت الدراسة المقارنة بين مواقع **طريق سرا يدي،عين بنت السلطان ،ورأس الحمراء (كاب دوغارد)** تأثير التفاعلات بين العمليات القارية والبحرية في تشكيل هذه الترسبات. وتشير النتائج إلى تطور باليو بيئي انتقل من بيئة شاطئية عالية الطاقة إلى منصة بحرية ضحلة ثم إلى بيئة لاجونية خلال العصر الرباعي

الكلمات المفتاحية:كتلة ايدوغ ,عنابة ,المعادن الثقيلة , الكالكارينيت , العصر الرباعي , البيئة القديمة , المستحاثات الدقيقة , البيتروغرافيا .

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GENERAL INTRODUCTION

GENERL INTRODUCTION

Calcarenites are among the most significant geological records reflecting environmental and climatic conditions during the Quaternary Period. They constitute one of the most important carbonate sediments found in coastal environments and provide valuable evidence of the environmental changes that affected the Earth during this period. The study of their petrographic characteristics offers insights into ancient depositional environments through the analysis of their mineralogical and biogenic components, sedimentary texture, porosity, and the diagenetic processes that occurred after deposition.

This study focuses on the Quaternary coastal formations of the Ain Achir area in the Annaba region of northeastern Algeria. The area is characterized by remarkable geological diversity, making it an ideal site for investigating Quaternary calcarenite deposits. The region has undergone successive climatic variations and sea-level fluctuations, which are recorded in the sedimentary characteristics and their evolution through time. Petrographic and paleontological data also provide valuable indicators for interpreting the environmental conditions that prevailed during sediment deposition.

In addition to petrographic investigations, heavy minerals represent valuable tools in sedimentological and provenance studies. These minerals are generally characterized by a specific gravity greater than 2.8 g/cm³ and include resistant minerals such as zircon, tourmaline, garnet, and apatite. They provide important information on the origin, transport, and depositional conditions of sediments. Despite their relatively low abundance, their high stability and resistance to weathering make them reliable indicators for identifying source rocks, reconstructing sedimentary history, and understanding the evolution of sedimentary basins (Mange & Maurer, 1992).

The aim of this study is to characterize the petrographic, paleontological, and heavy-mineral features of the Annaba–Ain Achir calcarenites in order to determine their origin, reconstruct the paleoenvironment, understand climatic and sea-level fluctuations affecting the coastal environment, and compare the obtained results with previous studies conducted along the Mediterranean coast. This research seeks to contribute to filling existing knowledge gaps concerning the origin and geological evolution of Quaternary calcarenites through an integrated petrographic, paleontological, and heavy-mineral approach

GENERAL INTRODUCTION

Keywords: Calcarenites, Petrography, Diagenesis, Fossils, paleoenvironment ,Quaternary, Annaba , Northeastern, Algeria , Heavy Minerals.

Problematic

The Quaternary coastal formations in the Annaba region are of significant geological importance; however, the petrographic and geochemical characteristics of calcarenite rocks remain insufficiently studied. This study therefore aims to understand and interpret the geological history of these formations by addressing **the following questions:**

- What is mineralogical characterististics of the calcarenites in Ain Achir?
- In with depositional environment where they formed?What is the origin of these deposits?
- Are they comparable to caclcarenites found in other parts?

Objective of the Stduy

This study aims to determine the origin of calcarenite rocks in the Edough massif, identify the environment in which they were formed, and characterize their petrograophical, textural and mineralogical properties, in order to interpret the depositional environment in which they were formed.

In this dissertation we aim to

This organized thesis begins in five chapters, preceded by a general introduction to clarify the problem, the objectives of the study, and the scientific significance of the area studied.

The first chapter presents the geographical and geological framework of the study area, describing the location of the Annaba study area, with climatic, hydrological and coastal dynamic conditions. It also addresses the regional geological framework of northeastern Algeria, the local geological context of the study area, and the structural structure of the studied area.

The second chapter is devoted to the materials and methods used in this work, and describe field studies that included describing rock detectors, completing stratigraphic sections, and sampling operations. Laboratory analyses are also carried out and presented, including petrographic studies using thin slides under a polarized microscope, granular analyses, and fossil studies based on identifying existing fossils. In addition, this chapter highlights the interpretation methods used in the classification of sandy limestone rocks and the reconstruction of ancient environments.

The third chapter focuses on the petrographic study of sandy limestone rocks, as it includes a macroscopic description of the rocks studied, their histological characteristics such as grain size, cementity, and porosity, in addition to their mineral classification, composition, and fossilization characteristics (diagenase).

The fifth chapter examines the heavy metal assemblages in the sediments under study in order to identify their source, assess sediment transport processes, and infer the geological characteristics of the source rocks. Heavy metals are valuable indicators in sedimentological studies due to their resistance to weathering and their ability to preserve information regarding the origin of the sediments and the history of their deposition.

The Sixth chapter is devoted to the paleontological study, with a presentation of the foraminifers and a description.The most important identified foraminifer's species, with their ecological interpretation, and proposing a biological division based on the discovered foraminifers assemblages.

deals with the interpretation and discussion of the results obtained in this study, and aims to reconstruct the sedimentation environment, clarify the ancient environmental development of the region, and evaluate the impact of climate changes during the Quaternary period. It also contains a comparison with other Mediterranean regions in order to place the study within a vast geological framework.

Finally, the thesis concludes with a general conclusion that includes a summary of the most important possible outcomes, highlighting the scientific contributions of the study, and proposing future work and research prospects .

CHAPTER II: GEOGRAPHIC AND GEOLOGICAL SETTING

Overview OF CLACARINITE

Calcarenites is a sandstone composed of limestone sand, formed mainly in tropical and coastal environments. Its formation is associated with the presence of sand dunes composed of sediments resulting from the fragmentation and erosion of coral reefs. These dunes are found in areas rich in limestone sand that is not fixed by vegetation. This sand undergoes wind transport and erosion (atomization), where the grains move closer to the ground surface by jumping, and then settle at lower wind speeds on the windward slope. When the next process occurs, sand dunes can face on the windward side and settle on the opposite side.

These limestone sand deposits are transformed into calcarinite rock thanks to the process (Diagenèse), a set of mechanical and chemical processes that affect the sediments after they are deposited, causing them to consolidate and turn into sedimentary rocks. Calcarenites is a sedimentary rock of calcareous origin.**(Flugel2010)**

Calcarenite sample collected from Ain achir ,EdougMssif ,North-eastern Algeria

Diagonas (rock metamorphism)

is the stage in which sediments turn into sedimentary rocks. This occurs as a result of several mechanical and chemical changes after the materials are deposited. These processes are divided into two main stages:

Burial and granule compaction

In this stage, new layers of sediment accumulate on top of old layers, gradually burying the old layers to a depth of hundreds or thousands of meters. This results in increased pressure that causes a reduction in porosity between the grains, whether of mineral or clay origin.

Adhesion of the granules (hardening)

During this stage, the water between the granules is saturated with dissolved minerals, and then the minerals are deposited inside the pores. This process basically works to stick the granules together to form a solid, cohesive

Geographic Setting

Geographicall Location

The city of Annaba is located in the northeastern part of Algeria and is considered one of the most important coastal cities overlooking the Mediterranean Sea. Its coastline extends for approximately 80 kilometers and includes a variety of sandy beaches, among which areSidi Salem Beach in the southeast, and Saint Cloud (RezguiRachid) and Chapuis (Rizi Amor) beaches in the northern part.

Among these beaches, only a limited number are characterized by their dark-colored sands, including the Military Beach, Victory Beach (also known as El Védro), and Ain Achir Beach, located near or within the RasGarde area.

This study focuses specifically on the analysis of sedimentary rocks known as calcarenites, which are found within the geological formations of the Edough Massif. This site provides a suitable geological environment for conducting detailed petrographic and geochemical analyses in order to better understand depositional characteristics and the evolution of the sedimentary environment in the region, based on geographical data (Google Earth, 2016).

Latitude: 36.90° N

Longitude: 7.77° E

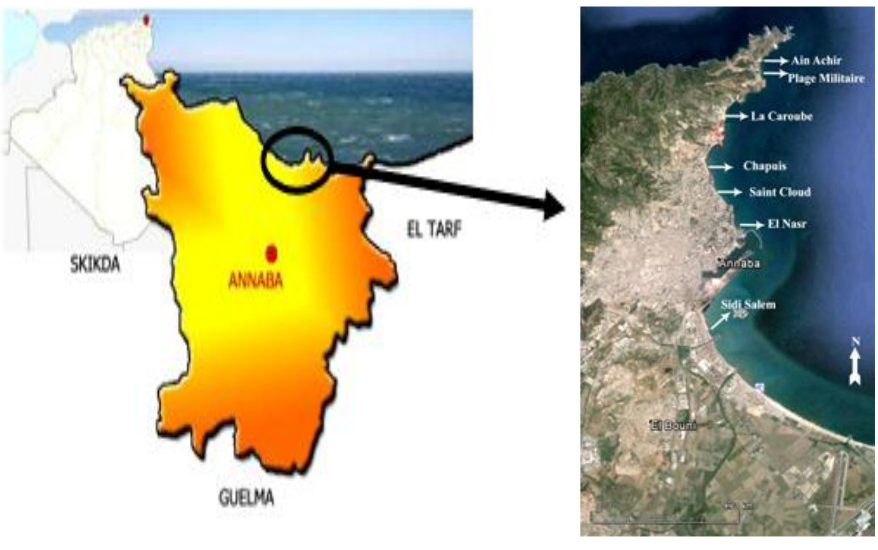


Figure 1 Location of the Annaba Coastline b) map of the annabacoastine (Google Earth2016),(Chemam.A,ledby:Hadj Zobir,2018)

1.1 The climat

The climate of Annaba is characterized by generally mild and dry conditions. During the winter season, precipitation levels are significantly higher compared to those in the summer. According to the Köppen–Geiger classification, the prevailing climatic conditions in this region fall under the Csacategory,

This reflects its Mediterranean character. The average annual temperature is about 17.9 °C (64.1 °F), while the average annual precipitation reaches approximately 671 mm (26.4 in). This is due to its location in the Northern Hemisphere, where summer occurs from June to the end of September.The Annaba region experiences warm, humid, dry, and largely clear summers, and long, cold, windy, and partly cloudy winters. Throughout the year, the temperature typically ranges between 46°F and 85°F and is rarely below 40°F or above 93°F. **Weatherspark.**

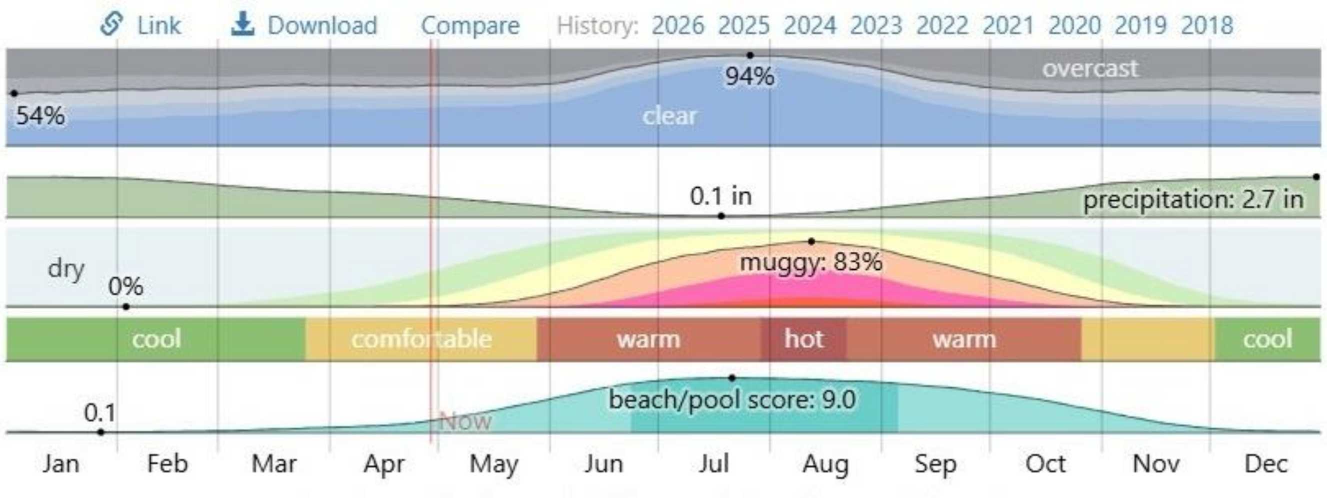


Figure. 2: map of climate annabaweather by month **weatherspark.**

Climate chart Monthly weather in Annaba

Tableau. 1: 1991 - 2021 Minimum temperature °C, Maximum temperature °C, Precipitation / Rainfall mm, Humidity, Rainy days. Data: 1999 - 2019: Average hours of sunshine

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature (°C)	10.2	10.3	12.6	15.3	18.8	23.4	26.6	26.8	23.6	20.3	14.8	11.5

Minimum Temperature (°C)	6.6	6.5	8.2	10.6	14.0	18.0	21.1	21.8	19.5	16.2	11.2	8.0
Maximum Temperature (°C)	14.1	14.4	17.3	20.1	24.0	29.0	32.5	32.6	28.5	25.2	18.9	15.3
Humidity (%)	77%	76%	75%	73%	68%	59%	55%	57%	65%	69%	73%	76%
Rainy Days (days)	9	9	8	7	5	2	0	2	5	7	10	9
Average Sunshine (hours)	6.3	6.9	8.2	9.6	10.9	12.2	12.4	11.4	9.6	8.3	7.0	6.4
Precipitation (mm)	95	80	68	61	40	11	2	12	43	64	97	98

1.2 Temperature

Annaba region witnesses a hot season that extends from two to three months, from June 21 to September 28, with an average temperature exceeding 80°F. August is considered the hottest month of the year, as its maximum temperature reaches F°85 .

The minimum is F°69 In January, the average temperature reaches its lowest level at F°46 which makes it the coldest month of the year and the cold season lasts from 3 to 9 months from November 30 to March 25 with an average temperature below F°65**. weatherspark.com**

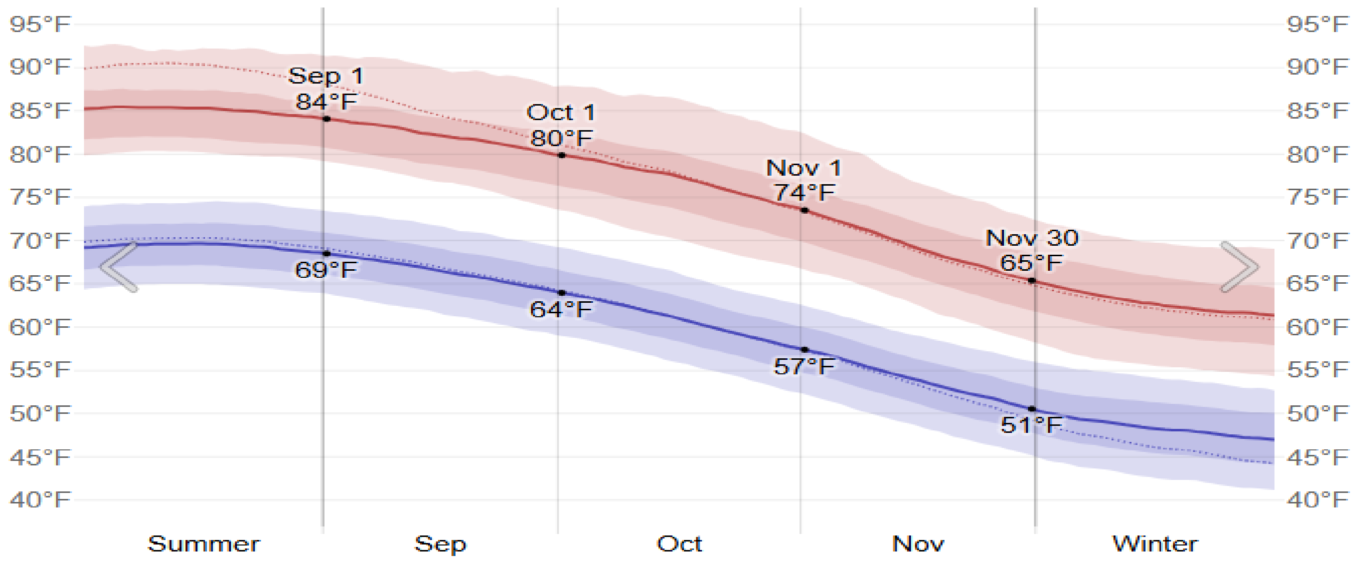


Figure. 3: The daily average high (red line) and low (blue line) temperature, with 25th to 75th and 10th to 90th percentile bands. The thin dotted lines are the corresponding average perceived temperatures**(weatherspark).**.

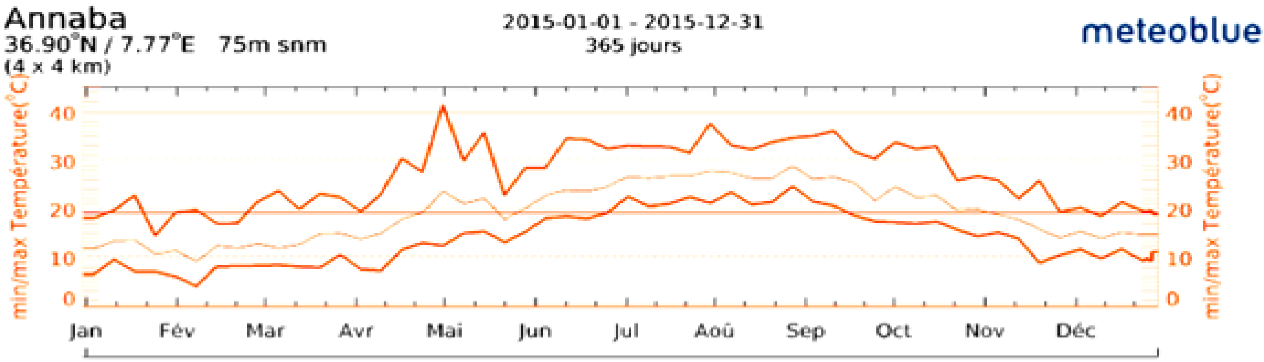


Figure .4: Over 12-month period ,during the year2015 ***(*Meteoblue ,2016)**

1.3 Humidity

Measuring the comfort level related to humidity is an important indicator that depends on the dew point, as this point limits the body's ability to dissipate heat through the evaporation of sweat from the surface of the skin, which enhances the feeling of coolness and comfort, unlike temperature, which is affected by daily changes day and night, as the change in the dew point is very slow, which means that humid days continue at night.In Annaba area .

The humid period of the year lasts for 4.4 months, from June 4 to October 17, during which time the comfort level is humid or miserable at least 21 percent of the time. The wettest month is August, with 24.6 wet days.

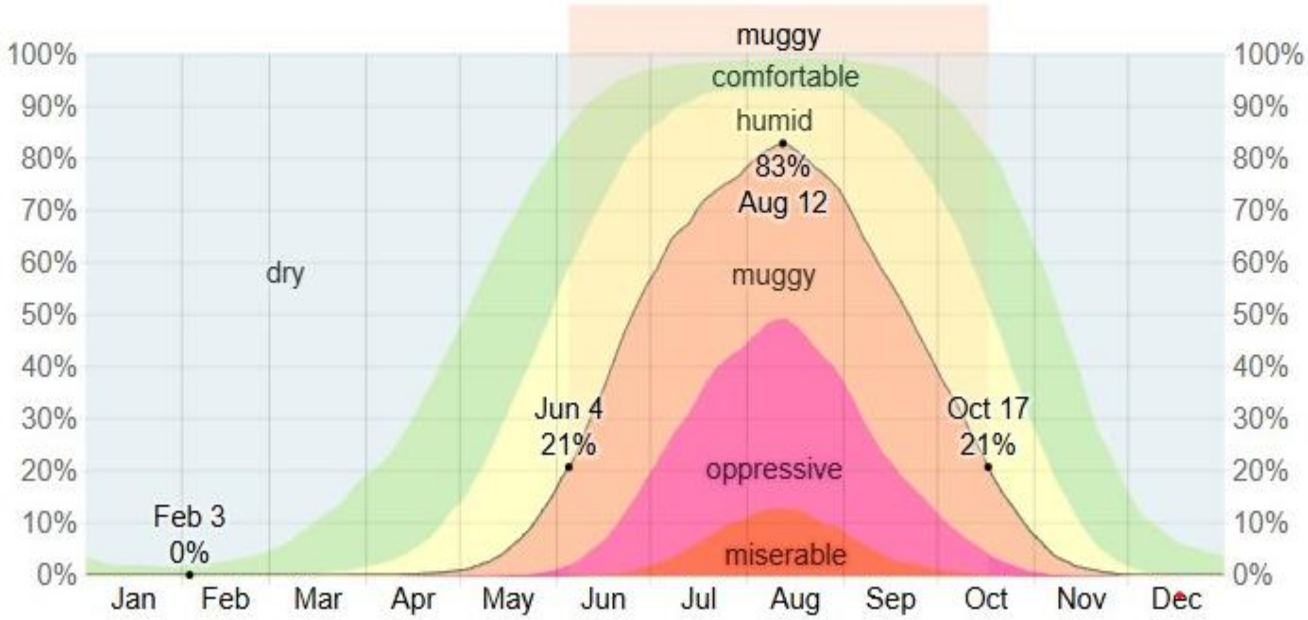


***Figure. 5*:**Map Humidity Comfort Levels in Annaba**(weatherspark).**

1.4 Rainfall

According to the Köppen climate classification, this region's climate is characterized by a mild and warm climate. Winters in Annaba are marked by significantly higher rainfall than in the summer. The prevailing climate is classified as type Csa, which corresponds to a Mediterranean climate characterized by hot summers, with an average annual rainfall of approximately 671 mm.

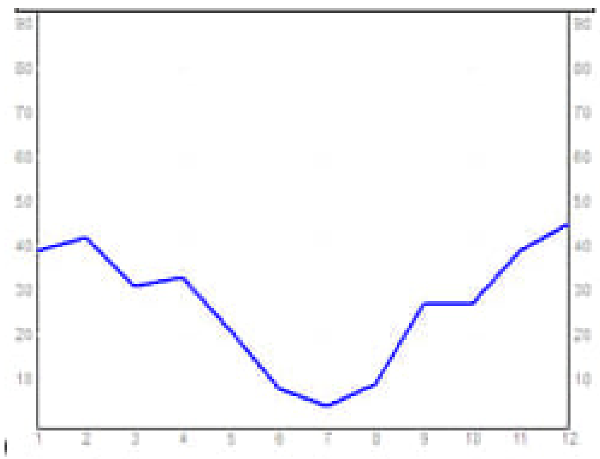


Figure 6: Les risques de pluie **(temperatureweather.com, 2016)** sont très élevés pendant ,la période allant de janvier à mars et d'octobre à décembre.Fugir

1.5 Wind

The Annaba region experiences marked seasonal fluctuations in wind speed and direction, which are linked to regional climate dynamics and Mediterranean marine influences. According to WeatherSpark data, the windiest period of the year is 5.9 months, from October 31 to April 26, with an average speed of more than 14.8 km/h. December is the most active month with an average of 17.9 km/h, which is similar to the dominance of winter marine air masses coming from the sea, which are often directed from north to south, as a result of differences in pressure and temperature between the sea and land. In contrast, the quietest period runs from April 26 to October 31, with August being the lowest average wind speed (11.3 km/h). During this summer period, the region is affected by the southwestern Sirocco winds, which are hot, dry winds of desert origin, typically lasting about a month. They contribute to raising temperatures and reducing and lowering humidity, reflecting the seasonal alternation between a humid marine effect in the winter and a dry continental effect in the summer.**WeatherSpark.**

a) **b)**

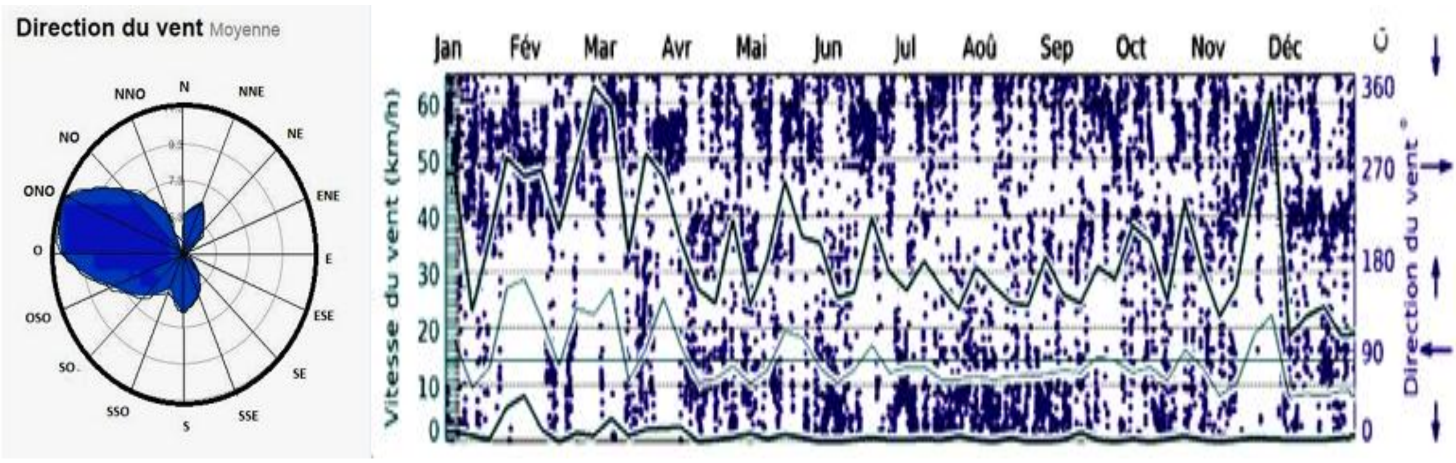


Figure 7: a) direction moyenne du vent pour la période 2012-2016 (fr.wisuki.com/2016)b) Vitesse et direction du vent(en degré 0°=Nord, 90°=Est, 180°=Sud et 270° =Ouest, les points violetsreprésentent la direction du vent pour l'année 2015(meteoblue, 2016)(Chemam,A.Hadj zobir .2018)

1.6 Hydrogeology

The AïnAchir–Seraïdi road area is characterized by a relatively simple hydrographic network, mainly influenced by its coastal and mountainous setting. Surface water circulation remains limited; however, it plays a significant role in the transport of sediments from elevated inland areas toward the coastline. The main hydrographic feature of the region is OuedSeybouse, one of the most important rivers in northeastern Algeria, extending over approximately 127 km before discharging into the Mediterranean Sea east of Annaba. In addition, Lake Fetzara, located south of Annaba, constitutes one of the largest freshwater bodies in the region. Seasonal precipitation, combined with steep topography, generates episodic runoff events, particularly during winter, enhancing sediment mobilization toward the coastal zone. These hydrodynamic processes promote the accumulation of clastic materials and their interaction with carbonate-rich marine waters, creating favorable conditions for the development and lithification of calcarenite deposits (Hilly, 1962).

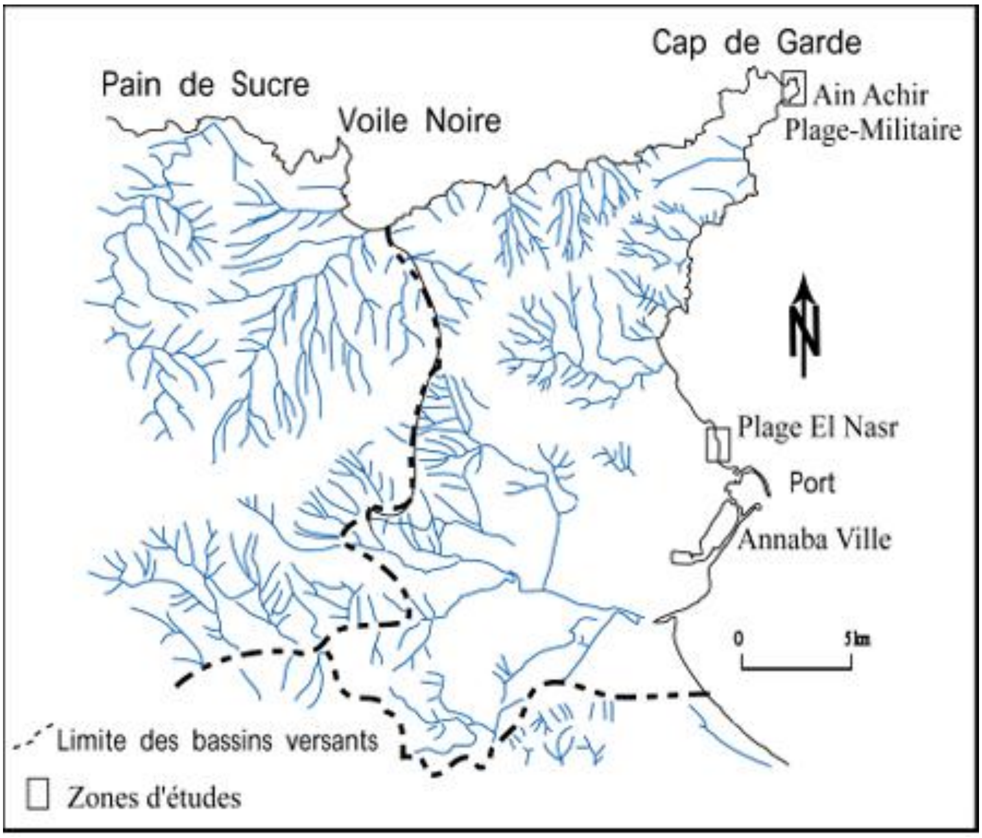


Figure 8: Map of the hydrographic network of the Annaba region(Hilly 1962), modified.

1.7 Relief And Erosion

The terrain of Annaba Province is mainly composed of the Edough Massif (52%), hills (28%), and plains represented by the Khiraza Plain (18%) (fr.wikipedia.org, 2016).
The Edough Massif () extends over approximately 50 km in a southwest–northeast (SW–NE) direction. Its central part reaches an elevation of 1008 m at Bozizi.
The southwestern and northeastern areas, particularly the Cap de Garde region, are characterised by relatively lower elevations, ranging between 200 and 300 m on average (Olarby and Zgiche, 2009 .

1.8 Coastal dynamics

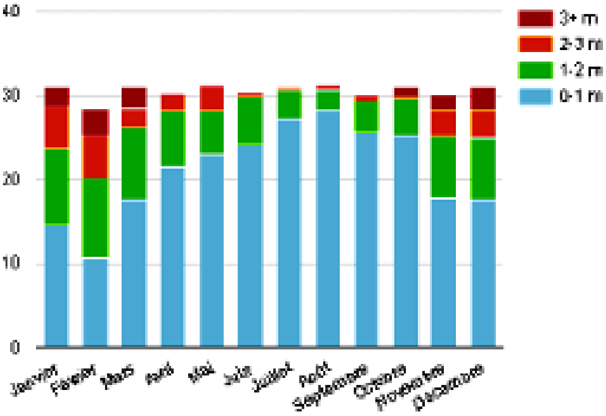
1.8.1 The impact of storms and sea currents on the coast

The Algerian coast is dominated by westerly or northwesterly winds, which turn into storms that are dangerous to navigation. These recurring storms bring waves fr om the northern sector and rarely come from the northeast, but they are more destructive.These storms can occur between December and March and sometimes continue until June in winter. Waves reach the Annaba coast mainly from the northeastern sector, while waves coming from the north spread throughout the year (Dar Al Bayda Meteorological Station, data recorded over a period of nine years).

1.8.2 Wave and bulge

The bulge is determined by periodic oscillations of the sea surface.They are formed by wind force the sea in the Annaba region is often rough (Figure). In winterthe wave height is high and can exceed 3 meters. In summer the waves rise Low (Figure) and does not exceed
1 meter (fr.wisuki.com/2016).
The Annaba coast is characterized by waves coming from north to northwest (Figure)
(fr.wisuki.com/2016).

a)



b)

Figure 9 :a)hauteur des vagues pour la période 2012-2016, b) direction moyenne de la houle pour la période 2012-2016( )(Chemam,A.Hadj zobir.2018).

2 .Regional geological framework

The Edough Massif shares a similar geodynamic and metamorphic evolution with the Alkapeca domain **(Alboran–Kabylia–Peloritani–Calabria) (Bouillin, 1986; Michard et al., 2006).**

The metamorphic formations of the Edough Massif are organized into two main tectonic units. The first, referred to as the Lower Unit, represents a Hercynian crust dated between 286 and 308 Ma (Bruguier et al., 2009). It is mainly composed of altered biotite gneisses and two-mica augen gneisses derived from arkosicprotoliths (HadjZobir, 2012; HadjZobir and Mocek, 2012). This unit also includes intercalations of leptynites, marbles, as well as mafic and ultramafic rocks **(Ahmed-Said et al., 1993; Gleizes et al., 1988; Hilly, 1962).**

The second unit, known as the Upper Unit, consists predominantly of various micaschists such as sericite- and chlorite-rich schists, locally associated with thin quartzite layers. The presence of acritarchs suggests an Ordovician to Devonian age for this unit **(Ilavsky and Snopkova, 1987).**

Linking these two units is an Intermediate Unit, composed mainly of garnet-bearing micaschists containing index minerals such as kyanite, sillimanite, or andalusite.

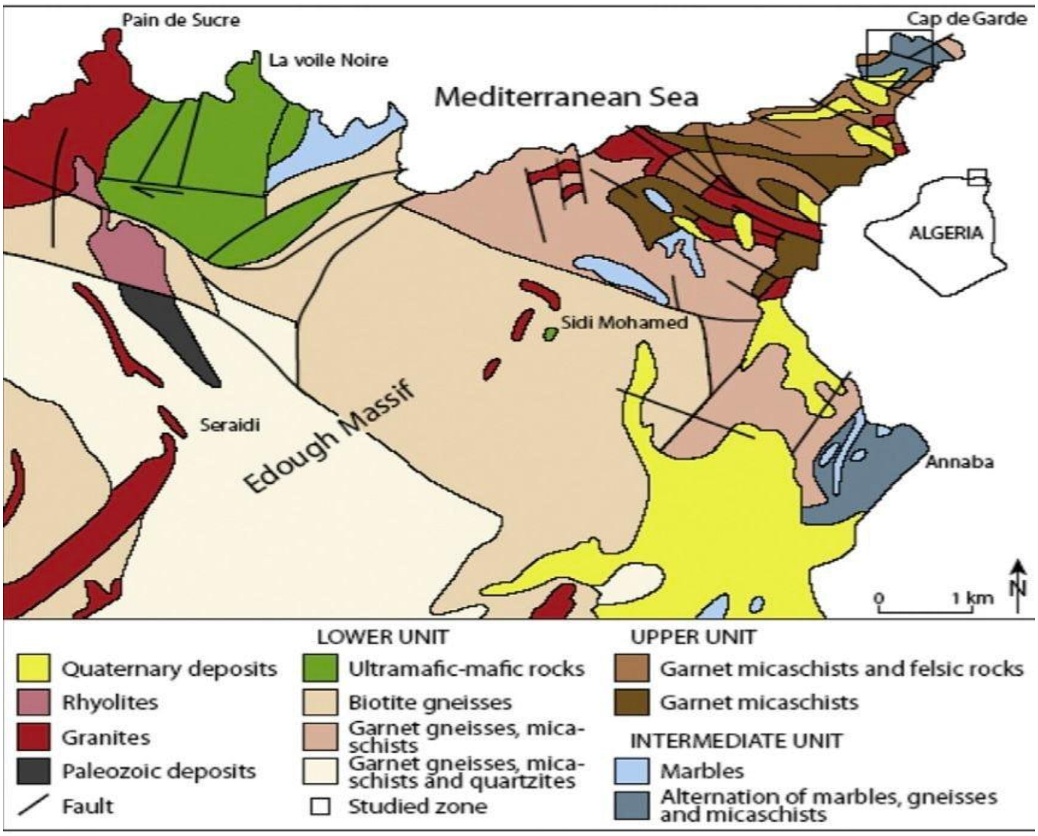


Figure 10:Simplified geological map of the Edough massif modified after the works of hilly (1962)

1.9 Local Geology

The study area extends along Saraidi Road, from the mountainous sector of Saraidi to Ain Asher Beach. This area presents a diverse geological framework characterized by the presence of metamorphic formations, mainly gneiss and mica schist, associated with the surface sedimentary deposits of calcarenite. The rock organization of this sector reveals a clear disparity between the ancient metamorphic base of the Idog massif and modern coastal sedimentary formations. Limestone outcrops, widely exposed along the coastline, reflect significant marine depositional activity and constitute favorable sites for field observation and sample collection.

1.10 Regional geology

Ain Achir is located in the northeastern sector of Annaba, within the municipality of seraidi, along the Mediterranean coastal zone known as Cap de Garde. It belongs to the Edough Massif, a coastal mountainous area characterized by steep vegetated slopes descending directly toward rocky and sandy beaches.

From a geological perspective, Ain achir is distinguished by the presence of extensive sedimentary outcrops, mainly composed of calcarenite , a bioclastic carbonate rock formed predominantly from shell fragments and other marine biogenic materials. The stratigraphic succession is clearly exposed, allowing the identification of sedimentary structures such as horizontal bedding and cross-bedding. In addition, the occurrence of fractures and minor faults within the rock formations indicates the influence of late tectonic events.

This coastal site constitutes an important natural field laboratory for petrographic and sedimentological analyses, providing valuable insights into the depositional environments and coastal evolution of northeastern Algeria.

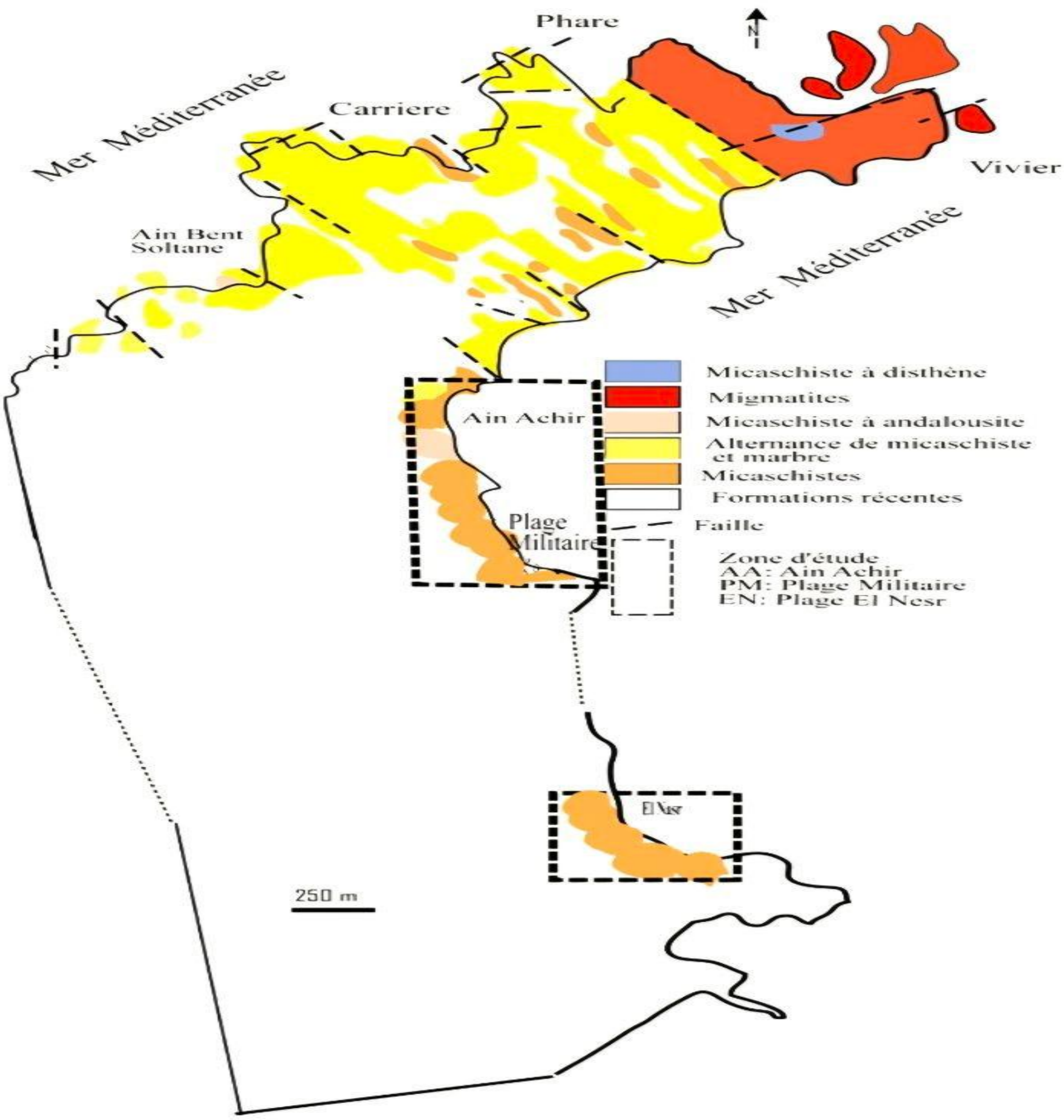


Figure 11:Simplified geological map of gardemodified **(** Ahmed Saidetal,1993; Capy and al.2001 HadjZobir and al.2014).

CHAPTER III : MATERIAL AND METHODS

CHAPTER III : MATERIAL AND METHODS

IINTRODUCTION

This study relied on a multi-stage methodology that combines field work and laboratory analyses, with the aim of studying sandy limestone rocks, determining their mineral and petrographic properties, and reconstructing ancient depositional environments.

1. Field work

1.1. Sampling

Data were collected through two main phases: fieldwork and laboratory work. In the first stage, samples previously present in the laboratory were taken according to the study site of the Edough massif area, describing the lithological characteristics and various sedimentary structures. Various rock samples representing the various rock types found in the Edough massif were also collected,

1.2. Lithological Description

Calcarent is characterized by a light yellow to beige color with a texture often reinforced by packstone and grainstone grains, and sedimentary structures such as cross-bedding are also evident. It is further characterized by medium to high porosity and weak to moderate cementation by calcite

Calcarent occurs as thick, cohesive layers of carbonate rock associated with reddish clay layers; it is relatively friable and porous and is rich in biogenic elements indicative of a marine depositional environment .

1.3. Location

The study site is located at Ain Asher within the Idoug Massif in northeastern Algeria, with the following geographic coordinates: 36.90° N latitude and 7.77° E longitude. The rock outcrop exhibits a general trend (NW–SE), with a slight, nearly horizontal dip of approximately 5° toward the east, indicating a nearly horizontal stratigraphic orientation. Lithologically, the rock sequence consists primarily of calcarenite and reddish clay formations.

CHAPTER III : MATERIAL AND METHODS

2. Laboratory Methods

2.1. Rock sampling

The second phase involved laboratory work, where rock samples, consisting of 11 samples , were subjected to a series of petrographic and mineralogical study. The samples were cut and prepared to suitable dimensions for installation on glass slides, and then thin, standard slides were made according to each rock sample. These slides were then studied using a polarized microscope to determine the mineral and textural composition of the rocks, identifying primary and secondary minerals, porosity properties, and traces of deposits.

The study also included sedimentological and paleontological studies to highlight the sediment's characteristics and environmental implications, by identifying key fossils such as foraminifera. Finally, the results were interpreted based on petrographic and environmental classifications, linking mineral and sedimentary data to the geological and climatic context of the area studied.

2.2 Particle Size Analysis

The preparation of samples for particle size analysis involves studying the nature of sand by examining the different sizes of its particles. This analysis also includes separating and classifying the grains according to their diameter using sieves. To perform particle size analysis, samples must be taken from the limestone to be studied. Particle size analysis involves several steps**:**

Homogenization, which involves shaping the sand into a grading cone: The sand is leveled to a single plane. Quartering: The goal of this process is to obtain 250 grams of sand from one kilogram. Drying in an oven at 80°C for 35 minutes. Sieving: Each sample is sieved for 15 minutes using a vibrating electronic sieve.

2.3 Morphoscopic analysis

Rock samples were prepared for various tests and analyses. The first step was the fragmentation stage, in which rock samples from the area were soaked in water for 24 hours to soften their structure and separate the individual grains. This was followed by washing and sieving: the samples were washed and passed through three sieves with mesh sizes of 125, 250, and 500 micrometers to classify the grain sizes, separate the minerals, and study them .

2.4 Preparation of Thin Sections from Friable Rocks

- **Objectives**

  Master the different stages of thin section preparation, adapt preparation techniques to friable materials (sediments, weathered rocks),Obtain a thin section suitable for optical microscope analysis

Introduction

Friable rocks are characterized by low cohesion and high porosity. In geology, their preparation requires vacuum impregnation to ensure grain cohesion before thinning. The materials and equipment used include a friable rock sample, low-viscosity epoxy resin, a vacuum chamber, a vacuum pump, a diamond saw, glass slides (standard size: 27 × 46 mm), a heating plate, abrasives (Sic: 80 → 1200 grit), a polishing machine, alcohol or acetone for cleaning, gloves, and safety goggles. Safety instructions include handling resins under a fume hood because of toxic vapors, wearing mandatory personal protective equipment (PPE), and being cautious when using rotating machines such as the saw and polishing machine.

2.4.1 Experimental Procedure

The experimental procedure begins with drying the sample at 40–60 °C for 12–24 h to remove moisture without causing cracking. The sample is then placed inside a vacuum chamber, covered with liquid epoxy resin, and subjected to a vacuum of approximately 10–50 mbar for 15–30 min, during which air bubbles are released. The vacuum is slowly released, and the resin is allowed to polymerize for 12–24 h at room temperature or in an oven at about 40 °C. The impregnated sample is cut into a slab approximately 1 cm thick using a low-speed diamond saw with controlled cooling to avoid excess water. One surface is then flattened and polished using abrasives from 240 to 600 grit and carefully cleaned. A thin layer of resin is applied before mounting the slab onto a glass slide, ensuring that air bubbles are removed, followed by hardening for at least 12 h.

2.4.2 Thinning and Polishing

The sample is progressively thinned using abrasives from 80 to 320, 600, and finally 1200 grit until a target thickness of approximately 30 µm is reached. Thickness is checked under the microscope when minerals become translucent. Final polishing is carried out using a fine abrasive such as diamond paste or alumina, followed by gentle cleaning to avoid grain loss. Optionally, a cover slip may be added and protected with resin.

2.4.3 Quality Assessment and Applications

A thin section is considered satisfactory if it has a homogeneous thickness of about 30 µm, no grain pull-out, good transparency, and no visible resin bubbles. The obtained thin sections allow the study of textures in sedimentology, mineralogical identification, and porosity analysis, possibly using colored resin.

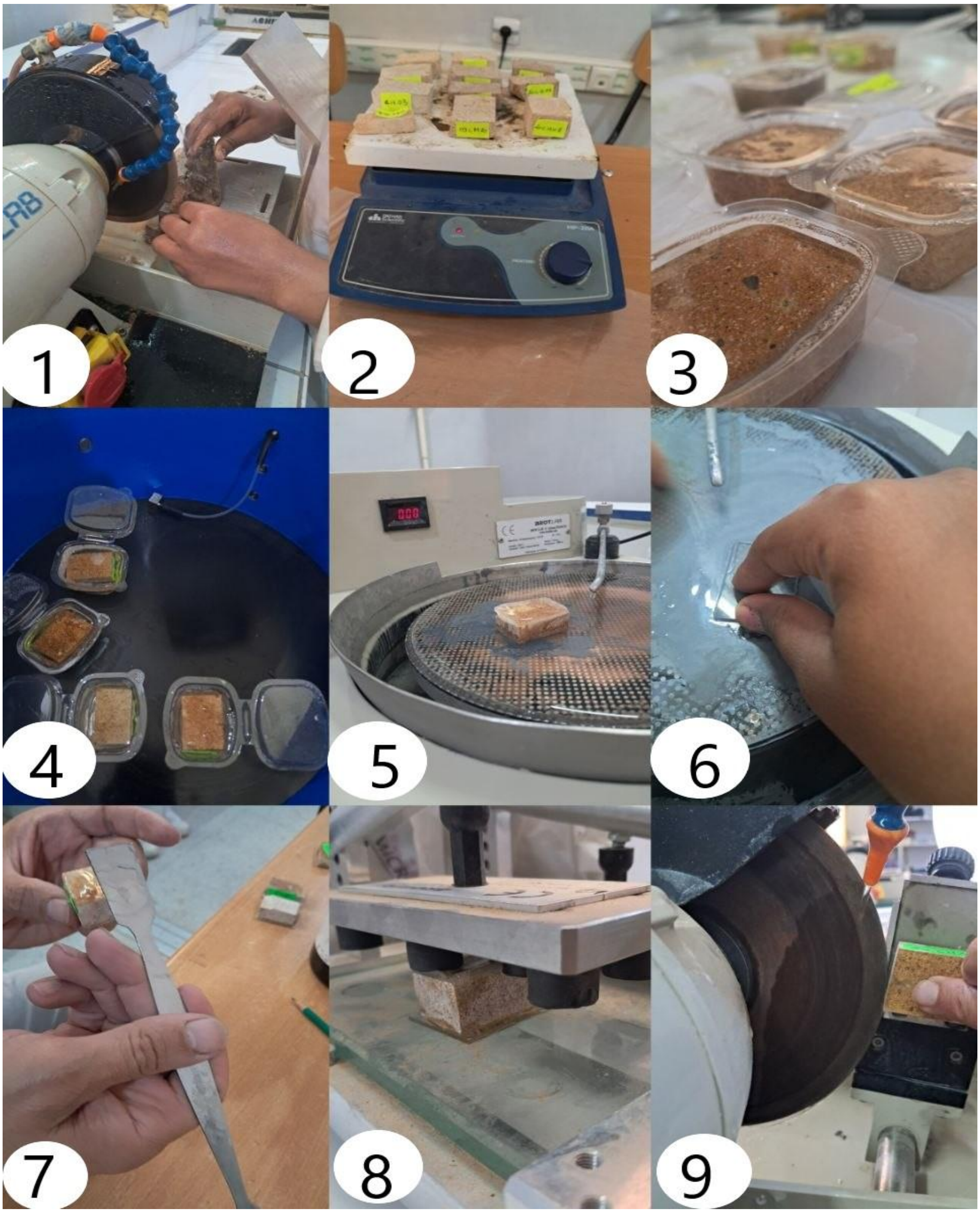


Figure 12 :Practical experiments conducted at the Kasdi Merbah University Laboratory **(2026)**

3. interpretation

To understand the mineralogical and biological composition of the calcarenite rock, a petrographic analysis was conducted on representative samples from various levels of the Cap du Gard sedimentary section. This analysis aims to identify the macroscopic and microscopic components of the sedimentary rock, whether biological or mineral, through an initial examination using a handheld lens and a binocular microscope, followed by a detailed analysis of thin sections using a polarizing light microscope. This approach allows for the identification of the rock's main components before proceeding to a detailed study of the thin sections.

CHAPTER IV : PETROGRAPHIC STUDY OF CALCARENITES

Introduction

Study was conducted on the various petrographic and mineralogical characteristics of the calcareous sediments in the Annaba-Ain Achir region. Several methods were used to characterize these sediments in order to determine their morphological, mineralogical, and textural characteristics and to understand their origin and depositional conditions.

1. Petrography and Mineralogy:

Examination of thin sections of samples taken from calcarenite formations reveals considerable diversity in petrography and mineralogy.

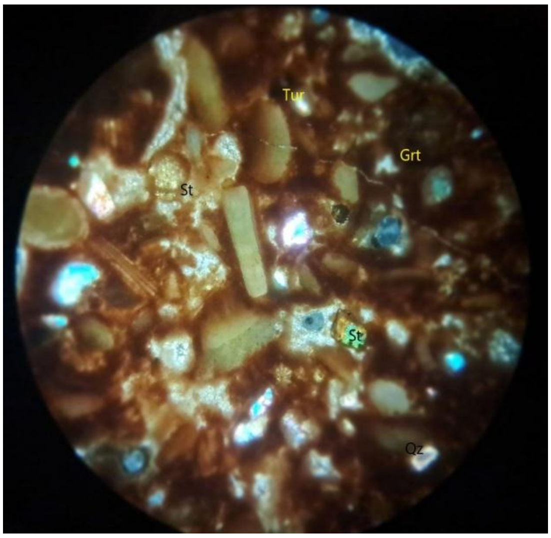


Figure 13:Sample [RS05]

The thin section is characterized by an abundance of calcareous biogenic remains, which appear compact, closely spaced, and interlocked. We observe that the biogenic remains have dissolved to form a porous matrix that fills the voids; the matrix also consists of microspars resulting from the recrystallization of micrite.

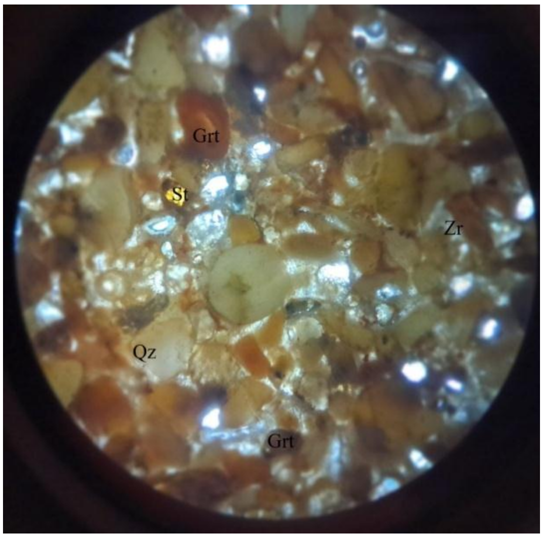


Figure 14:Sample[CM04]

The thin section reveals an abundance of partially cemented calcareous fragments containing fossils and a few irregularly scattered mineral grains; the presence of granite indicates that the rocks have been weathered, and the presence of stromatolites suggests a metamorphic source for the sediments.

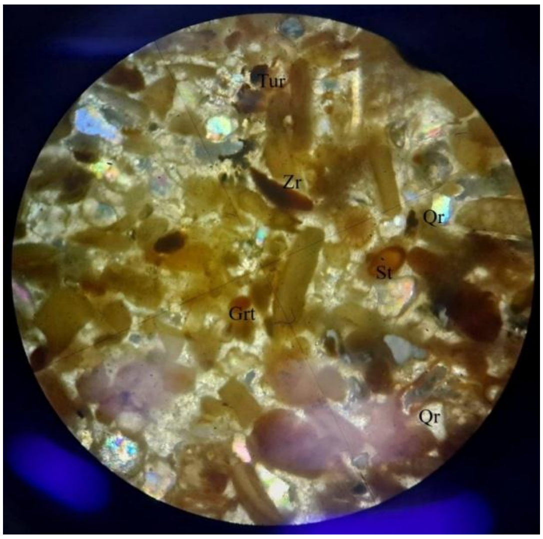


Figure 15:Sample[CM07]

This thin section reveals a calcareous rock rich in biogenic components, characterized by the presence of “Serpulide” calcareous tubes within the limestone, as well as an abundance of biogenic debris, microgranules, and ostracods; these micritic components are surrounded by a matrix. We observe a reduction and distortion in the original texture of the sediment, indicating the presence of areas where recrystallization has occurred.

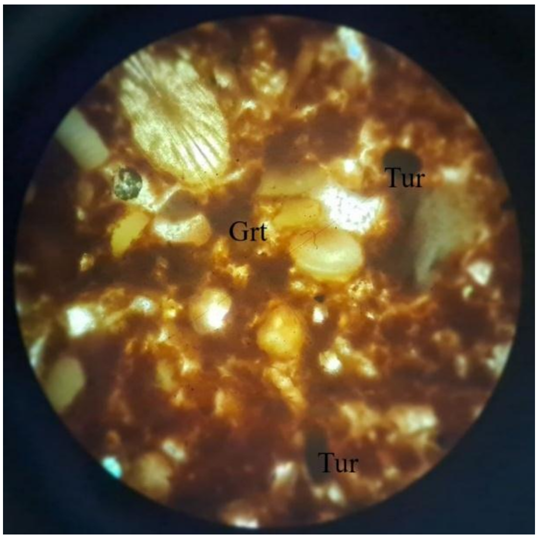


Figure 16:Sample[09CM20]

The thin section reveals a variety of microfossils, particularly Foraminifera and Estacada, distributed within this limestone. We also observe a brown, densely porous material filling the large voids in the rock matrix, which represents the macritic material, along with some tourmaline, indicating a continental origin .

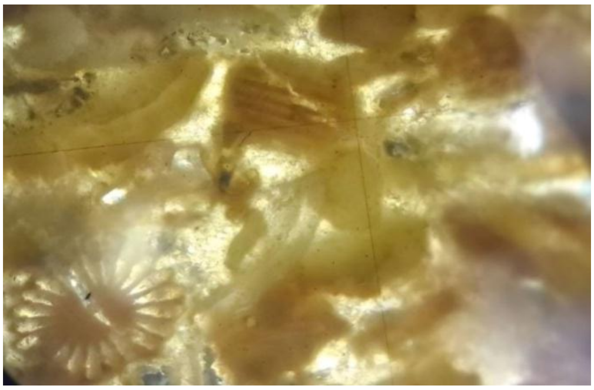


Figure 17:Sample[CH03]

This thin section reveals limestone rich in fossilised remains, and we can see a great deal of biological debris within it. The limestone also shows an accumulation of calcite crystals in the form of interlocking calcareous clusters of varying sizes, as well as dissolution marks associated with sedimentation processes.

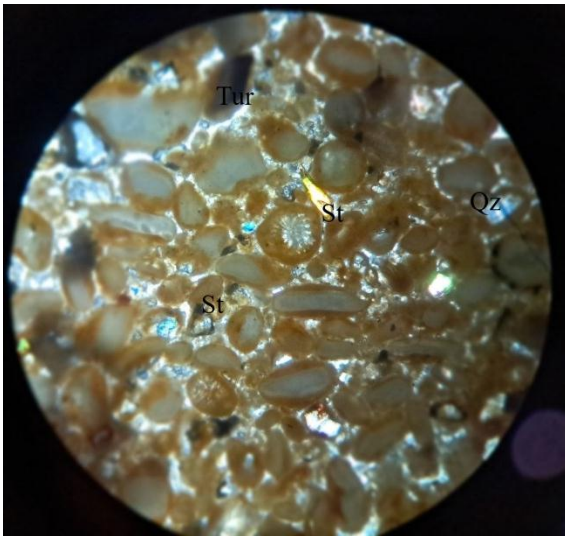


Figure 18:Sample[CH07]

The section reveals a more cohesive and well-structured granular texture containing foraminifera and intergranular voids; these variations are attributed to differences in the depositional conditions that affected the rock ,Foraminifera and ostracods within a granular texture characterised by very round grains, indicating relatively long-distance transport, and possessing good cohesion and interlocking. These grains are covered by a lustrous coating and are accompanied by the presence of heavy minerals, namely tourmaline, sterolite and quartz, as well as fossil remains that bind to a cementitious material that fills the interstitial voids and increases the cohesion of the texture.

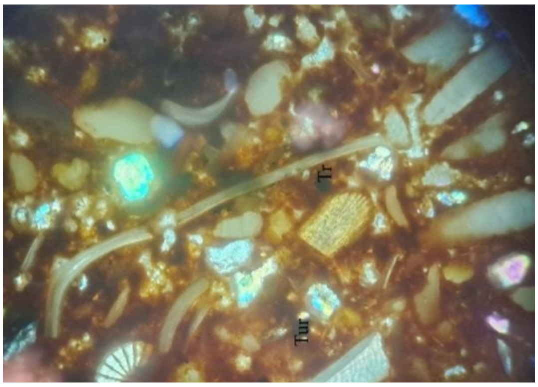


Figure 19:Sample[CH12]

The sample consists of carbonate rock and an abundance of compacted and cemented fossil remains mixed with biological debris. Furthermore, these remains have undergone dissolution, forming a binding material between the rock components, with scattered minerals that are nearly obscured due to the density of the material, which consists of cement rich in clay and minerals The presence of tourmaline and quartz indicates a clastic contribution associated with marine transport and redistribution.

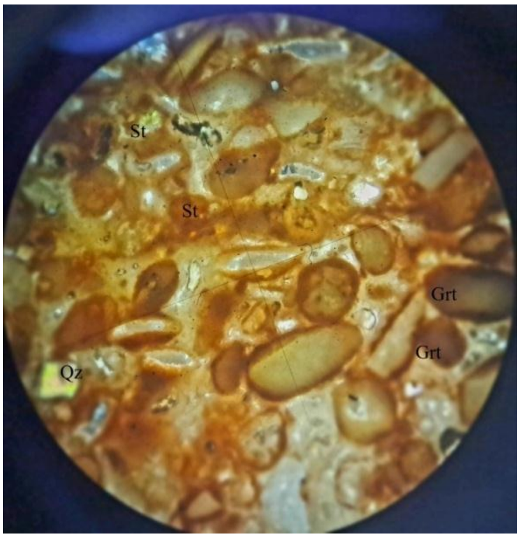


Figure 20:Sample[20CH08]

The slide shows grains of varying sizes with rounded edges, indicating relatively long transport during which they were subjected to continuous friction, which rounded off their sharp corners. The grains are held together by a cementitious material namely, calcareous cement which fills the interstitial spaces and increases the rock's cohesion.

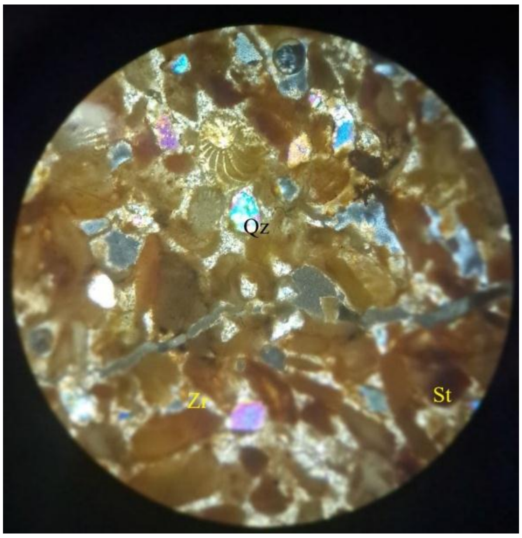


Figure 21: Sample [20CH12]

This slide shows well-preserved biological remains embedded in calcareous material. We also observe a fragment of ostracod, which provides ecological evidence of the contribution of biological components to sediment formation. The shallow depositional environment is conducive to the activity of living organisms, whose deposition and dissolution create porosity within the rock matrix and minerals, indicating dissolution. Continental and carbonate sources in the formation of the sediments. It also reflects the influence of diagenetic processes that contribute to the modification of the original texture. We also find that the sediments were subjected to sorting processes during transport and deposition.

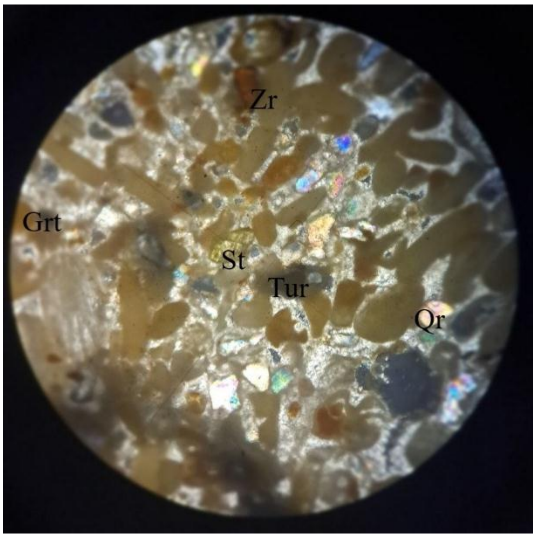


Figure 22:Sample[20CH14]

This section reveals organic components, namely foraminifera and partially obscured organic remains, indicating deformation of the original matrix and the dissolution of organic fragments to form the cementing matrix. It also shows scattered minerals, indicating the survival of the more resistant minerals, whose presence corresponds to the rock's contribution as a source of sediment.

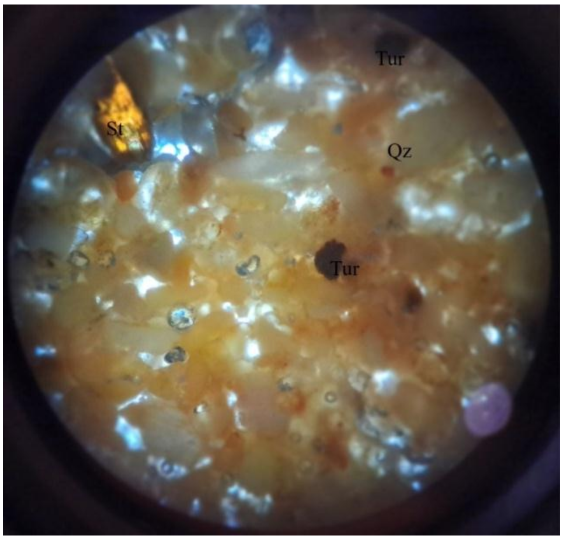


Figure 23: Sample [20CH15]

This section reveals the presence of agglomerated biological material that is difficult to distinguish due to tissue deformation, which has resulted in the fossils being transformed into fine crystalline calcite. The presence of tourmaline, quartz and sterolite suggests that the more resistant minerals have remained intact as a result of being redistributed by water currents.

2. Lithological Description

Thin sections reveal that the limestone consists primarily of fossil shell fragments, particularly foraminifera, and ostracods, along with other calcareous fossils and trace amounts of quartz and other heavy minerals, indicating continental and carbonate sources. The rock also reflects the influence of diagenetic processes that have altered the rock's original texture and contributed to its resistance to weathering and transport, as well as the sediment's It also reflects the impact of diagenetic processes that altered the rock's original texture and contributed to its resistance to weathering . The grains are cemented together by a calcareous matrix that fills the intergranular spaces, and the rock exhibits low to moderate porosity. The rock is characterized by a fine-grained, cohesive calcarenite texture.

3 Interpretation

The foraminifera and carbonate components indicate a significant biogenic contribution to the formation of the sediments. The presence of calcareous material also indicates diagenetic processes that contributed to rock cementation and reduced porosity. The fine-grained, cohesive texture reflects relatively calm depositional conditions with grain rearrangement during subsequent sedimentary transformation stages, confirming that these sedimentary characteristics were deposited in a marine environment conducive to the accumulation of carbonaceous detritus and biological activity.

CHAPTER V: MINERALOGICAL STUDY

Microscopic description

Microscopic analysis of minerals extracted from the sands of the Ain Achir region in Annaba allowed for the identification of the mineral composition of the sediments and the determination of the most significant and diverse mineral species comprising them. Microscopic observations revealed the presence of a diverse range of heavy minerals, the most significant of which are staurolite, garnet, tourmaline, diopside, epidote, and zircon, in addition to other minerals in varying proportions, clearly highlighting the morphology of the minerals under a polarizing microscope.

- **Tourmalin(Tur)**

They occur as black prismatic crystals with blunt edgesandor as subrounded crystals.

Staurotide (St)

The grains are honey-colored. Some grains are xenomorphicSometimesstaurotide is acicular or prismatic automorphic some show signs of wear .

- **Zircon(Zr)**

The grains are generally colorless to pale yellow and exhibit high relief. Most zircon grains are automorphic and prismatic Some grains display well-preserved crystal faces, while others are rounded to sub-rounded due to transport .Certain grains show signs of abrasion and mechanical wear.

- **Mica**

The grains are colorless to brownish in color. They occur as thin flakes with a platy habit Most mica grains are elongated and exhibit perfect basal cleavage. Some grains are bent, fractured, or partially altered ,Several grains show evidence of wear resulting from sedimentary transport.

- **Garnets (Grt)**

They are very abundant, ranging in color from pink to reddish, and in shape from sub-automorphic toxenomorphic some garnets contain inclusions.

- **Quartz (Qz)**

The quartz grains occur as subrounded crystals, varying in size up to 1 mm. The grains are sometimes yellowish-brown if they are covered with a thin film of oxidesHowever, most of the grains are milky white . Calcite is rare despite the presence of outcrops calcite crystals.

- **Disthen (ky)**

It occurs as prismatic grains, always bluish-gray in color. Sometimes the grains appear dark, depending on the amount of inclusions they contain.

- .**Rutil (Rt)**

This mineral occurs as small, elongated, needle-like crystals ranging in color from reddish brown to dark brown and black, with a diamond-like to metallic luster. The crystals are generally found within rocks and often have an asymmetrical to sub-symmetrical shape.

- **Epidote (Ep)**

This mineral is green in color. The crystals are prismatic and are usually rounded by wear.

- **Magnetite (Mag)**

The grains are black and opaque, exhibiting high density. Most magnetite grains are sub-angular to sub-rounded, although some preserve their original crystal morphology. Several grains display abrasion marks and mechanical wear resulting from sedimentary transport. Due to its high resistance to weathering, magnetite is commonly concentrated in sedimentary deposits.

- **Feldspar (Fsp)**

The grains are generally colorless, white, or pale pink and are transparent to translucent. Most feldspar grains are angular to sub-rounded, reflecting varying degrees of transport and weathering. Some grains preserve cleavage traces, whereas others exhibit signs of alteration. The preservation of fresh feldspar grains may indicate limited transport from the source area.

- **Calcite (Cal)**

The grains are colorless to white and are transparent to translucent. Most calcite grains are sub-angular to rounded and may occur as detrital carbonate fragments. Some grains display dissolution features and edge abrasion resulting from both chemical and mechanical processes during transport and deposition.

- **Biotite (Bt)**

The grains are brown to dark brown or black and commonly occur as thin platy flakes. Most grains are sub-angular and exhibit varying degrees of fragmentation and edge abrasion caused by sediment transport. Somegrains show evidence of weathering and partial alteration, reflecting the relatively low stability of biotite under surface conditions.

- **Black Mica**

The grains are dark brown to black and typically occur as thin flaky particles. Most grains are sub-angular and preserve their characteristic platy morphology. Several grains exhibit bending, fragmentation, and mechanical wear resulting from transport processes.

- **Muscovite (Ms)**

The grains are colorless to silvery and transparent to translucent. They commonly occur as thin elongated flakes with a well-preserved platy habit. Most grains are sub-angular to sub-rounded and may display slight bending or edge abrasion. Muscovite is relatively resistant to weathering and can remain preserved during prolonged sedimentary transport.

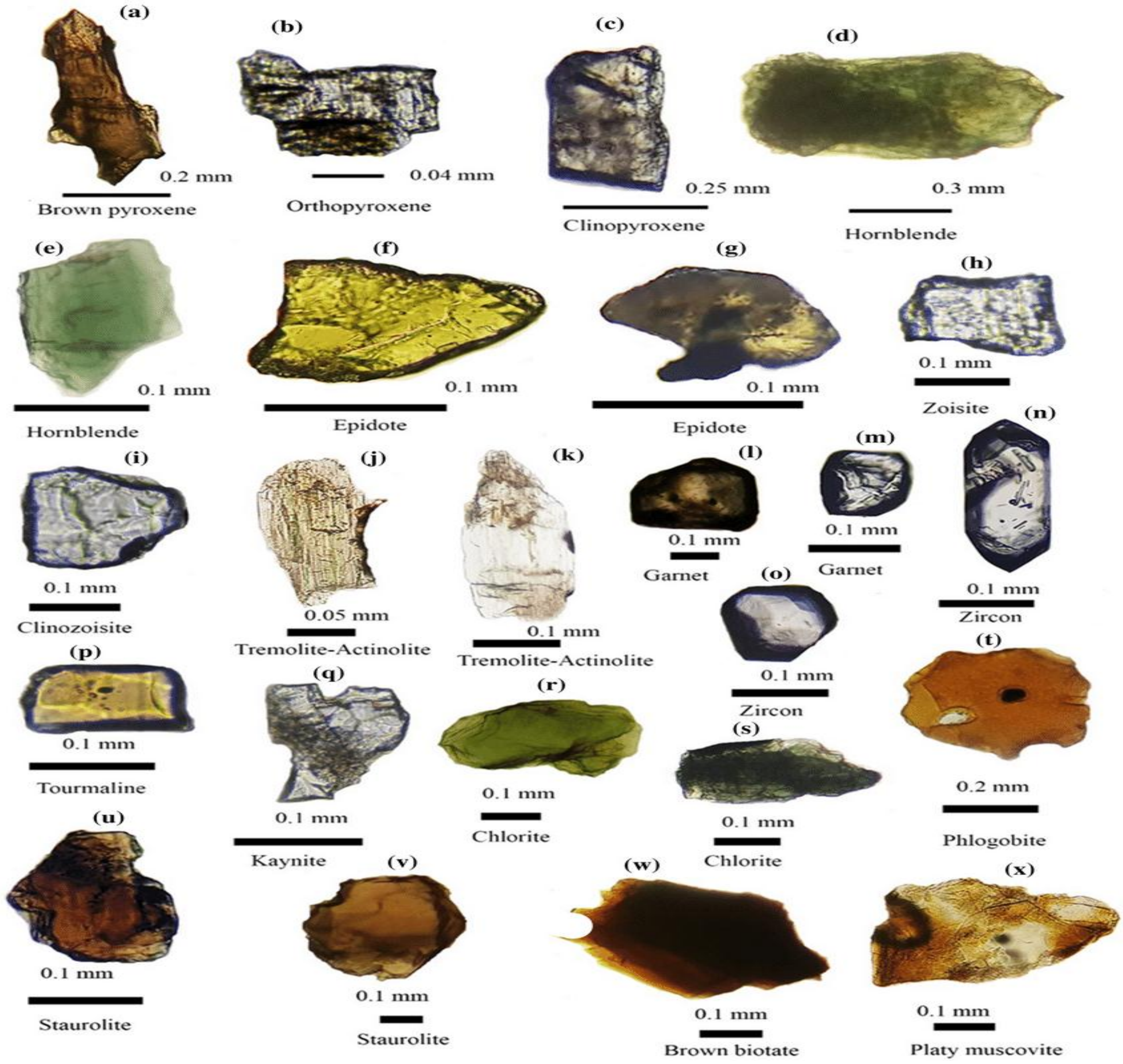


Figure 24:Representative heavy mineral grains commonly found in sediments and used in provenance and paleoenvironmental studies Al-Saady, Y.I., Al-Obaydi, M.M., Othman, A.A., & Hassan, S.E 2021

2 Mineralogical Analysis Under a Binocular Microscope

Mineralogical examination of sand samples collected from Ain Achir using a binocular microscope revealed a range of light minerals (quartz and calcite) and heavy minerals, including tourmaline, zircon, garnet, diopside, epidote, staurolite, and rutile, in addition to other minor phases. The identified minerals are shown in the following figures.

RS05[500]

RS05[250]

RS05[125]

Figure 25Photos microscopic image of various heavy minerals in the sample RS05[500,250,125]

Photomicrographic image of heavy minerals observed in sampleincludind

- RS05[500]: Qz (b) ,mica(c),St(o),Ky(d)
- RS05[250]:Tur (i,o) ,Grt (c,n,i,m) ,ky(h,f) ,Qz (q) ,mica black(e) ,mica(j), St (d,k),Rt (a)
- RS05[125]:Tur (a,k,d),Rt (b,e), Z r(h,j),Qz (i,f)

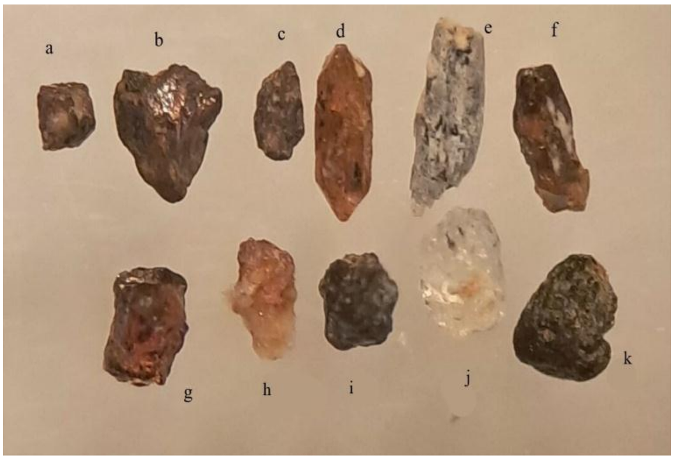
CH03

Figure 26:Photo microscopic image (s) of various heavy minerals in the sample [CH03].

Photomicrographic image of heavy minerals observed in sample including:

- [CH03]: Zr(f),Tur (a,b,i,l)St(e,k) .Ky(g,d).Grt(c,j)

CH07[250]



CH07[125]

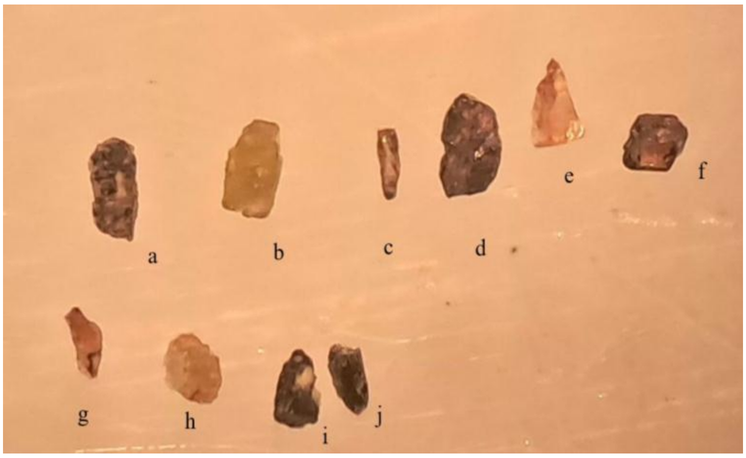


Figure 27:Photos microscopic image(s) of various heavy minerals in the sample[CH07]

Photomicrographic image of heavy minerals observed in sampleCH07, including:

- CH07[250]:Zir(d, g), QZ(j,h),St(f,a,c)Tur(i),
- CH07 [125] :St(a,d,g) Tur (i,j) Rt(c,f) Grt(b,e,,h)

20CH08

Figure 28:Photo microscopic image (s) of various heavy minerals in the sample[20CH08]

Photomicrographic image of heavy minerals observed in sample, including

- [20CH08]:St(b) Tur(a,g, j) Ep(m).

.

CH12 [500]

CH12 [250]

Figure 29:Photos microscopic image (s) of various heavy minerals in the sample[CH12]

Photomicrographicimages of heavy minerals observed in sample CH12 including:

- CH12[500]:Grt (e),Qz(d) and ,mica(g,b) , St (a,c)
- CH12[250]:St(,h,j,f,l) ,Tur(d),Rt(k,g)and Grt(a,i).Tur(b,c,h)

20CH14 [250]

20CH14 [125]

Figure 30:Photos microscopic image(s) of various heavy minerals in the sample[20CH14]

Photomicrographic image of heavy minerals observed in sample 20CH14, including:

- 20CH14 [250]:St (c,p,k,d,l)Zir(i,m)Grt (o) mica (j) Rt (f)Tur (g,h,e).
- 20CH14 [125]:St(a,i),Tur(c),Grt(g,j),Zr(e,f,b).

20CH15

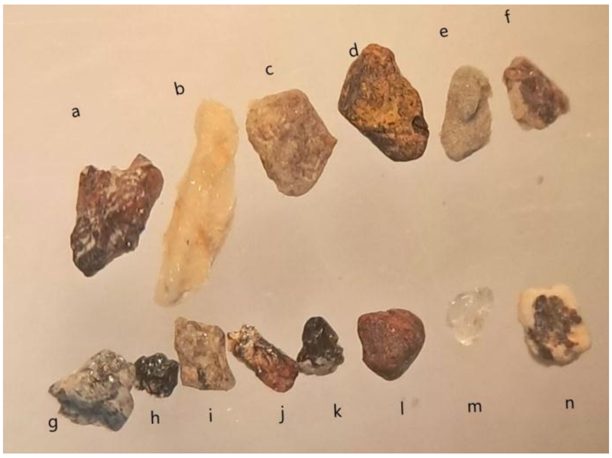


Figure 31:Photo microscopic image (s) of various heavy minerals in the sample[20CH15]

Photomicrographic image of heavy minerals observed in sample, including

- [20CH15]:St(a,j)Qz(b,m) Tur(h,k) ,Qz(m),Fsp(n),Grt(i)

3 Texture

The calcarenite in this area feels very grainy. Its layers are made of sand grains that vary from medium to coarse. When we looked at it in the field, we saw solid calcarenite layers that were yellow to light yellow. These layers were full of tiny fossils, like foraminifera, petropods, and brachiopods. Closer up, the samples showed grains that were medium to coarse with irregular cracks and different levels of hardness. This gives us clues about how the sediments formed and the strength of the water currents at that time.(**Daoui M .A, kiouas2024)**

4 Porosity

The calcarenites we studied don't have the same amount of open space (porosity) throughout the rock layers. We saw this clearly in the upper layers of the formation, where the rocks had different levels of internal holes and were crumbly. This crumbliness is related to how much clay cement is between the grains. This porosity comes directly from how the carbonate grains are arranged and how they're cemented together. It's an important property because it affects how easily water can pass through the rocks, how they act mechanically, and what they can be used for.(**Daoui M .A, kiouas 2024)**

5 Mineralogical composition

The mineral composition of the calc-carbonate rocks is based on calcium carbonate. According to previous studies, the study area of Annaba Ain Achir is characterized by weak erosion processes due to its flat topography and a hidden hydrographic system, where air currents (winds) and waves are the main factors causing erosion and contributing to the nourishment of sandy beaches, resulting in heavy sediment accumulations through the process of gradual sorting and the transport of sedimentary grains by water currents. Heavy minerals thus concentrate in certain areas while light grains settle in others; this is what we call hydraulic sorting, a factor that influences sediment composition.Round, sub-round, and polished grains indicate exposure to continuous friction in a marine environment with medium to high energy, where mineralogical studies have shown a clear variation in the distribution of heavy metals, indicating the diversity of sedimentary sources. Source rocks contribute to supplying sediments with mineral materials, and the prevalence of minerals to resistance to weathering during transport.

Zircon is one of the most important indicator minerals for sediment sources, as its morphological characteristics allow for the determination of the nature of the source rocks and the conditions of sediment transport. Prismatic grains are often associated with igneous sources, whereas rounded grains are associated with the recycling of ancient metamorphic rock sediments. This reflects the succession of several cycles prior to deposition. Maria **A., Mang, David T. Wright.**

CHAPTER IV:SEDIMENTOLOGICAL SYNTHESIS AND COMPARATIVE ANALYSIS

introduction

This chapter dives into a fascinating comparison of three coastal sites near Annaba: the Seraidi Road area, Ain Bent Sultan, and Ain Achir. What makes these spots so special are their beautifully exposed sedimentary layers and their shared history as shallow coastal environments—perfect for really digging into their sedimentology. We've thrown everything at them, from examining quartz grains under a microscope to measuring their calcium carbonate content and even using X-ray diffraction to figure out their mineral makeup. Our goal to piece together what these ancient environments were like. Ultimately, this synthesis offers some valuable clues about where the sediments came from, how they traveled, and the conditions that shaped the calcarenite we see today.

1 Region Ain Bent Sultan :

The Ain Bent Sultane area, located on the northeastern edge of Annaba city, is one of the unique coastal sites within the Ain Achir region, known for its geological richness. The area displays a striking contrast of rock formations, where calcarenite layers clearly overlie metamorphic rocks such as micaschists. One can sense the continuous interaction between land and sea, shaped by the Mediterranean's humid climate, which has contributed to the development of a shallow coastal depositional environment rich in sedimentary indicators.

In this study, the geological features of the area were carefully analyzed, and the results obtained from collected samples will be presented in the following sections.

1.1 the results obtained :

1.1.1 .Quartz Grain Morphoscopic Analysis – Synthesis :

Based on the morphoscopic analysis of the ten collected samples, we observed a clear predominance of rounded shiny grains (EL) across almost all the samples. This suggests that the sediments were transported over long distances, primarily by water currents, before being deposited. These grains exhibit signs of prolonged abrasion, such as smooth and polished surfaces, confirming their marine origin, most likely from a coastal depositional setting.

The presence of non-worn angular grains (NU) in moderate to low proportions in most samples points to a nearby sediment source, indicating that some material was transported over shorter distances, possibly through riverine or fluvial processes. Their sharp edges and limited signs of wear support this interpretation.

Meanwhile, dull rounded grains (RM) appeared in low percentages, which could be indicative of occasional aeolian (wind-driven) transport or reworking, especially in samples where terrestrial influence may have played a role.

In conclusion, the dominance of EL grains, combined with the secondary presence of NU and minimal RM, paints a picture of a shallow coastal marine environment influenced by fluvial inputs. This reflects a dynamic sedimentary regime where water played the central role in grain transport and deposition. These results align well with the environmental context of the studied region — the coastal fringe of Ain Achir and Seraidi, shaped by both marine and continental forces.

1.1.2 Calcimetry $Caco_3$ Content Analysis – Interpretation

The results of the $CaCO_3$ analysis across the ten samples reveal a notable variation in carbonate content, reflecting different depositional environments:

- Samples 4 through 7 show high $CaCO_3$ percentages (ranging from 68.93% to 70.54%), indicating they are carbonate-rich and likely represent well-developed calcarenite formations or shallow marine deposits with intense biogenic activity.
- Sample 3 also shows a moderately high value (54.91%), suggesting a marine influence but with slightly less carbonate accumulation.
- Samples 1, 2, 8, and 10 have intermediate carbonate values (between 19% and 41%), possibly representing mixed depositional settings influenced by terrigenous input.
- Sample 9, with a very low $CaCO_3$ content (5.56%), likely corresponds to a non-carbonate clastic environment, such as siliciclastic or terrestrial deposits.

Overall conclusion: The variation in $CaCO_3$ content supports the presence of multiple depositional facies in the study area, ranging from highly biogenic, shallow marine environments to more siliciclastic-dominated settings. This diversity aligns with the sedimentological and paleontological observations made throughout the research.

1.1.3 Micropaleontological Analysis and Paleoenvironmental Interpretation

Through careful microscopic examination of the studied sample, a rich and diverse assemblage of microfossils was identified. The most notable among them are benthic foraminifera such as Discorbitura, Elphidium, Nummulites, Quinqueloculina, and Lenticulinaloculosa, in addition to the presence of other important microfossil groups including Ostracodes, Gastropods, and Diploporaria (a type of Bryozoa).

This fossil diversity strongly indicates a shallow marine depositional environment, rich in life and favorable to benthic communities. Importantly, all the identified microfossils belong to the benthic group, meaning they lived on or near the sea floor, either embedded within the sediment or attached to it. Notably, no planktonic foraminifera were found in the sample, which supports the interpretation of a stable, low-energy setting—likely a protected coastal zone or continental shelf—where benthic organisms could thrive without significant disturbance from open marine currents.

These benthic foraminifera are particularly valuable in paleoenvironmental reconstructions, as their presence, diversity, and preservation help us understand past marine conditions, including temperature, salinity, water depth, and sedimentary dynamics. Additionally, their sensitivity to environmental changes makes them powerful tools in biostratigraphy and paleoclimatology.

(Betahar Mohamed Rouastaher, 2021)

4. Region Cap de Gardearea :

The Cap de Garde area, located in the northeastern part of Annaba Province, is one of the coastal zones known for its geological diversity. It belongs to the Edough mountain range and features exposed rock formations that reflect shallow marine depositional environments, clearly visible through the succession of sedimentary layers.

The studied rocks in this area show clear signs of continuous marine influence, with limited continental input. The samples analyzed in this study provided valuable data that contribute to reconstructing the ancient depositional conditions of the region, based on sedimentological features and associated fossil content.

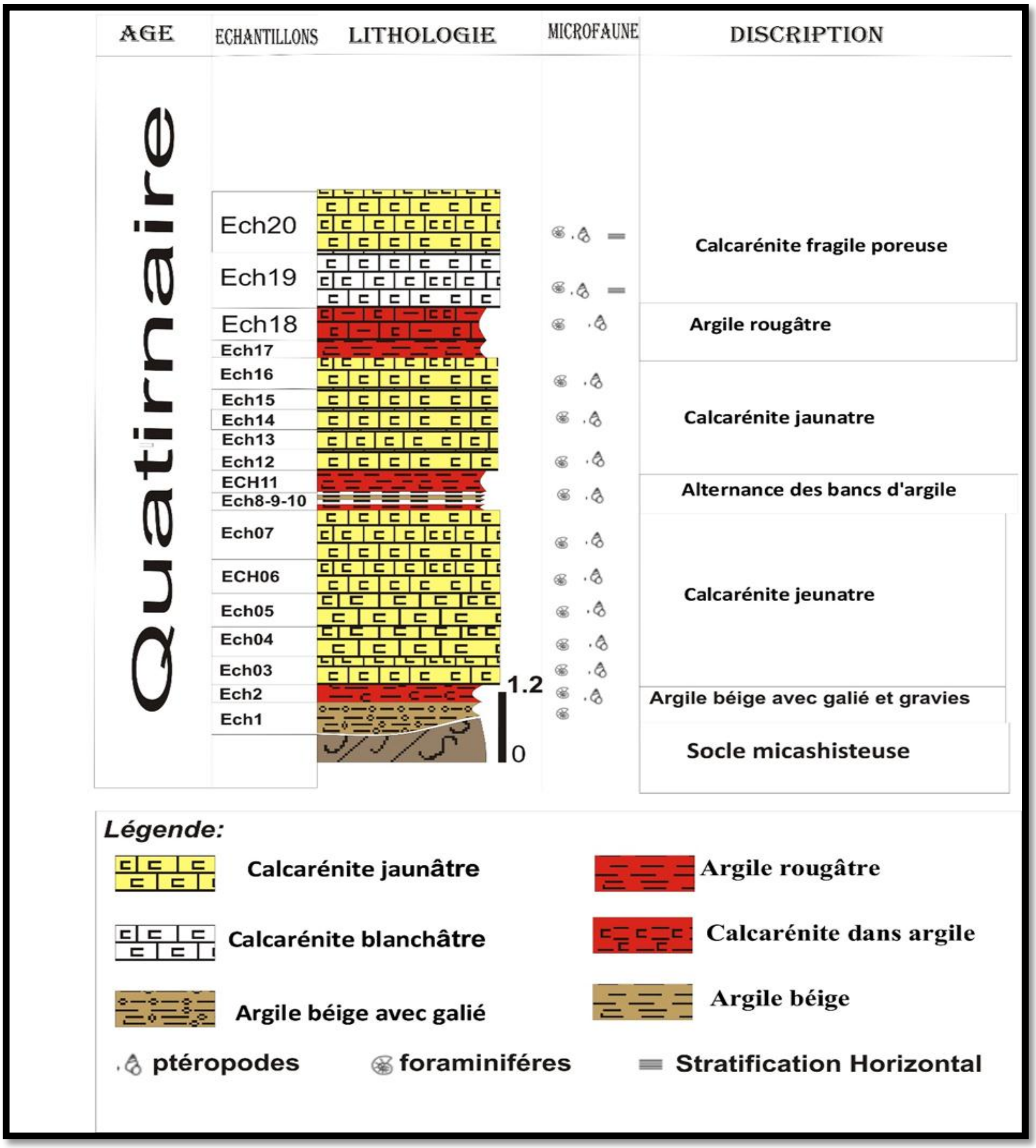


Figure 32 : lithostratigraphic column of the Ain Achir calcarenite formation.

In this study, the geological features of the area were carefully analyzed, and the results obtained from collected samples will be presented in the following sections.

2.1 the results obtained

2.1.1 Quartz Grain Morphoscopic Analysis – Synthesis :

Through the morphoscopic analysis of quartz grains under the binocular microscope, it was observed that rounded shiny grains (EL) dominate most of the samples. This suggests that these grains underwent long-distance transport by strong water currents, as evidenced by the polished surfaces and impact marks. Such features indicate a distant sediment source and a high-energy marine depositional environment. In contrast, a notable presence of non-worn angular grains (NU) reflects the influence of local sediment input—grains that have not been significantly transported or abraded, pointing to proximity to the depositional area. Dull rounded grains (RM) appeared in small proportions but suggest the occasional influence of aeolian (wind-driven) processes, either through reworking or brief exposure to atmospheric conditions.

Altogether, these findings illustrate a complex depositional setting shaped by both marine and continental inputs, with a clear dominance of coastal shallow marine characteristics. This dynamic reflects the environmental transitions and interactions that governed the area during sediment deposition

2.1.2 Calcimetry

From the analytical curve, it becomes evident that the calcarenites of Ain Achir generally exhibit high carbonate content, with an average of 44.8%, reflecting a predominantly marine depositional environment rich in biogenic activity. However, four levels—01 (2%), 02 (10%), 11 (1.2%), and 17 (4.8%)—stand out with noticeably lower $CaCO_3$ percentages.

These variations are not mere numerical deviations; they speak of environmental shifts. The lower carbonate levels may reflect moments of increased terrigenous input, perhaps linked to climatic fluctuations or changes in sediment supply dynamics. Such contrasts reveal a more complex sedimentary history, marked by alternating phases of calm carbonate accumulation and more energetic, possibly fluvially influenced, sedimentation. Ultimately, these data not only help trace the marine character of the area but also hint at episodes where the influence of the land made its presence felt—subtly shaping the lithological fabric of the calcarenites we observe today

2.1.3 Micropaleontological Analysis and PaleoenvironmentalInterpretation

Through the analysis of microscopic samples extracted from the calcareous formations in the Ain Achir region, a wide range of microfossils were identified. These included Benthic Foraminifera such as Elphidium, Lenticulina, Discorbitura, Nonion, Quinqueloculina, Ammonia, and Melonis. A limited presence of Planktonic Foraminifera from genera like Globigerinoides and Orbulina was also recorded.

These fossils indicate a shallow, benthic marine environment with relatively low depositional energy, where these types of organisms prefer to settle in the lower water layers, either within or directly on top of the sediments. The absence of planktonic species in most levels, and their scarcity when present, reinforces the hypothesis of a relatively protected environment, such as a semi-enclosed bay or an inner continental shelf (plate-form interne).

In addition to Foraminifera, the following were found:

- ✓ **Ostracodes**: These are microscopic crustaceans also indicative of a benthic environment, suggesting long-term stability in shallow marine sediments.
- ✓ **Gastropods:** Their presence indicates abundant biological activity on the seafloor, with the probable existence of marine plants or coral reefs.
- ✓ **Diploporaria (Bryozoans):** These further support the hypothesis of a relatively clear, shallow environment, as these organisms grow on solid substrates.

Furthermore, the presence of genera such as Ammonia beccarii and Elphidiumcrispum, which tolerate varying salinity levels, reflects a relatively continental influence (mixing zone), hinting at an interaction between marine and fluvial waters during certain periods.

Tableau 2:Mineralogical composition, grain charcteristics ,and geochemical interpetations of selected samples.

Sample	Dominant Minerals (XRD + context)	Grain Features	Geochemical Insight
Ech01	Quartz + minor feldspars/clays	Angular–sub-rounded, fine	Detrital source, low-energy, pre-marine continental input
Ech07	Calcite + Quartz + Bioclasts	Sub-rounded, sorted grains	Mixed marine input, early cementation, moderate $CaCO_3$

Ech17	**Quartz (pure)** + Fossils	Well-rounded, marine abrasion	High-energy marine setting, reworked calcarenite
Ech20	Quartz (>90%)	Very well-rounded, coarse	Aeolian or littoral sands, minor bioclastic debris

Ech17 XRD confirms high-purity quartz with negligible accessory phases—typical of mature,reworked marine shelf sands.

Tableau 3:Sedimentological Dynamics – Cap de Garde

Stratigraphic Level	**Lithology**	**Sediment Transport & Energy**	**Diagenesis**	**Environment**
Ech01 (Lower)	Sandy basal layer	Fluvial/marine transition, moderate energy	Minor cementation	Proximal shoreface
Ech07 (Middle)	Bioturbated limestone	Moderate energy, benthic fauna	Carbonate cement, burrows	Subtidal, marine shelf
Ech17 (Upper)	Fossil-rich calcarenite	High wave/current energy, reworking	Strong carbonate lithification	Outer shoal or platform top
Ech20 (Top)	Loose sands or beach ridge sediments	Wind and surface current influence	Minimal; modern sedimentation	Subaerial/marginal marine

(Daoui Mohamed Ali Kious Nasreddine Mohamed, 2022)

3 . Region Saraidi Road area

The Seraïdi Road area, located within the Edough massif in the northeastern part of Annaba, represents one of the coastal sectors distinguished by its varied sedimentary formations. The geological outcrops observed along this road display sequences indicative of a shallow marine depositional environment, with noticeable alternations between carbonate and siliciclastic layers.

The sedimentary structures and fossil content recorded in the calcarenite formations reflect a clear marine influence, with minor contributions from continental sources. The analysis of samples collected from this area provided significant sedimentological and micropaleontological data, allowing a better understanding of the depositional dynamics and the paleoenvironmental conditions that prevailed in this coastal setting.

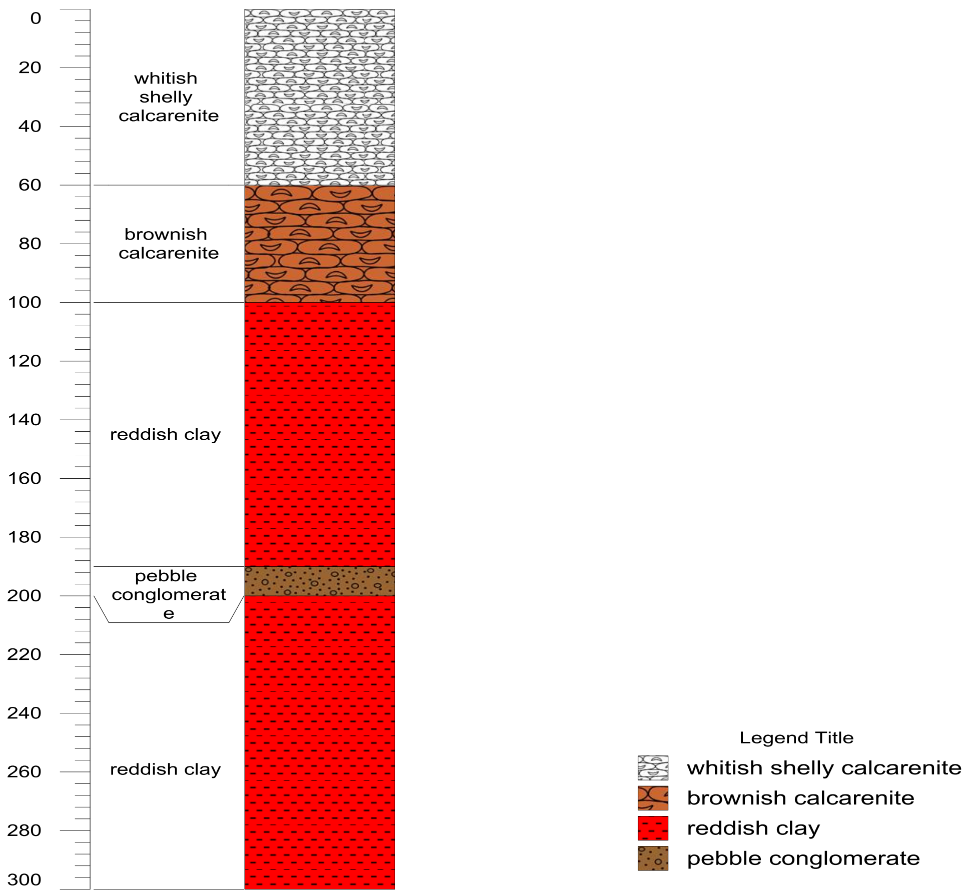


Figure 33 : lithostratigraphic column of the Ain Achircalcarenite formation

4.2 . results obtained

4.2.1 .Quartz Grain Morphoscopic Analysis – Synthesis :

The morphoscopic analysis of quartz grains in the five studied samples revealed a clear variation reflecting differences in sediment sources and transport conditions. Samples 1 and 4 showed a clear dominance of non-worn grains (NU), reaching up to 60%, indicating a nearby local source and near-instant deposition or short-distance transport by river or coastal waters.

In contrast, shiny worn grains (EL) dominated samples 2 and 3, with proportions exceeding 64% and reaching up to 70%, suggesting long-distance transport or repeated reworking by water currents, which is consistent with a high-energy marine environment.

Sample 5 presented a more balanced composition, with 56% NU grains and 37% EL grains, reflecting a mixed environment influenced by both recent sediment input and coastal water transport.

In all samples, the proportion of rounded matte grains (RM) remained low (between 4% and 7%), indicating minimal aeolian influence or long-distance transport.

Overall, the results suggest a shallow coastal depositional environment with variable energy, where local water action played a dominant role in sediment transport, with little contribution from wind-driven processes.

4.2.2 Calcimetry$CaCO_3$ Content Analysis – Interpretation :

The results of the calcimetry analysis for the studied formations revealed a clear variation in calcium carbonate ($CaCO_3$) content, reflecting differences in depositional environments. The first three samples recorded very low percentages (less than 1%), which clearly indicates a non-carbonate depositional setting dominated by siliceous input, such as coastal or fluvial environments strongly influenced by continental sources. These results suggest high-energy sedimentation and intense terrestrial input. In contrast, the fourth and fifth samples showed high $CaCO_3$ values of 57.14% and 72.32%, respectively, indicating a shallow and calm marine environment rich in carbonate-producing organisms such as foraminifera. These elevated values suggest deposition under favorable conditions for calcarenite formation, driven by biological marine activity and abundant carbonate supply. This shift in carbonate content reflects a clear environmental transition within the stratigraphic record, most likely representing a change from dominant continental or coastal settings to a stable shallow marine carbonate environment.

4.2.3 Micropaleontological Analysis and Paleoenvironmental Interpretation

Microscopic analysis of the sediment samples collected from the stratigraphic section in the Seraïdi Road – Ain Achir area (Annaba) revealed the presence of microfossils, mainly benthic foraminifera and ostracods, found exclusively in Sample 5, which corresponds to the calcarenite layer at the uppermost part of the sequence. This concentration of fossils indicates that the depositional conditions during that stage were favorable for the development and preservation of micro-organisms, unlike the underlying levels where such conditions were absent.

Several species of benthic foraminifera were identified, including Elphidiumcrispum, Elphidiumwilliamsoni, Rosalina bertheloti, and Quinqueloculinasp, all of which are indicative of a shallow and stable marine environment. Ostracods were also identified; these bottom-dwelling micro-crustaceans are highly sensitive to environmental changes such as salinity and temperature. In addition, Bryozoans were observed—colonial aquatic invertebrates that confirm the presence of a calm, life-supporting marine setting.

Altogether, these findings suggest that the calcarenite layer represents a shallow marine depositional environment rich in life and carbonates, providing optimal conditions for fossil preservation. This enhances the paleoenvironmental significance of the Ain Achircalcarenites, making them valuable markers for reconstructing ancient environmental and sedimentary dynamics in the region.

Chapter VI: Interpretation and Discussion

CHAPTER VII: INTERPRETATION AND DISCUSSION

1. Reconstruction of the depositional environment

The petrographic, mineralogical, paleontological, and sedimentological data collectively indicate that the Quaternary calcarenites of the Annaba–Ain Achir region were deposited within a shallow coastal marine environment influenced by both marine and continental sediment sources. Petrographic observations revealed abundant bioclastic components, including foraminifera, ostracods, bryozoans, and shell fragments, embedded within a carbonate matrix affected by micritization, recrystallization, dissolution, and cementation processes. These features indicate active biological productivity and subsequent diagenetic modification within a shallow marine setting. Fossil remains constitute the major framework grains, while carbonate cement fills intergranular pores and contributes to the lithification of the calcarenites.

The heavy mineral assemblage identified in the studied samples is dominated by tourmaline, staurolite, garnet, zircon, rutile, epidote, kyanite, mica, feldspar, and magnetite. These minerals are highly resistant to weathering and transport and therefore provide important information about sediment provenance. Their presence strongly suggests that a significant proportion of the siliciclastic fraction was derived from the metamorphic formations of the Edough Massif, particularly the mica schists, gneisses, and garnet-bearing metamorphic rocks that form the basement of the study area. The occurrence of garnet, staurolite, kyanite, and zircon is especially consistent with erosion of medium- to high-grade metamorphic source rocks exposed in the Edough region.

The rounded to sub-rounded morphology observed in many heavy mineral grains, together with the predominance of shiny rounded quartz grains (EL) reported in Chapter 4, indicates prolonged transport and reworking by marine currents. This interpretation is supported by the occurrence of polished quartz grains and by the hydraulic sorting processes responsible for concentrating dense heavy minerals within specific sedimentary levels. Such characteristics suggest repeated coastal reworking under moderate- to high-energy conditions.

2. Influence of Quaternary climatic variations

The comparative sedimentological analysis of Ain Bent Sultan, Cap de Garde, and Seraïdi Road demonstrates a common marine influence but different degrees of continental contribution. Ain Bent Sultan is characterized by carbonate-rich sediments and abundant benthic microfauna deposited in a relatively calm shallow marine environment. Cap de Garde reflects a more open marine platform subjected to higher hydrodynamic energy and intermittent terrigenous input. In contrast, the Seraïdi Road section records a progressive environmental evolution from continental or coastal siliciclastic deposits at the base toward carbonate-rich shallow marine calcarenites at the top. This transition is evidenced by the increase in $CaCO_3$ content, the appearance of benthic foraminifera and ostracods, and the mineralogical shift from quartz-dominated sediments to calcite-rich calcarenites.

The petrographic results are fully consistent with the sedimentological synthesis presented in Chapter 4. The abundance of carbonate bioclasts and marine microfossils corresponds to intervals characterized by high $CaCO_3$ values and shallow marine depositional conditions. Likewise, the occurrence of quartz, tourmaline, zircon, staurolite, and garnet confirms the continuous supply of detrital material from nearby continental and metamorphic sources. Consequently, the calcarenites represent mixed sediments produced through the interaction of marine carbonate production and terrigenous input derived from the erosion of the Edough Massif.

3. Influence of Quaternary climatic variations

Overall, the combined petrographic, heavy mineral, micropaleontological, and sedimentological evidence supports a depositional model involving a shallow marine platform periodically influenced by continental runoff and coastal reworking. The transition from siliciclastic-dominated deposits to carbonate-rich calcarenites reflects fluctuations in sediment supply, hydrodynamic conditions, and relative sea level during the Quaternary. This interpretation agrees with the regional comparison presented in previous studies from the Edough coastal domain, which describe a paleoenvironmental evolution from high-energy coastal settings toward more stable carbonate-producing shallow marine environments.

4. Tableau 4Comparative Table of Mediterranean Calcarenites

Region	Mineral Composition	Heavy Minerals & Petrographic Characteristics	Foram Presence	Stratigraphic Features	Deduced Paleoenvironment	Remarks
Algeria (Edough) Bouzenoune et al. (2017); Tebib et al. (2021); Daoui&Kious (2022); Bethaher&Rouas (2021); BelahbibDouaa (2026)	Quartz + calcite, abundant bioclasts	Heavy minerals dominated by **tourmaline, zircon, garnet, staurolite, rutile, epidote, kyanite, mica, feldspar, and magnetite**. Petrographic analysis reveals abundant bioclastic fragments (foraminifera, ostracods, bryozoans, molluscs), micritic matrix, sparitic cement, dissolution and recrystallization features. Provenance linked to the metamorphic rocks of the Edough Massif.	Rich except in certain layers (e.g., RemitaEch01)	Three layers: sterile lower unit, biotic middle unit, enriched upper unit	Beach → shallow platform → lagoon	Energetic transition, mixed marine-carbonate and terrigenous inputs, ecological stress at top; strong evidence of coastal reworking and hydrodynamic sorting.
Morocco (Tanger–Tétouan) Kadiri et al. (2006); Satta&Ciracì (2014)	Dominant quartz, traces of calcite	Heavy minerals generally dominated by zircon, tourmaline and rutile derived from continental sources; petrography dominated by quartz-rich sandstones.	Low to moderate	Beach/shore-lagoon alternation	Variable environment with strong continental influence	Possible strong diagenesis and reduced carbonate production compared with Edough.

Tunisia (Cap Bon) Negra et al. (2009); Zaghib-Turki et al. (1991)	Quartz + aragonite, shell fragments	Mixed siliciclastic-carbonate assemblage; petrography characterized by abundant shell debris and carbonate cement.	Moderate to high	Transgressive sequence	Shallow platform	Intermediate similarities with Edough, especially in carbonate production and faunal richness.
Libya (Tripolitania) El Hawat& Salem (2002); Makhous et al. (2001)	Quartz, limestone, gypsum locally	Petrography characterized by evaporitic and carbonate components; heavy mineral content generally limited.	Moderate	Carbonate-evaporitic alternation	Hypersaline lagoon to open marine conditions	Locally extreme salinity conditions unlike Edough.
Turkey (Izmir, Mersin) Özcan&Özcan (2004); Sakinç et al. (1999)	Quartz + feldspar, volcanic fragments	Heavy minerals include volcanic-derived pyroxenes and amphiboles; petrography reflects strong fluvial input.	Low to moderate	Deltaic sequence	Deltaic/estuarine environment	Intense continental inputs distinguish these deposits from the marine calcarenites of Edough.
Italy (Apulia, Sicily) Di Geronimo & La Perna (1999); Bosellini et al. (2001)	Quartz + calcite	Petrography dominated by bioclasticcalcarenites, abundant carbonate cement and marine fossils; minor resistant heavy minerals.	High	Calm transgressive deposits	Inner platform	Strong analogies with the upper Edough deposits in terms of fossil richness and carbonate sedimentation.

Greece (Crete, Cyclades) Kontakiotis et al. (2016); Dermitzakis&Papanikolaou (1981)	Quartz, calcite, minor dolomite	Bioclastic carbonates with benthic foraminifera; petrographic textures similar to shallow marine lagoonal deposits.	Rich (*Ammonia*, *Elphidium*)	Fine sediments deposited on platform	Tidal lagoon	Very similar to the upper Edough sequence, particularly regarding lagoonal conditions and microfaunal assemblages.

5. Comparative Synthése

The Edough calcarenites differ from most North African and eastern Mediterranean analogues by the combination of abundant marine bioclasts and a diversified heavy mineral assemblage (tourmaline, zircon, garnet, staurolite, rutile, epidote and kyanite), which clearly records a dual sediment supply. Petrographic observations indicate intense marine biogenic production, whereas the heavy mineral suite demonstrates significant terrigenous contributions from the metamorphic rocks of the Edough Massif. This mixed carbonate–siliciclastic signature places the Edough deposits between the carbonate-dominated platform systems of Italy and Greece and the quartz-rich coastal systems of Morocco and Turkey.

GENERAL CONCLUSION

General conclusion

The integrated sedimentological, mineralogical, petrographic, micropaleontological, and heavy mineral investigations conducted on the calcarenite formations exposed along the Edough Massif east of Annaba have provided significant insights into their depositional history, sediment provenance, and paleoenvironmental evolution. Through the study of several representative coastal sections, including Seraïdi Road, Aïn Bent Soltane, and Cap de Garde, it has been possible to reconstruct the environmental conditions that governed sediment deposition and the interactions between continental and marine processes during the Quaternary.

The heavy mineral study provided additional information on sediment provenance and transport mechanisms. The assemblage identified in the calcarenites is composed mainly of tourmaline, zircon, garnet, staurolite, rutile, epidote, kyanite, mica, feldspar, and magnetite. These minerals are characteristic of metamorphic source rocks and indicate that a significant part of the siliciclastic material originated from the erosion of the metamorphic formations of the Edough Massif. The predominance of resistant minerals such as zircon, tourmaline, rutile, and garnet also reflects repeated cycles of transport, sorting, and coastal reworking under marine conditions. Consequently, the heavy mineral assemblage confirms a mixed sediment supply resulting from both local continental erosion and marine redistribution processes.

Petrographic analyses further refined the environmental interpretation. Thin-section observations revealed abundant bioclastic components, including foraminifera, ostracods, bryozoans, mollusc fragments, and other skeletal debris embedded within a micritic to sparitic carbonate matrix. Several diagenetic features, such as dissolution, recrystallization, micritization, and cementation, were identified, demonstrating the post-depositional evolution of the calcarenites. The abundance of marine bioclasts confirms active biological production in a shallow marine environment and supports the transition from siliciclastic-dominated sedimentation to carbonate-rich deposition.

The sedimentological synthesis demonstrates that the Edoughcalcarenites are the product of complex interactions between marine carbonate production and terrigenous sediment supply derived from the surrounding metamorphic reliefs. The combined evidence from morphoscopy, mineralogy, heavy mineral assemblages, petrography, and micropaleontology indicates a paleoenvironmental evolution marked by a transition from a high-energy coastal or beach environment toward a shallow marine platform and finally lagoonal conditions characterized by enhanced biological productivity.

Comparison with similar Quaternary coastal deposits from other Mediterranean regions, including Morocco, Tunisia, Libya, Turkey, Italy, and Greece, reveals that the Edoughcalcarenites share many characteristics with Mediterranean shallow-marine carbonate systems. However, they are distinguished by the coexistence of abundant marine bioclasts and a diversified heavy mineral assemblage derived from the nearby metamorphic basement, highlighting the importance of both marine and continental processes in their formation.

Consequently, these formations represent a key reference for understanding the paleoenvironmental evolution of the northeastern Algerian coastline and its relationship with the wider Mediterranean basin.

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