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

Thesis

Presented to obtain

3rd Cycle Doctorate

Branch: Geology

Specialty: Applied Dynamic Geology

Title :

Characterization of Quaternary Deposits and Deformations in Eastern Algeria. Case of the Coastal Formations

Presented by :
DINAR Haythem

Publicly defended on 14/10/2023 in front of the following committee members:

N°	first and last name	Grade	University	Quality
01	BEN ZEGOUTA Mhd Said	Prof.	University of Oum El Bouaghi	President
02	KHIARI Abdelkader	Prof.	University of Oum El Bouaghi	Supervisor
03	BOUMEZBEUR Abderrahmane	Prof.	University of Oum El Bouaghi	Examiner
04	HADJI Rihab	Prof.	University of Setif 1	Examiner
05	YOUCEF BRAHIM El-Hadj	MCA	University of Batna 2	Examiner
06	SAADALI Badreddine	MCA	University of Oum El Bouaghi	Examiner

CHARACTERIZATION OF QUATERNARY DEPOSITS AND DEFORMATIONS IN EASTERN ALGERIA. CASE OF THE COASTAL FORMATIONS

(DINAR Haythem)

(ID:……..…)

Acknowledgments

I would like to take this opportunity to express my heartfelt gratitude to all those who have supported and contributed to the completion of my Ph.D. thesis.

First and foremost, I extend my deepest appreciation to my thesis advisor, Professor Mr. KHIARI Abdelkader, for his unwavering support, guidance, and expertise throughout this research endeavor. His invaluable insights, constructive feedback, and dedication have been instrumental in shaping the direction and quality of this work.

I would like to express my sincere gratitude to the president of the jury, Pr Ben Zegouta Mhd Said and the examiners of my thesis, Pr Boumezbeur Abderrahmane, Pr HADJI Rihab, Dr Saadali Badreddine and Dr Youcef Brahim Elhadj for their time, careful review, and valuable comments. Their critical evaluation has significantly enhanced the scholarly merit of this thesis.

I am particularly grateful to Professor Attila Çiner and Cengiz Yıldırım from Istanbul Technical University for providing me with the opportunity to pursue an internship at ITU. Their support, guidance, and knowledge sharing during the internship have enriched my research experience and broadened my perspectives.

I would like to acknowledge the faculty and staff of the Department of Geology at Larbi Ben M'Hidi University for their assistance, resources, and collaborative environment, which have greatly facilitated the progress of my research.

I am deeply indebted to my colleagues (GASMI Assia from LMGC Laboratory – Montpellier – France) and fellow researchers for their stimulating discussions, valuable insights, and technical assistance throughout this academic journey. Their intellectual contributions and camaraderie have been invaluable.

I would like to extend my appreciation to my friends and family for their unwavering support, understanding, and encouragement during the highs and lows of this endeavor. Their love, belief in my abilities, and words of encouragement have been a constant source of motivation.

Lastly, I would like to express my profound gratitude to the funding organizations, or scholarships that have provided financial support for my research (University of L'Arbi Beni

M'Hidi Oum El Bouaghi & Istanbul Technical University). Their generosity has made it possible for me to conduct this study and pursue my academic goals.

In conclusion, I am immensely grateful to all individuals and institutions who have played a part in the successful completion of my Ph.D. thesis on the topic of "Characterization of Quaternary Deposits and Deformations in Eastern Algeria: Case of the Coastal Formations." Your contributions, guidance, and support have been indispensable in achieving this milestone in my academic journey.

Dedication

To my beloved parents, Bouzid and Sallet Friha

I owe who I am today to your love, patience, and countless sacrifices. This modest work is a small token of appreciation for all that you have done, which is nothing short of incredible. May God Almighty bless you, and grant you good health, and long life, so that I may have the opportunity to repay you.

To my dear brothers, Tarek, Issam, Safa and Ikram

No dedication could ever express deeply enough what I feel towards you. I simply say, thank you, and I love you.

To my extended family, the DINAR family,

To my dear friends,

In commemoration of the sincere friendship that bound us and the wonderful moments we shared, I dedicate this work to you, wishing you a bright future filled with promising opportunities. In remembrance of our laughter, the good times we had, and the sleepless nights. In remembrance of everything we experienced together. I sincerely hope that our friendship will last eternally.

To all knowledge seekers,

Where the ink of scholars is more precious in the sight of God than the blood of martyrs.

Abstract:

This Ph.D. thesis is conducted to a broad comprehensive characterization of quaternary deposits and deformations in eastern Algeria. A specific focus on the investigation on these coastal formations was set. The coastal formations in this region are both the most recent and best-preserved, making them ideal for studying the geological history and neotectonics processes in the area.

Through field mapping and structural analysis, this study is aimed to identify and examine two main sedimentary units within the concerned formations which consist on: lower unit primarily, characterized by marine sediments, while the upper unit is composed of alluvial and colluvial deposits. By examining the composition and structural characteristics of these units, the geological processes and deformational history, associated with these deposits, can be determined.

The results of the study have revealed that both, the lower and upper units have indicated two significant deformational events. In the lower unit, two deformation events occurred: an early extensional structure north-south oriented, followed by a late compression structure with a west-east orientation. Likewise, in the upper unit, an early compression structure trending northeast-southwest was succeeded by a late extensional structure oriented west-east. These dated deformational events yield significant insights into late Quaternary tectonic activity in the region. Geomorphic features play a crucial role in the investigation of marine terraces along the Algerian coast. Softwares such as "MATLAB, ENVI, and ArcGIS" have been extensively used as tools to map these concerned areas. To achieve the task of mapping shoreline angles, cliffs, and synthesizing marine terraces, we utilized Lidar Elevation Model (LEM), Surface Classification Model (SCM), in conjunction with Google Earth support. The primary objective was to identify suitable marine terraces.

Additionally, the led study was aimed to explore the active tectonic impacts and the coastal landscape evolution regarding the North African active margin. In that purpose, emphasis on the Zemmouri, Ain Taya, Boumerdes, and Algiers reliefs was scheduled. By the use of advices such as marine terrace sequences and morphometric analysis of drainage patterns, the led research work was also intended to quantify patterns and aspects of coastal uplifts. The overall is planned to examine the active tectonic processes in this concerned region.

Thus, and as outcomes, the aimed research has contributed to a deep understanding of the neotectonics processes operating in the Eastern Algeria. Specific focus was put on marine terraces (quaternary deposits) and their deformations history (already and previously announced). Moreover, this directed study has enabled to establish a relationship between these recorded events and the seismic hazards for the aerial case study.

Finally, this research has provided interesting and valuable understanding for the geological evolution and geodynamic setting in the region, especially for the eastern Algeria.

As fruitful outcomes, this work has resulted in the publications of the following papers such as:

Uplifted marine terraces by active coastal tectonic deformation along the east of Algiers: implications for African and European plate convergence and sea-level curves

Morphometric analysis of sub-watersheds to evaluate relative tectonic activity. a case study of the northeastern of Algeria.

Geomatics-based assessment of the neotectonic landscape evolution along the Tebessa Morsott-Youkous collapsed basin, Algeria.

Moreover, additional research publications in that topics are scheduled in the near future

Development of an erosion map using geographic information systems (GIS) based on the hierarchical analytic process (AHP) case study of Boumerdes-Zemmouri, eastern Algiers.

Evaluation of active tectonics and geomorphic indices in Morsott basin, Algeria.

Keywords : Quaternary deposits, Coastal formations, Marine terraces, Active tectonics, Seismic risks, Zemmouri.

Résumé:

Cette thèse de doctorat vise une caractérisation exhaustive des dépôts quaternaires et des déformations dans l'est de l'Algérie, avec une attention particulière portée à l'étude des formations côtières. Les formations côtières de cette région sont à la fois les plus récentes et les mieux préservées, ce qui en fait un terrain idéal pour étudier l'histoire géologique et les processus néotectoniques de la région.

Grâce à la cartographie sur le terrain et à l'analyse structurale, cette étude vise à identifier et à examiner deux principales unités sédimentaires au sein de ces formations, à savoir l'unité inférieure principalement caractérisée par des sédiments marins, tandis que l'unité supérieure est composée de dépôts alluviaux et colluviaux. En examinant la composition et les caractéristiques structurales de ces unités, il est possible de déterminer les processus géologiques et l'histoire des déformations associées à ces dépôts.

Les résultats de l'étude ont révélé que tant l'unité inférieure que l'unité supérieure ont connu deux événements de déformation significatifs. Dans l'unité inférieure, deux événements de déformation se sont produits : une structure d'extension précoce orientée nord-sud, suivie d'une structure de compression tardive orientée est-ouest. De même, dans l'unité supérieure, une structure de compression précoce orientée nord-est-sud-ouest a été suivie d'une structure d'extension tardive orientée ouest-est. Ces événements de déformation datés fournissent des informations précieuses sur l'activité tectonique du Quaternaire tardif dans la région. Les caractéristiques géomorphiques jouent un rôle crucial dans l'étude des terrasses marines le long de la côte algérienne. Des logiciels tels que "MATLAB, ENVI et ArcGIS" ont été largement utilisés comme outils pour cartographier ces zones d'intérêt. L'objectif principal était d'identifier des terrasses marines appropriées en cartographiant les angles du littoral, les falaises et en synthétisant les terrasses marines, en utilisant le Modèle d'Élévation Lidar (LEM), le Modèle de Classification de Surface (SCM), avec l'utilisation de Google Earth.

En outre, l'étude visait à explorer les impacts tectoniques actifs et l'évolution du paysage côtier le long de la marge active d'Afrique du Nord. Dans cette optique, une attention particulière a été accordée aux reliefs de Zemmouri, Ain Taya, Boumerdes et Alger. En utilisant des méthodes telles que les séquences de terrasses marines et l'analyse morphométrique des schémas de drainage, la recherche avait pour objectif de quantifier les modèles et les aspects des soulèvements côtiers. Dans l'ensemble, l'étude avait pour but d'examiner les processus tectoniques actifs dans cette région spécifique.

Ainsi, les recherches menées ont contribué à une meilleure compréhension des processus néotectoniques opérant dans l'est de l'Algérie, en mettant l'accent sur les terrasses marines (dépôts quaternaires) et leur histoire de déformation déjà annoncée. De plus, cette étude a permis d'établir un lien entre ces événements enregistrés et les risques sismiques pour l'étude de cas aérien. En fin de compte, cette recherche a fourni une compréhension intéressante et précieuse de l'évolution géologique et du cadre géodynamique de la région, en particulier pour l'est de l'Algérie.

En tant que résultats fructueux, ce travail a abouti à la publication des articles suivants :

1. Terrasses marines soulevées par la déformation tectonique côtière active à l'est d'Alger : implications pour la convergence des plaques africaine et européenne et les courbes du niveau de la mer.

2. Analyse morphométrique des sous-bassins pour évaluer l'activité tectonique relative. Une étude de cas dans le nord-est de l'Algérie.

3. Évaluation de la géomatique de l'évolution du paysage néotectonique le long du bassin effondré de Tebessa Morsott-Youkous, en Algérie.

De plus, d'autres publications de recherche sur ces sujets sont prévues dans un proche avenir.

Mots-clés : Dépôts quaternaires, Formations côtières, Terrasses marines, Tectonique active, Risques sismiques, Zemmouri.

ملخص:

تم إجراء أطروحة الدكتوراه هذه بهدف توصيف شامل للترسبات الرباعية والتشوهات في الجزائر الشرقية، مع التركيز الخاص على دراسة تكوينات الساحل. تعتبر تكوينات الساحل في هذه المنطقة هي الأحدث وأفضل الحفظ، مما يجعلها مثالية لدراسة التاريخ الجيولوجي وعمليات النيوتيكتونيك في المنطقة.

من خلال رسم الخرائط الميدانية والتحليل الهيكلي، يهدف هذا البحث إلى التعرف وفحص وحدتي ترسيب رئيسيتين ضمن التكوينات المعنية، والتي تتألف من وحدة سفلى بشكل رئيسي، مميزة بالرواسب البحرية، في حين تتألف الوحدة العليا من ترسبات ألوفية وكولوفية. من خلال فحص تكوين وسمات الهيكل لهذه الوحدات، يمكن تحديد العمليات الجيولوجية وتاريخ التشوه المرتبط بهذه الترسبات.

أظهرت نتائج الدراسة أن الوحدتين، السفلى والعليا، قد أشارتا إلى حدوث حدثي تشوه مهمين. في الوحدة السفلية، حدثت حالتي تشوه: هيكل تمديدي مبكر موجه شمال-جنوبًا، تلاه هيكل ضغط متأخر ذو توجه شرق-غرب. بالمثل، في الوحدة العليا، تمت متابعة هيكل ضغط مبكر متجه نحو الشمال الشرقي بينما تبعته هيكل تمديد متأخر باتجاه الشرق-الغرب. تقدم هذه الأحداث التشوهية المؤرخة رؤى مهمة حول النشاط التكتوني في الرباعي المتأخر في المنطقة.

السمات الجيومورفولوجية تلعب دورًا حاسمًا في دراسة المسطحات البحرية على طول الساحل الجزائري. تم استخدام برامج مثل"MATLAB ، ENVI، و "ArcGIS بشكل مكثف كأدوات لرسم خرائط هذه المناطق المعنية. لتحقيق مهمة رسم خرائط زوايا الساحل والجرف، استخدمنا نموذج الارتفاع(Lidar (LEM ، ونموذج تصنيف السطح(SCM) ، بالتعاون مع دعم .Google Earth الهدف الرئيسي كان التعرف على المسطحات البحرية في المنطقة.

بالإضافة إلى ذلك، تهدف الدراسة إلى استكشاف تأثيرات الزلازل النشطة وتطور المناظر الساحلية فيما يتعلق بالحافة النشطة الشمالية الإفريقية. في هذا السياق، تم التركيز على مناطق زموري، عين الطاية، بومرداس، والجزائر. من خلال استخدام مختلف الطرق مثل تسلسلات المسطحات البحرية والتحليل المورفومتري لأنماط تصريف المياه، تم تصميم البحث أيضًا لقياس أنماط وجوانب الارتفاعات الساحلية. الهدف العام هو فحص عمليات التكتونية النشطة في هذه المنطقة المعنية.

وبالتالي، وكنتائج، ساهمت الأبحاث المستهدفة في فهم عميق لعمليات النيوتيكتونيات التي تعمل في الشرق الجزائر. تم التركيز بشكل خاص على المسطحات البحرية (الترسبات الرباعية) وتاريخ تشوهها. علاوة على ذلك، سمحت هذه الدراسة الموجهة بإقامة علاقة بين هذه الأحداث المسجلة ومخاطر الزلازل. أخيرًا، هذا البحث قدم تفاهمًا مثيرًا وقيمًا لتطور الجيولوجي والإعداد الجيوديناميكي في المنطقة، وخاصة في شرق الجزائر.

كنتائج هذا العمل أسفرت عن نشر الأوراق البحثية التالية:

1.التراس مارين مرتفع بواسطة التشوه النشط للساحل على طول شرق الجزائر: آثار التقارب بين الصفيحة الأفريقية والأوروبية ومنحنيات مستوى سطح البحر.

2.تحليل المورفومتري للأحواض الفرعية لتقييم النشاط التكتوني النسبي. دراسة حالة شمال شرق الجزائر.

3.تقييم التكتونيات النشطة ومؤشرات المورفومتري في حوض مورسوت، الجزائر.

وبالإضافة إلى ذلك، من المقرر نشر بحوث إضافية في هذه المواضيع في المستقبل القريب.

كلمات مفتاحية: الترسبات الرباعية، تكوينات الساحل، المسطحات البحرية، النشاط التكتوني، مخاطر الزلازل، زموري.

Thesis Structure

Chapter 1: General overview

The first chapter of the study introduced the subject and discussed the importance of looking into the deformations and deposits of the Quaternary in this area. It also emphasized the research's goals and the methodology utilized throughout the study.

Chapter 2: Study framework & problematic

The second chapter of the study focused on the concept of the study and its scope. It established the necessary foundations for the subsequent chapters. By clearly defining the study's boundaries, this section ensured that the research would be focused on a specific target.

Chapter 3: Literature review

This chapter provided an overview of the previous research on the deformations and deposits of the Quaternary in eastern Algeria. It also highlighted the gaps in the literature and provided a theoretical background. This section laid the foundation for the contributions made in subsequent chapters.

Chapter 4: Mechanisms for the formation and preservation of marine terraces

The fourth chapter of the study explores the various mechanisms by which marine terraces can be formed and maintained along the coast. Through an in-depth analysis, it revealed how these landforms contribute to the coastal uplift dynamics. The implications of these landforms for the understanding of coastal geology were also discussed.

Chapter 5: Investigating Topographic Parameters for Assessing Seismic Hazard Potential in Northeast Algeria

Following the previous chapters, the fifth chapter explored the link between the seismic hazard potential and the topography in Northeast Algeria. By evaluating the correlation between the seismic activities and the characteristics of the ground, this study provided valuable insight into the region's seismic risks.

Chapter 6: Analyzing Active Coastal Tectonic Deformation and Uplifted Marine Terraces in Eastern Algiers

The sixth chapter focuses on the Eastern Algiers case study (Zemmouri). It explores the various aspects of the coastal uplift and the active coastal tectonic deformation. Through an in-depth analysis, this chapter has provided a detailed comprehension of the marine terraces and coastal tectonic deformation's spatial distribution.

Appendices

This section includes the supporting documentation for the research study, including the data sheets, maps, and photographs.

LIST OF FIGURES

CHAPTER 2

Figure. 12: Geodynamic evolution of the western Mediterranean proposed by Camerlenghi (2009), Mauffret. (2004), and Mauffret. (2007a).

Figure. 13: Opening of the Algerian basin, and structuring of the Atlas and Tellian chains (Frizon de Lamotte. 2009

Figure. 14: Evolution of the East Algerian basin since the end of the Eocene and beginning of the Oligocene proposed by Frizon de Lamotte et al (2000)

Figure. 15: The Balearic Promontory: Northern edge of the Algerian basin. E.E.B : Escarpement of Emile Beaudot ; E.M : Escarpement of Mazarron

Figure. 16: Kinematics at the African-European plate boundary derived from Euler poles estimated by different authors and compiled by Serpelloni. (2007).

Figure. 17: (a) Distribution of seismicity at the African-European plate boundary (earthquakes of magnitude 4) (Serpelloni. 2007).

Figure. 18: Map of the focal mechanisms of earthquakes in the western Mediterranean (Billi. 2011).

Figure. 19: Seismicity map in the western Mediterranean, from 1973 to 2020 (NEIC catalog).

Figure. 20: Seismicity of northern Algeria and focal mechanism of major earthquakes (Yelles-Chaouche. (2006)).

Figure. 21: Depth of hypocenters of Algerian earthquakes (NEIC catalog from 1973 to 2020).

Figure. 22: Morpho-bathymetric map of the Algerian margin from Maradja data (after Domzig, 2006).

Figure. 23: Digital elevation model shows the main active structures along the Algerian coast. (DATA from USGS SRTM 30 m) (modified from Domzig, 2006).

Figure. 24: Digital elevation model shows the main active structures along the Algerian coast. (DATA from USGS SRTM 30 m) (modified from Domzig, 2006).

Figure. 25: (a) Distribution of gravity instability products along the Algerian margin (Cattaneo. 2010). (b) Longitudinal profile of the eastern branch of the Algiers Canyon. Two topographic anomalies (indicated by black arrows) are visible on the profile and coincide with reverse faults identified by Déverchère. (2005).

LIST OF PHOTOS

CHAPTER 4.

CHAPTER 6.

LIST OF TABLES

CHAPTER 6.

LIST OF ABBREVIATION

N	North
S	South
W	West
E	Est
DJ	Djebel
Fig	Figure
m	Meter
WSAC	West South American Coast
ENVI	Environment for Visualizing Images
T1	First Terrace
T2	Second Terrace
ShA	Shoreline angles
SRTM	Shuttle Radar Topography Mission
SL	Sea level
ALOS	Advanced Land Observing Satellite
DEM	Digital Elevation Model
USGS	United States Geological Survey
GPS	Global Positioning System
RSL	Relative Sea Level
MIS	Marine Isotopic Stage
MISS	Marine Isotopic Sube Stage
UTM	Universal Transverse Mercator
M_w	Moment Magnitude
PGA	Peak Ground Acceleration
ESL	Eustatic sea level
AMN	Algerian Monitoring Network
MSL	Mean Sea Level
CCKP	Climate Change Knowledge Portal
NEIC	National Earthquake Information Center
CRAAG	Center for Research in Astronomy Astrophysics and Geophysics
ESRI	Environmental Systems Research Institute

Table of Contents

CHAPTER. VI

ANALYZING ACTIVE COASTAL TECTONIC DEFORMATION AND UPLIFTED MARINE TERRACES IN EASTERN ALGIERS……………………………………………………………..119

Problematic

The coastal formations of eastern Algeria, located on the active african paleomargin between the European and African plates, show signs of ongoing and recent movement.

The formation of these coastal regions has been influenced by the accumulation of marine, eolian, and continental sediments. These deposits have been used to study the evolution of the neotectonic movement in northeastern Algeria.

Although the presence of Neogene-quaternary structures and deformations in post-napp structures has highlighted the importance of the neotectonic movement, the exact mechanisms by which this movement evolved are still not known. This gap in the knowledge of the region's evolution should be addressed through the use of a multidisciplinary approach.

Marine terraces are one of the key indicators of the ongoing neotectonic movement. Their uplift can provide us with valuable information on the Earth's crust's vertical movements. Furthermore, detailed mapping of these markers in certain areas can yield data on the ongoing evolution of the movement, especially in regions such as Algiers, Zemmouri, and Boumerdes, which have experienced significant seismic activity.

Geological and geomorphic data can provide a deeper understanding of coastal structures in Algeria by studying costal deformation and marine terraces. This knowledge can be used to evaluate the seismic hazards and other possible risks associated with the ongoing tectonic activities in the area.

The goal of this project is to enhance the understanding of the evolution of neotectonic structures in northeastern Algeria and the geodynamic processes that are taking place in the Mediterranean.

CHAPITER. I

GENERAL OVERVI

1. Introduction

The Quaternary period is the recent geological epoch, which started around 2.6 million years ago. It is characterized by the presence of a series of glaciations, which have left a significant sedimentary record in many parts of the world (Akziz. 2022). The Quaternary period is also characterized by the presence of a series of tectonic events, which have resulted in the development of a variety of deformation structures. It is found that the Algerian basin is about 150 00 km^2 basin. This basin is largely bounded by the algerian margin to the south. The oceanic nature of the basement is largely highlighted by 200 - 400 km long magnetic anomalies set trending N–S to NW–SE. Across the basin, the magnetic anomalies are sporadic and irregular which have resulted from an irregular accretion process at the back of subduction zones (Bouyahiaoui. 2015).

Contradictory, the regular anomalies observed under the eastern Algerian basin indicate that oceanic accretion has occurred in that area. While the geometries and the timings for proposing the basin formation vary from model to model. The reason is that the age of these anomalies is not known yet. For instance, Jijel region is situated in east Algeria and is a seismically prone area. It is due to the geographical location and the seismotectonic setting in the region of Algerian cost which corresponds to the plate boundary of Africa and Eurasia (Benhamouche. 2014) (Fig 1). Consequently, among the effect are seismites, which thereby correspond to the earthquake-triggered deformation sediment. The soft sediment features induced by earthquakes tend to cover a significant variety of structures. These structures include injection or expulsion of the fluidized material which occurs at shallow depth and appear to be fluid, wrinkled, and folded structures (Bouyahiaoui. 2015).

East Algeria region has experienced two destructive earthquakes having intensities i.e., Io=VIII and Io=IX. These earthquake intensities thereby caused tsunamis that damaged the lower part of the area drastically along with the coaster zone including bejaia, skikda, and the Balearic island across southern Spain (Harbi. 2011). The study of Quaternary deposits and deformations is important for several reasons. On the one hand, it allows an understanding of the history of the surface of the earth and the evolution of its landscape. On the other hand, it allows for assessing the current level of tectonic activity and identifying potential danger areas for future earthquakes and landslides (Benbakhti. 2018). The present thesis is devoted to the characterization of Quaternary deposits and deformations in eastern Algeria. It focuses on the study of coastal formations, which are the most recent and best-preserved ones.

2. Research Problem

In the prior studies regarding Eastern Algerian, some of the faults in the submarine have been determined through seismic analysis of the profile. It was viewed that about 4000 km for the seismic reflection profile has been collected from two seismic surveys which are carried forward between 1973 and 1977 by the Algerian company (Maouche. 2013). It is determined that the Miocene and the quaternary travertines that are deposited through hot springs can thereby reveal significant insight into the hydrothermal and neotectonic activity.

These travertine deposits through quaternary reveal significant information about neotectonic history across the globe (Boukhedimi. 2017). Several studies have been conducted to determine the quaternary deposit and the deformation across different areas of north Algeria. However, very few or limited studies have been conducted on the insight from eastern Algeria. Therefore, the research is conducted to fill the existing research gap and determine the insight into the quaternary deposit in eastern Algeria along with the tectonic activity impact. This research study is based on the premise that an understanding of Quaternary deposits and deformations is essential for an accurate analysis of tectonic activity (Amir. 2017). The specific research problem that is addressed in this thesis is based on a fundamental question what are the Quaternary deposits and deformations in eastern Algeria and how have they been affected by tectonic events? To answer this question, a study of the coastal formations has been conducted. These formations are the most recent and best-preserved ones and they have been affected by two main deformation events: an early deformation event, which has generated an N-S trending extensional structure, and a late deformation event, which has generated a W-E trending compression structure (Boukhedimi. 2017). Thus, it is intended to determine the timing and mechanisms of these deformations.

3. Research Aims and Objectives

The research study is aimed to characterize the Quaternary deposits and deformations in eastern Algeria with a special focus on coastal formations. While research objectives are:

1. To characterize the Quaternary deposits and deformations in eastern Algeria.
2. To identify the main sedimentary units and the deformational history of these units.
3. To date, the tectonic events have affected the area.
4. To assess the current level of tectonic activity in the area.

5. To identify potential danger areas for future earthquakes and landslides.
6. To map the succession of marine terraces in the Est coast of Algiers.

4. Research Questions

The research questions are:

1. What are the main sedimentary units in the area and their deformational history?
2. When did the tectonic events that have affected the area occur and what is the current level of tectonic activity in the area?
3. What are the potential danger areas for future earthquakes and landslides?

5. Significance of Research Study

One of the main goals of this study is to enhance our understanding of the Quaternary history of eastern Algeria. The study of these deformations will help us to better map the active tectonic features in the area and to assess the potential for future earthquakes (Maouche. 2017). In addition, this research is important because it provides a better understanding of how different deformation events can affect the morphology of coastal formations. This information is useful for both academic and practical purposes. In addition, this research study is also significant for the following reasons:

1. The research is conducted in a relatively understudied area.
2. The study of the deformations will help us to better map the active tectonic features in the area.
3. The research is important because it provides a better understanding of how different deformation events can affect the morphology of coastal formations.
4. The research is relevant for both academic and practical purposes.

CHAPTER. II

STUDY FRAMEWORK & PROBLEMATIC

1. Introduction

Due to its active seismic history, the Algerian Northeast region has been regarded as one of the seismic hotspots of the western Mediterranean. Tell Atlas' seismic activities are mainly linked to the faulted formations. Through studies on the Zemmouri and El Asnam faults, researchers were able to gain a deeper understanding of the region's geology. They also discovered that the multiple fault structures in the Tell Atlas region can contribute to the development of moderate earthquakes. Although these are less powerful than powerful ones, they still pose a threat to the local infrastructure and population.

Through their studies on the geological data collected from the region's past earthquakes, the researchers were able to gain an understanding of the various patterns of powerful seismic activities that have occurred in the area. It has been estimated that strong earthquakes that have a magnitude greater than 7.0 usually occur around 300 to 500 years from now. These types of seismic activities have the potential to cause extensive destruction and loss of life.

Conversely, data regarding the frequency of seismic activities revealed that moderate earthquakes commonly occur within the Tell Atlas. Such earthquakes, have a periodicity of about 25 to 30 years and are not as destructive. Nevertheless, they still pose a serious seismic hazard to the region.

One of the most important factors that researchers need to consider when it comes to studying the development of new subduction regions is the mechanism by which these areas are triggered. This chapter will provide an overview of current knowledge related to the passive margins that are activated during compression.

The chapter begins by reviewing the initial phase of the process that involves the passive margins' activation. Following that, we explore the different factors that can affect the development of new subducting regions. By taking a deeper dive into the details, we can gain a better understanding of the underlying processes. The case study of the Algerian margin, which is located in the western Mediterranean, is presented to illustrate the various criteria that are needed to evolve toward a subduction zone in the future. This region is an ideal site for studying the early stages of subduction initiation.

The role of subduction in the development of the mantle dynamics and plate tectonics has been acknowledged for a long time. Due to the presence of these regions, which are at the center of a major seismic risk, many studies have been conducted on the active and passive subduction margins. If the studies that have been conducted on these processes are able to provide a better understanding of the mechanisms that lead to the activation of new subduction zones, many unknowns will remain unanswered.

2. Geodynamic evolution of the north African margin

In this study, we will look closely at the Algerian part of the African active margin, which is characterized by a number of features related to the formation of a subduction zone. As a part of the convergence of the African and Eurasian plates, this young margin could potentially evolve into a subduction zone.

This section will review the geodynamic evolution of the Algerian margin and its structural heritage. We will also look into the various inversion mechanisms that are triggered by this feature.

2.1 The major structural units of North Africa

The Northern Algeria region is characterized by various geological and structural features that have been identified. These features will be presented first to allow us to study their current state and their geodynamic potential (Zahaf. 2022). (Figure. 2)

The coastal zone of Northern Algeria is bordered by two major orogens: The Tell and the Atlas (Ghoual. 2022). The atlas domain (the Saharan Atlas in Algeria, Figure. 1, 2) is limited to the south by the Southern Atlas Front. This platform, which was deformed during the Meso-Cenozoic era of North Africa, is regarded as the most significant feature of the region. A chain of mountainous ridges located in the NE-SW orientation is also known as the most important region of Northern Algeria.

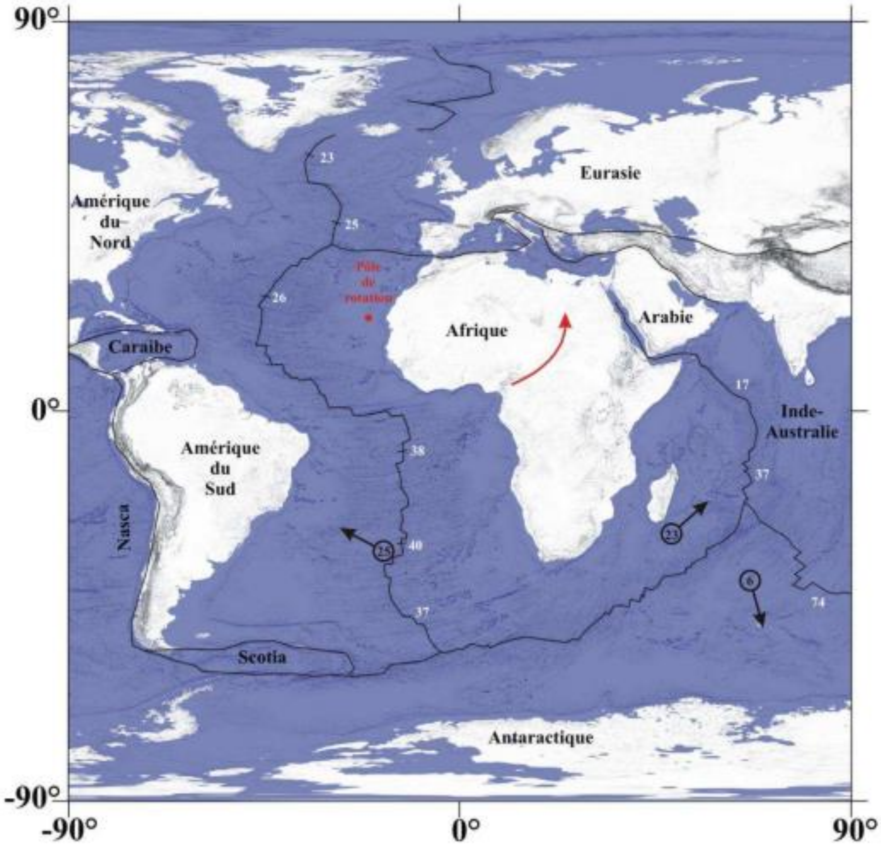


Figure. 1: Current configuration of tectonic plates North America, South America, Africa and Eurasia (modified from nocquet, 2002).

The Maghrebids are located in the peri-Mediterranean Alpine, which is an orogen of the Tethys that extends from the south of Spain to the Sicilian arc and the Rif chain in Morocco (Durand-Delga, 1969). This type of orogen has a history that is linked to the closing and opening of the Tethys "Alpine". The Maghrebids' orogen extends over 2000 kilometers from the south of Spain to the Calabrian-Sicilian arc (Dinar. 2018)(Figure. 2). It also includes the Tell chain in northern Tunisia and Algeria, as well as the African side of the Rif chain in Morocco (Figure. 2).

The Tellian domain is composed by layers that are related to the paleogeographic origins of various regions. The Tell chain includes three nappes: The External Zones (the Tellian nappes), the Flysch nappes (Figure. 3), and the Internal Zones (Kabylies, Figure. 4).

2.1.1 The External Zones

The external zones of the Tell are composed of allochthonous nappes that spanned a hundred kilometres to the South during the Middle Cretaceous era. They are composed of marls that were from the Middle Cretaceous era to the Paleogene age. From a paleogeographic perspective, the outer regions of the Magrebids are considered to be the northern margin of Africa, and this makes the southern portion of the Alpine Tethys' southern margin reverse (Frizon de Lamotte. 2006) (Figure. 3)

2.1.2 Flysch layers

The flyschs in the Maghrebis are related to the deposits of turbidities that were found in the Tethysian ocean during the Cretaceous period (Bouillin. 1986). There are two types of flyschs that are distinguished from the other species: the Mauretean and the Massylian. These two flyschs were deposited in a so-called "Maghrebin" gorge (Bouillin. 1970; Bouillin. 1986). This trench was formed by the narrow basin separating the European margin from the North African margin. It was formed by the internal zones (Bouillin. 1986) (Figure. 3)

The Massylian flysch was first deposited in the Maghrebian trench during the Cretaceous period. The flyschs were fed by the outer regions of the trench, which are similar to the regions where the Mauritanian flyschs were deposited. These flyschs are of African origin and were not fed by the internal zones of the trench (Bouillin. 1970; Bouillin. 1986). Currently, these flyschs are trapped between the internal and external zones of the trench (Figure. 4, 5).

2.1.3 The Internal zones

The Internal Zones can be subdivided into 2 sub-sets:

- The Kabyle platform

The internal massifs of the Maghrebids are mainly composed of a Hercynian crystalline basement (Bouillin. 1986). This paleogeographic domain, which was formed until the end of the Eocene, existed until the northern margin of the Tethyan ocean (Bouillin. 1986). The basement of the Kabyle region is frequently overlaid by sedimentary rock formations identified as the Oligo-Miocene Kabyle. These formations are primarily characterized by deposits from the Burdigalian epoch (Figure 5).

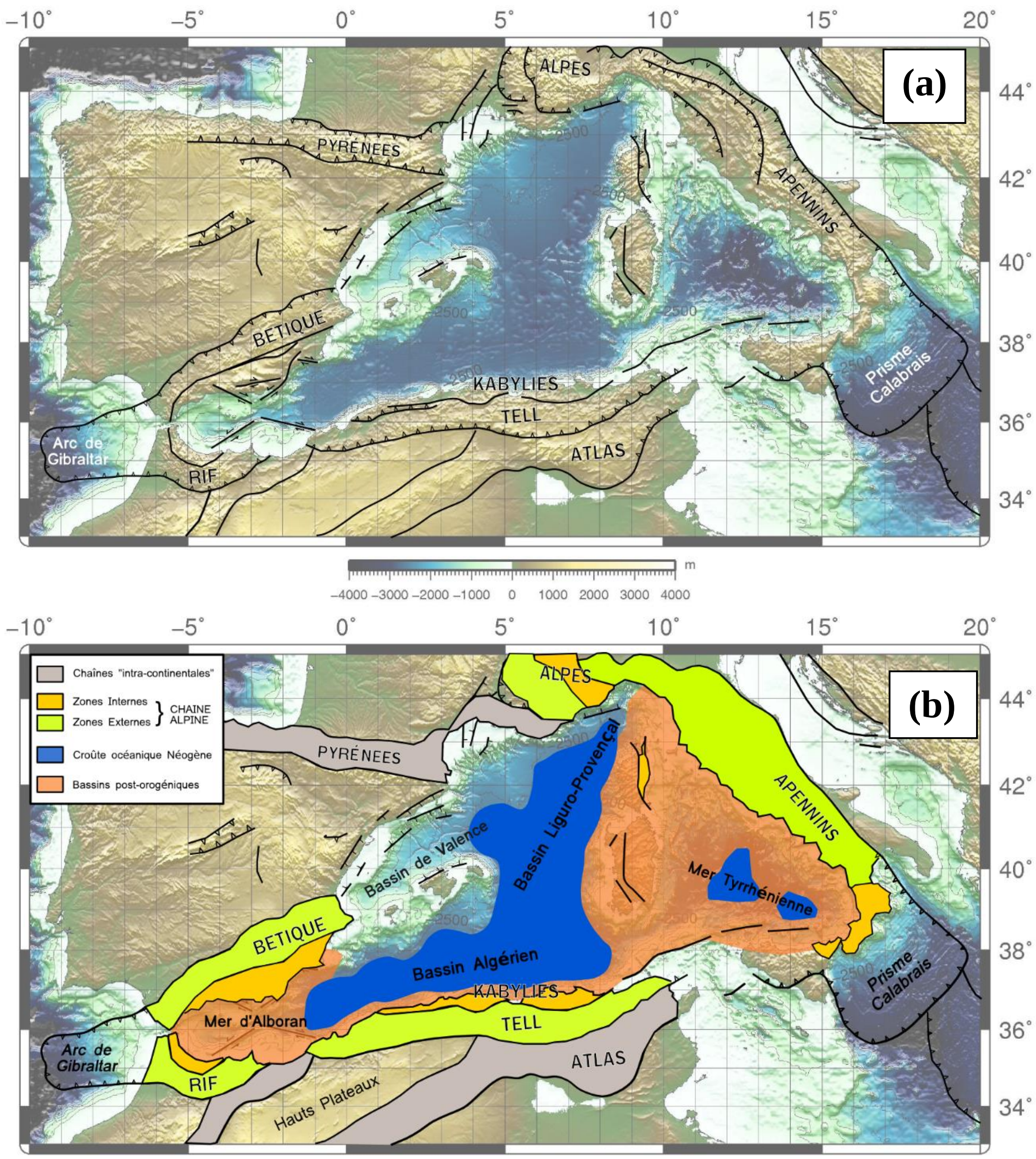


Figure. 2: - (a) Current tectonic context of the Western Mediterranean (modified from Billi and al. (2011)). (b) Main structural domains of the western Mediterranean (modified from Frizon de Lamotte. 2000 and Billi. 2011).

- The Kabyle Ridge

The Calcareous formations are composed of several narrow units that are part of the Mesozoic carbonate series (Figure. 5) From its innermost part, the carbonate series moves quickly to various basin series, intercalation, and epicontinental series. From its outermost part, the carbonate series crosses the intercalation of the Maghreb Basin beds. This part of the carbonate series then moves to the intermediate series between the two basins (Bouillin. 1992)

The field observations revealed that the limestone structure found in the Calcareous Ridge originated from a different part of the margin than the Kabyle basement. This suggests that the limestone structure originated from a more distal part of the southern european margin (Bouillin. 1986; Bouillin. 1992) (Figure. 3)

The various physical similarities between the internal blocks of Italy, Spain, Morocco, and Algeria were derived from the same paleodomain (origin) Bouillin (1986). All of these domains were believed to have been formed following the dislocation of the southern European paleodomain. The AlKaPeCa is a common name for the Alboran-Kabylie-Peloritain-Calabria region. From East to West, the group is represented by the massifs of small Kabylie, great Kabylie, Algiers, and Chenoua.

The complex's structural and geological characteristics have allowed us to study the region's original paleogeography before the Algerian basin was opened. This reconstruction of the region's history will help us understand the various structures of the Atlasian and Tellian chains during the Cretaceous period (Figure. 3). During this period, the internal zones of the Alpine Tethys and the outer tell formed a southern margin of the ocean basin. A series of Flysch deposits was also found in the Tethyan Basin (Figure. 3).

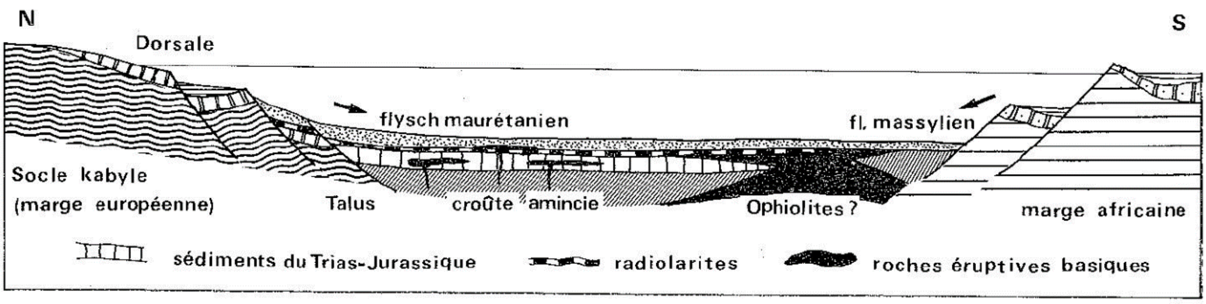


Figure. 3: Paleogeographic reconstruction at the end of the Cretaceous according to Bouillin (1986)

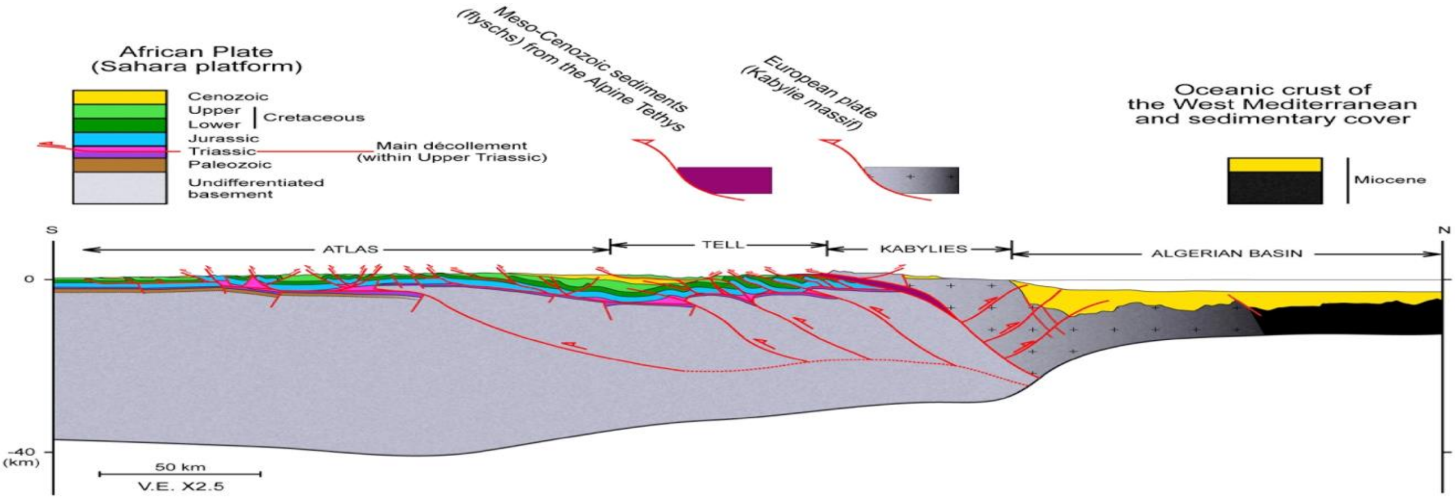
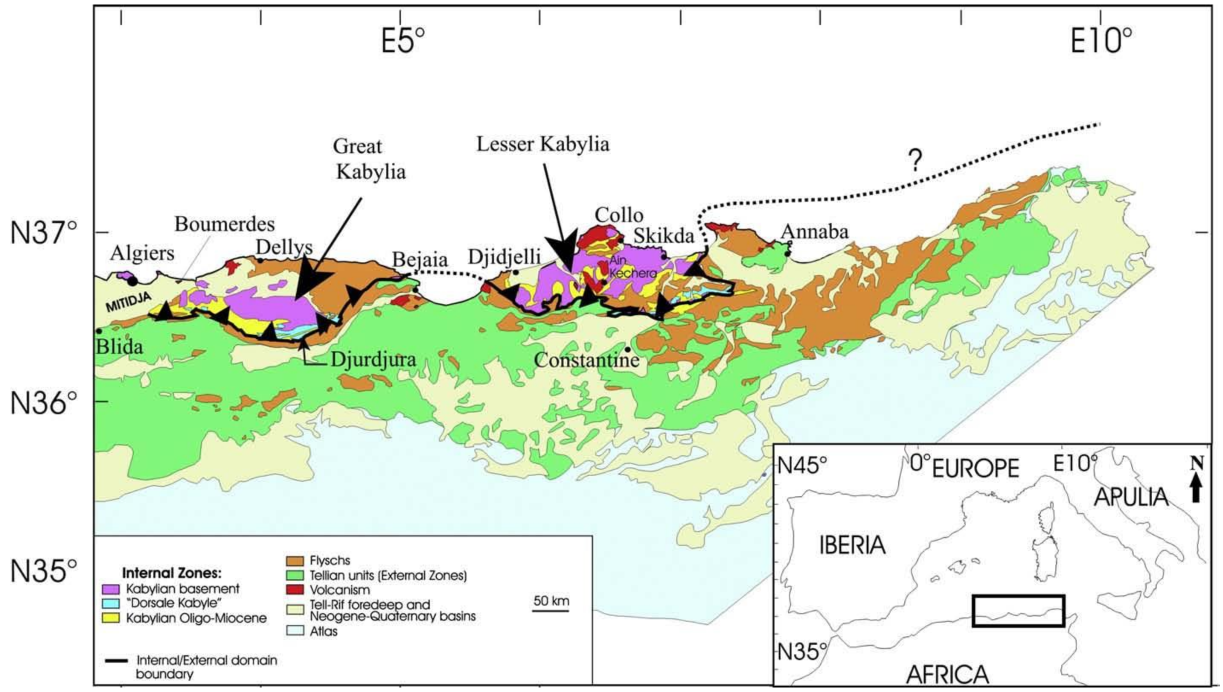


Figure. 4: The northern domain of Algeria, which includes the Kabylia, passes through the Southern Atlasic Front and the Algerian deep basin (modified by Frizon de Lamotte. 2011, Bracene and Frizon de Lamotte, 2002, Roca. 2004 and Benaouali-Mebarek. 2006).

Figure. 5: Geological framework of the NE Algeria region (modified from Domzig.



2006) The dark line is the boundary between the internal and external zones of the Alpine belt. The dashed line shows the offshore part of the thrust front that is not identified.

2.2 Formation context of the western Mediterranean and the Algerian basin

The geological evolution of the Mediterranean region is closely associated with the formation of the Alpine mountain chains (Doglioni. 1997; Gelabert. 2002). This connection arises from the complex interplay of tectonic forces involving the European and African plates, which were influenced by the magnetic anomalies of the Atlantic Ocean (Olivet. 1982; Dewey. 1989; Ricou, 1994; Rosenbaum. 2002a) (Figure. 6)

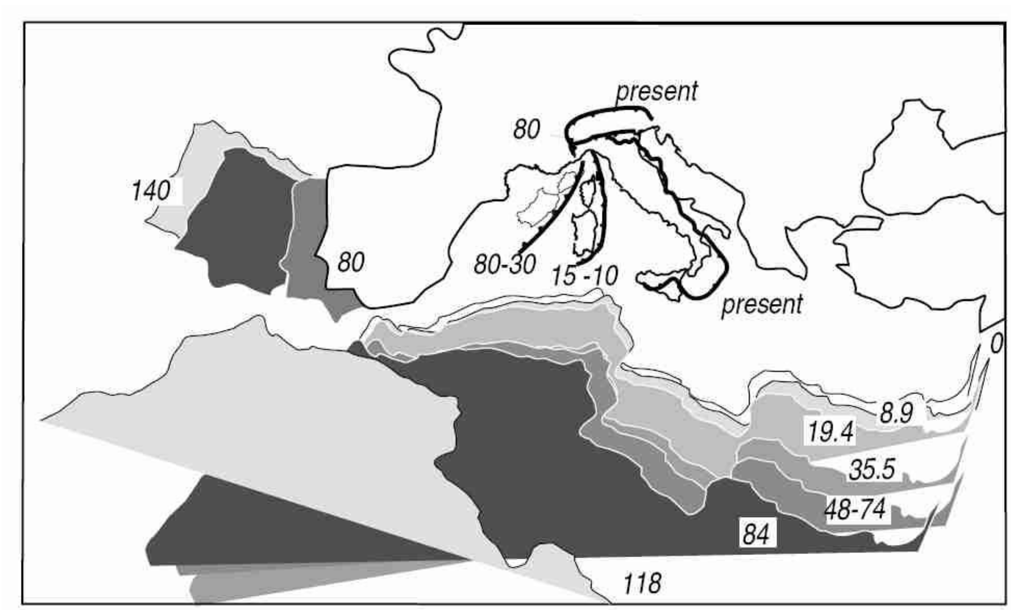


Figure. 6: Movement of the African plate compared to the fixed Eurasian plate (Faccenna. 2001) and the Tethyan subduction front from the Cretaceous to the present. The numbers indicate the ages in Ma for the different positions of Iberia, Africa and the Tethyan subduction front. We notice that at 84 Ma the convergence between Africa and Europe starts (dark grey plate) and that it is continuous and still ongoing today.

The formation of the western Mediterranean and the Algerian basin can be explained by going back to the Mesozoic era. During this time, the Alpine Tethys separated the African and European continents (Figure. 7)

- Mesozoic kinematics & initiation of the African-European convergence

The Alpine Tethys is the western branch of the Tethyan Ocean, and it formed as a result of the breakup of the Pangea during the end of Paleozoic-era (Frizon de Lamotte and al.). The movement of the Atlantic Ocean from the Central Atlantic to Iberia and Africa resulted in the formation of this oceanic corridor. The oceanic domain of E-W, which separated the African and European continents until the Cretaceous, has formed an oceanic corridor consisting of senestial transtension (Cavazza. 2004) (Figure. 7).

The African plate's trajectory changes following the South Atlantic's opening during the Late Cretaceous. This event triggered the convergence of the two plates, which will eventually lead to the establishment of the Alpine Tethys chains. The development of these chains occurred as a result of the collision between the European and African plates (Olivet. 1982; Dewey. 1989; Ricou, 1994; Rosenbaum. 2002; Cavazza. 2004; Schettino and Turco, 2011) (Figure. 6).

The formation of the Alpine Tethys chains following the collision between the African and European plates will be initiated by a stress regime that will gradually close the rift between the two plates. The convergence of the two plates will also affect the western Mediterranean's evolution.

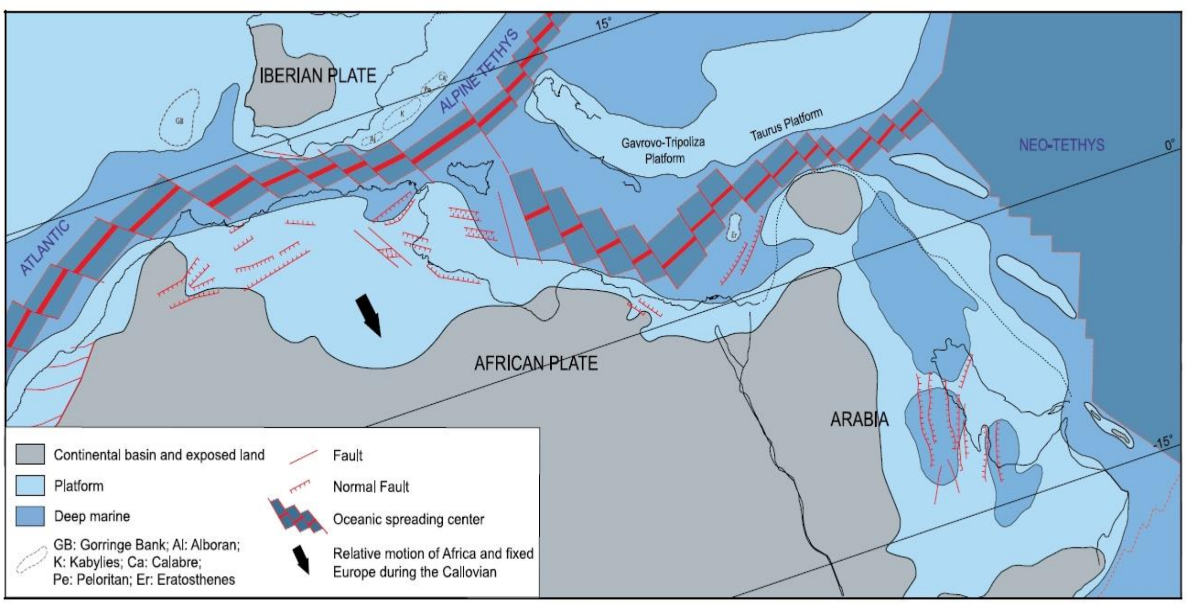


Figure. 7: Paleotectonic reconstruction of the Alpine Tethys at 165-160 Ma (Frizon de Lamotte. 2011). The westernmost part of the Alpine Tethys separates Iberia from Africa. This domain is connected to the west to the Central Atlantic. Note that the Alboran, Kabyle, Peloritan and Calabrian microblocks are located east of Iberia, and form the northern margin of the Alpine Tethys.

2.3 Formation of the Western Mediterranean back-arc basins

The formation of the Western Mediterranean basins was triggered by the extension and compression of the Mediterranean domain during the Oligocene. This resulted in the significant continental extension of the Alboran and Tyrrhenian basins, as well as the oceanization of the basins in the South Tyrrhenian, Algerian, and the Liguro-Provencal (Figure. 3). On the other hand, the formation of mountain chains in the region, such as the Maghreb, Apennines, and the Alps, also contributed to the formation of the mountain systems on the Mediterranean region (Figure. 3).

The rollback process is most widely accepted as the main explanation for the development and extension of the Alborian domain (Malinverno and Ryan. 1986; Royden. 1993; Lonergan and White, 1997). However, other mechanisms such as the reduction of the continental crust's thickness and the collapse of the lithospheric delamination are also considered (Dewey. 1988; Platt and Vissers. 1989; Seber. 1996; Platt. 1998). These are suggested by some authors. For instance, in the case of the Alborian domain, the reduction of the continental crust's thickness can be attributed to the delamination.

In 2012, Roure proposed a possible mechanism for opening the Algerian basin that challenges the rollback theories. This paper marks the first time that a new perspective has been presented regarding the possibility of the delamination.

- Seismic Tomography

The development of tomographic techniques has contributed to the concept of rollback as the process that led to the establishment of the Mediterranean basins. Through the use of seismic tomography, it has been possible to identify the presence of anomalous zones in the mantle that are related to the presence of dense material. This finding suggests that the Tethys ocean may have been an extinct subducted structure (Lucente. 1999; Spakman. 1993; Piromallo and Morelli, 2003; Spakman and Wortel. 2004). The discovery of the subducted masses in the Italian side of the Mediterranean has been regarded as an important contribution to the understanding of the opening of the region by roll-back (Spakman and Wortel. 2004) (Figure. 8).

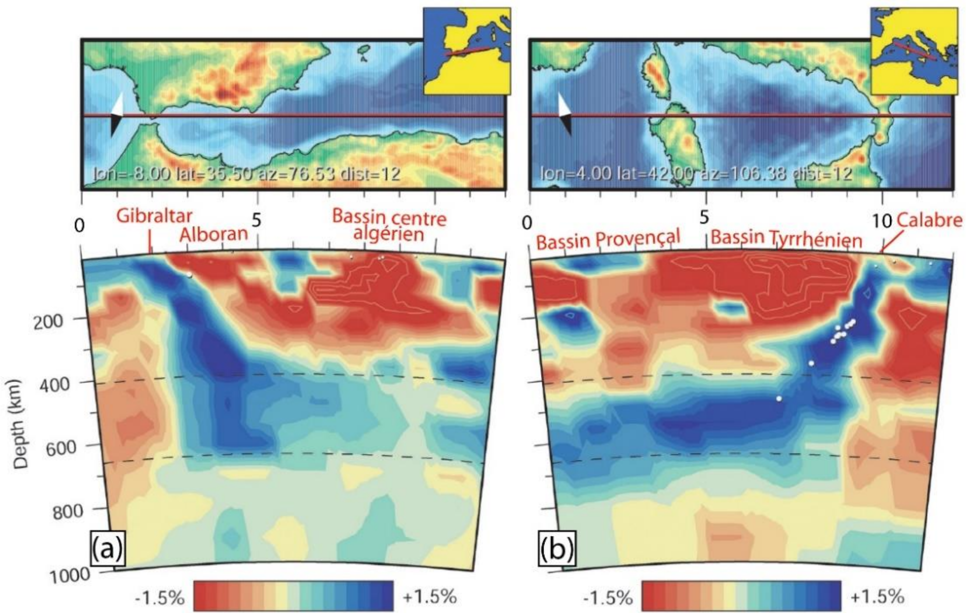


Figure. 8: Tomographic section through (a) the Strait of Gibraltar, the Alboran Sea and the Algerian basin and (b) the Liguro-Provençal basin, Corsica, the Tyrrhenian basin and Calabria (after Spakman and Wortel. 2004)

Several fragments of a type of rock known as a slab are currently being observed under the Alboran Arch and under the Calabria region in the east (Figure.8). These two regions have opposite dips, and it is generally believed that these pieces came from a single subduction zone (Figure. 9). However, under northern Africa, the footprint of this slab appears to disappear except under a part of the East African margin (Spakman and Wortel. 2004).

Various studies suggest that the absence of a subductal panel below the African margin is caused by a rupture or a lithospheric tear that occurred during the Middle Miocene. These studies suggest that the fragments of a slab were transported to the east and west after the collision of the inner zones with Africa (Lonergan and White, 1997; Carminati. 1998) (Figure.8, 9)

Through the combined analyses of various subduction zone markers, such as deformation, volcanism, and subsurface deformation, we can now reconstruct the history of the tethysian subduction front in the Mediterranean.

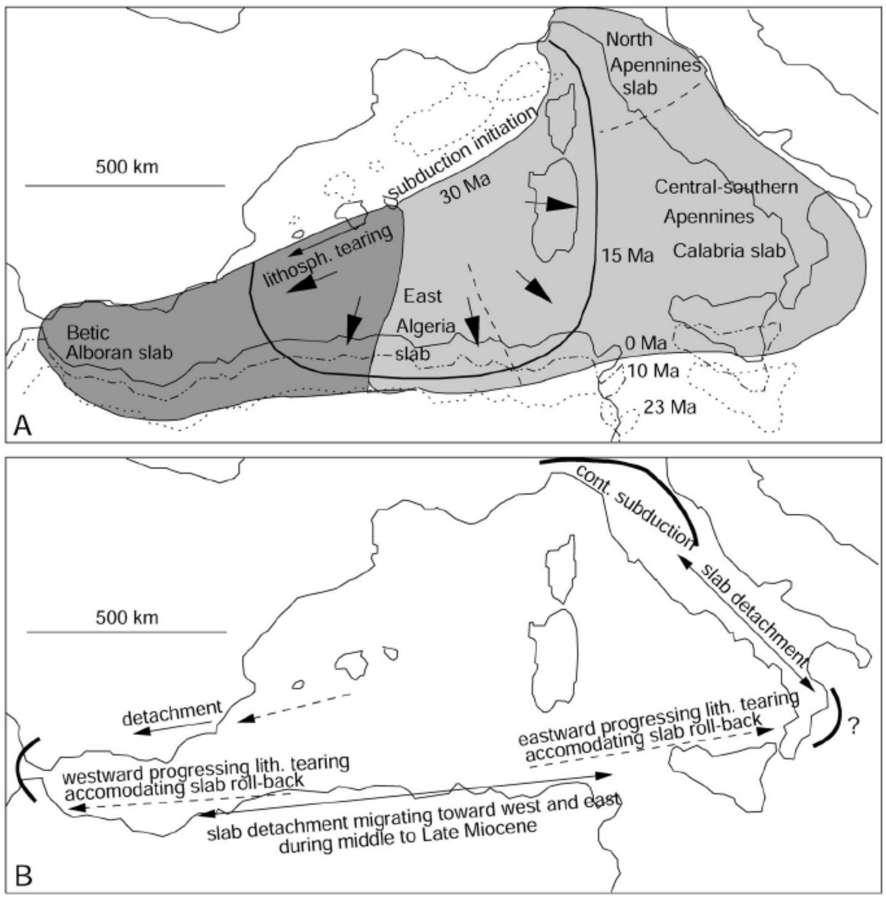


Figure. 9: A - Reconstruction of the western Alpine Tethys based on the amount of subducted lithosphere and slab geometry (Cavazza. 2004). The thick black line locates the position of the subduction front at ∼15 Ma, after slab detachment was initiated along the African margin, following the collision of the Kabylian blocks with Africa. B - Eastward and westward migration of slab fragments.

➢ Neogene Magmatism

The history of the Western Mediterranean and its progressive rupture under the African margin is argued by the testimonies of Neogene magmatism (Maury. 2000; Coulon. 2002). There are many different accounts of the various activities that occurred in the region (Savelli (2002)) (Figure. 10).

The Calco-alkaline type magmatism is characterized by a period of orogenic development that ranges from 30 to 24 Ma in the Balearic domain, and from 7 to 15 Ma in the southern region of the Western Mediterranean. Its age also decreases in the East in the Tyrrhenian Sea, and in Italy, starting from around 7 Ma to the present. The phase of strong thermicity that developed during this period could explain the panel's tearing or breaking in North Africa.

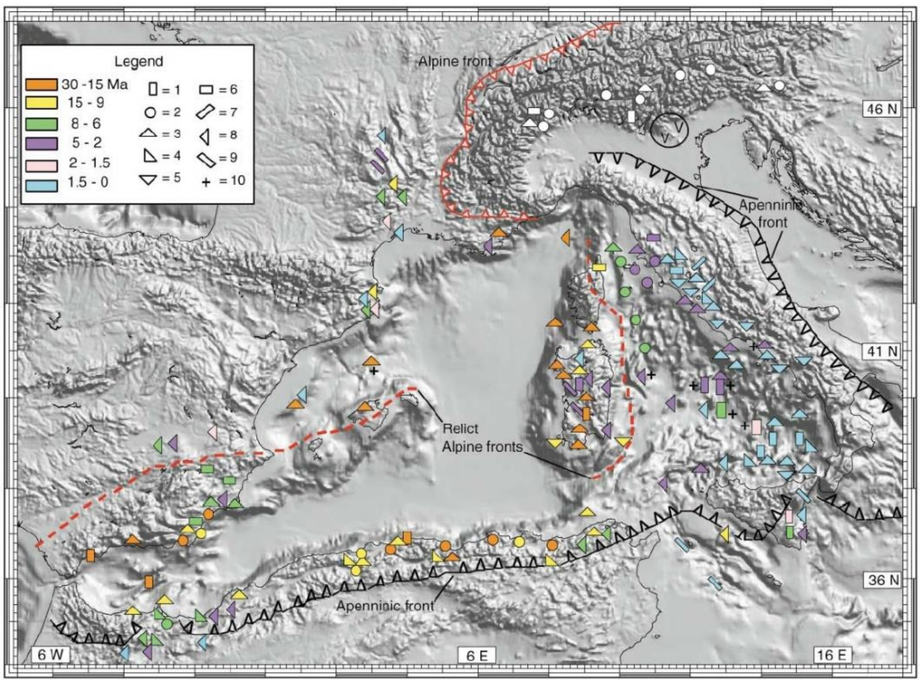


Figure. 10: Decrease of the age of magmatism in the western Mediterranean from west to east (Savelli, 2002)

The Western Mediterranean's history is characterized by several micro-blocks that are known to have poorly defined paleogeography. Despite the debate about their position, these blocks are mainly situated along the southern margin of the European plate (Figure. 11).

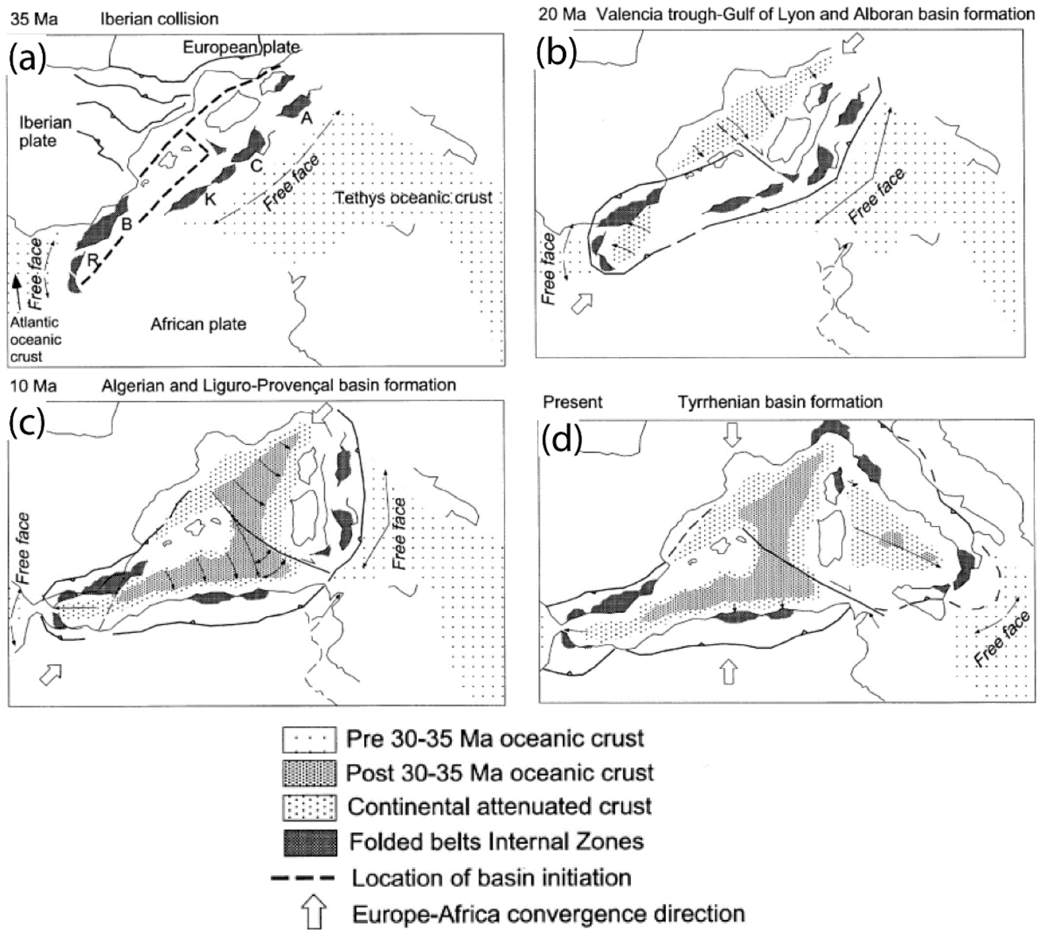


Figure. 11: Paleotectonic reconstruction of the Mediterranean from (a) 84-35 Ma and (b) to 35-30 Ma (by Gelabert. 2002).

The rifting phase in the Upper Oligocene starts in the Gulf of Lion and ends at the Burdigalien before moving toward the oceanization (Faccenna. 2001; Gelabert. 2002; Rosenbaum. 2002b). During this period, the rotation of the multiple blocks in the middle Lower Miocene basin, such as the Sarde and the Corso-Sardinian, is accommodated by a major stall fault located in the Balearic North Transfer Zone (Speranza. 2002). This feature, which is separated from the Valencia Basin by a major dextrous fault, is known to have contributed to the formation of the oceanic accretion in the area (Figure. 11)

The extension of the Balearic Promontory, which started south of the Kabylids, eventually moved to the southern part of the Tethysian Subduction Zone as the Tethysian retreated toward the south. The basin then develops until the Kabylides encounter with the North African margin at around 18 to 15 Ma (Lonergan and White, 1997; Frizon de Lamotte. 2000; Gelabert and al. (2002);

Rosenbaum. 2002b) (Figure.11, 14). The Mi-Miocene grounding of the Kabylides in Africa causes the subduction zone to be divided into two dipping panels, one of which then moves towards the West (Gibraltar)and the other towards the East (Calabria)(Lonergan and White, 1997) (Figure. 9, 11).

The migration from the West of the Gibraltar Arch to the East of the Tortonia diving panel would have led to the formation of the Alboran Block. The basin then opened following the rollback of the E-SE of the diving panel.

The evolution of the southern portion of the western Mediterranean, including the collision of the Kabyle and Alboran Plaque blocks with Africa, is still controversial. The exact timing of the opening of the Algerian Basin and the collision of the Plaque and Kabyle blocks with Africa are also still unclear.

- Two major hypotheses are proposed for the Algerian basin:

(1) One of the main hypotheses presented regarding the formation of the Algerian basin is that it occurred during the E-W Mi-Miocene period. It suggests that the basin's oceanic crust developed from the interaction of the Hannibal ridge and the Kabylies with Africa (Mauffret. 2004; Mauffret and. 2007a; Camerlenghi. 2009). According to this hypothesis, the movement of the basin toward the west of the Gibraltar Arc is linked to the collision of the Kabylies and Africa (Figure. 12). The Alboran plate's migration towards the West led to a deformation that occurred on the North West and South Balearic margins.

(2) Another hypothesis states that the basin formed from an opening in the N-S to NO-SE of the Alpine Tethys, which then moves to the S-SE. This is based on the idea that the Alpine Tethys' subduction zone moves through the N-S to the S-SE (Frizon de Lamotte. 2000; Gelabert. 2002; Rosenbaum. 2002b and references to the interior) (Figure. 11, 13).

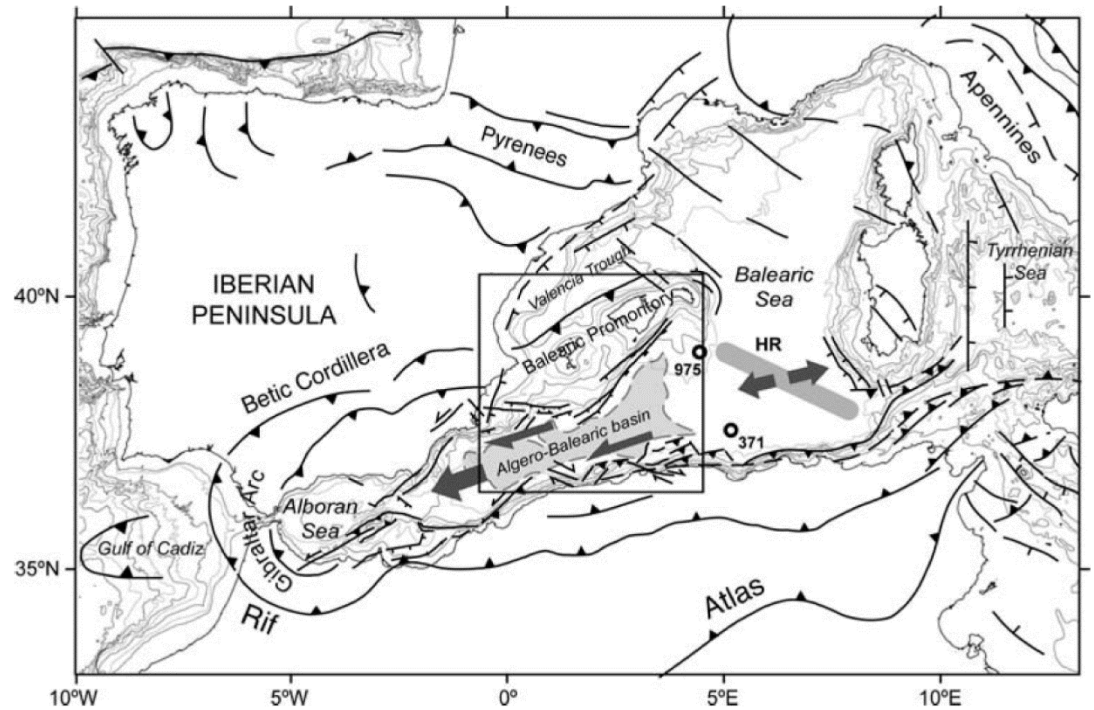


Figure. 12: Geodynamic evolution of the western Mediterranean proposed by Camerlenghi (2009), Mauffret. (2004) and Mauffret. (2007a). According to this scenario, the Algerian basin opens in the Miocene west of the Hannibal Rift Accretion Center (HR). The grey arrows indicate the accretion directions, and the westward opening of the Algerian basin.

2.4 Evolution of the Atlas and Telian domains & opening of the East Algerian basin seen from Africa

The formation of the Tello-Rifian chain occurred due to the gradual closure of the Tethys Ocean's western branch and the opening of the Algerian basin. On the other hand, the Atlas is an intra-continental chain that is situated in the fore country of the Tell.

The formation of the Algerian Atlas complex and its surrection were caused by two major tectonic events. One of these events is occurred at the end of the Eocene, and the other was occurred during the Pliocene.

The first episode of the Atlas, which occurred during the Eocene (Figure. 13.B) , was triggered by the activation of a weak zone of weakness due to a triasso-liassic rifting phase (Frizon de Lamotte. 2000; Frizon de Lamotte. 2006),. This event is regarded as the start of a large NE-SO orientation fold in the Atlas. It occurred during the same period that the Central Atlantic and Tethysian oceans were opened (Bracene and Frizon de Lamotte, 2002).

The AlKaPeCa domain is located in the Balearic Promontory, and it is believed that the subduction of the Tethysian ocean occurred under the Northern Palaeomargin of the Tethysian ocean (Frizon de Lamotte. 2000; Roca. 2004). (Figure. 14).

The AlKaPeCa domain's inner zones are situated in the position of an accretion prism that is related to the Tethysian subduction. This region will gradually be formed as the Kabylids move south and the basin Algerian gets developed (Figure. 13, 14).

The extensive episode that occurred on the southern European margin of the Kabylies during the Lower Miocene and Upper Miocene is regarded as the start of the rear extension-arc of the Algerian basin (Balearic Islands-Kabylies) (Aite and Gelard, 1997). This region is situated at the same time that the Numidian flyshs are deposited in the Tethyan ocean (Figure 14). The Kabylies eventually migrate south as the subduction continues to recede. Eventually, the basin collides with the North African Palaeomargin.

The effects of the "slab-pull"(Bracene and Frizon de Lamotte, 2002) and the placement of napes on the African plate are believed to have triggered the plate flexuration that led to the formation of the Flyschs domain. This event also triggered the emergence of the Flyschs Numidien. The Flyschs domain is located south of the inner zones (Benaouali-Mebarek. 2006).

Although the exact significance of the Atlas is still being debated, it has been established that it is a widespread feature across the Maghreb. It also predated the collision of the Kabilides and Africa (Benaouali-Mebarek. 2006) (Figure. 13).

The age of the African Internal Zones collision and the orientation of this collision are still under debate. According to data collected by Benaouali-Mebaraek et al 2006., the Flyschs domain has already been integrated into the Burdigaliens prism (Figure. 14). Some authors place the collision at 15 Ma(Pique. 1998a; Frizon de Lamotte. 2000; Benaouali-Mebarek. 2006), while others place it at 18 Ma(Lonergan and White, 1997) or 19 Ma (Schettino and Turco, 2006). In any case, the connection between the Kabylidae and Africa eventually leads to the formation of overlapping ground layers on the continent(Frizon de Lamotte. 2000; Benaouali-Mebarek. 2006) (Figure. 14).

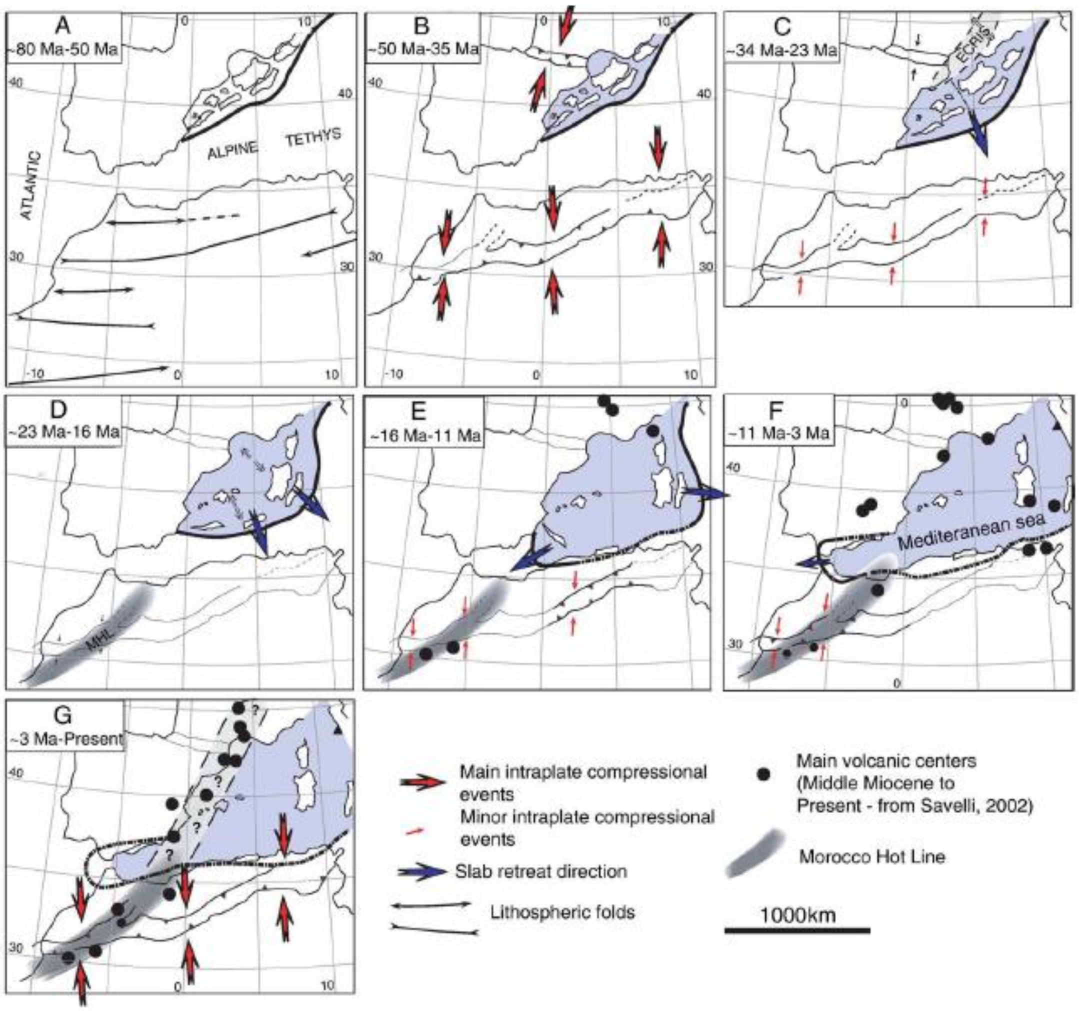


Figure. 13: Opening of the Algerian basin, and structuring of the Atlas and Tellian chains (Frizon de Lamotte. 2009).

The collapse of the Kabylids during the North African flexural episode is regarded as the end of this region's over-penetration. In the upper Miocene, the coastal chain is prone to experiencing a generalized over-penetration due to the rupture of a plate under the Algerian margin (Spakman and Wortel. 2004; Coulon. 2002).

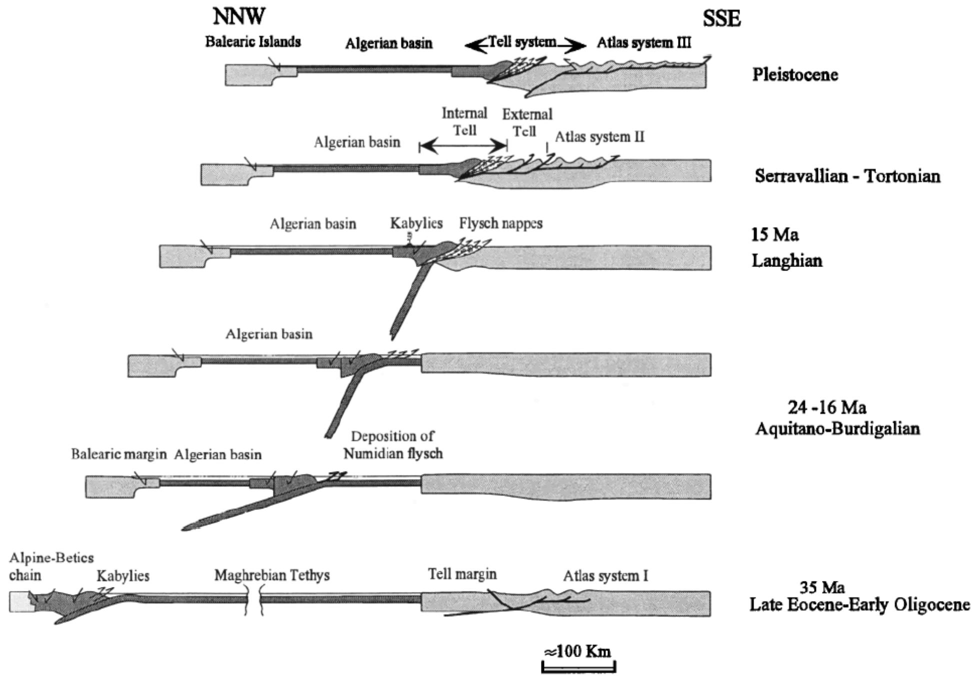


Figure. 14: Evolution of the East Algerian basin since the end of the Eocene and beginning of the Oligocene proposed by Frizon de Lamotte et al (2000)

The second major tectonic event that occurred in the Atlas during the Pleistocene led to the formation of various folds and an overlapping E-W orientation(Frizon de Lamotte. 2000; Bracene and Frizon de Lamotte, 2002). It is believed that this event triggered the second phase of the rapid surrection, which occurred after the relative tectonic quiescence (Bracene and Frizon de Lamotte, 2002). It is important to note that these two major phases of the history of the Atlas and the Upper Lutheran are not related to the collision between the Kabylides(Frizon de Lamotte. 2000; Bracene and Frizon de Lamotte, 2002).

The various models of the Algerian basin that are used to study its evolution show how difficult it is to come up with a consensus model. This is because the multiple movements that occurred in the basin during the past few million years have been linked to both lateral and N-S movements.

It is generally believed that the studies on the Balearic Islands and the North of Africa are focused on the E-O opening of the basin from the Alboran plate. However, studies on the westernmost part of the basin are not usually agreed on. This is because the region's margins are characterized by a very linear and stiff structure. This is also related to the structure of the transformations that occurred in the margins of Emile Baudot and Mazarron (Figure. 15).

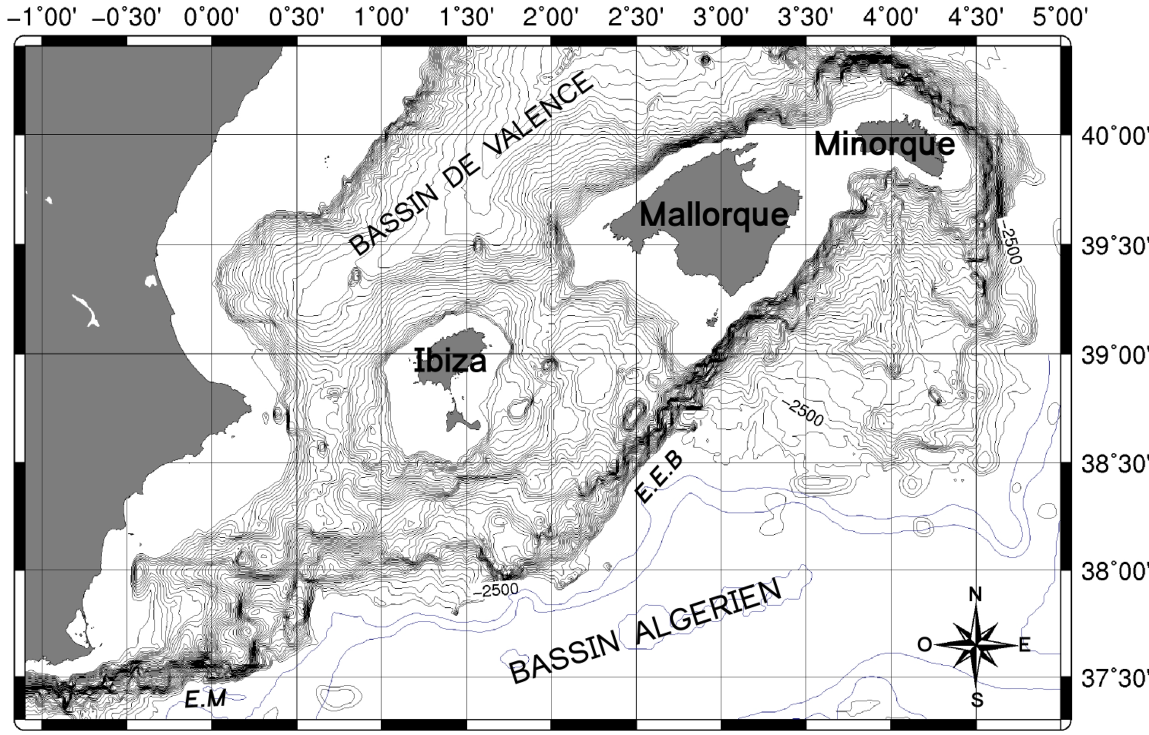


Figure. 15: The Balearic Promontory: Northern edge of the Algerian basin. E.E.B : Escarpement of Emile Beaudot ; E.M : Escarpement of Mazarron

3. Seismo-tectonic context

3.1 Current kinematics in the western Mediterranean

Through the analysis of GPS data, the data can be used to constrain the deformation's zones of accommodation and limit its mode of deformation. The seismicity and the associated mechanisms can also be used to define the mode of deformation (Leprêtre, 2012).

The studies conducted by (Calais. 2003; Nocquet and Calais, 2004; Serpelloni. 2007) showed that the relative rapprochement between Africa and Europe is at a velocity of 5 mm/year at the location of Algiers (Figure. 16).

The data collected by GPS can be used to constrain the deformation's zones of accommodation and limit its mode of deformation. Through the combination of the data and the associated mechanisms, it can also be used to define the mode of deformation. In 2003, studies revealed that the continent's relative rapprochement with Europe is at a velocity of 5 mm/year.

The difference between the estimated movements of European and African countries from geodetic data and those from geological data is explained by the increase in the obliquity of the convergence in the Mediterranean since 3 Ma. This phenomenon could also explain the higher velocity's previously estimated by (Demets. (1994))(6.4 mm/year, Figure. 17.b)

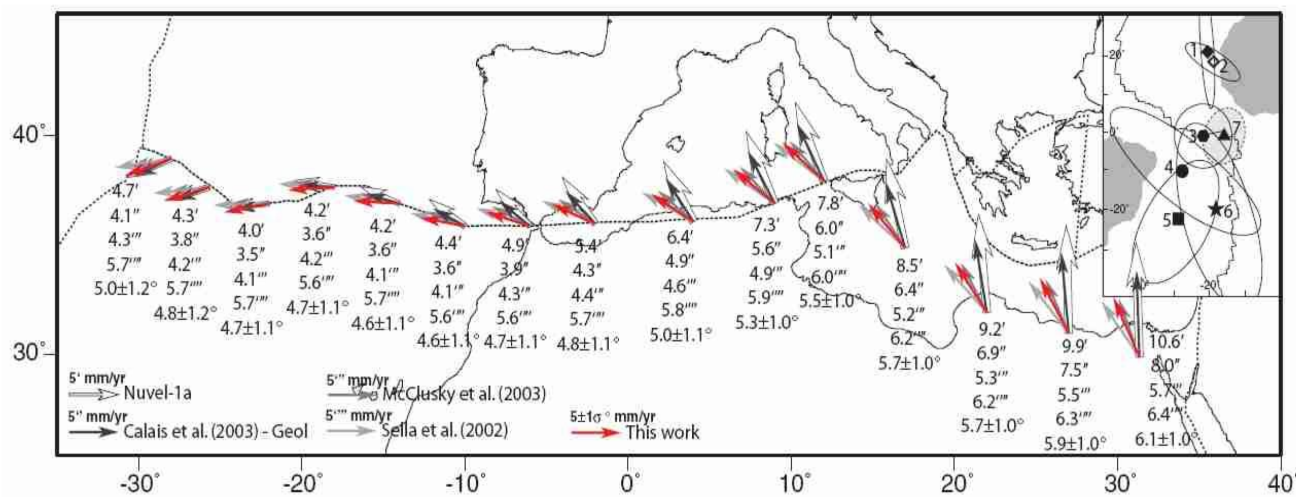


Figure. 16: Kinematics at the African-European plate boundary derived from Euler poles estimated by different authors and compiled by Serpelloni. (2007).

The data collected by the geodetic instruments allow researchers to study the variations in GPS velocity along a transect. (In 2007, Serpelloni and al) were able to estimate the rates of shortening along a northern Algeria region which is varying from 2.7 ± 0.9 mm/year to the east (profile 1, Figure. 17.a) to 3.9 ± 0.9 mm/year to the west (profile 2, Figure. 17.a). At sea, the estimated rate is in order to 1.6 ± 0.6 mm/year in the east, to 2.7 ± 0.6 mm/year in the west (Figure. 17.a).

3.2 Seismicity of the Western Mediterranean

The plate boundary between Europe and Africa has been characterized by various tectonic regimes. Some of these include transtensive, compression, and stall movements. It is located near the triple point of the Azores in Sicily.

The seismicity along the Strait of Gibraltar and in its Alboran region is sparse (Figure. 17.a). This suggests that the plate limit is diffuse and a wide band of deformation is developing. There have been numerous small earthquakes in the Gibraltar Arc. These are usually less powerful than magnitude 4 (Jimenez-Munt. 2001; Serpelloni. 2007).

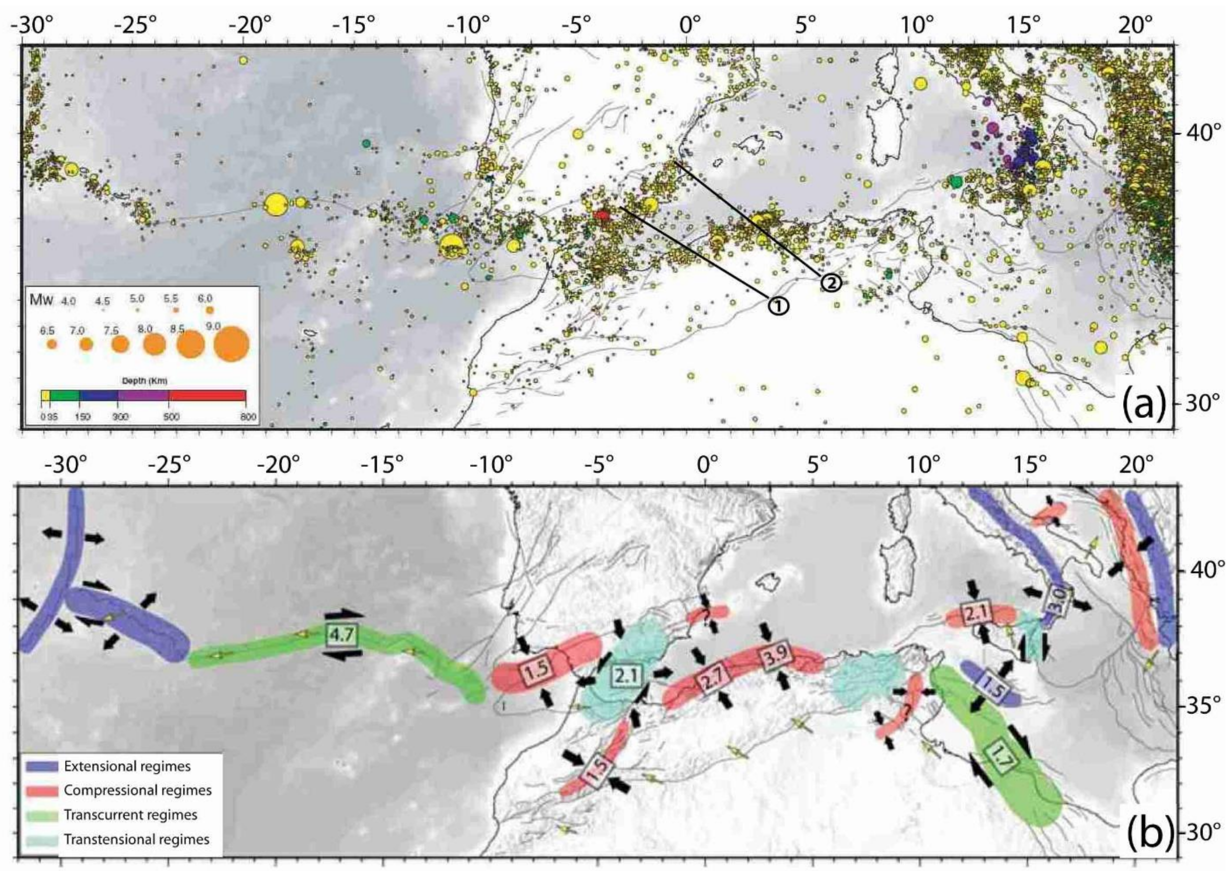


Figure. 17: (a) Distribution of seismicity at the African-European plate boundary (earthquakes of magnitude 4) (Serpelloni. 2007). Black lines indicate the location of GPS velocity profiles: (1) the eastern profile and (2) the western profile. (b) Deformation regimes generated at the plate boundary. Numbers correspond to deformation rates in mm/yr (Serpelloni. 2007).

The presence of transtensive deformation mechanisms in earthquakes is known to be significant (Stich. 2006; Serpelloni. 2007) (Figure. 17, 18). Most of these are observed at relatively shallow depths. Although some of these are recorded up to 650 kilometers away (Buforn. 1995), the majority of these are observed at relatively shallow depths. It is believed that deep earthquakes are associated with a subduction zone (Gutscher. 2002) (Figure. 2).

The northern part of Algeria, which is situated between the Tell and the Algerian offshore, is one of the most seismically active regions in the western Mediterranean (Oudni. 2016) (Figure. 17.a). The region is characterized by a wide band of seismicity that spans approximately 200 kilometers. The presence of a dominant regime that is caused by the convergence of Europe and Africa is expected to contribute to the establishment of a new basin in this region (Figure. 17,18). In the eastern part of Algeria, the intensity of seismic activity has been decreasing. In Italy, the intensity of seismic activity has been increasing in areas such as Sicily and Calabria (Figure. 17). Similar to the northern part of Algeria, the offshore section of the Sicilian North is also subjected to a compression regime (Figure. 17, 18).

3.3 Seismicity of Northern Algeria

The seismicity of Algeria's northern region is the result of the convergence of the European and African plates. Throughout its history, the country has experienced numerous earthquakes. Most of these were concentrated in the Tell (Figure. 19).

The devastating earthquake that occurred in Boumerds on May 21, 2003, has shown that the country's northern region is prone to experiencing seismic deformation. Other notable earthquakes that have occurred in this region include the Chenoua-Tipaza earthquake on October 29, 1989, El Asnam earthquake on October 10, 1980, Mascara on August 17, 1994, and Ain Temouchent earthquake on December 22, 1999 (Figure. 20, 21)

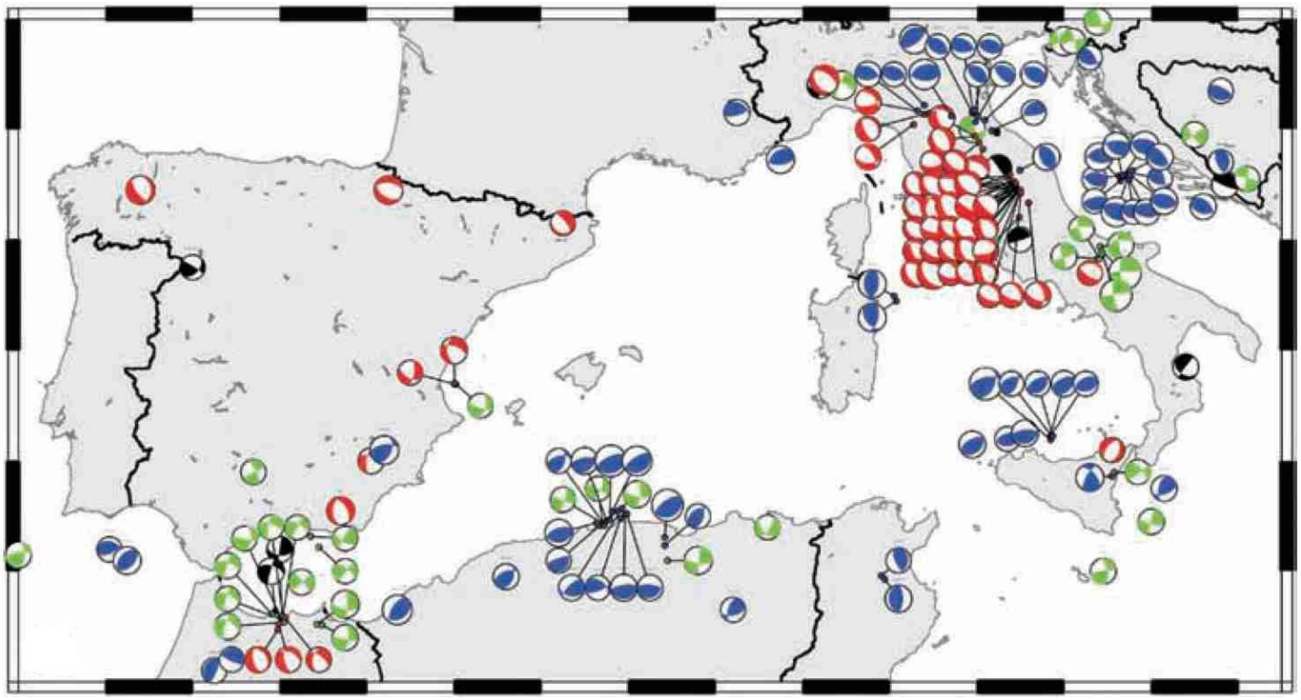


Figure. 18: Map of the focal mechanisms of earthquakes in the western Mediterranean (Billi. 2011).

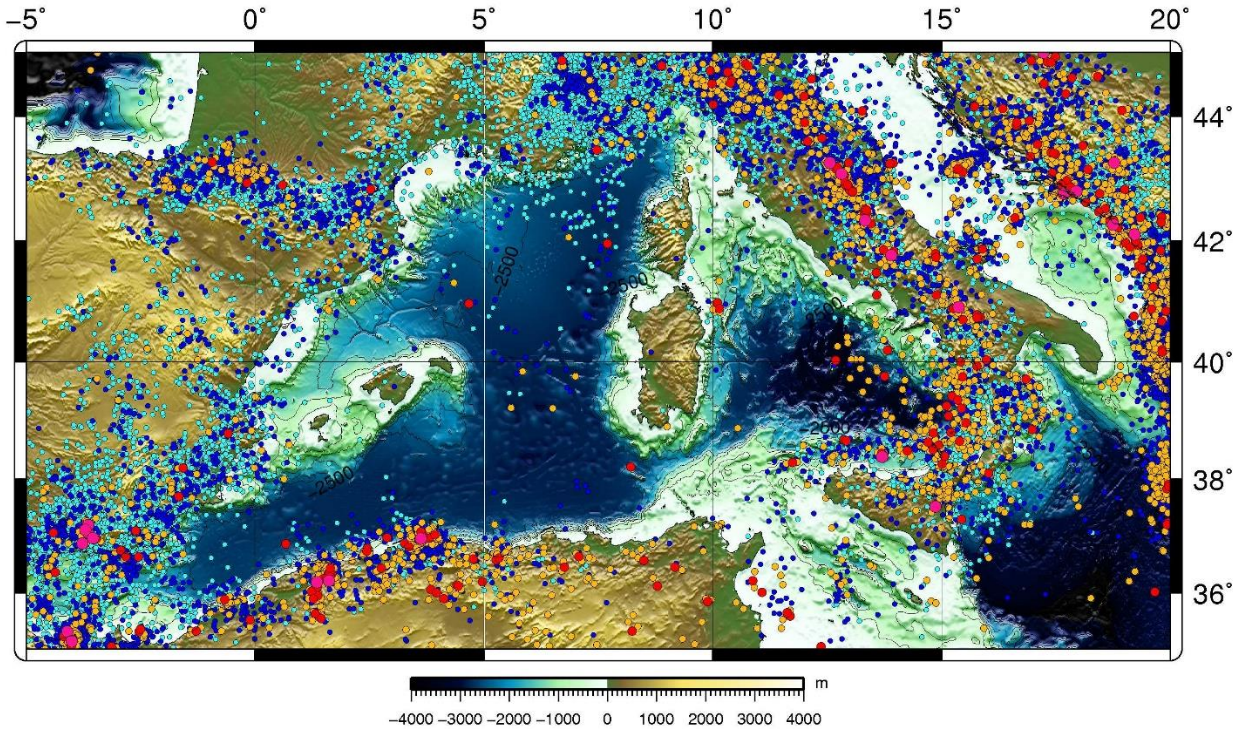


Figure. 19: Seismicity map in the western Mediterranean, from 1973 to 2020 (NEIC catalog). In light blue: $0 < Mw < 3$; in dark blue: $3 \leq Mw < 4$; in yellow: $4 \leq Mw < 5$; in red: $5 \leq Mw < 6$; in pink : $MW \geq 6$.

The importance of the seismic threat that the country's offshore regions pose is reinforced by the historical earthquakes that have occurred in the region, such as the Algiers earthquake in 1716 and the Djidjelli earthquake in 1856 or Boumerdès in 2003.

In the High Plateau, seismicity is almost non-existent. This region is characterized by a rigid block that deforms only at its edges (Figure. 20). Some small earthquakes can also be felt along the South Atlas front. These are usually less powerful than magnitude 4.0.

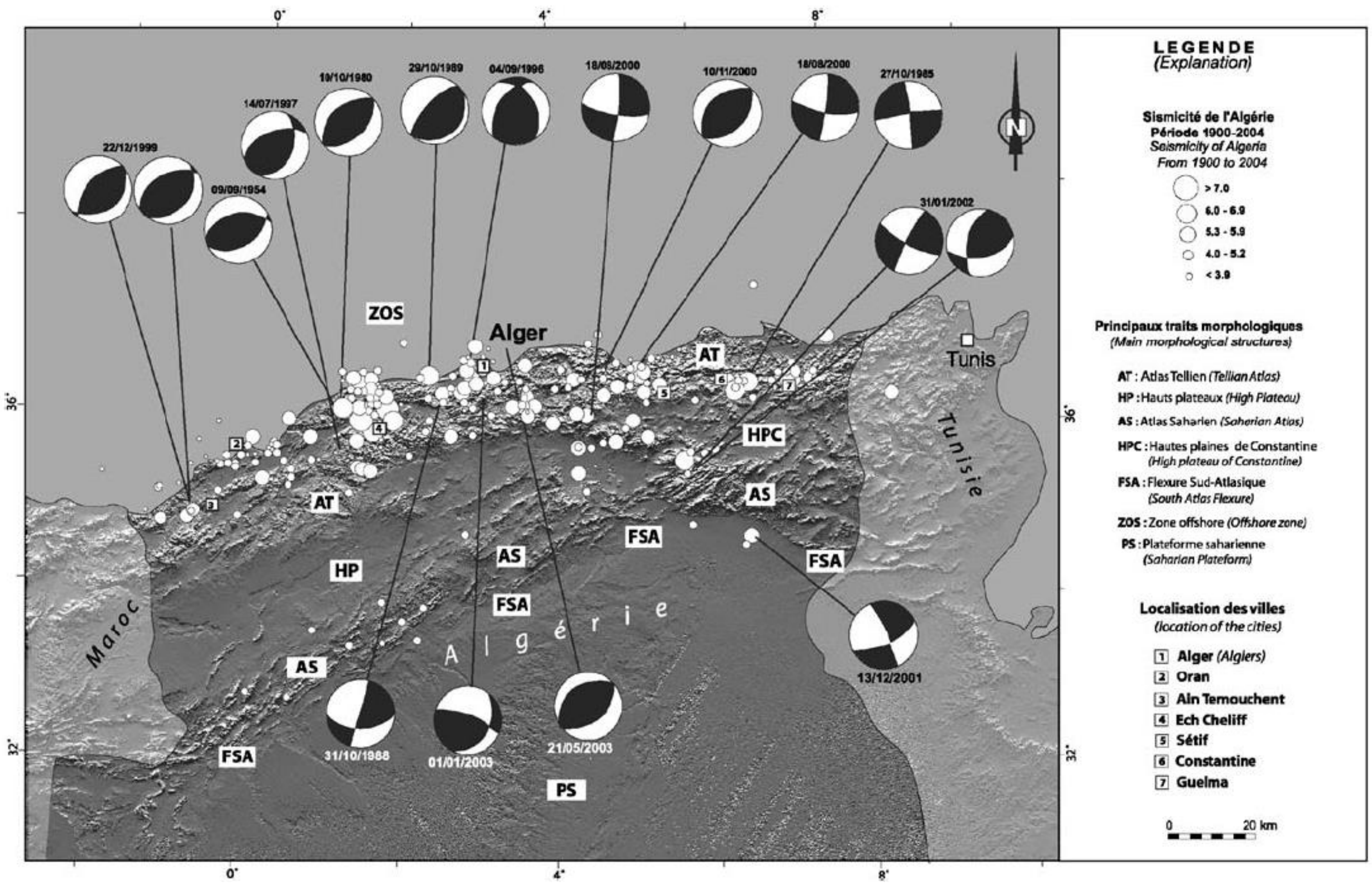


Figure. 20: Seismicity of northern Algeria and focal mechanism of major earthquakes (Yelles-Chaouche. (2006)).

These earthquakes are usually generated by the combination of reverse and fold-faults with NNE-SSO to E-W direction, along the Miocene suture between the internal blocks and the External Zones. The focal mechanisms in the region indicate that the NNW-SSE shortening direction is in central and eastern Algeria. On the other hand, the easternmost part of the country is more likely to be struck by a strike-slip mechanism (Figure. 20).

Although the small earthquakes in northern Algeria are usually less powerful than 5.5, some of them have been recorded with a magnitude greater than 7. For instance, the violent earthquake that happened in 1980, which had a magnitude of over 7, was caused by the El Asnam earthquake. The sources of these earthquakes are usually superficial, with hypocenters less than 30 kilometers deep (Figure. 21).

During the Quaternary, the results of active tectonics have caused the coastal areas of northern Algeria to uplift. This phenomenon can be seen in the marine terraces located in various regions, such as the Algiers region (Meghraoui, 1991; Authemayou. 2010; Maouche. 2011). The deformation caused by these activities has also affected the Neogene basins located along the coast, such as the Cheliff basin, the Mitidja basin, and the Tizi Ouzou basin (Yelles-Chaouche. 2006).

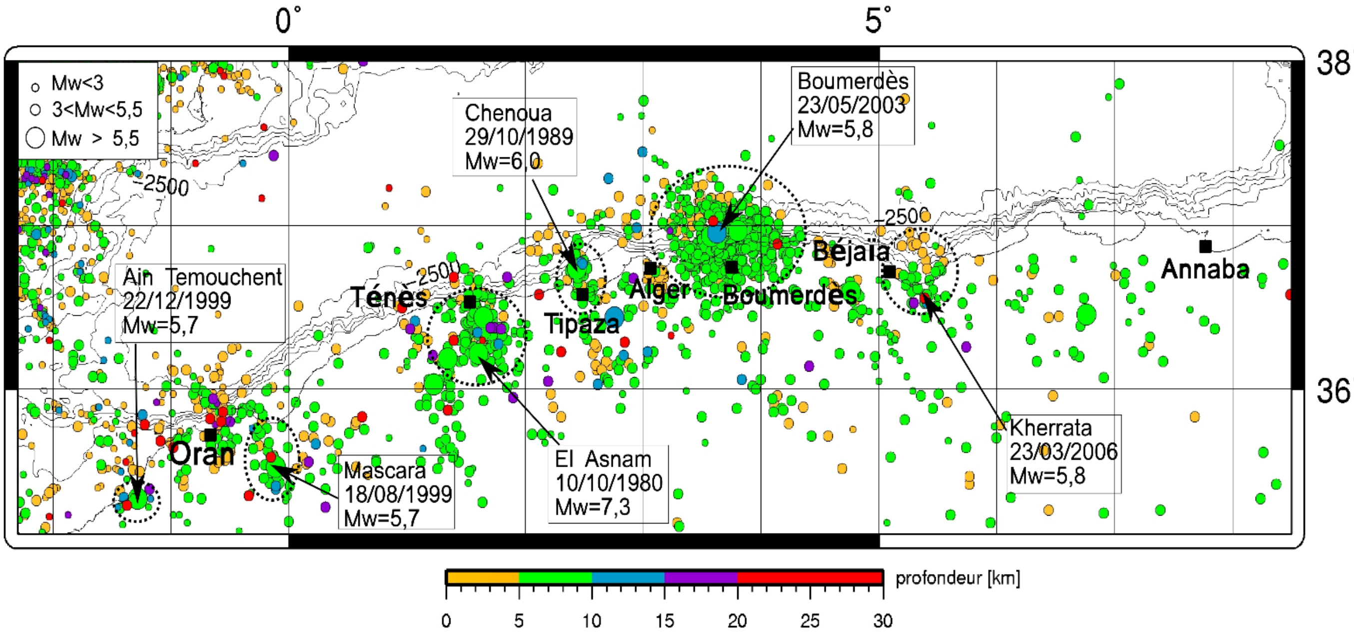


Figure. 21: Depth of hypocenters of Algerian earthquakes (NEIC catalog from 1973 to 2020).

The convergence of Europe and Africa has led to numerous earthquakes in northern Algeria. It shows that the country's margin is not passive, as it has been recording earthquakes with a magnitude of 7 or greater. However, the shallow depths of the hypocenters do not imply that we are in the presence of active margins. The geodesy and the various mechanisms at the earthquake sites testify to the fact that the region is currently subjected to a compressive regime.

Following the presentation of the compressive boundary conditions, the next step will be to study the morpho-structure and basin of the Algerian margin. This will be done in the next part. The analysis of the region's deformation indices will be focused on the recent activities related to the margin's compression.

4. Morpho-structure of the Algerian margin

The Algerian margin is the southern boundary of the western Mediterranean. It spans over 1,000 Km long and is located north of Africa's continental shelf (Figure. 22). It is bordered to the west by the Alboran Sea, to the north by Balearic Promontory, and to the south by the Tellian chain (Figure. 2).

The Algerian margin has a general E-W to NE-SW orientation (Figure. 22). It is characterized by a narrow continental shelf, with a width of around 5 to 10 Km on an average. It can widen locally and reach 40 Km wide as Neogene basins are located near the coast. On the other hand, the shelf appears to be significantly reduced in the offshore area between Ténes and Dellys (Figure. 22).

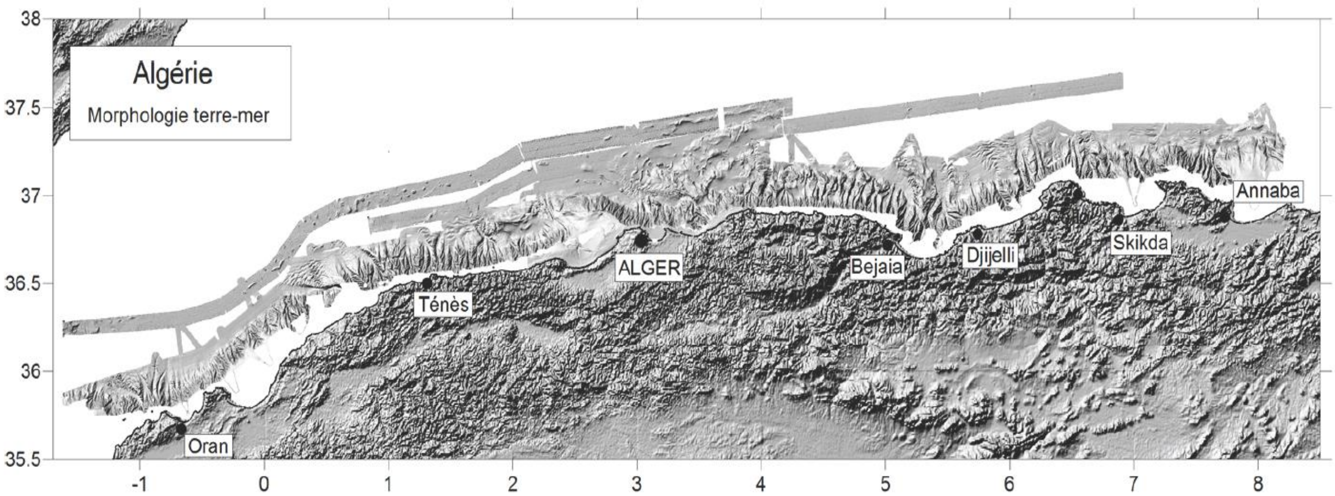


Figure. 22: Morpho-bathymetric map of the Algerian margin from Maradja data (after Domzig, 2006).

The Algerian margin is characterized by a steep and varied continental slope with an average slope of more than 10° and a maximum slope of more than 20° (Figure. 22). Numerous canyon structures are visible in the morphology. Some of these are known to be responsible for the construction of submarine fans.

The Algerian margin is bordered by the Algerian deep basin, which is characterized by a flat topography but also revealing various irregularities in the seabed due to the presence of saliferous tectonics.

5. Reactivation of the Algerian margin

There is some evidence suggesting that the Plio-Quaternary deformation in the Alboran Sea may have been triggered by the African-European convergence (Comas. 1999; Medaouri. 2012), the Algerian Basin (Domzig. 2006a; Yelles. 2009; Kherroubi et al, 2009). However, the exact timing, spatial extent, and diachrony of the deformation remain unclear. Furthermore, the possibility of a significant disruption of the Algerian Basin's margins is also poorly constrained.

The data collected during the MARADJA and MARADJA2-SAMRA oceanographic campaigns (seismic-reflection, CHIRP, SAR, reflectivity, coring and bathymetry) have revealed the presence of a renewed Plio-Quaternary deformation in the Algerian offshore.

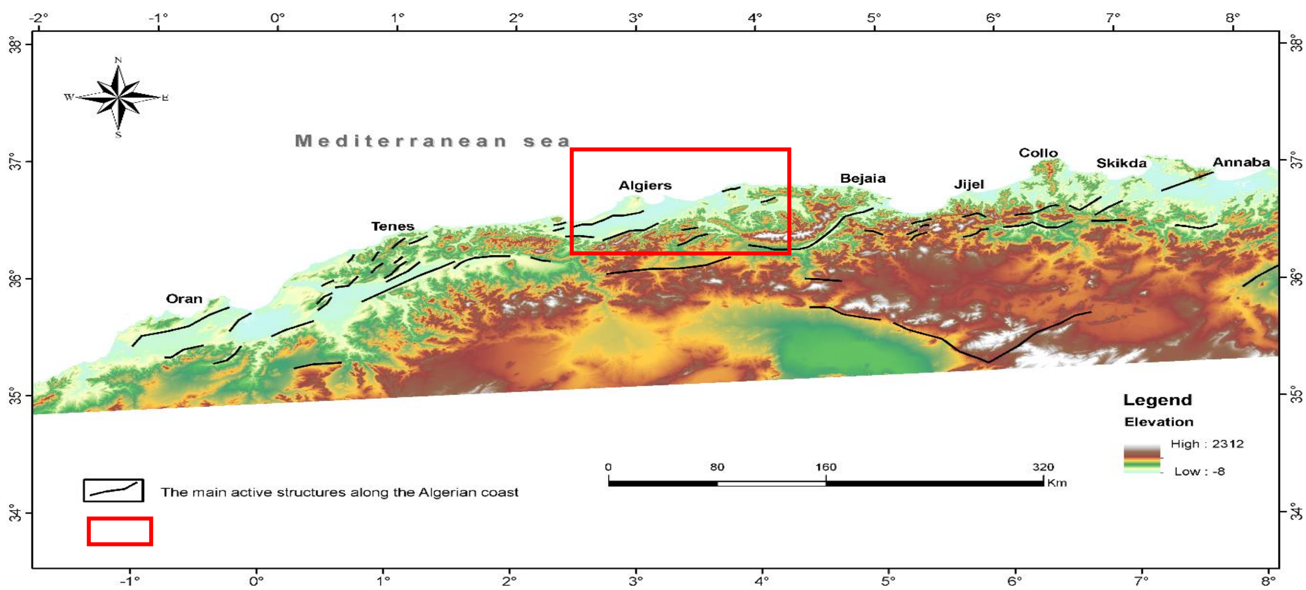


Figure. 23: Digital elevation model shows the main active structures along the Algerian coast. (DATA from USGS SRTM 30 m) (modified from Domzig, 2006).

Through the data collected during the campaigns, the researchers were able to identify various thrusts that were moving toward the continent (Domzig, 2006) (Figure. 23). They were able to identify a large portion of the continent that was affected by the deformation. These structures are not similar to those found in the Sea of Japan, which have normal faults reversed (Itoh. 2006).

Different types of geological objects can also be detected by indirect means, such as the presence of faults at depth. For instance, the deformation of the canyon direction has been linked to the presence of subsurface instabilities (Figure. 24).

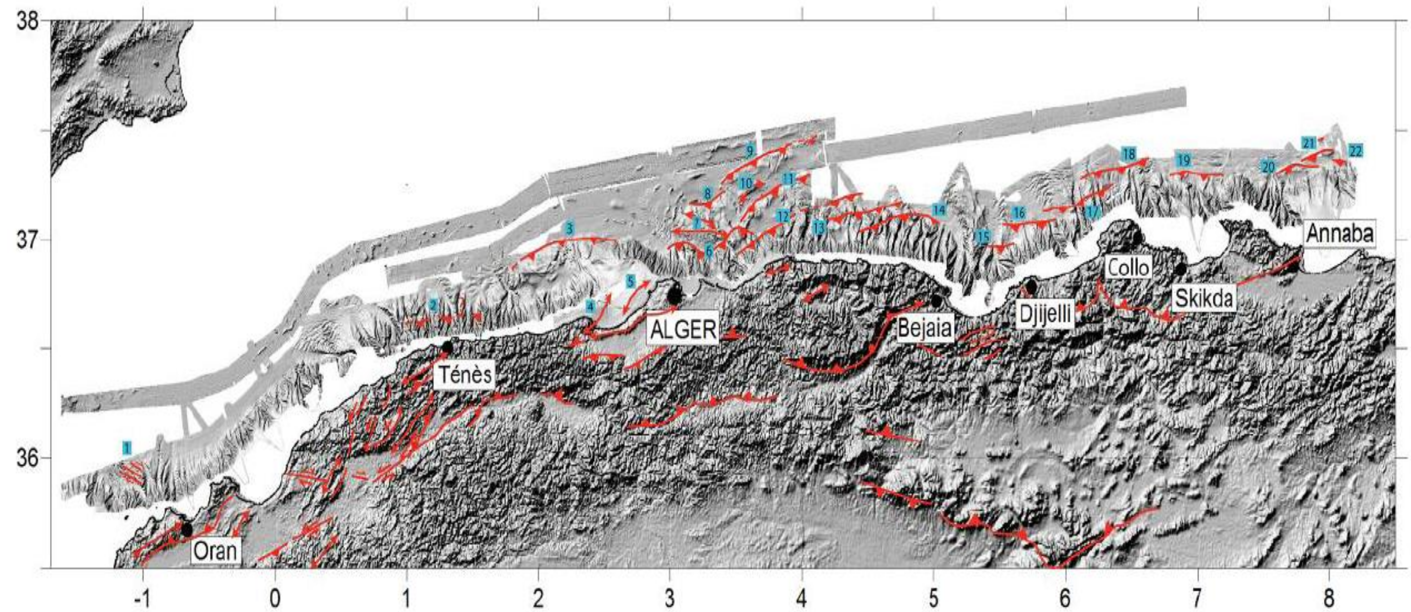


Figure. 24: Digital elevation model shows the main active structures along the Algerian coast. (DATA from USGS SRTM 30 m) (modified from Domzig, 2006).

5.1 The evolution of the canyons in the Est coast of Algiers

The course of a canyon is influenced by various factors, such as topography and eustatic variations. While a canyon profile that is in equilibrium will have a concave shape, a young canyon profile that is not in equilibrium will have a more convex one (Bekhouch. 2023). This is because tectonic movement can alter the course of a canyon. The deformation of a canyon can be a good indication of its condition (changes or alterations in the shape, structure, or characteristics of a canyon can provide valuable information about the current state of that canyon. if a canyon's shape, position, or other features have been altered due to geological processes or tectonic movements, it can be a useful indicator for assessing the canyon's current state or condition)

The characteristics of the canyon located in Algiers, which has well-formed meanders, are suitable for this analysis. A similar approach can be used to study the tectonics in a region by observing the possible canyon deflections (Bekhouch. 2023). The difference between the course of the canyon and the approach of the identified canyon is visible on the reflectivity data (Figure. 25). This can be a good indication of the canyon's condition.

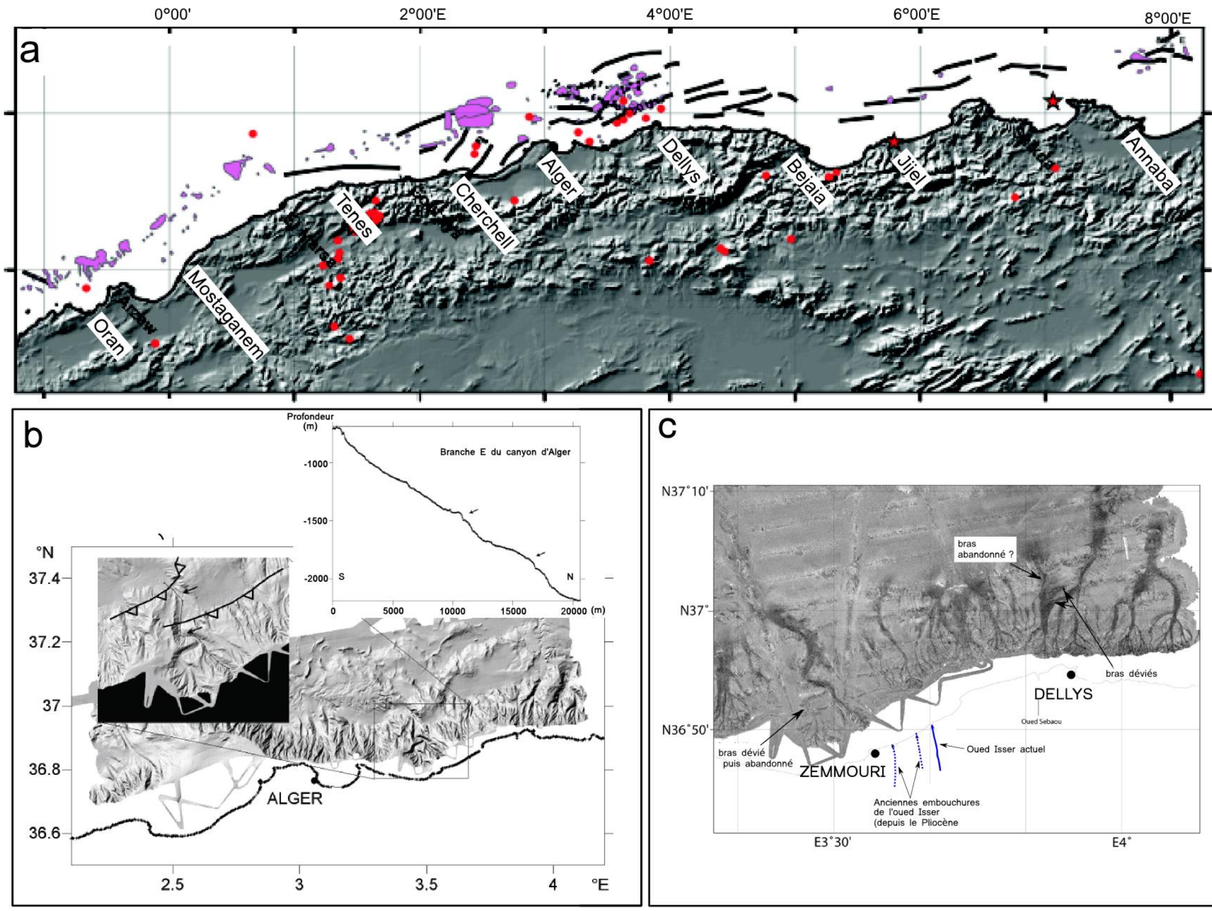


Figure. 25: (a) Distribution of gravity instability products along the Algerian margin (Cattaneo. 2010). Red circles locate epicenters of (instrumental) earthquakes of magnitude ≥5 and red stars 3 major historical earthquakes (after Kherroubi. 2009 in Cattaneo. 2010). (b) Longitudinal profile of the eastern branch of the Algiers Canyon. Two topographic anomalies (indicated by black arrows) are visible on the profile and coincide with reverse faults identified by Déverchère. (2005). This observation is in favor of a control of the faults on the morphology. In addition, the arrows shown on the inset locate the presence of deviations in the canyon trajectory at the approach of these faults (figure after Domzig, 2006). (c) Reflectivity map of the offshore area east of Algiers. A reflective facies

appearing dark on the map indicates a rough surface and thus a recent canyon activity (figure d). activity of the canyons (figure after Domzig, 2006).

Another approach that can be used to study the tectonics in a region is by observing the canyon's course. The direction of the canyon's course in Algiers suggests that the margin is moving toward the reverse faults. This region of the canyon is also known to uplift (Domzig, 2006) (Figure. 25).

The data collected from the canyon according to Domzig (2006) shows that the eastern portion of the canyon has a lower reflectivity than the western portion. This suggests that the western portion of the canyon was abandoned. According to Domzig, the reverse faulting in the canyon led to the eastward movement of the canyon. This phenomenon can also be observed in the canyon located in front of the Dellys, Zemmouri and Algiers (Figure. 25).

5.2 Deformation of superficial sediments

The geometry of the inversion has been studied in three different areas of the Algerian margin. These areas are the Tipaza sector (West Algiers), the Boumerds sector (East Algiers), and the Annaba sector (East Algerian) (Figure. 26).

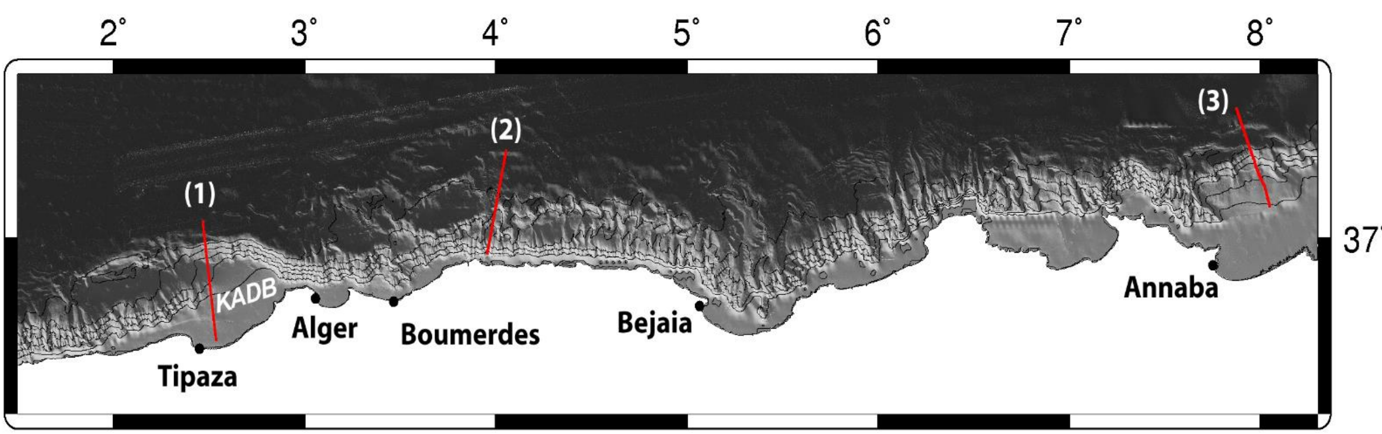


Figure. 26: Location of 3 profiles showing the surface structure of the Algerian margin for (1) the Tipaza sector (Figure. 27), (2) for the Boumerdès sector (Figure. 28) and (3) for the Annaba sector (Figure. 29). KADB: Khayr-al-Din ridge.

(1) Tipaza sector:

This sector is characterized by the presence of a bathymetric high in the Khayr-al-din basin, which has a width of about 40 Km (Figure. 26). The Khayr-al-din fault, which is located at the foot of the banc, is the longest known fault in the Algerian offshore. It has a length of approximately 80 Km. According to (Domzig. 2006a), the deformation observed in this area is confined to the foot of the margin (Figure. 27), which is contrary to what is observed in the east of Algiers (Figure. 28).

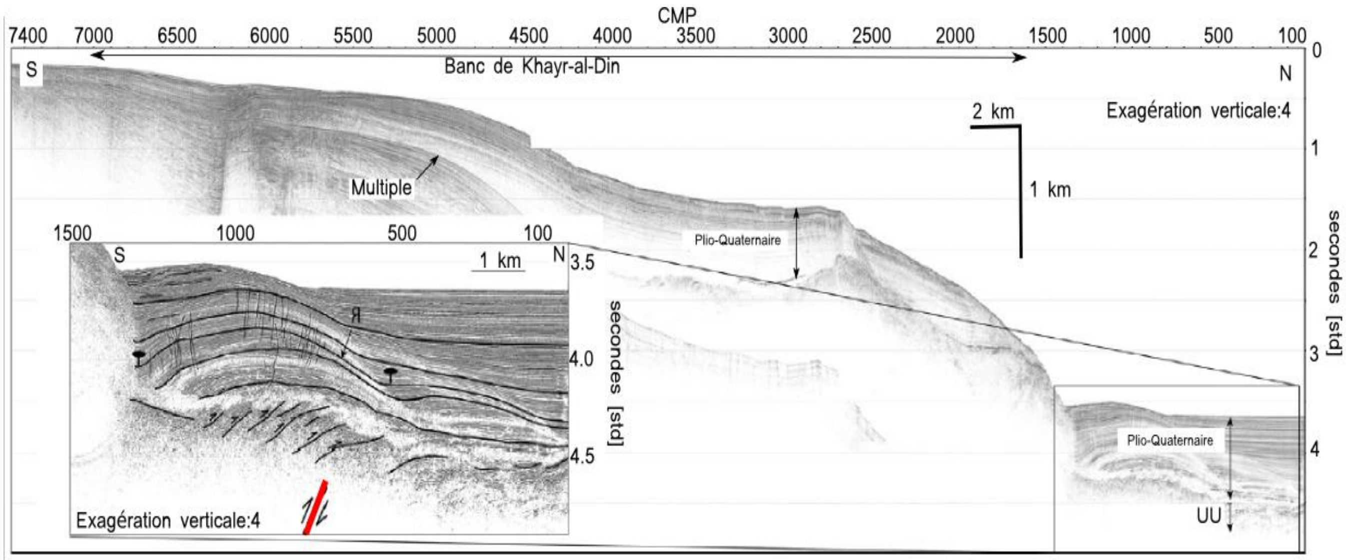


Figure. 27: seismic reflection profile 24-trace acquired during the 2003 MARADJA campaign off Tipaza, and intersecting the Khayr-al-Din bank (figure after Yelles. 2009).

(2) Boumerdès sector:

The Boumerds sector was placed under special attention following the earthquake that occurred in 2003(Bounif. 2003 (Bounif. 2004; Delouis. 2004; Yelles-Chaouche. 2004; Déverchère. 2005; Domzig, 2006). The area was characterized by the emergence of two different features: the continental slope and the large piggyback basins (substantial basins that form on the back of other tectonic features, often as a result of crustal deformation and tectonic forces). The seismic activity that occurred at Dellys in May 2003 (East Algiers, Figure. 26) triggered the reactivation of a north-verging ramp system in the basin (Cope, 2003; Déverchère. 2005; Domzig. 2006a) (Figure. 23, 28).

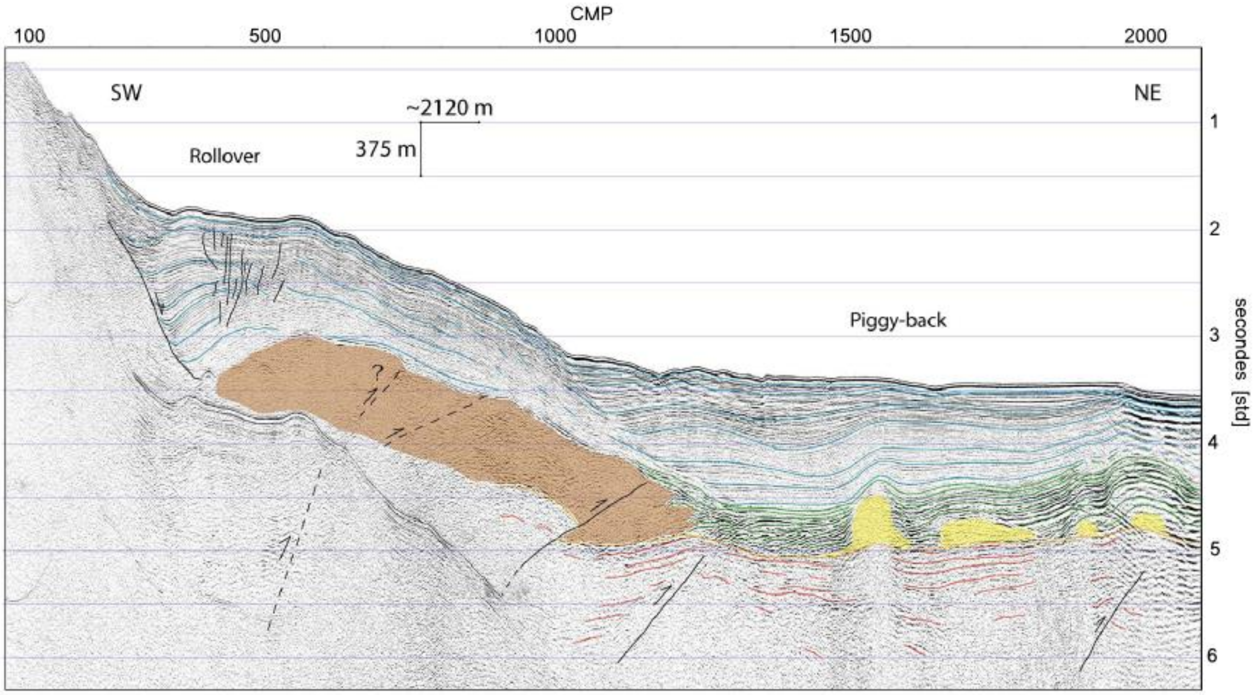


Figure. 28: seismic reflection profile 6-trace acquired off Boumerdes during the 2003 MARADJA campaign MARADJA in 2003 (vertical exaggeration: 6). In red: the sub-salt series. In orange: the base of the Messinian salt. In yellow: the Messinian salt (MU). In green: the upper evaporites (UU). In blue: the Plio-Quaternary sediments. In brown: detrital deposits (CU) (figure after Domzig, 2006).

(3) Annaba sector:

The extreme east of Algeria is a region of weak seismogenic activity (Harbi. 2003; Yelles-Chaouche. 2006; Harbi. 2010) (Figure. 19). Although this area is known to have numerous folds and thrusts, the recent discovery of these features at the foot of the margin suggests that this region may have been re-activated (Kherroubi. 2009) (Figure. 26)

The deformation experienced in the Boumerds region has resulted in the formation of growth strata behind folds and the emergence of perched basins in the open sea (Figure. 29). This region is more recent than in the Algiers region in terms of margin inversion. According to (Kherroubi. 2009), the onset of fault play in this area is estimated to be less than a 1Ma, and the rate of shortening is around 1mm/yr.

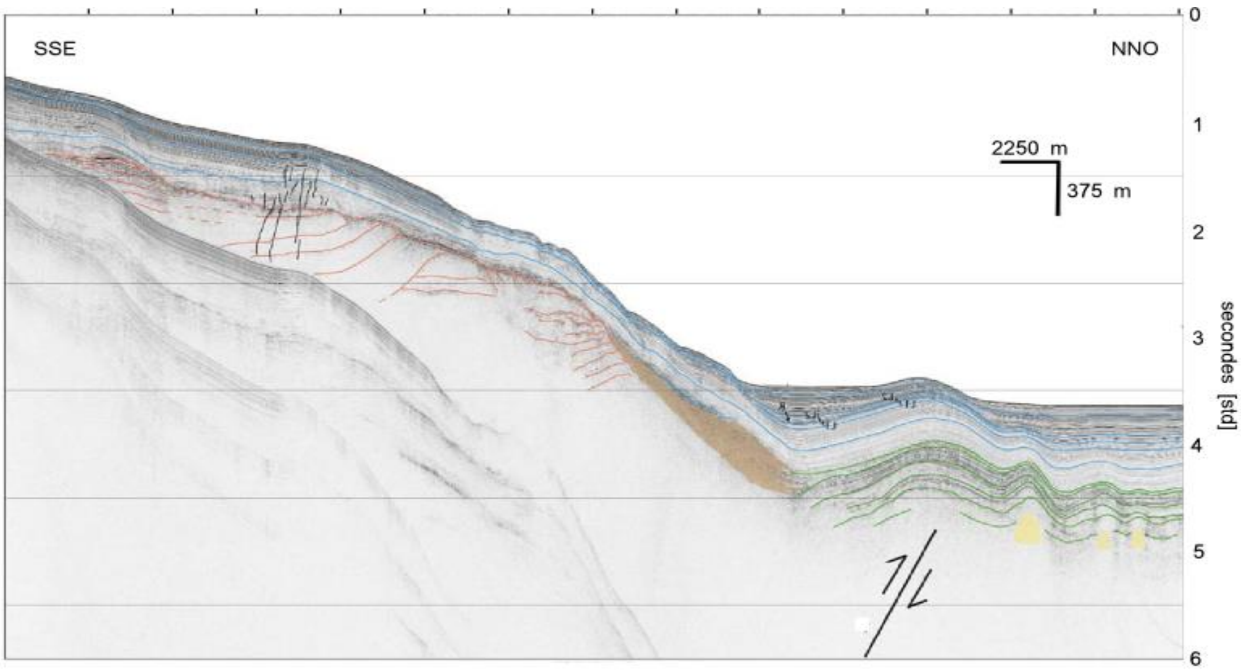


Figure. 29: Seismic reflection profile 72-trace acquired off Annaba (vertical exaggeration: 6) (figure after Domzig, 2006 and Kherroubi. 2009).

5.3 Sequential Stratigraphy

The stratigraphic record in a basin result from an interaction between several key factors, such as subsidence and/or regional uplift, sediment input, eustatism, and climate changes Tectonic activity is a crucial factor controlling the stratigraphy in most sedimentary basins (Williams & Dobb, 1993). Tectonics, in a broad sense, including folds, faults, as well as local and regional isostatic readjustments, directly affect the accommodation space within a basin through subsidence. Furthermore, tectonics also influence the eustatic sea level (tectono-eustatism), control the elevation of paleo-shorelines, and the sources and quantities of sediment inputs. In the case of mountain formation, the topography induced by tectonics can also have an impact on the local climate (Williams & Dobb, 1993). In our study, we have identified two distinct sedimentary units characterized by horizontal layers of sandstone and beach sandstone. These two primary terraces are overlain and topped by another deposit unit consisting of sand dunes and various vegetation types (refer to Figure 29a for illustration).

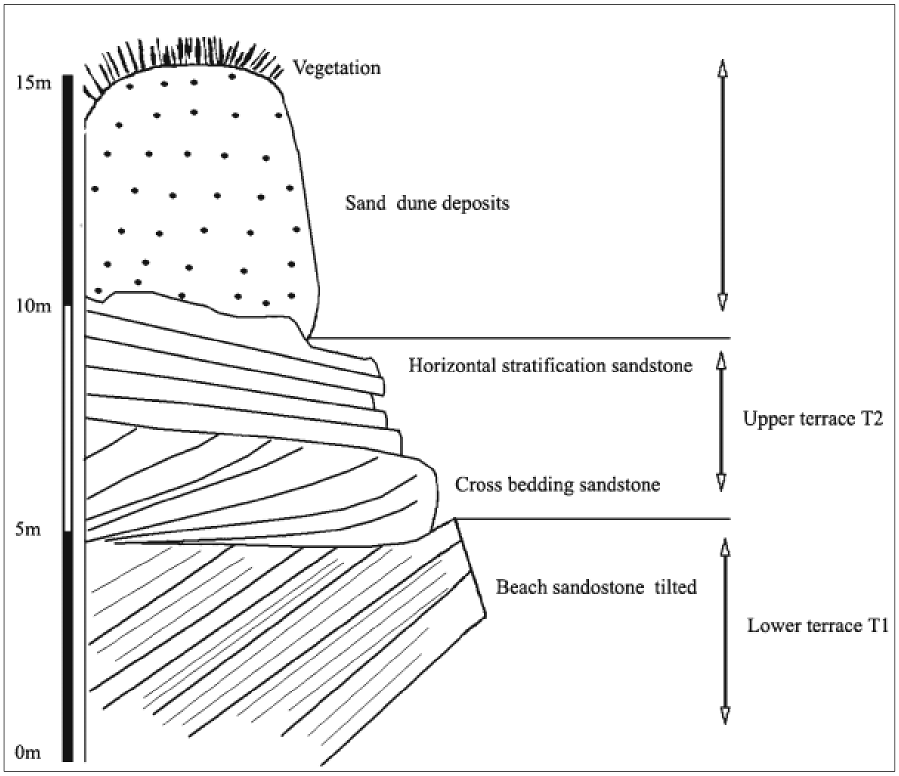


Figure. 29a: Cross section (field Sequence) of the studied Quaternary deposits.

5.4 Sedimentary record of the Oligocene geodynamic change in the Tellian Atlas

The change in the geodynamic context of the Maghrebian Tethys regions is evidenced by the shift from a passive-marginal-bounded area to a compressional-foreland basin (Guerrera and Martín-Martín, 2014). The basin's early Miocene sedimentary fill is composed of turbiditic sandstones from the north and the mature sandstones from the south (Thomas. 2010). (Figure. 29b).

The western Tell region has two structural positions where the deposits of the Oligo-Mioscene are located. On the one side, they are generally unconformably situated over the allochtanyous external units, such as the wedge-top portion of the Chelif Basin (Neurdin-Trescartes, 1992; Roure et al., 2012) On the other hand, they can be found in the southern nappes or in smaller Miocene basins (Courme-

Rault, 1984) (Figure. 29b). These deposits are associated with thrust-sheets that are difficult to track down in terms of their palaeogeographic origins. In the case that the Oligo and Miocene formations are transitional or lateral, then they should represent the Numidians.

In the western Tell region, Guardia and Fenet (1975) suggest that the Oligo-Miocene unit could have been associated with the former cover of the Senonian units, which formed the higher Rif Tell nappes.

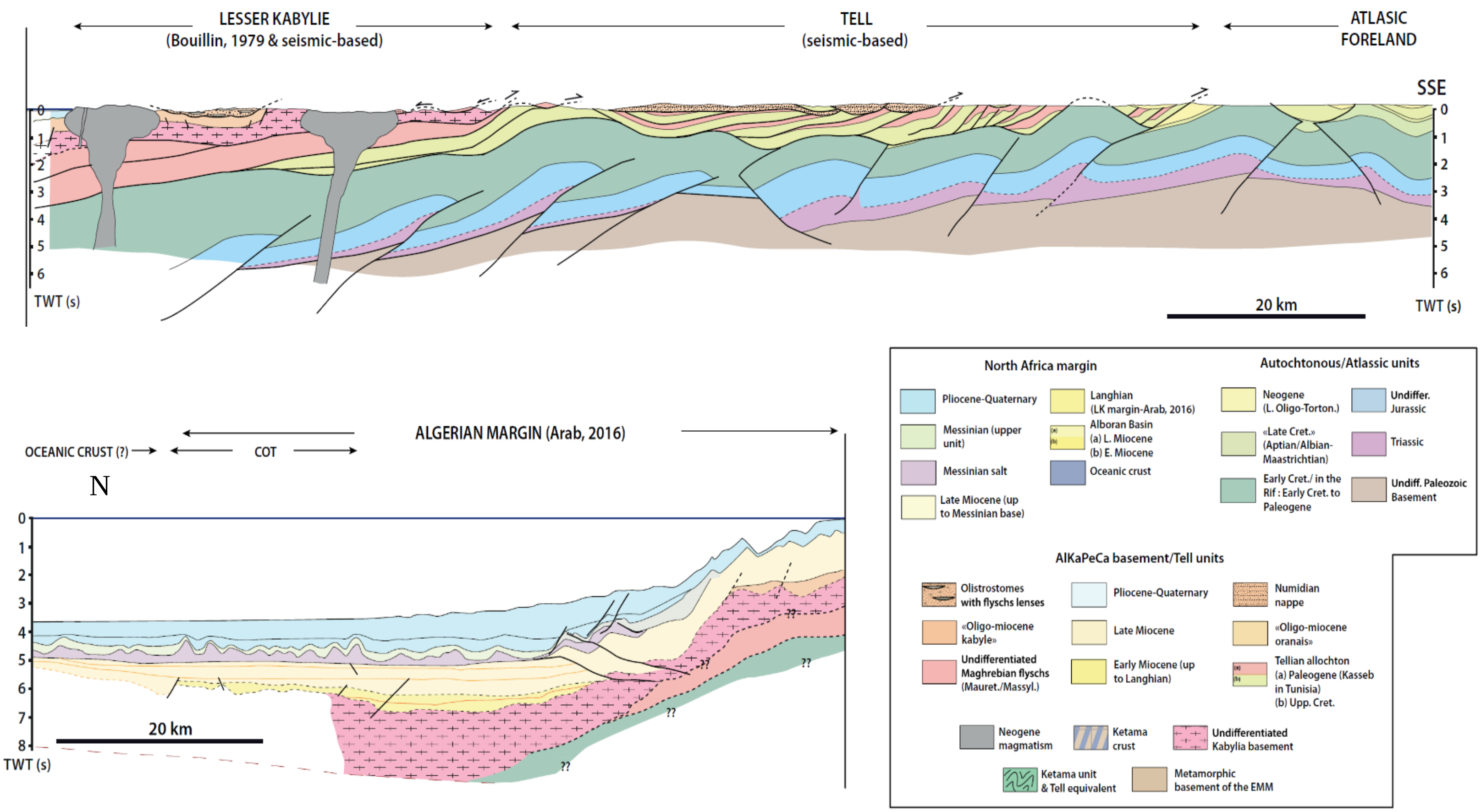


Figure. 29b: Cross-sections of the Tell-Atlas system. Sections were built using surface geology, wells and property reflection seismic data (modified from Leprêtre, 2018). Eastern Algerian Tell section, from the offshore through the Lesser Kabylie, Flyschs unit, the Tellian nappes, and the Atlas domain. Main map references are within the work by Bouillin (1979) and Vila (1978, 1980).

CHAPTER. III

LITERATURE REVIEW

1. Introduction

Tectonically active shorelines are particularly dynamic geomorphic landscapes, with heavily occupied facilities and infrastructure. Over glacial ages, the effects of sea-level changes influenced coastal locations in a piecemeal fashion, enhancing the terrain while leaving Former paleo-shorelines and marine terraces serve as fossil geomorphic indicators. Marine terraces are one of the most well-known coastal landforms, having evolved during the long-term interglacial sea-level high stand a hundred twenty-five thousand years ago. A larger protective potential distinguishes these terraces, which aids in their identification, mapping, and lateral correlation. They were also employed to evaluate vertical deformation coasts at neighborhood and local scales due to their high degree of protection and relatively younger age. The final interglacial marine terraces' relative abundance and geomorphic characteristics make them ideal geomorphic markers for reconstructing beyond sea-level placements and allowing comparisons among faraway under specific climatic and geological conditions. Thus, the current chapter has been developed in order to construct literature review by recruiting insight from the findings of the past studies. The chapter has effectively determined the sea level curves and its influence over marine terraces. Consequently, it has shed light on the tectonic activities as well as the events which has led toward destruction keeping a specific focus over the eastern Algeria. Moreover, the chapter has also further determined the impact of sea level curves over the fauna and the flora of the eastern Algeria. In order to attain significant findings, the potential danger of earthquake and landslide in the future has been discussed by discussing the past event happened in the east Algeria. Nonetheless, the chapter has also significantly set out the theoretical foundation as well.

2. Sea-level curves

Global or worldwide change in sea level relative to the land known as eustatic sea-level (ESL) variations, and vertical land motion of coastal regions with regard to the ocean surface, referred to as relative SL (RSL) change, produce sea-level (SL) shifts. Glacio-eustasy was a prominent long-time period process during the Quaternary, according to SL changes (Djouder,. 2017). Long-term climatic cycles put pressure on massive ice sheets' cyclical degradation and development (Figure. 30, 32), which are linked to ESL upward push and fall. (Scardino, 2020).

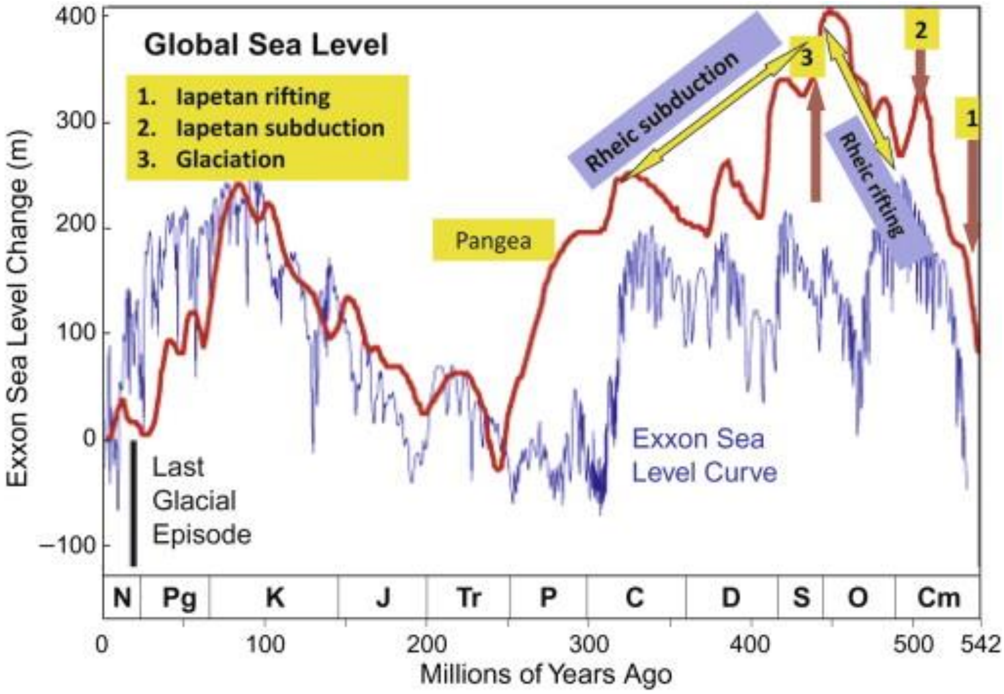


Figure. 30: Sea level changing (Murphy and Nance, 2013)

Weather and rock resistance, according to other research (Prémaillon. 2018), have a bigger impact on erosion than marine wave velocity (Djouder,. 2017). It has been found that there generally exist two potential types of sea level cruves. These include the relative sea level curve and the other is absolute sea level curve. The relative sea level curve offer the present position regarding the changes in the sea level regardless of the change which occur in the interjacent period level. Whereas, the absolute sea level curve which is also regarded as eustatic curve offer the ocean with the changes that are not affected by coastal formation (Djouder,. 2017). It is also viewed that the sea level curve generally influences the sequences of Marine Terrace mapped. Consequently, the high sea-level resolution of curve lead toward modelled terraces (Figure. 30, 31). While, the geometry of slow and old uplifting sequences is believed to be sensitive toward the noise of sea level. Such that the faster, and the younger uplifting sequences are believed to be favourable for the evolution of landscape modelling (de Gelder,. 2020).

2.1 Influence of Sea-Level changes on Marine Terraces

Marine terraces serve as essential geomorphic indicators used globally in the study of past climatic conditions and tectonic processes. They help to establish historical sea-level positions and measure ground deformation rates. (Meco,. 2020) (Figure. 33). A group of ten well-preserved raised marine terraces with interior borders that vary in height have been discovered in North America, indicating significant coastal uplift (Peñalver,. 2021). Topographic maps, aerial photographs, and a 2 m resolution Digital Elevation Model (DEM) were used to identify and map marine terraces, which were supported by large observations.

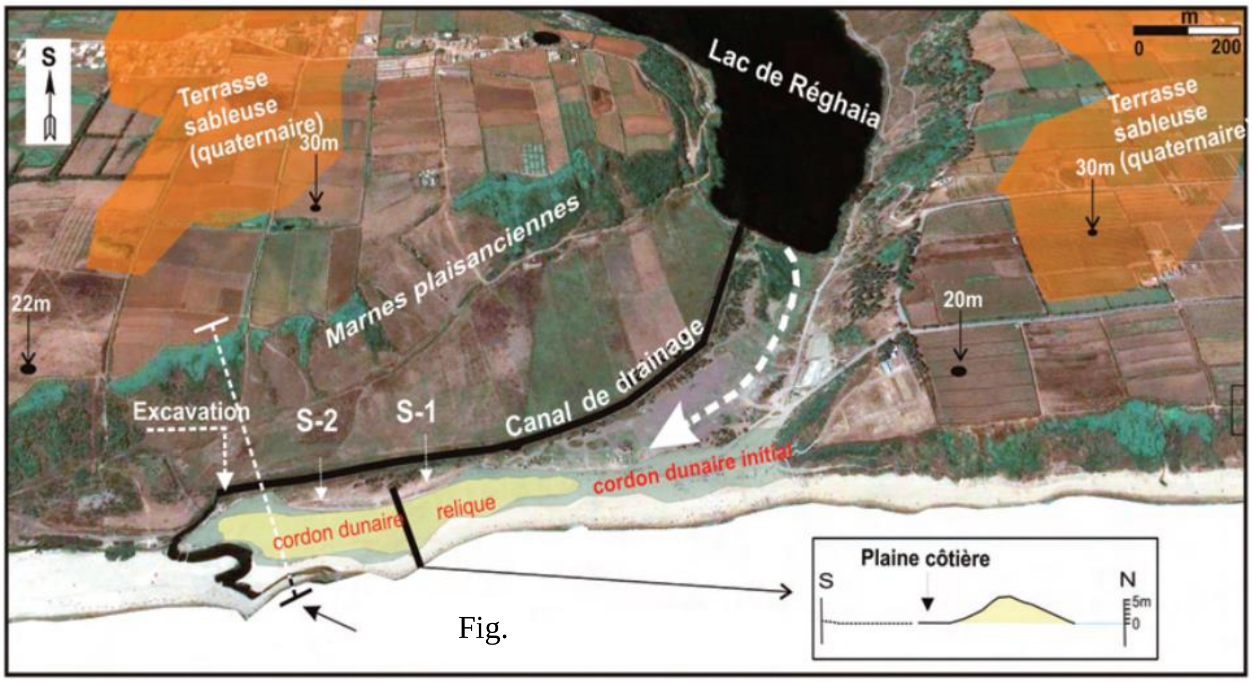


Figure. 31: Map shows the Geomorphology of Zemmouri area. in box topographic profile.

Selecting samples from the terraces were OSL dating in Central Peru, allowing us to link them to prior Pleistocene Marine Isotope Stage (MIS), sea level highstands and the long-term uplift rate (Peñalver,. 2021) (Figure. 33). The below (figure. 32) shows how the sea-level variations tend to influence marine Terrance sequence.

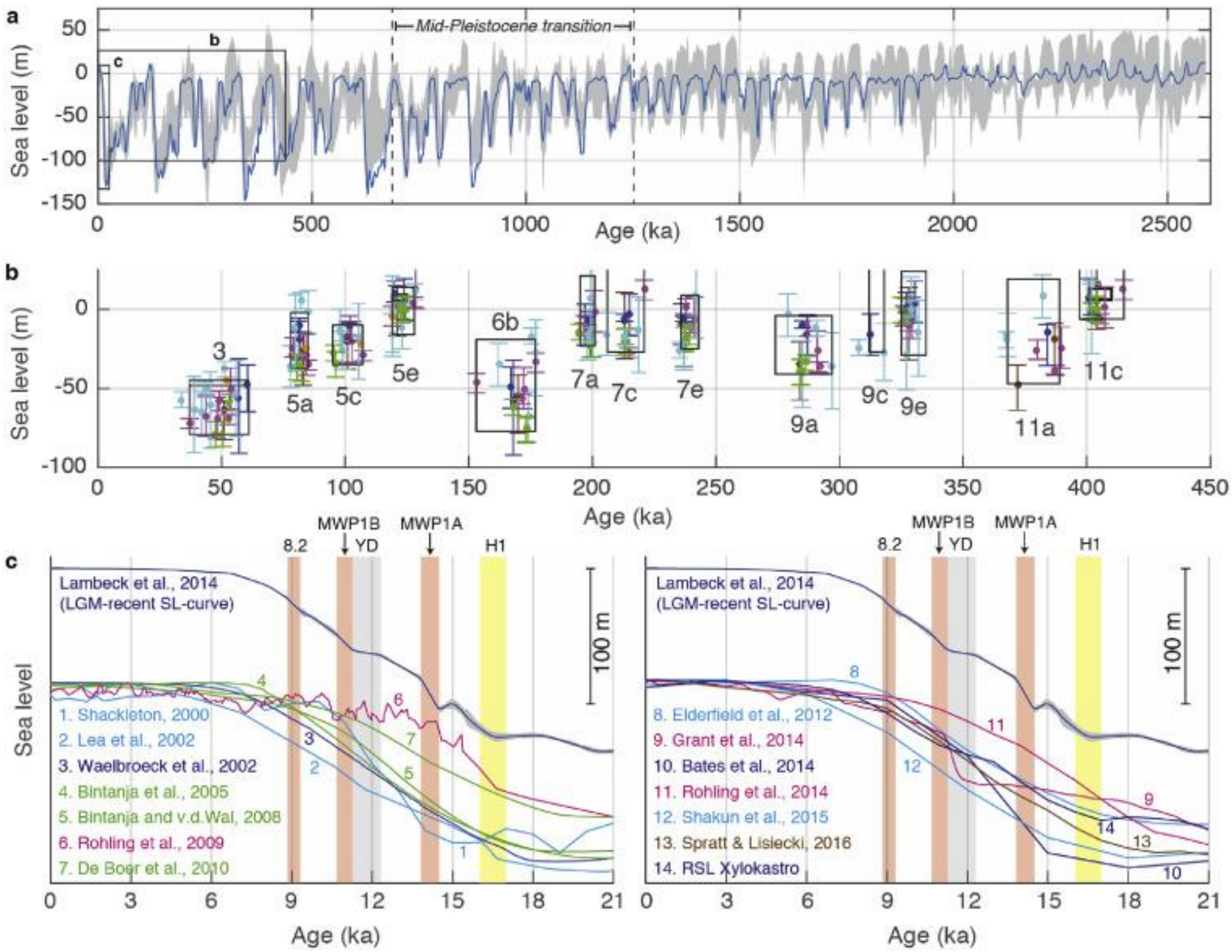


Figure. 32: Sea-level curve influence on marine terrace sequence (Source: de Gelder. 2020)

The referencing points used to link the marine terrace measurements, which are based on the results and timing limits provided by past research, are one of the most major downsides of using the database (Meco,. 2020). The WSAC reference variables are scattered in a variety of ways in other cases, resulting in lengths of up to 600 kilometres to the nearest confined point in Central Peru (Figure. 32). This could potentially have a big impact on people's perceptions of the magnitude of the marine terraces at certain places. Furthermore, some of the referring components' geochronological control may be relied entirely on courting approaches with the aforementioned uncertainties (Peñalver,. 2021).

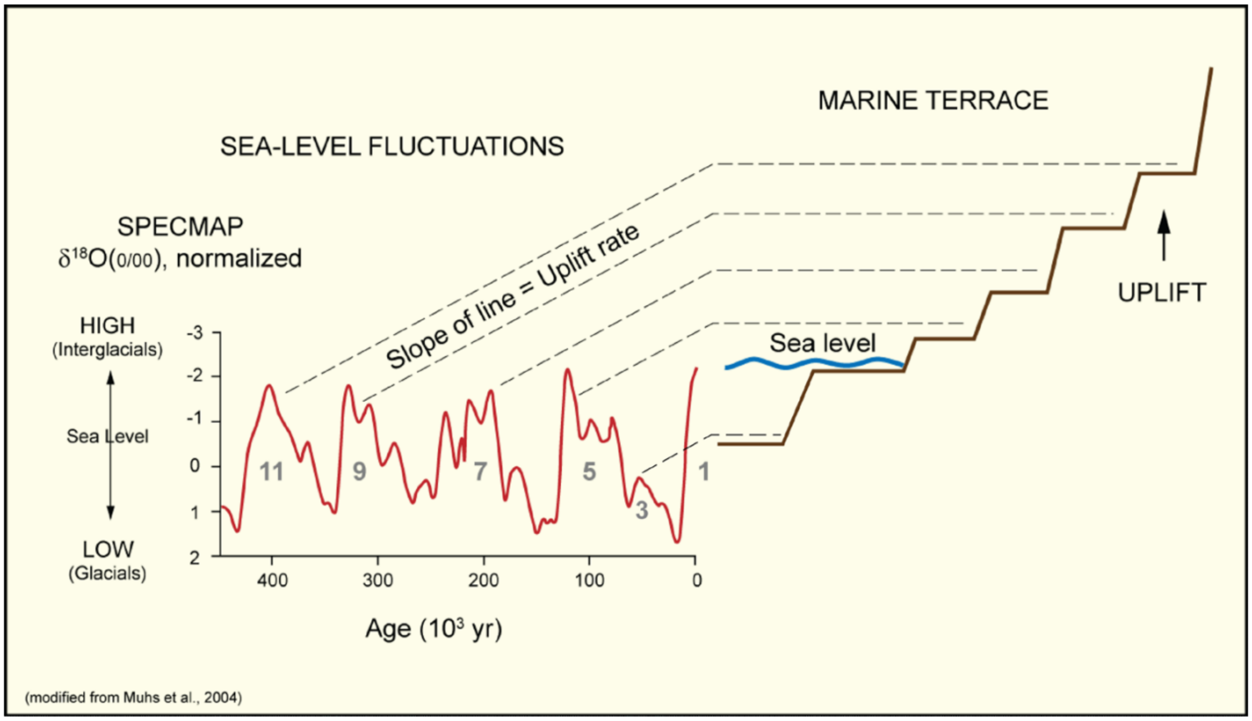


Figure. 33: Schematic diagram showing how Sea-level curve influence on marine terrace sequence

2.2 Tectonic activities and events in the area

The tectonic activities or the events are considered as the events led by mountain building, volcanoes and earthquakes in general. It is considered as the plate boundaries where the two or more than two plates are in contact alongside with the linear faulting zone. The plate tectonic is considered as the study of the crustal slabs and how these interact with the edges (Maouche. 2013). The seismic activity in eastern Algeria is relatively frequent. Since 1950, approximately 8,800 individuals have lost their lives due to the direct consequences of earthquakes. Additionally, about six of these earthquakes triggered tsunamis, resulting in further destruction and casualties. Similarly, certain regions of Algeria are also susceptible to significant and severe flood-related damages (Harbi, 2011).

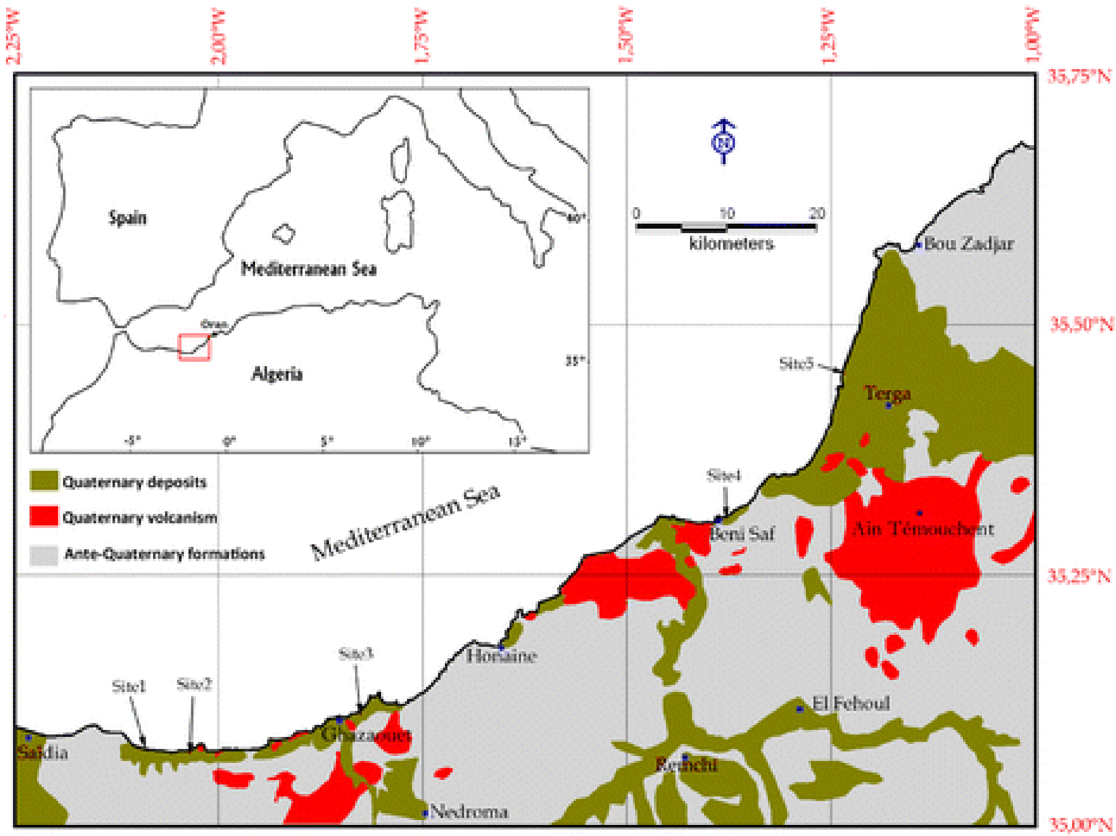


Figure. 34: Evidence of seismites in coastal Quaternary deposits of western Oranie (northwestern Algeria)

In eastern Algeria, seismic activity is evident, but it typically occurs at moderate to higher magnitudes (M≤6.3). The most recent major seismic event in the region was the Constantine earthquake (Ms = 5.7, mb = 5.4; Benouar, 1993). However, a larger offshore event occurred near Jijeli in 1856 (Figure 34). Historical records of seismic activity in the area reveal a history of destructive earthquakes occurring on a significant scale. The seismicity map depicted in (Figure 35) covers the eastern Algeria region from 1357 to 1996, with events registering Io ≥ VII and M ≥ 4. This figure illustrates that epicenter distribution exhibits a tendency to concentrate within several distinct zones (Figure 35).

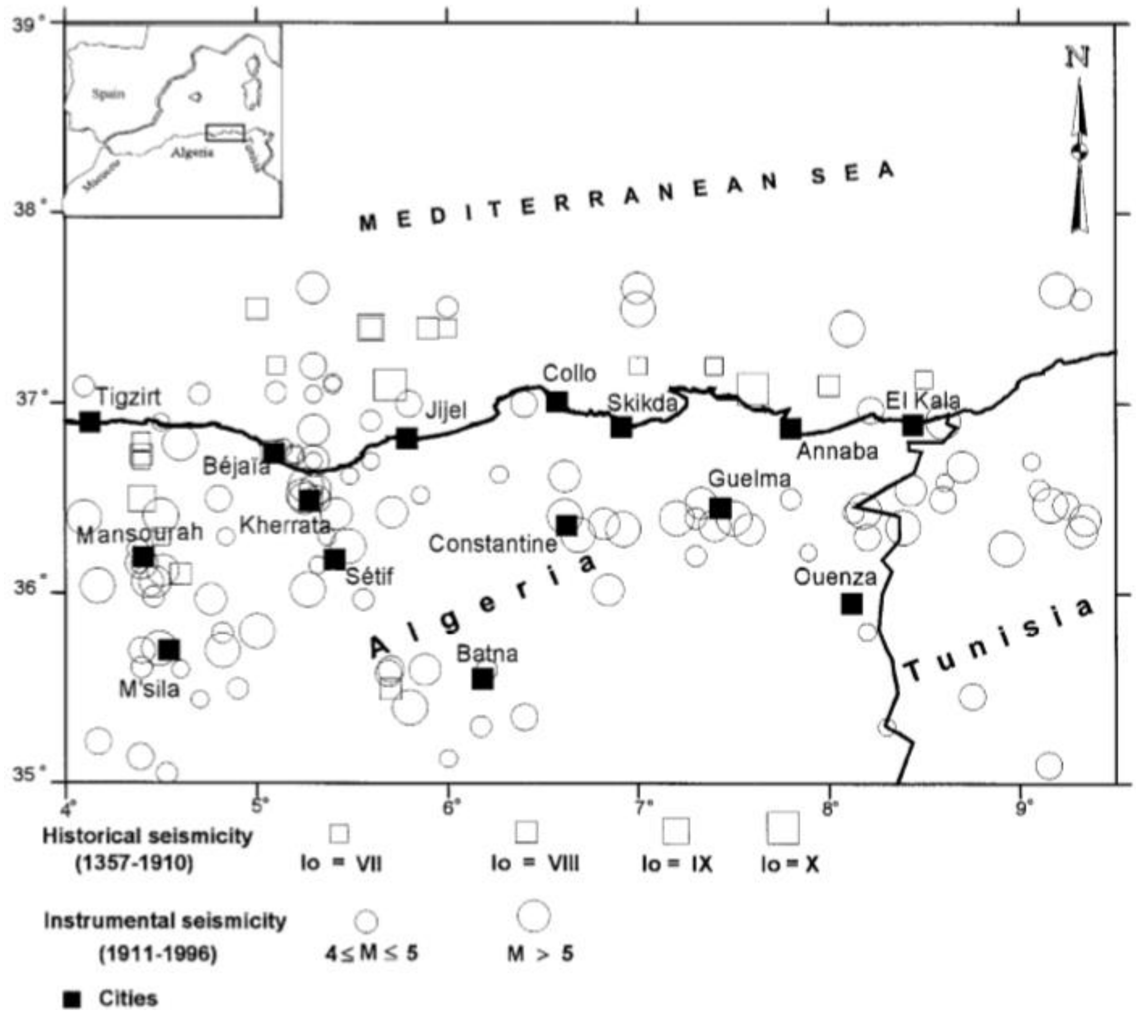


Figure. 35: Distribution of epicenters across the east of Algeria (Source: Harbi. 1999).

According to the information collected by the Algerian monitoring network, various regions in Northern Algeria are affected by seismic activities. One of these is the Chlef region, where several active zones can be found. In 1922, a violent earthquake occurred in this area (Figure. 36). One of the first structures that can be identified is the Tenes Abou El Hassen Fault, which is located near Ténes. It has a steep south flank and is situated in an anticline. According to recent studies, the anticline has overlapped faults and a northwest dip.

The overlapping faults are located along the fold hinge. They allow the movement of metamorphic rocks over the Neogene sandstones. It has been observed that the violent earthquake that occurred in 1922 was caused by the structure.

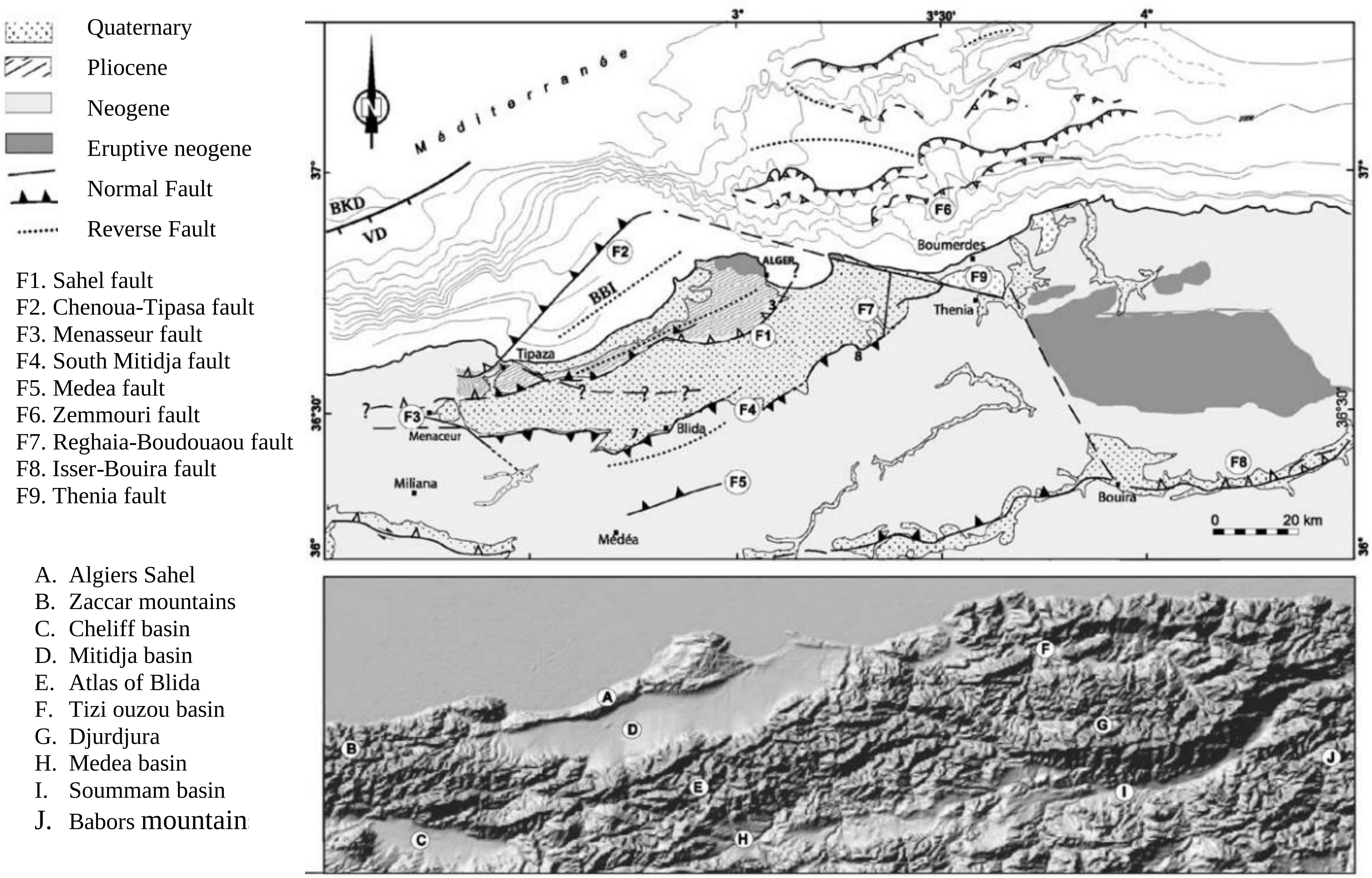


Figure. 36: (a) Structural map of the Algiers region, (b) SRTM (DEM model) active structures.

Another geological feature is the coastal fault situated near the Ténes region's shoreline. This active fault is particularly prominent along the coastal area to the west of Ténes. The northeast-directed flexures display steep northern slopes. Additionally, there is an approximately 15 to 20 kilometers long fault aligned with this same geological feature.

The flexures and faults located in this area separate the lower and higher deformed zones. They extend into the sea until they reach a distance of about 15 kilometers from the coastal boundary (Figure. 36). It is assumed the features will continue to develop along the coast northward. Numerous structures are known to exist in the region of Chlef. The Oued Fodda or Chlef fault is a reverse structure that has a dip of about 50 to 60 degrees to the northwest. It is linked by an asymmetric anticline and an uplifted southeastern flank. The entire extent of the fault is marked by the deformation of Plio-Pleistocene bedrock and the presence of recent alluvial deposits. The surface rupture of the fault during the 1980 earthquake extended its length by about 47 kilometers. It is located near a point about three kilometers from El Abadia. Through studies conducted on the fault, it has been estimated that the displacement rate has increased significantly. According to the data collected during the past few years, most of the displacement probably occurred during the Holocene.

The Bled Bahari Karouch is located northeast of Oued Fodda. It is part of a group of structures that extends from the Oued Fodda Fault to form the eastern portion of the uplifted compartment. Its characteristics vary, which suggests that it has a strike-slip component at its southern end and an overlap at its northern and northeastern portions. This region is also connected to a seismic belt that developed following the 1980 earthquake. It is likely part of an extensive diffuse zone that includes faults and folds located at the Oued-Fodda Fault's eastern boundary (figure. 36). Aerial photos show the Ouled Fars and Red Mountains Fault forming a straight lineament that separates the recent alluvium from the Holocene bedrock. A steep flexure is also present parallel to the lineament. It is believed that the fault is a reverse structure that's located beneath the uplifted regions (Figure. 36)

The Oued Ras fault, situated to the southwest of the previously mentioned fault, exhibits a southeast-dipping flexure that causes deformation in the Villafranchian molasses, sandstones, and conglomerates. This geological feature is categorized as a reverse structure with a northwest dip.

Seismic activity is frequently experienced in the Algiers region, particularly within the Neogene Mitida Basin. This area features multiple fault lines, folds, and a series of conjugate faults running from northwest to southeast. These geological structures contribute to the elevation of the coastal region and its slopes (Figure 36). The western part of Algiers is characterized by the presence of a major structure that's approximately 60 kilometers long. The region is also affected by the recent tectonic deformations. Some of these include the Mahelma and Attatba regions, which are characterized by strike-slip faults. In the sea, two major structures are known to be located in the area: the Khayr Eddine and Chenoua faults (Figure. 36). The southern part of Algiers is also characterized by several faults that run parallel to the Mitidja and Blida massifs. These areas are known to be affected by tectonic deformations (Figure. 37). Some of these are located in the Menaceur and Mitidja regions. These faults are linked to significant historical seismic earthquakes.

In 2003, a powerful earthquake occurred in the eastern part of Algiers, which revealed the activities of the Reghaia and Zemmouri marine faults. The seismic movement in the region also highlighted the coastal zone's tectonic uplift (Figure. 37).

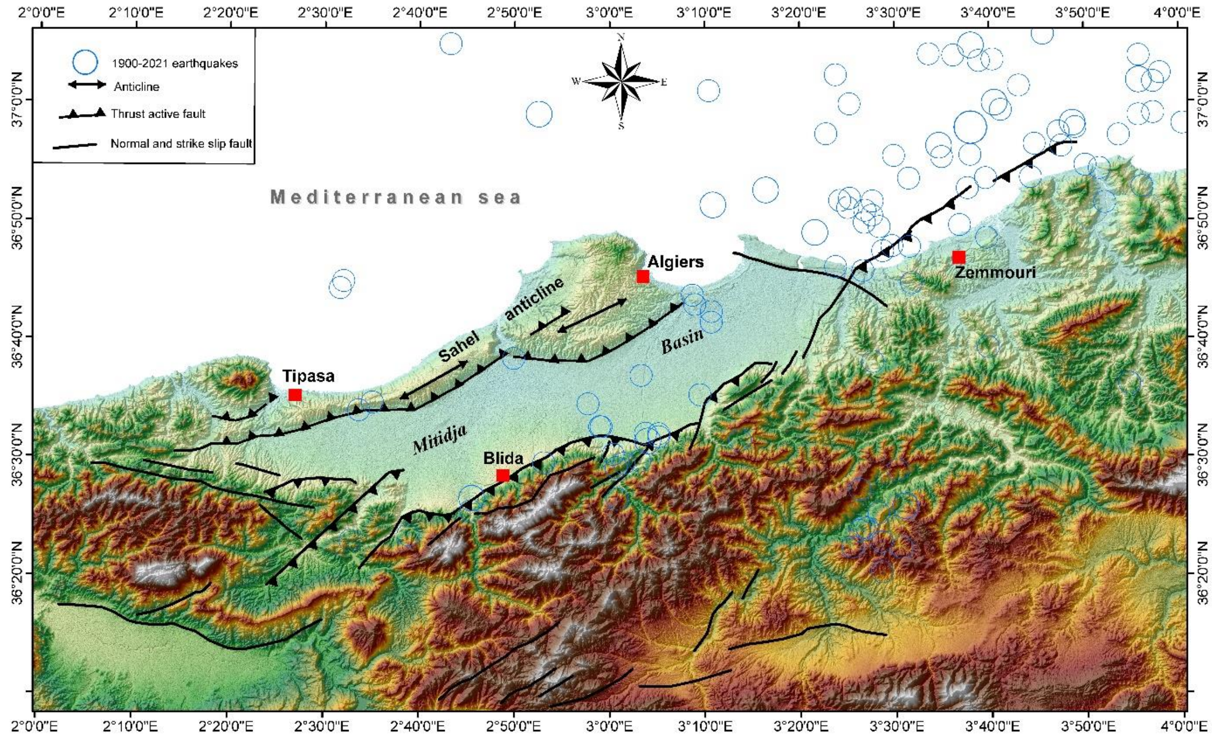


Figure. 37: NeoTectonic and seismicity map shows the distribution of earthquakes in the Mitidja basin and study area from 1900 to 2022 (M≥ 4, modified from Maouche and al. 2018). (USGS DATA, SRTM 30 m)

Frequent earthquakes can be felt in Kabylie due to the Issour Bouira fault, which is located in the Mitidja basin. This fault is capable of transferring deformation to the Kabyle region. The deformation is observed along the Oued Tamar and Dra El Kremis faults.

When examining the map from east to west, a distinct pattern of seismic activity becomes evident. Particularly noteworthy is the concentration of seismic events in the Guelma and Constantine basin, including a notable earthquake with a magnitude of 6.0 (Figure 38). Moving westward, we encounter the vicinity of Batna, where the Mac-Mahon earthquake, registering at a magnitude of 4.9, affected Ain Touta and the surrounding areas. Additionally, microseismic activity has been observed in the Kherrata region in recent years. It's worth noting that a significant portion of these epicenters is situated in close proximity to the coastline. Furthermore, offshore regions exhibit features indicating land formations and submarine faults, as illustrated in Maouche et al.'s 2013 study (Figure 38). The Algerian margin comprised of the basement blocks which migrated from the European margin and docked against the African plate in response to the southward rollback of the Maghrebian Tethyan slab in the Early Miocene.

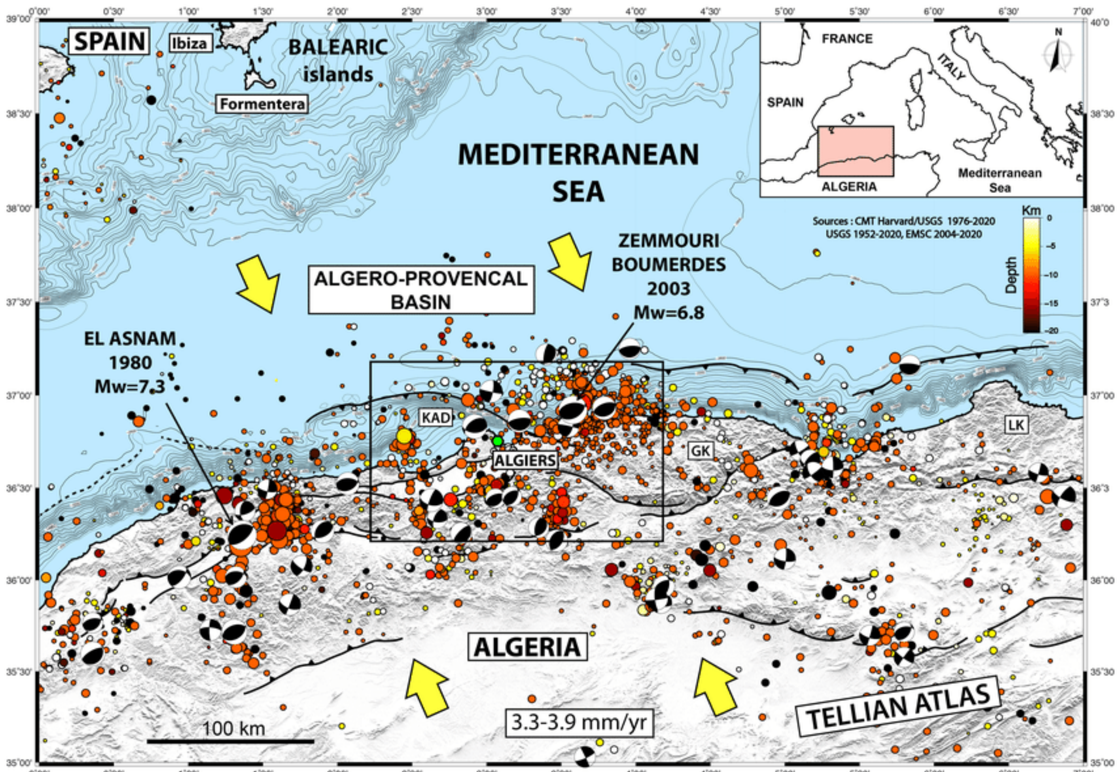


Figure. 38: Epicentral distribution map of the main historical and instrumental M≥3 (earthquakes in North of Algeria). (Strzerzynski, 2021)

2.3 Impact of sea level curves on the flora and fauna in the Eastern Algiers

As a result of the earth's systematic warming, the melting of mountain glaciers and polar ice sheets adds water to the ocean, and the warming of the water within the seas results in enlargement and therefore increased volume. The global mean sea level has risen about 210–240 millimetres (mm) since 1880, with roughly a third of that rise occurring in the preceding half-decade (Authemayou,. 2017) (Figure. 39). Currently, the once-a-year upward thrust is about 3mm per year. Natural variability in local winds and ocean currents causes regional differences, which can occur across time spans ranging from days to months or even decades. Ground rise, subsidence, changes in water tables as a result of water extraction or other water management, and even the effects of neighbourhood erosion are all regionally different variables that can have a substantial impact (Meco,. 2020).

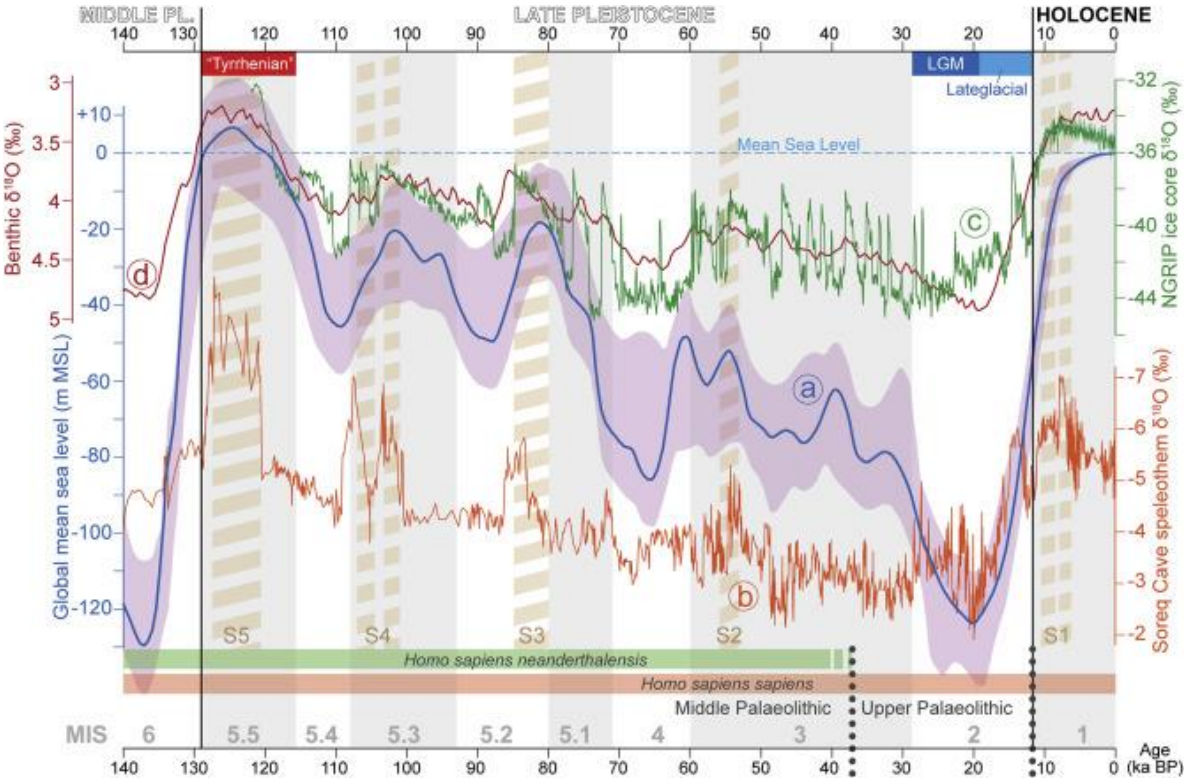


Figure. 39: Quaternary Sea level changes (Source: Benjamin. 2017).

It is thereby analysed that the rising level of sea does not just stresses over the physical coastlines but also over the coastal ecosystem (Figure. 39). While, the saltwater intrusion could be contaminating the aquifer of freshwater. However, many of these sustain the agricultural and the municipal supplies of water as well as the natural ecosystem. Hence, as the worldwide temperature continued to be warm, the rising sea level kept for the long time. This is because there exist significant lag for reaching the equilibrium. On the other hand, the magnitude rely over the strong future carbon dioxide emission rate and the global warming. Consequently, the speed may also increased relying over the ice-sheet melting and the glacier rate. These all are influencing the eastern Algeria at wide scale level (CCKP, 2021). it can be determined that extreamly variable yields are resulted due to the high variability of annual total precipitation from year to year (Kourat, Smadhi & Madani, 2022).

2.4 Potential of future earthquake and landslide in Algeria

Algeria has largely experienced significant destructive earthquakes across the last centuries. For instance, the city of EI Asnam was damaged severly during the year 1954 and the 1980. While, the magnitude was 6.7 and 7.3 respectively. While, during the year 1989, 5.9 magnitude earthquake struck the coastal area of Mont Chenouna Tipasa which occurred at approximately 150 km for the Zemmouri. Most of the instrumental and historical earthquake has damaged the Algerian coastal area over the past few centuries (Boukhedimi. 2017). These earthquakes have thereby suggested significant active deformation for the margin along with the conjunction with the definite offshore extent for active coastal faults. As per the study of Bezzeghoud. (2017), the potential active geological structure across the Boumerdès, Zemmouri, Algiers and El Asnam has largely experienced disastrous earthquakes. While most of the other earthquakes has been occurred around Mitidja Basina and the Chlef (Figure. 40). Hence, underlining the seismic activity across the area was notable. The significant event and the most potential event occur in the east Algeria was Zemmouri with the magnitude of 6.8. This event was second largest after the El Asnam event that occurred during 1980. It thereby struck the eastern part pertinent to the capital city of Algeria. It occurred in the area where not even one catalogues report the strong event occurences in the past (Figure 32).

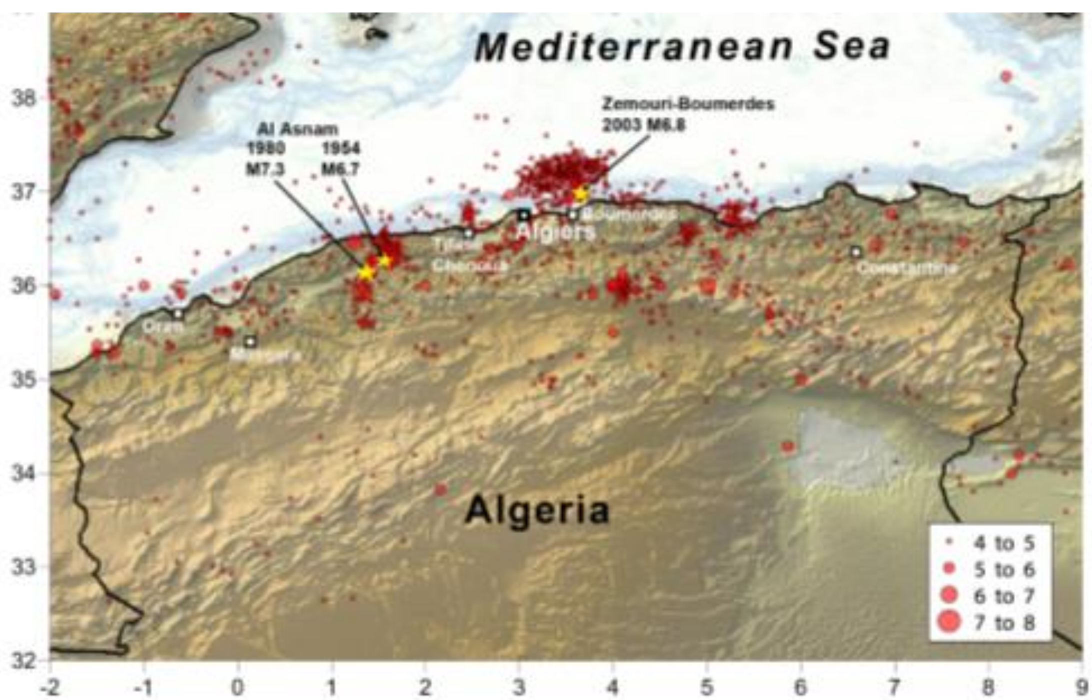


Figure. 40: Seismicity of North of Algeria (Source: Bezzeghoud. 2017).

The earthquakes have caused increased level of damages and has caused about 2278 fatalities leaving 11450 indivdual injured while 250,000 homeless. Consequently, the building in the areas were also notably influenced. Such as about 6000 builidings were destroyed during the event while 20800 housing unit were damaged severely. The earthquake is regarded as disastrous event due to the El Asnam earthquake which occurred near the capital city of Algeria (Maouche. 2013). Consequently, the macroseismic study by Harbi (2011) demonstrated that the Zemmouri-Boumerdès earthquake has thereby impacted significant area having the radius of about 150 km across the epicentral locality (Figure. 41). The notable intensity has been experienced during the potential shock which has been observed for Corso, Zemmouri and the Bordj Menail. Hence, the zone which depicted the intense degree of X has been concentrated along with the coast among Dellys and the El Marsa which was linked with the poorly engineering building and the site effects (Figure. 41).

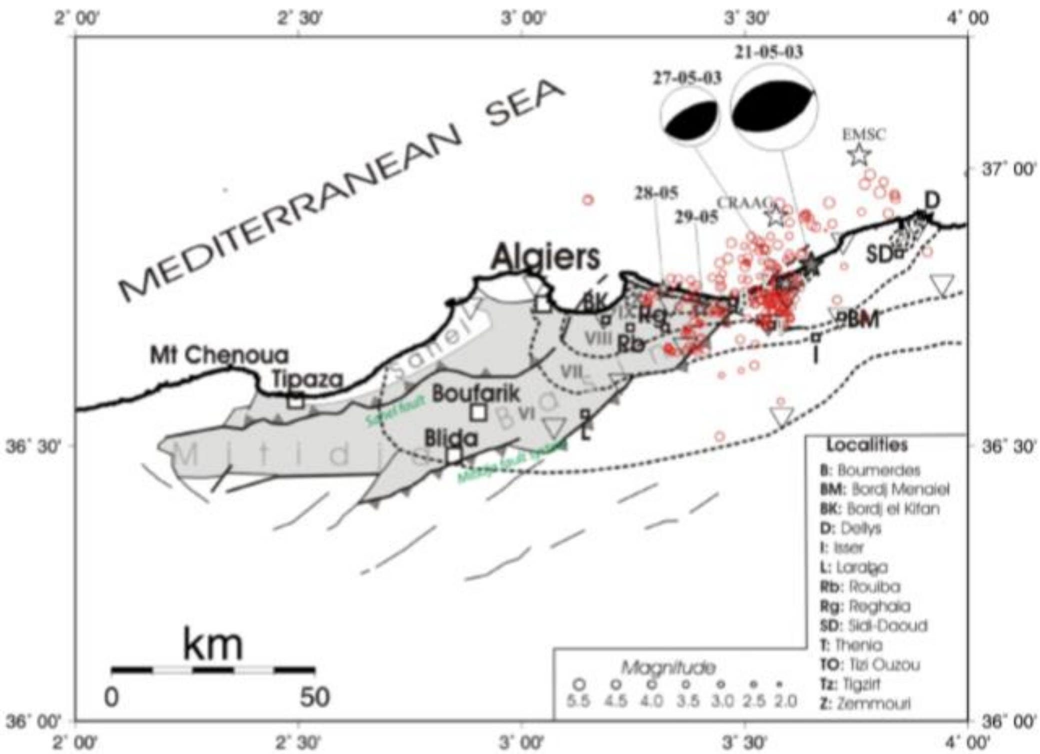


Figure. 41: Tectonic event in Algiers region (Source: Bezzeghoud. 2017).

It is thereby believed that the Algeria is widely prone toward drought, floods, locust infestation, earthquakes and tsunamis. While, between the year 2015 and the year 2017 Algeria is found to be affected by the floods across different regions. Thus, the future of earthquake and the landslide in the eastern Algeria is perceived to be medium. This thereby means that there is about 10 per cent significant chances for the damaging earthquakes at different parts of eastern Algeria which might shake the project across the upcoming 50 years (Thinkhazard. 2021). On the basis of these insight, the influence of earthquake must be considered across all the project specifically in the construction and the designing. The planning decision of the project, construction method and the project design need to be taken into account for determining the level of earthquake. However, detailed insight needs to be undertaken for adequately accounting the hazard level (Thinkhazard. 2021).

2.5 Theoretical framework

Wave-reduce structures can be preserved as marine terraces if they are not exposed to the high-energy wave regime. This is accomplished through tectonic uplift of the landmass or eustatic sea degree fall (Scardino. 2020). The amount of water stored in polar ice sheets is an essential factor in determining sea level. The amount of water stored within the polar ice caps has an inverse relationship with sea level. Eustatic sea level decreases during international glaciation and rises at some point during interglacial.

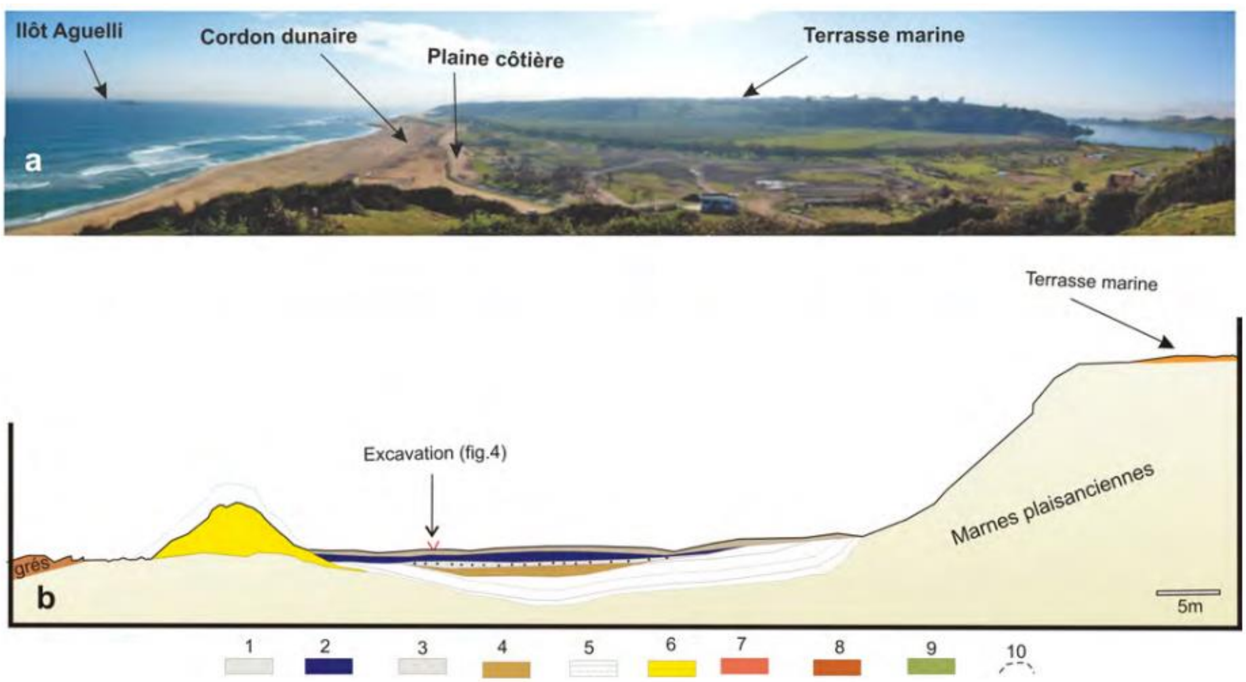


Figure. 42: a. Photo present Landscape view of Zemmouri site combined with coastline and marine terraces (eastward view in April 2020). b. North-south geological cross-section. (Authemayou. 2017)

Rapid desertion or reoccupation of a wave reduction platform might be caused by eustatic changes (Authemayou. 2017). Tectonic pressures are required to elevate the marine terrace such that as sea level rises, the marine terrace remains above modern-day sea level (Figure. 42). At some point during the abandonment and subsequent elevation of the maritime terrace, marine or silt deposits may be maintained on raised terraces (Meco. 2020) (Figure. 42).

2.6 Chapter Summary

This book review chapter looks into the study of the deposits and deformations of the Quaternary in Eastern Algeria, focusing on the coastal formations. It offers an in-depth analysis of the knowledge and research regarding this region's deformations and deposits. This chapter's introduction serves as a starting point for the study, emphasizing the importance of understanding the region's deformations and deposits. It also explores the coastal formations' geomorphic and geological properties, which are linked to the sea-level changes and tectonic activities. It starts with an introduction that describes the study's context. It also explores how the coastal formations of Eastern Algeria can be characterized using their geomorphic and geological attributes.

This section explores the data collected from the sea-level curves to gain a deeper understanding of the distribution and formation of marine terraces in Eastern Algeria. It also covers how sea-level changes affect coastal formations' preservation and development. The events and tectonic activities that are occurring in the study area are further explored in this chapter.

The maps provide a historical overview of the seismic activities in Northern Algeria, including their potential to affect coastal regions. This chapter also covers the potential for landslides and earthquakes in Algeria. It delves into the understanding of these hazards, as well as the likelihood of seismic activities in the region, in the context of coastal deposits.

The theoretical framework for the investigation is presented in this section, which establishes the main ideas and procedures used in the research. These include the use of analytical tools, numerical methods, and modeling approaches. The theoretical framework serves as the starting point for the thesis' subsequent chapters.

This literature review chapter summarizes the current research and knowledge related to the study of the deformations and deposits in Eastern Algeria. It specifically focuses on the coastal formations. The chapter also covers the different factors that can affect coastal regions, such as seismicity, sea-level changes, and tectonic activities.

CHAPITER. IV

MECHANISMS OF FORMATION AND PRESERVATION OF MARINE TERRACES

1. Introduction

Numerous marine terraces can be found across the world's coastal regions. They have been studied extensively due to their importance in preserving environmental records and past sea-level movements. The preservation and formation of these landforms are complex, and they are affected by various geomorphic, climatic, and tectonic forces.

The goal of this chapter is to investigate various mechanisms in relation to formation and maintenance of marine terraces. Understanding these processes will allow us to gain a deeper understanding of coastal geology and how these landforms evolved. It will also help us develop effective strategies for managing coastal areas and assessing their environmental impacts.

1.1 Tectonic Processes:

Marine terraces are formed through the various mechanisms that are involved in the tectonic process. For instance, the movement of vertical tectonic plates can affect the distribution and elevation of coastal areas. On the other hand, faults, folding, and regional activities can lead to the creation of subsidence or differential uplift.

Through the study of the various mechanisms that play a role in the creation and maintenance of marine terrace, we can gain a deeper understanding of coastal geology and how tectonic forces affected the landscape's evolution.

1.2 Sea-Level Changes:

Fluctuations in sea level over time are important factor that can affect the preservation and creation of marine terraces. Significant changes in sea levels caused by global warming and ice-sheet dynamics, which can lead to the submergence or exposure of coastal areas. Comprehending the magnitude and timing of past sea-level movements is vital for reconstructing the paleoenvironment and interpreting the stratigraphy and age of marine terraces.

1.3 Wave and Coastal Processes:

Various coastal processes, such as erosion, wave action, and sediment transport, are responsible for the formation of marine terraces. The beach deposits and wave-cut platforms are important components of the marine terrace structure's development.

The relationship between coastal morphology, wave energy, and sediment supply can influence the surface attributes, slope, and elevation of marine terraces. By studying the various coastal and wave processes, we can gain a better understanding of how sedimentation and erosion affect the development of marine terraces.

1.4 Preservation and Dissection:

The long-term maintenance and preservation of marine terraces are crucial for understanding the geological history of their environment. Different factors, such as coastal uplift, tectonic activity, and erosion, can result in their destruction or preservation. Through the study of marine terraces, we can learn about the magnitude and timing and changes in the landscape during the past few million years.

The goal of this chapter is to investigate the various mechanisms that contribute to the preservation and formation of marine landforms. It offers a wealth of knowledge on coastal dynamics, sea level changes, and the gradual evolution of coastal areas. The research will utilize field observations in some coast areas, and geomorphological analyses to attain an in-depth comprehension of the subject. The findings of this study will contribute to the understanding of coastal processes, as well as hazard assessment and the interpretation of environmental records.

2. Marine terraces: Geomorphic indicators of coastal uplift dynamics.

A marine terrace is a geomorphological marker that can provide a detailed analysis of the coastal region paleo-dynamic's. It can also be used to measure the rate of coastal uplift. The complex interaction between tectonic movement, sea level fluctuations and erosion of the neighboring continent is responsible for the formation of these terraces (Bradley and Griggs, 1976; Merritts and Bull, 1989; Anderson, 1990; Muhs. 1990; Lajoie. 1991) (Photo. 1)

Photo. 1: Succession of marine terraces resulting from the interaction between sea level fluctuations, tectonic movements along an active margin and the erosion of the continent. (Panoramic view of cap Bougaroune, Skikda coast (see Figure. 45), North-Eastern of Algeria, 37°05'22.2"N 6°28'01.2"E).

For many years now, the use of marine terraces has been studied and analyzed to measure the vertical movement of coastal tectonic plates along different active margins. Some of the most prominent studies that have been conducted on this subject include those by (Johnson, 1919; Guilcher, 1954, 1980; Paskoff, 1970; Chappell, 1974; Pirazzoli, 1983; Pillans, 1983; Merrits and Bull, 1989; Goy. 1992; Macharé and Ortlieb, 1992; Ortlieb. 1992, 1996; Zazo, 1999; Zazo. 1994; Rosenbloom and Anderson, 1994; Perg. 2001; Pedoja, 2003; Feuillet. 2003; Cantalamessa and DiCelma, 2004; Marquardt. 2004; Kim and Sutherland, 2004; Ota and Yamaguchi, 2004; Dumont. 2005; Pedoja. 2006; Melnick. 2006).

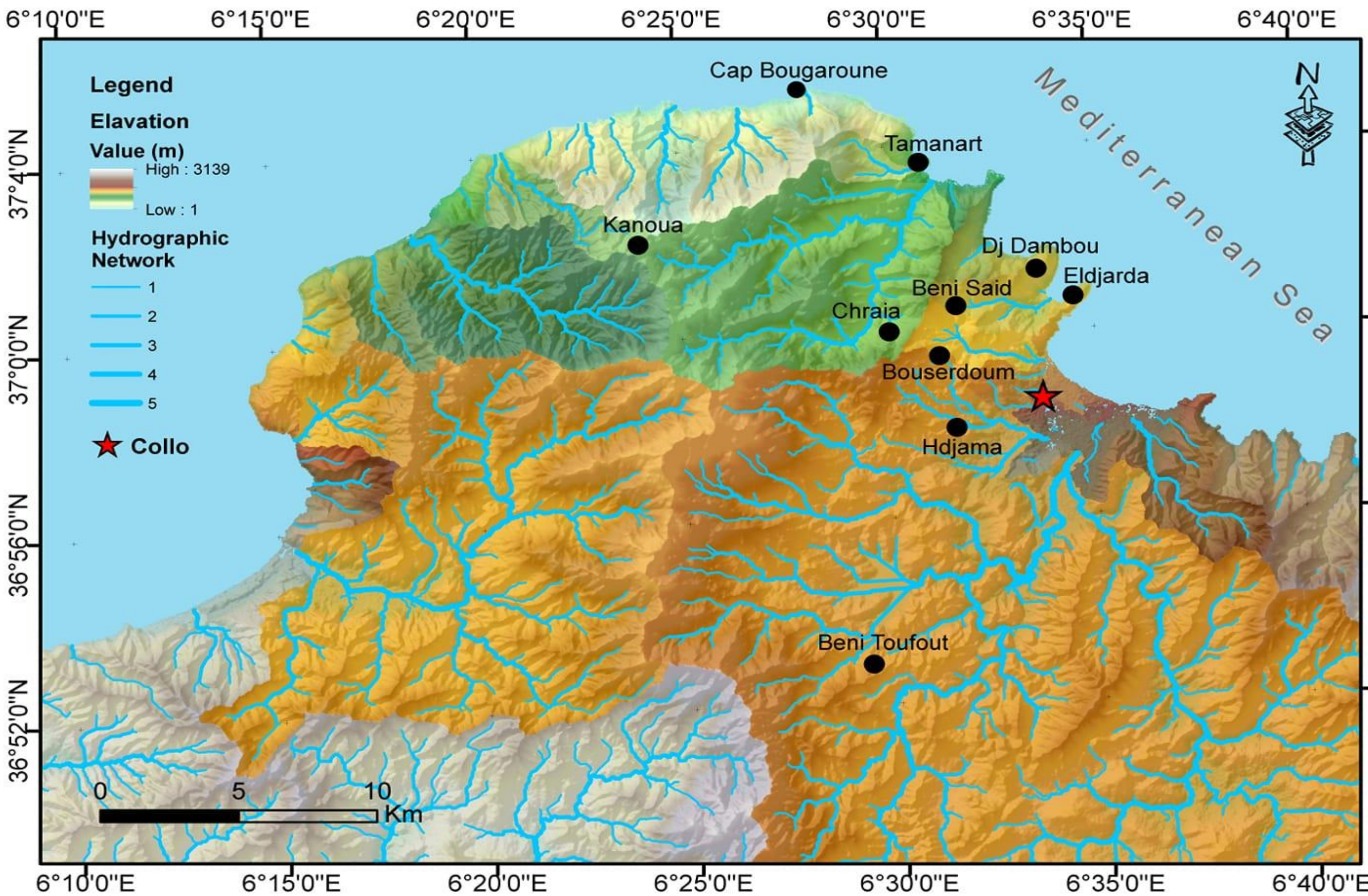


Figure. 43: Coastal zones and Hypsometric map of Skikda region and surrounding

A marine terrace can be limited by an active coastal cliff or an escarpment on either side of the ocean. On the mainland side, it can be dominated by a former coastal cliff or escarpment (Figure 44).

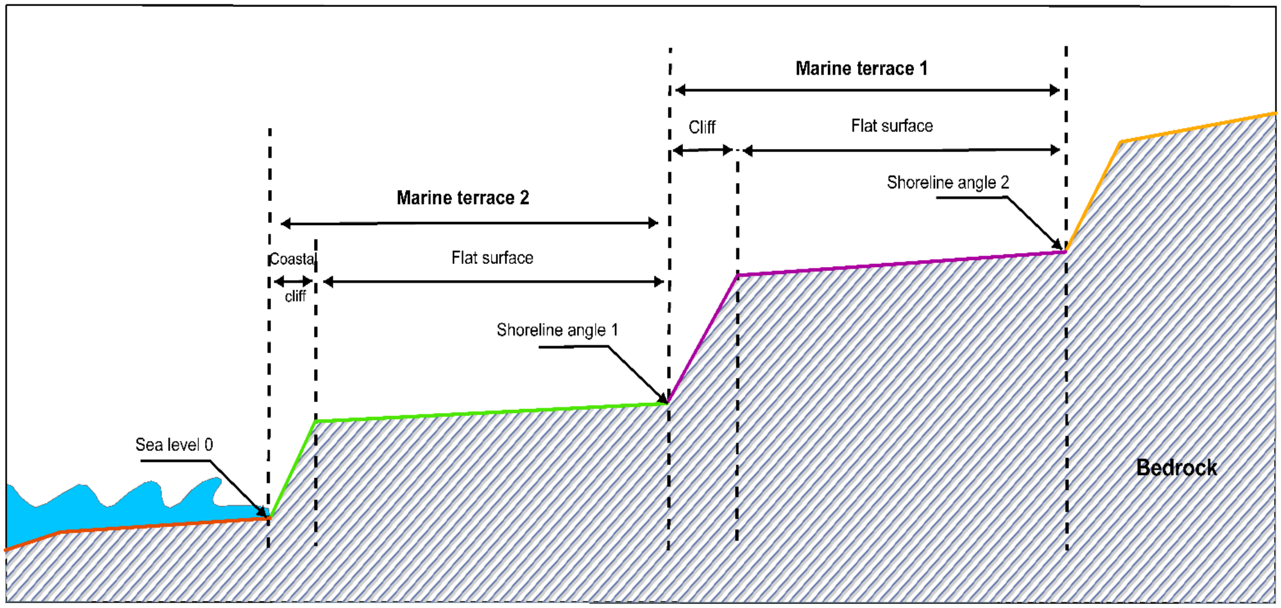


Figure. 44: Diagram of the main features that define a marine terrace. An emergent escarpment corresponds to an ancient coastal cliff. The semi-horizontal surface corresponds to an ancient abrasion platform, covered or not by sediments. The foot of the cliff represents the former sea level 0. For an uplift greater than the variations in sea level, the marine terrace 1 was formed before the marine terrace 2, i.e. the oldest terraces are the highest terraces.

A marine terrace is formed when marine erosion occurs in the littoral zone, which is at the ocean-continent boundary during a high sea level (interglacial stage). It is a surface of marine abrasion that has been raised and preserved due to the effects of coastal tectonics (Figure. 44). This type of surface can be found covered or not by sediments, and it is out of the reach of coastal erosion agents.

Several marine terraces can develop during interglacial periods, and as they undergo uplift, they create a continuous sequence of stepped marine terraces when the uplift process persists. The highest marine terrace is considered to be the oldest, while the lowest one is the youngest (Figure 44). The average elevation of the high eustatic levels during the last few million years has been the same order as that during the end of the Pleistocene (Siddall. 2006). This morphological succession is the result of margin uplift.

Although marine terraces can be formed during low coastal uplift or subsidence, they can also be eroded after their formation. This makes a sequence of marine terraces exceptionally rare (Rosenbloom and Anderson, 1994; Anderson. 1999; Saillard et al). and others believe that these marine terraces only represent a sequence of chronostratigraphic events. Although marine terraces may form during glacial periods, they are unlikely to be preserved as they are usually eroded during the rise in sea levels, or will eventually become submerged. These are also associated with high sea levels. In 1986, for instance, in a study entitled "Thematic and morphological characteristics of marine terraces," authors Chappell and Shackleton noted that these are often preserved on active margins that are undergoing surrection.

During marine regressions, marine terraces are usually covered by shallow marine deposits, such as littoral sands with faunal remains, or continental deposits at river mouths. These are referred to as deposit marine terraces. On the other hand, if these are not covered by sedimentary deposits, then they are referred to as marine abrasion terraces (Figure. 45).

Besides these two types of deposits, there are also other types of sediment on marine terraces that are not covered by sedimentary deposits. These include contemporary deposits and sediments that were produced after the formation of the marine terraces, and these have not the same temporal significance (Figure.45 ; Figure. 46). Therefore, it is important to study the various stratigraphic successions of these deposits to determine their history. For clarity, we have separated the types of marine terraces into two categories: those that are not covered by sedimentary deposits and those that are covered by variable thickness deposits. The first is called marine abrasion terraces, while the second is called marine depositional terraces. The general term marine terraces refer to these two types of structures (Figure. 45).

After being raised, marine terraces are not subject to marine erosion, and they can be affected by continental erosion processes such as diffusion, incision, and erosion of the escarpment by diffusion. These processes are linked to various weathering phenomena.

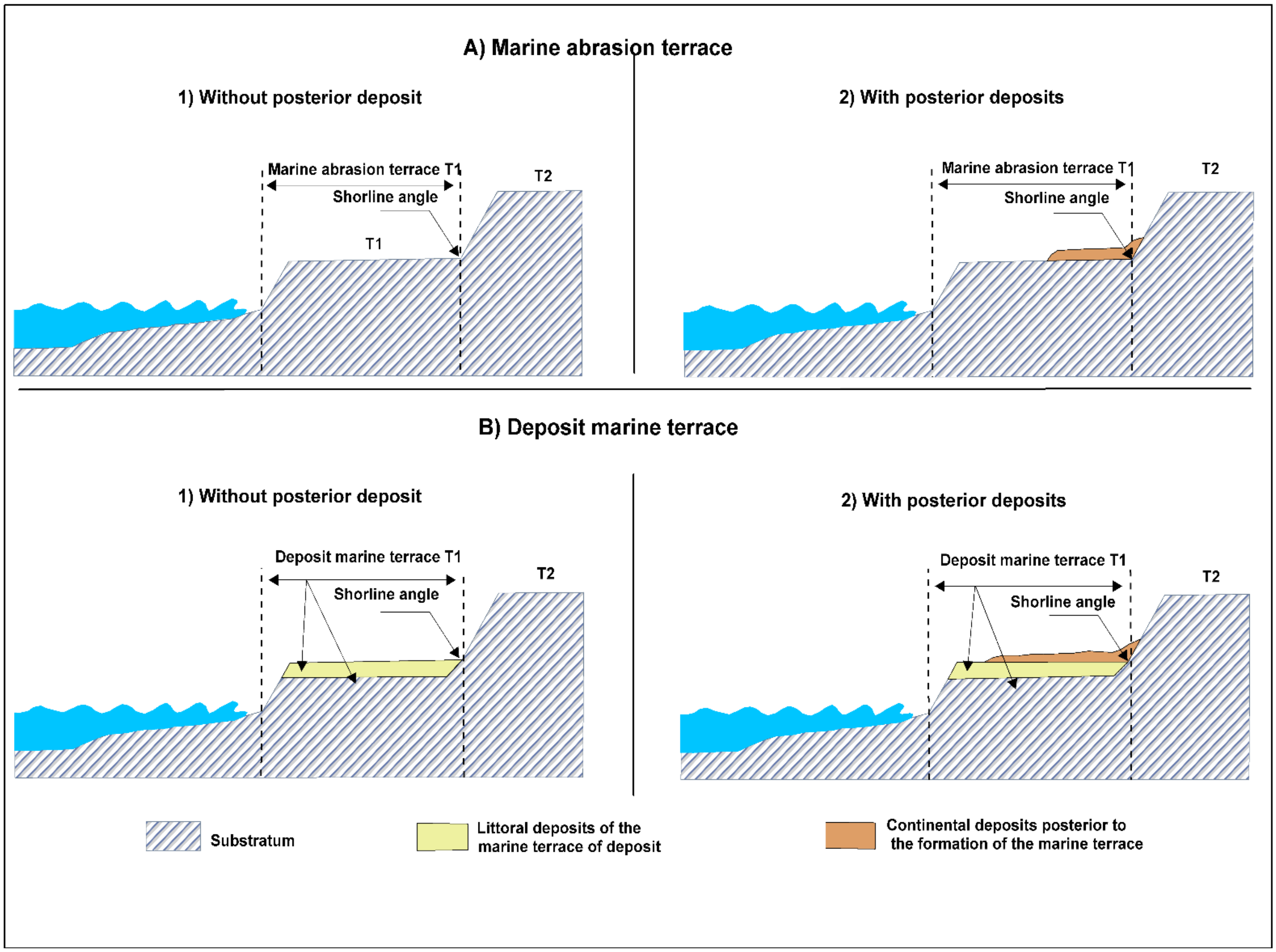


Figure. 45: The two types of morphology covered by the general term marine terrace in the case of a succession of two terraces T1 and T2, T2 being the older. (A) Marine abrasion terraces. (1) These correspond to marine abrasion surfaces that erode directly into the bedrock, without any sedimentary cover linked to the formation of the terrace, and (2) with some continental deposits subsequent to the formation and abandonment of the terrace by the sea. (B) Marine depositional terraces. (1) They are covered with sedimentary deposits contemporary with the formation of the terrace. These deposits are of variable thickness (centimetric to metric) and (2) these terraces can also preserve deposits subsequent to their formation and abandonment by the sea (see Figure. 46). The foot of the cliff of T1

corresponds to the angle between the escarpment of T2 and the flat surface of the T1 terrace and marks the marine paleo-level 0, responsible for the formation of the T1 terrace.

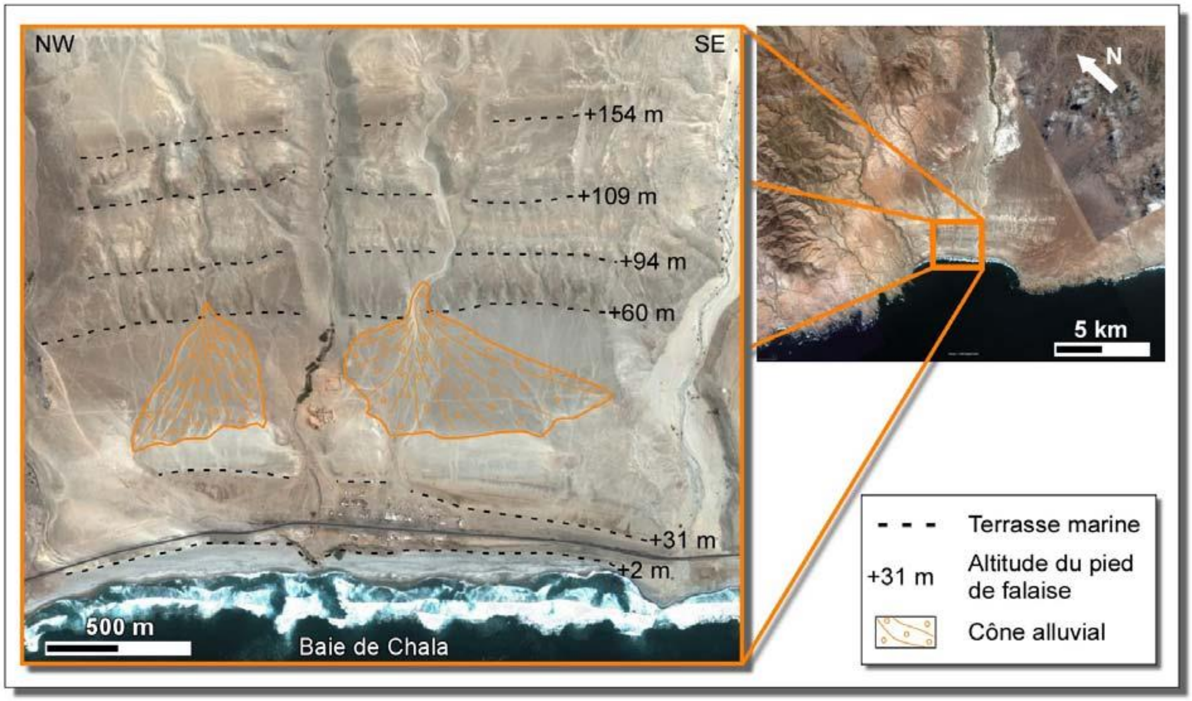


Figure. 46: Natural example of later deposits overlying a marine terrace level. Two alluvial fans rest on the surface of the marine terrace at +60 m. Chala Bay, southern Peru (15.8°S)

3. Marine terraces as spatiotemporal markers of margin deformation and quantification.

The study of marine terraces is a field that involves quantifying the coastal uplift over a million years. Since the geological processes that led to the formation of these features have been active for at least a million years (Rosenbloom and Anderson, 1994; Anderson. 1999).

One of the most important factors that can be considered when it comes to studying the dynamics of the marine environment is the morphology of marine terraces. This feature allows us to identify the position of the marine paleo-level that has been displaced by tectonics.

Understanding the position of the marine terrace can be performed by taking into account the age of the paleo-sea level and the amplitude and elevation of this feature. This can then be used to calculate the coastal uplift rate from the area. Furthermore, sequences of marine terraces can provide a comprehensive record of the tectonic history and eustatic variation of a region.

One of the most interesting features of studying marine terraces is their spatial and temporal resolution. This allows one to get a good idea of the variability and uplift of the marine environment. For instance, during an interglacial glacial cycle, the average duration of the cycle is around 100 ka. With that in mind, the temporal information that a marine terrace provides is roughly equivalent to around 100 ka. The various factors that can affect the development and maintenance of marine terraces during the interglacial period include the high sea level and the marine regression during the glacial period. In order to prevent the erosion of the terrace, the coastal uplift should be high enough to maintain its integrity. This will also help prevent the erosion of the terrace from happening during the eustatic cycle.

A marine terrace is a geomorphological object that can be used as a geochronological tool for the study of the dynamics of a coastal region over a million years. It can provide a fine temporal resolution of around 100 ka. Another interesting feature of our research is the way we use the spatial and temporal resolution of marine terraces. For instance, we have been able to study multiple sequences of marine terraces on the active margin of Zemmouri. In order to study the dynamics of the coastal environment over a million years, we are currently working on two studies: 1) a quantitative study of the continental plate's response to convergence processes and 2) a qualitative study of the historical evolutions of the region's coastal morphology. Through the use of a spatial-temporal approach, we can also highlight the various factors that contributed to the evolution of the coastal environment.

The marine terrace sequences in various coastal areas have been remarkably preserved due to the high degree of aridity and the low rate of erosion. These conditions allow researchers to study the dynamics of coastal areas during the last Ice Age (Alpers and Brimhall, 1988; Houston and Hartley, 2003; Riquelme, 2003; Riquelme et al, 2007; Riquelme. 2008; Hinojosa and Villagrán 1997; Hinojosa 2005; Dunai. 2005; Nishiizumi. 2005; Kober. 2007). In addition, these sequences have been preserved under a very low continental erosion rate, which is very important for the study of coastal dynamics.

4. Mechanisms of formation and preservation of marine terraces

The interface between the ocean and the continent is constituted by three parts: 1) the foreshore: the space between the high and low tides, 2) a part of the coastline, above the high tide, directly influenced by the action of marine waters and 3) a part always submerged and formed by the underwater action of the waves that break. Moreover, the coastline is not always fixed, it corresponds to a momentary position of the coastline according to the successive transgressions and regressions that may have left marks of an old position.

4.1 Agents of coastal erosion

4.1.1 Waves and swell

The waves that are pushed by the wind are referred to as forced waves. The waves that are created outside the area where they were initiated are called swell. The size and duration of these waves depend on the wind's strength and the size of the water body that they hit.

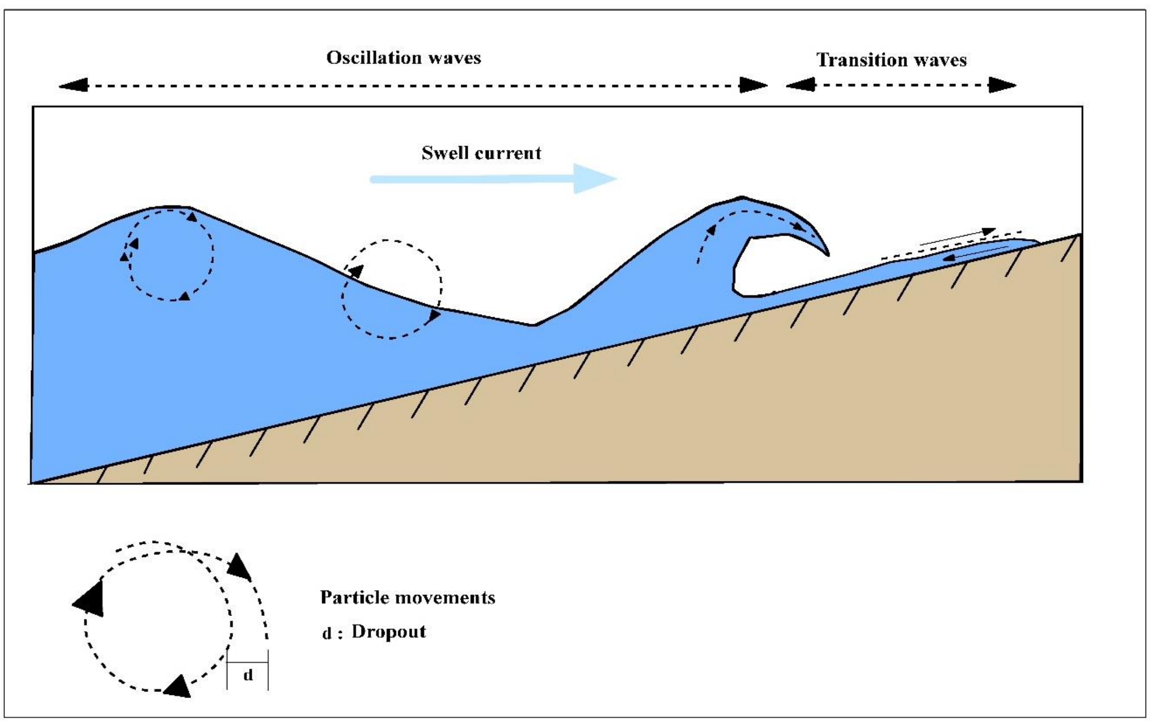


Figure. 47: Particle movements in waves, from Derruau, 1974.

The origin of waves can be explained by an undulatory motion, which occurs when the water molecules are animated by an orbital motion. This causes a weak current, which is referred to as the swell current. The particles in the direction of the movement of the swell are then displaced by the resulting waves (Figure. 47)

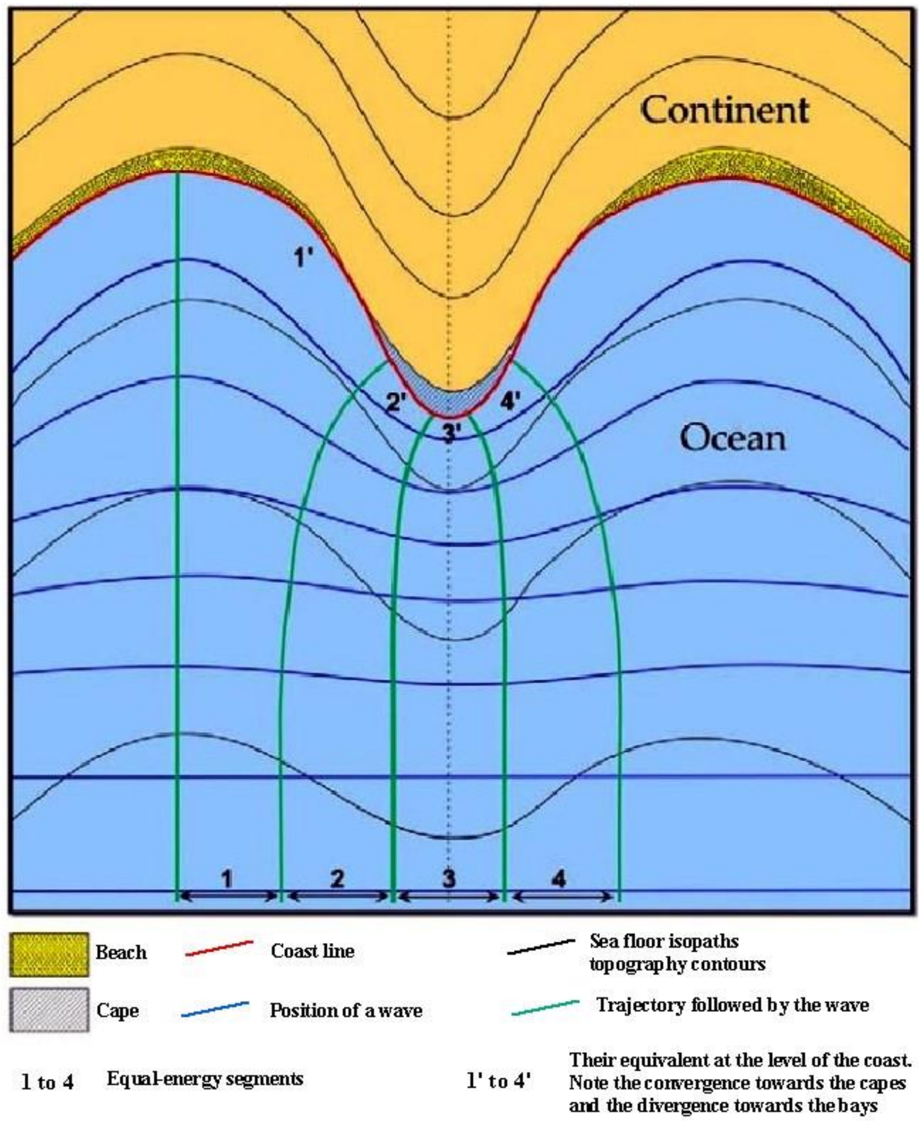


Figure. 48: Refraction of waves on an irregular seafloor (Bloom 1998) modified**,** this can affect the formation and distribution of sediments. The energy from waves is mainly concentrated on headlands, which can lead to erosion. On the other hand, the energy from waves in bays can disperse over a larger area, which tends to supports the accumulation of sediments.

The orbital motion of each particle is performed in a quasi-circular manner, with the diameter decreasing rapidly with depth. This is related to the wavelength of the wave (Figure. 50) (Bloom, 1998). As water depth decreases, the waves change their direction and velocity. When the depth is less than half of the distance between two waves, they interact with the bottom and become perpendicular to the isobaths. This phenomenon allows the waves to converge and form a parallel path to the coast. On the other hand, when the waves enter the bays, they are less vigorous brakers and diverge more frequently.

The energy that is concentrated at the capes is more than what is brought to the bays. This is because the bays are responsible for the deposition of sediments and the erosion of the capes. The rocky reefs found in the capes are the result of the waves' marine abrasion. On the other hand, in bays, the energy is lower, which favors the deposition of sediments. This natural process tends to regularize the coastline (Figure. 48; Figure. 49).

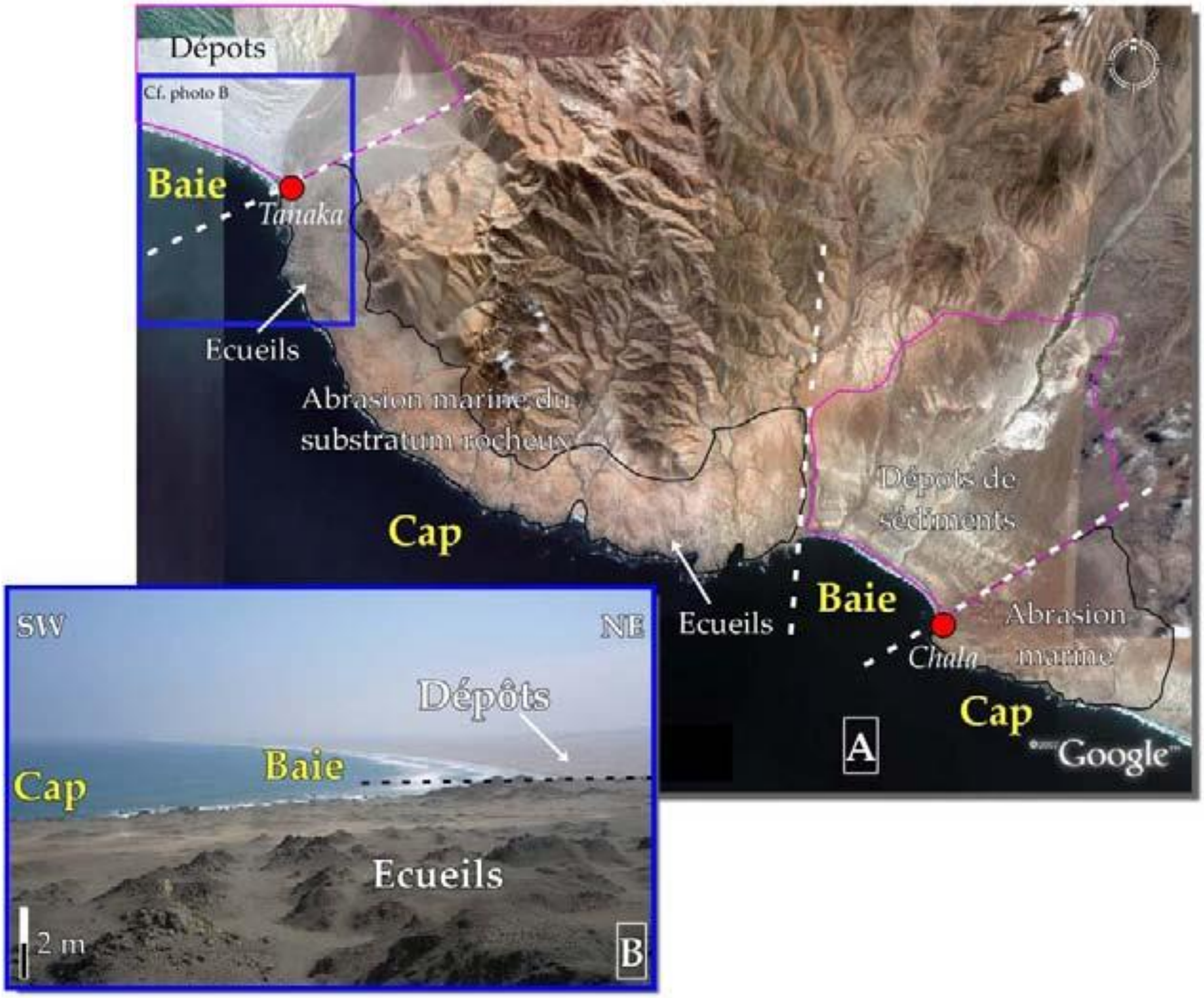


Figure. 749: Concrete example of the impact of wave energy, which arrives at the continent, on coastal morphology. (A) Satellite image extracted from Google Earth of the area between Tanaka and Chala, South Peru (15.72°S - 15.85°S). The dashed lines separate the areas of headlands and bays, i.e. those where there is abrasion from those where there is sedimentation. (B) Field photograph at Tanaka village level that illustrates the presence of reefs at the headlands and sedimentary deposits in the bays.

The shape of the waves changes as they go through this natural process. For instance, the base of the waves gets slower down as they approach a strong detachment from the swell circle (Figure. 50).

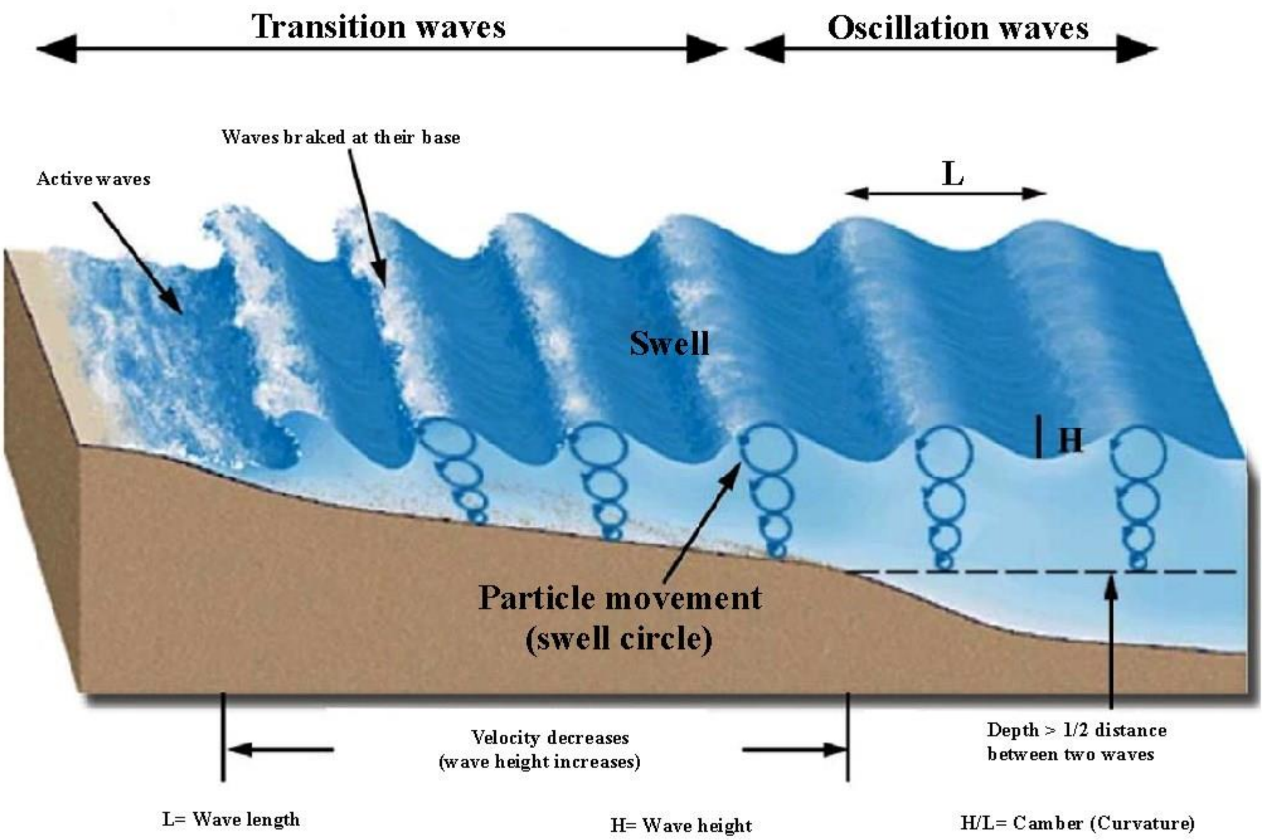


Figure. 50: The gradual transition between the constant wavelength (oscillation waves) and the breaking waves (transition waves). When the water level is less than half of the distance between the two waves, the waves' base and break are slowed down. The waves on the continent are erosive, and they form an abrasion surface on the marine terrace escarpment. By breaking, they contribute to the eroding coastal cliff and form the future marine terrace.

The waves breaking off the coastal cliff contribute to the collapse of the cliff in blocks. They also exert significant pressure on the shore and cause solid and water elements to sink. As these breaking waves withdraw, they cause suction and put additional pressure on the shore. From the oscillation waves, we can pass to transition waves (Figure. 50).

It is also not known how the waves on the bottom before the cliff break-up behave. Although it is assumed that they are below a depth equal to about 5 times the height of the waves, this does not exceed ten meters. When the bathymetry of the waves is less than the depth of the waves, the waves gradually erode the coastline until they form a platform or a pier at the foot of the cliffs.

The wave dynamic can be computed by analyzing two equations (Sunamura and Trehaile, 2000). The energy of a swell can be dissipated during its course in shallow water, while the remaining part can be used to hit the cliff. The role of these energies is important because they play a vital role in the mechanical erosion of coastal cliffs and platforms. They remove the debris from the substratum and transport blocks and particles along the platform. They also reduce the remaining debris to fine, dissolved materials, which are not able to break free from the waves and contribute to the plane's destruction.

4.1.2 Coastal currents

The tidal currents and the littoral drift are two types of currents that affect the coastal pattern. Although refraction can reduce the obliquity of the waves, they don't strike the shore perpendicularly, and instead generate a current known as littoral drift. As the waves recede, the particules are pushed by the waves, and this causes a transport parallel to the coast (Figure. 51). Since the waves don't move in the same direction at the same time, the longshore drift is usually oriented toward the largest ones (Derruau, 1974).

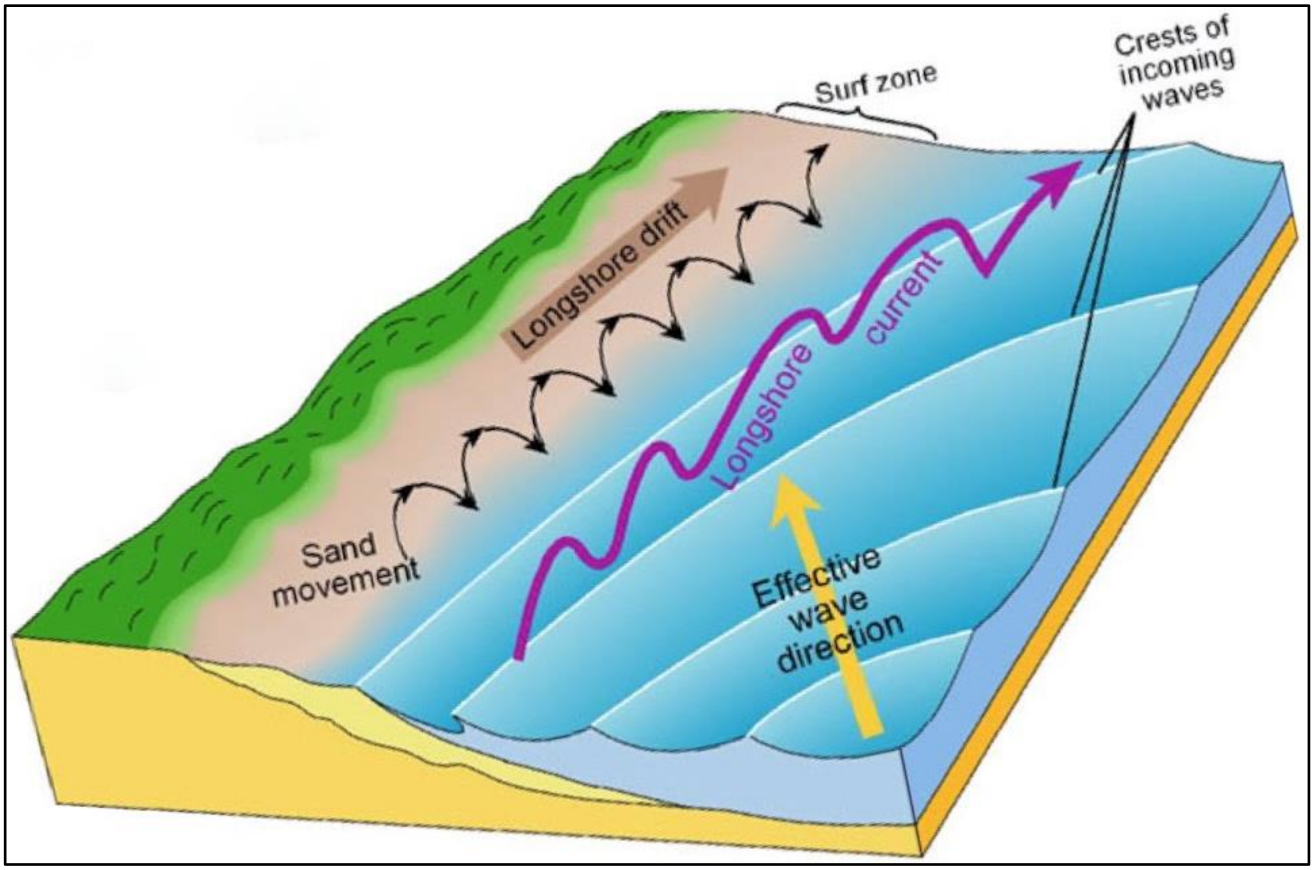


Figure. 51: Longshore drift. The debris's zigzag trajectory creates a lateral movement parallel to the coast. This is the result of the debris's movement.

The tide is a type of transition wave that has both an oscillating and a transition wave characteristic. The molecules that produced it orbit an elliptical long axis, and they show a variety of changes in their level and direction (Figure. 53). These changes are caused by the difference between the level of two points and by gravity (Derruau, 1974).

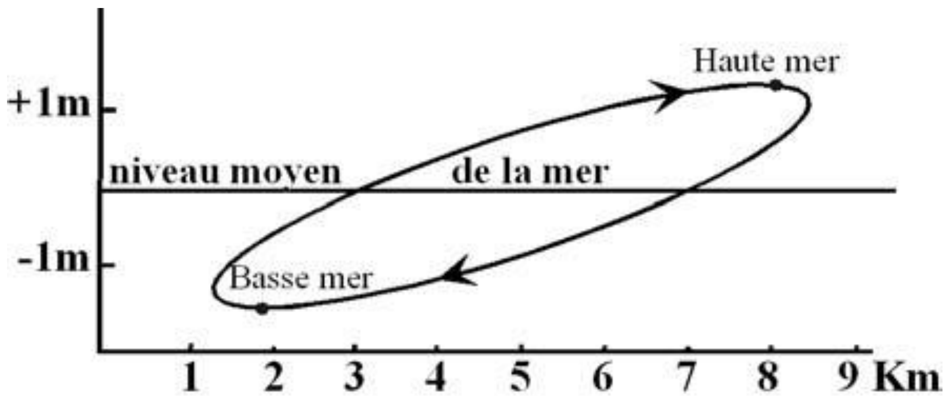


Figure. 52: Orbit of the particles in the tidal wave, (Derruau, 1974)

4.1.3 Wind, chemical alteration and biological activity

The wind can raise the sea level during storms and barometric depressions. It can also create waves by lifting the sand from the beaches, which can break the coastal cliff. It can additionally encourage the formation of spray, which can weaken the cliffs and cause them to move to the mainland (alteration of the rock by salt water).

In addition to the physical effects of the swell, it is also important to consider the biological activity and chemical alteration that can occur during the process of chemical weathering. In their article, (Kirk and Stephenson 2000) noted that the number of immersion and evaporation cycles in the tidal zone is a significant factor that contributes to the development of chemical weathering.

The spray above the sea level can also weaken the minerals in the cliffs, which then allows them to fall. This process can also encourage the formation of blocks, which can break the cliffs. Due to the salinity of the air, the cliffs are vulnerable to landslides and runoff. This suggests that undercutting isn't the only agent of cliff shaping.

Although it is difficult to determine the biological activity of the swell, most authors have attempted to estimate it. Living organisms mainly perform various actions, such as building reefs and damping waves. They also disjoining rocks by using diaclases. Encrusting algae are also known to be excellent markers of the vertical displacement of the coastline during seismic deformations (Ortlieb.

1996). When these organisms die, they turn white as they are raised above the surface zone, which highlights the vertical displacement that has occurred.

Photo. 2: The two forms of shoreline: the erosion zone, located at the cape and associated with a coastal cliff, and the accumulation zone, a zone protected from wave energy, located in bays, at the end of a river and associated with a beach, (Photograph at Collo, Skikda, 37°05'02.3"N 6°24'32.2"E).

Due to the effects of marine erosion, the coastline morphology in certain areas is usually composed of a cliff and a flat surface (platform) that has been eroded by waves. this platform can develop in two different directions: at the depth under the water level by wave action, or inland due to the erosion of the cliffs (Figure. 45).

Photo. 3: Natural examples of coastal cliffs and erosion platform in Delles, Boumerdes 36°54'24.0"N 3°55'22.1"E . The platier (erosion platform) is mainly eroded by wave action. It develops in two directions: inland by erosion of the cliffs and at depth, under the water level, by wave action. The coastal cliff in the photograph is ~10 m.

The accumulation of sediment forms mainly occurs in areas sheltered from wave energy. These are located in bays, at the mouth of the drainage system's drainage network. The sediments are mainly composed of marine fauna (lamellibranchs, gastropods etc.), also various other fine elements and boulders.

Although marine terraces can be preserved in these areas, they can be easily eroded in bays due to the presence of sediments. This is why we have chosen to refer to these as preserved marine terraces. These are two types of shoreline forms that are commonly found in areas with high energy zones. The first is marine abrasion terraces, which are not covered by sediments, while the second is marine depositional terraces, which are covered by sediments (Figure. 45. Photo. 2,3).

4.2 The formation of marine terraces

4.2.1 Eustatism and isotopic stages: the chronology of sea level variations in the Pleistocene.

The marine terraces are the marks of sea level variations that can be seen on a moving coast. The global sea level has varied during the last 12,000 years, and these are controlled by eustatic cycles (e.g. Chen. 1991; Lajoie. 1991; Gallup. 1994; Ludwig. 1996; Siddall. 2006; Fleming. 1998; Lambeck. 2002). These cycles are triggered by the sea level drop that occurred during the ice age and the rise that occurred during the interglacial. A complete eustatic cycle is observed during the late Pleistocene (Figure. 53)

The eustatic cycles follow a pattern alternating between interglacial and glacial periods. During an ice age, the lowest sea level is the minimum altitude that can be reached during the eustatic cycle.

During an interglacial period, the high sea level is the maximum altitude that can be reached during the eustatic cycle (Figure. 53). During an ice age, the glaciers and ice caps can store a huge amount of water, which lowers the sea level.

The water that is released from the ice caps during interglacial periods is stored in the oceans, which then rises. When two or more glacial and interglacial periods occur within a eustatic cycle, the resulting high and low sea levels are observed (Bradley and Griggs, 1976; Lajoie. 1991). These variations can be traced back to the changes in the oxygen isotopic composition of the deep ocean's subsurface (Figure. 53).

The current sea level scale is constantly being refined and improved by taking into account the data collected by coral or marine terraces. Some of the data used include those presented by (e.g. Cabioch and Ayliffe, 2001; Chappell, 1974; Chappell. 1996; Yokoyama. 2001a; Siddall. 2006) .

The isotopic variation in the oxygen levels in the ocean floor samples is studied by taking into account the amount of ^{18}O in the samples taken from benthic foraminifers or planktonic foraminiferas. The water's ^{18}O to ^{16}O ratio is influenced by the volume of ice, which is measured by the ice sheets. In

(1973, Opdyke and Shackleton) suggested that the ocean's ^{18}O to ^{16}O split is caused by the flow of meltwater from the continental glaciers.

The ice age is characterized by a higher amount of ^{18}O than the interglacial period. The isotopic substages (IS) are defined by the amount of ^{18}O in the samples taken. As the number of these stages increases, the order of these isotopic samples is also increasing. Also, the odd and even numbers of glacial and interglacial periods are used to differentiate these periods. The complexity of the ocean's eustatic cycle allows us to distinguish the various levels of marine oxygen from the low relative levels.

The interstades are distinguished using either the letters (a, b, c, d, e) or decimals (e.g. 5.1, 5.2, 5.3). to accurately identify the different levels of marine oxygen, we use the nomenclature a, c, e represents high relative marine levels and b, d to low relative marine levels (Figure. 53).

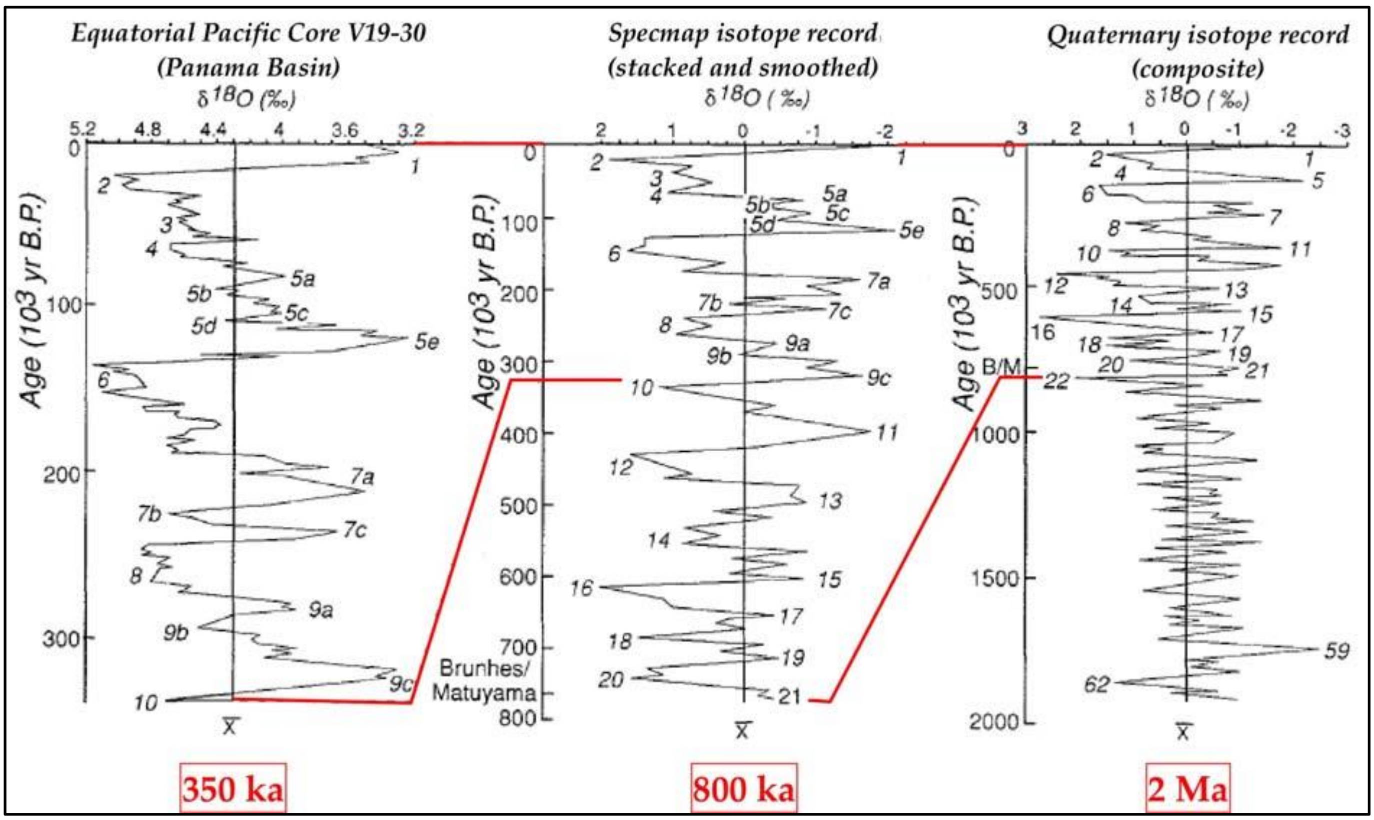


Figure. 53: Eustatic cycles and different isotopic stages over the last 2 Ma (after Burbank and Anderson, 2001, modified). Note the change in cyclicity at 800 ka. Beyond 800 ka, eustatic cycles are less well constrained. Odd numbers correspond to interglacial stages and even numbers to glacial stages. The letters a, c and e correspond to interglacial interstages and b, d, to glacial interstages.

4.2.2 The processes of formation of marine terraces

A marine terrace is formed due to the continuous erosion of the continent's coastal land. This process produces a coastal cliff and a flat surface (Figure. 54; Photo. 4; Figure 58).

The waves that break at high tide can weaken the coastal cliff's bottom. The spray can also contribute to the weakening of the cliff by causing it to sag. Due to the wave erosion, the substratum above the basal notch may collapse. This could maintain a vertical coastal cliff (Bradley and Griggs 1976).

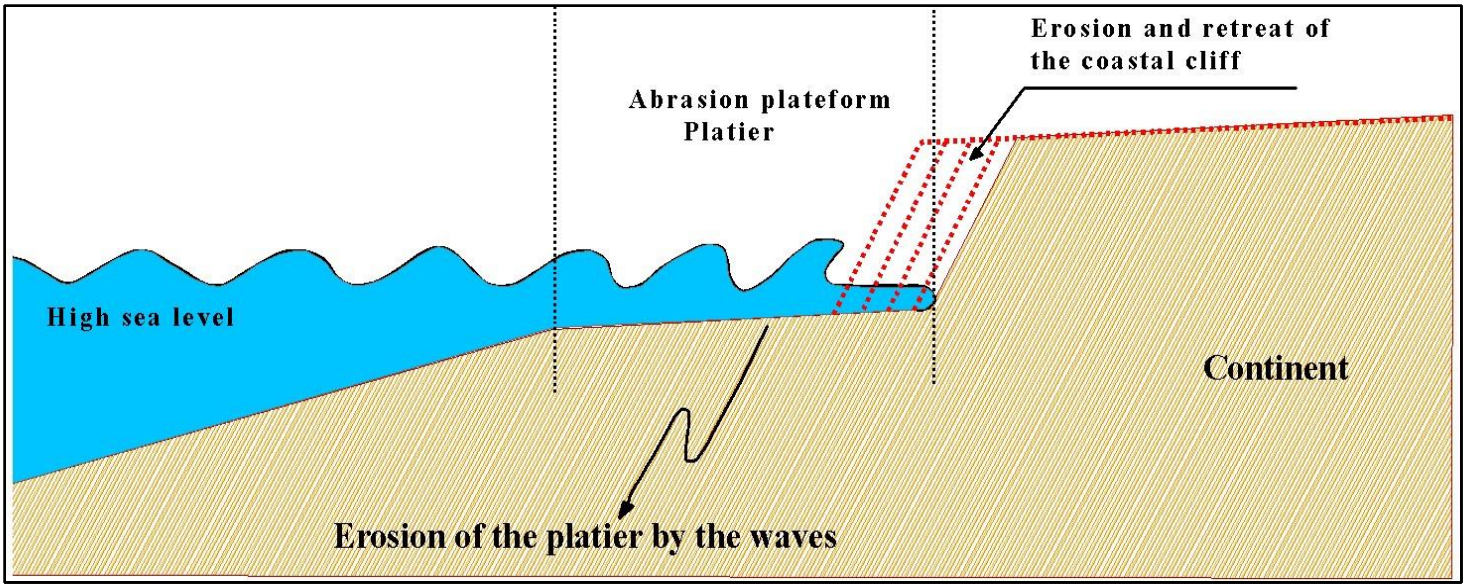


Figure. 54: The process of formation of a marine abrasion terrace during a high sea level. A terrace is formed with the retreat of the coastal cliff and the development of the flats. The arrows indicate the main eroding areas.

The retreat of the coastal cliff is only performed if the beach at the base has a rudimentary slope, which will encourage the waves to break. The submerged platform known as the Platier (erosion platform) is also formed as the coastal cliff retreats. As it widens, the area around it becomes more unstable.

The materials from the coastal cliff are dragged along the plane in order to create an abrasion platform (Figure. 57). This platform then extends out to sea until all of the debris has been reduced to fine sediment. During low tide, the platform gets subjected to subaerial alteration (Anderson. 1999).

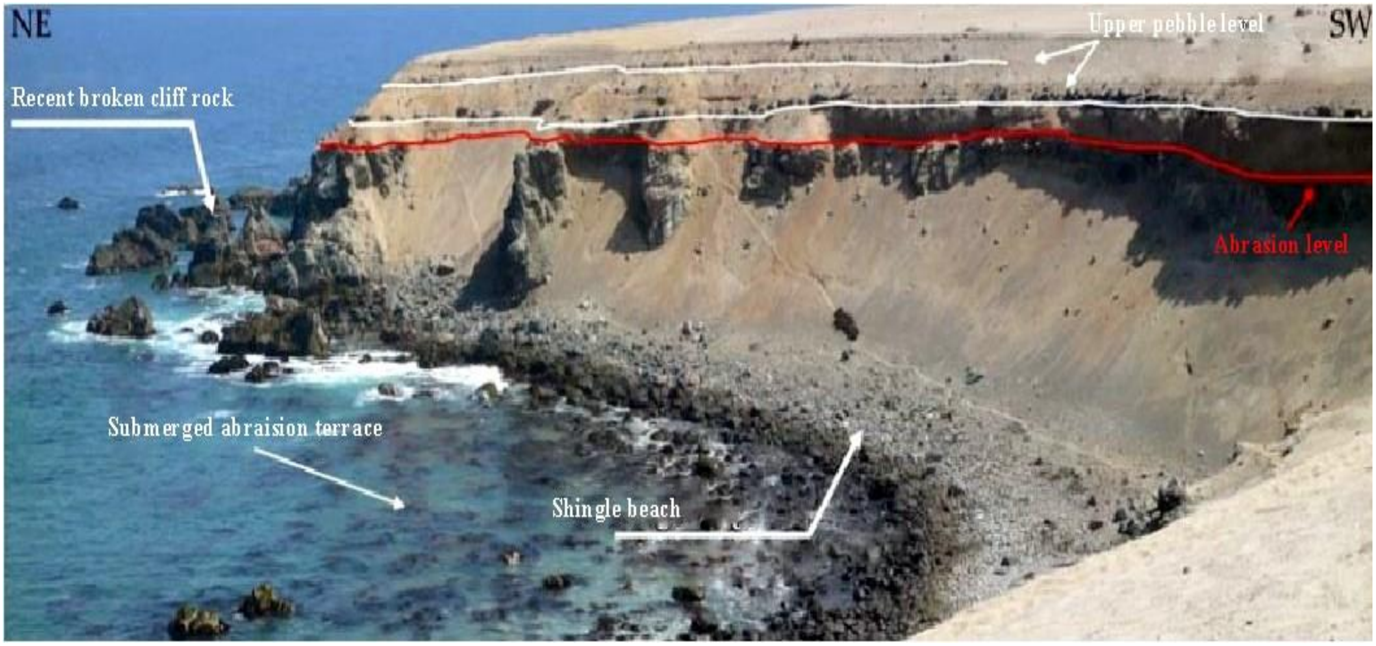


Photo. 4: Natural example of a coastal cliff subject to littoral erosion. the interface between the sea and the ocean is characterized by a shingle beach, which is still eroded and submerged due to the effects of erosion factors. Above a coastal cliff, there are marine terrace deposits. These deposits can be distinguished from the abrasion level, which is shown in red, and the sedimentary deposits, which are shown in white.

The dip and lithology of the cliffs outcropping by the layer have an influence on the development of the platform and its coastal cliffs. There are various factors that can affect the platform's overall structure, such as the rock strength, platform irregularity, and the persistence of cliff debris (Trenhaile, 2000).

The strength of the bedrock and the narrowness of the platform abrasion are some of the factors that can affect the development of the platform and its coastal cliffs. Depending on the direction of the dip of the layers, the coastal cliff's development and erosion will be different. A cliff with horizontal layers can be used as a staging area for the development of platforms. The vertical or sub-vertical drop of the bedrock can increase the irregularity of the bedrock, decreasing the erosive energy required to move the foot and produce narrower platforms. On the other hand, a seaward dip of bedrock can cause the cliff to slide and be unstable, while a dip of the same direction toward the continent can stabilize it and prevent it from developing. In addition to this, the superposition of impermeable layers can also affect the littoral cliff's stability (French, 1997; Pedoja, 2003; Figure 55).

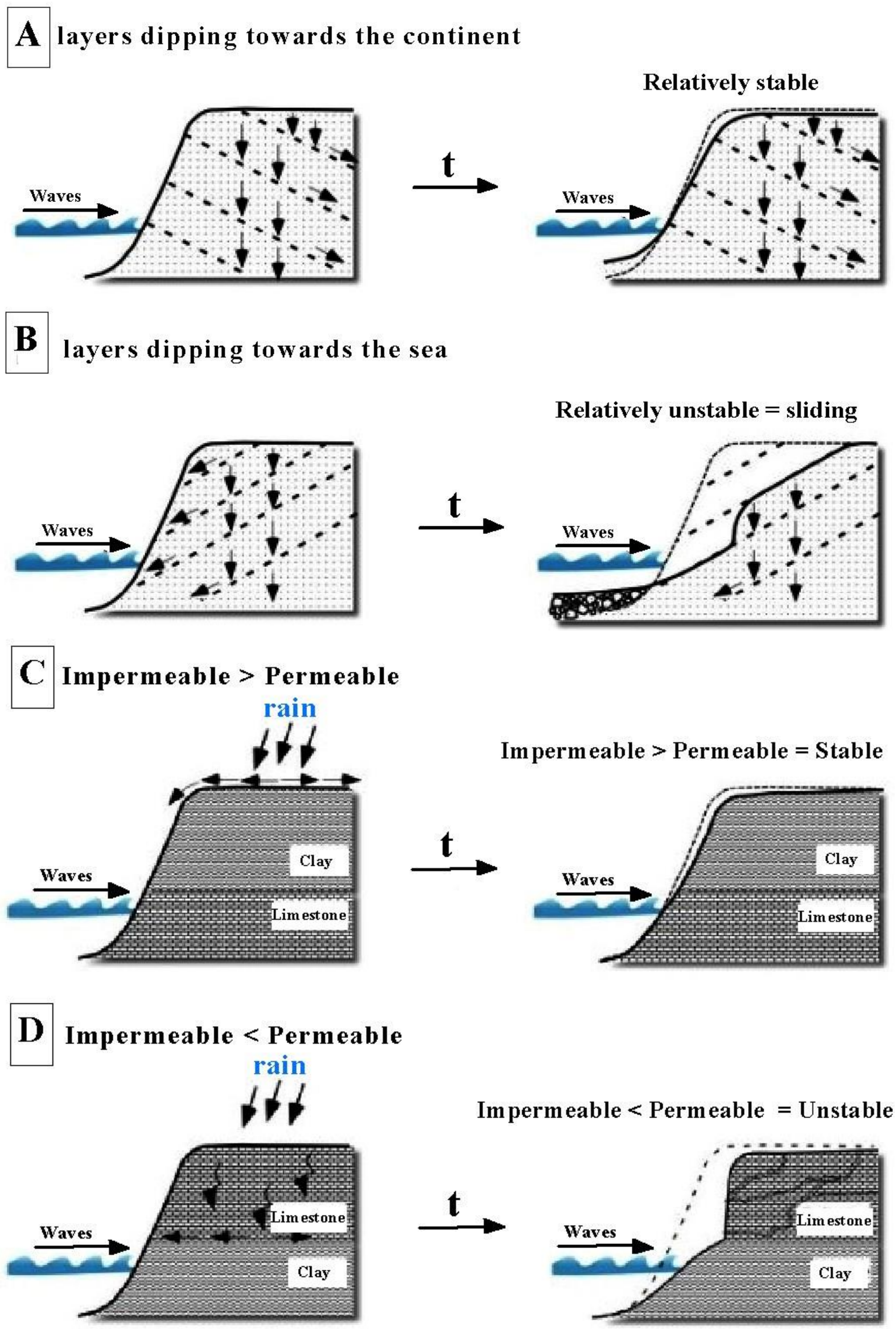


Figure. 55: Influence of dip layers (A - B) and lithology (C - D) on the development of coastal cliffs (French, 1997, modified). The arrow and the letter "t" indicate the evolution over time of the coastal cliff according to the different parameters.

The stability of the ground level at this intersection is very important in the development of marine terraces. If the sea level remains stable for a long time, the formation of the marine terrace will widen, and the coastal cliff will be removed (Cf. Rosenbloom and Anderson, 1994; Anderson. 1999; Trenhaile, 2000; de Lange and Moon, 2005). However, if the sea level changes rapidly, the removal of the coastal cliff will take much longer.

The longer the transgression, the more difficult it will be to remove the cliff. The elevation of the coastal cliff is influenced by various factors such as the velosity of the uplift of the area, the time it takes between the two interglacial periods, and the duration of marine erosion (Ortlieb 1987).

The major interglacial periods that occurred during the last few million years resulted in the formation of marine terraces with high escarpments (coastal cliff) and wide platier. These characteristics make it possible to identify these types of marine terraces with the isotopic stages of the Pleistocene, such as the 5th, 9c and 11.

Due to the deposition of suspended sediments and the continuous erosion of the coastal cliff, the platform will eventually reach a steady state and will be inclined toward the sea by around 24° (Bradley and Griggs 1976). This type of platform is generally flat, but it can also maintain topographical variations due to differential erosion or because the time required to remove it by abrasion has not been enough (e.g. rocks of varying size; Figure. 13; Photo 5).

The high level of sediment supply can cover the surface of the platform with a thick layer of sediment, which can be caused by the marine regression process (e.g. during marine regression; Bradley and Griggs, 1976; Lajoie. 1991). Nowadays, we are talking about the formation of marine terraces, which are composed of deposits that are either built by the waves or are located at the outlet of a river or inside a bay (Gilbert, 1890; Ortlieb, 1987). The various levels of these deposits are usually located at the sea or at an outlet of a river.

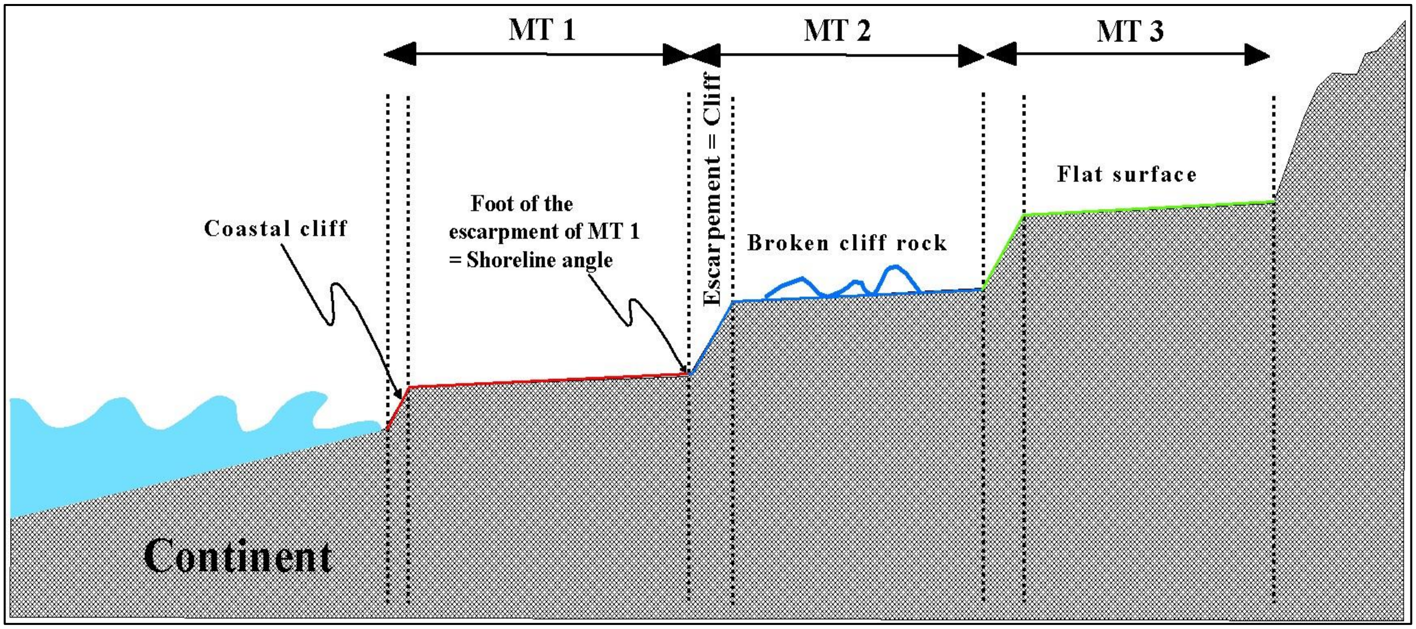


Figure. 56: Morphology of marine terraces. Succession of three marine terraces, from MT 3, the oldest, to MT 1, the youngest. MT 3 (in green) consists of a flat surface, that is to say a flattened plane during the formation of the terrace, and a escarpment. MT 2 (in blue) present broken cliff rock along the platier because the time required for complete abrasion and flattening was not sufficient when the terrace was formed (or the rocks were more resistant). MT 1 (in red) is composed of a flat surface and a escarpment which corresponds to the coastal cliff still active, that is to say which is subject to coastal erosion. The escarpment foot of MT 1 materializes the paleo marine level 0 responsible for its formation.

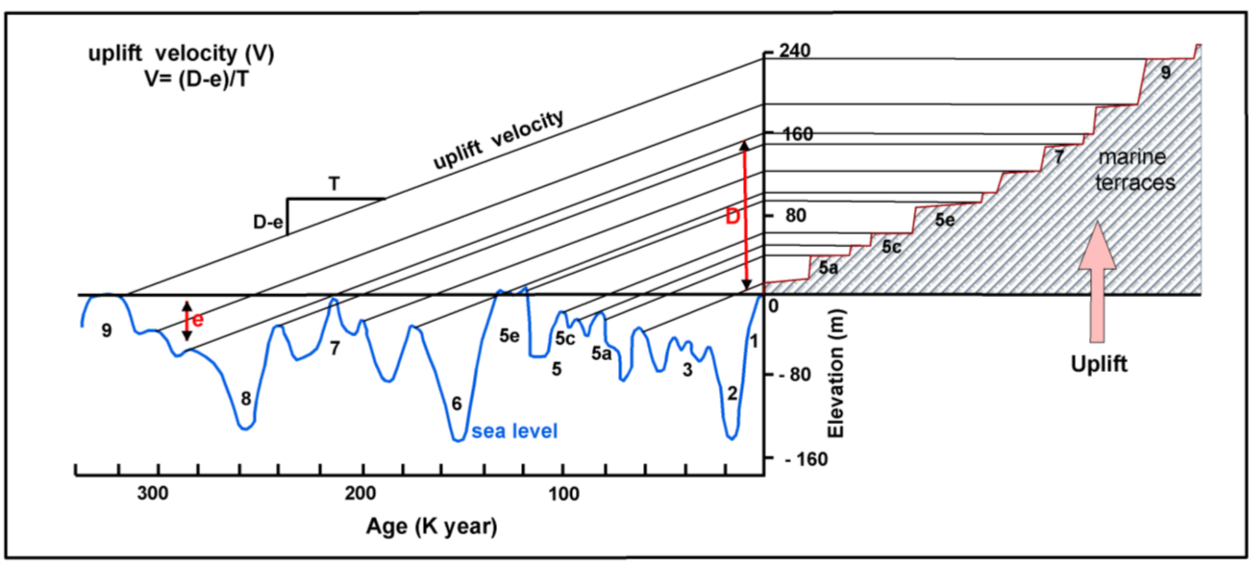


Figure. 57: Theoretical Correlation between marine terrace elevation and sea level curves

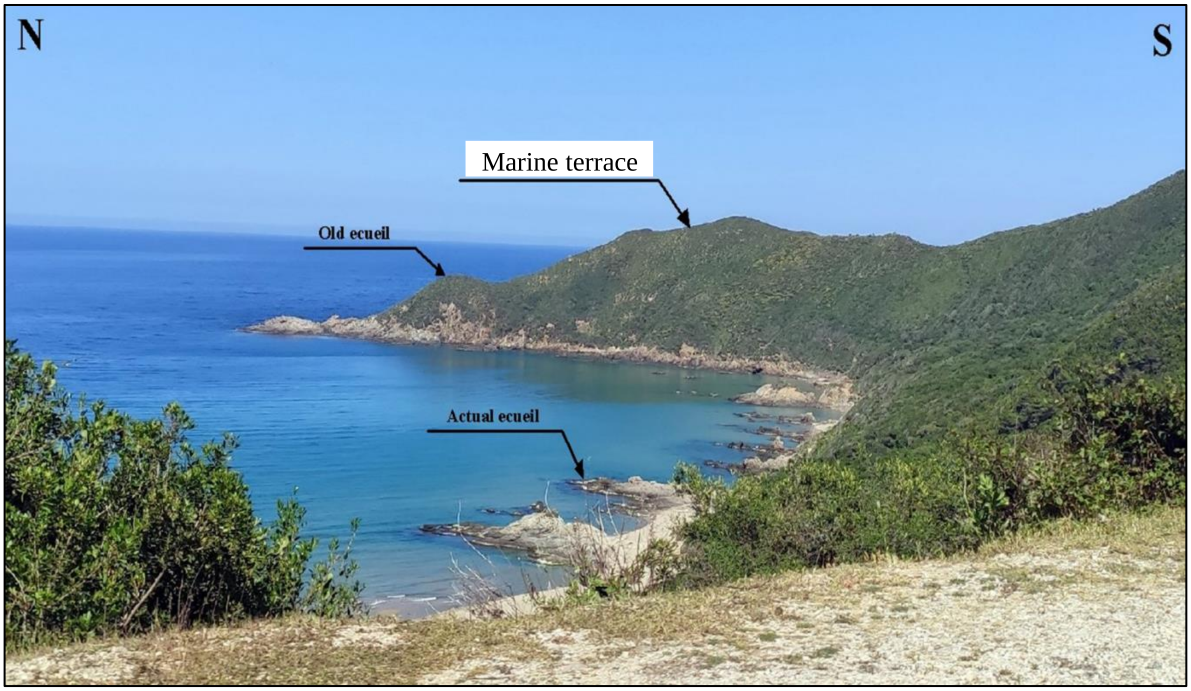


Photo. 5: Natural Photograph of ecueil in Collo, Skikda 37°09'18.9"N 6°24'42.4"E. The "ecueil" or broken rocky cliff is actual when its base is still submerged and subjected to marine erosion. The old ecueil was raised with the marine terrace that holds it and preserved.

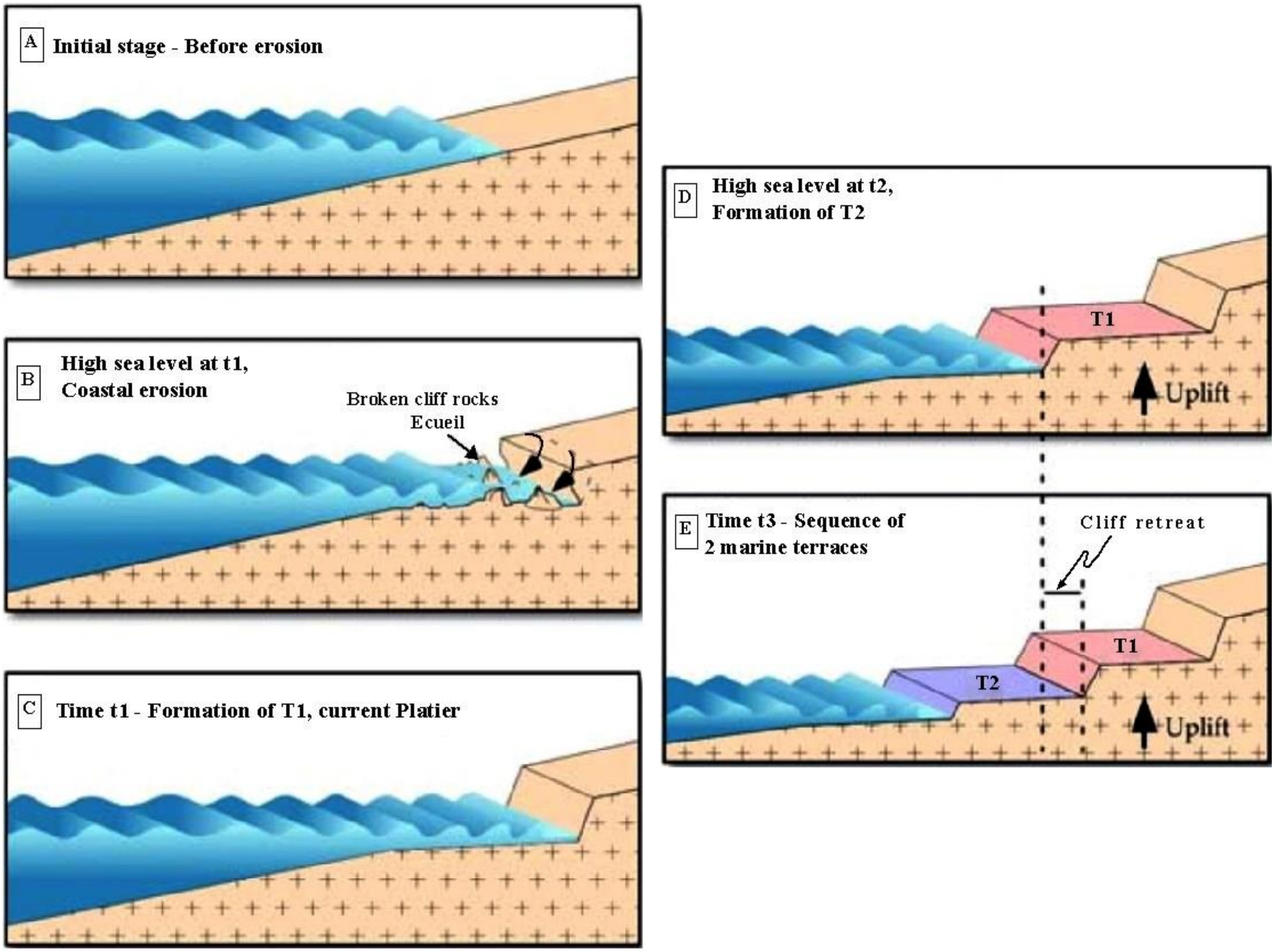


Figure 58: The different stages of formation of a sequence of marine terraces.

A: Initial stage - Coast before wave erosion.

B: Beginning of the formation of the marine terrace during a high sea level at (time t1): notching of the cliff. The presence of "ecueils" linked to more resistant rocks, less easily eroded. The time necessary for their total abrasion is not sufficient.

C: The T1 marine terrace is formed, the platier is completely flattened (time t1). The terrace has a slope of a few degrees towards the sea.

D: The marine terrace T1 was raised and preserved during the glacial stage (fall in sea level) and/or the rapid uplift of the continent - The marine terrace T2 is formed, according to the same pattern, during the interglacial stage (time t2).

E: The marine terrace T2 raised and preserved during the glacial stage (time t2) and the rapid uplift of the continent. During the formation of T2, the coastal cliff retreated and T1 was eroded, also the width of its surface decreased. Two marine terraces were formed at time t1 and t2.

4.3 Preservation of marine terraces

The coastal morphology of a region is preserved when the sea level decreases as a result of coastal uplift or regression. This happens when the marine erosion on the terrace is preserved. A new coastal cliff can then be created, limiting the terrace from bottom. During the high marine level of the isotopic stage or isotopic sub-stage, the new cliff can be eroded.

The various uplift and formation of marine terraces over time have formed a series or sequences (Figure. 15). However, when the sea level reaches a high enough, the coastal cliff can be removed, which can lead to the destruction of these marine terraces (Anderson. 1999; Saillard. accepted).

When the sea level exceeds a certain level, a marine terrace can be eroded. This can happen if the uplift was not enough to prevent the area from being eroded by coastal erosion agents. On the other hand, if the time between the high marine levels and the time between the uplift is short, then the terrace can be eroded (Ortlieb, 1987; Rosenbloom and Anderson, 1994).

A sequence of marine terraces cannot preserve the records of the various eustatic variations that occurred during the past few thousand years. However, it can provide a valuable insight into the geodynamic changes of the margin that occurred during the time.

A marine terrace's complete morphology includes an ancient coastal cliff (escarpment), a plane surface eroded by waves, and the angle between the escarpment and the plane surface above it (shoreline angle). This marks the former coastline's position when the sea level was high enough (Figure. 59).

The vertical displacement of a marine terrace can be calculated by taking into account the current elevation of the cliff foot (shoreline angle). This data can then be used to determine the lifting velocity and the vertical displacement of the area (Figure. 58).

The ocean's rate of coastal erosion is similar to that of an ancient marine level in a given region (Wallace 1990). This means that the current abrasion platform is similar to an ancient coastal cliff. As the sea level rises, each high level can create an abrasion platform and coastal cliff.

After the marine terrace has emerged and uplifted, it is subjected to the various environmental processes that affect the continent's topography. These include river erosion, wind and weather, and biological and environmental degradation (Figure. 50).

The coastal paleo-cliff's escarpment is subject to erosion. As the top portion of the escarpment is eroded, the resulting sediments cover the entire foot of the cliff. The other effects of this erosion include a decrease in the slope and a uniform profile. Depending on the diffusion constant in the area studied, the surface of the escarpment tends to become less steep (Figure. 56).

The rapid and steady erosion of the escarpment is accompanied by a decrease in its slope as the area's elevation changes (Bradley and Griggs, 1976; Wallace, 1990; Lajoie. 1991; Anderson. 1999). This phenomenon can be quantified and modeled using diffusion parameters. For instance, by incising and dissecting the escarpment, it can be dissected and reconstructed to form a discontinuity along the marine terrace.

As the base level of the escarpment decreases, the scarp will become deeper and older, and the older the terraces become, the more deposits they produce (Anderson. 1999). This evolution is linked to the continental erosion and the deposits it produces. This is why it is important to consider the various aspects of the design of the marine terrace cliff when it comes to estimating its elevation (Figure. 59).

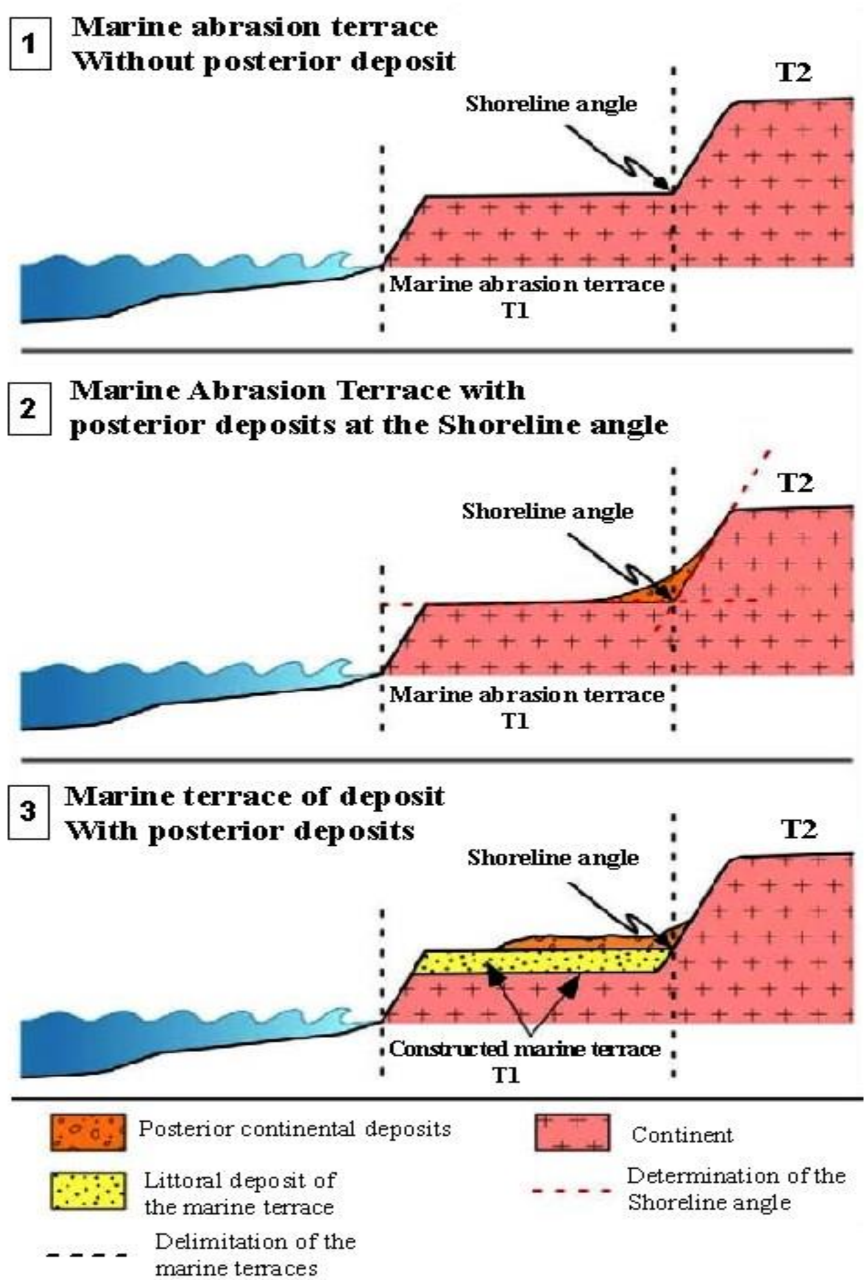


Figure. 59: The elevation of the shoreline angle of a marine terrace is determined by the morphology of its various components. This is a vital criterion that can be used to recognize the marine terrace as it materialized at the paleo marine level 0, which is the level at which the sea level was created. Measuring the vertical displacement of the terrace is also used to estimate the uplift that it suffered due to its formation.

(1) The elevation of a marine abrasion terrace's shoreline angle is determined by the angle between its flat surface and the cliff.

(2) When a marine abrasion terrace has posterior deposits on its base, these deposits hide the cliff's base. The elevation of this type of terrace is difficult to determine due to its geometric profile. The elevation of the shoreline angle, measured by the intersection between the average slope of the escarpment and the flat surface of the terrace.

(3) The elevation of the shoreline angle of a marine terrace of deposits, which is composed of posterior deposits, is related to the angle between the cliffs and the summit of the deposits. It is important to know the thickness of these deposits in order to perform a precise stratigraphic analysis.

5. Chapter Summary

This chapter explores the various factors that affect the preservation of marine terraces. As geomorphic markers, these features can provide researchers with valuable information on coastal uplift dynamics and the evolution of the environment. This chapter's introduction talks about the importance of studying the various aspects of marine terraces. It also highlights their significance in coastal management, paleoenvironmental restoration, and hazard assessment. It emphasizes the link between geomorphic, climatic, and tectonic processes.

The first part of this chapter focuses on the various aspects of marine terraces that are influenced by tectonic processes. It explores how these movements, which include subsidence or uplift, contribute to the distribution and elevation of these features along the coastlines. It also covers the various factors that can affect the creation of these features. Well, the second part of this chapter explores the various factors that influence the creation of marine terraces. This section shows how changes in the sea level caused by climate variations and global factors can lead to the submergence or exposure of coastal areas. The magnitude and timing of past sea-level movements are crucial in understanding the stratigraphy and age of marine terraces.

The role of coastal and wave processes in the formation of marine terraces is explored in this section. It shows how different factors such as coastal morphology, erosion, and sediment transport influence the surface and slope characteristics of these features. Besides these, the chapter also explores how various other factors such as wind, biological activity, and ocean currents can affect the development of these features. The importance of dissecting marine features is further explored in this section, which looks into how various processes, such as coastal uplift, erosion, and tectonic activity, can affect their long-term survival or destruction. It emphasizes the value of this skill in piecing together the landscape's past changes and determining how these mechanisms worked.

The research covered in this chapter contributes to our knowledge of coastal dynamics and sea-level changes. The study also serves as a valuable tool in coastal landscape evolution.

This chapter's research combines geochronological, geomorphological, and field observations techniques to gain a deeper understanding of the formation and preservation of marine terraces. It also provides valuable insight into coastal hazard assessment, coastal management, and paleoenvironmental records.

CHAPITER. V

INVESTIGATING TOPOGRAPHIC PARAMETERS FOR ASSESSING SEISMIC HAZARD POTENTIAL IN NORTHEAST ALGERIA

1. Introduction

Although Algeria and its neighbors are located within the tectonic plates' boundaries, seismic activity has been observed in recent years. One of the most notable earthquakes in the country was the magnitude 7.1 El Asnam earthquake that occurred in 1980. This occurred near the town of Chlef in the Northern part of the country. Even though destructive earthquakes are rare, they can still occur. The strongest recorded earthquake in the last century was the magnitude 6.0 earthquake that occurred in 1985 in Constantine. The historical archives also show that destructive earthquakes have been occurring in the country during the last two centuries.

The ground motion analysis is performed to determine the seismic hazard at a site. This step is the first step in the process of estimating the seismic risk. It also integrates the building's vulnerability. During the 60s, a probabilistic method was developed in the US. In 1968, a study conducted by Cornell suggested that annual ground motion exceedances should be calculated and introduced into a temporal process known as Poisson occurrence. Through probabilistic seismic hazard studies, ground motion can be predicted to exceed certain levels at a given site. The method for calculating the seismic hazard involves identifying the source zones, an attenuation ground motions model, and a description of the seismicity of the region. In 1976, the USGS released the first comprehensive map of the US that included seismic hazard information. Two years later, McGuire introduced the concept of dispersing seismic motion. After the USGS released the seismic hazard information, the agency shifted to a probabilistic method for calculating the nuclear facility's seismic risk (Bernreuter. 1989). The new method was mainly concerned with analyzing the source zones and the recurring earthquakes (Frankel 1995). Although the main component of the method remained the same, the advances in this area were mainly due to uncertainties.

The oldest known map of the seismic hazard in Algeria is the Macrosistic Intensity Map created by Perrey in 1848. In 1973, Roussel proposed a map that included five intensity zones. As part of the country's first seismic hazard study, which was conducted in 1978 by Mortgat and Shah 1978, a study was conducted using an earthquake catalog from 1790 to 1975.

In 1996, Bezzeghoud and colleagues updated the maps of the seismic hazard in Algeria by adding seven intensity zones to the previous ones. These intensity maps were created based on the data collected from a catalog of the country's seismicity from 1365 to 1992. Several studies have been conducted on the country's seismic hazard using different probabilistic and deterministic methods (Hamidatou and Sbartai 2016, 2017).

The results of the study revealed that the probabilistic method used for estimating surface ground motion included various uncertainties. On the other hand, the deterministic method generated a specific ground motion parameter for each scenario (Sitharam. 2015). This study serves as a basis for assessing the site's surface ground motion condition.

The study also revealed that previous studies underestimated the surface ground motion condition in the Northeast of Algeria. To improve the accuracy of the ground motion assessment, a topographic slope map was created using data collected from the DEM (Figure. 65).

In the past, various studies have been carried out on the ground motion parameter in Algeria using different deterministic and probabilistic methods. According to (Cornell et al, 1968), the use of probabilistic methods indicates that significant ground movement is expected due to the seismic hazards. In (1978, McGuire) presented five steps in the hazard analysis process. These include identifying the potential earthquake sources, characterizing the geophysical, geometric, geological, and seismic source parameters, developing site-specific hazard maps, and identifying the attenuation patterns of seismic waves.

The authors of this study used the evaluation of the earthquake hazard by Kloko and Sellevoll in 1992 to estimate the seismic hazard parameters in Algeria.

2. The tectonic and geological context and the destructive effects of Earthquake

The tectonic regime in this region of the Alpine chain is mainly compressional since the start of the Cenozoic. The late Quaternary N-S to NW-SE main direction has resulted in a shift in the direction of the strike (Meghraoui 1988). The Neogene and Quaternary post-nappes basins exhibit striking folds and other reverse faults. According to (DeMets. 1990), the rate of movement is around 4 to 6 millimeters per year.

The structural domain of this region has been under a compression regime since the start of the Cenozoic (Figure. 1). The main thrust faults in this region are located in the NE-SW strike direction. These are often formed in echelon systems, such as the Tipaza and El Asnam faults (Aoudia. 2000).

The northern part of Algeria is located on the Mediterranean Sea's Southern side. It is regarded as the most active seismogenic zone in the region (Figure. 61). This activity is caused by the collision between the Eurasian and African continental plates. As expected, the seismicity is distributed across a wide deformation area.

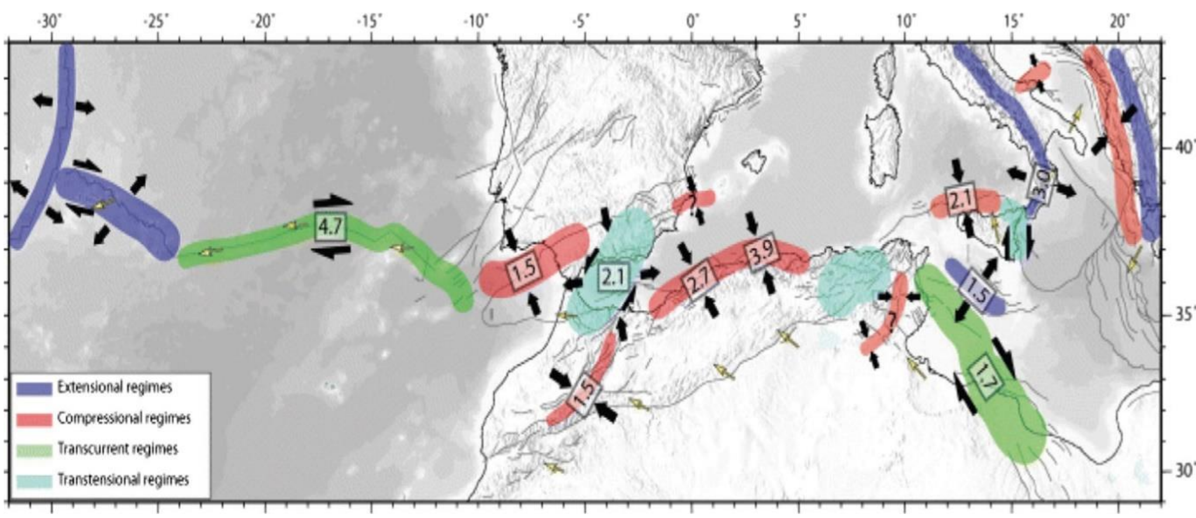


Figure. 60: The major kinematics and tectonics features of the Nubia-Eurasia plate boundary. Deformation rates are in mm/year (Serpelloni. 2007)

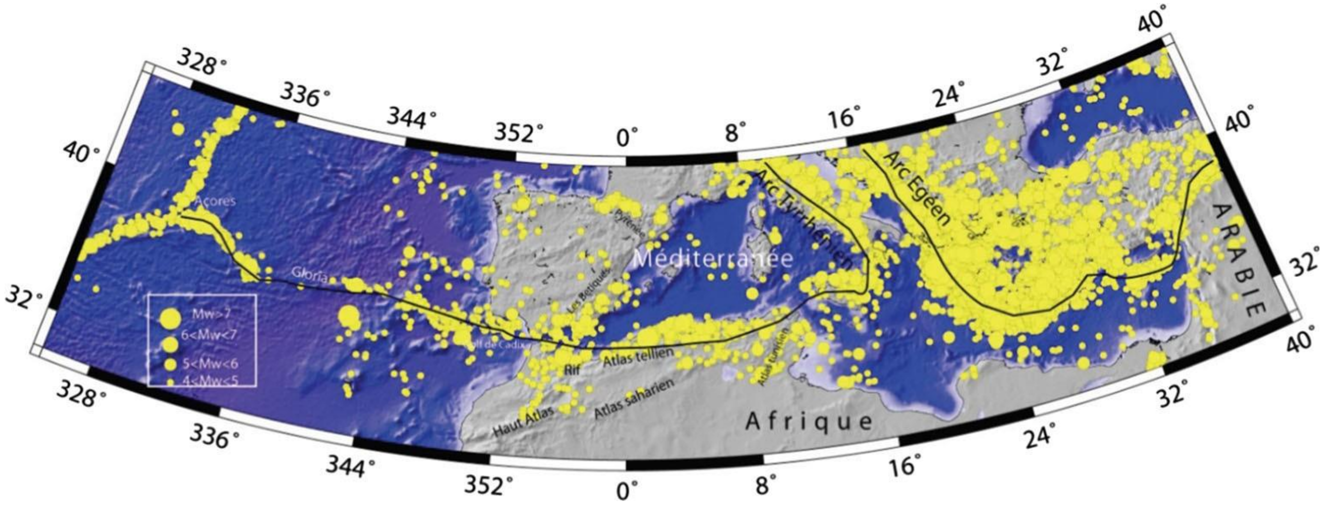


Figure. 61: Superficial and medium seismicity (h \ 150 km, M (4; source NEIC) from Central Atlantic to eastern Mediterranean 1973–2008 (Belabbes, 2008)

The northern part of Algeria is divided into four structural domains related to the multiple closing and openings of the Mediterranean Sea during the Mesozoic and Cenozoic periods. Some of these include the Tell Atlas, the High Plateaus, the Saharian Atlas, and the Sahara Platform (Figure. 61).

The Tell is located in the eastern portion of the Rif-tell system, which is an active collision area between Africa and Eurasia. It is also the continuation of the Tellian Chain. This region has been characterized by the multiple deformations and structural features that have been observed in the area (Meghraoui 1988; Boudiaf 1996; Yelles-Chaouche. 2006).

In its history, the northern part of Algeria has experienced numerous destructive earthquakes. The most significant earthquake that occurred in this region was the magnitude 7.1 earthquake that occurred on October 10, 1980, which was felt in various areas. Other powerful earthquakes that have been observed in this region include the magnitude 5.9 earthquake that occurred on October 29, 1989, and the 6.8 earthquakes that occurred on May 21, 2003 (Figure. 62).

3. Earthquake Catalog

Sbartai and Hamidatou (2017) prepared an earthquake catalog for the northeast region of Algeria, which included data from various international and national agencies. They then developed correlations between different magnitude scales and produced a unified surface magnitude scale.

The goal of this study was to characterize the seismic sources in the region through the earthquake catalog. The map shows the distribution of seismic events in Eastern Algeria from 1365 to 2018 (Figure. 62)

4. Linear Sources

The structural map of the Alpine chain (Vila 1977), which includes the Algerian-Tunisian borders and Eastern Algeria, was created by the CRAAG. Detailed information about the geological features and fault lines in the region was presented by Meghraoui (1988).

All of the sheets of Coiffait (1992) and Vila (1980) were georeferenced and then merged to form a complete study area. The data collected during this process were then used to create a fault map and to identify the maximum reported magnitudes along the various sources. The digitization and georeferencing of seismotectonic maps were carried out using ArcGIS 10.8

5. Areal Sources

The source areas of the seismic waves were identified based on the studies carried out in the past few decades. These studies were conducted in Northern Algeria (Hamdache. 1998; Harbi. 1999; Aoudia. 2000; Yelles-Chaouche. 2006; Hamidatou and Sbartai 2017). Hamdache was defined as four source zones in the region.

Harbi analyzed the data collected by the seismic sensors in the Eastern Tellian Atlas. She found that the data were correlated with the neotectonic faults located in the region which was founded on geological and geophysical data. These studies were carried out by different researchers (Hatzfeld 1978, Vila 1980; Meghraoui 1988, Harbi 1996, Bezzeghoud. 1996)(Figure. 63).

Different data files were also analyzed during the study, such as those from the CRAAG, IGN, and USGS. These data sources were used to analyze the data. (Aoudia. 2000) then defined twelve source zones within the Tell Atlas using the data collected during the study (Figure. 64). These zones were categorized based on their characteristics and the distribution of active and well-defined Neogene and Quaternary faults. They also looked into the relationship between earthquakes and geological structures, as well as the clustering patterns of earthquake epicenters.

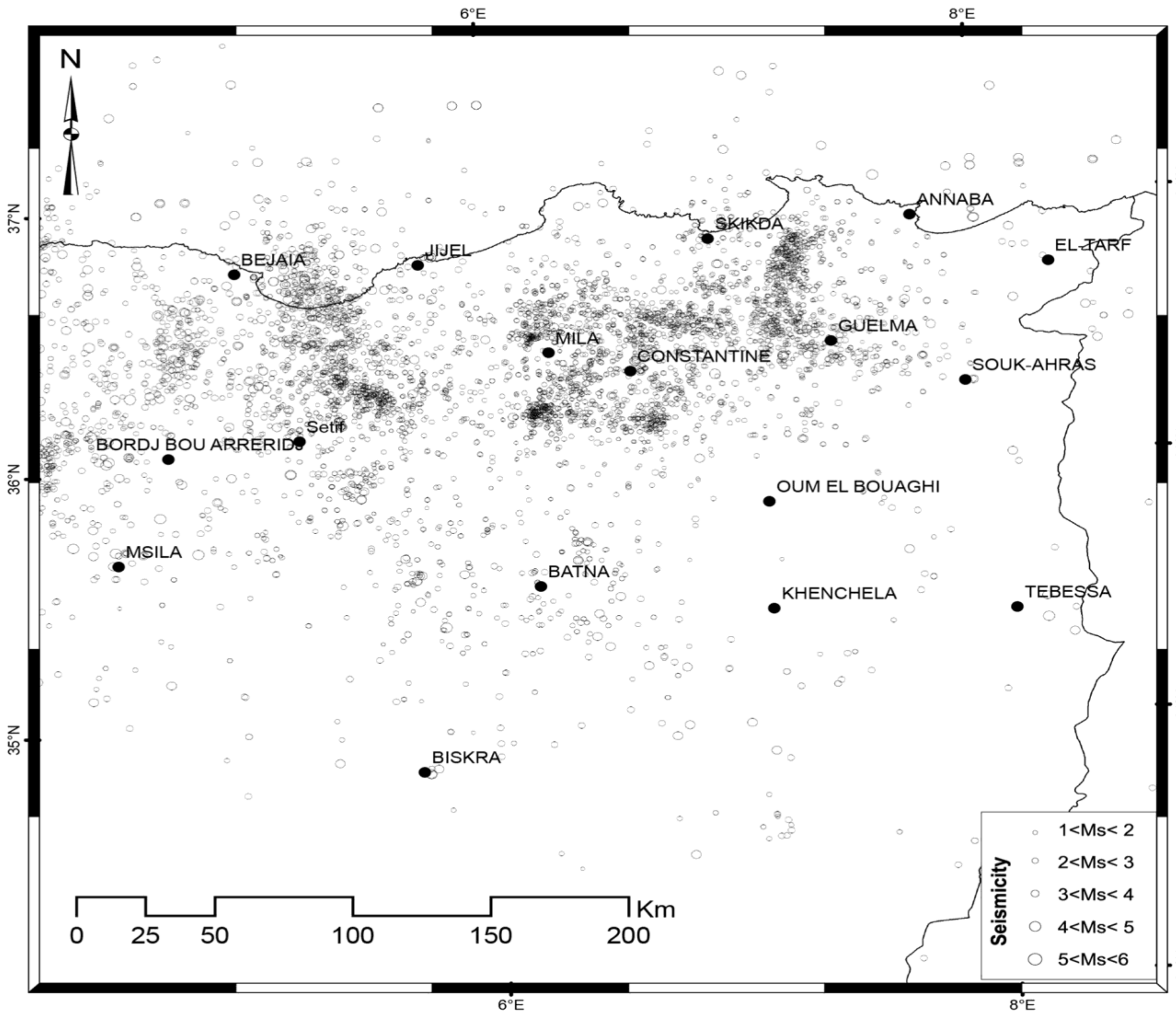


Figure. 62: Map represent the Distribution of seismic events in the Northeast of Algeria (Hamidatou, 2017)

In the study conducted by Chaouche. (2006), the researchers used the data collected by the Algerian monitoring network. They also analyzed the data from the field studies carried out after the devastating earthquakes that hit the country. This type of seismicity can be observed in different areas with different seismic activities and characteristics. The study, conducted by Hamidatou and Sbartai in 2017, focused on the Constantine region. It identified five source zones that were characterized by their seismicity, geology, and tectonic characteristics. (Figure. 62) shows the various seismic sources in and around Northeast Algeria. All of these are treated to be as area sources.

5.1. The Offshore of Annaba-Skikda-El Taref Zone

The offshore seismic zone of Northern Algeria, which includes the areas of Annaba, Skikda, and El-Taref, seems to be relatively calm at present. However, since the seismic activity in the western part of the zone has been recorded, it can only be stated that the intensity VI earthquake that occurred on December 2, 1961, happened in the Gulf of Annaba.

The seismic activity in the zone could reach a maximum intensity of 5.5. The data collected from the Annaba offshore fault system revealed that the region has been experiencing a compressive activation. The presence of active structures has also been contributing to the activation of the margin foot (Yelles-Chaouche. 2006).

There have been no seismic activities in the area linked to the various activities in the seismic zone. This could be because the region has not had a seismological station for a long time.

5.2. The Offshore Jijel-Bejaia-Tizi Ouzou Zone

The seismic activity in the offshore JBT Zone, which includes the cities of Jijel, Tizi Ouzou, and Bejaia, has been considered to be the most significant historical event in the region. On August 22, 1856, an earthquake with a magnitude of 9 happened off the coast of Jijel. It is regarded as the strongest earthquake to hit the coastal zone of this region during the pre-1900 period.

5.3. The Guelma Zone

The Guelma Neogene basin is characterized by a different structure. It is located between the E-W dextral strike-slip faults and the N-S to NNE-SSW bound normal fault systems (Meghraoui 1988). According to a study conducted by Aoudia. 2000, the various fault systems in this area intersect the sub-parallel shear zones.

The (Figure. 62) shows the various clusters of earthquakes that have been detected in the region. The strongest earthquake that the region experienced was on February 10, 1937, which had a magnitude of 5.2 with intensity VIII and was centered near the region (Harbi 2001). In 1908 and 1928, two powerful earthquakes with intensity VIII were also felt in the area (Aoudia. 2000). On September 20, 2003, the last significant earthquake that had been recorded in the region was a magnitude 4.8 (Yelles-Chaouche. 2006).

Although the seismic activity in the basin is similar to the main incident, it is located at the fault levels of the basin. The Hamam Nbailis and Bouchegouf fault systems are situated in the region and are connected to the hydrothermal vents that were previously active (Vila 1980; Harbi. 1999).

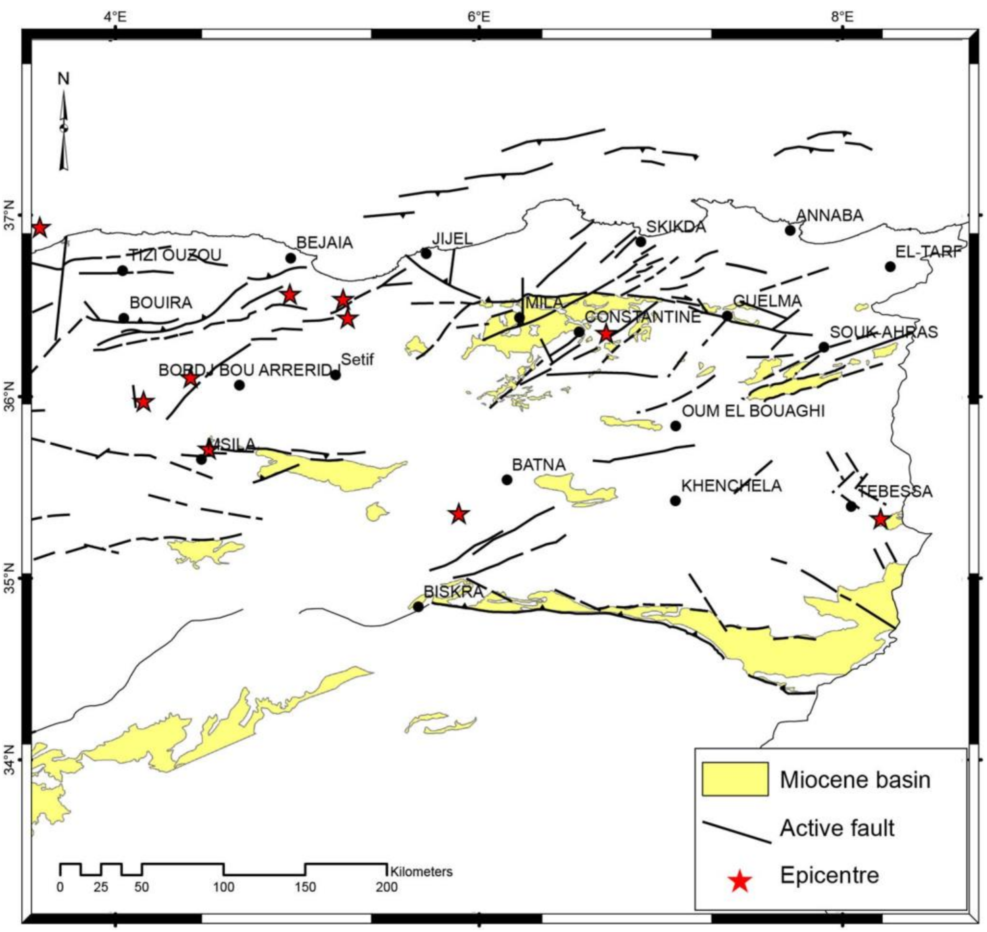


Figure. 63: Seismotectonic map of the Eastern Tellian Atlas of Algeria (Meghraoui 1988; CRAAG, Domzig 2006)

5.4. The Constantine Zone

The Constantine basin is characterized by its high altitudes and narrow valleys. Its geomorphology also shows that the area has a variety of volcanic deposits that are located in the margins of the valleys (Aoudia. 2000). These deposits are aligned in a similar direction as the direction of the seismic activity that occurred during the earthquake that occurred on October 27, 1985 (Bounif. 1987).

The presence of neotectonic structures, such as the Ain Smara, Sigus, and Constantine fault systems, which are located in the region's plio-quaternary, has been interpreted as tectonic activity (Figure 04).The characteristics of these structures, which are situated near the hydrothermal vents, suggest that tectonic activity is occurring in the area. Although there have been no strong earthquakes in the region before 1900, it is believed that the area was affected by multiple powerful earthquakes during the instrumental period.

These powerful earthquakes have been categorized into three categories: the Ms5.4 earthquake on August 4, 1908, the Ms5.0 earthquake on August 6, 1947, and the Ms5.7 earthquake on October 27, 1985 (Yelles- Chaouche. 2006; Bounif. 1987).

The strike-slip focal mechanism of the last earthquake is in agreement with the observed deformation and surface ruptures in the region's elevated zone. This region's morphology is likely to be supported by transcurrent motions rather than compressional ones.

Based on the spatial extent of the seismic activity during the 1985 aftershock sequence, it is estimated that the maximum fault length of the Constantine fault system is 30 kilometers. Using the empirical relationship between the strike-slip and the tectonic activity, it is believed that the region can experience powerful earthquakes of magnitude 6.5.

5.5. The Hodna Zone

The Neogene Hodna Basin is situated south of the Setif region and belongs to the Tellian Atlas. The region's topography is broken down into valleys and ridges due to the reverse faults and folds of the E-W to SW direction (Aoudia. 2000). The multiple compressive structures can be seen in anticlines of the basin that are located northeast of the deposit at Chott El Hodna (Meghraoui 1988) (Figure. 63).

The region has been struck by various earthquakes, including the M’Sila earthquake that occurred on February 12, 1946, and the Jan 1 1965 earthquake. The seismicity generated by the E-W to NE-SW anticlines can be observed in the area (Yelles-Chaouche. 2006). One of these is the Chott El Hammam fault-fold, which is located on its southeast slope and has an overlap of the ante-neogenous substratum (Meghraoui 1988).

The fault, which is around 30 kilometers long, is capable of producing an earthquake with a magnitude of around 7 (Aoudia. 2000). The presence of various Pleistocene deposits in the Chott El Hammam fold has also contributed to the development of recent seismic activities.

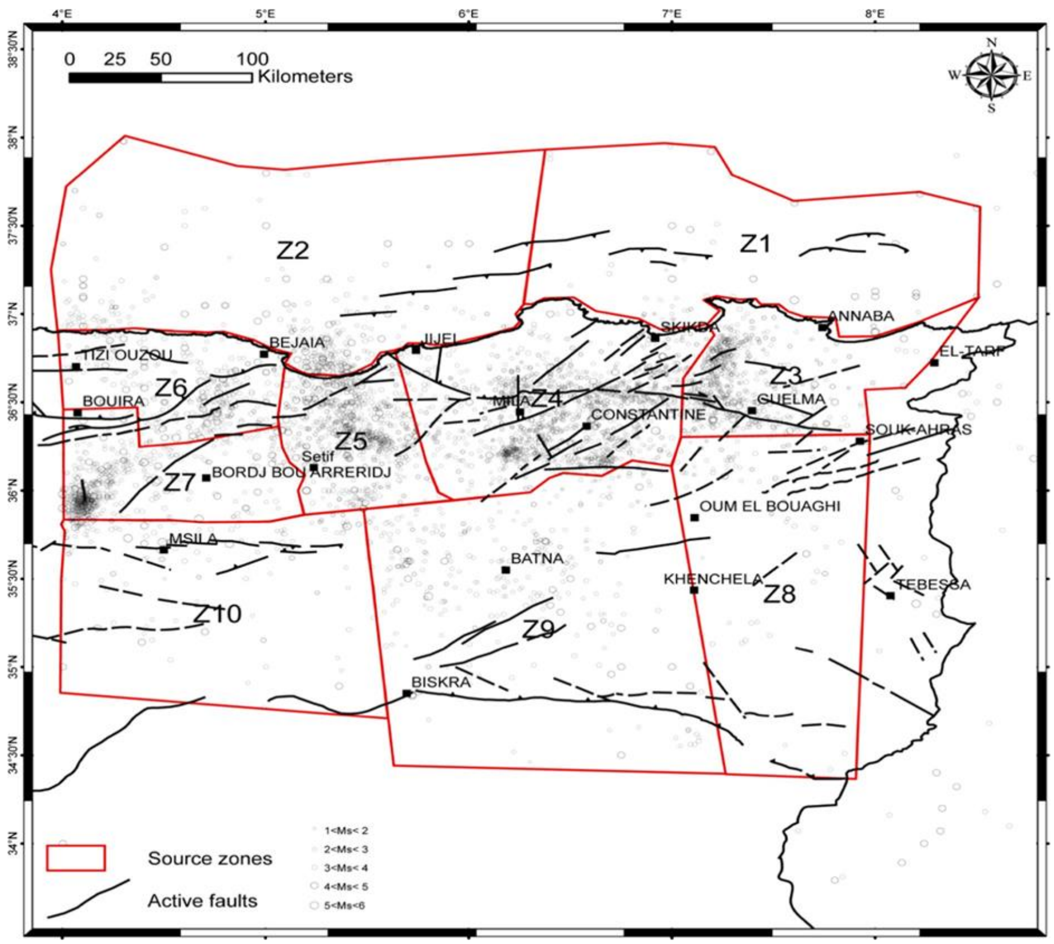


Figure. 64: The boundaries of the study area and the source zones and the active faults within the study area

5.6. The Tizi Ouzou Zone

The Babors Mountains are located east of the Soumam Valley and are an extension of the Djurdjura Mesozoic chain (Aoudia. 2000). The area is characterized by its various underground formations, such as the Plio-Quaternarys. These are not present in the region's aquifers (Meghraoui 1988). The Kherrata limestone massif, which is situated within the Babors zone, is known to be the seat of active quasi-permanent seismicity (Harbi 2001).

According to the region's seismic history, the seismic activity in the area is relatively moderate (Aoudia. 2000). However, on February 17, 1949, an earthquake with a magnitude of over 4.7 occurred (Harbi 2001). The fault located in the Babors Mountains is known to be responsible for the continuous seismic activity in the region. In 1950, Rothe mapped the fault situated on anticline N70E, which had surface ruptures. According to various studies conducted by (Meghraoui 1988; Harbi. 1999; Aoudia. 2000; Yelles- Chaouche. 2006), the fault is located in a region of constant activity.

5.7. The Bibans Zone

The Bibans have three main zones of seismicity. One of these is the area known as the Sour El Ghozlane, which is characterized by its various topographic features. It is the site of the fourth-largest earthquake in Algeria, following the 1954 Orleansville earthquake, the 1980 El Asnam earthquake, and the 2003 Boumerdes earthquake. On June 24, 1910, an earthquake with a magnitude of 6.6 occurred in this region (Benouar 1994).

This seismic activity was felt and recorded in the region up to the Bibans Mountain chain's eastern limits. Apart from this, the region was also struck by several major earthquakes. These include the earthquake that occurred on September 22, 1886, which was felt from the Bibans to the Soummam Valley. On August 15, 1931, an earthquake with a magnitude of 5.2 was felt near the Djebel Dirah. On December 25, 1954, an earthquake with a magnitude of 5.2 was felt. On October 30, 1975, an earthquake with a magnitude of 5.4 was felt (Aoudia. 2000).

The second region considered is the Beni-Ilmane. This complex area is characterized by the transition between the Hodna Mountains and the Bibans chain. Its seismicity is centered on the south side of the Beni-Ilmane village. It follows the Azrou-Choukchot-Nador deformation corridor, which is located in the northern part of the region. The bulk of the seismic cloud is generated by the various aftershocks of the 2010 earthquake (Abacha 2015).

This seismic activity is considered to be the second significant event to occur within the last 50 years following the February 21, 1960 earthquake, which had a maximum intensity of 5.5. It was mainly studied through macroseismic indications (Benouar 1994).

The third region considered is the Mansourah region, which is located in the northern part of the country and has a total elevation of 920 meters. It is characterized by three major earthquakes. One of these is the January 8, 1887 earthquake, which had a magnitude of 5.2 and an intensity of VIII (Harbi 2001).

The second significant earthquake that occurred in this region was the April 16, 1943 earthquake, which killed nine individuals and injured 11 others (Benouar 1994). The third major earthquake that hit the region was the magnitude 5.2 earthquake that occurred on November 24, 1973.

One of the most significant earthquakes that occurred in this region during the 1850s was the earthquake that hit the area of Zamora-Genzet, which was located near the Setif and Bou Arreridj regions. It had a maximum intensity of 4.6 and a minimum intensity of VII (Harbi 2001).

5.8. The Saharan Atlas Zone

The border between the Sahara and the Southern Algerian Atlas is a structural line consisting of various sections that have varying definitions and ages. This boundary is located in the Northeast of Algeria and borders the Aures Mountains and Constantine. The latter domain, which is composed of overlapping and fold-structured sections, dates back to the Cenozoic and Mesozoic periods.

Although the current tectonic activity in the area is relatively insignificant, several studies have revealed the presence of recent tectonic activities in this region. One of these studies revealed the existence of a large fault in the Eastern section of the Northern Saharan Atlas. This fault, which is located near the Ouenza, passed through the Mesloula region and would have been active until the end of the Quaternary. Through aeromagnetic studies, the researchers were able to identify the fault's NE-SW location (Vila 1980).

The area around the Tebessa-Ouenza axis has relatively weak seismicity. It passes through the Oum El Bouaghi, Biskra, and Souk Ahras regions. It also has a small section at the edge of the two Atlas ranges. In 1869, a violent earthquake destroyed the city of Biskra. This occurred in an area that is located near the Tebessa-Ouenza axis (Roussel 1973; Harbi. 2010).

5.9. The Batna Zone

The area is usually characterized by neogenic lands that are located near the Belezma Mountains and the Ain Regada platform (Guemache 2010). This region is situated at the intersection of two tectonic lines. One of these lines is the Tenes-Negrine, which is a large shear zone that extends over 700 kilometers long. This zone is located south of Negrine to the Southeast, and the Gulf of Gabes.

The Gafsa dextral strike is also located in the South-East and is expected to join the Batna line. Another structural line that is related to a sinistral strike is the Sidi Ferdjani El Kantra lineament (Guemache 2010), which extends for around 400 kilometers from the coast near the village of Sidi Ferdjani to the El Kantara sector of the South West.

The area between the Aures Mountains and the Hodna Mountains has a relatively weak seismicity. Three significant earthquakes that are known to have affected this region are the N'gaous Earthquake of January 17, 1885, which was 50 kilometers from Batna, the MacMahon earthquake of March 16, 1924, and the earthquake of the year 268 of Tazoult-Lambese. The three earthquakes are regarded as the reference earthquakes of this zone.

5.10. The Mansourah Zone

The eastern part of this region is characterized by mountains that are located near the Jebel M'aadid, which is the origin of the Hodna Mountains. To its south, the Neogene Hodna basin is similar to the active Neogene basins of other regions such as the Tellian Atlas. This region also has a series of anticlines related to the recent deposits-oriented NE-SW in the area.

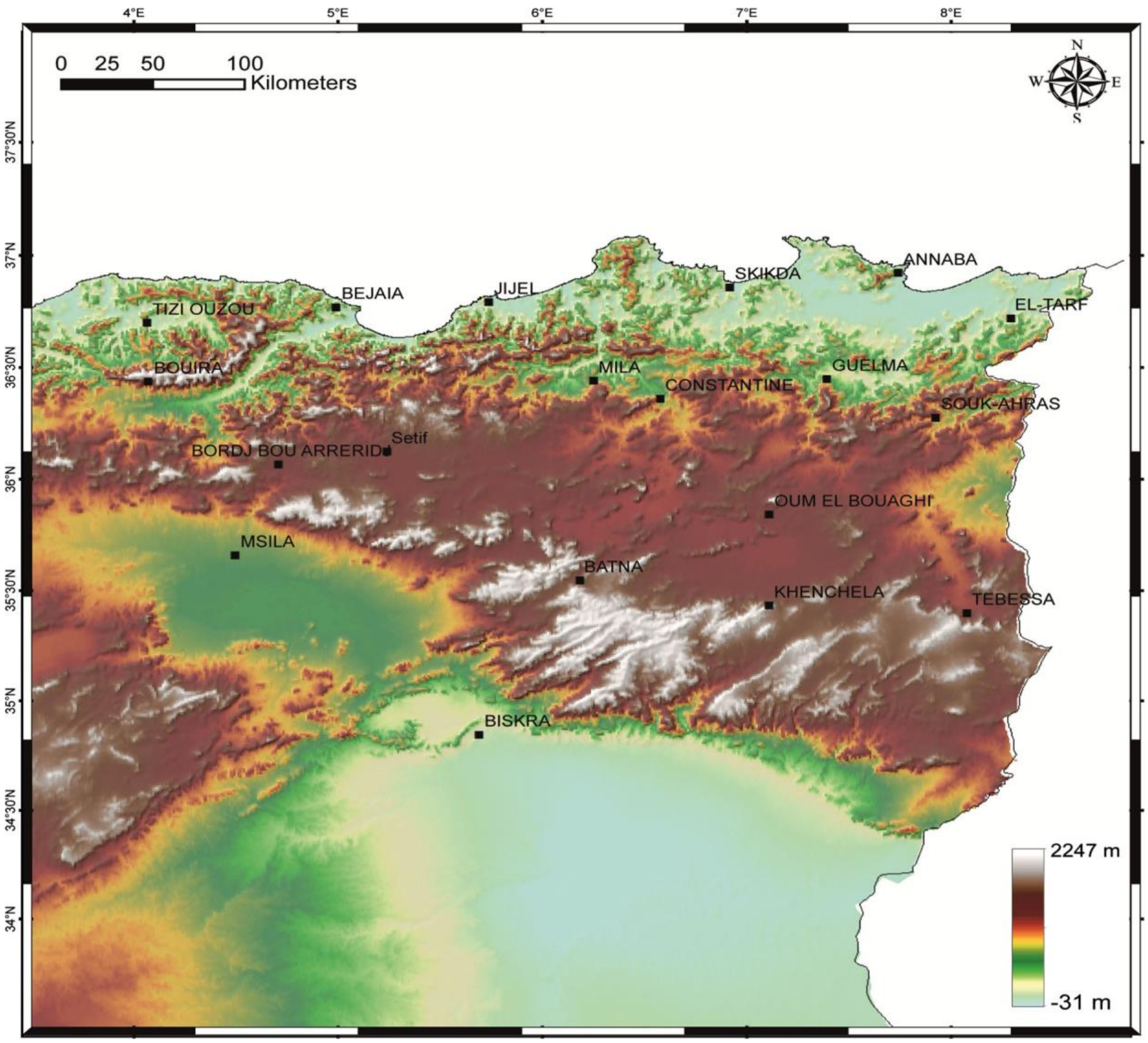


Figure. 65: Digital elevation model (SRTM DEM) for the entire Northeast of Algeria (250m resolosion)

A study conducted by Vila and Meghraoui (1980, 1988) revealed that the region has a series of fold-fault structures. One of these is the Chott El Hammam reverse fault, which is located near the Boutaleb anticline's SE flank. It could have caused the largest earthquake to occur in the region during the January 1965 earthquake. Five people died and 25 others were injured due to the earthquake, which had a magnitude of 5.4 and maximum intensity of VII (Benouar 1994).

The presence of numerous folded Pleistocene deposits on the Chott El Hammam fold has been identified as one of the factors that have contributed to the development of this region's recent seismic activity (Harbi 2001). In 1988, Meghraoui noted that a fault measuring 60 kilometers long can produce a powerful earthquake. Three major earthquakes occurred in the area in December 1885. The first earthquake, which had a magnitude of 5.9, killed 33 individuals and injured 17 others. It destroyed a portion of M'sila village (Harbi 2001). In the Berhoum region, two powerful earthquakes occurred within the same corridor as the M'sila earthquake that occurred in 1965. These two earthquakes were the magnitude 5.5 earthquake that occurred on February 12, 1946, and the 5.3 earthquakes that occurred on November 24, 1973. The two incidents caused the deaths of 277 individuals and injured over a hundred others (Harbi 2001).

6. Generation of Slope Map

The study area's slope map was created using the ArcGIS 10.8 software from ESRI's DEM platform. It was then imported into the World Geodetic System using the Coordinates of the World (WGS-1984). Before proceeding with any terrain analysis, the DEM was projected to the Universal Method of Sampling (UTM) system, which is ideal for resampling a 200 m grid (Figure. 66).

The spatial analyst tool used by ESRI's software was utilized to evaluate the slope map generated by the DEM for the study area. The generated slope map was then exported to a vector format and used to represent the various grid points (Figure. 66)

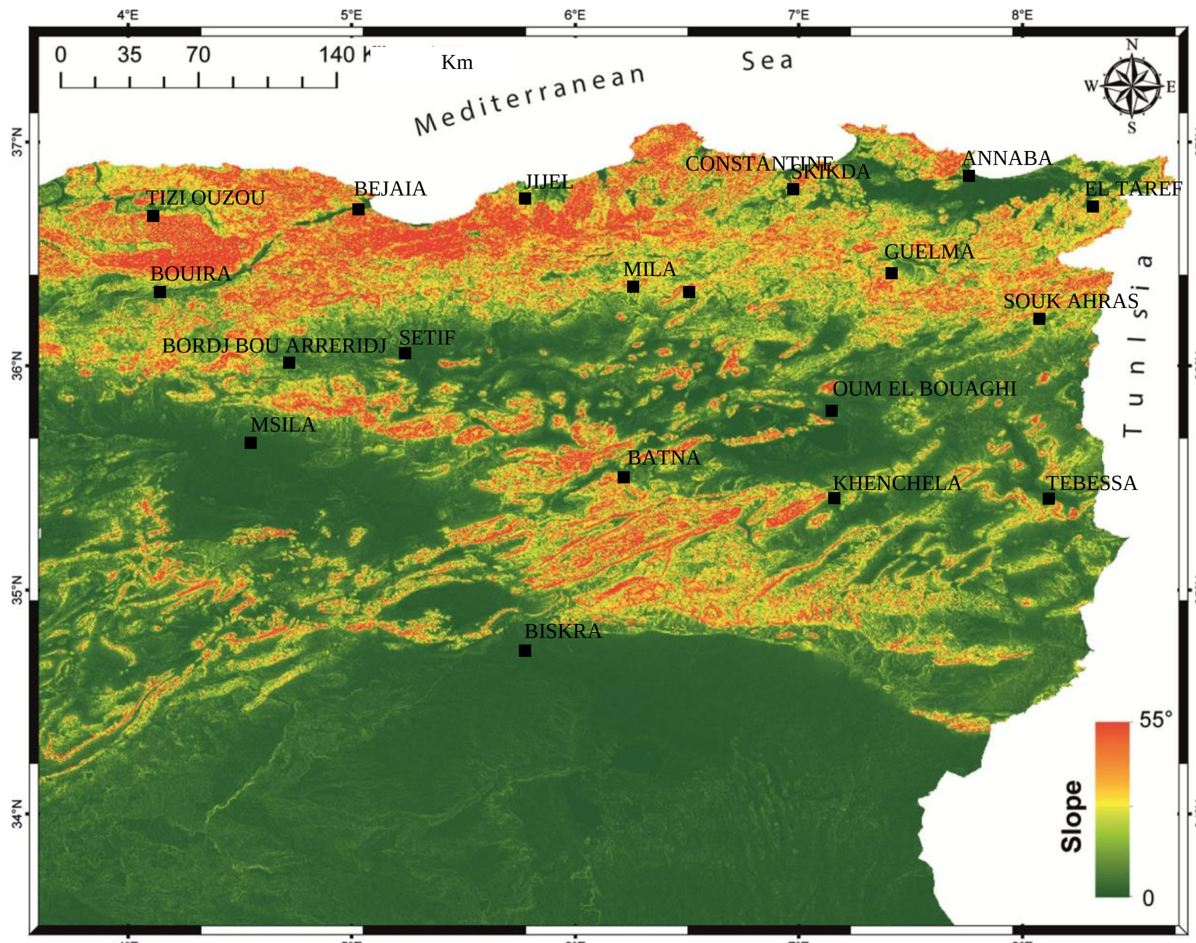


Figure. 66: Slope map of the Northeast of Algeria (gradient values)

7.PGA maps and their interpretations

The map (Figure. 67) shows the expected values of ground acceleration that are likely to happen during an earthquake over a period of about 475 and 2000 years. These values represent the peak intensity of the ground movement that may occur in the region. The higher the ground acceleration values, the more vulnerable the region is to ground movement that's stronger during an earthquake.

The values of ground acceleration that were expected to happen during the course of about 475 years have been exceeded on an average once every 475 years. This indicates that although the level of shaking that these values can provide is relatively rare, it has a 10% chance of happening within the next 50 years.

The values of ground acceleration that were expected to happen during the course of about 2000 years have been exceeded on an average once every 2000 years. This indicates that although the level of shaking that these values can provide is relatively rare, it has a 2% chance of happening within the next 50 years.

When it comes to assessing the vulnerability of an area to seismic activities, the values of the PGA should be considered. The higher the values, the more likely it is that ground movement will be stronger. This can affect the design and construction of various infrastructure, as well as the response planning for emergencies.

7.1 Interpretation of the PGA values:

The peak ground acceleration values are shown in the PGA values. They represent the maximum force that the ground can exert during an earthquake.

The values of the PGA range from 0.02 up to 0.27 (Figure .67) and from 0.08 up to 0.34 in (Figure. 68) indicate that there is a significant ground shaking during powerful earthquakes with significant distances and magnitudes.

The higher the value within this range, the more vulnerable the area is to ground movement, which could cause more hazards and structural damage.

7.2 Implications:

The values of the PGA range from 0.08 up to 0.34 (Figure. 68) suggest that certain areas might require special attention when it comes to building and construction standards and implementing measures to cope with the expected ground movement during more powerful earthquakes.

These values can be utilized by decision-makers, engineers, and seismologists to evaluate the seismic hazards and possible risks associated with the development and infrastructure projects within the study area.

It is also important to consider the various aspects of emergency preparedness and land-use planning when it comes to developing and implementing infrastructure projects in the study area.

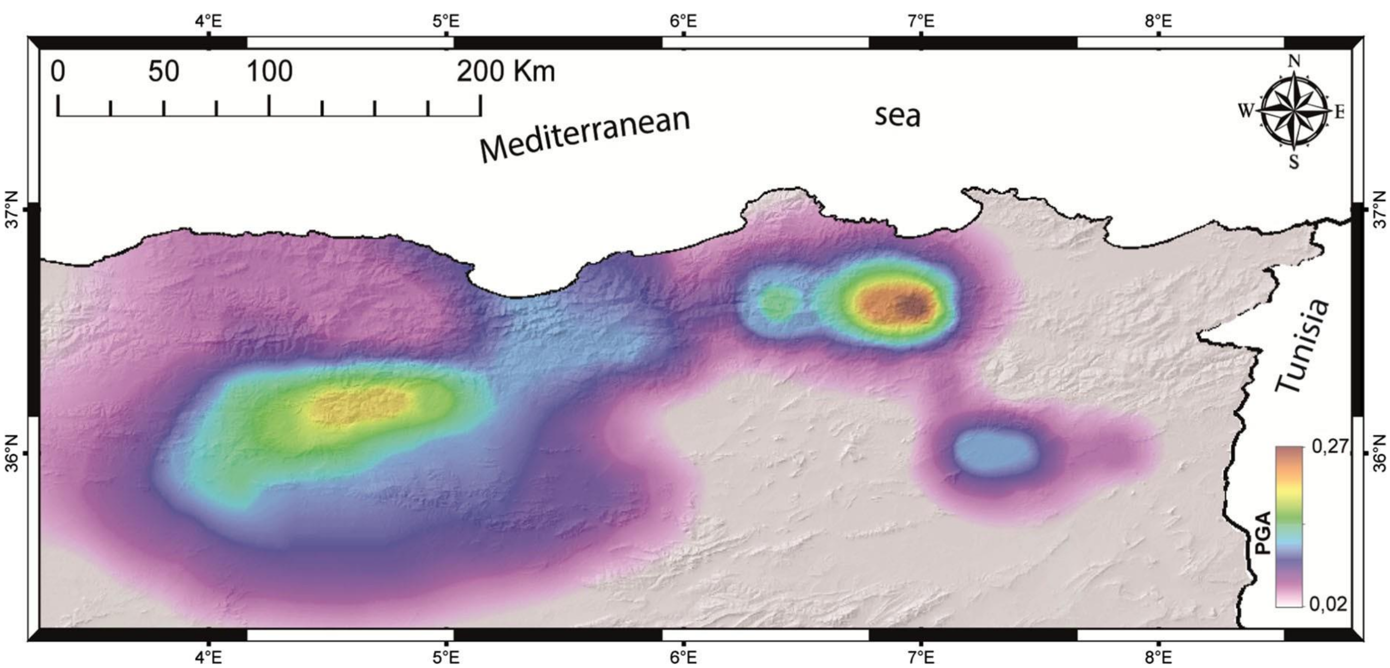


Figure. 67: PGA values (g) corresponding to a return period of 475 years (10% probability of exceedance in 50 years) (Hamidatou. 2019)

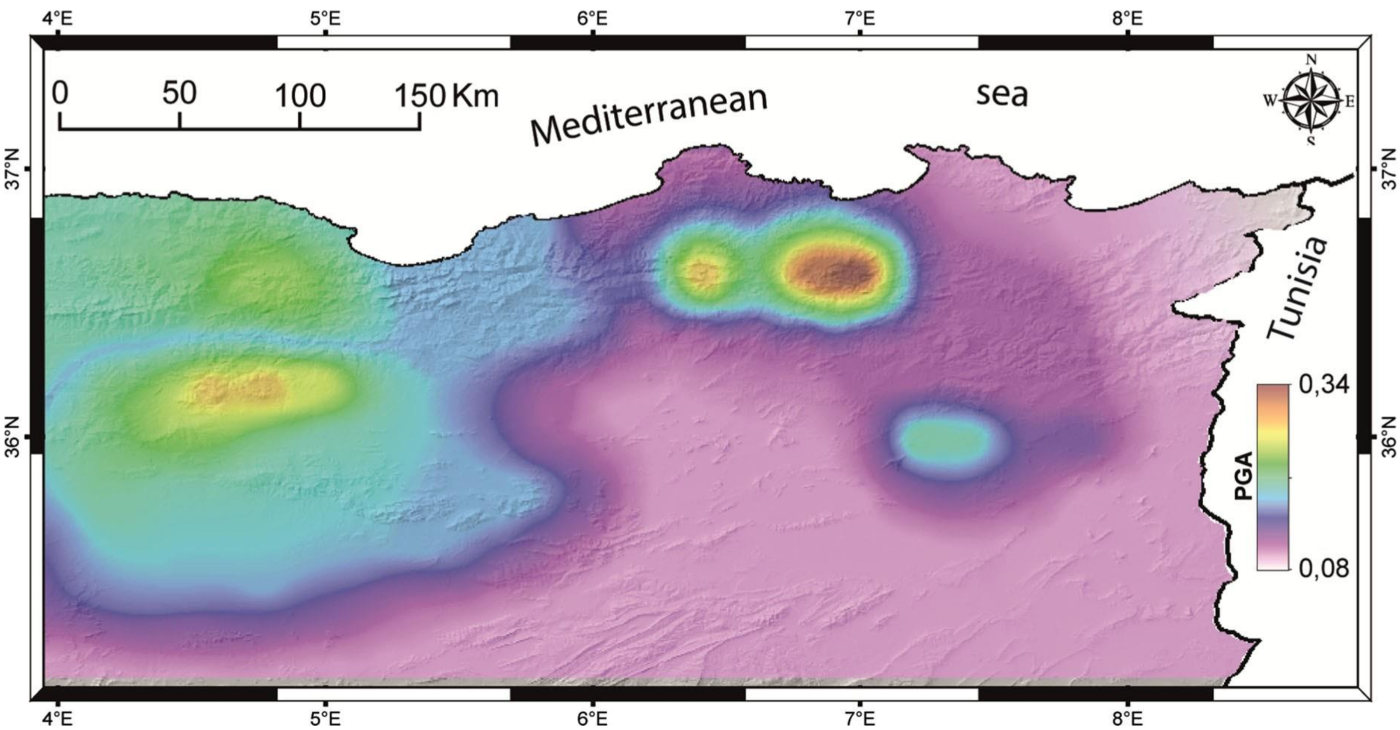


Figure. 68: PGA values (g) corresponding to a return period of 2000 years (2% probability of exceedance in 50 years) (Hamidatou. 2019)

9. Conclusions

The findings of this study contribute to the understanding of the seismic hazards in the region of Algeria's northeast. The existence of seismicity in the area suggests the possibility of strong and moderate earthquakes. To better assess the seismic hazard, further studies are needed to understand the various active structures in the region. In addition to this, studies are also needed on the vulnerability of buildings in major cities.

The study used a probabilistic method to evaluate the seismic hazards in the area. The results of the analysis were then used to develop a theoretical framework for the study.

The results indicated that although the cities of Guelma, Mansourah, and Constantine are relatively low-risk seismic areas, they are still vulnerable to damaging earthquakes due to a large number of unreinforced concrete and inductile structures in the region. These types of buildings could also contribute to the development of unstable ground conditions.

The data collected during the study were then analyzed to determine the probability of a major earthquake occurring in the area. However, the results of the analysis were not able to provide a comprehensive understanding of the seismic hazards in the region.

Even if there are multiple methods used to evaluate the seismic hazards in the region, the results of the analysis were still able to provide a comprehensive understanding of the potential threat. This will allow decision-makers to implement effective measures to minimize the risk of seismic activities.

The parameters of the seismic hazards were estimated using the multiple methods available in the study. These included the estimated b-value of each seismic source zone, the constant b-value, and the de parameters of seismicity.

CHAPTER. VI

ANALYZING ACTIVE COASTAL TECTONIC DEFORMATION AND UPLIFTED MARINE TERRACES IN EASTERN ALGIERS

1. Introduction

Dynamic processes have affected the landscape of Eastern Algiers over the past few decades. These include active coastal deformation and marine terraces that have uplifted. Understanding the various mechanisms and impacts of these processes is very important in order to understand the region's tectonic evolution.

The aim of this chapter is to investigate the effects of dynamic processes on the coastal landscape of Eastern Algiers (Figure. 69). We will look into the underlying mechanisms that have affected the landscape's evolution and formation. In addition, we'll try to analyze their impacts on our knowledge of sea-level curves and plate convergence.

The region's geology is characterized by an intricate interplay of forces, such as the plate convergence between the European and African plates (Figure. 70). This resulted in the coastal zone's deformation, which uplifted marine terraces. These geological landmarks offer valuable clues to the region's past tectonic activities.

Through the use of various techniques, such as geological mapping, remote sensing, and field surveys, we'll be able to identify the succession of marine terraces in the coastal zone's deformation. We'll also be able to study the distribution and characteristics of the uplifted marine terraces to gain a deeper understanding of the region's past tectonic activity.

The results of this study can help us understand the dynamics of the region's tectonic activity, as well as its broader implications. In addition, their significance can be analyzed in the context of sea-level changes and plate convergence. This knowledge is important in managing coastal tectonic deformation-related hazards, such as land instability and earthquakes. The purpose of this chapter is to review the recent activities of dynamic processes in Eastern Algiers and Zemmouri region (Figure. 69), such as the uplifted marine terraces and coastal tectonic deformation. The findings of this research will serve as a valuable guide for coastal hazard management and assessment in the area.

2. Geological background and studied area

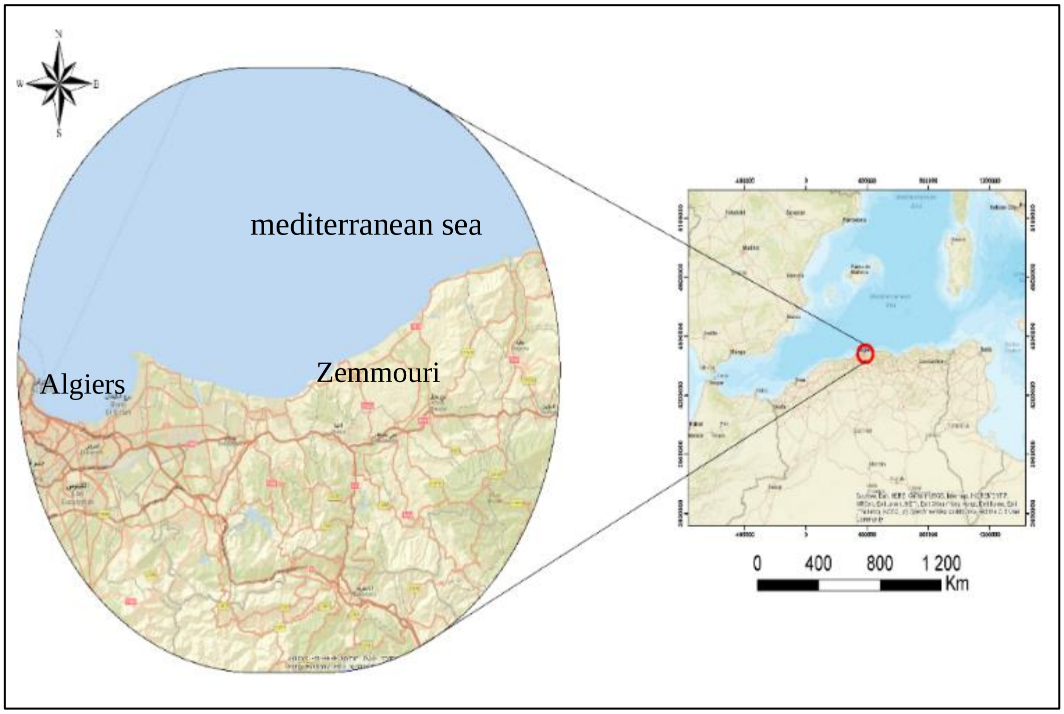


Figure. 69: Location map of the study area.

The Tell Atlas thrust belt, located in northern Algeria, has a convergence rate of 4 to 6 millimeters per year toward Europe (Nocquet and Calais, 2004; Serpelloni. 2007). This region's Quaternary folding structures have been identified as key components of the coastal zone (Figure 69), The active deformation characterized by E-W to NE-SW trending fold structures and associated reverse and thrust faults are evidenced by the significant shortening of the Tell Atlas (Figure 74) (Meghraoui and Doumaz, 1996). The Algiers region has two active structures that are both northeast and southwest to Est west trending (Figures 70). These structures are the Mitidja Quaternary Basin's southern (Blida thrust and fold system) and northern (Sahel anticline) edges. The prominent morphological features of the Blida rocky mountain region have changed over the years. The region's elevation has increased significantly, reaching a height of over 500 meters (Figure 74).

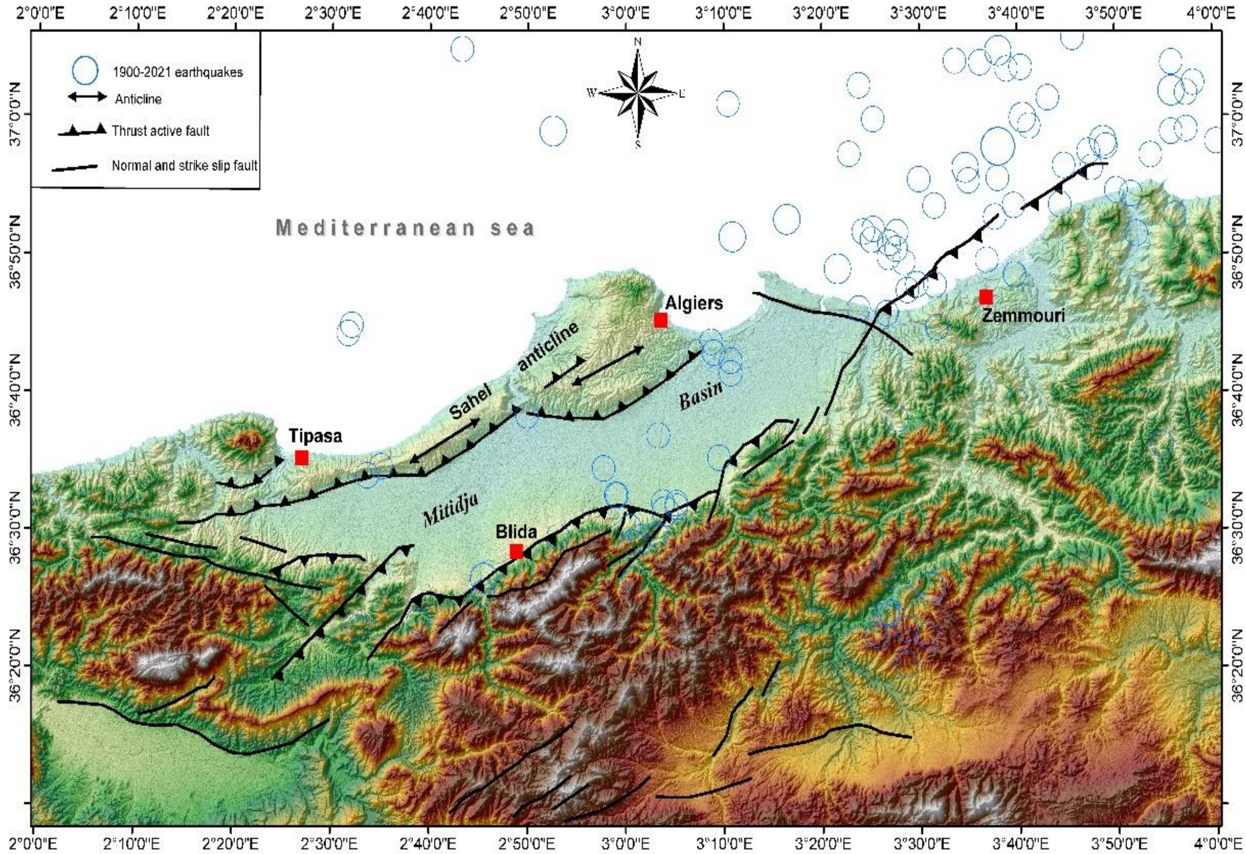


Figure. 70: Neotectonic and seismicity map shows the distribution of earthquakes in the Mitidja basin and study area from 1900 to 2021 (M≥ 4, modified from Maouche and al. 2018). (USGS DATA, SRTM 30 m)

The study area is predominantly composed of Paleozoic and Cenozoic basement rocks (figure. 3, 4) that are mainly folded and overlain by strong folds and overthrust structures (Durand Delga, 1969). The active faults of the Metidja basin (Figure. 70) are on the ENE-WSW trending and right-stepped faults (Meghraoui, 1988). This fault system can extend to the coastline and its offshore extension was reactivated during the Zemmouri earthquake in 2003 Mw 6.8 (Ayadi. 2008; Belabbes. 2009; Bounif. 2004; Meghraoui. 2004). The ENE-WSW trending and 70-km-long Sahel anticline shows thrust and flexing faulting on the southern flank of the Quaternary units. The northern half of the anticline shows a sequence of late-Pleistocene and Holocene marine terrace units that have unconformity with the Miocene and Pliocephalic units (Figure. 71, 72) (Meghraoui, 1991).

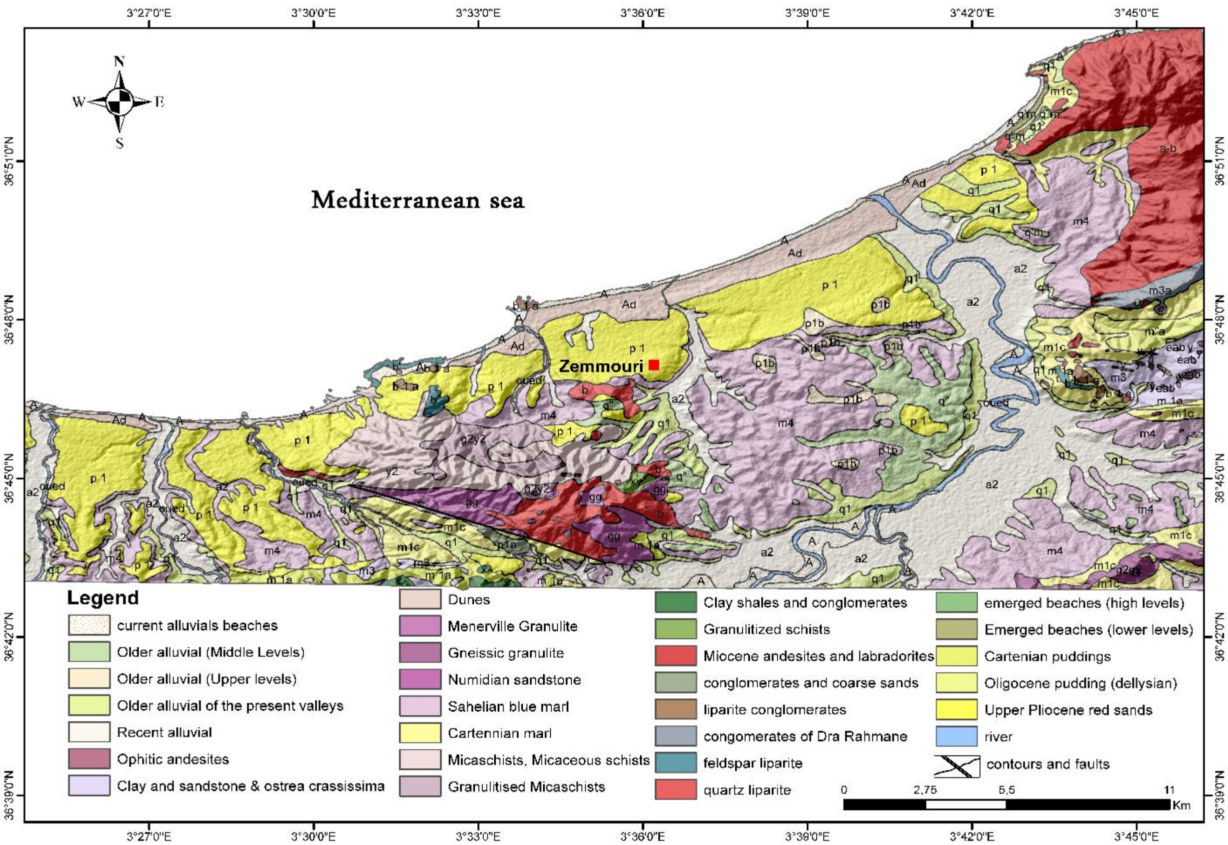


Figure. 71: Geological map (with relief, SRTM-12.5m topographic data) of the Zemmouri region and surroundings.

The seismicity catalog (Table. 1) shows that earthquakes with powerful magnitudes have occurred along the Mitidja basin's southern and northern edges and surroundings (Benouar, 1994; Harbi. 2007; Mokrane. 1994) (Figure. 71). These earthquakes were most likely caused by shallow seismic sources (Table 01) and occurred in 1365, 1716, and 1825 (Ambraseys and Vogt, 1988). The most recent earthquakes in the coastal zone of Algiers have been attributed to the shallow focal depth and reverse tectonics. These earthquakes, which occurred from 1988 to 2003, were the most destructive. The most notable of these was the disastrous earthquakes of Tipasa in 1989 and

Zemmouri in 2003. (Bounif. 2004; Meghraoui, 1991). these two earthquakes are related to N 45E to N60E seismic activities that extend offshore (Ayadi. 2008; Bounif. 2003).

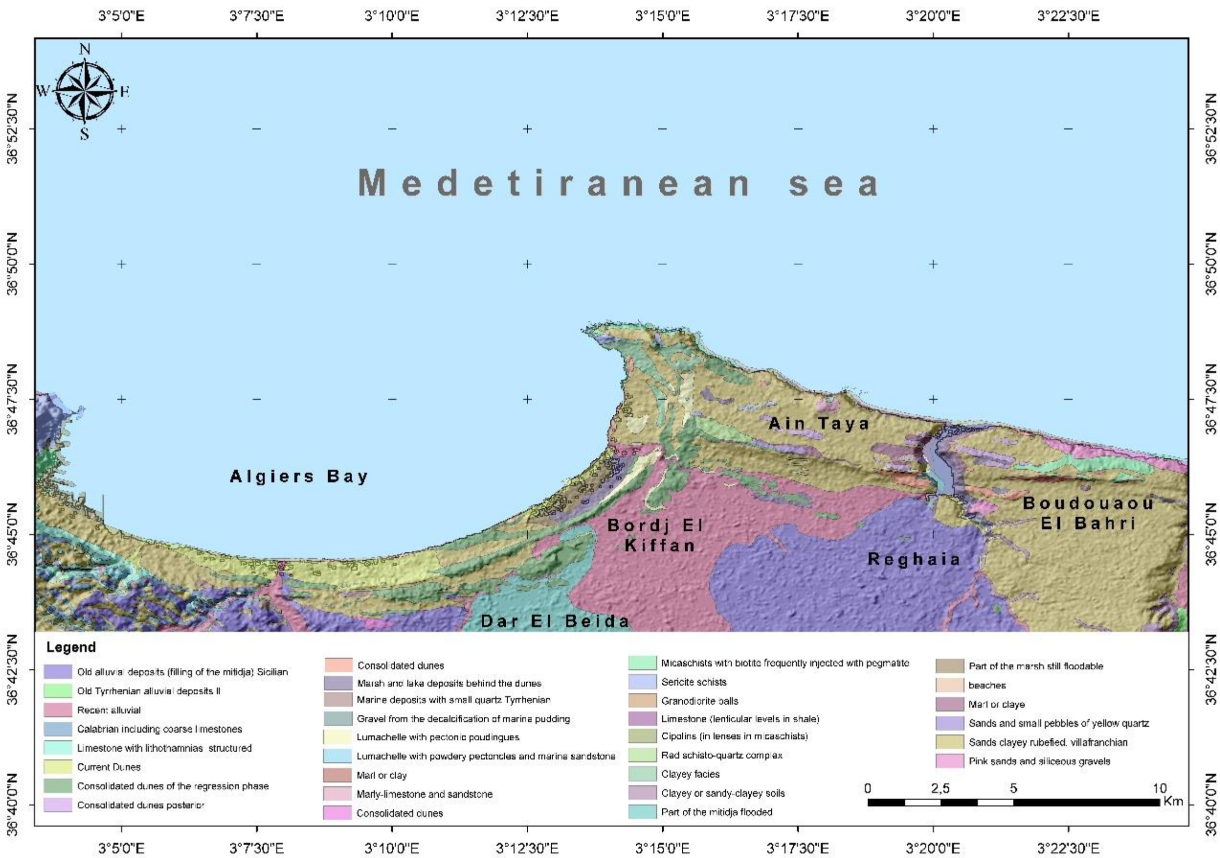


Figure. 72: Geological map (with relief, SRTM-12.5m topographic data) of the Ain Taya-R'ghaia region and surroundings.

Table. 1: The seismicity catalog of the most powerful earthquakes in the northern Algeria (Harbi, 2013)

Day	Lat ° N	Lon ° E	Intensity	Remark	Location
1342	36.992	3.913	-	Destructive	Dellys
03/Mars/1359	36.771	3.044	-	Doubtful	Algiers
18/January/1365	36.772	3.051	XEMS	locality coordinates, destructive, offshore event, Tsunami	Algiers region
22/September/1522	36.911	2.52	IX MM	locality coordinates, offshore event	N of Tipasa
03/February/1716	36.671	2.952	IX EMS	locality coordinates, Tsunami	Algiers region
12/Mai/1716	36.74	3.13	VIII MM	Doubtful	Algiers
29/November/1722	36.772	3.054	VII MM	locality coordinates	Algiers
06/Mai/1773	36.593	2.441	-	offshore event, Tsunami	Tipasa
09/October/1790	35.701	2.653	IX–X MM	Doubtful	West Oran
25/August/1804	36.802	2.801	IX MM	Macroseismic location, offshore event	North Sidi Fredj
21/August/1856	36.823	5.792	VIII EMS	Macroseismic location, offshore event, locality coordinates, destructive (Ms>6)	Djijelli
22/September/1860	36.809	2.511	VIII MM	Macroseismic location, offshore event	N of Tipasa
25/September/1885	36.813	2.506	V MM	Macroseismic location, offshore event	N of Tipasa
15/January/1891	36.562	1.851	IX MSK	Macroseismic location, destructive (Ms>6)	Gouraya Mountains
27/October/1989	36.621	2.332	VIII MSK	Ms=6	Chenoua
04/September/1996	36.909	2.818	VII MSK	Ms=5.7	Algiers
21/Mai/2003	36.831	3.652	X EMS	Mw=6.8	Zemmouri

3. Geomorphologic parameters impacting the marine terraces

3.1 Hillshade with 3D view and Hydrographic network

The data and the method were collected through uplifted terraces and coastal zones. The geomorphology related to the Tell Atlas demonstrates that the NE-SW is the trending active fold that is crossing the drainage systems (Figures. 70, 73).

We can utilize the information collected by the combined map of the hydrographic network and the Hillshade map to analyze the link between the water features' distribution and terrain. Doing so allows to study how the landscape affects the water's behavior and flow patterns. It also helps to identify potential areas of interest.

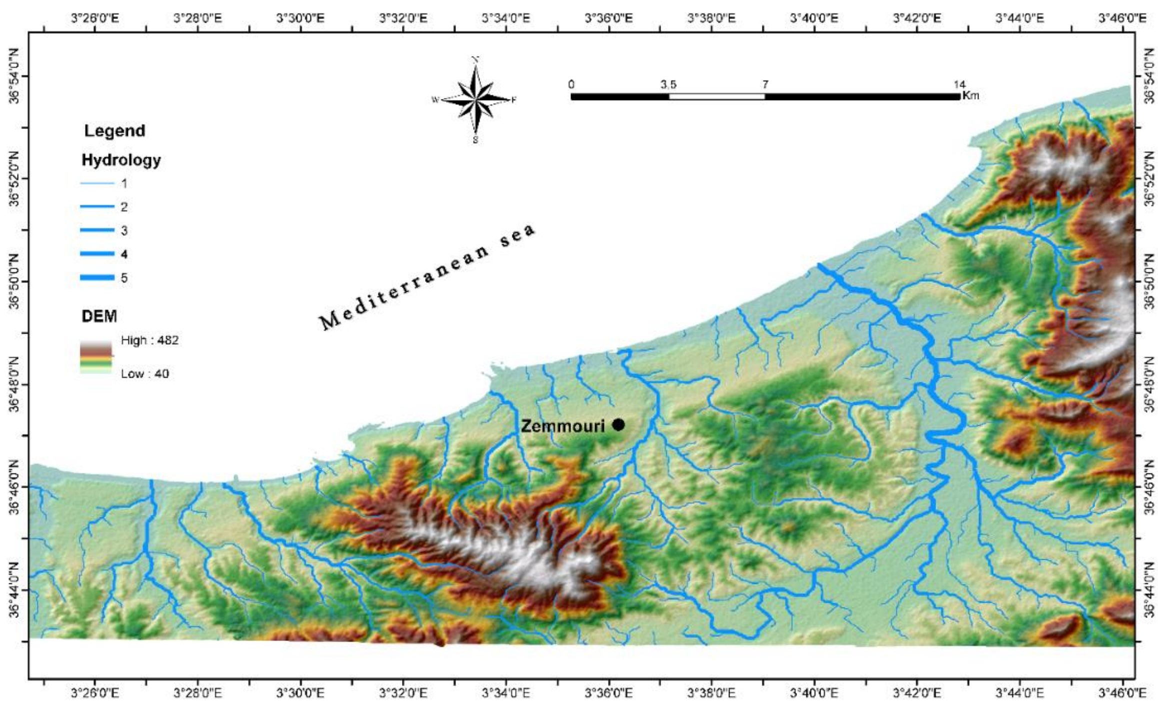


Figure. 73: Hillshade view and the hydrographic network of the study area

The enhanced understanding of the Hillshade map combined with the hydrographic network in Zemmouri provides valuable information on the region's water features and topography. The Hillshade map uses shading techniques to show the elevation of the land. It displays different colors with elevations ranging from 40 to 482m to help visualize the land's contours and slopes.

Darker areas tend to have steeper slopes, while light regions are more gently sloping. We can gain a deeper understanding of the region's landforms and topography by examining this map.

The hydrographic network consists of five graduated lines that show the distribution and presence of various water features, such as streams, rivers, and other watercourses. The sizes of these lines indicate the importance or magnitude of these features. These lines allow for the identification of water bodies' connectivity, drainage systems, and flow patterns in the region of Zemmouri.

3.2 Hypsometric map

The Zemmouri area elevation encompasses notable influence over the scale of marine, morphology and the alluvial terrace (Figure 74). Similarly, it has also caused Paleo-wave notches and the staircase morphology across these areas. For studying the coastal geomorphology pertinent to the region, aerial photographs and satellite imagery was used. These were used to characterize the landscape features of the area at a wide level. On the contradictory, the digital elevation model was also utilized for characterizing the feature of the landscape in the region which includes ALOS, SRTM, and DEM along with the 3-arc elevation model.

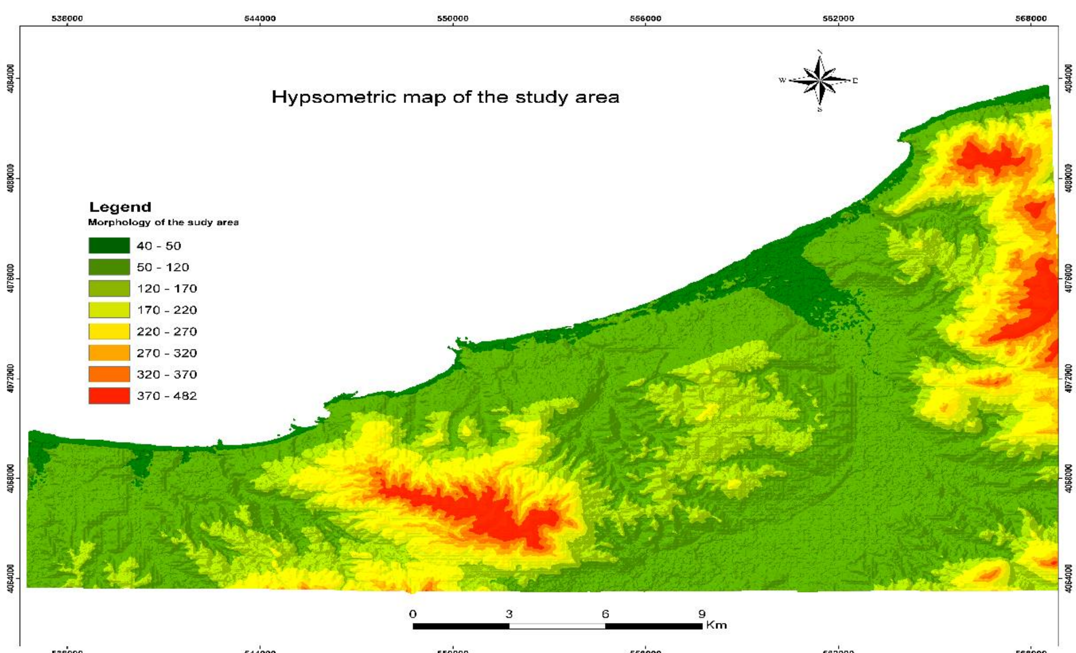


Figure. 74: Hypsometric Map of the Zemmouri region

On the other hand, the morphology pertinent to the marine terraces is widely linked with the sea level, slope index, channel length, width, and height. These can also be distinguished from several other types of terraces due to the basin elongation ratio, steepness index, and other slope factors (Figure 5). In one of the studies performed by Mastronuzzi, Mastronuzzi, and Sansò (2002), the southern Italy coastal regions were studied also included the Apulia region. These studies have been performed in Patagonia, Argentina, and High Atlas Morocco (Rostami. 2000; Boulton. 2014).

3.3 Slope map

We can use the slope map of the Zemmouri area to identify regions with varying degrees of steepness and determine areas most prone to landslides. This information can be useful in identifying suitable locations for the construction of infrastructure or determining the landscape's dynamics.

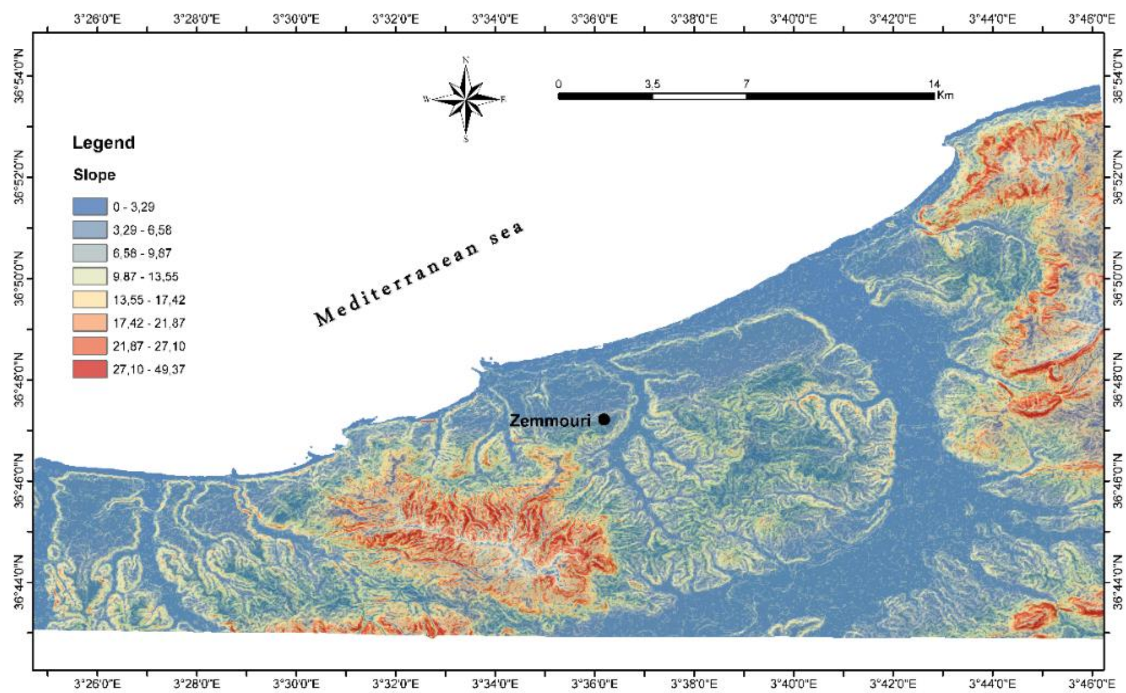


Figure. 75: Slope map of the study area (ALOS 12.5 m DATA from USGS)

The eight-class slope map of Zemmouri region illustrates the diverse features of the landscape, each of which is characterized by a distinct color. It features a range of slopes that can be distinguished by the individual colors. The first group of slopes, shown by a specific color, is composed of areas with moderate to gentle slopes ranging from 0 to 3.29. As the map moves across the landscape, the terrain gradually becomes steeper. The terrain depicted in the map is rugged, and the subsequent classes exhibit progressively steeper slopes. The colors indicated on these surfaces correspond to varying degrees of steepness. The last group, highlighted by its distinctive color, represents the areas with the most notable inclines ranging from 27.10 to 49.37, and these typically feature elevated ridges or steep cliffs.

3.4 Surface classification model map (SCM)

The surface classification model for the Zemmouri area shows the various levels of marine terraces represented with different color (Haythem. 2023). These landforms are known to indicate the past sea levels and provide valuable information on the region's geological history. The levels of marine terraces in the Zemmouri area are determined by the relationship between the area's ancient shoreline and the sea's current levels. These are the terraces that were formed due to the effects of coastal processes and waves during the past few decades (Haythem. 2023).

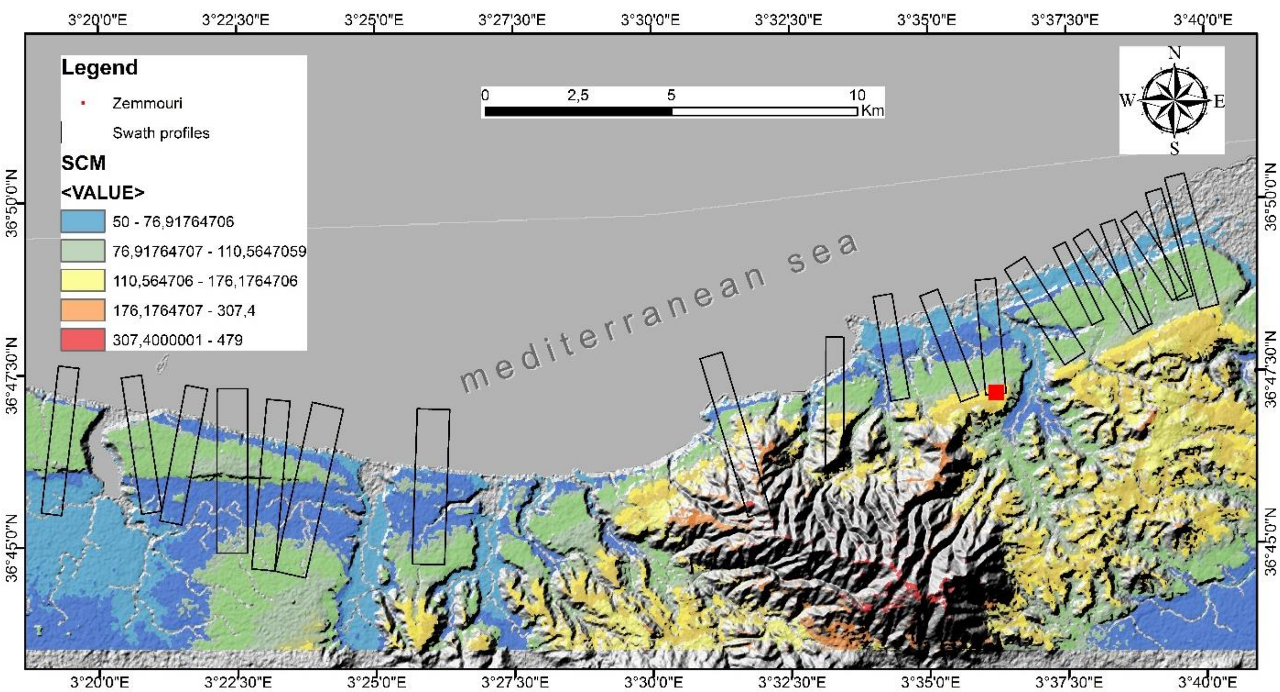


Figure. 76: Surface classification map present the different levels of the marine terraces in the Zemmouri region

The SCM map examine the attributes and spatial distribution of marine terraces in Zemmouri region (Haythem. 2023). By taking a closer look at the data, they can gain a deeper understanding of the uplift and tectonic history of the area. In addition, this information can help predict the effects of sea level changes in the past and present (Taib. 2022).

The spatial and temporal variations of marine terraces can be correlated with other data such as coastal landforms, seismic activity records, and sedimentary deposits. By integrating these data, researchers can gain a profound understanding of the link between sea level changes, tectonic forces, and marine terraces' formation and evolution.

The collected data of the study was undertaken through satellite images which were taken in the Zemmouri uplifted area. these images thereby offered a potential landscape as well as the geomorphological markers which can be identified easily. The geomorphological markers include Shoreline Angeles and marine terraces (Taib. 2022). Consequently, with the data that has been collected for the study, the research has been able to conduct a significant number of studies including Zemmouri landscape mapping and the identification pertinent to the scarp which is parallel to the coastline. Alongside this, we also developed notable digital elevation models which can be subsequently utilized for studying the landscape. The post-processing and the documentation were carried out through tools that are offered by ArcGIS and MATLAB. These also involve the extraction pertinent to topographical and hydrographic maps. These data were further utilized for the generation of a comprehensive analysis of the morphometric parameters of the marine terrace as well as the association with the sea-level curves in the region of Zemmouri. In the other section, the variation and distribution were focused on the marine terraces as well as the coast. Similarly, the quantitative geomorphology pertinent to the marine terraces involves the utilization of GPS, geographical coordinates, and elevation data on a wide scale.

4. Parameters influencing the formation of marine terraces on Zemmouri region

The effects of rising sea levels and the erosive actions of waves on marine terraces have been studied to reveal their geomorphic features. The lower portions of these structures are gradually modified as the waves erode them. In addition, the rising sea levels can cause the submergence of certain sections of these structures. Although tectonic uplift is the primary mechanism through which these types of geomorphic features are formed, it is also important to note that the sea levels are rising due to the effects of environmental changes.

Tectonic uplift is the process that occurs when coastal regions are subjected to various activities, such as earthquakes and volcanic eruptions (Taib. 2022). These processes expose the former sea levels. These types of natural structures are known to form through the abrasion and denudation of marine surfaces. Marine terraces are characterized by flat surfaces with sloping slopes on both sides (Figure. 8).

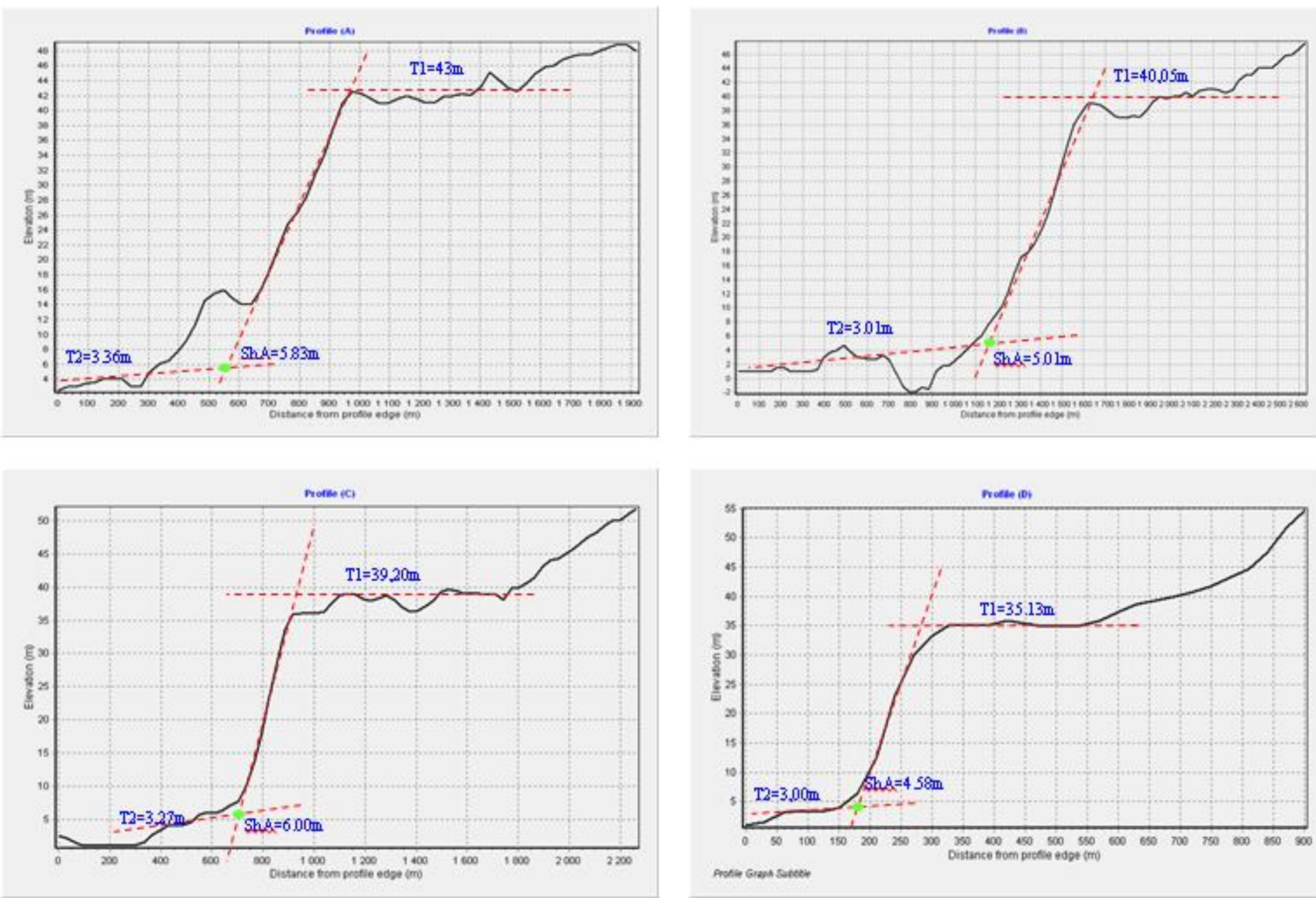


Figure. 77: Profiles presented the two levels of marine terraces plotted perpendicularly to the coast line (see Figure. 79)

The tall and steep nature of the marine terraces and the surrounding shoreline of the Eastern Algiers coast can be seen in (Figure. 76) A study conducted by Gelder and colleagues in 2020 revealed that sea level fluctuations have a significant influence on the appearance and function of marine terraces. Other studies conducted by Matsumoto and Chen in 2021 and 2020 revealed that the wind and waves can contribute to the development of rocky shore platforms. The elevation and shape of marine terraces can be determined by the difference between horizontal and vertical erosion. Water depth also has a significant effect on the patterns related to energy loss.

Over time, the erosive actions of waves on the marine terraces in Algiers have changed significantly. In 2011, a study conducted by Maouche and colleagues revealed that the coastal thrusting could affect the vertical and horizontal erosion patterns of marine terraces in Algiers. The research also highlighted the presence of significant coastal uplifts following the earthquakes that occurred in the Zemmouri region in 2003. According to Maouche and colleagues, notches have been observed on the terraces prior to and after the Holocene period. Considering the different features of the area's marine terraces, it's clear that the waves' erosive actions have affected the geomorphology of the region.

5. Marine terraces in Zemmouri region

The marine terraces located in the Zemmouri region are important geological features (Figure. 78). They are formed through the various processes that occur in the area, such as marine erosion and tectonic uplift. The terraces can serve as an important historical reference point and provide insight into the region's geomorphic and tectonic history (Figure. 76, 77).

The study determined that the two marine terraces in Zemmouri are located at varying elevations. The lower terrace is about 1 meter above sea level, while the upper terrace is 43 meters above sea level (Figure. 77). The data collected from these terraces provide valuable historical information on the past sea level changes and the region's tectonic history.

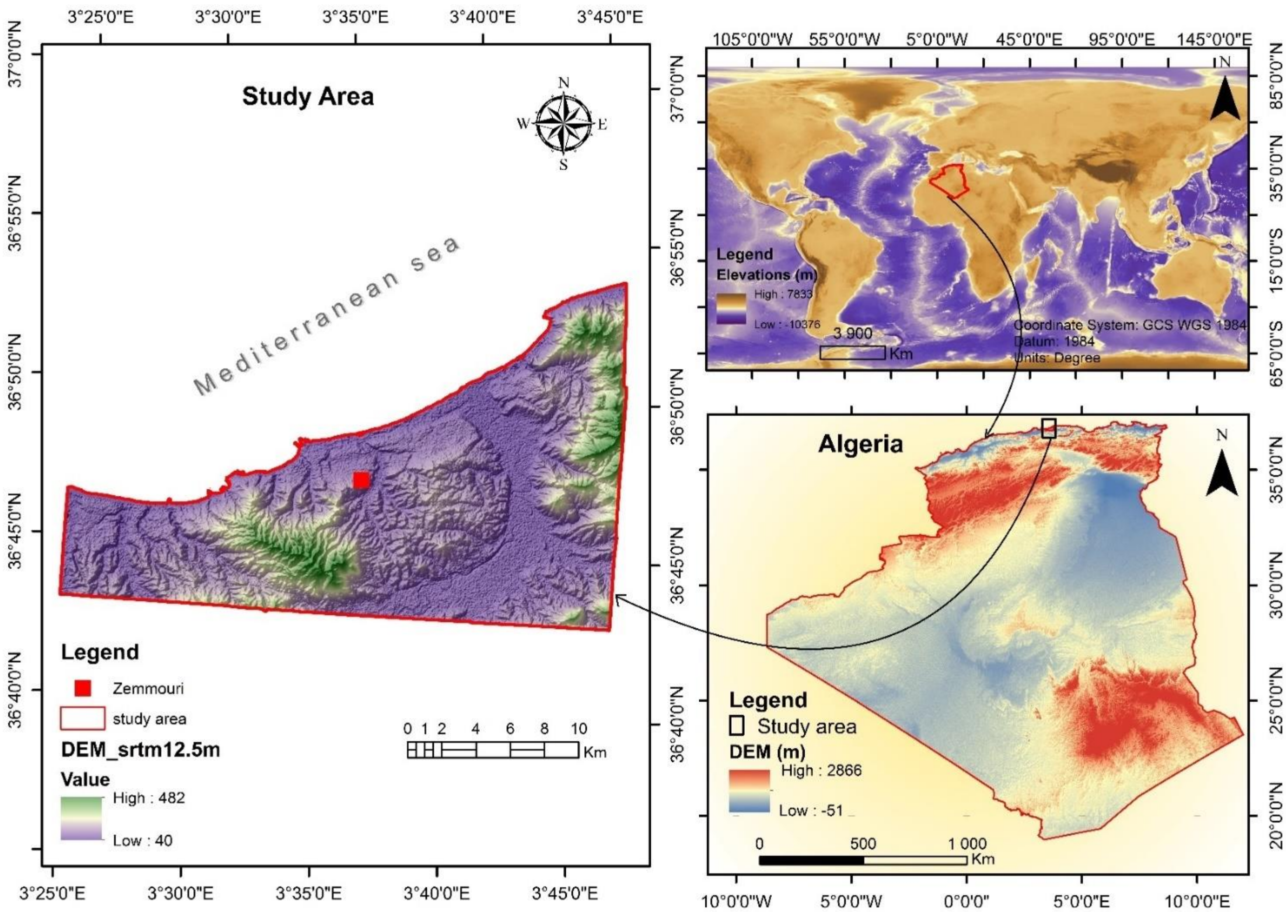


Figure. 78: Map shows the location of the Zemmouri region

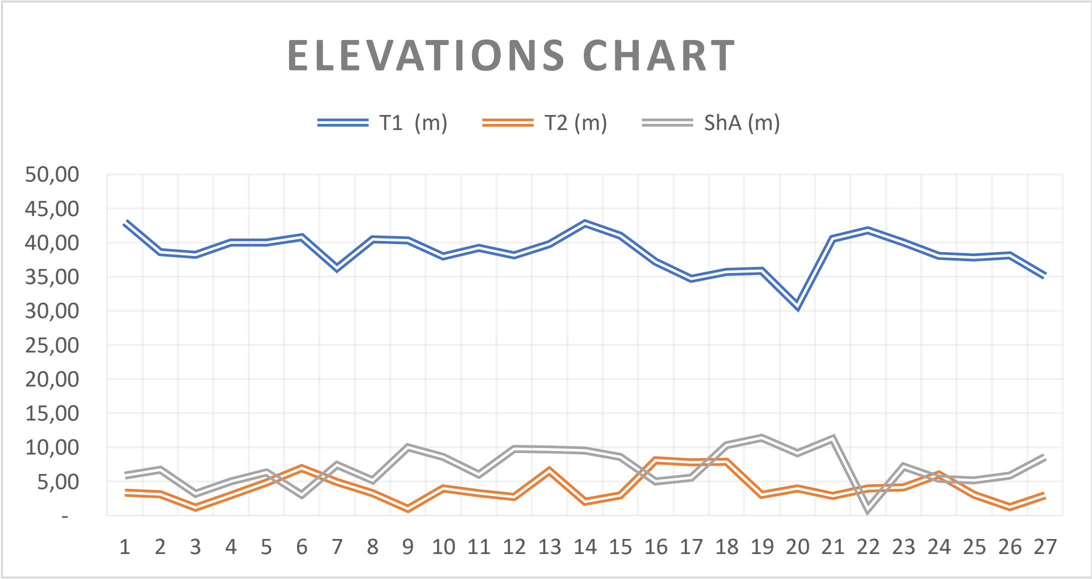


Figure. 79: Comparison of elevation between T1, T2, and Shoreline angles

N°	Lon ° E	Lat ° N	T1 (m)
1	3,71	36,84	43,00
2	3,70	36,83	38,58
3	3,68	36,81	38,24
4	3,67	36,82	40,05
5	3,67	36,82	40,00
6	3,66	36,81	40,82
7	3,66	36,81	36,30
8	3,66	36,81	40,46
9	3,65	36,81	40,32
10	3,65	36,81	38,00
11	3,64	36,81	39,20
12	3,64	36,81	38,16
13	3,64	36,81	39,75
14	3,63	36,81	42,84
15	3,63	36,81	41,00
16	3,63	36,81	37,24
17	3,62	36,81	34,73
18	3,62	36,81	35,68
19	3,61	36,81	35,85
20	3,61	36,80	30,71
21	3,60	36,79	40,54
22	3,60	36,79	41,79
23	3,59	36,79	39,99
24	3,59	36,79	38,07
25	3,58	36,79	37,83
26	3,55	36,79	38,13
27	3,55	36,79	35,13

N°	Lon ° E	Lat ° N	T2 (m)
1	3,70	36,85	3,36
2	3,69	36,85	3,09
3	3,67	36,83	1,19
4	3,66	36,83	3,01
5	3,66	36,83	4,84
6	3,66	36,83	6,98
7	3,65	36,82	4,89
8	3,65	36,82	3,31
9	3,64	36,82	1,00
10	3,64	36,82	4,00
11	3,64	36,82	3,27
12	3,63	36,82	2,75
13	3,63	36,82	6,54
14	3,63	36,82	2,00
15	3,62	36,81	3,00
16	3,62	36,81	8,11
17	3,62	36,81	7,82
18	3,61	36,81	7,93
19	3,61	36,81	3,08
20	3,61	36,81	4,00
21	3,60	36,81	2,88
22	3,59	36,81	4,00
23	3,59	36,81	4,15
24	3,58	36,80	6,00
25	3,58	36,80	3,04
26	3,55	36,79	1,25
27	3,55	36,79	3,00

N°	Lon ° E	Lat ° N	ShA (m)
1	3,70	36,85	5,83
2	3,69	36,84	6,74
3	3,68	36,82	3,24
4	3,67	36,82	5,02
5	3,66	36,82	6,35
6	3,66	36,82	3,07
7	3,65	36,82	7,46
8	3,65	36,82	5,16
9	3,65	36,82	10,03
10	3,64	36,82	8,61
11	3,64	36,82	6,00
12	3,64	36,82	9,75
13	3,63	36,82	9,70
14	3,63	36,81	9,54
15	3,62	36,81	8,57
16	3,62	36,81	5,02
17	3,62	36,81	5,51
18	3,62	36,81	10,34
19	3,61	36,81	11,40
20	3,61	36,81	9,18
21	3,60	36,80	11,26
22	3,59	36,81	0,99
23	3,59	36,80	7,22
24	3,58	36,80	5,41
25	3,58	36,80	5,17
26	3,55	36,79	5,90
27	3,55	36,79	8,58

Table. 2: Presentation of the field work result. Marine terraces and shoreline elevation

Through the field work conducted at 81 locations (Table. 2), we were able to collect valuable data such as the latitude and longitude coordinates of the locations, as well as the elevations at sea level of the First and the second terrace and the shoreline angle. This data enabled them to study the various morphological features of the marine terraces.

To determine the location of the two marine terraces, we used four profiles (A, B, C, D) positioned perpendicular to each coastline (Figure. 77). Then we analyzed these profiles to determine the key points of interest. The results of the analysis revealed that the two flat levels of terraces are located at different elevations. In Table.2 we created a representation of the data collected from different field locations.

To ensure that our results were correct, we took field photos of the four profiles. (Photos. 6, 7, 8 and 9) supported the findings and further highlighted the marine terraces' location.

Our findings have helped illuminate the history of the geomorphic traits of the Zemmouri area, revealing the interplay between the forces of tectonic movement and marine erosion. By studying the traits of the marine terraces, we can gain a deeper understanding of the region's past geological processes.

Photo. 6: Succession of Marine terraces (Profile A) (Lon 3,71E Lat 36,84N)

Photo. 7: Succession of Marine terraces (Profile B) (Lon 3,67E Lat 36,82N)

Photo. 8: Succession of Marine terraces (Profile C) (Lon 3,55E Lat 36,79N)

Photo. 9: Succession of Marine terraces (Profile D) (Lon 3,60E Lat 36,79N)

6. Chapter summary

The elevated marine terraces located in the Zemmouri district are the product of a recurring cycle of marine erosion and tectonic uplift. This process unfolds in the following manner:

1/ The elevated coastline is raised by tectonic uplift. This uplift exposes a flat surface above the sea level.

2/ The exposed surface is then shaped by various erosional processes. This natural phenomenon eventually forms a marine terrace.

3/ The uplift continues to raise the marine terrace above the sea level. This eventually leads to the formation of a new terrace at a higher elevation.

4/ The repeated cycle leads to the formation of numerous marine terraces, each with progressively higher levels than the previous one.

The overall uplift that has occurred over the years is reflected in the elevated levels of the marine terraces. The profile and shape of these structures provide insight into the various erosional processes that affected them.

The study analyzed the coastal distribution, elevation, and evolution characteristics of the marine terraces in the region of Zemmouri. It was revealed that the continuous deformation of the coast is caused by the convergence of the European and African plates.

The detailed study of the elevated marine terraces allowed researchers to gain a deeper understanding of the region's tectonic history. It also helped develop sea-level curves comprehension.

The findings of this study have important geohazard and scientific implications for the region. Understanding the various processes that have affected the region's coastal environment is very important for developing a better understanding of the dynamics of the natural world. According to the study, the Zemmouri district has experienced earthquakes because of the convergence of the Eurasian and African plates. In addition, the intense tidal movements that have occurred in the area have also affected the erosion of the marine terraces.

The study also revealed that the various factors that have affected the coastal environment have been linked to the development of sea-level curves in the eastern part of Algiers and the Zemmouri district. These curves are known to be influenced by the effects of both decreasing and rising sea levels. As a result, the study concluded that the continuous movement of the coast has been instrumental in the preservation and formation of the elevated marine terraces in the region.

General Conclusion

The objective of this thesis was to provide a comprehensive analysis of the deformations and deposits of the Quaternary in Eastern Algeria, focusing on the coastal regions. Through this study, various aspects of the region's geological history were revealed. The findings and implications of each chapter are highlighted below.

The first chapter of the study introduced the subject and discussed the importance of looking into the deformations and deposits of the Quaternary in this area. It also emphasized the research's goals and the methodology utilized throughout the course of the study.

The second chapter of the study focused on the concept of the study and its scope. It established the necessary foundations for the subsequent chapters. By clearly defining the study's boundaries, this section ensured that the research would be focused on a specific target.

Chapter 3's literature review provided an overview of the previous research on the deformations and deposit of the Quaternary in eastern Algeria. It also highlighted the gaps in the literature and provided a theoretical background. This section laid the foundation for the contributions made in subsequent chapters.

The fourth chapter of the study explores the various mechanisms by which marine terraces can be formed and maintained along the coast. Through an in-depth analysis, it revealed how these landforms contribute to the coastal uplift dynamics. The implications of these landforms for the understanding of coastal geology were also discussed.

Following the previous chapters, the fifth chapter explored the link between the seismic hazard potential and the topography in Northeast Algeria. By evaluating the correlation between the seismic activities and the characteristics of the ground, this study provided valuable insight into the region's seismic risks. The findings of this study can help improve the accuracy of the seismic hazard maps in the region and inform the planning for the development of infrastructure and land use.

The sixth chapter focuses on the Eastern Algiers case study (Zemmouri). It explores the various aspects of the coastal uplift and the active coastal tectonic deformation. Through an in-depth analysis, this chapter has provided a detailed comprehension of the marine terraces and coastal tectonic deformation's spatial distribution.

The findings of this study can help improve the accuracy of the seismic hazard maps in the region and inform the planning for the development of infrastructure and land use. They also provide valuable insight into the plate convergence and tectonic processes in the area.

The thesis has made significant progress in our knowledge of Quaternary deposits and coastal deformations in eastern Algeria, particularly in the region's coastal formations. The comprehensive analyses and investigations in each chapter have contributed to the knowledge of tectonic, seismic, and geological aspects of the area.

The findings of this study can help improve the accuracy of the seismic hazard maps in the region and inform the planning for the development of infrastructure and land use. It also provides valuable insight into the complex geological processes in the area. More research in this field can help us develop effective strategies and practices for sustainable development

Recommendations

To enhance the findings of this thesis regarding the vertical displacement of marine terraces related with the seismic events in eastern Algeria, it is imperative to focus on further research topics, following these key recommendations.

First, continuous research and monitoring of Quaternary deposits and coastal deformations must be prioritized to track changes linked to ongoing tectonic and geological processes.

Second, conducting a comprehensive seismic hazard assessment, regularly updating hazard maps, and using the latest research findings to inform infrastructure development and land-use planning are essential steps.

Lastly, initiating public awareness and education campaigns to inform the local population about seismic risks is crucial in reducing the potential impact on lives and property. These efforts, when implemented, will significantly bolster the region's resilience in the face of ongoing geological and tectonic dynamics, promoting a safer and more sustainable future.

References

Abacha, I. (2015). Study of the seismicity of the Northeast region of Algeria. Thesis of doctorate. Ferhat Abbas-Setif University (Algeria).

Abacha, I., Boulahia, O., Yelles-Chaouche, A., Semmane, F., Beldjoudi, H., & Bendjama, H. (2019). The 2010 Beni-Ilmane, Algeria, earthquake sequence: statistical analysis, source parameters, and scaling relationships. Journal of Seismology, 23(1), 181-193.

Aite Mohamed, O., & Gelard, J. P. (1997). Distension néogène post-collisionnelle sur le transect de Grande-Kabylie (Algérie). Bulletin de la Société geologique de France, 168(4), 423-436.

Akziz, Djamal, Zoubida Nemer, Bruno Colavitto, Mohamed Said Guettouche, Abdeldjalil Goumrasa, and Abdelhakim Belaroui. "Geomorphic analysis and quaternary neotectonic deformation in the eastern Babors chain, Bejaia, Algeria." Journal of African Earth Sciences 185 (2022): 104387.

Alase, Abayomi. "The interpretative phenomenological analysis (IPA): A guide to a good qualitative research approach." International Journal of Education and Literacy Studies 5, no. 2 (2017): 9-19.

Alpers, C. N., & Brimhall, G. H. (1988). Middle Miocene climatic change in the Atacama Desert, northern Chile: Evidence from supergene mineralization at La Escondida. Geological Society of America Bulletin, 100(10), 1640-1656.

Alshenqeeti, Hamza. "Interviewing as a data collection method: A critical review." English linguistics research 3, no. 1 (2014): 39-45.

Amir, L., and Barbara Theilen-Willige. "Coastal risk and water flow analysis in eastern algeria (Western Mediterranean)." Univ J Geosci 5, no. 4 (2017): 99-111.

Aoudia, A., Vaccari, F., Suhadolc, P., & Meghraoui, M. (2000). Seismogenic potential and earthquake hazard assessment in the Tell Atlas of Algeria. Journal of Seismology, 4, 79–98.

Arifin, S. R. M. (2018). Ethical considerations in qualitative study. International Journal of Care Scholars, 1(2), 30-33.

Authemayou, C., Pedoja, K., Heddar, A., Molliex, S., Boudiaf, A., Ghaleb, B., ... & Nexer, M. (2017). Coastal uplift west of Algiers (Algeria): pre-and post-Messinian sequences of marine terraces and rasas and their associated drainage pattern. International Journal of Earth Sciences, 106(1), 19-41.

Bekhouch, G., Puckett, T. M., Khiari, A., Djerrab, M. R., Meguelatti, A., & Dinar, H. (2023). Optimized event stratigraphy of Cenomanian-Turonian ostracods of North Africa and the middle east. Journal of African Earth Sciences, 105061.

Belabbes, S. (2008). Characterization of active deformation by Radar interferometry (InSAR): Blind and hidden seismic faults of the Tellian Atlas (Algeria) and the Rif (Morocco) along the African-Eurasian plate boundary.

Benaouali-Mebarek, N., de Lamotte, D. F., & Roure, F. (2006, June). Post Cretaceous Deformation in the Tell-Atlas System in Central Algeria. In 68th EAGE Conference and Exhibition incorporating SPE EUROPEC 2006 (pp. cp-2). European Association of Geoscientists & Engineers.

Benbakhti, Imene Meriem, Said Maouche, Djelloul Belhai, Assia Harbi, Jean-François Ritz, Ghilles Rabai, Ahmed Rezouk, and Fawzi Doumaz. "Characterizing the active tectonics in the Oran region (Algeria) and recasting the 1790 earthquake." Journal of Seismology 22, no. 6 (2018): 1549-1561.

Benhamouche, A., A. Nedjari, Y. Bouhadad, D. Machane, E. Oubaiche, and N. Sidi Said. "Field evidence of seismites in Quaternary deposits of the Jijel (Eastern Algeria) coastal region." Journal of seismology 18, no. 2 (2014): 289-299.

Benjamin, Jonathan, Alessio Rovere, Alessandro Fontana, Stefano Furlani, Matteo Vacchi, Robyn H. Inglis, Ehudi Galili. "Late Quaternary sea-level changes and early human societies in the central and eastern Mediterranean Basin: An interdisciplinary review." Quaternary International 449 (2017): 29-57.

Benouar, D. (1993). The seismicity of Algeria and adjacent regions during the twentieth century. PhD-Thesis, Imperial College of Science, Technology and Medicine, Univ. London, p. 712.

Benouar, D. (1994). Magnitude-intensity and intensity-attenuation relationships for Atlas region and Algerian earthquakes. Earth- quake Engineering and Structural Dynamics, 23, 717–727.

Bernreuter, D. L., Savy J. B., Mensing R. W., & Chen J. C. (1989). Seismic hazard characterization of 69 nuclear plant sites East of the Rocky Mountains, NUERG/CR-5250 (Vol. 1). Washington, DC: US Nuclear Regulatory Commission.

Bezzeghoud, M., Ayadi, A., Seba¨ı, A., A¨ıt Messaoud, M., Mok-rane, A., & Benhallou, H. (1996). Seismicity of Algeria between 1365 and 1989: Map of maximum observed intensities (MOI).

Bezzeghoud, Mourad, Abdelhakim Ayadi, B. Caldeira, João Fontiela, and JF Borges. "The largest earthquakes in Algeria in modern times: the El Asnam and Zemmouri-Boumerdès faults." Earth Physics 29 (2017): 183.

Billi, A., Faccenna, C., Bellier, O., Minelli, L., Neri, G., Piromallo, C., ... & Serpelloni, E. (2011). Recent tectonic reorganization of the Nubia-Eurasia convergent boundary heading for the closure of the western Mediterranean. Bulletin de la Société Géologique de France, 182(4), 279-303.

Blanco-Chao, R., Pedoja, K., Witt, C., Martinod, J., Husson, L., Regard, V., ... & Arozarena-Llopis, I. (2014). The rock coast of South and Central America. Geological Society, London, Memoirs, 40(1), 155-191.

Bloom, A. L. (1998). Geomorphology: a systematic analysis of late Cenozoic landforms (No. 551.79 BLO).

Boudiaf, M. A. (1996). Seismotectonic study of the region of Algiers and Kabylie (Algeria). PhD thesis, University of Mont- pellier, p. 274.

Bouillin. J. P. (1986). Le" bassin maghrebin"; une ancienne limite entre l'Europe et l'Afrique a l'ouest des Alpes. Bulletin de la Société géologique de France, 2(4), 547-558.

Bouillin. J. P., Dumont, T. H. I. E. R. R. Y., & Olivier, P. H. I. L. I. P. P. E. (1992). Organisation structurale et sedimentaire de la paleomarge nord tethysienne au Jurassique dans les monts Peloritains (Sicile, Italie). Bulletin de la Société géologique de France, 163(6), 761-770.

Boukhedimi, Mohamed Amine, Amina Louni-Hacini, Youcef Bouhadad, Jean-François Ritz, Djamel Machane, Azzeddine Benhamouche, and Hamid Bourenane. "Evidence of seismites in coastal Quaternary deposits of western Oranie (northwestern Algeria)." Journal of Seismology 21, no. 3 (2017): 539-549.

Bounif, A., Bezzeghoud, M., Dorbath, L., Legrand, D., Deschamps, A., Rivera, L., & Benhallou, H. (2003). Seismic source study of the 1989, October 29, Chenoua (Algeria) earthquake from aftershocks, broad-band and strong ground motion records. Annals of Geophysics.

Bounif, A., Dorbath, C., Ayadi, A., Meghraoui, M., Beldjoudi, H., Laouami, N., ... & Maouche, S. (2004). The 21 May 2003 Zemmouri (Algeria) earthquake Mw 6.8: relocation and aftershock sequence analysis. Geophysical Research Letters, 31(19).

Bounif, M. A., Haessler, H., & Meghraoui, M. (1987). The Con- stantine earthquake of October 27, 1985: Surface ruptures and aftershock study. Earth and Planetary Science Letters, 85, 451–460.

Bouyahiaoui, Boualem, F. Sage, A. Abtout, Frauke Klingelhoefer, K. Yelles-Chaouche, P. Schnürle, A. Marok. "Crustal structure of the eastern Algerian continental margin and adjacent deep basin: implications for late Cenozoic geodynamic evolution of the western Mediterranean." Geophysical Journal International 201, no. 3 (2015): 1912-1938.

Bracène, R., & de Lamotte, D. F. (2002). The origin of intraplate deformation in the Atlas system of western and central Algeria: from Jurassic rifting to Cenozoic–Quaternary inversion. Tectonophysics, 357(1-4), 207-226.

Bradley, W. C., & Griggs, G. B. (1976). Form, genesis, and deformation of central California wave-cut platforms. Geological Society of America Bulletin, 87(3), 433-449.

Brinkmann, Svend, and Steinar Kvale. Doing interviews. Vol. 2. Sage, (2018).

Burbank, D. W., & Anderson, R. S. (2001). Geomorphic markers. Burbank, DW & Anderson, RS, Tectonic Geomorpholgy. Malden:(ed.) Blackwell Publishing, 13-32.

Cabioch, G., & Ayliffe, L. K. (2001). Raised coral terraces at Malakula, Vanuatu, Southwest Pacific, indicate high sea level during marine isotope stage 3. Quaternary Research, 56(3), 357-365.

Calais, E., Vergnolle, M., San'Kov, V., Lukhnev, A., Miroshnitchenko, A., Amarjargal, S., & Déverchère, J. (2003). GPS measurements of crustal deformation in the Baikal-Mongolia area (1994–2002): Implications for current kinematics of Asia. Journal of Geophysical Research: Solid Earth, 108(B10).

Camerlenghi, A., & Pini, G. A. (2009). Mud volcanoes, olistostromes and Argille scagliose in the Mediterranean region. Sedimentology, 56(1), 319-365.

Cantalamessa, G., & Di Celma, C. (2004). Sequence response to syndepositional regional uplift: insights from high-resolution sequence stratigraphy of late Early Pleistocene strata, Periadriatic Basin, central Italy. Sedimentary Geology, 164(3-4), 283-309.

Carminati, E., Wortel, M. J. R., Meijer, P. T., & Sabadini, R. (1998). The two-stage opening of the western–central Mediterranean basins: a forward modeling test to a new evolutionary model. Earth and Planetary Science Letters, 160(3-4), 667-679.

Carminati, E., Wortel, M. J. R., Spakman, W., & Sabadini, R. (1998). The role of slab detachment processes in the opening of the western–central Mediterranean basins: some geological and geophysical evidence. Earth and Planetary Science Letters, 160(3-4), 651-665.

Cavazza, W., & Stampfli, G. M. (2004). The TRANSMED Atlas. The Mediterranean Region from Crust to Mantle: The Mediterranean Region from Crust to Mantle: Geological and Geophysical Framework of the Mediterranean and the Surrounding Areas. Springer Science & Business Media.

Cazeaux, Clive. Art, research, philosophy. Taylor & Francis, 2017.

CCKP, 2021. Algeria. (Online) Available at: https://climateknowledgeportal.worldbank.org/country/algeria/impacts-sea-level-rise

Chappell, J. (1974). Geology of coral terraces, Huon Peninsula, New Guinea: a study of Quaternary tectonic movements and sea-level changes. Geological Society of America Bulletin, 85(4), 553-570.

Chappell, J., Omura, A., Esat, T., McCulloch, M., Pandolfi, J., Ota, Y., & Pillans, B. (1996). Reconciliaion of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records. Earth and Planetary Science Letters, 141(1-4), 227-236.

Chen, J. H., Curran, H. A., White, B., & Wasserburg, G. J. (1991). Precise chronology of the last interglacial period: 234U-230Th data from fossil coral reefs in the Bahamas. Geological Society of America Bulletin, 103(1), 82-97.

Clemmensen, L. B., Andreasen, F., Nielsen, S. T., & Sten, E. (1996). The late Holocene coastal dunefield at Vejers, Denmark: characteristics, sand budget and depositional dynamics. Geomorphology, 17(1-3), 79-98.

Coiffait, PhE. (1992). A post-nappe basin in its structural frame- work: The example of the Constantine basin (North-East Algeria). PhD Thesis, University of Nancy.

Comas, M. C., Platt, J. P., Soto, J. I., & Watts, A. B. (1999). 44. The origin and tectonic history of the Alboran Basin: insights from Leg 161 results. In Proceedings of the ocean drilling program scientific results (Vol. 161, pp. 555-580).

Cope, T. D. (2003). Sedimentary evolution of the Yanshan fold-thrust belt, Northeast China. Stanford University.

Cornell, C. A. (1968). Engineering seismic risk analysis. Bulletin of the Seismological Society of America, 58, 1583–1606.

Cortés-Sánchez, M., Morales-Muñiz, A., Simón-Vallejo, M. D., Bergadà-Zapata, M. M., Delgado-Huertas, A., López-García, P., ... & Vera-Peláez, J. L. (2008). Palaeoenvironmental and cultural dynamics of the coast of Málaga (Andalusia, Spain) during the Upper Pleistocene and early Holocene. Quaternary Science Reviews, 27(23-24), 2176-2193.

Coulon, C., Megartsi, M. H., Fourcade, S., Maury, R. C., Bellon, H., Louni-Hacini, A., ... & Hermitte, D. (2002). Post-collisional transition from calc-alkaline to alkaline volcanism during the Neogene in Oranie (Algeria): magmatic expression of a slab breakoff. Lithos, 62(3-4), 87-110.

Dannels, Sharon Anderson. "Research design." In The reviewer’s guide to quantitative methods in the social sciences, pp. 402-416. Routledge, 2018.

de Gelder, G., Jara-Muñoz, J., Melnick, D., Fernández-Blanco, D., Rouby, H., Pedoja, K., ... & Lacassin, R. (2020). How do sea-level curves influence modeled marine terrace sequences?. Quaternary Science Reviews, 229, 106132.

De Lamotte, D. F., Bracene, R. A. B. A. H., Benaouali, N. A. R. I. M. A. N. E., & Roure, F. R. A. N. Ç. O. I. S. (2002, May). Crustal structure of the Maghrebides along a central Algerian transect. In 64th EAGE Conference & Exhibition (pp. cp-139). European Association of Geoscientists & Engineers.

de Lamotte, D. F., Leturmy, P., Missenard, Y., Khomsi, S., Ruiz, G., Saddiqi, O., ... & Michard, A. (2009). Mesozoic and Cenozoic vertical movements in the Atlas system (Algeria, Morocco, Tunisia): an overview. Tectonophysics, 475(1), 9-28.

Delouis, B., Vallée, M., Meghraoui, M., Calais, E., Maouche, S., Lammali, K., ... & Yelles, K. (2004). Slip distribution of the 2003 Boumerdes-Zemmouri earthquake, Algeria, from teleseismic, GPS, and coastal uplift data. Geophysical Research Letters, 31(18).

DeMets, C., Gordon, R. C., Argus, D. F., & Stein, S. (1990). Current plate motion. Geophysical Journal International, 101, 425–478.

DeMets, C., Gordon, R. G., Argus, D. F., & Stein, S. (1994). Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions. Geophysical research letters, 21(20), 2191-2194.

Derruau, M. (1974). Un guide géologique et géomorphologique aux volcans du Velay: P. Bout, Les Volcans du Velay, itinéraires géologiques et géomorphologiques en Haute-Loire. In Annales de géographie (Vol. 83, No. 456, pp. 226-226). Persée-Portail des revues scientifiques en SHS.

Déverchère, J., Yelles, K., Domzig, A., Mercier de Lépinay, B., Bouillin. J. P., Gaullier, V., ... & Dan, G. (2005). Active thrust faulting offshore Boumerdes, Algeria, and its relations to the 2003 Mw 6.9 earthquake. Geophysical research letters, 32(4).

Dewey, J. F., Helman, M. L., Knott, S. D., Turco, E., & Hutton, D. H. W. (1989). Kinematics of the western Mediterranean. Geological Society, London, Special Publications, 45(1), 265-283.

Dewey, J. F., Shackleton, R. M., Chengfa, C., & Yiyin, S. (1988). The tectonic evolution of the Tibetan Plateau. Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences, 327(1594), 379-413.

Djouder, F., & Boutiba, M. (2017). Vulnerability assessment of coastal areas to sea level rise from the physical and socioeconomic parameters: case of the Gulf Coast of Bejaia, Algeria. Arabian Journal of Geosciences, 10(14), 1-20.

Dinar, H., Oudni, A., Khiari, AK, & Zeddam, R. Structural and Geotechnical Characterization of the Tagharist–Yabous-Khenchela Dam (North-East Algeria). CIGCM 2018 , 50.

Doglioni, C., Gueguen, E., Sàbat, F., & Fernandez, M. (1997). The western Mediterranean extensional basins and the Alpine orogen. Terra Nova, 9(3), 109-112.

Domzig, A., (2006). Active and recent deformation, and sedimen- tary tectonic structuration of the Algerian submarine margin. PhD thesis, Dissertation, Inst. Univ. Eur. de la Mer, Brest Univ., Brittany, France, p. 333.

Domzig, A., Yelles, K., Le Roy, C., Déverchère, J., Bouillin. J. P., Bracène, R., ... & Pauc, H. (2006). Searching for the Africa–Eurasia Miocene boundary offshore western Algeria (MARADJA'03 cruise). Comptes Rendus Geoscience, 338(1-2), 80-91.

Dumitrescu, L., & Maury, F. (2000). Al2O3 coatings on stainless steel from Al metal-organic chemical vapor deposition and thermal treatments. Surface and Coatings Technology, 125(1-3), 419-423.

Dunai, T. J., López, G. A. G., & Juez-Larré, J. (2005). Oligocene–Miocene age of aridity in the Atacama Desert revealed by exposure dating of erosion-sensitive landforms. Geology, 33(4), 321-324.

Durand-Delga, M. (2011). La recherche géologique française en Algérie du Nord après 1962. Travaux du Comité français d'Histoire de la Géologie, 3(10), 217-222.

Etikan, I., & Bala, K. (2017). Sampling and sampling methods. Biometrics & Biostatistics International Journal, 5(6), 00149.

Faccenna, C., Becker, T. W., Lucente, F. P., Jolivet, L., & Rossetti, F. (2001). History of subduction and back arc extension in the Central Mediterranean. Geophysical Journal International, 145(3), 809-820.

Fleming, K., Johnston, P., Zwartz, D., Yokoyama, Y., Lambeck, K., & Chappell, J. (1998). Refining the eustatic sea-level curve since the Last Glacial Maximum using far-and intermediate-field sites. Earth and Planetary Science Letters, 163(1-4), 327-342.

Frankel, A. (1995). Mapping seismic hazard in the Central and eastern United States. Seismol Res Lett 66(4):8–21

French, J. E., Heaman, L. M., Chacko, T., & Srivastava, R. K. (2008). 1891–1883 Ma Southern Bastar–Cuddapah mafic igneous events, India: A newly recognized large igneous province. Precambrian research, 160(3-4), 308-322.

Frizon de Lamotte, D., Raulin, C., Mouchot, N., Wrobel-Daveau, J. C., Blanpied, C., & Ringenbach, J. C. (2011). The southernmost margin of the Tethys realm during the Mesozoic and Cenozoic: Initial geometry and timing of the inversion processes. Tectonics, 30(3).

Frizon de Lamotte, D., Saint Bezar, B., Bracène, R., & Mercier, E. (2000). The two main steps of the Atlas building and geodynamics of the western Mediterranean. Tectonics, 19(4), 740-761.

Frizon de Lamotte, D., Zizi, M., Missenard, Y., Hafid, M., Azzouzi, M. E., Maury, R. C., ... & Michard, A. (2008). The atlas system. In Continental evolution: the geology of Morocco (pp. 133-202). Springer, Berlin, Heidelberg.

Gallup, C. D., Edwards, R. L., & Johnson, R. G. (1994). The timing of high sea levels over the past 200,000 years. Science, 263(5148), 796-800.

Gilbert, G. K. (1890). Lake Bonneville (Vol. 1). United States Geological Survey.

Goldman, Alvin I. "The Journal of Philosophy." Freedom of Speech (2018): 283-301.

Ghoual, AR, Khattabi, M., & Dinar, H. (2022). Gelology and geomorphology of Jebel Sidi R'Ghis.

Goy, J., Macharé, J., Ortlieb, L., & Zazo, C. (1992). Quaternary shorelines in southern Peru: A record of global sea-level fluctuations and tectonic uplift in Chala Bay. Quaternary International, 15, 99-112.

Grassmann, S., Cramer, B., Delisle, G., Hantschel, T., Messner, J., & Winsemann, J. (2010). pT-effects of Pleistocene glacial periods on permafrost, gas hydrate stability zones and reservoir of the Mittelplate oil field, northern Germany. Marine and petroleum geology, 27(1), 298-306.

Guemache, M. A. (2010). Geodynamic evolution of the seismo- genic basins of Algiers (Algeria): Multidisciplinary approach (geological and geophysical methods). PhD Thesis, USTHB, Order No.: 01/2010-D/S.T. Algiers

Guerrera, F., Martín-Algarra, A., & Martín-Martín, M. (2012). Tectono-sedimentary evolution of the 'Numidian Formation' and Lateral Facies (southern branch of the western Tethys): constraints for central-western Mediterranean geodynamics. Terra Nova, 24(1), 34-41.

Guilcher, A. (1954). Morphologie littorale du calcaire en Méditerranée occidentale (Catalogne et environs d'Alger). Bulletin de l'Association de Géographes Français, 31(241), 50-58.

Guilcher, A., & Hallegouët, B. (1981). Le haut cordon de galets pléistocène de Ruvein-en-Plovan (Finistère) et ses enseignements généraux. Quaternaire, 18(2), 75-82.

Gutscher, M. A., Malod, J., Rehault, J. P., Contrucci, I., Klingelhoefer, F., Mendes-Victor, L., & Spakman, W. (2002). Evidence for active subduction beneath Gibraltar. Geology, 30(12), 1071-1074.

Hamdache, M., & Retief, S. J. P. (2001). Site-specific seismic hazard estimation in the main seismogenic zones of north Algeria. Pure Applied Geophysics, 158, 1677–1690.

Hamdache, M., Bezzeghoud, M., & Mokrane, M. (1998). Estima- tion of Seismic hazard parameters in the northern part of Algeria. Pure and Applied Geophysics, 151, 101–117.

Hamidatou, M., & Sbartai, B. (2016). Deterministic assessment of seismic risk in Constantine city. Northeast Algeria Nat Hazards. https://doi.org/10.1007/s11069-016-2693-2.

Hamidatou, M., & Sbartai, B. (2017). Probabilistic seismic hazard assessment in the Constantine region, Northeast of Algeria. Arabian Journal of Geoscience. https://doi.org/10.1007/s12517- 017-2876-5.

Harbi, A. (1996). The Algerian Eastern margin: Results of a study by seismic reflection (Vol. 762, p. 124). Algiers: C.R.A.A.G.

Harbi, A. (2001). Analysis of seismicity and highlighting accidents Assets in North-East Algeria. PhD Thesis, University of Algiers.

Harbi, A., Antonella, P., & Giuliano, F. P. (2010). Seismicity of Eastern Algeria: A revised and extended earthquake catalogue. Natural Hazards. https://doi.org/10.1007/s11069-009-9497-6.

Harbi, A., Benouar, D., & Benhallou, H. (2003). Re-appraisal of seismicity and seismotectonics in the north-eastern Algeria Part I: Review of historical seismicity. Journal of Seismology, 7(1), 115-136.

Harbi, A., Maouche, S., Vaccari, F., Aoudia, A., Oussadou, F., Panza, G. F., & Benouar, D. (2007). Seismicity, seismic input and site effects in the Sahel—Algiers region (North Algeria). Soil Dynamics and Earthquake Engineering, 27(5), 427-447.

Harbi, A., Peresan, A., & Panza, G. F. (2010). Seismicity of Eastern Algeria: a revised and extended earthquake catalogue. Natural hazards, 54(3), 725-747.

Harbi, A., S. Maouche, and A. Ayadi. "Neotectonics and associate seismicity in the Eastern Tellian Atlas of Algeria." Journal of Seismology 3, no. 1 (1999): 95-104.

Harbi, Assia, Mustapha Meghraoui, and Said Maouche. "The Djidjelli (Algeria) earthquakes of 21 and 22 August 1856 (I0 VIII, IX) and related tsunami effects Revisited." Journal of seismology 15, no. 1 (2011): 105-129.

Harvell, D., Aronson, R., Baron, N., Connell, J., Dobson, A., Ellner, S., ... & Ward, J. (2004). The rising tide of ocean diseases: unsolved problems and research priorities. Frontiers in Ecology and the Environment, 2(7), 375-382.

Hatzfeld, D. (1978). Seismotectonic study of the Ibero-Maghrebian collision zone. Ph.D., Thesis, Grenoble (France), p. 281.

Haythem, D., Khiari, A., Zineb, M., Taib, H., Hana, N., & Bilal, B. (2023). Uplifted marine terraces by active coastal tectonic deformation along the east of Algiers: implications for African and European plate convergence and sea-level curves. BOLETÍN GEOLÓGICO Y MINERO , 134 (2), 57-67.

Heddar, A., Beldjoudi, H., Authemayou, C., SiBachir, R., Yelles-Chaouche, A., & Boudiaf, A. (2016). Use of the ESI-2007 scale to evaluate the 2003 Boumerdès earthquake (North Algeria). Annals of Geophysics, 59(2), S0211-S0211.

Hinojosa, L. F., & Villagrán, C. (2005). Did South American Mixed Paleofloras evolve under thermal equability or in the absence of an effective Andean barrier during the Cenozoic?. Palaeogeography, Palaeoclimatology, Palaeoecology, 217(1-2), 1-23.

Hinojosa, L. F., Armesto, J. J., & Villagrán, C. (2006). Are Chilean coastal forests pre-Pleistocene relicts? Evidence from foliar physiognomy, palaeoclimate, and phytogeography. Journal of Biogeography, 33(2), 331-341.

Houston, J., & Hartley, A. J. (2003). The central Andean west-slope rainshadow and its potential contribution to the origin of hyper-aridity in the Atacama Desert. International Journal of Climatology: A Journal of the Royal Meteorological Society, 23(12), 1453-1464.

Javadi, M., & Zarea, K. (2016). Understanding thematic analysis and its pitfall. Demo, 1(1), 33-39.

Jiménez-Munt, I., Fernàndez, M., Torne, M., & Bird, P. (2001). The transition from linear to diffuse plate boundary in the Azores–Gibraltar region: results from a thin-sheet model. Earth and Planetary Science Letters, 192(2), 175-189.

Johnson, D. W. (1919). Shore processes and shoreline development. John Wiley & Sons, Incorporated.

Johnson, Jessica L., Donna Adkins, and Sheila Chauvin. "A review of the quality indicators of rigor in qualitative research." American Journal of Pharmaceutical Education 84, no. 1 (2020).

Kechidi, S., Castro, J. M., Monteiro, R., Marques, M., Yelles, K., Bourahla, N., & Hamdache, M. (2021). Development of exposure datasets for earthquake damage and risk modelling: the case study of northern Algeria. Bulletin of Earthquake Engineering, 19(12), 5253-5283.

Khelif, M. F., Yelles-Chaouche, A., Benaissa, Z., Semmane, F., Beldjoudi, H., Haned, A., ... & Kherroubi, A. (2018). The 2016 Mihoub (north-central Algeria) earthquake sequence: seismological and tectonic aspects. Tectonophysics, 736, 62-74.

Kherroubi, A., Déverchère, J., Yelles, A., De Lépinay, B. M., Domzig, A., Cattaneo, A., ... & Graindorge, D. (2009). Recent and active deformation pattern off the easternmost Algerian margin, Western Mediterranean Sea: New evidence for contractional tectonic reactivation. Marine Geology, 261(1-4), 17-32.

Kober, F., Ivy-Ochs, S., Schlunegger, F., Baur, H., Kubik, P. W., & Wieler, R. (2007). Denudation rates and a topography-driven rainfall threshold in northern Chile: Multiple cosmogenic nuclide data and sediment yield budgets. Geomorphology, 83(1-2), 97-120.

Kourat, T., Smadhi, D., & Madani, A. (2022). Modeling the Impact of Future Climate Change Impacts on Rainfed Durum Wheat Production in Algeria. Climate, 10(4), 50.

Lambeck, K., Esat, T. M., & Potter, E. K. (2002). Links between climate and sea levels for the past three million years. Nature, 419(6903), 199-206.

LaValle, P. D., Lakhan, V. C., & Trenhaile, A. S. (2000). Short term fluctuations of Lake Erie water levels and the El Niño/Southern Oscillation. The Great Lakes Geographer, 7(1), 1-8.

Leprêtre, A., Klingelhoefer, F., Graindorge, D., Schnurle, P., Beslier, M. O., Yelles, K., ... & Bracene, R. (2013). Multiphased tectonic evolution of the Central Algerian margin from combined wide-angle and reflection seismic data off Tipaza, Algeria. Journal of Geophysical Research: Solid Earth, 118(8), 3899-3916.

Lonergan, L., & White, N. (1997). Origin of the Betic-Rif mountain belt. Tectonics, 16(3), 504-522.

Lucente, F. P., Chiarabba, C., Cimini, G. B., & Giardini, D. (1999). Tomographic constraints on the geodynamic evolution of the Italian region. Journal of Geophysical Research: Solid Earth, 104(B9), 20307-20327.

Ludwig, B., Auzet, A. V., Boiffin, J., Papy, F., King, D., & Chadoeuf, J. (1996). Etats de surface, structure hydrographique et érosion en rigole des bassins versants cultivés du Nord de la France. Etude et gestion des Sols, 3, 53-70.

Ludwig, J., Tongway, D., Hodgkinson, K., Freudenberger, D., & Noble, J. (1996). Landscape ecology, function and management: principles from Australia's rangelands. Csiro Publishing.

Macharé, J., & Ortlieb, L. (1992). Plio-Quaternary vertical motions and the subduction of the Nazca Ridge, central coast of Peru. Tectonophysics, 205(1-3), 97-108.

Malinverno, A., & Ryan, W. B. (1986). Extension in the Tyrrhenian Sea and shortening in the Apennines as result of arc migration driven by sinking of the lithosphere. Tectonics, 5(2), 227-245.

Maouche, S., Meghraoui, M., Morhange, C., Belabbes, S., Bouhadad, Y., & Haddoum, H. (2011). Active coastal thrusting and folding, and uplift rate of the Sahel Anticline and Zemmouri earthquake area (Tell Atlas, Algeria). Tectonophysics, 509(1-2), 69-80.

Maouche, Said, Abdeslam Abtout, Nacer-Eddine Merabet, Tahar Aïfa, Atmane Lamali, Boualem Bouyahiaoui, Sofiane Bougchiche, and Mohamed Ayache. "Tectonic and Hydrothermal Activities in Debagh, Guelma Basin (Algeria)." Journal of Geological Research (2013).

Maouche, Said, Youcef Bouhadad, Assia Harbi, Yasmina Rouchiche, Farida Ousadou, and Abdelhakim Ayadi. "Active tectonics and seismic hazard in the Tell Atlas (Northern Algeria): a review." The Geology of the Arab World---An Overview (2019): 381-400.

Marquardt, C., Lavenu, A., Ortlieb, L., Godoy, E., & Comte, D. (2004). Coastal neotectonics in Southern Central Andes: uplift and deformation of marine terraces in Northern Chile (27 S). Tectonophysics, 394(3-4), 193-219.

Mattei, M., Cipollari, P., Cosentino, D., Argentieri, A., Rossetti, F., Speranza, F., & Di Bella, L. (2002). The Miocene tectono-sedimentary evolution of the southern Tyrrhenian Sea: stratigraphy, structural and palaeomagnetic data from the on-shore Amantea basin (Calabrian Arc, Italy). Basin Research, 14(2), 147-168.

Mauffret, A. (2007). The northwestern (Maghreb) boundary of the Nubia (Africa) plate. Tectonophysics, 429(1-2), 21-44.

Mauffret, A., Frizon de Lamotte, D., Lallemant, S., Gorini, C., & Maillard, A. (2004). E–W opening of the Algerian Basin (western Mediterranean). Terra Nova, 16(5), 257-264.

McGuire, R. K. (1978). FRISK: Computer program for seismic risk analysis using faults as earthquake sources. U.S. Geological Survey. Open file report 78-1007.

McGuire, R. K., & Arabasz, W. J. (1990). An introduction to probabilistic seismic hazard analysis. In S. H. Ward (Ed.), Geotechnical and environmental geophysics (Vol. 3, pp. 333–353). Tulsa: Society of Exploration Geophysicists.

Meco, J., Lomoschitz, A., Koppers, A. A., Miggins, D. P., Huertas, M. J., Betancort, J. F., & Soler-Onís, E. (2020). Late Miocene and Early Pliocene coastal deposits from the Canary Islands: New records and paleoclimatic significance. Journal of African Earth Sciences, 164, 103802.

Medaouri, M., Bracene, R., Déverchère, J., Graindorge, D., Ouabadi, A., & Yelles-Chaouche, A. K. (2012). Structural styles and neogene petroleum system around the Yusuf-Habibas ridge (Alboran basin, Mediterranean sea). The Leading Edge, 31(7), 776-785.

Meghraoui, M. (1988). Geology of seismic zones of northern Algeria, active tectonics, paleoseismology, and seismotectonic synthesis. PhD Thesis, University of Paris-Orsay, p. 356.

Meghraoui, M. (1991). Blind reverse faulting system associated with the Mont Chenoua-Tipaza earthquake of 29 October 1989 (north-central Algeria). Terra nova, 3(1), 84-92.

Meghraoui, M., Maouche, S., Chemaa, B., Cakir, Z., Aoudia, A., Harbi, A., ... & Benhamouda, F. (2004). Coastal uplift and thrust faulting associated with the Mw= 6.8 Zemmouri (Algeria) earthquake of 21 May, 2003. Geophysical Research Letters, 31(19).

Melnick, D., & Echtler, H. P. (2006). Morphotectonic and geologic digital map compilations of the south-central Andes (36–42 S). In The andes (pp. 565-568). Springer, Berlin, Heidelberg.

Merritts, D., & Bull, W. B. (1989). Interpreting Quaternary uplift rates at the Mendocino triple junction, northern California, from uplifted marine terraces. Geology, 17(11), 1020-1024.

Missenard, Y., Zeyen, H., Frizon de Lamotte, D., Leturmy, P., Petit, C., Sébrier, M., & Saddiqi, O. (2006). Crustal versus asthenospheric origin of relief of the Atlas Mountains of Morocco. Journal of Geophysical Research: Solid Earth, 111(B3).

Moon, V., Bradshaw, J., Smith, R., & de Lange, W. (2005). Geotechnical characterisation of stratocone crater wall sequences, White Island Volcano, New Zealand. Engineering geology, 81(2), 146-178.

Muhs, D. R., Bush, C. A., Stewart, K. C., Rowland, T. R., & Crittenden, R. C. (1990). Geochemical evidence of Saharan dust parent material for soils developed on Quaternary limestones of Caribbean and western Atlantic islands. Quaternary Research, 33(2), 157-177.

Murphy, J. Brendan, and R. Damian Nance. "Speculations on the mechanisms for the formation and breakup of supercontinents." Geoscience Frontiers 4, no. 2 (2013): 185-194.

Nishiizumi, K., Caffee, M. W., Finkel, R. C., Brimhall, G., & Mote, T. (2005). Remnants of a fossil alluvial fan landscape of Miocene age in the Atacama Desert of northern Chile using cosmogenic nuclide exposure age dating. Earth and Planetary Science Letters, 237(3-4), 499-507.

Nocquet, J. M., & Calais, E. (2004). Geodetic measurements of crustal deformation in the Western Mediterranean and Europe. Pure and applied geophysics, 161(3), 661-681.

Olivet, J. L., Bonnin, J. E. A. N., Beuzart, P. A. U. L., & Auzende, J. M. (1982). Cinematique des plaques et paleogeographie; une revue. Bulletin de la Société géologique de France, 7(5-6), 875-892.

Ortlieb, L., Barrientos, S., & Guzman, N. (1996). Coseismic coastal uplift and coralline algae record in northern Chile: The 1995 Antofagasta earthquake case. Quaternary Science Reviews, 15(8-9), 949-960.

Ortlieb, L., Zazo, C., Goy, J., Hillaire-Marcel, C., Ghaleb, B., & Cournoyer, L. (1996). Coastal deformation and sea-level changes in the northern Chile subduction area (23 S) during the last 330 ky. Quaternary Science Reviews, 15(8-9), 819-831.

Ota, Y., & Yamaguchi, M. (2004). Holocene coastal uplift in the western Pacific Rim in the context of late Quaternary uplift. Quaternary International, 120(1), 105-117.

Oudni, A., Dinar, H., & Zedam, R. (2016). Geological and geotechnical characterization of the Tagharist dam basin.

Paskoff, R. (1978). Sur l’évolution géomorphologique du grand escarpement côtier du désert chilien. Geographie physique et Quaternaire, 32(4), 351-360.

Pedoja, K. (2003). Les terrasses marines de la marge Nord Andine (Equateur et Nord Pérou): relations avec le contexte géodynamique (Doctoral dissertation, Ph. D Thesis, Université Pierre et Marie Curie, Paris).

Pedoja, K., Husson, L., Johnson, M. E., Melnick, D., Witt, C., Pochat, S., ... & Garestier, F. (2014). Coastal staircase sequences reflecting sea-level oscillations and tectonic uplift during the Quaternary and Neogene. Earth-Science Reviews, 132, 13-38.

Pedoja, K., Husson, L., Regard, V., Cobbold, P. R., Ostanciaux, E., Johnson, M. E., ... & Delcaillau, B. (2011). Relative sea-level fall since the last interglacial stage: are coasts uplifting worldwide?. Earth-Science Reviews, 108(1-2), 1-15.

Pedoja, K., Ortlieb, L., Dumont, J. F., Lamothe, M., Ghaleb, B., Auclair, M., & Labrousse, B. (2006). Quaternary coastal uplift along the Talara Arc (Ecuador, Northern Peru) from new marine terrace data. Marine Geology, 228(1-4), 73-91.

Peñalver, L., Pedoja, K., Martin-Izquierdo, D., Authemayou, C., Nuñez, A., Chauveau, D., ... & Husson, L. (2021). The Cuban staircase sequences of coral reef and marine terraces: A forgotten masterpiece of the Caribbean geodynamical puzzle. Marine Geology, 440, 106575.

Perg, L. A., Anderson, R. S., & Finkel, R. C. (2001). Use of a new 10Be and 26Al inventory method to date marine terraces, Santa Cruz, California, USA. Geology, 29(10), 879-882.

Pillans, B. (1983). Upper Quaternary marine terrace chronology and deformation, south Taranaki, New Zealand. Geology, 11(5), 292-297.

Pirazzoli, P. A. (1991). World atlas of Holocene sea-level changes.

Pirazzoli, P. A. (1993). Global sea-level changes and their measurement. Global and Planetary Change, 8(3), 135-148.

Pirazzoli, P. A. (1997). Sea-level changes: the last 20 000 years. Oceanographic Literature Review, 8(44), 785.

Pirazzoli, P. A. (2005). A review of possible eustatic, isostatic and tectonic contributions in eight late-Holocene relative sea-level histories from the Mediterranean area. Quaternary Science Reviews, 24(18-19), 1989-2001.

Piromallo, C., & Morelli, A. (2003). P wave tomography of the mantle under the Alpine-Mediterranean area. Journal of Geophysical Research: Solid Earth, 108(B2).

Platt, J. P., & Vissers, R. L. M. (1989). Extensional collapse of thickened continental lithosphere: A working hypothesis for the Alboran Sea and Gibraltar arc. Geology, 17(6), 540-543.

Ricou, L. E. (1994). Tethys reconstructed: plates, continental fragments and their Boundaries since 260 Ma from Central America to South-eastern Asia. Geodinamica acta, 7(4), 169-218.

Riquelme, R., Lira, I., Pérez-López, C., Rayas, J. A., & Rodríguez-Vera, R. (2007). Interferometric measurement of a diffusion coefficient: comparison of two methods and uncertainty analysis. Journal of Physics D: Applied Physics, 40(9), 2769.

Riquelme, R., Martinod, J., Hérail, G., Darrozes, J., & Charrier, R. (2003). A geomorphological approach to determining the Neogene to Recent tectonic deformation in the Coastal Cordillera of northern Chile (Atacama). Tectonophysics, 361(3-4), 255-275.

Roca, A. L., Kahila Bar-Gal, G., Eizirik, E., Helgen, K. M., Maria, R., Springer, M. S., ... & Murphy, W. J. (2004). Mesozoic origin for West Indian insectivores. Nature, 429(6992), 649-651.

Rohling, E. J., Grant, K., Hemleben, C. H., Siddall, M., Hoogakker, B. A. A., Bolshaw, M., & Kucera, M. (2008). High rates of sea-level rise during the last interglacial period. Nature geoscience, 1(1), 38-42.

Rosenbaum, G., Lister, G. S., & Duboz, C. (2002). Reconstruction of the tectonic evolution of the western Mediterranean since the Oligocene. Journal of the Virtual Explorer, 8(January).

Rosenbloom, N. A., & Anderson, R. S. (1994). Hillslope and channel evolution in a marine terraced landscape, Santa Cruz, California. Journal of Geophysical Research: Solid Earth, 99(B7), 14013-14029.

Rothé, J. P. (1950). The Kherrata earthquakes and the seismicity of Algeria. Bull. Serv. Cart. Geol. Algeria, 4th Ser., Geophysics, n. 3.

Roulston, K., & Choi, M. (2018). Qualitative interviews. The SAGE handbook of qualitative data collection, 233-249.

Roulston, Kathryn, and Myungweon Choi. "Qualitative interviews." The SAGE handbook of qualitative data collection (2018): 233-249.

Roure, F., Casero, P., & Addoum, B. (2012). Alpine inversion of the North African margin and delamination of its continental lithosphere. Tectonics, 31(3).

Roussel, J. (1973). Active areas and frequency of earthquakes in Algeria 1716–1970. Bulletin Society History Natural North Africa, 64(3), 11–227.

Royden, L. H. (1993). Evolution of retreating subduction boundaries formed during continental collision. Tectonics, 12(3), 629-638.

Royden, L. H. (1993). The tectonic expression slab pull at continental convergent boundaries. Tectonics, 12(2), 303-325.

RPA. (Rules of Algerian earthquake). (2003). CGS, Algeria.

Sàbat, F., Gelabert, B., Rodríguez-Perea, A., & Giménez, J. (2011). Geological structure and evolution of Majorca: Implications for the origin of the Western Mediterranean. Tectonophysics, 510(1-2), 217-238.

Sarna-Wojcicki, A. M., Lajoie, K. R., Meyer, C. E., Adam, D. P., & Rieck, H. J. (1991). Tephrochronologic correlation of upper Neogene sediments along the Pacific margin, conterminous United States.

Savelli, C. (2002). Time–space distribution of magmatic activity in the western Mediterranean and peripheral orogens during the past 30 Ma (a stimulus to geodynamic considerations). Journal of Geodynamics, 34(1), 99-126.

Scardino, G., Sabatier, F., Scicchitano, G., Piscitelli, A., Milella, M., Vecchio, A., ... & Mastronuzzi, G. (2020). Sea-level rise and shoreline changes along an open sandy coast: Case study of gulf of taranto, Italy. Water, 12(5), 1414.

Schettino, A., & Turco, E. (2006). Plate kinematics of the Western Mediterranean region during the Oligocene and Early Miocene. Geophysical Journal International, 166(3), 1398-1423.

Schettino, A., & Turco, E. (2011). Tectonic history of the western Tethys since the Late Triassic. Bulletin, 123(1-2), 89-105.

Seber, D., Barazangi, M., Tadili, B. A., Ramdani, M., Ibenbrahim, A., & Ben Sari, D. (1996). Three-dimensional upper mantle structure beneath the intraplate Atlas and interplate Rif mountains of Morocco. Journal of Geophysical Research: Solid Earth, 101(B2), 3125-3138.

Seitzinger, S. P., Harrison, J. A., Dumont, E., Beusen, A. H., & Bouwman, A. F. (2005). Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: An overview of Global Nutrient Export from Watersheds (NEWS) models and their application. Global biogeochemical cycles, 19(4).

Serpelloni, E., Vannucci, G., Pondrelli, S., Argnani, A., Casula, G., Anzidei, M., ... & Gasperini, P. (2007). Kinematics of the Western Africa-Eurasia plate boundary from focal mechanisms and GPS data. Geophysical Journal International, 169(3), 1180-1200.

Shackleton, N. J., & Opdyke, N. D. (1973). Oxygen isotope and palaeomagnetic stratigraphy of Equatorial Pacific core V28-238: Oxygen isotope temperatures and ice volumes on a 105 year and 106 year scale. Quaternary research, 3(1), 39-55.

Shimada, K., Kamoshida, T., Itoh, M., Nishino, S., Carmack, E., McLaughlin, F., ... & Proshutinsky, A. (2006). Pacific Ocean inflow: Influence on catastrophic reduction of sea ice cover in the Arctic Ocean. Geophysical Research Letters, 33(8).

Ship, S., Anderson, J., & Domack, E. (1999). Late Pleistocene–Holocene retreat of the West Antarctic Ice-Sheet system in the Ross Sea: part 1—geophysical results. Geological Society of America Bulletin, 111(10), 1486-1516.

Siddall, M., Bard, E., Rohling, E. J., & Hemleben, C. (2006). Sea-level reversal during Termination II. Geology, 34(10), 817-820.

Silva, P. G., Harvey, A. M., Zazo, C., & Goy, J. L. (1992). Geomorphology, depositional style and morphometric relationships of Quaternary alluvial fans in the Guadalentin Depression (Murcia, Southeast Spain). Zeitschrift für Geomorphologie, 36(3), 325-341.

Spakman, W., & Wortel, R. (2004). A tomographic view on western Mediterranean geodynamics. In The TRANSMED atlas. The Mediterranean region from crust to mantle (pp. 31-52). Springer, Berlin, Heidelberg.

Spakman, W., & Wortel, R. (2004). A tomographic view on western Mediterranean geodynamics. In The TRANSMED atlas. The Mediterranean region from crust to mantle (pp. 31-52). Springer, Berlin, Heidelberg.

Spakman, W., van der Lee, S., & van der Hilst, R. (1993). Travel-time tomography of the European-Mediterranean mantle down to 1400 km. Physics of the Earth and Planetary Interiors, 79(1-2), 3-74.

Strzerzynski, P., Dominguez, S., Boudiaf, A., & Déverchère, J. (2021). Tectonic inversion and geomorphic evolution of the Algerian margin since Messinian times: Insights from new onshore/offshore analog modeling experiments. Tectonics, 40(2), e2020TC006369.

Taib, H., Benabbas, C., Khiari, A., Hadji, R., & Haythem, D. (2022). Geomatics-based assessment of the neotectonic landscape evolution along the tebessa-morsott-youkous collapsed basin, Algeria. Geomatics, Landmanagement and Landscape, (3).

Taib, H., Benabbas, C., Khiari, A., & Dinar, H. (2022). Morphomertic analysis of sub-watersheds to evaluate relative tectonic activity. a case study of the Northeastern Algeria.(Tebessa).

Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic analysis. The SAGE handbook of qualitative research in psychology, 2, 17-37.

Thinkhazard. 2021. Algeria. (Online) Available at: https://thinkhazard.org/en/report/4-algeria/EQ#:~:text=In%20the%20area%20you%20have,in%20the%20next%2050%20years.

Tomaszewski, Lesley Eleanor, Jill Zarestky, and Elsa Gonzalez. "Planning qualitative research: design and decision making for new researchers." International Journal of Qualitative Methods 19 (2020): 1609406920967174.

Trenhaile, A. S. (2000). Modeling the development of wave-cut shore platforms. Marine Geology, 166(1-4), 163-178.

Trenhaile, A. S. (2002). Modeling the development of marine terraces on tectonically mobile rock coasts. Marine Geology, 185(3-4), 341-361.

Tuffour, Isaac. "A critical overview of interpretative phenomenological analysis: A contemporary qualitative research approach." Journal of Healthcare Communications 2, no. 4 (2017): 52.

Turco, E., Schettino, A., Pierantoni, P. P., & Santarelli, G. (2006). The Pleistocene extension of the Campania Plain in the framework of the southern Tyrrhenian tectonic evolution: morphotectonic analysis, kinematic model and implications for volcanism. In Developments in Volcanology (Vol. 9, pp. 27-51). Elsevier.

Unternehr, P., Curie, D., Olivet, J. L., Goslin, J., & Beuzart, P. (1988). South Atlantic fits and intraplate boundaries in Africa and South America. Tectonophysics, 155(1-4), 169-179.

Verity, G. E., & Anderson, D. W. (1990). Soil erosion effects on soil quality and yield. Canadian Journal of Soil Science, 70(3), 471-484.

Vila, J. M. (1977). Constantine's geological map (1/200 000) and its note, produced in 1977 and published by the Ministry of Industry and Energy, Mines and Geology Department, Geological Map Service of Algeria.

Vila, J. M. (1980). The alpine chain of eastern Algeria and Alge- rian-Tunisian borders. PhD-Thesis, Univ. Paris VI, p. 633.

Villemant, B., & Feuillet, N. (2003). Dating open systems by the 238U–234U–230Th method: application to Quaternary reef terraces. Earth and Planetary Science Letters, 210(1-2), 105-118.

Wallace, J. M., Smith, C., & Jiang, Q. (1990). Spatial patterns of atmosphere-ocean interaction in the northern winter. Journal of Climate, 3(9), 990-998.

Wolin, E., Stein, S., Pazzaglia, F., Meltzer, A., Kafka, A., & Berti, C. (2012). Mineral, Virginia, earthquake illustrates seismicity of a passive-aggressive margin. Geophysical Research Letters, 39(2).

Yamato, P., Husson, L., Becker, T. W., & Pedoja, K. (2013). Passive margins getting squeezed in the mantle convection vice. Tectonics, 32(6), 1559-1570.

Yelles, A., Domzig, A., Déverchère, J., Bracène, R., de Lépinay, B. M., Strzerzynski, P., ... & Djellit, H. (2009). Plio-Quaternary reactivation of the Neogene margin off NW Algiers, Algeria: the Khayr al Din bank. Tectonophysics, 475(1), 98-116.

Yelles-Chaouche, A. K., Djellit, H., Beldjoudi, H., Bezzeghoud, M., & Buforn, E. (2004). The Ain Temouchent (Algeria) Earthquake of December 22nd, 1999. Pure and Applied Geophysics, 161(3), 607-621.

Yelles-Chaouche, A., Boudiaf, A., Djellit, H., & Bracene, R. (2006). La tectonique active de la région nord-algérienne. Comptes Rendus Geoscience, 338(1-2), 126-139.

Yelles-Chaouche, A., Khelif, M. F., Haned, A., Chami, A., Aidi, C., Beldjoudi, H., ... & Benaissa, Z. (2019). The Algiers (north central Algeria) earthquake of August 1st, 2014 Mw 5.5 in the Algiers Bay tectonic context. Journal of Seismology, 23(2), 287-302.

Yelles-Chaouche, A., Roger, J., Déverchère, J., Bracene, R., Domzig, A., Hébert, H., & Kherroubi, A. (2009). The 1856 tsunami of Djidjelli (Eastern Algeria): Seismotectonics, modelling and hazard implications for the Algerian coast. In Tsunami Science Four Years after the 2004 Indian Ocean Tsunami (pp. 283-300). Birkhäuser Basel.

Yokoyama, Y., Purcell, A., Lambeck, K., & Johnston, P. (2001). Shore-line reconstruction around Australia during the last glacial maximum and late glacial stage. Quaternary International, 83, 9-18.

Zahaf, N., Sabeg, R., & Saadali, B. (2022). Contribution to the study of the deep water table in the Ain Babouche region.

Zazo, C., Goy, J. L., Somoza, L., Dabrio, C. J., Belluomini, G., Improta, S., ... & Silva, P. G. (1994). Holocene sequence of sea-level fluctuations in relation to climatic trends in the Atlantic-Mediterranean linkage coast. Journal of Coastal Research, 933-945.

Zazo, C., Silva, P. G., Goy, J. L., Hillaire-Marcel, C., Ghaleb, B., Lario, J., ... & González, A. (1999). Coastal uplift in continental collision plate boundaries: data from the Last Interglacial marine terraces of the Gibraltar Strait area (south Spain). Tectonophysics, 301(1-2), 95-109.