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Western High Atlas Morocco The complex reef of Cap Ghir, Upper Jurassic Oxfordian

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Abstract – The Upper Jurassic of the Moroccan margin, particularly in the Agadir Essaouira basin, and specifically in its western part towards the Atlantic Ocean, is characterized by geological diversity. The reef association of Cap Ghir in the western High Atlas is mainly composed of bioconstructions such as colonies of stromatoporoids, which are abundant during the initial reef formation. These colonies exhibit massive or globular forms similar to those of corals. Other bioclastic elements such as bivalves and gastropods are also found, which contribute to reef construction and are often cemented by algal or microbial micrite. The area is characterized by an abundance of branches and masses, generally exhibiting Framestone and Bindstone textures, indicating a turbulent environment.

Keywords – Reef,Upper Jurassic, Oxfordian, Argovian, Rauracian, Sequanian, Cape Ghir, Agadir.

I. INTRODUCTION

Coral reefs are natural formations in marine environments that create a barrier through the intervention of various living organisms, primarily hermatypic corals, Cnidarians, and Scleractinians and Hydrocorals, which are associated with microscopic symbiotic algae called zooxanthellae. Coral reefs have existed for at least 203 million years and are among the oldest ecosystems in the world. Since that time, their formation process has remained essentially the same (Leonard.C, 2019).

[1]During the Late Jurassic, there was a significant expansion of reefs worldwide. This growth resulted from the relative rise in sea levels, which created vast epicontinental seas, as well as favorable climatic conditions for the development of reef platforms. This led to extensive reef development along the northern and southern Tethyan margins (Ourribane 2000 and al).

Several researchers have conducted biostratigraphic studies aimed at determining the exact age of the reef complex in this region. However, despite these efforts, the precise age of the reef remains uncertain. Duffaud in 1960 and Ambroggi in 1963 describe terrains of "Argovian, Rauracian-Sequanien" age, which are the subject of this study. Ager in 1974 abandoned this old nomenclature and attributed the reef complex to the Upper Oxfordian-Lower Kimmeridgian. Adams et al. in 1980 place the reef within the Lalla-Oujja formation, attributed to the Middle and Upper Oxfordian. Hussner in 1985 mentions a Kimmeridgian stratigraphic context without specific reference to the reef. Ourribane et al. in 1999 and Ourribane in 2000 propose several reef episodes dating from the Late Oxfordian to the Early Kimmeridgian, based on foraminifera.

The aim of this study is to investigate the Jurassic reef complex located in the Cap Ghir Anticline, approximately 40 km from Agadir. This reef complex, named the Cap Ghir Reef Complex (Morocco), holds a particular position on the African continent due to its southern and western location, closer to the Atlantic Ocean than to the Tethys (Bertrand M.G. 2005 et al).

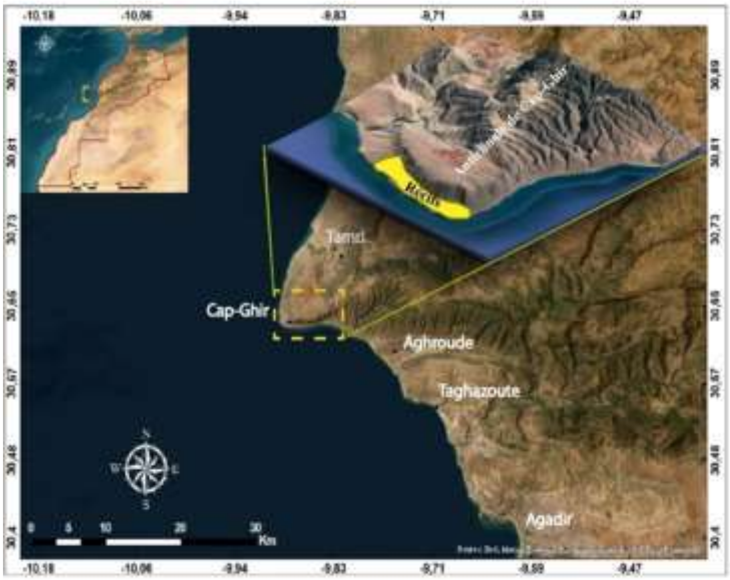

Figure 1. Cap-Ghir reef location

II. MATERIALS AND METHOD

The results presented in this dissertation have been obtained through rigorous work involving the use of a variety of investigative approaches and techniques. In this context, observations were made directly in the field The aim of this study is to produce a geological cross-section and a detailed lithostratigraphic log, layer by layer, in the Cap-Ghir study area. This involves describing the various benches, measuring their thickness and collecting the associated samples. Analysis of these data will enable facies and sedimentary figures to be identified, and discontinuities to be highlighted. The ultimate aim is to monitor the evolution in time and space of Oxfordian formations in the Cap-Ghir anticline.

III. THE DISTRIBUTION OF CORAL REEFS IN CAP-GHIR

In the Cap-Ghir region (High Atlas Atlantic), the reefs are divided into two periods during the Upper Jurassic: the Oxfordian and the Kimmeridgian:

Oxfordian reefs:

[4]These appear in the bio-constructed limestone rocks of the Argovian and Rauracian-Sequanien. They are more or less rich in organisms, generally consisting of massive or branching corals, stromatoporoids, Diceras, Nerineas, and bryozoans (Ourribane 2000 et al).

Kimmeridgian reef:

Kimmeridgian deposits its sediments on a set of bioclastic limestones that seal the Oxfordian reef. It appears in a carbonate bar, showing various facies and encompassing several bioconstructed lenses primarily by stromatoporoids and rich in microbialites. It is characterized by a large association of organisms such as stromatoporoids, chaetetids, and corals. The accompanying fauna, although not very diverse, consists of some hexacorals, including the species Stylina tubilifera and the genus Thecosmilia, rare specimens of bryozoans, lamellibranchs, gastropods, and small textulariids (Ourribane 2000 and al).

Cross-section of the Rauracian-Sequanien at Cap Ghir

This section was conducted by Ambroggi (1963) at 800 meters from the NNW part of the lighthouse projection, specifically in the tidal zone. The sea has cleared a magnificent reef on limestone slabs, from top to bottom of the section. The Rauracian-Sequanien reef ledge mainly appears as a ledge of dolomitic limestone or dolomite with massive-shaped polyps at the base of well-bedded limestones, with a white patina at the top. The dolomite of the lower series is deposited on the Argovian, as shown in the section above. This formation reaches up to 40 meters in thickness. In detail, the bedded limestones of the upper series do not exceed 12 to 15 meters to the west, and it is noted that towards the eastern part, the thickness of the lower dolomite decreases to 10 meters (Ambroggi 1963).

Figure 2. Sequanian Rauracian section from Cap-Ghir (Ambroggi 1963), modified

IV. IDENTIFICATION AND CHARACTERISTICS OF DIFFERENT REEFS AT CAP GHIR

The Cap Ghir reef complex consists of several different coral associations, often dating back to the Upper Oxfordian and Lower Kimmeridgian. It is characterized by multiple carbonate lenses built by stromatoporoids, massive or branching corals, encrusting algae, and other fossils such as lamellibranchs (Megalodontidae), gastropods (Nerineas), brachiopods, echinoderm spines, bryozoans, etc.To study these coral assemblages, we conducted a cross-sectional analysis showing the stages of reef formation, which occurred in four stages: the stabilization stage, colonization stage, diversification stage, and domination stage. Additionally, a longitudinal section was conducted to observe the evolution of various fossils occupying the Cap Ghir region.

A. East-West Cross-Section of Cap Ghir

The East-West cross-section located a few meters south of the lighthouse projection at Cap Ghir will be used to describe the four stages of reef formation at Cap Ghir.

1. Stabilization Stage

The stabilization stage, or pioneer stage, precedes the colonization of the coral reefs. It represents the pre-reef stage, highlighting a major ecological shift with the recording of bioclastic deposits on loose substrate characterized by the bioclastic nature of the basement, indicating initial attempts at construction under unfavorable conditions: high energy, leading to a significant rate of bioclastic fragments.

Figure 3. The first stage of stabilization of the Cap-Ghir reef formations

- **Stromatoporoids**

Stromatoporoids are marine organisms whose skeleton is composed of horizontal calcitic elements (laminae) interconnected by discontinuous vertical elements (pillars), creating a grid-like appearance in the fossil. They can take on various forms, such as balls, sheets, or tubes, depending on their living environment. During the Devonian period, stromatoporoids were the primary reef builders. They do not constitute a separate phylum but rather a class of sponges. It is worth noting that older literature often mistakenly classified stromatoporoids as Cnidarians.

Figure 4. Stromatopores in parallel beds

- **Algal activity**

4Algal activity is represented by a dark micritic bank, indicating microbialites, as shown in the figure. This activity is interpreted as the activity of red algae, primarily marine organisms, well-represented in deep waters (100 to 250m). There are 164 species of freshwater red algae, known for their resilience to extreme conditions (Treyture.C.L et al., 2014), potentially adapted to reef environments. These algae contribute to the stabilization of the substrate by settling on various fragments of benthic organisms (Ourribane 2000 and al.)

Figure 5. A dark micritic shoal indicating algal activity

- **Microbialites**

Microbialites, generally referred to as stromatolites, are rocks formed by the layering of fine layers of limestone produced very slowly by mats of photosynthetic bacteria. These fine layers of limestone can be ribbon-like, flat, undulating, or zigzagging. They can also encircle shells (oncoliths), which are irregularly and discontinuously laminated cortexes.

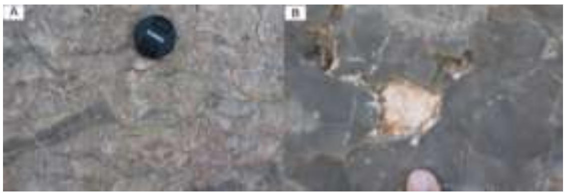

Figure 6:Microbialites (A), B;Oncoliths (B)

- **Echinoderms**

This reef platform of Cap Ghir is characterized by the presence of classes belonging to the phylum Echinodermata, such as sea urchins. Sea urchins are peculiar animals; they lack a head, tail, or even a right or left side. They do not possess bilateral symmetry like us; they lack an axis passing through the body, delineating right from left. Their symmetry is radial; echinoderms have their bodies divided into five usually equal parts.

Within this reef mass, there are broken sea urchins (Figure 7; A) accompanied by the presence of bioclastic debris (Figure 7; B), indicating a battle between the organisms stabilizing the environment and the environmental dynamics.

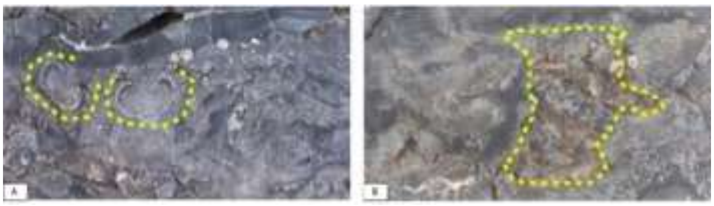

Figure 7. Sea urchin debris (A), bioclastic debris (B).

2. **Colonization Stage**

[4]This stage is characterized by the establishment of encrusting organisms (bindstone or framestone) and is marked by the abundance of stromatolites, with less significant algal activity than in the previous stage. Towards the end of this stage, the appearance of colonies of branching corals at the top of the reef lens indicates the end of colonization and the beginning of the next stage of diversification (Ourribane 2000 et al).

Figure 8. The second colonization stage of reef formation.

3. **Diversification Stage**

[4]This stage corresponds to a phase of flourishing and development of the reef, characterized by an increase in the density of colonies of branching corals associated with stromatoporoids. This coexistence is reflected in a variety of textures, such as baffelstone, framestone, and bindstone, indicating that the environment is subject to high energy (Ourribane 2000 et al).

Figure 9. The third diversification stage of reef formation

4. **Domination Stage**

[2]There is a dominance of massive coral colonies, typically with a globular shape, associated with some species of chaetetids and stromatoporoids. The reef flat area is covered with highly bioclastic limestone beds, containing large poorly sorted fragments of bioconstructors, indicating that this reef phase is likely coming to an end due to a shoreline shift. A decrease in the quantity of bioconstructors and bioclasts from west to east can be observed, accompanied by an increase in the micrite content in this zone.

Figure 10. The last stage of reef domination

B. North-South lateral cross-section parallel to the ocean at Cap Ghir

We conducted a North-South cross-section parallel to the ocean in the western part of the lighthouse projection to understand the evolution of reefs with other species occupying this area. This terrain is characterized by paleontological diversity, manifested by the abundance of several fossils such as crinoids, nerineas or gastropods, cnidarians, and debris from lamellibranchs of various sizes. In some areas, we observe that some fossils are more or less destroyed, indicating that they have undergone significant energy. This diversity of fossils occupies the limestone of the Oxfordian but is hidden in some areas by Quaternary deposits (detrital sand). Moving towards the North, we find a large part of the branching corals eroded by the intervention of wadis entering the sea.

We divided this cross-section into three parts based on the size of the fossils to track the change in sizes of species from South to North. The first corresponds to the zone of megalodontids and nerineas, the second represents the zone of massive corals, and the last corresponds to the zone of branching corals.

I. The zone of megalodontids and nerineas

In this zone, there is a significant presence of lamellibranchs (megalodontids) in various forms. There are bivalves that are completely attached and not separated, as well as bivalves that are separated. Additionally, gastropods (nerineas) and cephalopods are present in this area. Separated bivalves as well as gastropods have been observed in both cross-sectional and longitudinal sections. Moving northward, there is a decrease in the frequency of nerineas, a decrease in single-valve megalodontids, and an increase in those with two valves.

II. Lamellibranches

Lamellibranches, or bivalves, belong to the phylum of aquatic mollusks, whether freshwater or shallow saltwater. They are characterized by a bivalve shell with a dorsal and ventral edge, as well as bilateral symmetry. They were named bivalves by LINNE in 1767 due to their shell, acephalous according to CUVIER in 1795 because their head is indistinct, and phlecyopods according to GOLDFUSS in 1821 because their foot is laterally compressed in the shape of a plowshare. Their most common name is lamellibranches according to BLAINVILLE in 1816. Bivalves appeared at the very beginning of the Paleozoic era and experienced rapid development during this time. They have been abundant since then and are still prevalent today. They are frequently found in reef marine environments, such as Rudists, which were confined to the Jurassic and Cretaceous periods.

Figure 12:The abundance of a single lamellibranch valve

Figure 11:A large lamellibranch valve

Gastropods

The most common form of gastropods in this zone appears in different sizes. Gastropods are distinguished from other marine mollusks by their conical univalve calcareous shell, which spirals in a conical shape with a differentiated head. They also have highly developed feet and can be either dextral (spiraling clockwise) or sinistral (spiraling counterclockwise). Like other marine mollusks, their way of life is well adapted to various environments.

Figure 13. The last stage of reef domination

Figure 13. The transition from the Megalodontidae zone to the massive reef zone.

Figure 14. Large Gastropods

III. The zone of massive reefs

This zone corresponds to species of large size compared to the area where gastropods and bivalves are found. It is also characterized by the presence of complete bivalves, which are rare and large in size (Figure: 88). Generally, this zone is marked by the abundance of small-sized massive cnidarians (7-10 cm), and as we move further north, the size of these cnidarians increases (up to 70 cm).

The fossils of cnidarians are represented by colonial or solitary corals secreting a hard calcareous exoskeleton (Lecointre G., 2013), appearing towards the end of the Precambrian period (Robin B., 1988). These animals are anthozoans grouped in the taxon (order) of Scleractinia (formerly known as

Madreporaria) within the Hexacorallians, for post-Paleozoic forms, and in the extinct clades Tabulata and Rugosa (Tetracorallians), for Paleozoic forms (Kayal E. et al., 2013).

Figure 15. Image represents massive Cnidaria

Figure 16. A complete lamellibranch with two valves.

IV. The zone of branching reefs

This zone is characterized by the abundant presence of large branched organisms, such as bryozoans, as well as small mollusks and algae. Bryozoans become larger towards the north, sometimes reaching up to 6 meters, and are accompanied by some small-sized massive cnidarians. This zone is marked by the abundance of large bryozoans that primarily develop in limestone rocks.

Figure 17. Image shows branching reefs.

V. CONCLUSION

The two cross-sections, one along the North-South axis and the other along the East-West axis, that we conducted to study and determine the association of the reef complex of Cap Ghir, allowed us to conclude that the Cap Ghir reef is mainly composed of bioconstructions such as colonies of stromatoporoids, which are most abundant during the initial stage of reef formation. These colonies appear in massive or globular forms, resembling corals. We also observe the presence of other bioclasts such as bivalves and gastropods, which contribute to the construction of these reefs. They are often cemented by micrite of algal or microbial origin. As mentioned earlier, this zone is characterized by the abundance of branching and massive structures. The entirety of these bioconstructions generally shows an association of Framestone and Bindstone textures, which are good indicators of a turbulent environment.

[4]The branching forms that primarily develop during the diversification phase appear in the form of clusters and vertically erect, highly branched tubes. This morphology represents an adaptation in response to a relatively turbulent environment. In general, biological construction occurred under moderate to high hydrodynamic conditions, likely related to variations in paleobathymetry (Ourribane 2000 et al).

[2]The association of this reef with back-reef breccias, patch reefs, and fine lagoon limestones further east indicates a relatively shallow environment for the reef. This suggests that it developed in a platform area with moderate to high agitation, following a significant sea level drop that hindered reef construction. It is likely that this reef formed in the proximal part of the subtidal zone, at a depth ranging from 1 to 30 meters. The high environmental energy, illustrated by the abundant presence of bioclastic fragments and intraclasts

in addition to back-reef conglomerates, indicates that this reef is located in the exposed zone of the inner shelf edge (Ourribane 1999 et al).

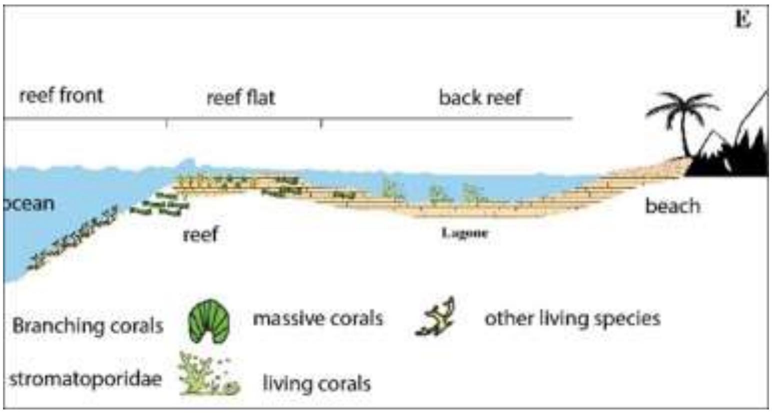

Figure 18. Reconstitution of the paleoenvironments of the Oxfordian reef complex of Cap-Ghir Agadir.

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