

Original article

Stratigraphic Architecture and Depositional Environments of the Paleozoic Successions in Jabal Al-Hasawna and Wadi Ash-Shatti, SW Libya: A Field-Based Synthesis

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Abstract

This paper presents a comprehensive field-based analysis of the stratigraphic successions and depositional environments in the Jabal Al-Hasawna and Wadi Ash-Shatti regions of southwestern Libya. Based on a detailed seven-day geological field excursion, the study documents a chronological sequence ranging from the Precambrian basement to Quaternary deposits, with a primary focus on the Paleozoic strata. Key formations investigated include the Al-Hasawna (Late Cambrian), Tanazzuft (Silurian), and the Devonian Awaynat Wanin Group (Bir Al-Qasr, Edri, Quttah, Dabdab, Tarut, and Ashkidah formations). The field data reveal a dynamic geological history characterized by significant transgressive-regressive cycles. The transition from the stable cratonic basement to the fluviodeltaic Al-Hasawna Formation is marked by a profound nonconformity. Subsequent Silurian marine transgressions deposited the graptolitic shales of the Tanazzuft Formation. The Devonian successions are notably characterized by coarsening-upward progradational cycles, intense bioturbation (dominated by Skolithos and Tigillites ichnofacies), and the widespread occurrence of ferruginous oolitic sandstones, indicating storm-dominated, shallow marine to restricted lagoonal environments. By integrating lithological, ichnological, and structural field observations across multiple sites, this study provides a unified model of the region's stratigraphic evolution, highlighting the complex interplay between sea-level fluctuations, sediment supply, and tectonic stability.

Keywords. Jabal Al-Hasawna, Wadi Ash-Shatti, Stratigraphy, Depositional Environments, Devonian Formations.

Introduction

The geologic history of southwestern Libya is well documented in the massive sedimentary successions exposed along the margins of the Murzuq Basin [1]. The Jabal Al-Hasawna and Wadi Ash-Shatti areas are important natural laboratories for understanding the stratigraphic architecture of the Paleozoic in North Africa. These regions reveal an almost continuous, though occasionally discontinuous, series of rocks that record the transition from Precambrian basement tectonism to long intervals of marine and continental sedimentation [2]. The main aim of the study is to integrate the field observations made during a recent geological field trip to Jabal Al-Hasawna and Wadi Ash-Shatti. The research seeks to establish the depositional settings and stratigraphic associations of the uncovered formations, the oldest being the Precambrian rocks and the youngest being the Quaternary deposits. Special attention is given to the Devonian successions, the complex successions of facies, rich ichnofabrics, and economically valuable, but hard to recover, iron ore deposits [3]. Although the general stratigraphic template of the Murzuq Basin has been developed through previous studies of the region [1, 2] (Figure 1), the paper is based solely on primary field data, such as lithological descriptions, sedimentary structures, and paleontological evidence, to create a localized, high-resolution model of the deposit. The use of external literature is only as a means of contextualizing and supporting these field-based interpretations.

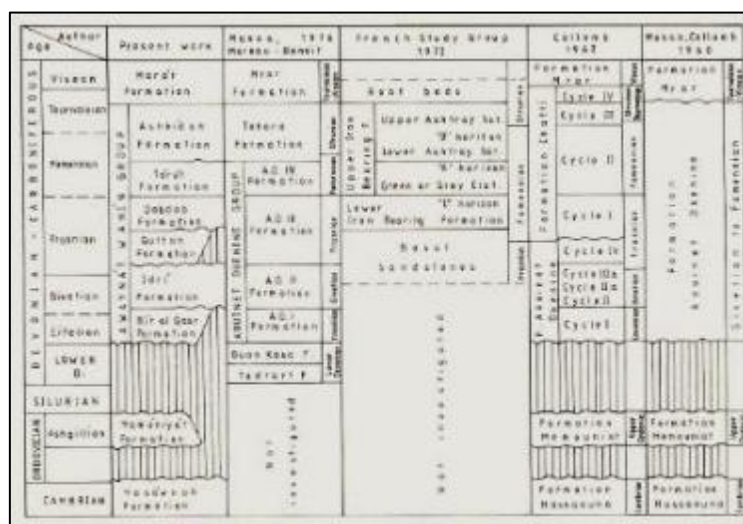


Figure 1. Stratigraphy of the Wadi Ash Shatti area. After Seidle and Rohlich, 1984

Methodology

The results in this paper are based on a field campaign that was conducted in a systematic seven-day period in the months of December 2025 in the Jabal Al-Hasawna and Wadi Ash-Shatti localities (Figure 2).

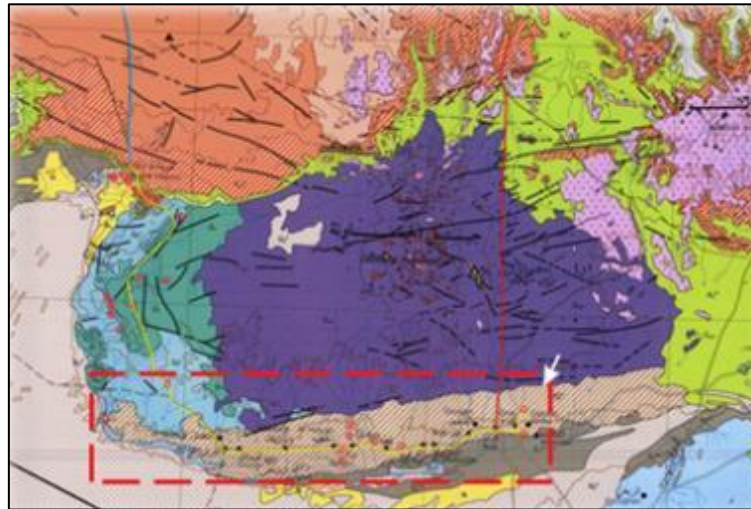
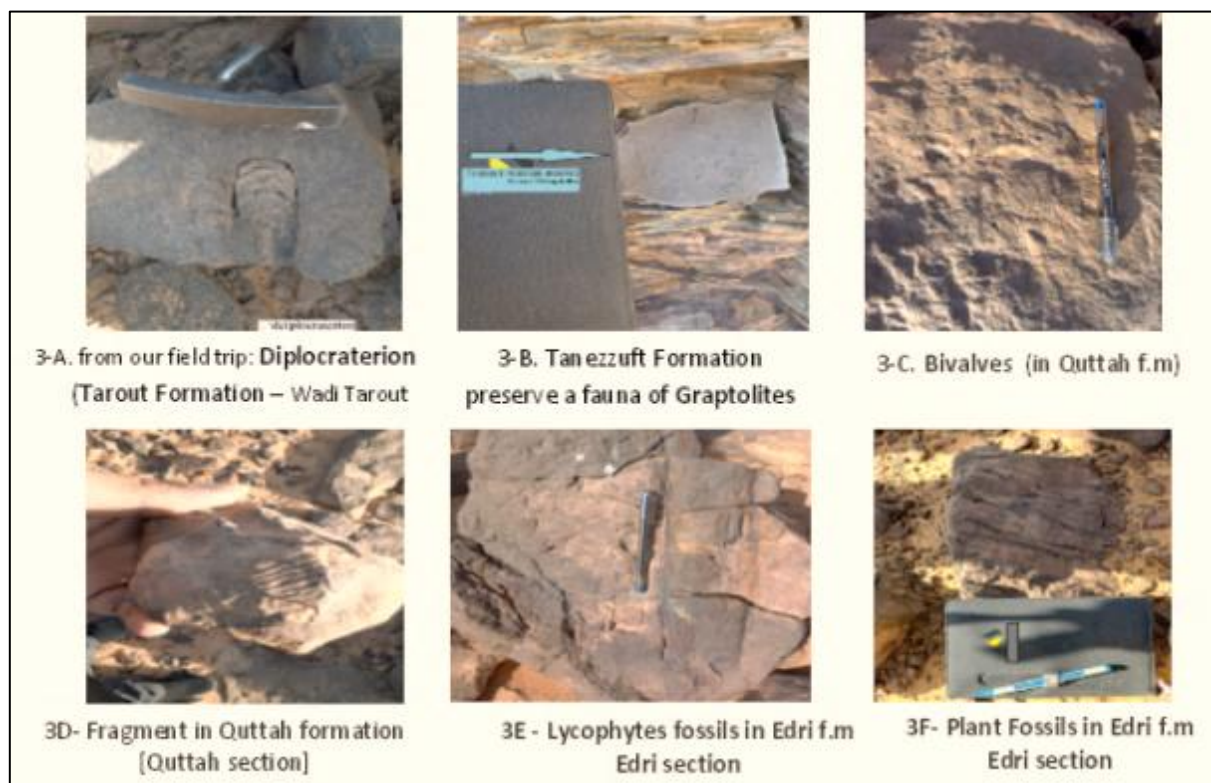


Figure2. Map of locations

The methodology was a typical field geology methodology that concentrated on: **1. Lithostratigraphic Logging:** Microscopic determination of the thickness of sections and lithological description (e.g. grain size, sorting, color, mineralogical composition, e.g., ferruginous oolites and clean feldspars). **2. Sedimentary Structure Analysis:** Ranging: Recognition and interpretation of physical sedimentary structures like Hummocky Cross-Stratification (HCS), wave ripples, flaser bedding, and cross-bedding to infer depositional energy and processes. **3. Ichnological/Paleontological Survey:** Tabular data on trace fossils (e.g., Skolithos, Tigillites, Diplocraterion, Bifungites) and macrofossils (e.g., graptolites, brachiopods, fish fragments, plant debris) to limit paleoenvironmental conditions and relative ages (Figure 3). **4. Structural and Stratigraphic Mapping:** Bedding attitudes, contact relationships (conformable and unconformable), and identification of key sequence boundaries and parasequences.



Figures 3. Trace and macrofossils from our field

Results

Stratigraphic Successions and Field Observations. The field investigations reported a wide range of geological units. The findings are given in chronological sequence, starting with the oldest basement rocks, followed by the youngest sedimentary cover.

Precambrian Basement and Al-Hasawna Formation (Late Cambrian).

The youngest rocks in the study area were found in Jabal Al-Hasawna (Wadi Badran), belonging to the Upper Tebisitian Series. The complex basement mainly comprises bi-mica granite (with biotite, muscovite, and very pure orthoclase and plagioclase feldspars) (Figure 4), and biotite schist with Precalidonia age zonalities. The schist also occurs as enclaves that fit with the granitic intrusions. There is a radical nonconformity between this basement complex and the overlying Al-Hasawna Formation (Figure 5). This contact is characterized by basal conglomerates with well-rounded pebbles and boulders, indicating that there must have been considerable erosion and subaerial exposure before deposition. The Thickness of the Al-Hasawna Formation itself, which extends up to 250 meters, is characterized by fine- to medium-grained sandstones with some intermittent levels of gravel and clay. The strata have very shallow dips (more than 5 degrees), indicating that there was not much tectonic deformation after the deposition.



Figure 4. Sample of Granite from Wadi Badran (Jabal Al-Hasawna)

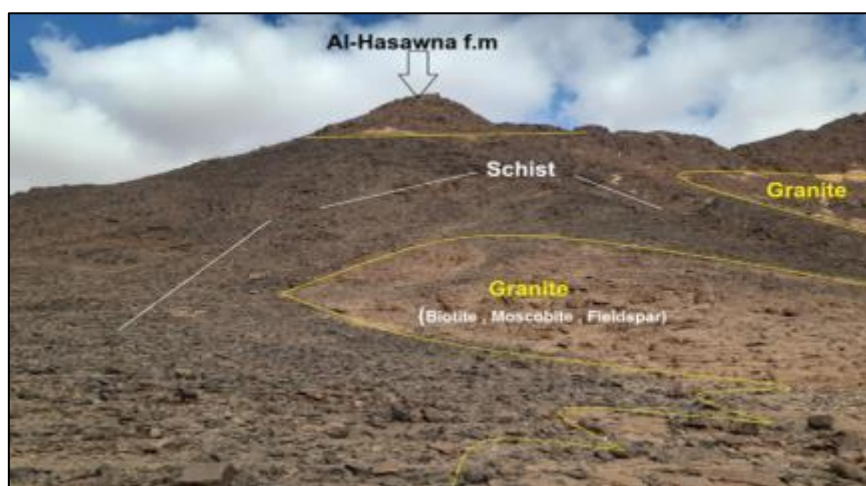


Figure 5. The Al-Hasawna formation overlies Precambrian Rocks in Wadi Badran (Jabal Al-Hasawna)

Silurian Succession: Tanazzuft Formation

The Tanazzuft Formation (Silurian - Early Llandoveryan) was studied in the Bir Al-Qasr area, west of Wadi Ash-Shatti, and in Al Hattiyat Al-Duwaysah. It is lithologically characterized by laminated shales, mudstones, and intercalated clays and rare and very fine-grained sandstones with a few thick beds (Figure 6). Paleontologically, the clayey strata contain a typical deep-water fauna, such as graptolites (*Climacograptus rectangularis*, *Coronograptus cf. gregarius*, *Glyptograptus sp.*) and orthocone cephalopods. In Al Hattiyat Al-Duwaysah, there is also a high degree of bioturbation, ripple marks, and above all, supratidal facies as evidenced by the existence of gypsum in the shale layers. There was also evidence of ancient tidal action, including the presence of nip and spring formations that were related to high-spring tides that were found below a thin-bedded layer of sandstone (Figure 7).

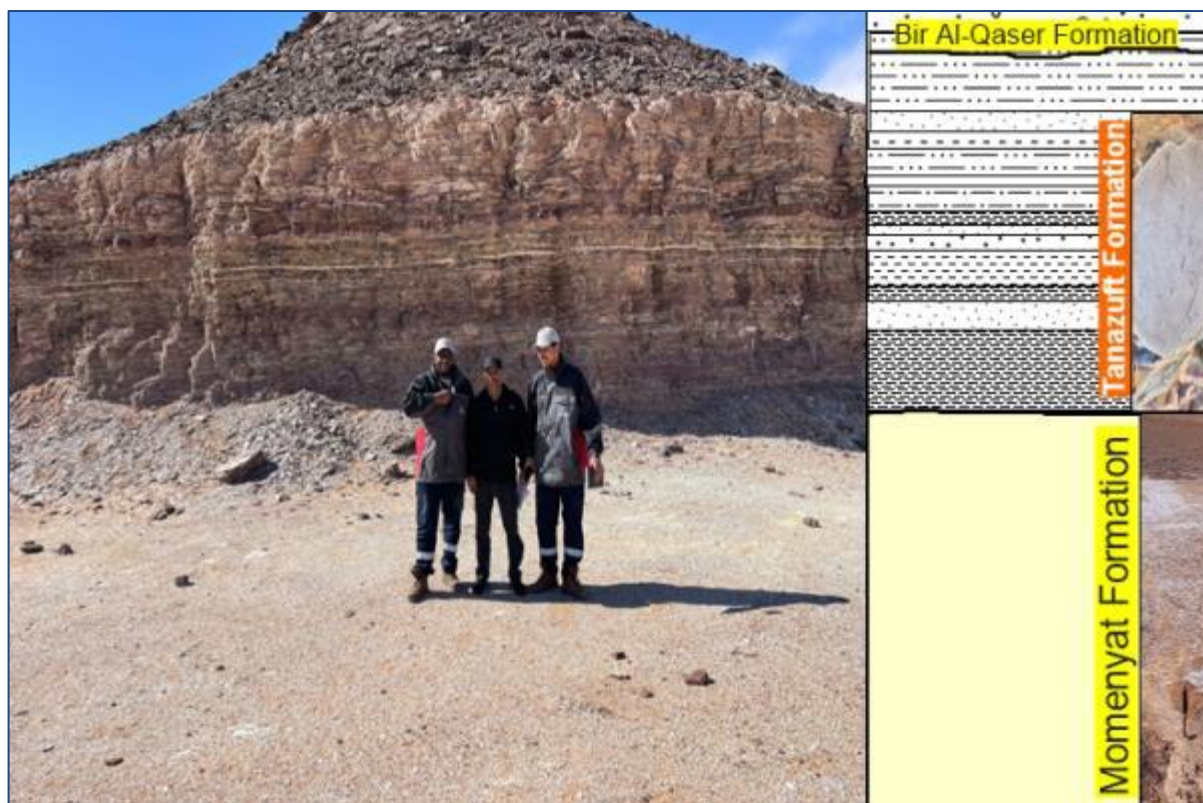


Figure 6. The Tanazuft Formation was studied in the Bir Al-Qaser area



Figure 7. Presence of NIP and spring formations (In Al Hattiyat, Al-Duwaysah Area)

Devonian Succession: Awaynat Wanin Group

The Devonian strata of Wadi Ash-Shatti are complicated and examined in a number of type sections displaying a number of progradational and transgressive cycles.

Bir Al-Qasr Formation

The Tanazuft Formation is overlaid by a tectonic unconformity (with a thick storm-bed sandstone) by the Bir Al-Qasr Formation (Figure 8), a lower sequence of intercalated sandstones and mudstones containing a rich Skolithos-dominated ichnofabric. The top sequence shows a coarsening-upward trend to become fine-grained current-rippled sandstones to form clinof orm-like bodies. The upper section of the formation (about 30m thick) at Qaret Alqullah shows two cycles of coarsening-upwards. The top cycle is varicolored mudstones with traces of roots (indicating flood plain environments) and is topped with coarse, scoured sandstones with channel lags (a shift to a continental fluvial system) (Figure 9).

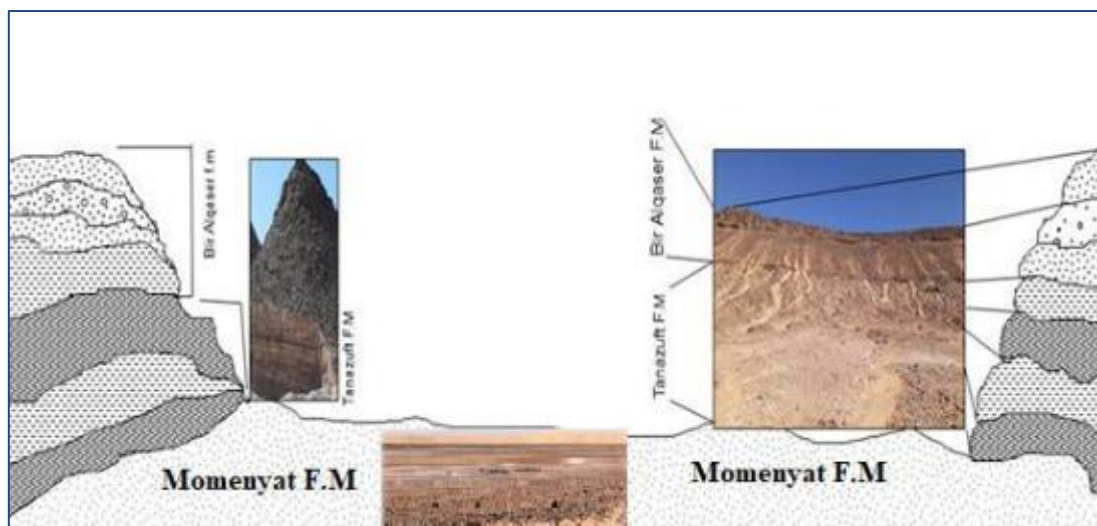


Figure 8. The Tanazuft Formation is overlaid by a tectonic unconformity (with a thick storm-bed sandstone) by the Bir Al-Qasr Formation, at Qaret Alqullah and Alddwisa Area

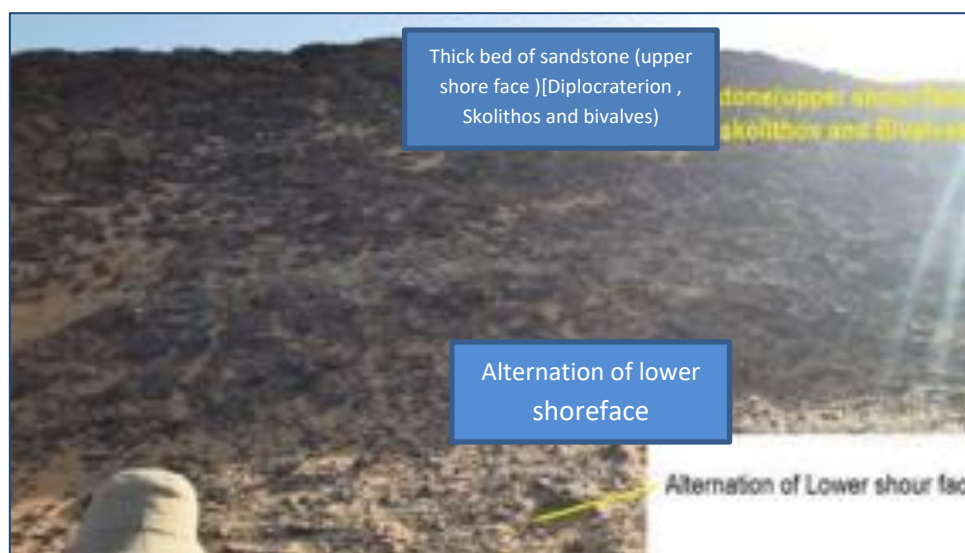


Figure 9. The upper section of the Bir Al-Qasr formation at Qaret Alqullah

Edri Formation

The Edri Formation (it is about 44m thick) is unconformably overlying the Bir Al-Qasr Formation. It is typified by two regressive successions (S1 and S2). S1: A tidal flat (as shown by flaser bedding) changes to a fluvial system. S2 is a Tract of Lowstand Systems (LST) fluvial system, and is covered by a Highstand Systems Tract (HST) flooding surface, and in (Figure 10 {A,B,C}) Some characteristics of Edri formation. The formation is full of trace fossils (Chondrites, Tigillites, Diplocraterion, Spirophyton), and has early plant fossils (Lycophytes). The paleocurrent evidence shows that the flow direction is towards the West-Northwest.



10A- Flonet current ripple (Edri formation)

**Figure 10. Some characteristics of the Edri formation**

Quttah Formation Correlated with the Awaynat Wanin Formation IV, the Quttah Formation (30m thick) is divided by a significant unconformity. The lower unit is made up of fine-grained claystones and silty claystones containing *Skolithos*, *Diplocraterion*, and *Bifungites fezzanensis*. The topmost unit, which lies unconformably on the bottom, is a very bioturbated, upward-fining sandstone sequence (coarse conglomeratic base to well-sorted fine sandstone top) that is dominated by bivalves and *Skolithos* (Figure 11).

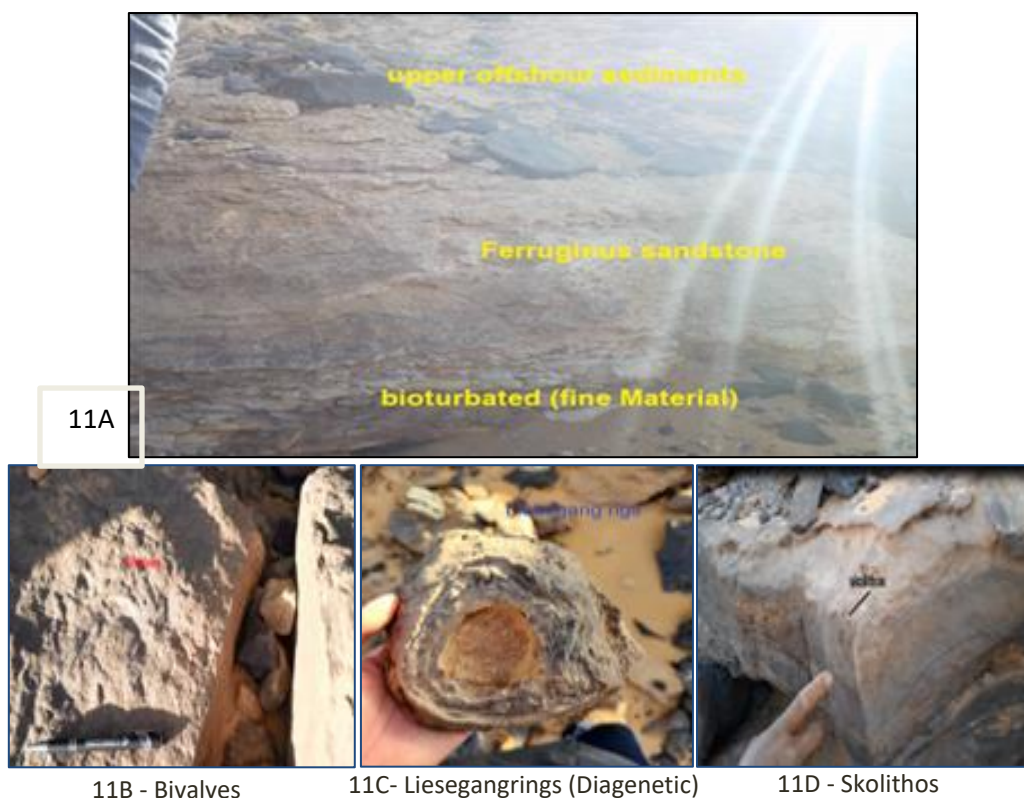


Figure 11. bioturbation (fine material) – ferruginous sandstone, Bivalves - Liesegang rings (Diagenetic)-Skolithos- bioturbation – ferruginous sandstone, in Quttah Formation

The Dabdab Formation (Upper Frasnian)

The Dabdab Formation is a fairly thin (12-13m) sequence that is pervasively ferruginous. It has a tendency to thin upwards. The bottom is made up of silty claystone mixed with partly ferruginous sandstone, topped by hardgrounds. A layer of ferruginous oolite (iron ore member) is formed by siderite, berthierine, manganese oxides, and pyrite, which form the upper part that is 2 meters thick (Figure 12). Tigillites (Skolithos) has significantly bioturbated the entire formation, and there are rare brachiopods and placoderm fish fragments.

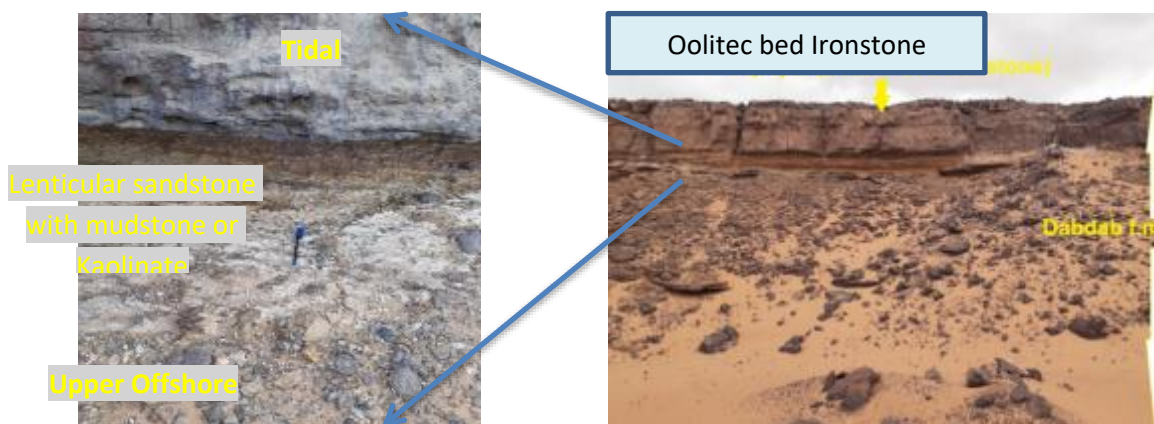


Figure 12. Dabdab Formation

Tarut Formation (Early Famennian)

This sequence is a typical progradational Highstand Systems Tract (HST), and it is exposed at Wadi Tarut and is 15m thick. It has a transgressive base and wears out upwards out of intercalated claystones and siltstones (with varied ichnofauna: Planolites, Thalassinoides, Phycodes) to oolitic sandstones with pure predominance of Tigillites. It is distinguished by the presence of huge fragments of fish bones and tiny brachiopods (Figure 13).



Figure 13. Tarut Formation in Wadi Tarut

Ashkidah Formation (Upper Famennian-Lower Tournaisian)

The 34 m thick Ashkidah Formation has been characterized by a noticeable coarsening-upward trend subdivided into three sections. The bottom section is horizontally laminated shales and silty claystones (Offshore Face) (figure 14). The central section is a unique Ferruginous Oolitic Sandstone having Hummocky Cross-Stratification (HCS) and wave ripples (figure 15), and severely burrowed by *Skolithos*. It has a high oxidized iron (35-50%) and phosphorus (>1.0%). The top portion is alternating shales and sandstones, which is a sequence of upward shoaling.

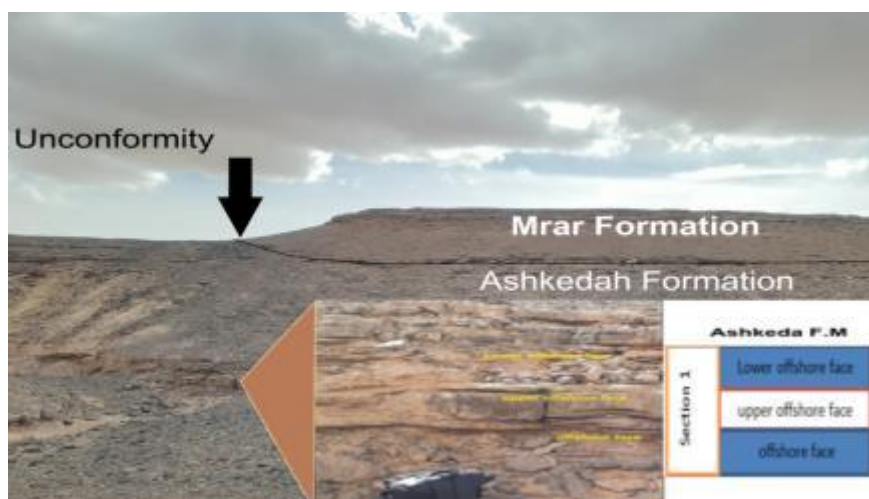


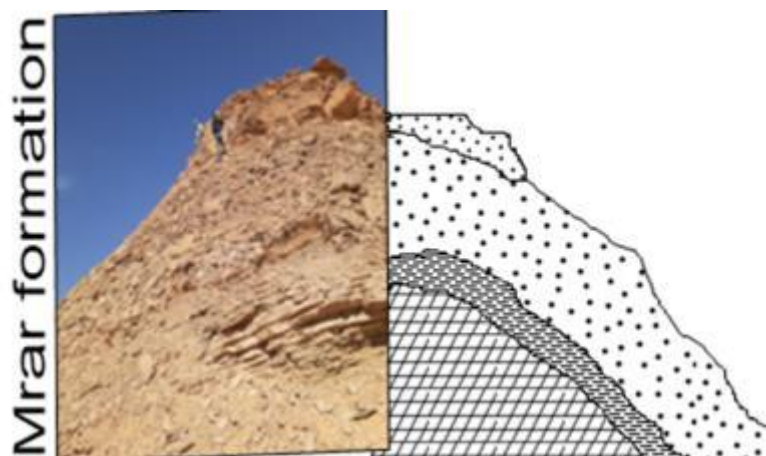
Figure 14. Horizontally laminated shales and silty claystones (Offshore Face) - Ashkidah Formation



Figure 15. Ferruginous Oolitic Sandstone - Ashkidah Formation

Marar Formation (Carboniferous)

Lower Carboniferous tidal flat environment. Features Hummocky Cross-Stratification (HCS), indicating periodic major storm events on the shelf. (Marar Formation at this location is characterized by a diverse mix of carbonate, shale, sandstone, and notably, thick-bedded sandstone units) (Figure 16).



(figure 16). Marar Formation(Carboniferous)

The Late Jurassic to Early Cretaceous Succession

Mssak Formation (sometimes called the Mssak Formation) is a very important sedimentary sequence in Southwest Libya, a major portion of the Late Jurassic to Early Cretaceous sequence. It plays a crucial role in the reconstruction of the paleoclimate of the North Africa of this time.

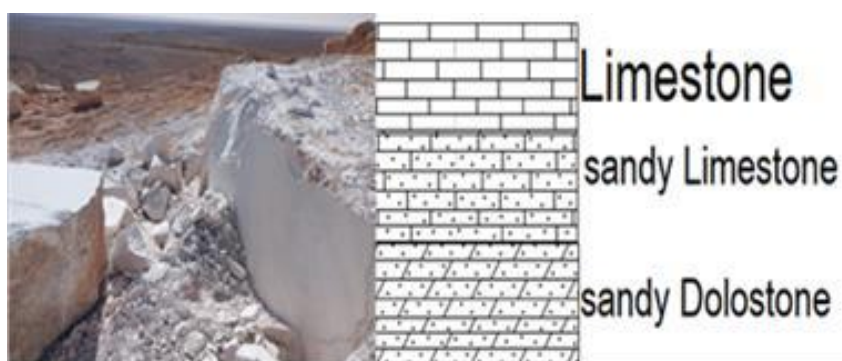
General Composition: Comprising of mainly claystone and conglomerate with claystone as the major lithology. Stratigraphic Division: Divided into two main members: Jarmah Member: Comprising of the bottom portion, which is about 83 meters thick in the region under study. It has a complex lithology with white and light brown quartz sands, gray and green clay beds, very coarse-grained and thickly bedded argillaceous sandstone and siltstone with cross-bedding. Poor sorting of sediments, clay galls and desiccation cracks and ripple marks, and plant fossil detritus are common. Awbari Member: The upper portion, which is dark-brown siliceous conglomerate, violet siltstone pebbles and cross-bedding. This will shift upwards to brownish-black, ferruginous and siliceous sandstone and microconglomerate. Generally, it consists mostly of claystone. Paleoenvironment and Paleontological Significance: Paleoenvironment: Mssak Formation suggests a fluvial depositional environment, which has river systems and the lakes. The existence of ancient gravel levels and paleo-deposits indicate the presence of a very different climate as compared to the present one. Paleontological Significance: It is of great paleontological interest being among the Libyan locations where one finds genuine dinosaur footprints. These are called the Fezzan Dinosaur tracks, which are dated to the Early Cretaceous. They are distinctly visible, three-toed tracks of Theropods (carnivorous dinosaurs), which is a great finding in the formation.(figure 17).



(figure 17).Dinosaur footprints (within Mssk Formation

The Pleistocene or Tertiary

Mahrugah Formation is on display to the east of the locality of Wadi Tarut. This formation is a low-salinity lacustrine system, with an upward-fining sequence. It is changing its lithology basal sandy dolostone to sandy limestone, which is to be followed by a thick, massive unit of lacustrine limestone (figure 18). This non-marine and fresh-water-influenced deposit environment is further supported by the existence of the plant fossils. The Mahrugah Formation has a geological age of either the Pleistocene or Tertiary.



(figure 18) Mahrugah Formation - in Qaret Mahrugah

Discussion

Depositional Evolution and Regional Stratigraphic Integration. The extensive field observations of Jabal Al-Hasawna and Wadi Ash-Shatti help to create a complete model of stratigraphic and environmental development of the area [4].

The deep nonconformity of the Precambrian Upper Tebisitan Series and the Cambrian Al-Hasawna Formation is a very important regional indicator. It marks a significant geodynamic transition between active Precambrian magmatism and tectonism to a lengthy era of geological stability, denudation and later subsidence of the basin [3]. The high purity and purity of feldspars in the basement granites indicate that large amount of feldspars can be used in industries, and the basal conglomerates of the Al-Hasawna Formation indicate the onset of high-energy fluviodeltaic deposition. A major Silurian marine transgression is the subsequent deposition of the Tanazzuft Formation. Graptolites and orthocone cephalopods in laminated shales are evidence of an environment of deep water, low energy towards the base of the storm waves [5]. But the supratidal facies (gypsum) and tidal nip and spring structures at Al Hattiyat Al-Duwaysah do show that this marine basin underwent major variations in facies laterally, with localized evaporitic conditions and shallowing.

The successions of the Devonian (Bir Al-Qasr up to Ashkidah) are highly cyclic, which is mainly reflected in the form of coarsening-upward parasequences [1]. These cycles document recurring movements of deeper offshore conditions to shallow, high energy shoreface or tidal conditions. An example is the record at the base of the Bir Al-Qasr Formation to the Edri Formation of a drastic change in a shallow marine shoreface to a braided fluvial system, caused by a relative decline in sea level (regression). This shift to a continental regime is ideally captured in the presence of root traces and channel lags in the upper Bir Al-Qasr at Qaret Alqullah.

The prevalence of ferruginous Oolitic sandstones [4] is a distinct feature of the Upper Devonian strata (the Dabdab, Tarut and Ashkidah formations). The field evidence, including Hummocky Cross-Stratification (HCS), and wave ripples in the Ashkidah Formation, indicates strongly that these iron-rich sediments were deposited in a Deep and Storm dominated environment. The iron ore member of the Dabdab Formation, relating to hardgrounds and a thinning-upward sequence, on the contrary, indicates a more limited, shallow marine or lagoonal environment. Iron mineral (siderite, berthierine) precipitation necessitates unique physicochemical circumstances that are typically linked to sediment starvation in maximum flooding surfaces or in narrow basins where there is a significant continental runoff [4]. The large phosphorus content (>1.0%) of the Ashkidah ores is a known metallurgical problem, which demonstrates the complicated geochemical interaction at deposition.

The field data highlights the huge importance of trace fossils in the interpretation of depositional energy and environments [6]. One of the trends that have been observed throughout the Devonian formations is the shift in ichnofabrics: - Low-Energy/Deeper Water: The finer-grained lower sections of the sequences (e.g., lower Tarut Formation) are dominated by diverse assemblages of Planolites, Thalassinoides and Chondrites (Cruziana ichnofacies). - High-Energy/Shallow Water: As sequences become coarser up to shoreface sandstones the variety of assemblages is replaced by vertical dwelling burrows based on mono-specific associations of Titillates (Skolithos ichnofacies) and Diplocraterion. This is adaptation to the changing substrates and high wave/tidal energy. The Edri Formation observation that bioturbation is not normally present with high-energy cross-bedding, but is present with wave ripples, places a strong emphasis on the dynamic, episodic nature of sedimentation (e.g., storm events followed by intervals of biological colonization).

Conclusion

The geological fieldwork of Jabal Al-Hasawna and Wadi Ash-Shatti offers a solid, empirical ground on which the Paleozoic development of southwestern Libya can be determined. Stratigraphic record records a shift of a stable, eroded Precambrian craton to a dynamic marine basin with large swings of sea-level. Deep marine transgressions characterized the Silurian period, and the Devonian successions document complicated, cyclical progressions of offshore marine to fluvial and confined lagoonal. Using a combination of lithological, sedimentary structures (HCS, cross-bedding), and high-resolution ichnological shifts (Cruziana to Skolithos

ichnofacies) enables accurate reconstructions of the paleoenvironment. Moreover, the field context of the ferruginous oolitic sandstones supports the fact that they were formed in storm-dominated and limited shallow marine environments, which are essential to the regional stratigraphy and economic analyses in the future.

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