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Facies Analysis of Memouniat Formation, Ghadames Basin, NW Libya: An Integrated Approach of Cores and Wireline-Logs

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ABSTRACT: *Analysis of available cores and wireline logs from 19 wells within the Ghadames (Hamada) Basin demonstrates that the Memouniat Formation consists mainly of three depositional facies bounded by time stratigraphic markers. Within this stratigraphic framework, the identified sequences of sedimentary texture and structures indicate that the gross facies changed laterally northwestward from fluvial-channelized dominated facies, to wavy laminated and bioturbated shoreface sands, and eventually to basinal-offshore silt/shale.*
The depositional sand trends in each mappable stratigraphic unit ***(****1-4****)*** *show channelized-type sands increase southward, indicating that the source of channels lay in that direction. Marine shale predominated in the northwest, which direction led increasingly further offshore.*
KEYWORDS: *Memouniat Formation, Ghadames Basin, Cores, Wireline-Logs, Facies Analysis.*

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I. INTRODUCTION

Facies analysis, using cores and wireline logs, is a crucial technique in geology for understanding the depositional environment and predicting reservoir quality [1]. Cores provide direct samples of the rock, while wireline logs offer indirect measurements of rock properties, allowing for a comprehensive understanding of the subsurface. Most times, core samples are not available for the analysis, thereby leading to the sole dependency on wireline logs. Facies is the fundamental unit for the analysis and interpretation of the environment of deposition. Interpretation of the environment in which facies were deposited from analysis of cored sequences and wireline logs involves relating the identified lithofacies to the physical and biological processes that produced them.

In the last ten years, exploration companies have accelerated efforts to tap the vast potential gas/oil reserves from the subsurface, upper Memouniat Formation in the Ghadames **(**Hamada**)** Basin, NW Libya.

Ghadames **(**Hamada**)** Basin has been the focus of hydrocarbon exploration since the early 1970s, with the discovery of El Hamra and Emgayt Fields in concession NC8A and Al Kabier Field in concession NC7A in the southern part of the basin. The Arabian Gulf Oil Company **(**AGOCO**)** has continued exploration activities in this basin, including several thousand kilometers of seismic lines **(**2D & 3D**)** and drilling of many wells.

I. 1 Location of the study area.

The study area of Ghadames **(**Hamada**)** Basin encompasses approximately 150,000 km², and it is located in the NW portion of Libya between latitudes 28°00 N to 32º20' N and longitudes 10°00E to 14º00E **(**Fig. 1**)**.

I.2 Objectives

1- Utilize well-log suites and available core data for the identification of the main environmental facies package of the Memouniat Formation.

2- Log-facies map construction to define the trends of the principal recognized facies of the Memouniat Formation in the studied area.

II. GEOLOGICAL SETTING.

The Ghadames Basin is a large intracratonic sag basin developed on the passive northern margin of Gondwana. It covers an area of 350,000km², with the basin center located in Algeria. The Libyan portion represents the eastern flank of the basin, rising towards the Tripoli-Tibisti Uplift (TTU), with a small sub-basin, the Zamzam Depression **(**ZZD**),** extending towards Misratah **(**Fig. 2**)**. The Libyan portion of this basin contains more than 16000ft **(**4877m**)** of Paleozoic-Mesozoic sediments. The basin is bounded in the west by the Amguid-El Biod Uplift in Algeria, and to the south by the Hoggar Massif in Algeria [3]. In Libya, the Ghadames **(**Hamada**)** Basin, shown in Figure 2, occupies the northwestern part of Libya and is structurally bounded from the north by the Nafusa Uplift, from the south by the Qarqaf Arch, from the east by the Tripoli Soda Arch, and from the west partially bounded by the Themboka Uplift.

The early Paleozoic history of the basin was controlled by the northwest-southeast Acadian-Caledonian (Post-PanAfrican) tectonic trend [7]. However, the Hercynian orogeny reached its peak during the Late Carboniferous, and major new tectonic elements were formed, including the Qarqaf and Nafusah Uplifts in Libya, and the entire area was uplifted and subjected to intense erosion during the Permian [3]. **(**Fig. 3**)** The structure map on the top of Ordovician **(**Fig. 4**)** shows that the strata dip generally westward at a rate of approximately **(**16ft/1km**)**.

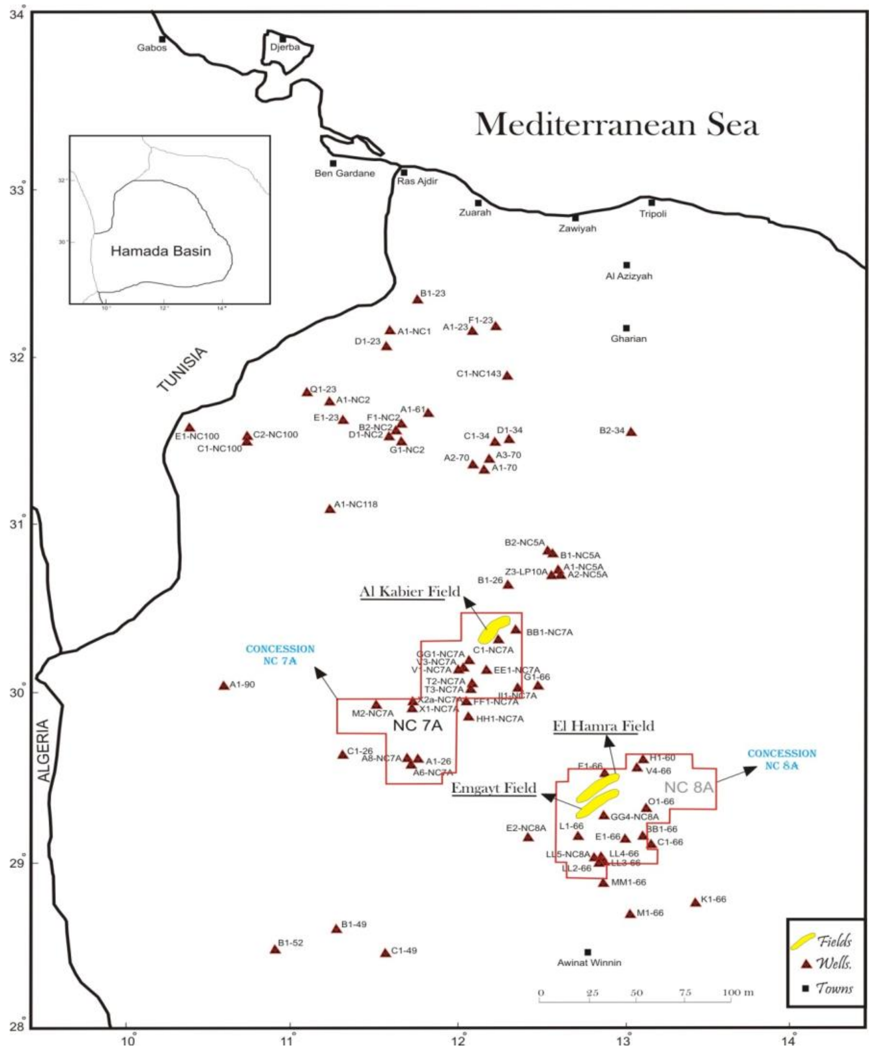

Figure 1. Location map of the study area, Ghadames (Hamada) Basin, NW Libya [2].

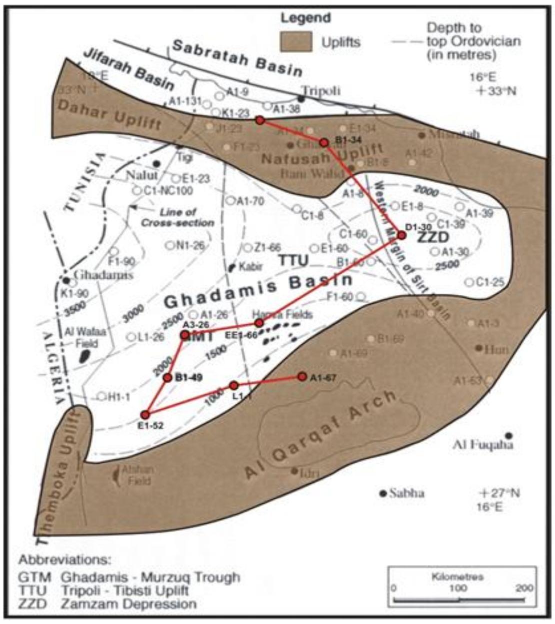

Figure 2. Tectonic Elements of Ghadames Basin. **(**Modified after [3], [4], [5], and [6])

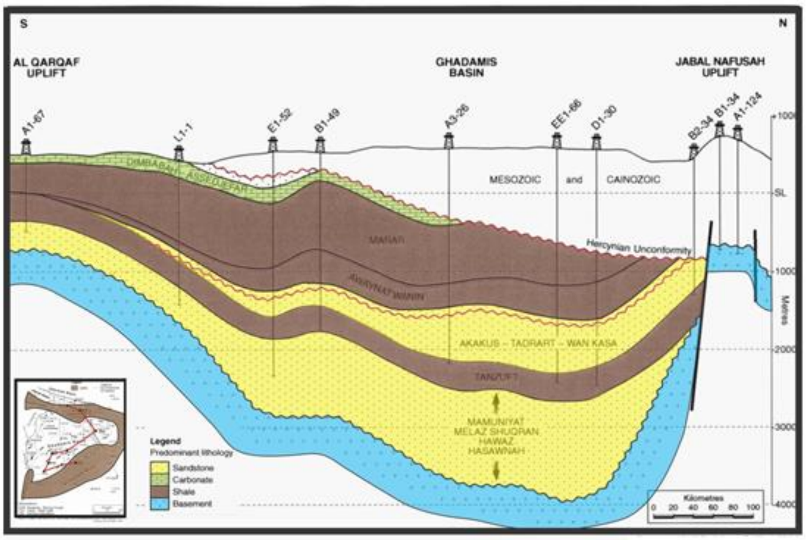

Figure 3. N-S Structural Cross-Section illustrates the Paleozoic succession in the Ghadames Basin, and the effect of the Hercynian unconformity **(**Modified after [3].).

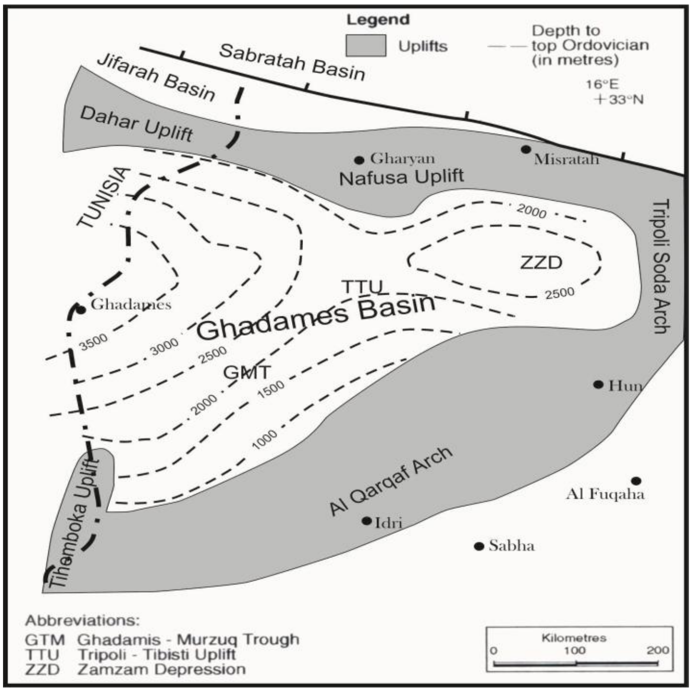

Figure 4. Structure map on top of Ordovician (Modified after [3]).

Stratigraphically, the Upper Ordovician Memouniat Formation in the study area is about (100 to 720ft) thick. The lower boundary is erosive with the underlain Melez Chograne Formation, and its upper boundary is unconformable with the Silurian Tanezzuft Formation (Fig. 5).

The isopach map of Memouniat Formation (Fig. 6) indicates a rapid increase in thickness in the (NW) direction of the study area, as the response to the structurally low basin area (Fig. 4). However relative decrease of thickness is much more pronounced in the NE direction here probably where the upper Ordovician Memouniat strata may onlap a NE striking paleogeographic high rising from the underlying erosional Melez Chograne surface.

The present depth to the top of the Memouniat Formation is in the order of -1880 to -12500ft (-573 to -3810m), while the maximum present depth of burial of the Memouniat Formation in the study area is attaining more than -12500ft; this deep burial accounts for the relatively high consolidation nature of these sands. The distinction between the Memouniat and Tanezzuft Formations is always possible and clear (in all well-logs) by referring to the relatively high radioactive basal part of the Tanezzuft Formation, which has been used as a datum in this study.

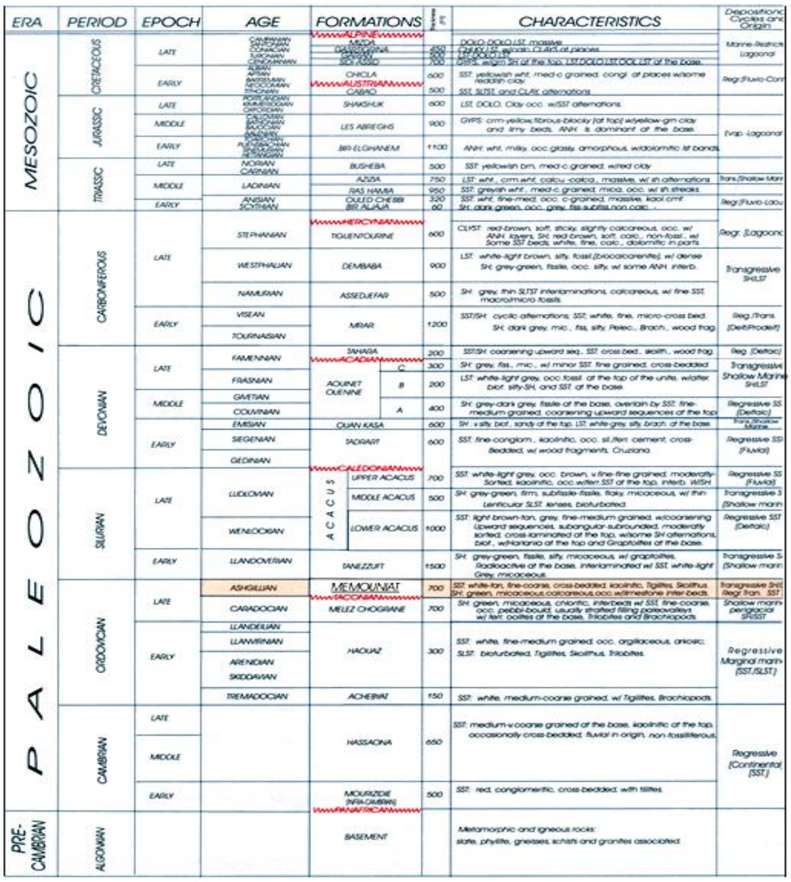

Figure 5. Paleozoic stratigraphic framework, Ghadames Basin. [2]

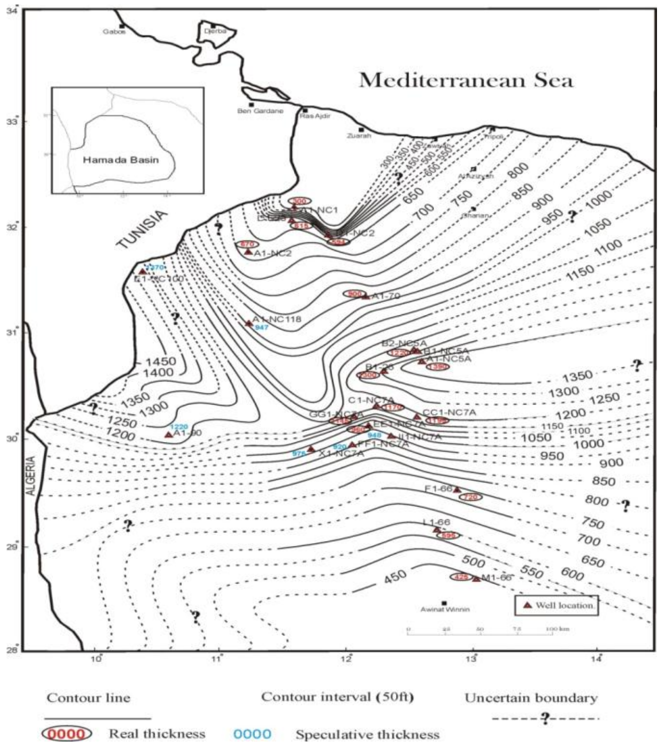

Figure 6. Isopach map of Memouniat Formation Ghadames Basin.

Nineteen (19) exploratory wells with well-log suites and seven (7) available cores, which mainly concentrated in NC1 and NC8A concessions (Table 1, Fig. 7), were used for facies recognition and log-facies map construction. These (19) wells were drilled to about 5640 ft and 7598 ft.

The recovered 201ft from seven cores **(**Table 1, Fig. 7**)** were described by using a graphic core description sheet **(**Fig. 8**)**, in which a vertical scale of 1cm to 4ft was selected, so that the graphic core log could be compared directly with the wireline logs.

Following the detailed core description, Schlumberger's Petrel 2010 version software was used for processing the data. The well logs were placed against each other to facilitate correlation and assessment of data quality. The lateral facies relationships were investigated with the aid of well log suites to generate a stratigraphic cross-section within which possible lateral facies changes could be examined and mapped. The following techniques were adopted for the data analysis:

- Lithology Identification:

The GR and SP logs were used for lithology identification. However, the gamma ray log is also used as a measure for grain size and subsequently for inferring depositional energy.

- Well Log Facies Identification:

The shape of gamma ray log signatures is a basic tool for the interpretation of facies and depositional environments. Four types of gamma ray trends or shapes can be recognized when examining the log curves. Cylindrical shape (represents uniform distribution), Bell shape (Fining upwards sequences), Funnel shape (coarsing upward), and Spiky-serrated shape (represents alternating small fine and coarse pulses).

- Determination of Well Log Stacking Pattern and Sequences:

The log curve shapes, morphology, and the nature of the lower and upper boundaries with adjacent shale units are used to recognize the log motifs of the available GR/SP curves.

The stacking patterns of the gamma ray (GR) logs were used to characterize the rate of deposition and sequences. In these sequences, a retrogradation stacking pattern is associated with a fining upward trend in the gamma ray log, a coarsing upward trend in the gamma ray curve means a progradational stacking pattern while a blocky trend in the gamma ray curve represents an aggradational stacking pattern, and a spiky shape GR log response showed a serrated shape with abrupt terminations and facies dipping seaward.

Well No.	*Well Name*	*Available cores at Mem. Fm.*	*Available well-log Suites*
1	D1-23	**(1 Core)** ✓	SP.
2	B1-26	**-**	SP.
3	F1-66	**(2 Cores)** ✓	SP.
4	GG1-66	**(2 Cores)** ✓	SP.
5	L1-66	**-**	SP.
6	M1-66	**-**	SP.
7	A1-70	**-**	SP.
8	A1-90	**-**	SP.
9	E1-NC100	**-**	SP. & GR
10	A1-NC118	**-**	SP. & GR
11	A1-NC1	**(2 Cores)** ✓	SP. & GR
12	A1-NC2	**-**	SP.
13	D1-NC2	**-**	SP. & GR
14	A1-NC5A	**-**	GR
15	B1-NC5A	**-**	SP. & GR
16	B2-NC5A	**-**	SP. & GR
17	C1-NC7A	**-**	SP. & GR
18	CC1-NC7A	**-**	SP. & GR
19	EE1-NC7A	**-**	SP. & GR

Table 1. Targeted wells are used for multiple purposes in the study area.

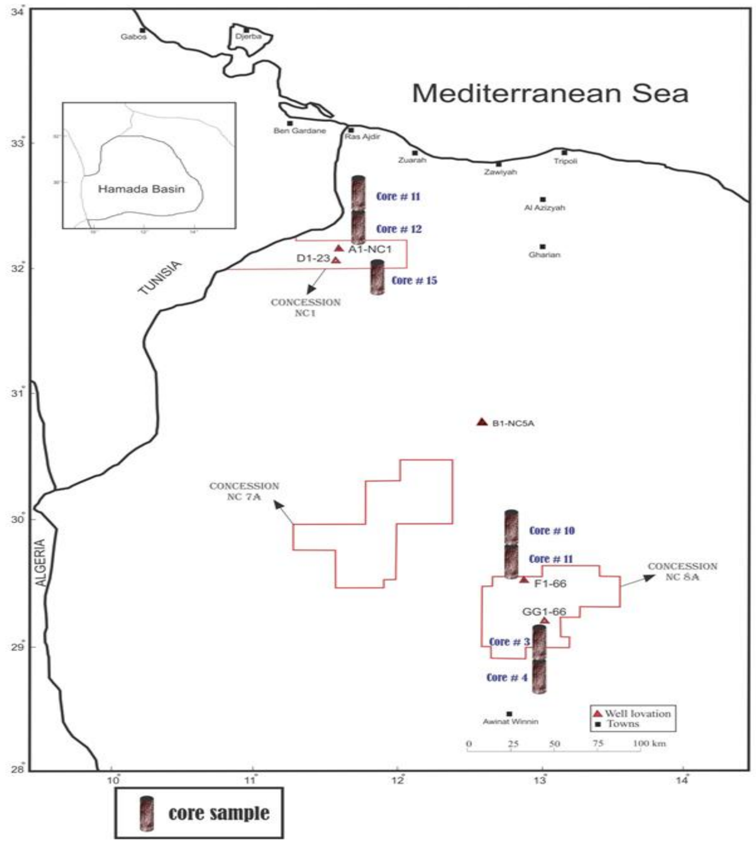

Figure 7. Base map for available cored wells **(**GG1-66, F1-66, D1-23, and A1-NC1**)** in the study area.

Table 2. Graphic facies log form, used for the description of cores cut in some wells in the Memouniat Formation, Ghadames **(**Hamada**)** Basin, NW Libya.

Depth (ft)	GR log (API) SP log (MV) GR (GAPI) 0.0 – 150.00 SP (MV) -80.00 – 20.000	Grain size m slt v.f f m c v.c.Cong.	Oil show Ex. G. Fr.	Gross lithology	Sedimentary Structure	Litho. facies	Depositional environment	Core Sample

IV. STRATIGRAPHIC CROSS SECTION (TIME STRATIGRAPHIC UNIT)

Regional stratigraphic cross section (Fig. 8) was constructed using the base of the persistent high radioactive shale of Tanezzuft Formation as a regional datum, as this horizon marks a rapid and wide spread transgression and it is believed to approximate a relatively flat paleosurface, and can be traced from well to well providing a meaningful stratigraphic relationship, within which observed facies are correlatable and can be examined in terms of lateral facies changes.

In this stratigraphic cross-section, the lateral relationship between identified facies in cores has been examined, and the traces of GR-log and/or SP-curve were used to define lithological changes at each control point. The Memouniat Formation in the study area can be divided into three sectors (channel fill sand-dominated sector, proximal sand-dominated sector, and basinal offshore silt/shale-dominated sector). Whereas in each well, sand and shale beds may occur interbedded at different levels. The lower limit of the Memouniat Formation can be defined by Melez Chograne Shale at some locations (wells M1-66, F1-66, D1-23, and A1-NC1), whereas its presence across the correlatable wells could be speculative, marking an arbitrary lower boundary.

Within the establishing stratigraphic framework (Fig. 8), the facies changes laterally from much channelized sandstone facies to the south, passes northward to a much transgressive high-energy marine sand facies, which eventually grades into a basinal offshore silt/shale facies.

Accompanying these regional basin-ward facies changes is a notable decrease in grain size of the Memouniat Formation (northward). Increasing distance from south to north reflects an increase in the shale sections (vertically) in each correlated well.

Hence, another vertical change in facies regarding the development of some carbonate horizon, especially in wells (B1-26, B1-NC5A, and A1-70) of the middle sector, which may suggest a subsequent transgression marking the beginning of this horizon, to much more marine reworked sand at the top. We have regarded this carbonate horizon or its equivalent in this study as a facies from the Memouniat Formation; it appears to be infill topographic lows on the eroded and irregular Memouniat surface, and thins or is absent over topographic highs. It may have an unconformable relationship with the overlying Tanezzuft Formation, which truncates this carbonate horizon at some locations, as in well A1-70.

Moreover, its location appears to be either associated with shallow depth (wells A1-70, B2-NC7A, and B1-NC7A) (Fig. 8), topping the Memouniat Formation, whereas it could be seen in the deeper section of the Memouniat Formation at great depth (well F1-66). Its thickness reaches 85ft to the north and decreases to 40ft to the south, and sometimes is completely missed, especially in the southern part of the basin in the vicinity of wells (M1-66, L1-66, EE1-NC7A, and CC1-NC7A). The discontinuity of this limestone may suggest that coastal inundation was active through valley incisions in the southern part of the study area. This carbonate facies may be interpreted to have comparatively shorter periods of localized carbonate production during episodes of marine inundation.

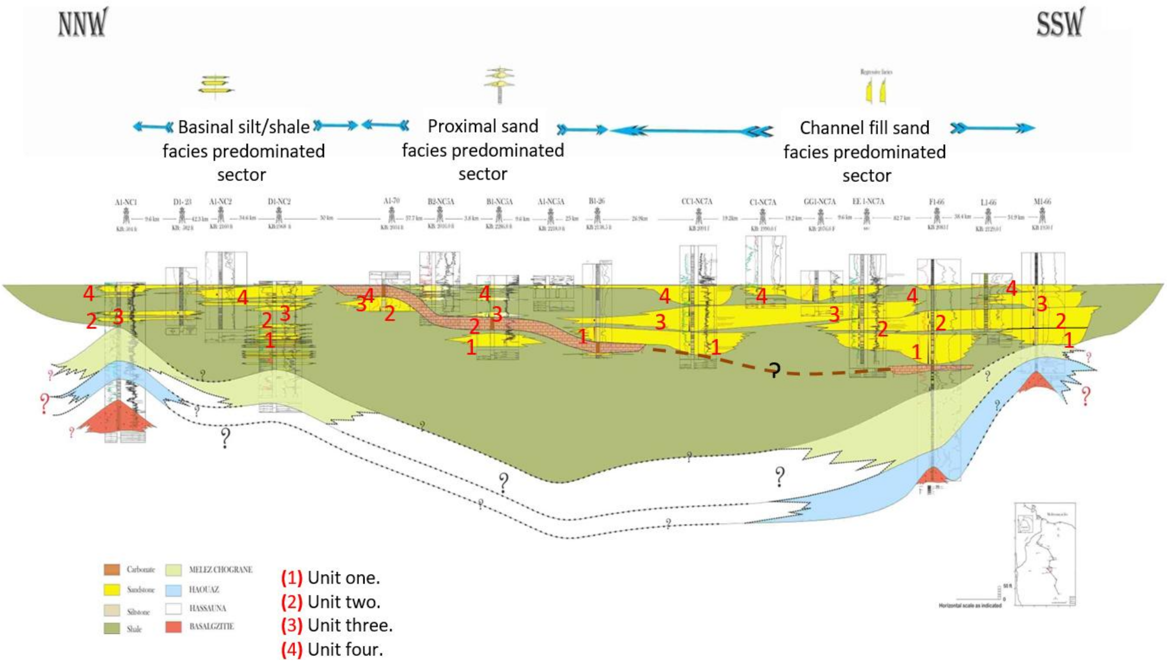

Figure 8. Regional stratigraphic cross-section, showing possible correlation of the selected Memouniat Formation, units (1-4) and their facies predominant sectors Ghadames Basin, NW Libya.

V. ENVIRONMENTAL FACIES RECOGNITION THROUGH CORES EXAMINATION

Sedimentary structures are the larger-scale features of sedimentary rocks. The majority of structures form by physical processes, before, during, and after sedimentation, whereas others result from organic and chemical processes. Sedimentary structures, particularly those formed during sedimentation, have a variety of uses: for interpreting the depositional environment in terms of processes, water depth, wind strength, etc, for determining the way up of a rock sequence in an area of complex folding, and for deducing the palaeocurrent pattern and paleogeography [8].

V.1 Primary sedimentary structures, textures, and their associated facies.

The observed sedimentary structures and textures in the examined cores indicate that there was an interplay between fluvial channels and marine processes in the study area.

Three possible facies channel fill sands (Fig. 9), proximal sands (Fig. 10), and basinal silt /shale (Fig. 11) have been recognized.

Figure 9. Channel fill sands in channel fill facies predominated sector, core #4 (6187-6224ft) in well GG1-66.

Figure 10. Proximal sands in proximal facies predominated sector, core #12 (5828.8-5843.8ft) in well A1-NC1.

Figure 11. Basinal (offshore) silt/shale facies predominated sector, core #15 (6256-6311.6ft) in well D1-23.

V. 1.1 Channel fill sandstone facies:

The channels fill sand facies (Figs. 12-15) consist of occasional trough x-lamination (Fig. 16), basal scours, and rip-up clasts (Fig. 17). Horizontal lamination associated with wavy lamination may be observed at some levels of the sand-fill sequence, which may suggest periods of variation in energy conditions (Fig. 18).

Some evidence may suggest tidal processes may affect sedimentation, like flaser-sands structures could be seen at some places (Fig. 19). Bioturbations are less abundant in this facies, but may be present at some levels (Fig. 20).

The grain size of this facies tends to be from medium to coarse-grained, where the relative abundance of clay clasts is higher.

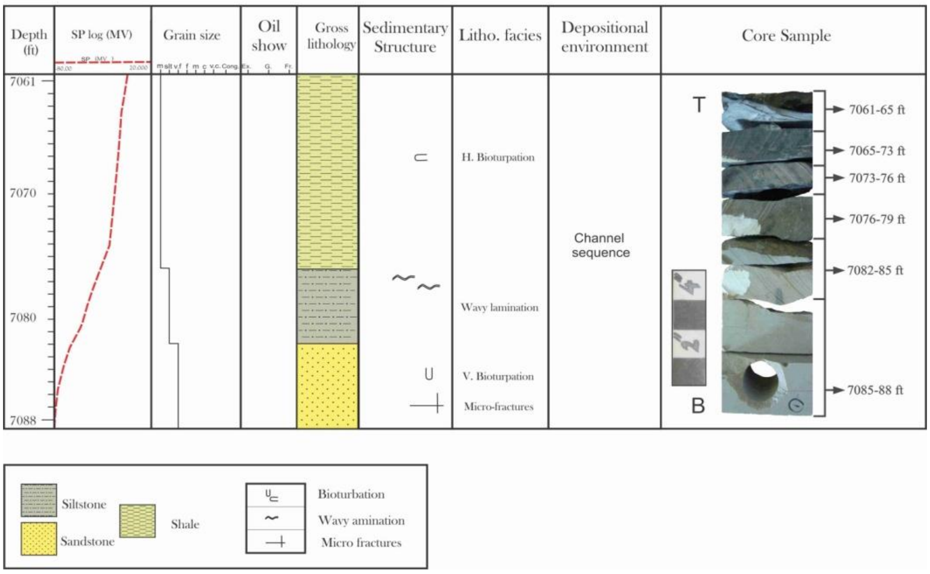

Figure 12. Graphic facies log of core #10, at interval (7061-7088ft), in well F1-66, illustrating sequence grading upward from V. bioturbated, m-c grained sands at the base to H. bioturbated, f. grained sands at top, channel fill sands facies, Memouniat Formation, Ghadames Basin.

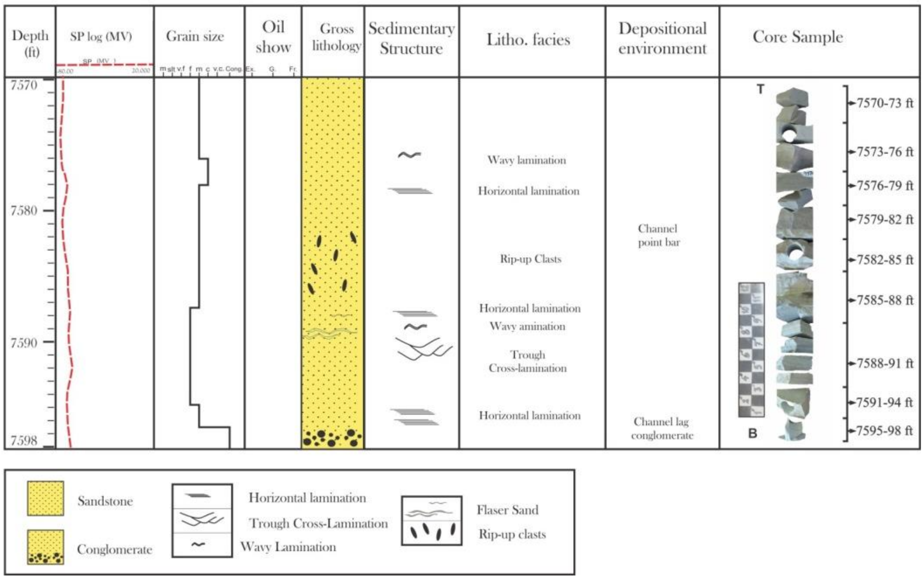

Figure 13. Graphic facies log of core #11, at interval (7570-7598ft), in well F1-66, showing sequence grading upward from horizontal to trough x-lamination, coarse grained sands at the base to horizontal laminated, wavy laminated, m. grained sands at top. Suggesting proximity to point bar deposits, channel fill sands facies, Memouniat Formation, Ghadames Basin.

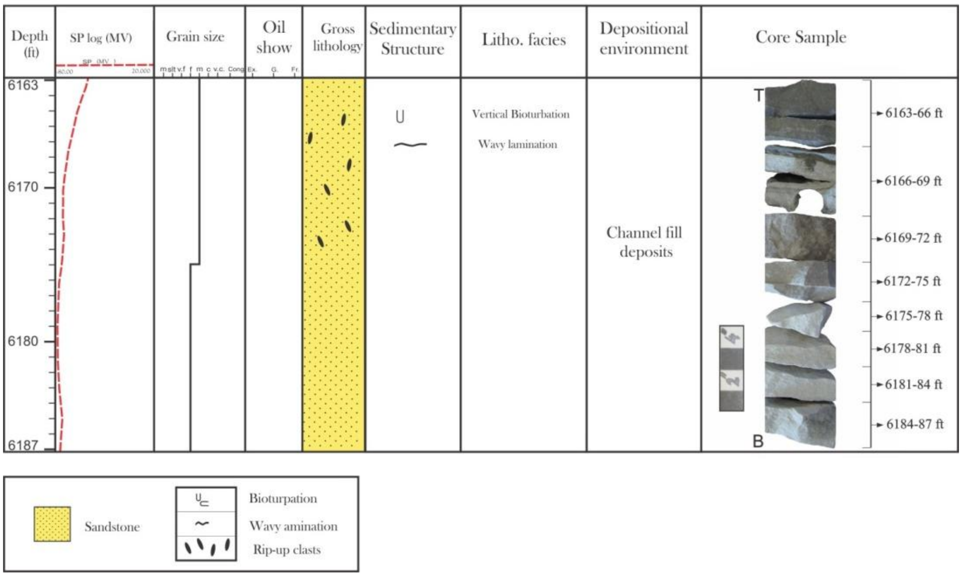

Figure 14. Graphic facies log of core #3, at interval **(**6163-6187ft**)**, in well GG1-66, showing f-m. sands characterized by rip-up clasts, some wavy lamination and v. bioturbation at top, channel fill sands facies, Memouniat Formation, Ghadames Basin.

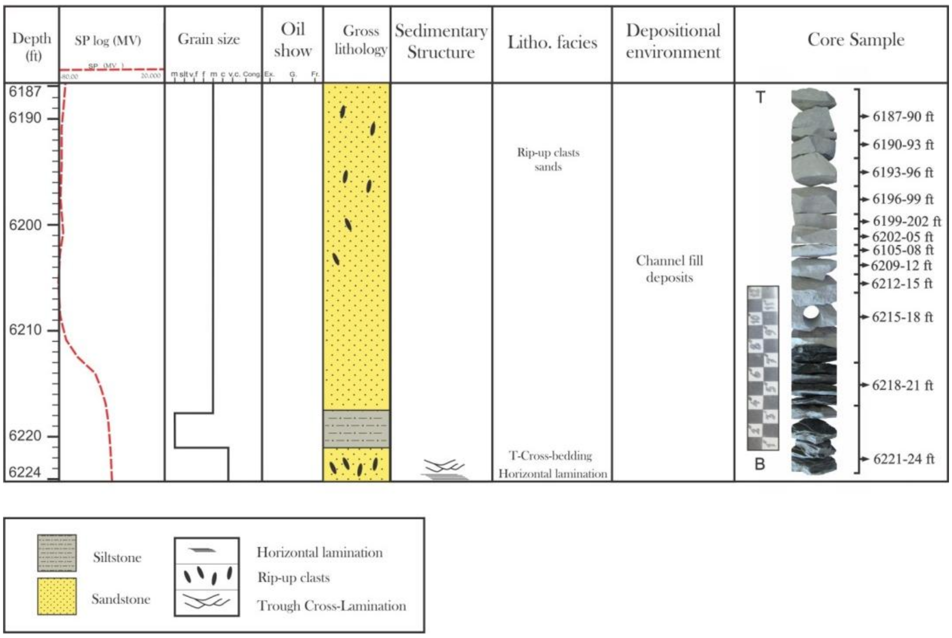

Figure 15. Graphic facies log of core #4, at interval **(**6187-6224ft**)**, in well GG1-66, illustrating a sequence of fining upward grain size, characterized by trough x-lamination at base **(**scour nature**)** and of rip-up clasts sands at top, channel fill sands facies, Memouniat Formation, Ghadames Basin.

Figure 16. Trough x-lamination in channel fill sands facies predominated sector, core #11 (7598-7570ft) in well F1-66.

Figure 17. Rip-up clasts (circles) in channel fill sand facies predominated sector, core #3 (6163-6187ft) in well GG1-66.

Figure 18. Horizontal and wavy lamination primary sedimentary structures in channel fill sands facies predominated sector, core #11 (7570-7598ft) in well F1-66.

Figure 19. Flaser-sands structures in proximal sands facies predominated sector, core #12 (5828.8-5843.8ft) in well A1-NC1

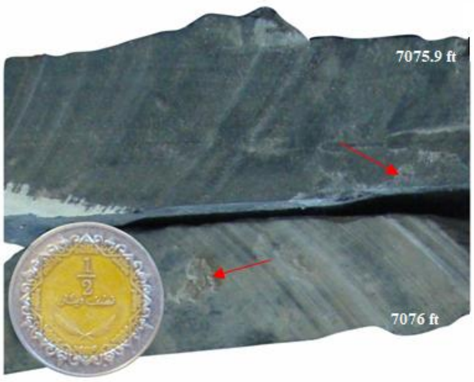

Figure 20. Bioturbation (indicated by arrows) in channel fill sands facies, core #10 (7061-7088ft) in well F1-66.

V. 1.2 Proximal (shoreface) sand facies:

The proximal sand facies **(**shoreface**)** **(**Figs. 21 and 22**)** was deposited basinward from the channel fill facies in a shallow marine water environment in which wave processes predominated. Parallel lamination associated with wavy lamination **(**Fig. 23**)**, occasionally with the truncated surface **(**Fig. 24**)**, may be seen in this facies, reflecting periodic variation in wave energy through the agitated environment. Bioturbation is more severe in shaly parts of this facies, where high water turbulence affects sandy facies.

The sedimentation rate could restrict faunal diversity in this proximal **(**shoreface**)** sand facies. The mean grain size tends to be of fine sand.

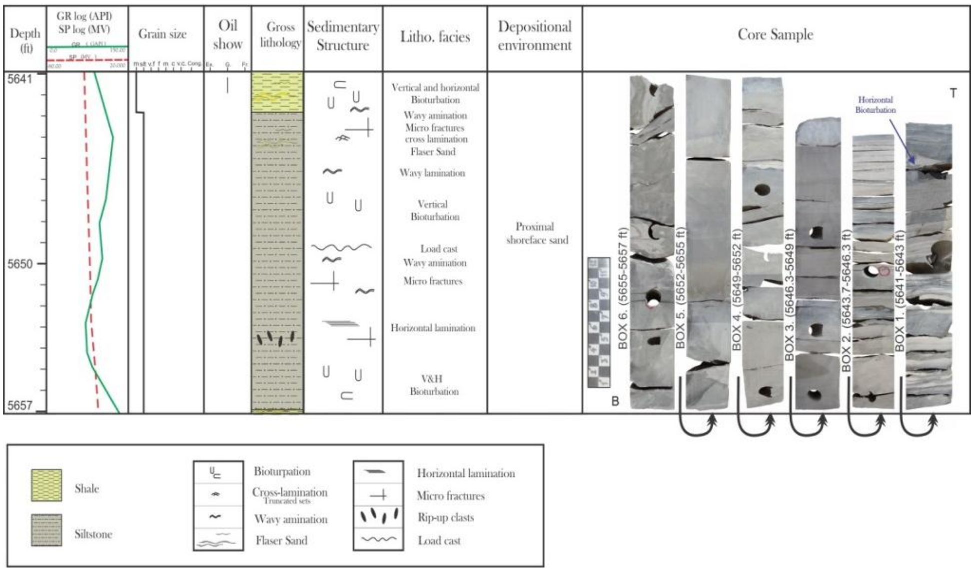

Figure 21. Graphic facies log of core #11, at interval **(**5641-5657ft**)**, in well A1-NC1, showing proximal shoreface sandstone heterogeneity where sands have been reworked by marine processes, Memouniat Formation, Ghadames Basin.

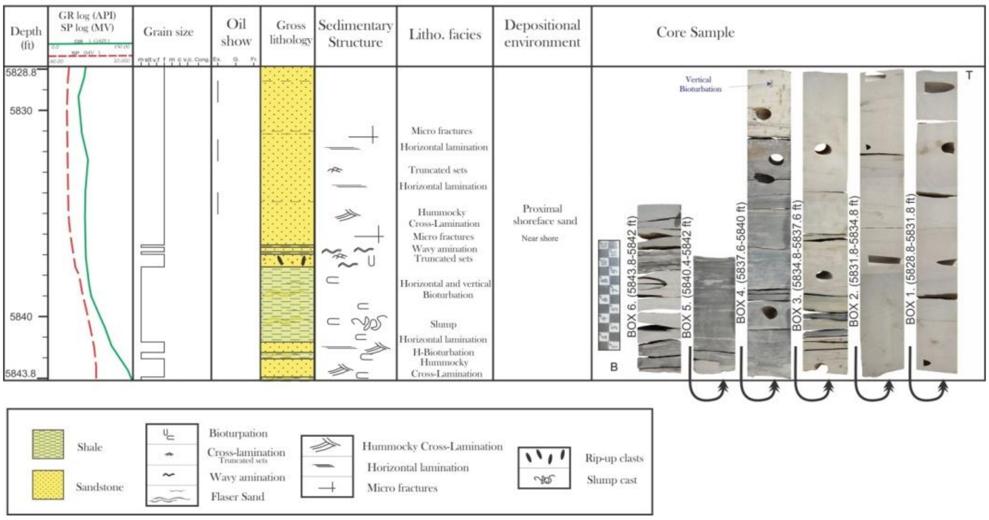

Figure 22. Graphic facies log of core #12, at interval **(**5828.8-5843.8ft**)**, in well A1-NC1, showing some reworked sandstone as indicated by some sedimentary structures and grain sizes, proximal shoreface facies, Memouniat Formation, Ghadames Basin.

Figure 23. Horizontal and wavy lamination primary sedimentary structures in proximal sands predominated sector, core #12 **(**5828.8-5843.8ft**)** in well A1-NC1.

Figure 24. Truncated surface primary sedimentary structures in proximal sands predominated sector, core #12 **(**5828.8-5843.8ft**)** in well A1-NC1.

V. 1.3 Basinal (offshore) silt/shale facies:

The basinal offshore silt/shale facies **(**Fig. 25**)** is characterized by lenticular silt/sands and muds **(**Fig. 26**)** occasionally with parallel lamination **(**Fig. 27**)** and of intensive bioturbation **(**Fig. 28**)**. The mean grain size of this facies tends to be fine silt and mud.

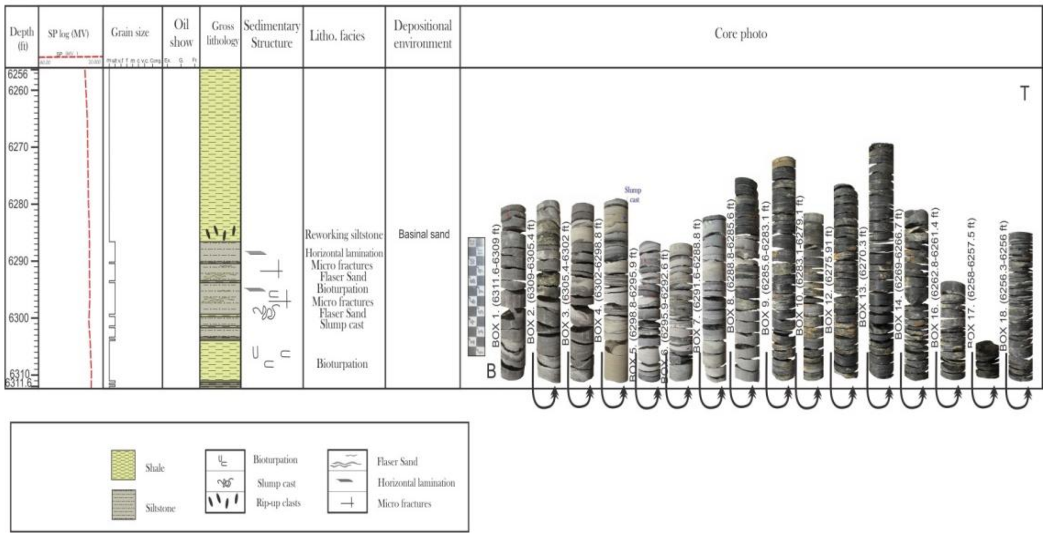

Figure 25. Graphic facies log of core #15, at interval **(**6256-6311.6ft**)**, in well D1-23, showing extensive bioturbation in silty-shaly sandstone of basinal offshore facies, Memouniat Formation, Ghadames Basin.

Figure 26. Lenticuler silt/sands and muds in basinal predominated sector, core #15 (6256-6311.6ft) in well D1-23.

Figure 27. Horizontal lamination in basinal silt/shale predominated sector, core #15 (6256-6311.6ft) in well D1-23.

Figure 28. Bioturbation in basinal silt/shale predominated sector core #15 (6256-6311.6ft) in well D1-23.

V. 2 Secondary sedimentary structures and their associated facies.

The modification of primary sedimentary structures by sediment loading and differential compaction or possibly by deep-seated basement faulting has been observed at many levels of the examined cores.

Microfractures (Figs. 29 and 30) are the most evidence of postdepositional (secondary) sedimentary structures in the studied cores associated with the channel fill facies and the proximal sand facies, respectively.

Sediment loading slump-like feature (Fig. 31) is mainly associated with the basinal silt/shale facies. These features may suggest that this rock has experienced some deformation in moderate to deep burial. Many questions remained unsolved regarding these fractured sandstones. Moreover, the potential is obvious for effective fractures and their characterization to have an application in the exploration and development of the Memouniat Formation.

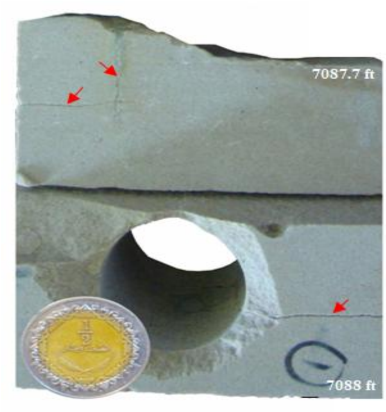

Figure 29. Micro fracture structures (indicated by arrows) in channel fill sand facies predominated sector, core #10 (7061-7088ft) in well F1-66.

Figure 30. Micro fracture structures (indicated by arrows) in proximal sand facies predominated sector, core #11 (5641-5657ft) in well A1-NC1.

Figure 31. Micro fracture structures (indicated by arrows) in proximal sand predominated sector, core #11 (5641-5657ft) in well A1-NC1.

Figure 31. Slump like structure in basinal silt/shal facies predominated sector, core #15 **(**6256-6311.6ft**)** in well D1-23.

VI. WIRELINE-LOG CHARACTERISTICS

VI.1 Log shapes:

The shape of a gamma ray (or SP) log through a sand body is often thought of as a grain size profile [9]. Three basic log shapes are recognized: funnel (coarsening upward), cylinder (blocky), and bell (fining upward) (Fig. 32) [9], [10]. These three shapes can be subdivided into smooth (relatively homogeneous) or serrate (with interbedded thin shales). Log shapes typically reflect changing depositional energy from high (clean, coarser sand) to low (shaly, finer sand).

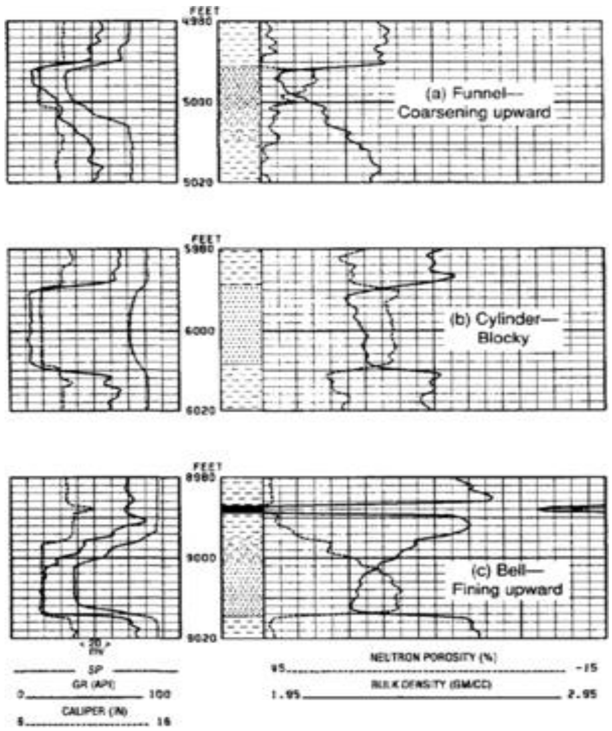

Figure 32. Characteristic log shapes for different types of sand bodies set in shale, (a) Funnel shape, coarsening upward. Note that this is the shallowest interval, so the shale is least compacted. (b) Cylinder shape, blocky. Note that the SP log is featureless because the borehole salinity is the same as the formation salinity. (c) Bell shape, fining upward. Note that coal is present in addition to shale [9], [10].

- Funnel shapes imply upward-increasing energy, which may be found in distributary mouth bars, delta lobe fringes, deep-sea fans, and other environments.
- Cylinder shapes reflect relatively constant energy levels and can include eolian dunes, low sinuosity distributary channels, and beaches.
- Bell shapes represent waning-current sequences, which can include alluvial point bars, deltaic distributaries, and deep-sea fan channels.

VI.2 Well log types of the Memouniat Formation:

As cores are not available on many of the studied wells, another type of data must be used to identify the environmental facies and characterization of the sandstones of the Memouniat Formation. Wireline logs, which are run routinely on most wells, were examined as facies tools for identifying sand-body types. Well logs types of the Memouniat Formation can be seen in **(**Fig. 33**),** in which different sand types (1-4) are defining their dominating sectors. The main observations made out of the GR **(**Gamma Ray**)** and SP **(**Spontaneous Potential**)** curves are:

a) The trend of the curves is inclined to the right **(**decreasing in clay contents upward**)**, or inclined to the left **(**increasing clay contents upward**),** or sometimes of a blocky nature **(**clay contents are uniform**)**, or spiky nature of the fining or coarsening upward grain size.

b) Nature of the basal contacts of the studied sandstone **(**is it gradational or sharp?**)**.

c) The general appearance of the curve is whether it is smooth or serrated, as interbedded with some shale.

The observed GR-SP log signatures of various studied facies in the cored interval of Memouniat Formation characterize four unit types (1-4) **(**Fig. 33**)**. Practical comparison of GR-SP curves with available core description shows that the blocky SP curve represents (unit1 in well GG1-66, Fig. 33)**,** which may refer to stacked braided channels, having sharp base and top, characterized by the overall same grain size with little variation in clay contents. They may, in general, represent the best reservoir because of their lower mud contents.

The SP curve sloping to the left **(**unit 2 in well F1-66, Fig. 33**)** corresponds with interpreted meander channel sand sequences. In these sequences, the sands are characterized by a sharp basal contact and of fining-upward fashion. The curve is generally smooth in the lower part and becomes more serrated toward the top, recording an overall increase in shale lamination. Eventually, these channels were abandoned, marking possible good porous and permeable sand at the base **(**clean sand**)**, as evidenced by some hydrocarbon shows at some intervals.

The GR curve sloping to the right **(**unit 3 in well B1-NC5A, Fig. 33**)** corresponds with beach, coastal sand, or deltaic (shoreface) deposits. These deposits are characterized by a sharp upper contact and a gradational base, which account for overall coarsening-upward grain size. The curve is generally serrated toward the bottom, recording an overall increase in shaly laminations. Possible oil shows may be encountered at the top of the sand unit.

The serrated **(**spiky**)** GR curve characterizes (unit 4 in well A1-NC1, Fig. 33) a basinal (offshore) nature**,** showing occasionally small fining or coarsening log signature. The serrated nature usually corresponds to the presence of shaly interbeds. Generally, this shaly sand unit lacks hydrocarbon shows as they are relatively mud-saturated.

The SP log characteristics are also investigated and occasionally compared with GR curves in most available wells. The SP curve is usually less definitive than the GR curves, especially in wells **(** A1-NC118, B2-NC5A **),** and in some cases, the trends of the curve are even reversed in wells **(**C1-NC7A, D1-23**)**.

In general, the SP curve is less reliable than GR for interpreting depositional facies, as it is affected by some factors such as:

1- Fluid formation salinity.

2- Diagenesis.

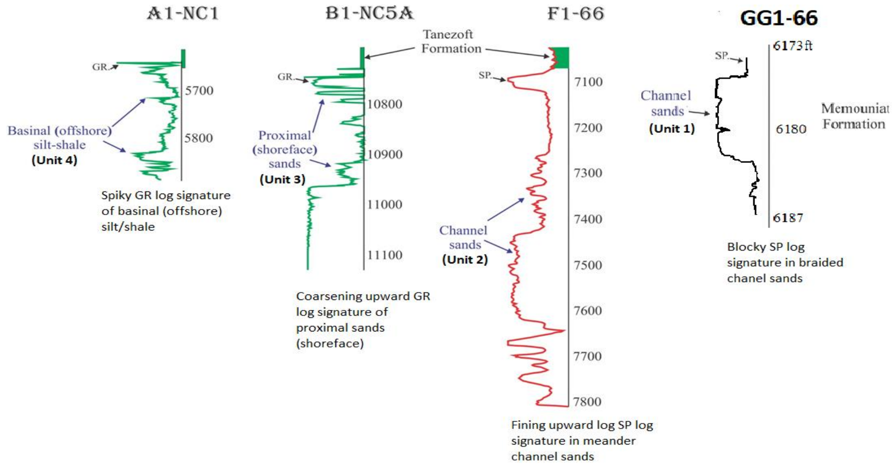

Figure 33. Well log types showing GR.-SP. Log signatures of the Memouniat Formation in some studied wells, Ghadames Basin, NW Libya.

VI.3 Log-facies maps for units 1-4

Figures 34-37 are log facies maps for sandstone units 1-4, showing the different facies and their log shape characteristics, which permit recognition of facies from each other [11].

Log facies maps **(**Figs. 34-37**)** show that the channel sands and proximal shoreface sands are dominating the southern and central parts of the study area, while the most likely basinal **(**offshore**)** silt/shales are dominating the northern part of the study area. However, the carbonate facies locally defines the NE/SW corners of the study area on the level of the unit **(**2**)** **(**Fig. 35**)** and unit **(**4**)** **(**Fig. 37**)**, and this may suggest its discontinuity and its depositional nature.

As indicated in section (6.1**)**, the GR-log signature of channel sandstone is of bell shape, characterized by a fining upward sequence serrated with shaly laminations at the upper part, which affects on physical properties of the facies, sometimes characterized by a blocky shape at some levels, which represents a good stacked sandstone unit to be drilled.

The sandstones of proximal sand are characterized by a coarsening upward fashion of GR-log signature and a transitional base with the silt, shale lower units, and a sharp, remarkable top at the end of the unit. These sands reflect a high mode of depositional flow regime.

The offshore basinal silt/shale is characterized by the spiky nature of the log signature marking the northernmost basin edge, having a thickness of 20ft and usually enclosed between marine shales as in wells D1-23 and A1-NC1, which suggests their marine offshore nature.

The mappable sandstone units 1-4 will show lateral facies changes in transitional mode, or even where the maps effectively may depict the main trends of their depositional system, and also the direction from which clastics were derived.

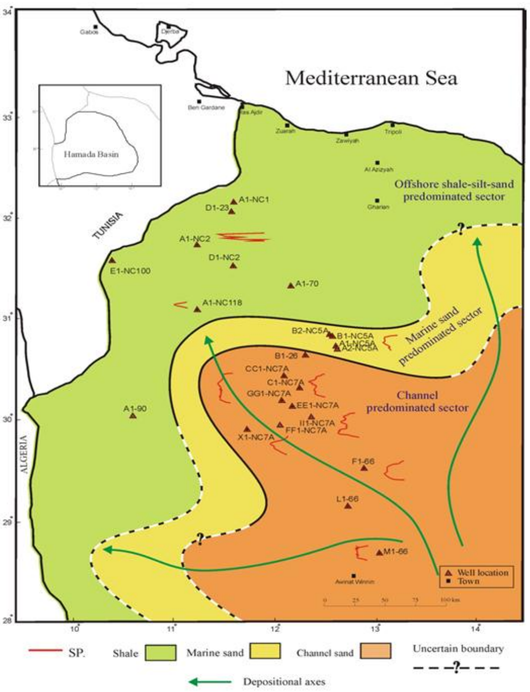

Figure 34. Log facies map of sand unit (1) for Memouniat Formation, Ghadames Basin.

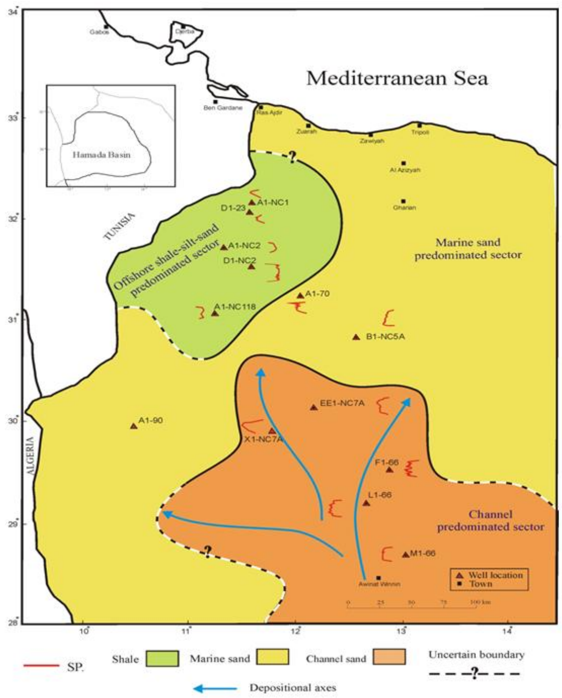

Figure 35. Log facies map of sand unit (2) for Memouniat Formation, Ghadames Basin.

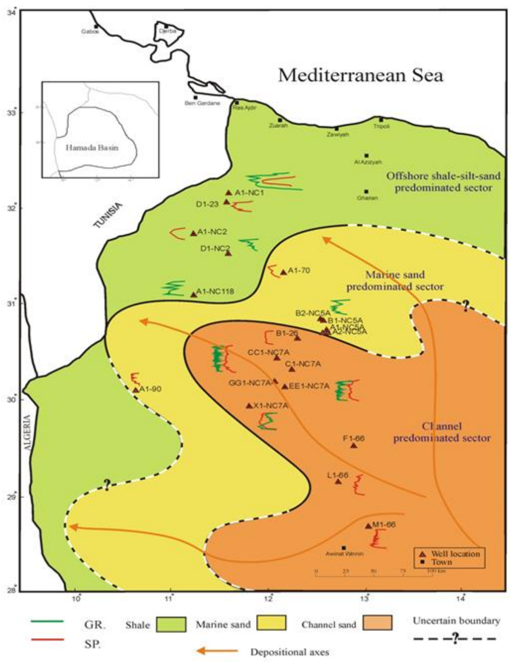

Figure 36. Log facies map of sand unit (3) for Memouniat Formation, Ghadames Basin.

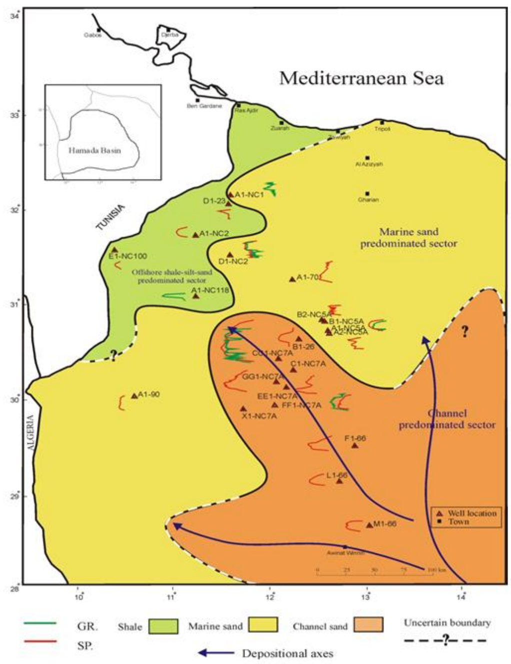

Figure 37. Log facies map of sand unit (4) for Memouniat Formation, Ghadames Basin.

VII. SUPERIMPOSED LOG FACIES MAPS FOR UNITS 1-4

The heterogeneity of the Memouniat Formation can be seen laterally using a sand axes map (Fig. 38) and can be seen vertically using **a** composite facies map (Fig. 39). In this composite log facies map, penetration of different facies types (units) could be recovered. However, penetration of the good stacking thickness present in each mapped unit is highly unlikely. This may relate to differential compaction and of different channel supply and shift of channel courses through time.

The channel shift could be seen in (Fig. 38), which may be caused by intensive sedimentation in a relatively stable basin area [12].

In the superimposed slice maps (Fig. 40), the vertical sequence in any well can penetrate different sands at different locations. As a result, one can conclude that the southern and central parts of the study area in the vicinity of wells M1-66, L1-66, F1-66, EE1-NC7A, GG1-66, NC7A, CC1-NC7A, A1-NC5A, B1-NC5A, and B2-NC5A have probably a great chance to recover clean sandstones of channelized and shoreface facies. However, the northern part of the study area in the vicinity of the wells D1-NC2, A1-NC2, D1-23, and A1-NC1 will be characterized mostly by silty-shaly sandstones of basinal offshore facies.

By using Figure 40, in case of selecting some areas to be drilled and penetrating the four horizons at locations (1, 2, 3, 4 and 5), priority must be given to location (5), even though at this location less thickness (20-50ft) of the prospected sands (1-4) will be recovered, but of good reservoir characteristics represented by clean reworked sands of wave dominated sector in which winnowing out of the clay was very pronounced leaving behind the good clean coarser materials which may have a good secondary dissolution porosity.

Location (2) must be a penetrating good, thick sequence of channel sands, which may have good characteristics if the bottom coarse-grained part of the channel was recovered rather than the top fine-grained part, because the top-most part of the channel may have some shale laminations which destroy the reservoir property of this sand unit. This second priority location is characterized by primary porosity at the basal part of the channel, which may be partially filled with silica cement and reducing porosity.

Locations (1, 3, and 4) are of the least priority because they are penetrating most likely the silty shale units, which are of low quality; hence, in these locations, reservoir characterizations will be deteriorated.

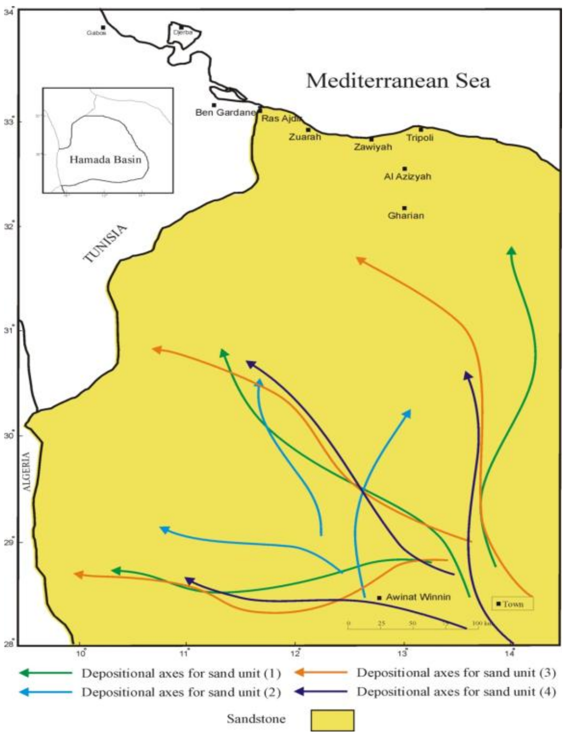

Figure 38. Depositional axes map for sand units 1-4 in the Memouniat Formation, Ghadames Basin.

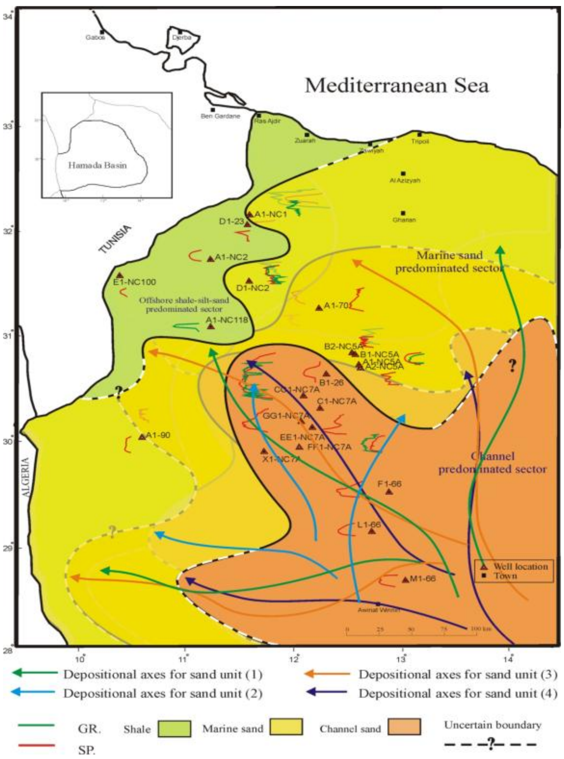

Figure 39. Composite log facies map of Memouniat Formation, Ghadames Basin.

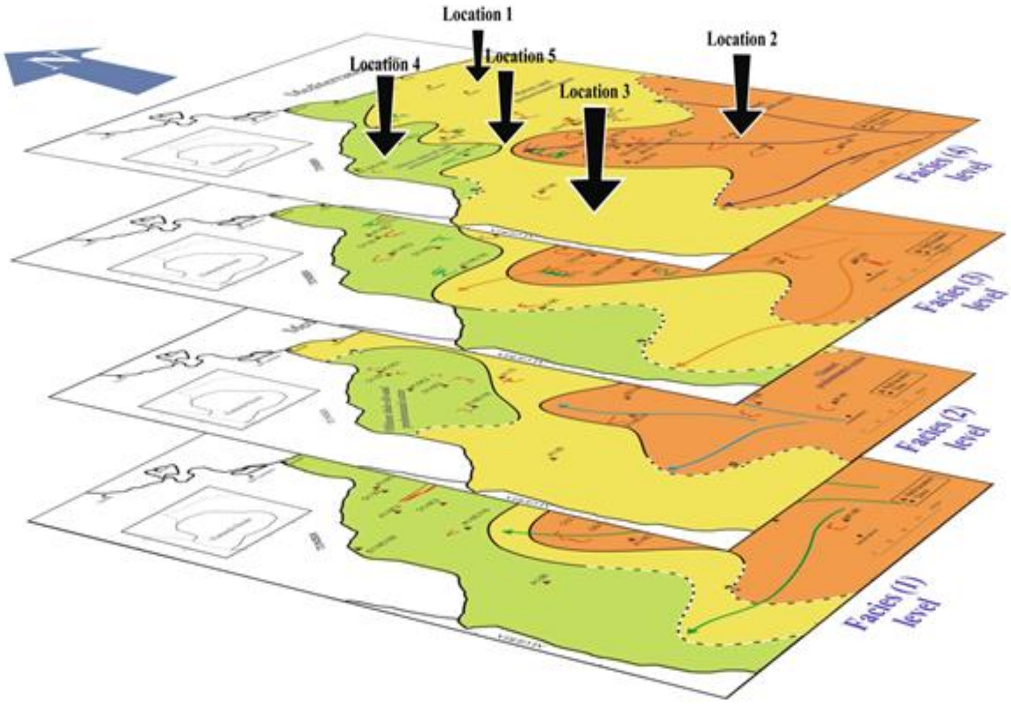

Figure 40. Superimposed slice maps for studied units 1-4 in the Memouniat Formation, Ghadames Basin. The vertical arrows at the top indicate the location priority for better recovered facies.

VIII. CONCLUSIONS

Well-to-well correlation incorporating the facies data derived from cores and GR-log and SP-log characteristics has revealed that the Memouniat Formation in the area of study, the Ghadames **(**Hamada**)** Basin, consists mainly of three depositional units bounded by time-stratigraphic markers. Within the established stratigraphic framework, the identified facies change predictably northwestward from channelized-dominated sands (Units 1 and 2) to wavy laminated sands of proximal shoreface (Unit 3), and eventually to basinal-offshore bioturbated silt/shale (Unit 4).

The established composite log facies map and the superimposed slice maps for the studied sand units **(**1-4**)** provide the basis for predicting the regional facies distribution of the Memouniat Formation throughout the Ghadames Basin.

The reliability of using wireline logs in presenting and defining the fundamental depositional facies was also investigated. The GR-log was found to be more accurate than the SP-log in identifying facies packages, making correlations, and where cores were not available or where the primary sedimentary structures were obscured by bioturbation or by the unconsolidated nature of the sands.

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