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Stratigraphic sequential analysis, paleo- environment and oil interest of the Upper Silurian - Lower Devonian (F6 reservoir) of Southeastern Algerian Sahara: case of Hassi Mazoula field and its bordering regions (Illizi basin).

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ABSTRACT/RESUME

Abstract: *Hassi Mazoula field is located in the Southeastern corner of the Algerian Sahara. It belongs to the meridional flank of Ahara spur which separate two big sedimentary basins: Berkine northwards and Illizi southwards.*

The F6 Reservoir, of Upper Silurian-Lower Devonian Age, consists of sandstones, silts and shale. It's divided into eight lithologic units; from bottom to top: M1, M2, A, B1, B2 units make the lower series and C1, C2, C3 units form the upper series. Caledonian unconformity separates them.

Key concepts in sequential stratigraphy involve understanding how certain geometric relationships between rock layers occur in its original deposition environment. Changes of deposition environments (due to climate, tectonics, subsidence and others) have economic importance when they cause significant lateral changes in sediment deposition patterns. The analysis of the spatio-temporal distribution of the deposits makes it possible to highlight the petroleum systems and locate the reservoir levels, the possible sources and the cover rocks.

Sequentially, the F6 Reservoir consists of five deposition sequences: three sequences in the Upper Silurian (S1, S2 and S3) and two sequences in the Lower Devonian (S4 and S5).

Paleo-environmental changes determine tract systems in each sequence; when we draw the limits of good sandstone bodies in each tract system, its leads to judging the possibilities of hydrocarbons in each sequence at the scale of this studied area.

In this case, lowstand systems tract of S4 and S4 sequences seem to constitute good petroleum targets.

I. Introduction:

The Illizi basin is the most studied part of the Algerian Sahara [1]. Over than 85 oil and gas fields have been discovered in the Cambro-Ordovician, Siluro-Devonian and Carboniferous oil-gas reservoirs [2, 3]. All of them are associated to important structural elements [1, 4]. However, the peripheral areas are less studied; quite other's, well defined, could have great interest for up-coming explorations. The fields already discovered and drilled by some wells, need particular attention to be more prospected: their structures are unclear, sandstone bodies wrong defined and size of some ones may highly exceed their traps, as is the case of Hassi Mazoula fields. Its additional exploration will undoubtedly increase reserves.

Thereby, this research aims to characterize the F6 Reservoir of that field in order to draw a good sandstone bodies limits and realize a future development plan.

II. Geological setting of the study area

This region is located in the Northwest corner of the Illizi Basin (Figure 1). Its geographical coordinates are: 28 ° 00 ' and 28 ° 50' North latitude and 7 ° 30 'and 8 ° 00' east longitude [5]. The field of Djoua West is located in the North East of Hassi Mazoula and Issaouane field is South-South West of these last one [6].

Geologically, Hassi Mazoula field is situated on the southern flank of a large caledonian structure, named «Ahara Spur» with an East-West orientation [7].

At the local scale, the region is characterized by folded structures which can be alternating anticlines with synclines located on both sides of major faults. They have very high vertical amplitudes [8] (Figure 2). In detail there are three individual compartments which are from North to South: Hassi Mazoula North, Hassi Mazoula B including Hassi Mazoula East (MZE), Hassi Mazoula D (MZD). Then Hassi Mazoula South including Hassi Mazoula C (MZC) [9] (Figure 3).

The production oil began on August 1965 with a current scheme containing more than 28 wells [10]. The overall surface impregnated with oil is 46 Km^2 and is higher than the one of adjacent Tin Fouyé field which is 38 Km^2 [9].

III. Presentation of the F6 Reservoir

The type lithological column of the Illizi basin consists of a generally detrital sedimentary series extending from Cambrian to Paleocene where Paleozoic terms occupy two-thirds of the total thickness series [4, 11, 12]. The Upper Silurian-Lower Devonian (F6 Reservoir) is typically 400 m thick [7, 13].

After connecting the palynological biozones to the underground logging units and the lithostratigraphic units that make up the series, the F6 was divided into three formations and eight litho-stratigraphic units, comprising From bottom to top: the shaly-sandstone Formation of Mederba (units M1 and M2), the Oued Tifist Formation (units A and B), and the Hassi Tabankort Formation (units C1, C2, and C3) [7, 9, 13, 14, 15, 16]: (Figure 4).

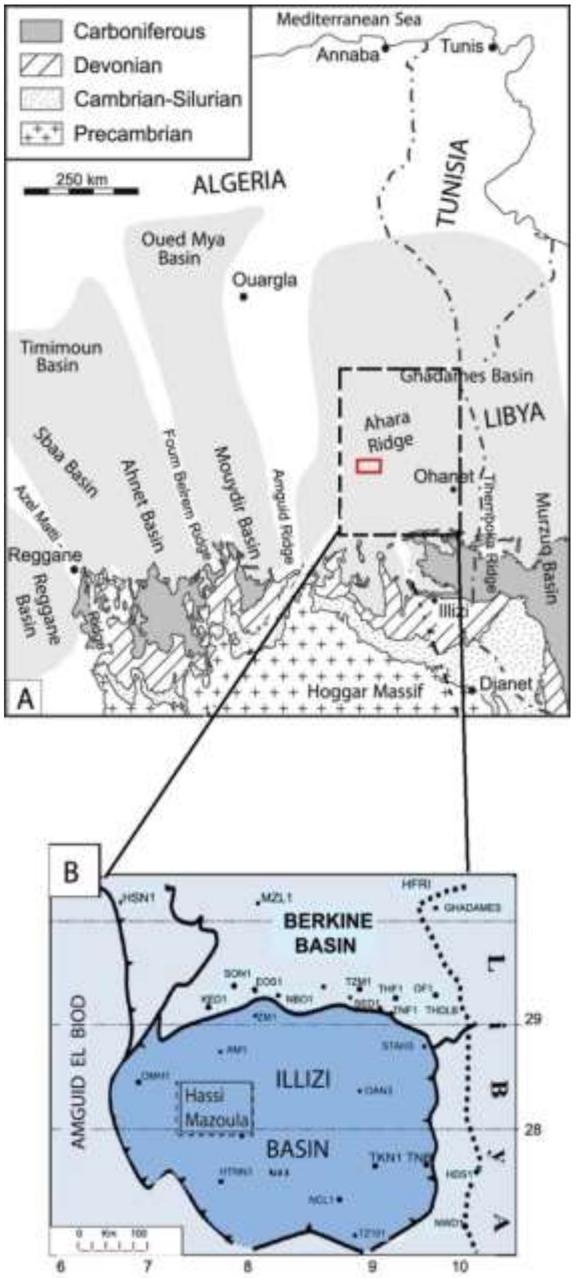

__Figure 1.__ Geographical location of the Illizi Basin (a) and the study area (b).

a) Shaly-sandstone Formation of Mederba: after Lower Silurian graptolite shale, this Formation marks the return to sandstone sedimentation. It corresponds to the **M1** and **M2 units** that are correlated at the basin scale, with facies variations towards the North. These units correspond in the region of Fadnoun (South Illizi) to pre-beach deposits dominated by storm currents and / or tidal currents sometimes truncated at the top by fluvial channels.

b) Oued Tifist Formation, Upper Silurian Age, it contains:

- The **A unit**: 15 to 50 meters thick. It corresponds to deposits of fluvial systems in braids evolving vertically to upright and estuarine systems influenced by tidal currents.

- The **B units** (B1 and B2) are 50 meters approximately thick. In the Ahara spur, it's only some meters thick. These units are composed of fine heterolithic sandstones and shale siltstones deposited in a marine environment dominated by tides.

c) The Hassi Tabankort Formation of Lower Devonian Age has three units; they are reduced to a few meters around the Tihemboka spur and completely absent on the Ahara one, which are from down to top

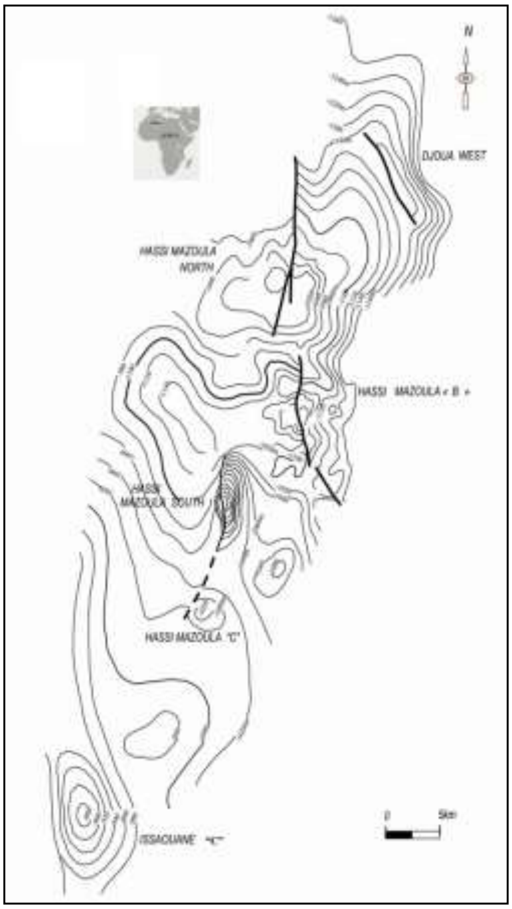

***Figure 2.** Isobaths map at the top of the F6 of Hassi Mazoula field.*

- **C1 unit** is 20 to 70 meters thick in outcrops of Tassilis (in the South). It corresponds to sandstones formed by river channel deposits that become vertically straight fluvial channels deposits.

- C**2 unit** is 20 to 60 meters thick in the outcrops of the Tassilis, it consists mainly of silty argillites interbedded with sandstone.

- **C3 unit** is 80 meters thick on average in outcrops of Tassilis. It is reduced to a few meters in the south of Hassi Mazoula field and completely absent at the North. The base of this formation is made of coarse gravel sandstone evolving upward medium to coarse sandstone.

In the studied area with the total absence of the Middle Devonian, the upper limit of the C3 unit and also the F6 Reservoir coincide with the Frasnian unconformity; the Upper Devonian shales contact the sandstone Formation of Hassi Tabankort. The Devonian terms are separated from the Silurian terms by the caledonian unconformity. The lower limit of the F6 Reservoir being fixed to the last Lower Silurian graptolite shale beds [17].

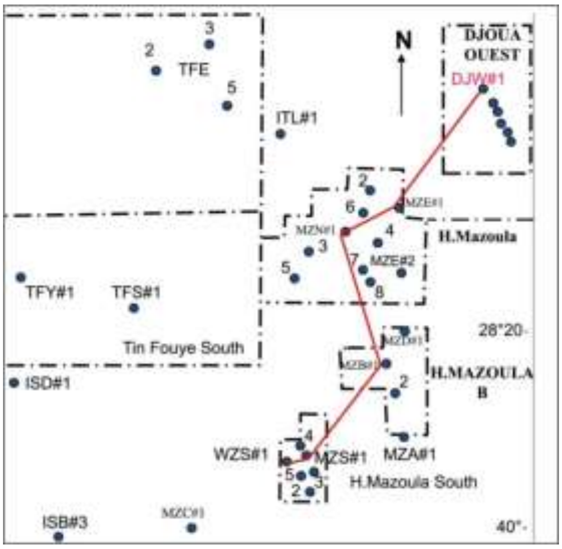

***Figure 3**. Wells positioning plan and correlation profile (Hassi Mazoula fields).*

In Hassi Mazoula North, B, South and C, the oil reservoirs are the sandstone of C3 unit and the top of C2 unit. These sandstones are composed by several bars interbeded by fine, very fine to medium sandstone with a same water contact inclined towards North-North East. So they constitute a same reservoir. The C1 unit sandstone is all aquiferous up to the top except in the structurally higher field of Hassi Mazoula South [9].

IV. Methodology:

This work is done in 2 steps:

1-The lithological and petrographic characterization of the F6 reservoir is based on the description of the cores (380 m), the microscopic observation of more than 500 samples taken from the MZN- 1 (reference well), MZE-1, MZS-1, ISB-3, TFY-4, DJW-1 and DJW-3 wells (Figure 3) and the radio-crystallographic interpretation data available from the Technological and Development Division (DTD/Sonatrach).

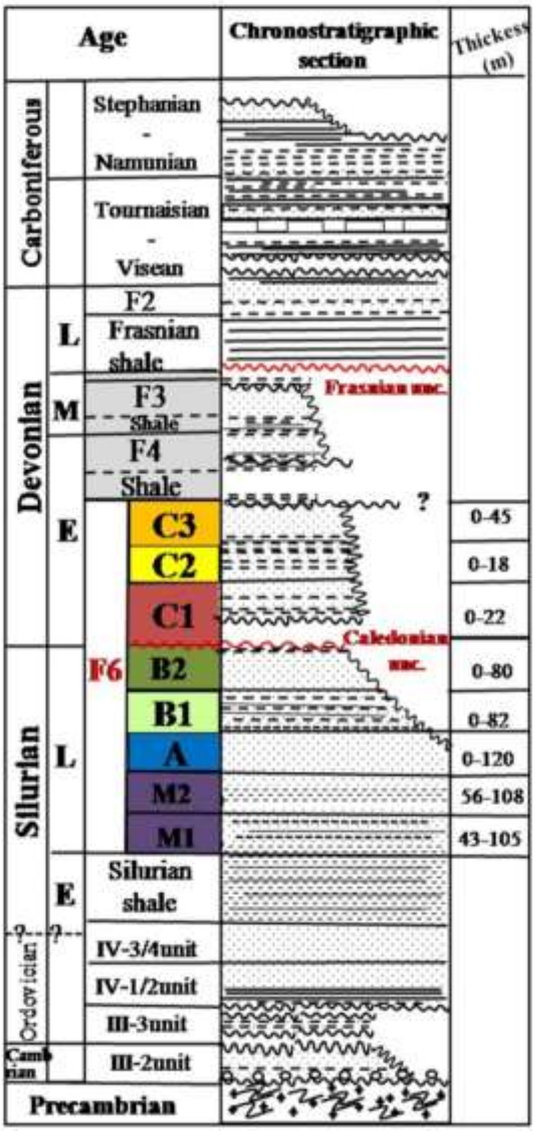

***Figure 4**. Stratigraphical column of the Paleozoic in the Ahara Spur and its bordering regions (establish according to several documents).*

2- The definition of the basic stratigraphic units which can make it possible to establish isochronous correlations through the wells.

In the concept of sequential stratigraphy, the sedimentary bodies are organized according to a basic unit called "the genetic sequence of deposition" [18, 19, 20, 21]. It is a stratigraphical unit composed of a relatively consistent (concordant) sequence of genetically linked strata. It is limited at the down and at the top by unconformities [22, 23] that can laterally evolve into concordance. The notion of a depositional sequence is therefore above all a geometric concept (spatio-temporal organization of layers) [24, 25].

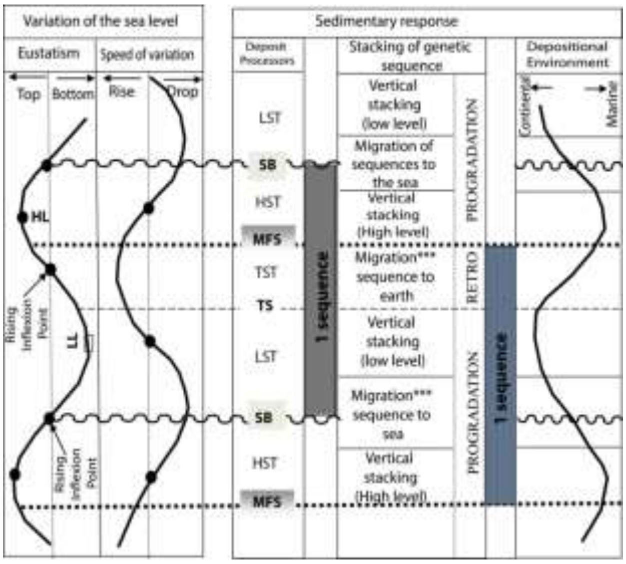

***Figure 5.** Comparison between system tracts sequential analysis and the stacking pattern of genetic sequences (from VAIL.1991) and HOMEWOOD et al., 1992, (in COJAN.I and RENARD.M .1999).*

Note: *the separation between the third order sequence of VAIL/Exxon which limits correspond to rapid fall of sea level of CROSS, 1988 and GALLOAY, 1989 whose limits correspond to the surfaces maximum flood (fast sea level rise).*

These sedimentary tract consist of elementary sequences [26, 27]) of the 5th order [23] called according to the authors "genetic sequences" [18] , Guillocheau (1989) [in 23],[25],[28] or "parasequences" Van Wagoner (1995) [in 22] , Van Wagoner (1985) [in 23], [29]; they are elementary bricks of sequential stratigraphy. Generally between 1 and 10m thick, they correspond to a complete cycle of variation in sea level [27, 23, 30]). Finally, the sedimentary tracts are themselves grouped into limited sedimentary sequences at their base and at their summit by unconformities [25, 31, 22] (Figure 5).

V. Sequential analysis

Sedimentological, logging and petrographic analyzes have defined five genetic sequences of deposition in the Upper Silurian-Lower Devonian (F6) range of the Hassi Mazoula field, corresponding respectively (Figure 6) to:

- Three sequences in the Upper Silurian**: S1**, **S2** and **S3**.
- Two sequences in the Lower Devonian**: S4** and **S5**.

V.1. Sequence 1 (S1)

It’s composed by two systems tract: the TST and the HST; the transgressive systems tract is represented only by its upper part of "Wenlock" Age. It consists of black shale with some white silty lenses, and of silty-shale with planer cross bedding alternating with small layers of bioturbated siltstones colored in beige to greenish. This is the typical graptolite schists facies which is interpreted

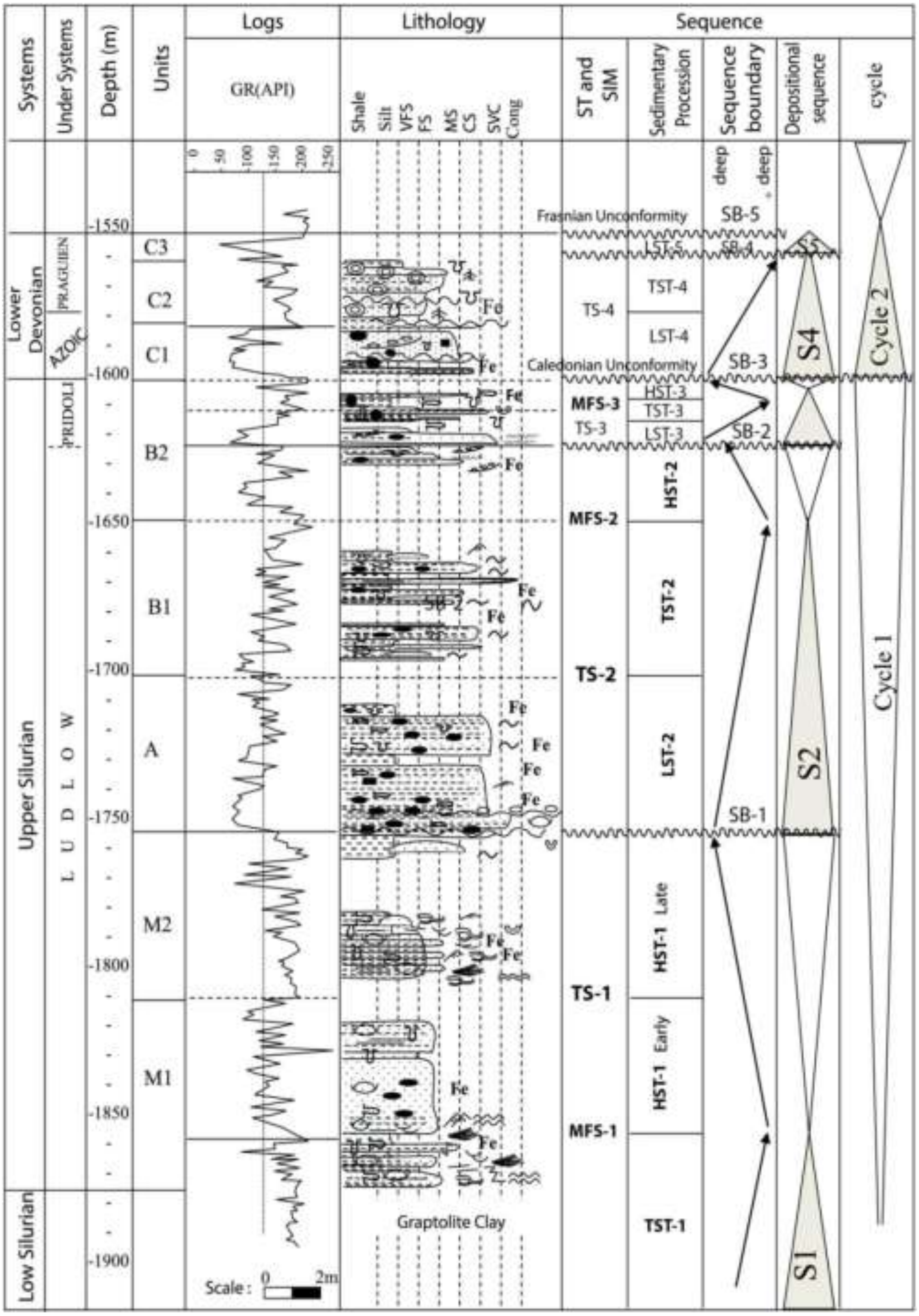

Figure 6. The stacking of sub-surface sedimentary sequences and sedimentary tracts in the Hassi Mazoula region (reference wells).

It is a surface of ravine by the swell. It is observed in the pre-beach deposits. Erosion is due to the action of wave currents on the sediment during relative sea level rise (Swift (1968 and 1991), Proust (1995 and 2001) [in 12]);

offshore deposits [32, 33, 34]). Above, these are deposits which correspond to the lower part of the unit M1; they down to top consist of:

-very fine beige sandstones with planer cross-beds interrupted by shale pebbles levels and bioclastic accumulations; this facies alternate with compact black shale and bioturbated shaly siltstones.

- fine to medium sandstone, beige to green in color, friable, with fishbone stratification.

- bioturbated grey shale with siltstones lenses; and abundant fossils debris. These are mainly varieties of Brachiopods and Tentaculites.

The last shale level is thicker and more bioturbated; it highlights a maximum flood surface (MFS-1) (Figure 7 and 8). The gamma ray curve also confirms this level by a very pronounced setback.

Highstand Systems Tract (HST)

It is composed of an early system tract (HST-1 early) and another late (HST-1 late**)** [35].

- HST-1 early:

It contains at its base the upper shoreface deposits covering the offshore shale. From down to top, there are:

- fine to medium sandstone with ripple wave bedding and abundant bioclasts, upwards medium beige sandstone few shaly with horizontal lamination, interbedded with fine shale layers;
- medium to fine sandstones, grey to greenish, with sub-horizontal lamination and thin layers of shales, its slightly bioturbated;
- fine to very fine grey sandstone, very shaly, with wave ripple, intensely bioturbeted with *Planolites* and *Teichichnus* at the bottom of the bed and by Skolithos at their top [36].

These deposits associated with storm episodes whose currents redistribute them in the open-sea environment [37].

The log recording (GR) corresponding to this prism shows a cylindrical shape curve while the end of the tract, is signaled by a brief inversion of the gamma ray signal. It marks a transgressive surface (TS-1) (Figure 8 and 9). It is also expressed on the West Djoua cores by a red conglomeratic level rich in bioclastic debris and mud clasts (Figure 8).

these deposits are called lag deposits (Van Wagoner (1990) [in 30].

The logging signal shape shows a funnel form evolving from shale pole to sandstone.

The first meters are grayish not-bioturbated argillites with millimeter trough stratification. This facies is interpreted as lower offshore deposits [32].

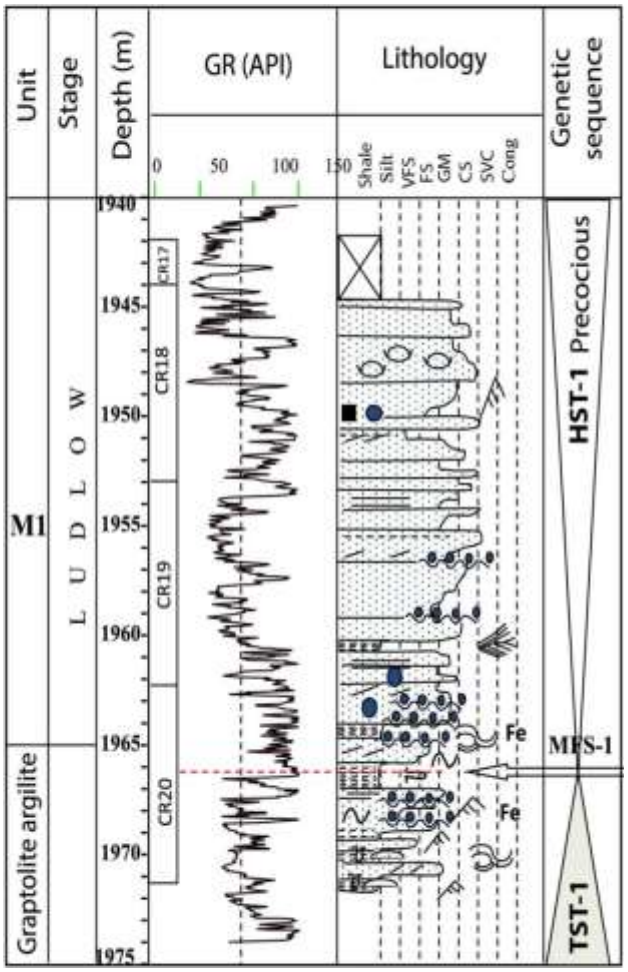

Figure 7. *Illustration of the maximum flooding surface (MFS - 1) of the S1 sequence (Well of Djoua west field).*

HST-1 late:

This facies reflects the arrival of periodic contributions of sandstone related to exceptional storm currents. These erode the sandstone in the proximal parts of the platform and deposit them in the distal parts of the basin as gravitational deposits [38]. . The emersion surface between unit M2 and A shows petrographically by the concentration of lithic clasts (up to 20% of total rock volume), hence the maximum grain size exceeds 1.075 mm (Figure 10). They are scattered throughout the basal part of the A unit, and responsible poor sorting sediment.

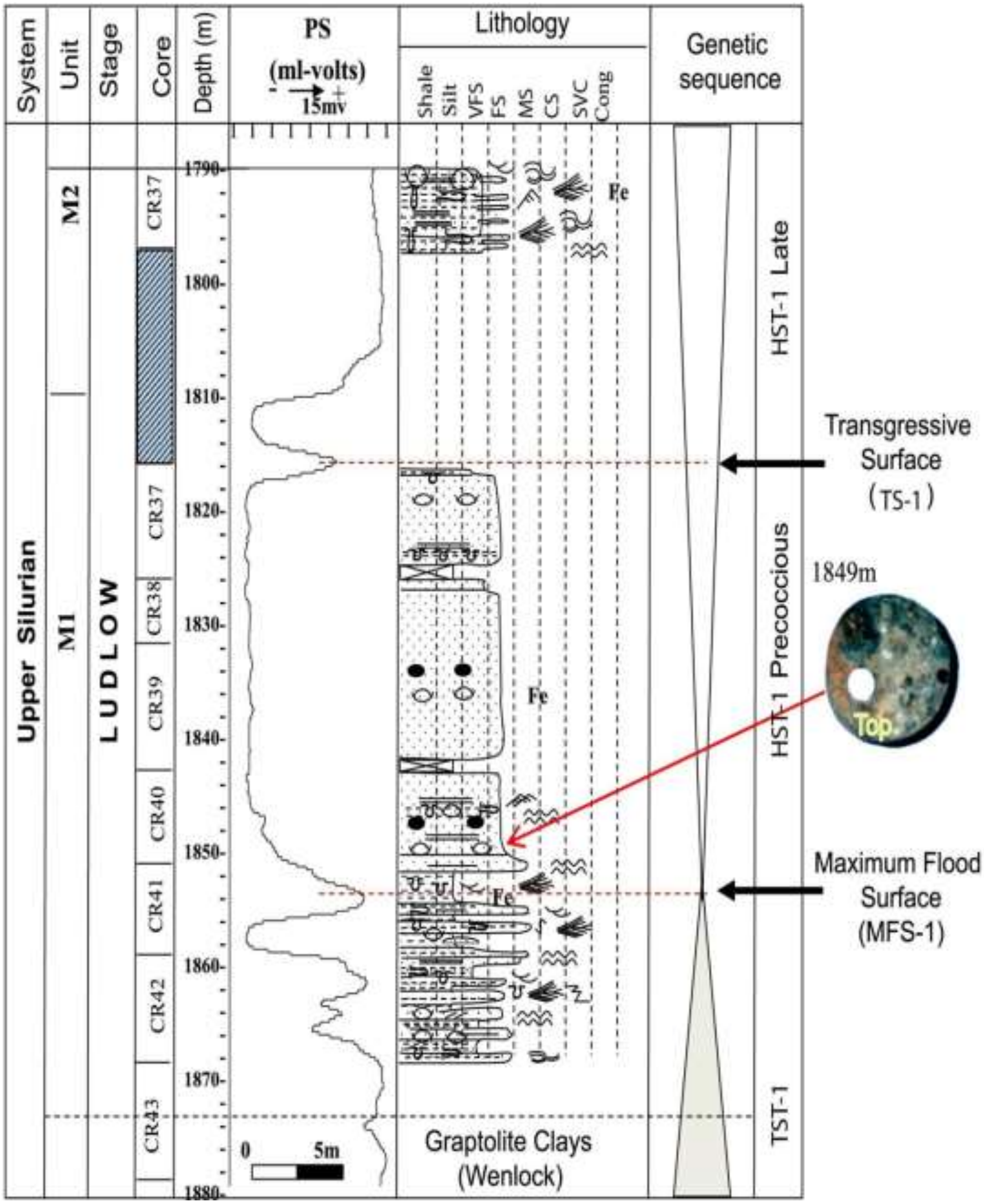

Figure 8. *Illustration of the MFS - 1 and TS-1 surface of the S1 sequence (Well Hassi Mazoula).*

V.2. Sequence 2 (S2)

From Ludlow to Pridoli Age. The end of Graptolite shale deposits corresponds to a large and progressive inflow of detrital material from Southeast since Upper Silurian to Lower Devonian [39]. This change is due to epirogenic movements during Wenlock. They tilted the platform to northwest and withdrawaled the sea in the same direction. Caledonian movements caused by East-West compressive constraint emphasize the Cambro-Ordovician structuration and also contribute to this change [34].

The Upper Silurian sedimentary evolution (Ludlow) is a complete sequence corresponds to A and B1 units and the lower part of B2; it is contains three sedimentary tracts: a LST, a TST and a HST (Figure 11).

Lowstand Systems Tract (LST-2)

This consists of prograding deposits corresponding to fluvial channels; it is formed during the fall of the relative sea level from which the fluvial systems are in minimal accommodation [17].

The platform is relatively flat, the absence of vegetation and the high rate of detrital inputs ,have favored the appearance of a fluvial braided system [12]. Braided fluviatile channels filled with poorly graded hetero-granular sandstone are associated with coarse quartz gravels, and oblique bedding underlined by mud casts beds.

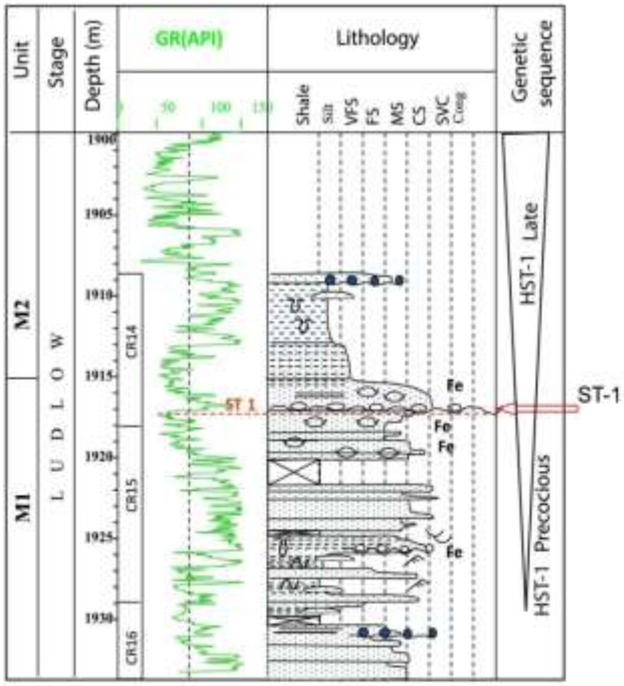

Figure 9. *Illustration of the TS-1 surface between the high-level marine tracts of the S1 sequence (Well of Djoua West). Coarse sandstones reddish and conglomerates abundant pebbles shales and bioclastic clast.*

The important arrival of detrital material and the temporary rise of the relative sea level allowed the evolution of fluvial systems in vertical aggradations [40]. In this case, the channels begin to fill and the bars are developed. The facies of the channel bars consist of fine to medium-sized, well-sorted sandstones, alternating with grey-color, more or less oxidized, bioturbated shale with beige to white siltstones lenses.

The evolution of the fluvial system is accompanied by a fall in sediment charge on a platform that has become increasingly flat [41]; these conditions allow the birth of a meandering stream system [12].

The meandriform fluvial systems described at the top of this tract is formed by fine to medium, sandstone facies , beige to greenish in color, successively intersected by conglomeratic levels organized in fine oblique beds. This system is characterized by lack shales from floodplain [37].

From A unit to B unit, the meandering system is associated with the tidal plain; it develops in estuarine environments influenced by tidal currents [41].

The shale plugs [12] well developed at the top tracts is represented by bioturbated shale. The transgressive surface (TS), the limit of this tract, is located at the floodplain shale base, that confirms the development of peak GR and PS peak signals.

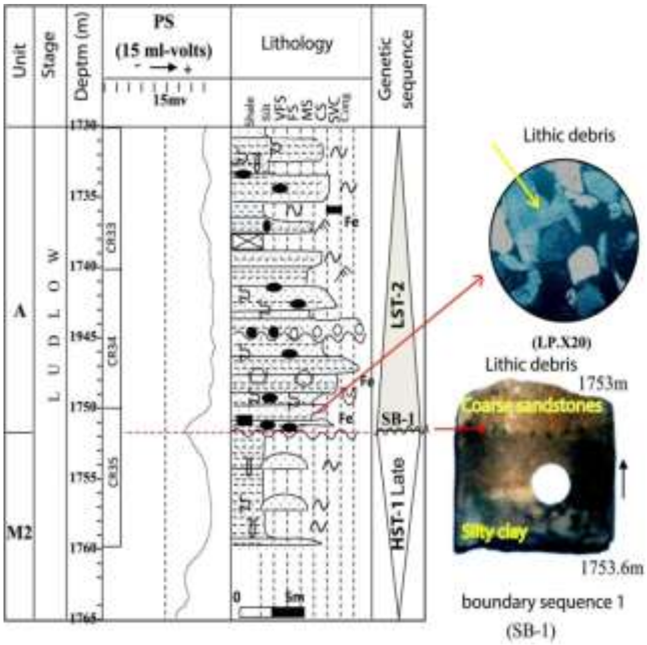

Figure 10. *Illustration of the SB-1 sequence boundary going from S1sequence to S2 sequence (Wells of Hassi Mazoula): Lithic clasts.*

Transgressive Systems Tract (TST-2)

The deposits of this retrograde interval consist of fluvial bars and the floodplain at the base then the environment becomes more marine. The silty-shales, grey o black-grey with through ripples current and bioturbated by the *Planolites*, *Chondrites* and *Diplocraterion* type [36] are described at B1 base are corresponds to the shalely part of the tidal plain.

During a period of high sea level, the sedimentation occurs by decantation of the fine particles favoring the bioturbation [42]. Thin medium sandstone layers are du to episodic depositions made by tidal currents [43]. This sedimentation coincides with deposits of the subtidal domain [31, 44].

The fore-beach facies is described at the top of the B1 unit; it consists of black gray argillite beds with rare bioturbations due to *Planolites* and *Condrites* [45]. It is also characterized, by the occasional thin sandstone beds. They are very fine sandstones and whitish silt stones with rare fine bioturbations of *Planolites* type [36, 45]; they correspond to calm periods where decantation of the fine particles took place [12, 46].

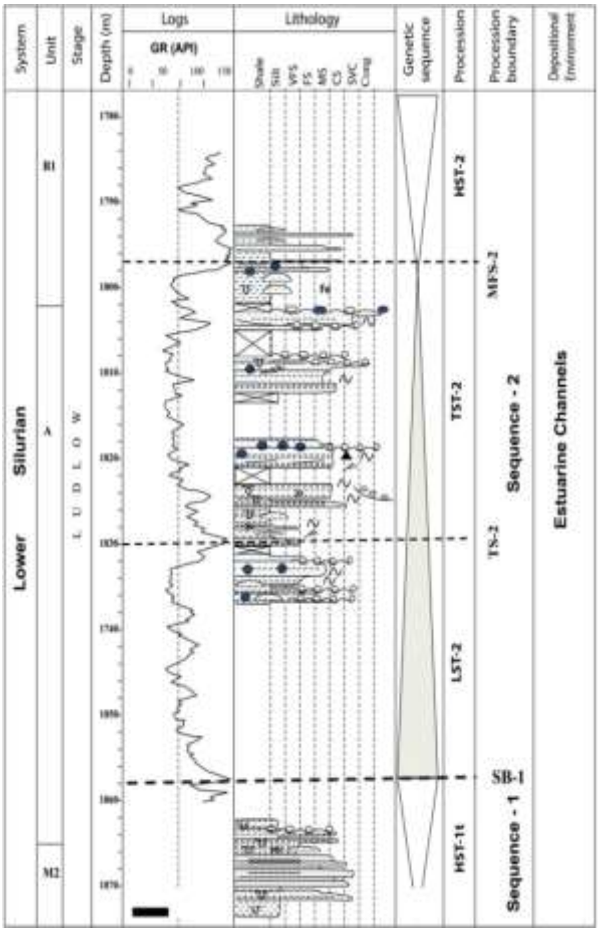

***Figure 11**. The various tracts component of the second sequence (Djoua West well).*

The upper limit of this interval is a maximum flooding surface (MFS-2) well expressed by the logging signal. It coincides to marine shale described in West of Djoua field.

- Highstand Systems Tract (HST-2)

The prograding tract is characterized by the vertical stacking of typical litho-facies of increasingly proximal deposit environments [30]. The progradant tract takes place during a period of relative fall sea level in the continental domain [26]. Accommodation decreases, the shoreline and sedimentary systems migrate to the basin [47].

The Upper Silurian period (Upper Ludlow (?) - Pridoli) [14]) is marked by an important development of tidal facies on a very flat platform which had favored extension of tidal currents [12]. At the same time, a resumption of caledonian movements led to the emersion vast regions [4, 34, 48]).

The tidal plain is excavated by tidal channels filled with medium to coarse shaly sandstone with erosive bases (Plate 1: photo 1), organized in troughs bedding with draping shale, followed by fine shaly sandstones with oscillatory ripples. These sandstones are characterized by a high percentage of shale clasts and Brachiopods.

Then characteristic facies of the estuarine bars will develop [31, 49]). They are composed of medium to coarse, sandstones with oblique-planar bedding and shale draping. The plans of the stratifications plan are frequently underlined by pebbles shale. This facies is more or less bioturbated. These bars sometimes lie on shale facies corresponding foot of bars (Plate1: photo 2).

V.3. Sequence 3 (S3)

We can distinguish this truncated sequence under the caledonian unconformity; the log signal (GR) is funnel-shaped at the bottom and cylindrical at the top (Figure 12). They are fluvial systems developed at the top of B1 unit [12].

The setting up of these systems is linked to a beginning of transgression relayed by a local and rapid fall relative sea level (forced regressions). The early movements of the Caledonian phase (Upper Silurian: Pridoli) are responsible for this event [47], which is confirmed by the eustatic diagram of ROSS C A (1988) [in 48].

The lower part of this sequence is composed by deposits of fluvial channels (Plate 1: photo 3) equivalent to a low system tract (LST-3). They are surmounted by channel bars facies (Plate 1: photo 4) which constitute a transgressive interval (TST-3); the maximum flooding surface is located in the shaly-siltstone level where occurs pedogenesis (Plate 1: photo 5) as environment is strictly continental [50]. The HST-3 is formed by the floodplain facies (Plate1: photo 6); it’s often absent or of reduced thickness following erosion due to the Caledonian orogenic phase [39, 51].

The sequence top is crossed by strong fluvial incisions contemporary of the maximum of relative sea level fall [22, 38]). This is the limit of the third sequence (SB-3) that corresponds to the caledonian unconformity [13, 47] (Figure 12).This boundary is located at the GR deflection due to facies variations ranging from the shale covering B2 unit to the medium to coarse sandstone with oblique-bedding of C1 unit.

V.4. Sequence 4 (S4)

The Upper Silurian period (Pridoli) is also marked by a resumption of Caledonian movements. They caused the emergence of vast regions [39, 34, 41, 51], the erosion of which will feed the enormous series of the Lower Devonian in Illizi basin [30, 40, 43, 47, 52].

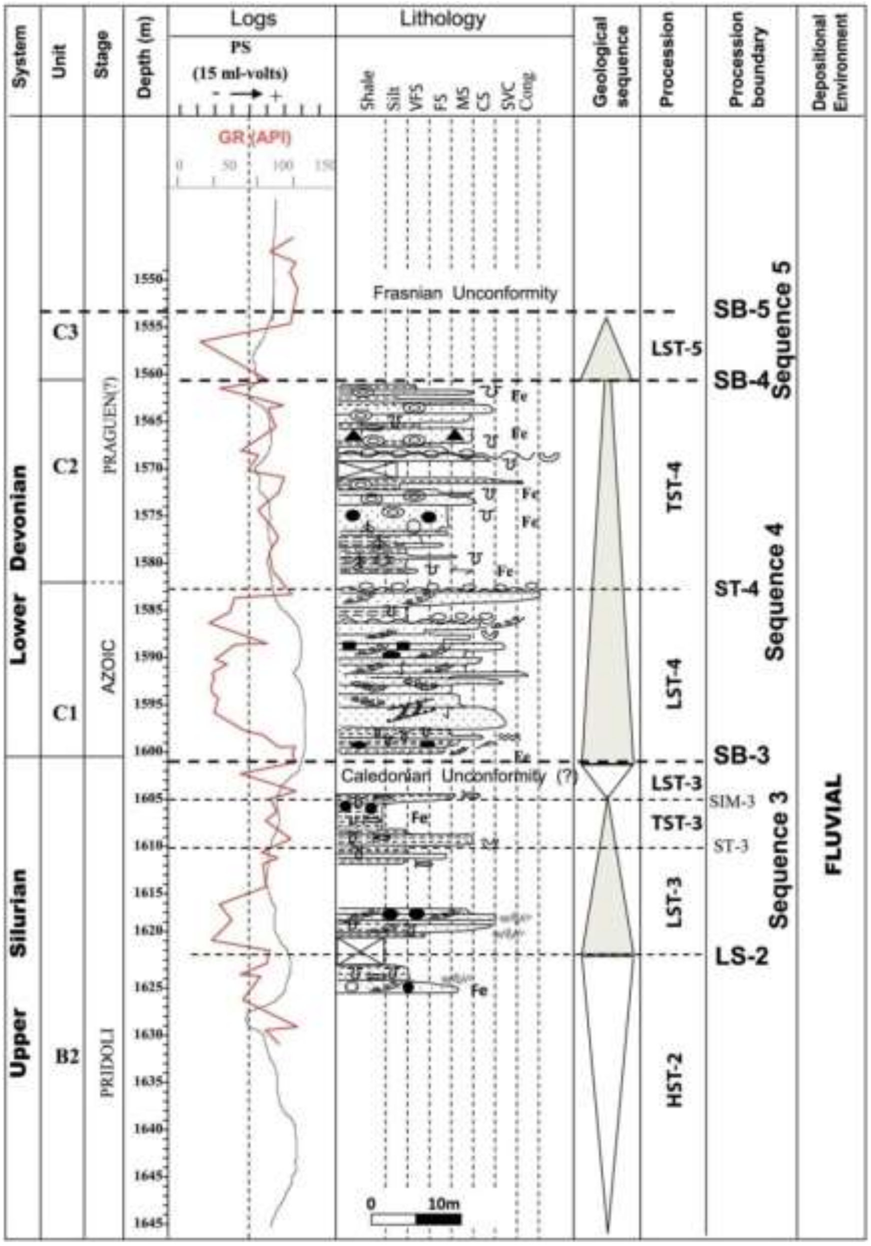

Figure 12. *The various tracts component of the third sequence (Hassi Mazoula well).*

The fourth sequence is azoic in its lower part and Praguian (?) age at the top [13, 14, 17]; it results from the stacking of two sedimentary tracts: a LST-4 and a TST-4. They are equivalent of C1 and C2 units deposited in a braided fluvial environment evolving towards the coastal plain (Figure 12).

The vegetation appears at lower Devonian (Praguian) [53].This favors conservation of river walls and maintains the meandering system. The development of this system is favored by a rise relative sea level [12, 34, 40]). The discontinuity of coring in the wells studied does not allow individualizing this facies.

Lowstand Systems Tract (LST-4)

The sediments of this LST are fluvial type braided at the base, weakly sinuous and meandering at the top.

The braided systems developed on a relatively flat platform are favored by relatively high charge sediment, lack of floodplain facies and the vegetation [39, 52, 54]. The channel deposits are coarse to very coarse, beige-colored, hetero-granular, and poorly sorting with trough cross-bedding and planar cross bedding. The layering plans are underlined by pebble beds and quartz grains (Plate 2: photo 7).

Sometimes, there are beige, fine to medium sandstones, with well stored grains, planar cross-stratifications underlined by shaly levels and slightly bioturbated. These are possibly longitudinal bars of braided channels [31, 55].

This facies evolve upwards to sandstones with oblique-planar stratification or to a massive set. The beds top is traced by mud clasts and vertical burrows of «Skolithos" type [36]. This probably corresponds to fills of fluvial channels that are slightly sinuous similar to the deltaic distributary channels [12].

That set alternate with the bar deposits formed essentially by medium, beige-colored sandstones, well-stored, with oblique planar stratifications and sliding-figures. They sometimes have fishbone structures [42], frequent shaly flaser bedding and mud clasts. The beds top has many "Skolithos" burrows and rarely roots traces [56] (Plate 2: Photo 8. The presence of oblique-plane bedding with sliding figures, current ripples and traces of roots is interpreted as deposits of the margins of the channels [57]. The GR signal is serrated cylindrical shape. The end of this tract is a TS-4 marked by the abrupt migration of the GR signal from sandstone to the shale.

Transgressive Systems Tract (TST-4)

The sediments that correspond to the TST of the fourth sequence are deposited in the coastal plain on the flanks of the spurand in the lakes on the surface of this relief [54, 58]. Deposits found in the transitory lakes, typically belonging to temperate climatic zones [58, 59]); the alluvial plains are flooded and the fluvial channels build sandstone lobes in the lakes. During dry periods, lakes can dry out, which favors the formation of paleo-sols locally [60] (Plate 2: photo 9). This facies association is interpreted as lacustrine deposits in detrital environment [12].

Lake bottom deposits correspond to rhythms reflecting cyclicity between dry and wet seasons in temperate climates [31]; dry periods are characterized by the deposition of siltstone or fine sandstone with plain lamination and wet seasons corresponding to stratified shale. The existence of wrinkles is related to the movement of wind on the surface of the lake [31].

During the wet periods, soils undergo leaching due to the presence of roots, and the environmental conditions become less favorable to oxidation, and the iron then migrates in ferrous form thus giving the dark color to the shale. As stated previously, during the dry periods, the oxidation causes rust around the roots at first, then give a lateritic soil [59]; in addition, if the time exposure is long enough, occurs the concentric structures in spherules form include some quartz grains whose crystal edges are sometimes reddish due to the presence of hematite [31, 59]. According to Cojan and Renard (2013) [54], the pedogenetic concretions probably cause this phenomenon [31, 58, 61]. This allows for emersion-related deposit unconformities to be observable [62]; this is the top of this sedimentary sequence and corresponds to a detachment of gamma ray; that is without high-level marine prism deposits (Catuneanu O (2006) [in 63]).

V.5. Sequence 5 (S5)

This sequence is the equivalent of C3 unit. It is probably of *Praguian* age [10, 14, 15] and represented only by a low-level marine prism (LST-5).

The abrupt and instantaneous fall relative sea level favors the continental deposits of the fluvial type with a slight marine influence [13, 52] (Plate2: photo 10 and 11). These deposits are:

- meandering fluviatile detected at the base of this formation and, located between the right fluvial system and the estuary. Channel filling corresponds to coarse sandstone at the base. As the flow velocity decreases the fine materiel is showing a fining-up sand. Facies of sandstone show large oblique stratifications with current ripples characterize meander bars [23]. The existence of shale draping and rare bioturbations is indicative of a tidal influence [23, 56].
- fluvial weakly sinuous, It is an intermediate system between the braided fluvial system and the meandering system. Moreover, the weakly sinuous fluvial system results from the confluence of fluvial channels in braids [12].

In the proximal parts of the system described above, it is very difficult to differentiate between the braided fluvial system and the weakly sinuous system; we go from one to the other without really being able to differentiate what is deposited with the one and / or the other. But, in the distal parts of the system, the marine influence is more or less marked by the presence of glauconite between the detrital grains [49].

Weakly sinuous fluviatile channels are mostly recognized by erosive bases [64]. The presence of coarse sandstones, with oblique stratification underlined by shale at the top of the beds; the few vertical bioturbations indicates a bar facies. Channel deposits alternate with bar deposits. The presence of oblique-plane bedding with sliding figures, current ripples and traces of roots are interpreted as margin channels deposits [56, 64].

The frasnian tectonic phase was highlighted in the Illizi basin by the absence of the Middle Devonian sedimentary series [54, 65]; the Upper Devonian lies directly on the Lower Devonian series. This unconformity closes the fifth sequence and at the same times the reservoir F6 [15, 47, 66].

VI. Regional sequences correlation in the study area and its bordering regions

To establish the geometry of the Siluro-Devonian sedimentary bodies across the Hassi Mazoula region, a regional North-South correlation has is drawn at the scale of the deposit sequences and its sedimentary tracts (Fig.3). The datum plane is frasnian unconformity (Fig. 13).

According to the correlation section of the depositional sequences and the sedimentary tracts, we can distinguish:

- **The fifth sequence** is eroded completely northwards in West Djoua by frasnian movements; can reach 20 m thick in Hassi Mazoula South. Caledonian movements erode most of this sequence, from the Emsian and all the middle Devonian. The effects of these events are weakened southwards of the studied area and beyond the Ahara spur [34, 40].
- **The fourth sequence** is limited at its base by the caledonian unconformity; it is distorted by during and after-depot movements. This deformation is marked mainly at Hassi Mazoula North and B. The sequence thickness is 55 m approximately at West Djoua and 70m estimated at west of Hassi Mazoula South. The lowest thickness is marked at Hassi Mazoula North.
- **The third sequence** is the least thick of all the sequences described, from 20 m North to Djoua West and 65 m approximately to Hassi Mazoula South. The change in thickness is in the opposite direction of the previous sequence, it is a confirmation that the sequence 4 has filled the old topography created by the caledonian events. The small thickness of this sequence is always interpreted by the effect of caledonian movements, which plays at the same time as sediment deposition.
- The thickness of the **second sequence** is greater than 100 m at West Djoua and can reach 55m at Hassi Mazoula South (WMS - 1); this decrease in thickness is interpreted by the inclination of the platform towards the Northwest [51] and detrital sedimentation from the southeastern outcrops of the basin [46].
- The upper part of **first sequence** is correlated to the basin scale. The high level marine tract is 90 m thick on average throughout the study field and its surrounding fields. This similarity of thickness is the consequence of :

-the detrital deposits are positioned on a thick shale series (Graptolite schist) [65].

-Sedimentation took place in a calm marine environment where the sedimentation is by decantation of the particules [32]. It can be high energy due to the action of storm currents that redistribute detrital inputs and deposit them in a widely available environment (open marine) [54]

- the effect of tectonic events is weak [39, 40, 43, 51, 67].

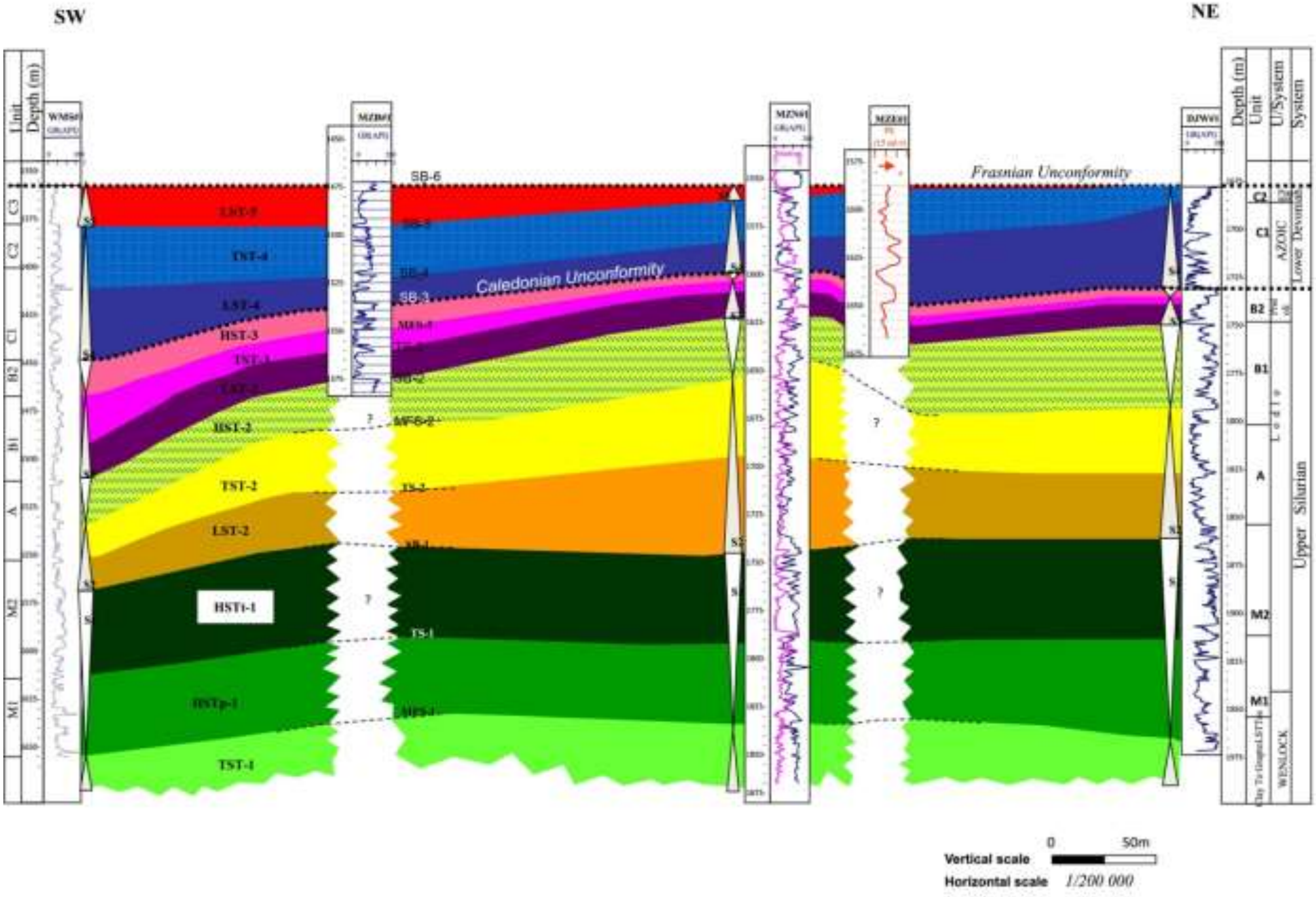

Figure 13. *Cross section (SW-NE) of sedimentary sequences and tract systems in Hassi Mazoula*

VII. Interpretation

The Hassi Mazoula field and its bordering regions is located on the southern flank of the large structure named Ahara spur. It is a structural unit of east-west direction that separates the Berkine basin from the Illizi basin. This spur is formed by movements probably Caledonian [34].

On a thick shaly-sandstone series of Cambrian and Ordovician, the Lower Silurian shale is deposited during a major transgressive phase [30, 53, 67]. Above, shaly-sandstones series show thickness changes on both sides of the spur [4]. The lasted Upper Silurian deposits are eroded under the Caledonian unconformity [65]). Lower Praguian fluviatile sediments pinch out on either side of a recently exposed structure of the Ahara spur [54]. During the Praguian occurs a large transgression all over the eastern Sahara while lacustrine and fluviatile facies are deposited on the spur [34, 55]. As the spur rise up, the deposits of the Devonian and then the Silurian eroded during falling sea level. During the Frasnian, the activity of the spur has ended and offshore shales overlap all this structure [34, 51].

The resumption of tectonic movements is largely marked at the end of the Paleozoic (Hercynian events), the effect of which is intensely observed in the west of the Ahara spur on the Maouar structure. Consequently, the Triassic put in contact with the Ordovician.

VIII. Oil interest

The importance of applying the concepts of sequential stratigraphy lies in the fact that in addition to that they allow to specify the age of the formations; they are obviously used with a view to oil research; insofar as they make it possible to locate any areas that could constitute petroleum objectives [68, 69]).

In Hassi Mazoula field, the Upper Silurian is all invaded by water [66]. Mostly good reservoirs are located in Lower Devonian and linked to fluvial channel deposits. They consist of fine to coarse sandstones found mainly at the base of sequences 4 and 5. Their organization correspond to a lowstand systems tract occurring while begin a new eustatic cycle [22, 25]).

The interpreted as LST-4 and LST-5 deposited during reactivation of Caledonian movement periods. These ones uplifted the region [39, 43], the deposit of LST-4 and LST-5 is during the reactivation of the Caledonian movements. The detrital sediments are frequents in a continental to shallow marine environment; so the erosion fed the sedimentary series with coarse detrital material which favors the formation of good reservoirs [46].

IX. Conclusions

The sedimentological and petrographic analysis has defined in the Upper Silurian-Lower Devonian (F6 reservoir), of the Hassi Mazoula field, five depositional sequences corresponding respectively to:

Sequence 1: (Lower Ludlow): It is made of three sedimentary tracts: a TST (summit part only), an early HST and a late HST, deposited globally in an offshore environment up grading towards the shoreface.

Sequence 2: (Ludlow- Lower Pridoli) It results from the stacking of three sedimentary tracts; an LST, a TST, and an HST, broadly reflecting a fluvial environment, moving vertically to a shallow marine environment, with a come back an estuarine environments at the end of the sequence.

Sequence 3: (Pridoli). It results from the stacking of three sedimentary tracts; an LST, a TST, and an HST formed by fluvial channel deposits, toped by fluvial bar facies and floodplain.

Sequence 4: It is azoic in its lower part; it is Praguian age at the top. It results from the stacking of two sedimentary tracts; an LST and a TST. The corresponding depositional environment change vertically from braided fluvial system toward the coastal plain.

Sequence 5: probably of Praguian age and truncated under the frasnian unconformity. It shows a single sedimentary tract (LST), typical of meandering fluvial environment at the top and weakly sinuous at the base of the sequence.

Reservoir F6 it look like being the best-reservoir potential. Source rocks are the graptolite black shale of the Lower Silurian. The shale of the Upper Devonian represents the cap rock. The Upper Silurian sequences are all aquiferous in the Hassi Mazoula field. But in the bordering regions, they may be oil producing. The LST of the last and the fifth sequence is the only one that produces oil at the Hassi Mazoula field.

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Nomenclature

HL: High Level
LL: Low level
LST : Lowstand Systems Tract

T ST: Transgressive Systems Tract
HST: Highsand Systems Tract
HST-late: late Highsand Systems Tract
HST-early: early Highsand Systems Tract
MFS: Maximum Flooding Surface
TS: Transgressive Surface.
SB: Sequence Boundary
Shale: Shale
Silt: Siltstone
VFS: Very Fine Sandstone
FS: Fine Sandstone
MS: Medium Sandstone
CS: Coarse Sandstone
VCS: Very Coarse Sandstone
Cong: Conglomerate.
HMZ : Hassi Mazoula Nord Field
MZE: Hassi Mazoula Est Field
MZS: Hassi Mazoula Sud Field
TFT :Tin Fouyé Tabankort
ISB : Issaouane B Field
Beicip-Franlab: Office of Industrial Studies and Cooperation of the French Petroleum Institute
UTM: Universal Transverse Mercator
DTD : Development and Technical Division
INCT : Institut National de Cartographie et Télédétection

Photo : 1

Photo : 2

Photo: 3

Photo: 4

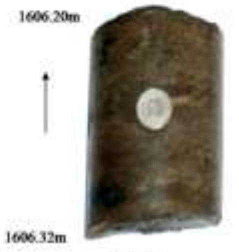

Photo : 5

Photo : 6

Plate 1. Photos of cores (sequence number 2

***Photo 1**: Sandstone fine to medium, white to reddish, compact, obliquely stratified, underlined by coarse elements*

***Photo 2**: Very fine shaly sandstone, greenish in color, bioturbated*

***Photo 3**: Sandstone, medium to coarse, beige with oblique stratification.*

***Photo 4**: Medium-grained, shaly, greenish-gray sandstone with confused stratification.*

***Photo 5**: Shale and marbled silts (purplish marmorisation).*

***Photo 6**: Very fine sandstone with silty shale, whitish, hard and bioturbated.*

Photo : 7

Photo : 8

Photo : 9

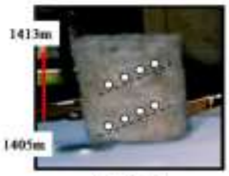

Photo : 10

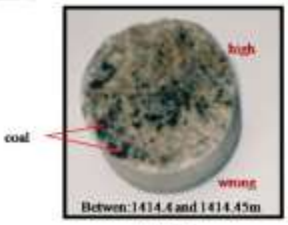

Photo 11

Plate 2: Photos of cores (sequence number 4 and 5)

***Photo 7**: Very fine and very shaly sandstone, beige to reddish, root and paedogenesis.*

***Photo 8**: Coarse sandstone with oblique stratification, underlined by coarse elements.*

***Photo 9**: large roots correspond to vertical sleeves 20 to 5 cm long and 5 cm in diameter filled with shale and with very small lateral branches. They are surrounded by red blood cells (oxidized). Small burrows and mud crack are associated with this facies.*

***Photo 10**: Coarse sandstone with oblique stratification underlined by course grains of quartz.*

***Photo 11**: Fine to medium sandstone, quartzized, crossed by coal beds.*

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