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THE APTIAN SERIES IN THE KASSERINE - EL KEF AREA (TAJEROUINE PERMIT): SEDIMENTARY CHARACTERS AND PETROLEUM POTENTIAL

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ABSTRACT

In the Tajerouine Permit, Aptian series well crop out in several sectors. The Jebel Bou El Hanèche, located in Central-Western Tunisia, about 10km to the ENE of Kalaa Khasba city, could be considered as one of the best outcrops of Aptian series. Within the Northern flank of the Jebel Bou El Hanèche anticline, Aptian series are expressed by well individualised massively to bedded carbonates frequently crossed by NW-SE to NE-SW fractures. The Aptian series reaching a total thickness of 500m are mainly constituted of fractured bioclastic carbonates rich in orbitolinids, bivalves and oyster fragments. Sandstones which are obviously less common than carbonates (only 10m in total thickness) are included within a decametric unit (40m in thickness) in which sandstones are interbedded with silty shales and carbonates. Sandstones which show low-angle cross-beddings are formed of fine-grained and well-sorted quartz material. Laterally, toward the North, such as in Jebel Ben Rhazouane and in Oued Djoumane, sandstones which appear more common, constitute clearly thicker units. In Oued Djoumane, for example, siliciclastic deposits (1300m in total thickness), include frequent sandstone units which could reach more than 100m in thickness.

In terms of reservoirs aspects, in addition to fracturing which is common and affecting all types of carbonates and sandstones, the bioclastic carbonates of Jebel Bou El Hanèche exhibit frequent plurimetric to larger “karsts”. In fact, these “karsts” are the expression of dolomitisation processes transforming initial fine-grained bioclastic limestones into obviously porous and permeable coarse-grained dolosparitic material, showing intercrystal and vuggy pores. Similar pore types and “karstification” features were also identified in the Douleb field in which they have contributed to the improvement of the reservoir quality (Ouahchi et al., 1998; Troudi et al., 2010).

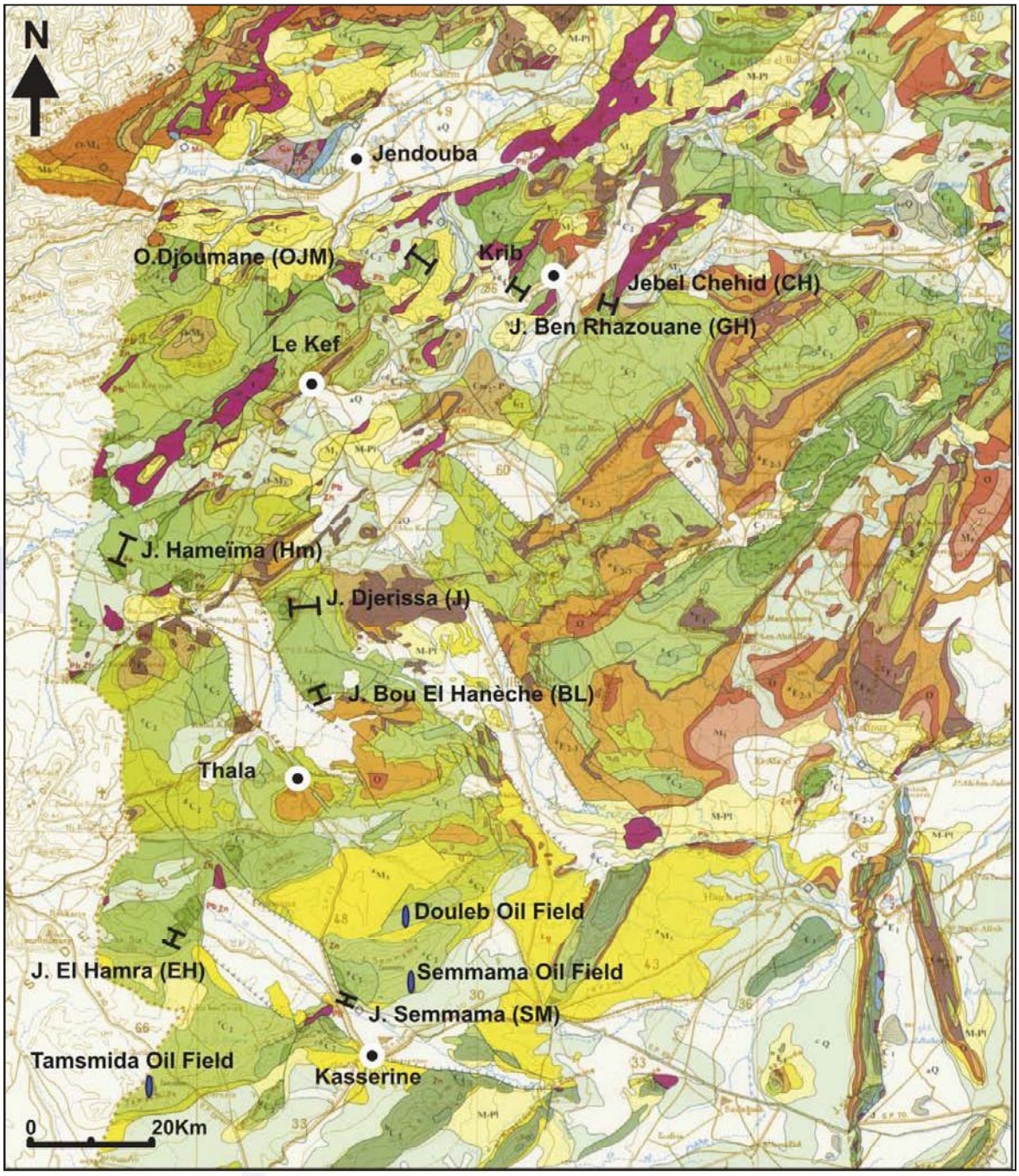

Fig. 1: Location of the studied sections on the 1/500.000 geological map of Tunisia

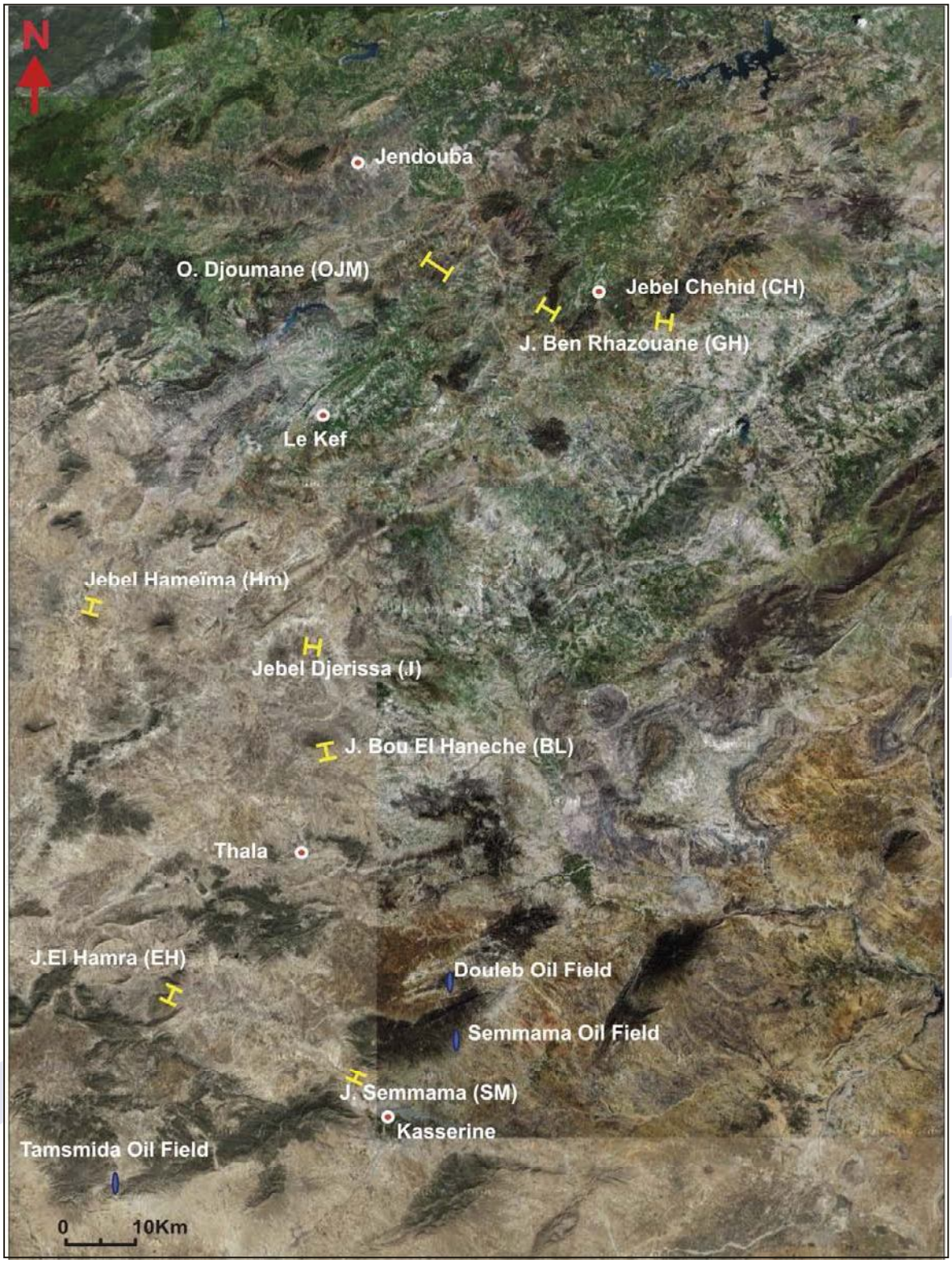

Fig. 2: Location of the studied sections on a "Google Earth" map

On the whole, the Aptian carbonates and sandstones constitute within the Tajerouine Permit a potential target sourced from the Fahdene Albian black-shales and/or from eventual underlying thinly bedded carbonates and marlstones.

INTRODUCTION

In Central Tunisia, the Aptian series which are mainly constituted of fractured carbonates and sandstones, constitute, at least locally, interesting hydrocarbon targets. The Douleb field, located in the Kasserine area, is an example of a proven field producing oil from the Aptian fractured carbonates of the Serdj Formation (or its lateral equivalent). In the Tajerouine Permit, outcrop geological studies confirm the petroleum interest of the Aptian facies. However, lateral changes in thickness and facies are frequent and locally rapid. The main purpose of this paper will be to focus on the main reservoir layers in terms of thickness, lateral extension and pore types, pore volumes and their interconnection. On the other hand, in addition to classical source rocks such as the Fahdene Albian black-shales, other black-coloured laminated facies, Aptian or older in age, could constitute additional organic-rich facies eventually sourcing the Aptian reservoir units.

I/ LITHOSTRATIGRAPHY OF THE APTIAN SERIES AND VERTICAL EVOLUTION OF FACIES

A/ The Aptian series in the southern part of the Tajerouine Permit

The Jebel Bou El Hanèche (Fig. 1, 2) is considered as one of the best interesting outcrops in which the Aptian series are well individualised and apparently continuous and relatively conformable.

In the Jebel Bou El Hanèche section (Fig. 3), the Aptian facies are organised into three formations corresponding from base to top to:

- the Hamada Formation equivalent (230m);
- the Serdj Formation (155m);
- the Hameïma Formation (135m).

1- The Hamada Formation equivalent

The Hamada Formation equivalent (Lehmann et al., 2009) which is well exposed in the western part of the Jebel Bou El Hanèche section (Plate 1, photo A), mainly consists of marls and marlstones locally silty and admitting argillaceous limestone and limestone intercalations containing oysters, ammonites and locally orbitolinids.

Locally, marlstones and argillaceous limestones are laminated and exhibit a dark grey to a black colour suggesting an eventual content of organic matter. The measured TOC content of these facies appears very low (see organic matter analyses paragraph).

Plate 1

Photo A : Western part of the Jebel Bou El Haneche showing the 3 massive carbonatic units of the Serdj Formation overlying the bedded carbonates of the Hamada Formation equivalent

Photo B : Dark grey fine- grained limestone rich in orbitolinids (A), dolomitised (B), and showing solutions cavities (C). Jebel Bou El Hanèche, first unit

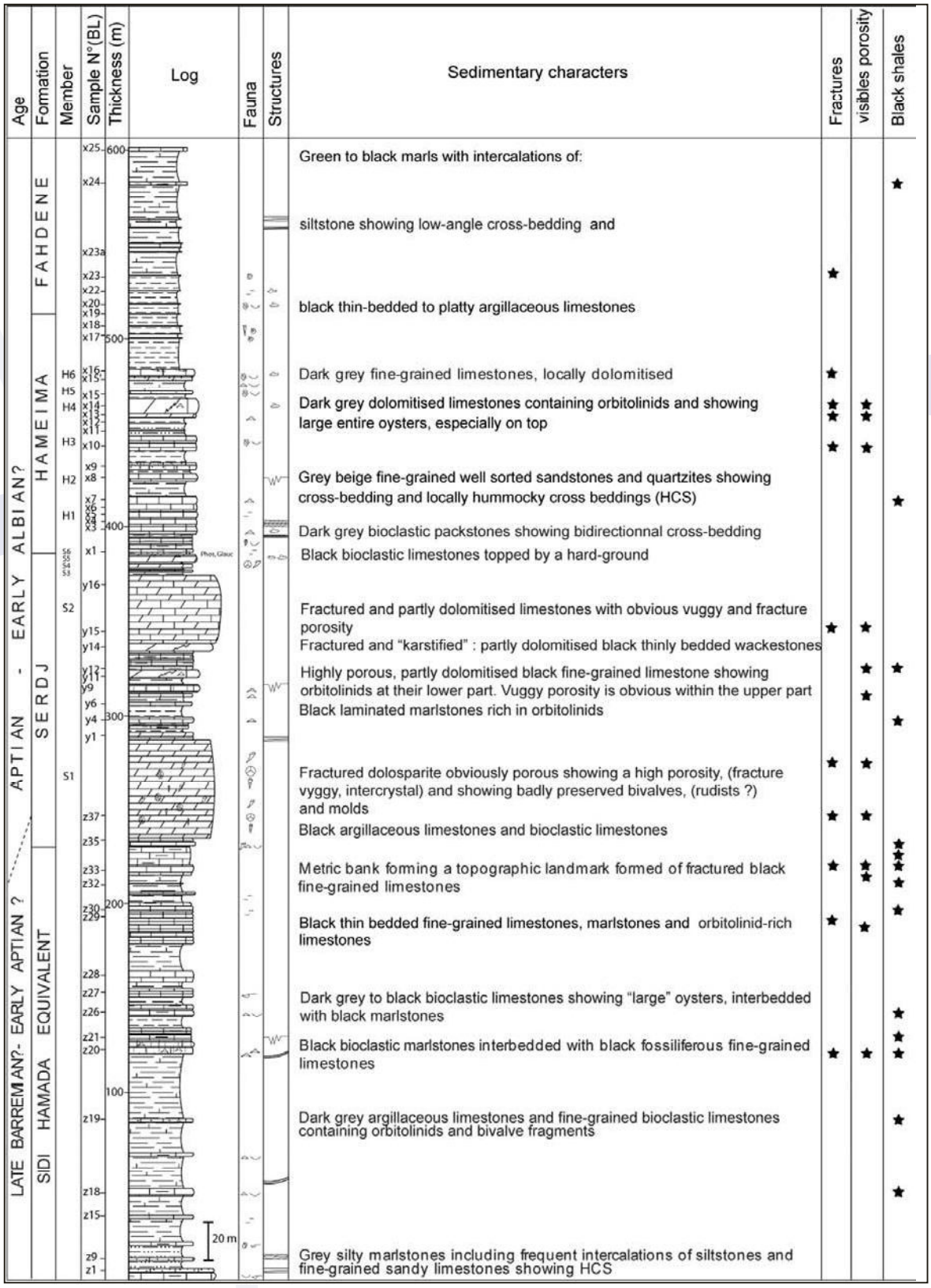

Fig. 3: Synthetic log of the Jebel Bou El Hanèche section (BL)

2- The Serdj Formation

The Serdj Formation which outcrops, in totality, in the western and central part of the Jebel Bou El Hanèche, could be subdivided into three main units (Plate 1, photo A):

- The lower (first) and the upper (third) units, respectively 59m and 47m in thickness, consist of massively bedded "rock bar" dolomites and dolomitised limestones (Plate 1, photo B), highly fractured and showing frequent moldic to vuggy pores and, locally, badly preserved solitary rudists, corals and sponges.

- The median unit (second), 43m in thickness, is characterised by the frequent intercalation of dark grey to black marlstones and argillaceous limestones rich in orbitolinids.

3- The Hameïma Formation

The Hameïma Formation which is particularly visible in the eastern part of the Jebel Bou El Hanèche, includes at least, 6 massively bedded dolomitised limestones bodies (Plate 3, photo A) forming "cliffs" (Chihaoui, 2009; Chihaoui et al., 2010) which are separated by bioclastic argillaceous limestones locally rich in orbitolinids and showing

progradation structures (Plate 3, photo A) and sometimes HCS. Locally, these bioclastic carbonates are interbedded with bioclastic sandy limestones, quartzites and bioclastic sandstones containing large entire oysters.

Within the upper of the Hameïma formation, marls intercalations rich in bivalves are frequent. In addition, limestone beds show at their top condensation features illustrated by a high bioturbation activity associated to a clear encrustation with ammonites.

B/ The Aptian series in the Northern part of the Tajerouine Permit

The Jebel Ben Rhazouane section (Fig. 1, 2, 3) is considered as a representative section of the northern part of the Tajerouine Permit. The Aptian series (Chitta, 1979), about 1050m in total thickness, include three main units:

- The first unit (300 m) which is mainly constituted of claystones with thin intercalations of fine-grained sandstones and quartzites, doesn't exhibit visible macrofauna. It may constitute the lateral equivalent of the upper part of the M'cherga Formation.

Quartzites show low-angle cross beddings and HCS. Fine-grained and well-sorted sandstones show asymmetric ripple marks (Plate 2, photo B) suggesting a progradation of clastic material from South to North.

Plate 2

Photo A : Panoramic view showing the lensoïd silty to sandy unit (F) intercalated in marls and marlstones. The Oued Djoumane OJM section

Photo B : Panoramic view showing 3 sandstone beds: A, B (bed showing wave ripples), C. The Jebel Ben Rhazouane Gh section.

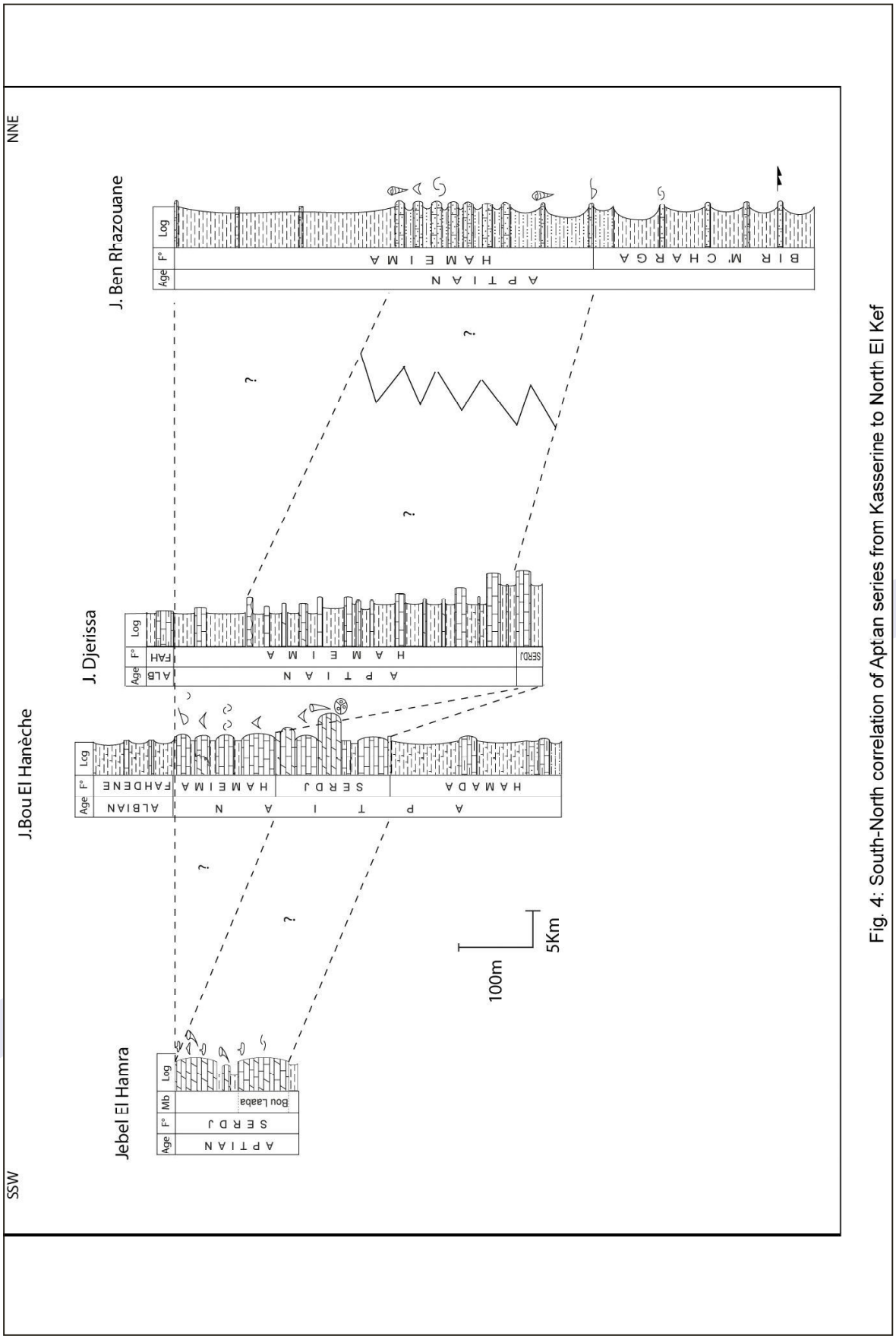

Fig. 4: South-North correlation of Aptan series from Kasserine to North El Kef

Plate 3

Photo A : First massive carbonatic unit (H1) of the Hameima Formation showing cross beddings. The Jebel Bou El Hanèche section

Photo B : Fine-grained sandstones base showing crescent casts (Red arrow) and flute casts (black arrow). The Jebel Chehid CH section

Some beds exhibit, at their base, groove-casts, bounce-casts and flute-casts suggesting a sliding of silts and fine-grained sands on a sloping profile from South to North.

- The median unit (270 m)

The median unit is characterised by the intercalation of frequent and relatively thick sandy beds within a clayey and silty series. Sandstone bodies (50 cm to 2.5 m in thickness) which generally exhibit a lensoid geometry and which contain fragments and molds of bivalves, oysters and gastropods, are basically composed of fine to medium-grained and well-sorted quartz grains. Certain sandy bodies show wave ripples and HCS suggesting tempestitic episodes during the deposition of this median unit.

According to the bioclastic composition of sandstones and carbonates which are locally rich in orbitolinids, the median unit could be correlable to the Hameïma Formation.

- The third unit (300 m) is mainly constituted of green marlstones and silty claystones admitting rare intercalations of metric sandstone bodies. The upper part includes frequent intercalations of orbitolinid-rich limestones.

Sandstone and sandy-limestone beds show low-angle cross beddings, convolute beddings and HCS suggesting episodic storm deposits.

II/ APTIAN SERIES CORRELATIONS AND DEPOSITION ENVIRONMENTS

A/ South – North correlation of Aptian series from Kasserine to North El Kef sector

From the Jebel Bou El Hanèche to the South and to the North Aptian series exhibit clear changes in thickness, facies and reservoir aspects.

In the Jebel Bou El Hanèche, the Aptian series are expressed by the three distinct formations: Hamada Formation equivalent, Serdj and Hameïma Formations.

Laterally, to the North, Aptian facies get thicker at Jebel Djerissa (Fig. 4) and clearly more at Jebel Ben Rhazouane. In addition, silicoclastic deposits are obviously more common and could be interbedded with carbonatic deposits.

In Jebel Jerissa, Aptian facies are mainly represented by the Hameïma Formation which is relatively thicker and constituted of comparable facies to those described at Jebel Bou El Hanèche. However, the massive bioclastic carbonates of the Serdj Formation are clearly reduced in thickness.

More to the North, in Jebel Ben Rhazouane, Aptian series are clearly thicker and show more marly, clayey and sandy facies expressing a relatively deepening of the deposition environment and also frequent episodic clastic discharges intercalation.

Plate 4

Photo A : General view showing the fourth massive carbonatic units (I, II, III, IV) of the Serdj Formation in the Jebel El Hamra East

Photo B : Visible moldic to vuggy porosity within the second carbonatic unit of the Serdj Formation in the Jebel El Hamra East

On the other side, to the South, at Jebel El Hamra, the Aptian deposits are clearly thinner and mainly represented by fractured carbonatic layers constituting the Serdj formation. The latter is organised into for massively bedded carbonatic units separated by argillaceous carbonates. The 4 units (Plate 4, photo A) which constitute topographic landmarks are constituted of bioclastic dolomitised limestones highly fractured (Plate 10, photo 1) and showing visible pores mainly corresponding to moldic and vuggy pores (Plate 4, photo B). Some units are topped by karstified and organic-bored emergence surfaces.

B/ Correlation of Aptian series in the southern part of the Tajerouine Permit

B1- South East - North West correlation in North Thala area

From Jebel Bou El Hanèche to Jebel Hameima (Fig. 5), the Hameima Formation constitutes the predominating Aptian facies. In fact, the Serdj carbonates which are reduced in thickness, show particular facies. In addition, the Hameima Formation which is thicker and more marly, includes frequent sandy and argillaceous intercalations. The sandy beds, plurimetric thickness, are composed of fine-grained and well-sorted quartz grains.

The relative thickening of Aptian Hameima facies in Jebel Hameima and also in Jebel Jerissa could reflect a subsidence activity preferentially interesting the Jebel Djerissa area. The numerous visible faults in this area (at the border of the Kalaa khasba graben) could, at least partly, be active during the Aptian period.

B2- West – East Correlation in North Kasserine area

From Jebel El Hamra to Jebel semmama (Fig. 6), the massively bedded Serdj carbonates are clearly reduced.

More in detail, correlations within the Jebel El Hamra sector itself, show local and rapid changes of thickness suggesting an intimate relation-ship between Aptian sedimentation and contemporaneous tectonic movements. In fact, only few hundreds of meters from the main section to the West, the Serdj Formation which gets thinner (from 150 to 105m), shows obvious progradation structures suggesting a relative shallowing toward the West, probably in relation with a distensive syn-sedimentary tectonic activity, responsible of the creation of horsts and grabens and favouring subsidence processes, especially in the depressed compartments, such as the eastern “block”. In contrast, the western “block” in which the Serdj thickness is reduced may correspond to a horst.

However, to the East, at Jebel Semmama, the reduced Aptian series are mainly represented by the Serdj Formation including the Bou Laaba Member which corresponds to a massively bedded carbonatic unit (only

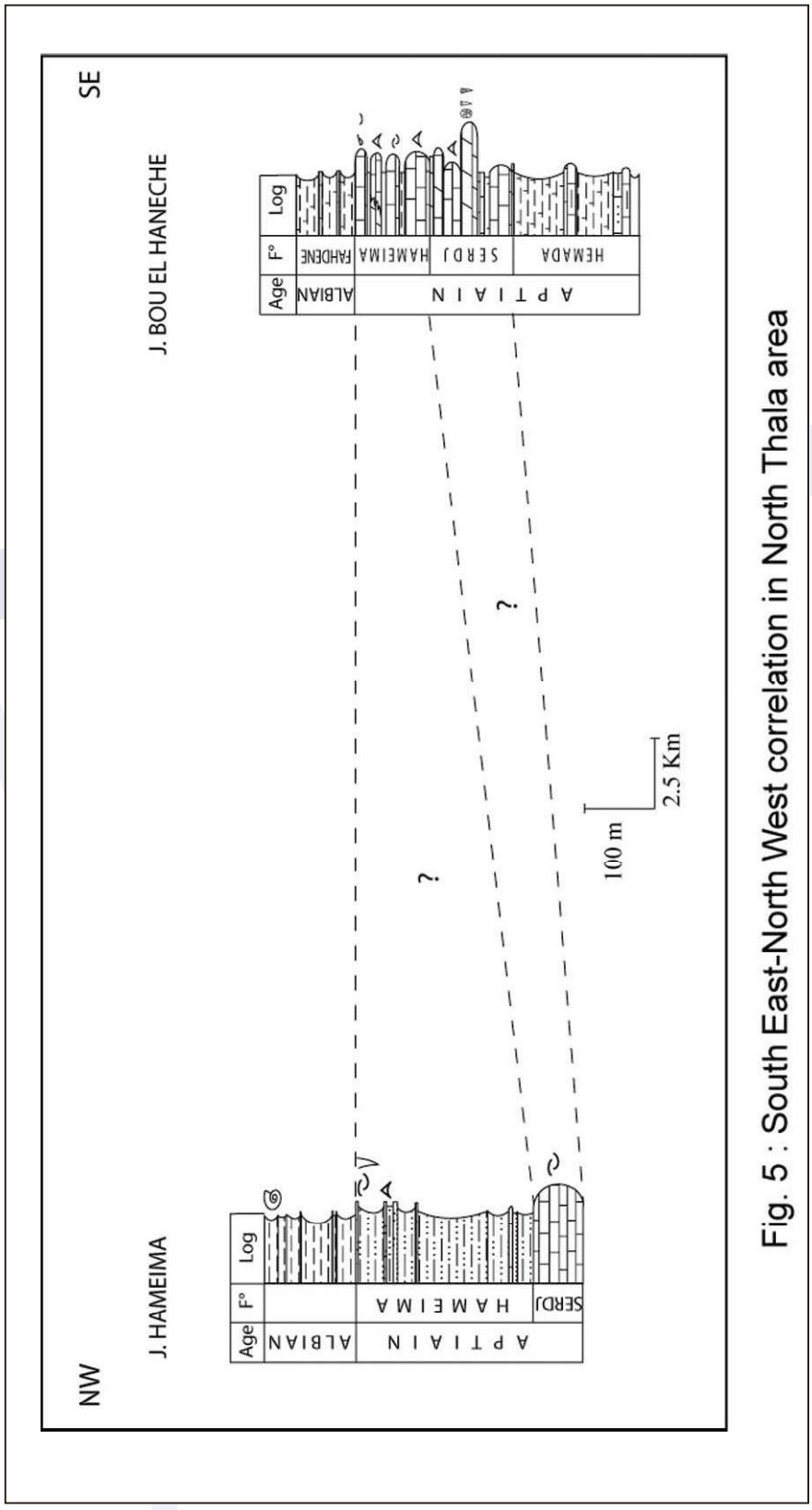

Fig. 5 : South East-North West correlation in North Thala area

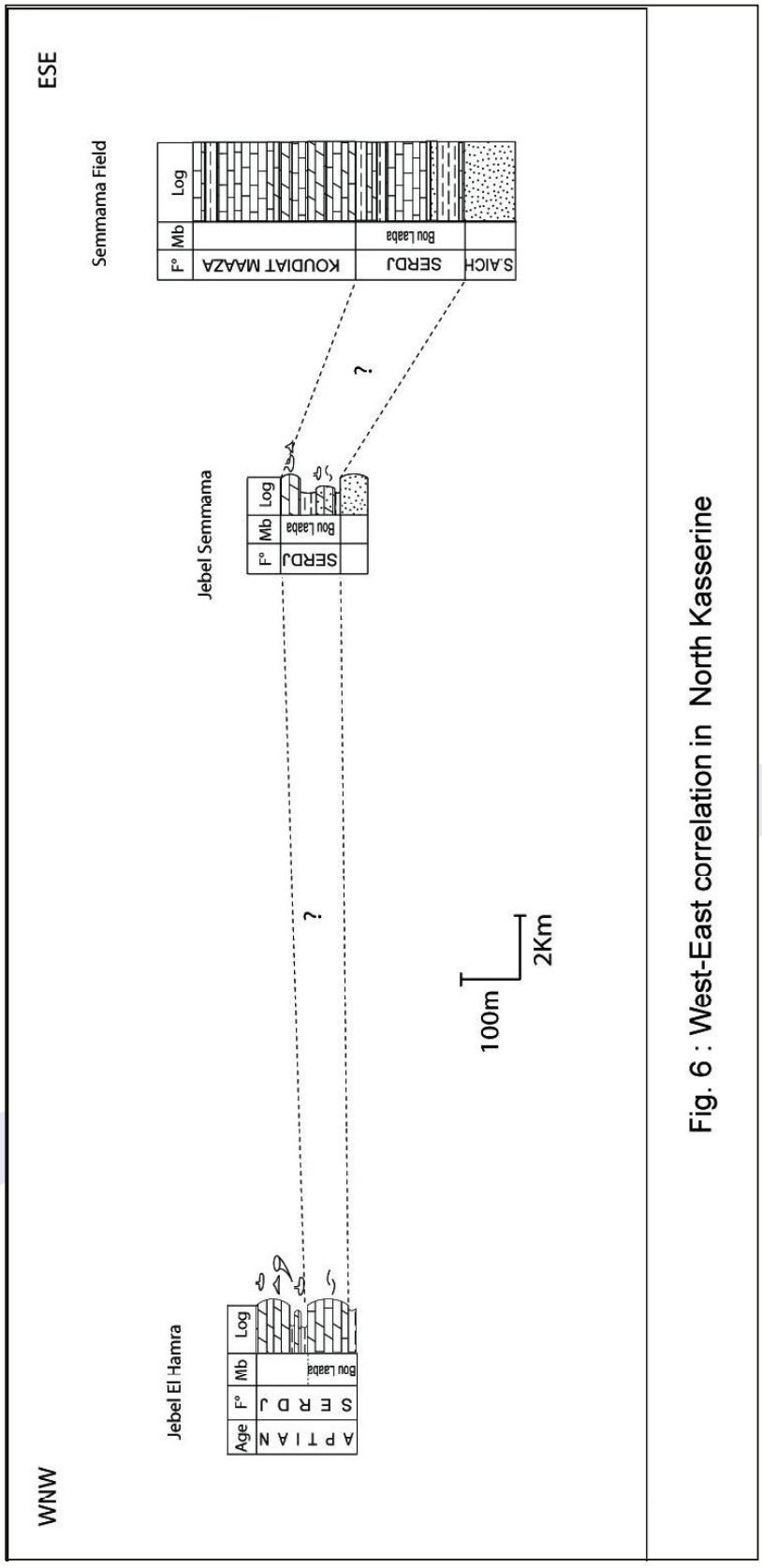

Fig. 6 : West-East correlation in North Kasserine

30m in thickness), directly overlying silty claystones interbedded with carbonatic sandy beds. The latter directly overlie the Sidi Aïch silty claystones and sandstones.

The Bou Laaba unit is mainly constituted of bioclastic dolomitised limestones locally rich in bivalves, corals, sponges, orbitolinids and showing moldic to vuggy pores. It is topped by a highly bioturbated and bored surface corresponding to a hard ground.

Aptian facies of Jebel Semmama are perfectly correlable with the Aptian proven reservoirs, especially the Douleb field (Fig. 6). In addition to the massive Serdj carbonates forming a classical proven reservoir, the dolomitic sandstones of the lower Serdj (below the massive Bou Laaba unit), called "bed bars" in the Douleb field (Troudi et al., 2010) also constitute proven reservoir layers.

On the whole, the relative thinning of the Serdj carbonatic facies in the Jebel Semmama area suggests that the latter appears as more resistant comparatively to the Jebel El Hamra sector.

C/ West - East correlation of Aptian series in the northern part of the Tajerouine Permit

West – East correlation from the Oued Djoumane area to the Jebel Ben Rhazouane area and more to the East, at the Jebel Chehid, the Aptian series shows clear changes in thickness and facies (Fig. 7).

In Oued Djoumane area, the Aptian series consist of silty claystones and marls admitting the intercalation of well individualised lensoïd bodies (Plate 2, photo A) composed of siltstones to fine-grained and well-sorted sandstones.

The 2 thickest lensoïd bodies, respectively 11m and 9m in thickness may correspond to relatively deep sea fan clastics deposited and partly "detached" into lobes (Plate 2, photo A) on a sloping profile.

The basal part of some siltstone and quartzite beds show groove-casts and flute-casts suggesting sliding processes toward the NE; (most of the measured directions are between N140 and N160).

The thickening of the Aptian series (1520m) associated to the predominant marly to shaly lithology suggest a subsiding and a relatively deposition environment deepening clearly illustrated in the Oued Djoumane area.

On contrary, more toward the East of the Jebel Ben Rhazouane area, the Aptian series appear thinner; in addition, they include more frequent intercalations of thicker and more bioclastic carbonates and coarser sandstones. In fact, in the Jebel Chehid area, the Aptian series which unconformably overlie Triassic siltstones and claystones, appear thinner (only 270m in thickness). Within the upper 165m, bioclastic carbonates and sandstones are clearly frequent. Carbonatic beds which are topped by hard grounds and which exhibit obvious organic borings, could illustrate

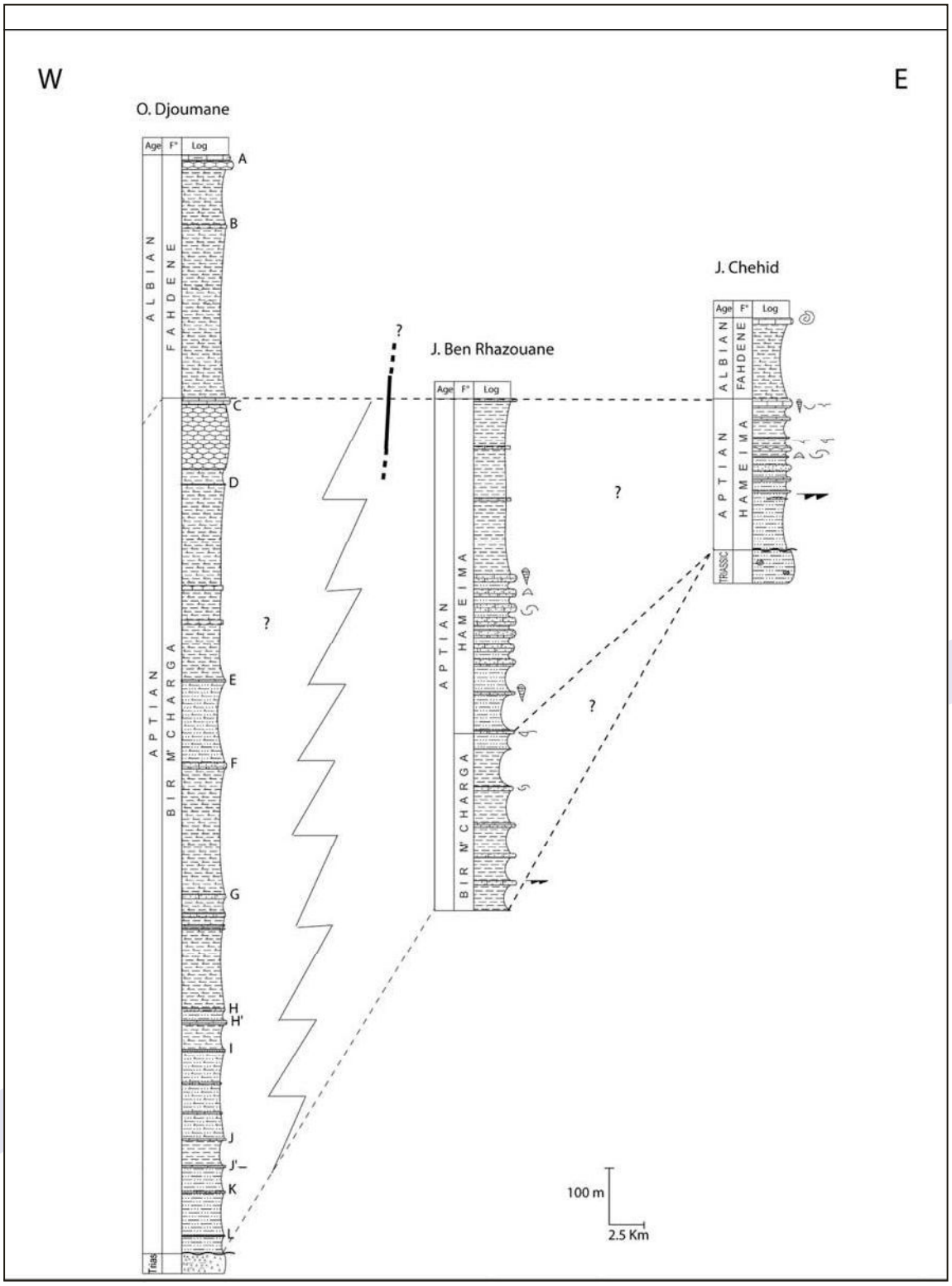

Fig. 7: West-East correlation of Aptian series in the Northern part of the Tajerouine Permit

sedimentary discontinuities in relation with a low deposition rate episodically occurring during the Aptian sedimentation.

The massively bedded sandstones which are relatively thick in the Jebel Chehid area, reaching 10m, showing a lensoid geometry, are composed, at least partly, of medium to coarse-grained well-sorted quartz grains. These sandstones offer the highest values of porosity and permeability (see the Porosity-Permeability analyses paragraph).

On the other hand, the lowest sandstone bodies show, at their base, groove-casts, flute-casts and crescent-casts (Plate 3, photo B). All these features associated to the slump marks identified in other beds, suggest a sliding of the clastic material on a slope toward a preferential direction around the West-South-West. Most of the measured directions are between N70 and N110.

In addition, immediately above the sandstone bodies showing good petrophysical properties, dark-grey laminated to nodular limestones containing pyrite crystals (Plate 6, photo B) and locally interbedded with carbonates and marls have been identified. These relative organic-rich facies (Sassi et al., 1991; see organic matter analyses paragraph) suggest episodic reducing conditions propitious to the organic matter preservation.

On the basis on E - W Aptian series correlations and according to the identified sedimentary features, the Jebel Ben Rhazouane occupies an intermediate area between a relatively deep marine and depressed zone developed to the West (in Oued Djoumane) and a clear shallower and higher area toward the East (near the Jebel Chehid sector). The relatively coarse size of the sand grains confirms the relatively proximal setting of the Jebel Chehid area.

On the whole, correlations of the Aptian series on a South - North transect, from Jebel El Hamra to Jebel Ben Rhazouane, show that most of facies lateral changes which generally are transitional, illustrate a deposition model of a ramp dipping toward the North.

This model ramp involving progradation – retrogradation processes, could explain the probable diachronic sedimentation along the studied South-North transect, especially during the clastics deposition. The onlapping of the bedded Hameïma bioclastic and sandy carbonates on the massive Serdj carbonates suggests that the Hameïma deposits could be contemporaneous (in the northern part of the Permit) or posterior (in the southern part of the Permit) to the Serdj deposition.

Progradation processes (obvious in most studied outcrops) commonly occur during humid episodes and especially during sea level fall phases and/or contemporaneous tectonic movements. Retrogradation processes classically occur during sea level rise inundations.

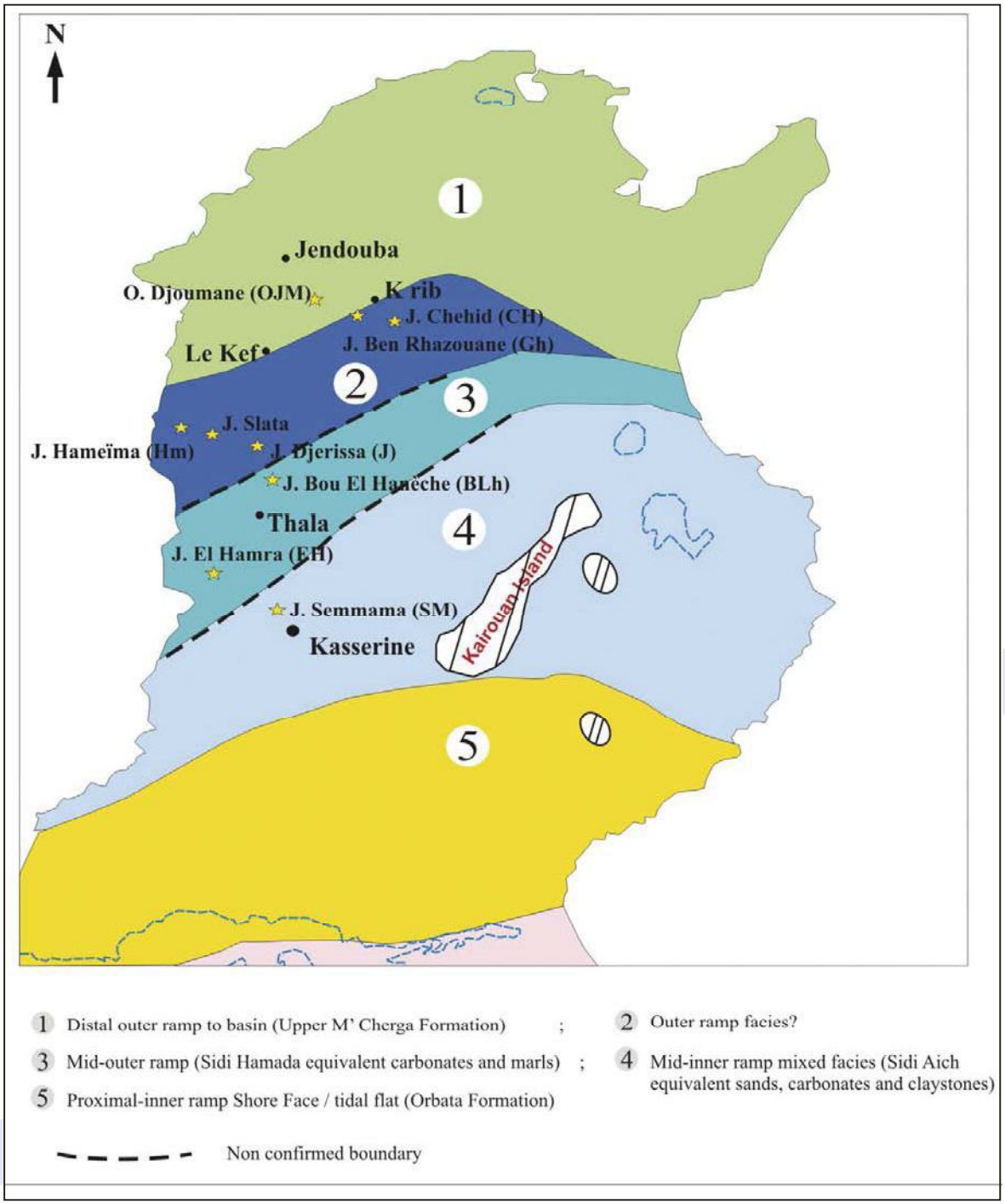

Fig. 8: The main paleogeographic domains during the Early Aptian in the Tajerouine Permit (Ouahchi et al, 1998; Mejri et al., 2006; modified)

III/ THE MAIN PALEOGEOGRAPHIC DOMAINS IN THE TAJEROUINE PERMIT, DURING THE APTIAN – ALBIAN SEDIMENTATION

On the basis of previous studies (M'Rabet, 1982; Ben Ferjani et al., 1990; M'Rabet et al., 1995; Ouahchi et al, 1998; A. Arnaud-Vanneau et al., 2005; ETAP, 2006; Mejri et al, 2006; Chihaoui, 2009; Chihaoui et al., 2010; Negra et al., 2010) and our present data, based on sedimentologic studies and regional correlations of the Aptian series, different paleogeographic domains are identified in the Tajerouine Permit. These domains could be slightly different and exhibit some changes during the deposition of the Hamada Formation equivalent (probably Early Aptian in age) and the Serdj-Hameïma deposition (Aptian according A. Arnaud-Vanneau et al., 2005 or Late Aptian - Albian in age according Chihaoui et al., 2010).

A/ The main paleogeographic domains during the Early Aptian

Before the deposition of the Sedj-Hameïma Formations, the Tajerouine Permit includes three main paleogeographic domains.

1- The southern part of the Tajerouine Permit including the Jebel Bou El Hanèche - Jebel El Hamra "trend" (domain 3; Fig. 8), the dark-grey marls and argillaceous limestones containing orbitolinids, bivalves and locally ammonites (of the Hamada Formation equivalent) suggest a mid-outer ramp environment.

Below these transgressive marlstones, the shallower deposits rich in sandy intercalations which could constitute the upper part of the Sidi Aïch Formation equivalent, suggest a transitional change toward the South to a Mid-inner ramp environment (domain 4) in which the Sidi Aïch clastics are well represented.

2- The Northern part of the Tajerouine Permit includes two paleogeographic domains
- An Outer ramp domain (2) including Jebel Djerissa, Jebel Slata, Jebel Hameïma and Jebel Ben Rhazouane.
- A distal outer ramp to "basial" environment (1), developed more to the North, including the Oued Djoumane and favouring the deposition of deeper deposits correlable with the upper M'cherga deposits.

B/ The main paleogeographic domains during the Serdj-Hameïma sedimentation, Late Aptian – Albian interval

The ramp model is also confirmed during the the Serdj-Hameïma sedimentation (probably Late Aptian - Albian in age). Comparatively to the previous period, a general shallowing tendency is identified during this period from South to North. This general shallowing could indicate a

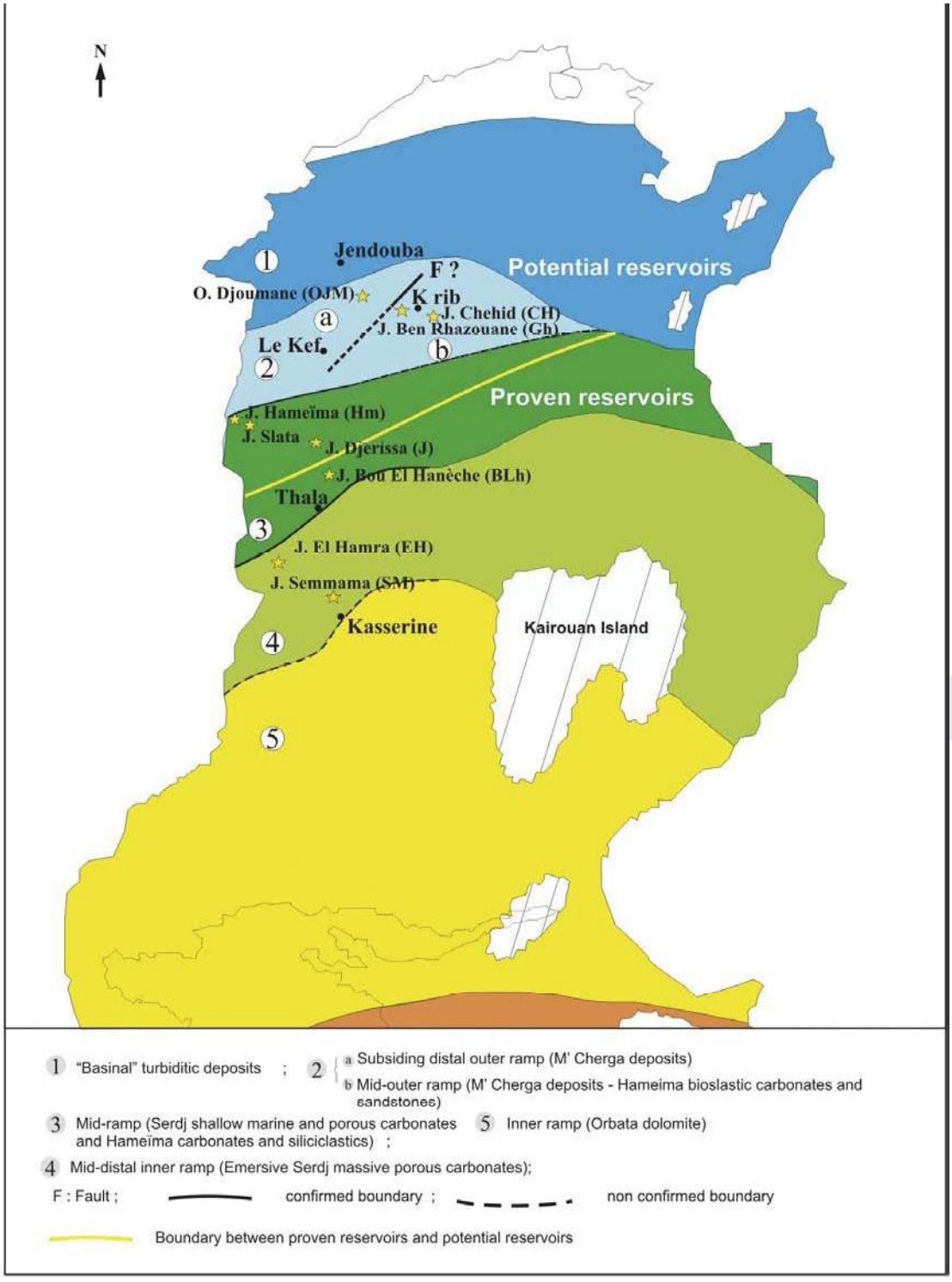

Fig. 9: The main paleogeographic domains during the Late Aptian-Albian interval in the Tajerouine Permit (Ouahchi et al, 1998; Mejri et al., 2006; modified)

relatively elevated sedimentation rate followed by an infilling tendency of most of the accommodation space previously created.

1- The southern part of the Tajerouine Permit including the Jebel Bou El Hanèche, Jebel Djerissa and Jebel Hameïma sectors (Fig. 9) corresponds to a mid-ramp setting (domain 3) favourable to the deposition of the Serdj shallow marine and porous carbonates and the Hameïma carbonates and clastics. These facies progressively change to the South to a shallower environment (domain 4) corresponding to a mid-distal inner ramp setting occupied by the emersive porous carbonates of the Serdj Formation.

2- The northern part of the permit is occupied by an outer ramp domain which could be compartmented into two sub-domains:

- The North-Western part including the Oued Djoumane area, is a relatively deep and subsiding domain (2a) corresponding to a distal outer ramp setting favouring the deposition of the "basinal" M'cherga deposits.

- The South-Eastern part including the Jebel Ben Rhazouane and the Jebel Chehid sectors is relatively higher in paleotopography and more proximal corresponding to a mid outer ramp setting (domain 2b) favouring the deposition of the Hameïma bioclastic carbonates and sandstones directly on the M'cherga claystones.

Concerning origins of clastics supply, the lateral coarsening of the quartz grains from West (Oued Djoumane) to East (Jebel Chehid) suggest a source (or sources) more closed to the Jebel Chehid. These sources could correspond to islands (Heldt et al., 2010) located to the North-East or to the East of Jebel Chehid.

The upper boundary of the Aptian Hameïma deposits is indicated by a transgressive surface expressed by a high condensed level rich in ammonites.

IV/ RESERVOIR CHARACTERS: POROSITY-PERMEABILITY ANALYSES INTERPRETATION AND MAIN POTENTIAL RESERVOIR LAYERS IN THE APTIAN SERIES OF THE TAJEROUINE PERMIT

A/ Porosity-Permeability values of the Aptian carbonates and sandstones in the southern part of the Tajerouine Permit

In the southern part of the Tajerouine Permit, especially in Jebel Bou El Hanèche, Jebel Hameïma and Jebel El Hamra, the porosity and permeability analyses (ETAP, 2009, 2010; Fig. 10) have concerned sandstones, sandy carbonates and carbonates showing visible pores.

At Jebel Bou El Hanèche and Jebel El Hamra, most of Aptian facies consist of carbonates that are expressed by partly to wholly dolomitised bioclastic limestones. Within these carbonates, most of measured porosity values

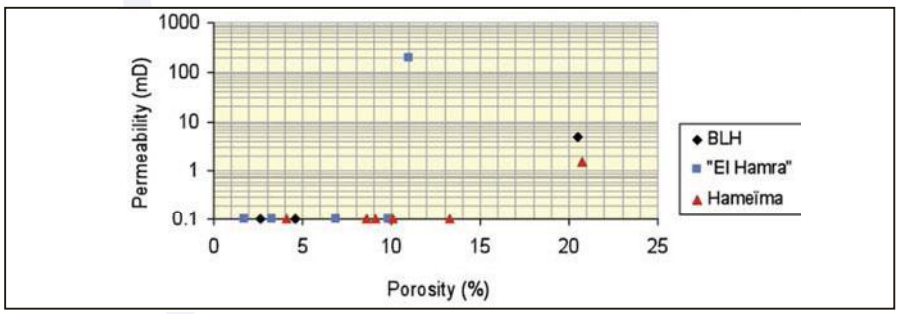

Fig. 10: Cross-plot permeability versus porosity of Aptian carbonates in the southern part of the Tajerouine Permit (J. Bou El Hanèche – J. El Hamra – J. Hameïma)

Plate 5

Photo A : Partly open fractures of the third massive carbonatic unit (H3) of the Hameima Formation. The Jebel Bou El Hanèche section

Photo B : Visible vuggy porosity within the third massive carbonatic unit (H3) of the Hameima Formation. The Jebel Bou El Hanèche section

(Fig. 11, 12) are low (ranging from 2 to 21% with a mean porosity value of 4% in Jebel El Hamra and 9% in Jebel Bou El Hanèche). Permeability values are commonly very low (<0.1mD). The highest permeability values (5 and 197mD) coincide with the highest values of porosity (respectively 20.5 and 11%).

At Jebel Hameïma where sandstones and sandy carbonates are clearly more represented, porosity values measured in sandstones are relatively higher than those measured in carbonates. In fact, porosity values range from 4 to 21% with a mean porosity value of 11%. All the measured permeability values are less than 0.1mD except the most porous sample (21%) which provides a low to mean permeability value (1mD). This sample was collected from bioclastic dolomitic sandstones showing moldic pores.

B/ Porosity-permeability values of the Aptian sandstones in the northern part of the Tajerouine Permit

In the northern part of the Tajerouine Permit (Jebel Ben Rhazouane - Oued Djoumane - Jebel Chehid area), porosity and permeability analyses (Fig. 11) have essentially concerned sandstones which are more or less cemented with carbonatic crystals. Sandstones of this sector show the best measured values of porosity and permeability.

- At Jebel Ben Rhazouane, the porosity values range from 2 to 19%, with a mean porosity value of 10%. The permeability values range from less than 0.1mD to 1mD.

At Oued Djoumane, the porosity values range from 5 to 13% (Fig. 11) with a mean porosity value of 8% while all the measured permeability values are less than 0.1mD.

- At Jebel Chehid, the porosity values range from 2 to 30mD with a mean porosity value of 14% (Fig. 11). The permeability values range from less than 0.1mD to 337mD. The most porous samples (20% and 30%) show also the highest permeability values (respectively 97mD and 337).

The highest porosity and permeability values were measured in medium to coarse-grained sandstones which are preferentially located in the Jebel Chehid. In contrast, the lowest porosity and permeability values were measured in the fine-grained sandstones and siltstones of the Oued Djoumane section.

The sandstone bodies which are relatively frequent in the middle part of the Jebel Ben Rhazouane section and which show a fine to medium-grained size, have intermediate values of permeability.

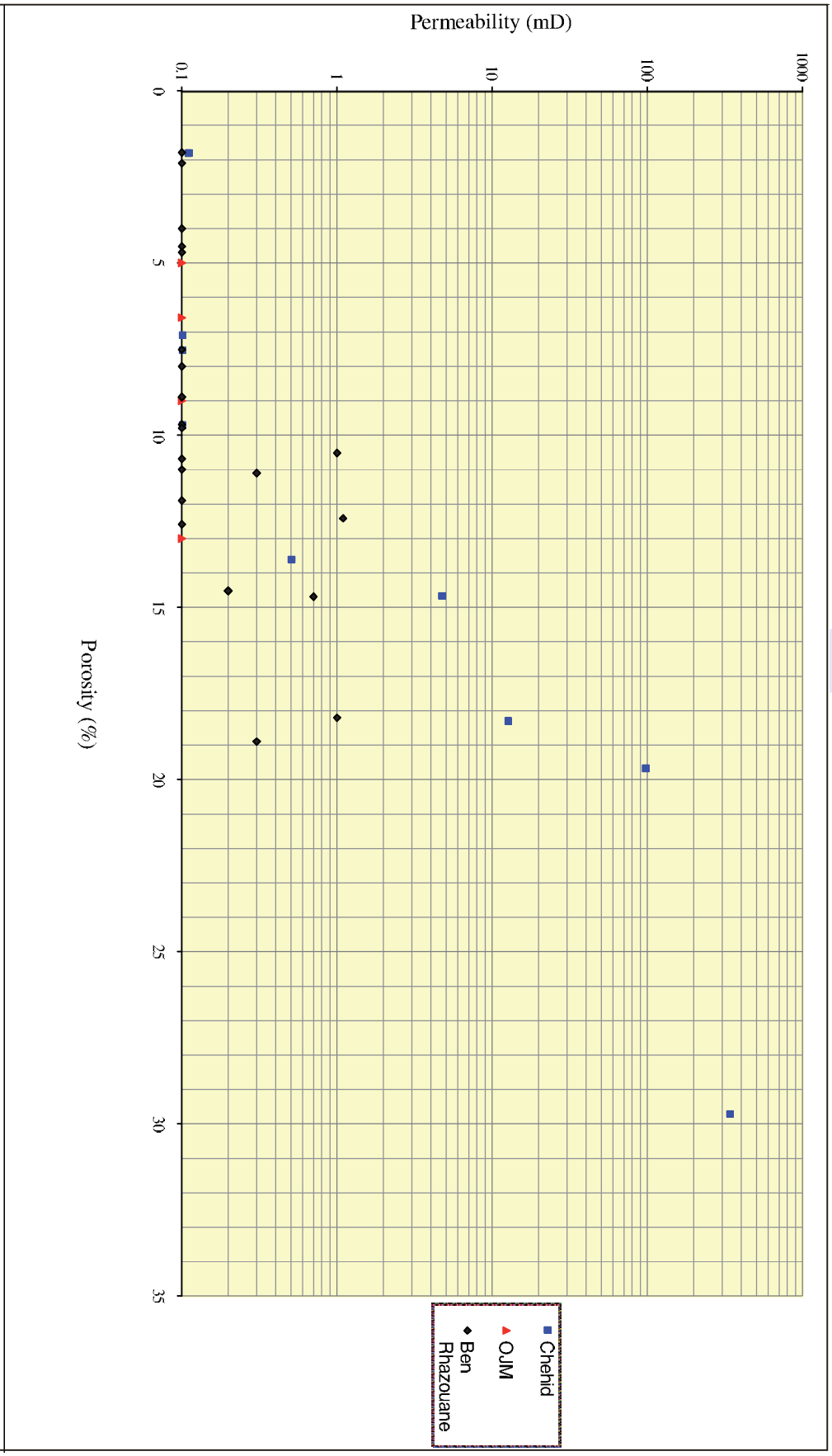

Fig. 11: Cross-plot of permeability versus porosity of the Aptian sandstones in the northern part of the Tajerouine Permit (J. Ben Rhazouane – Oued Djoumane – J. Chehid)

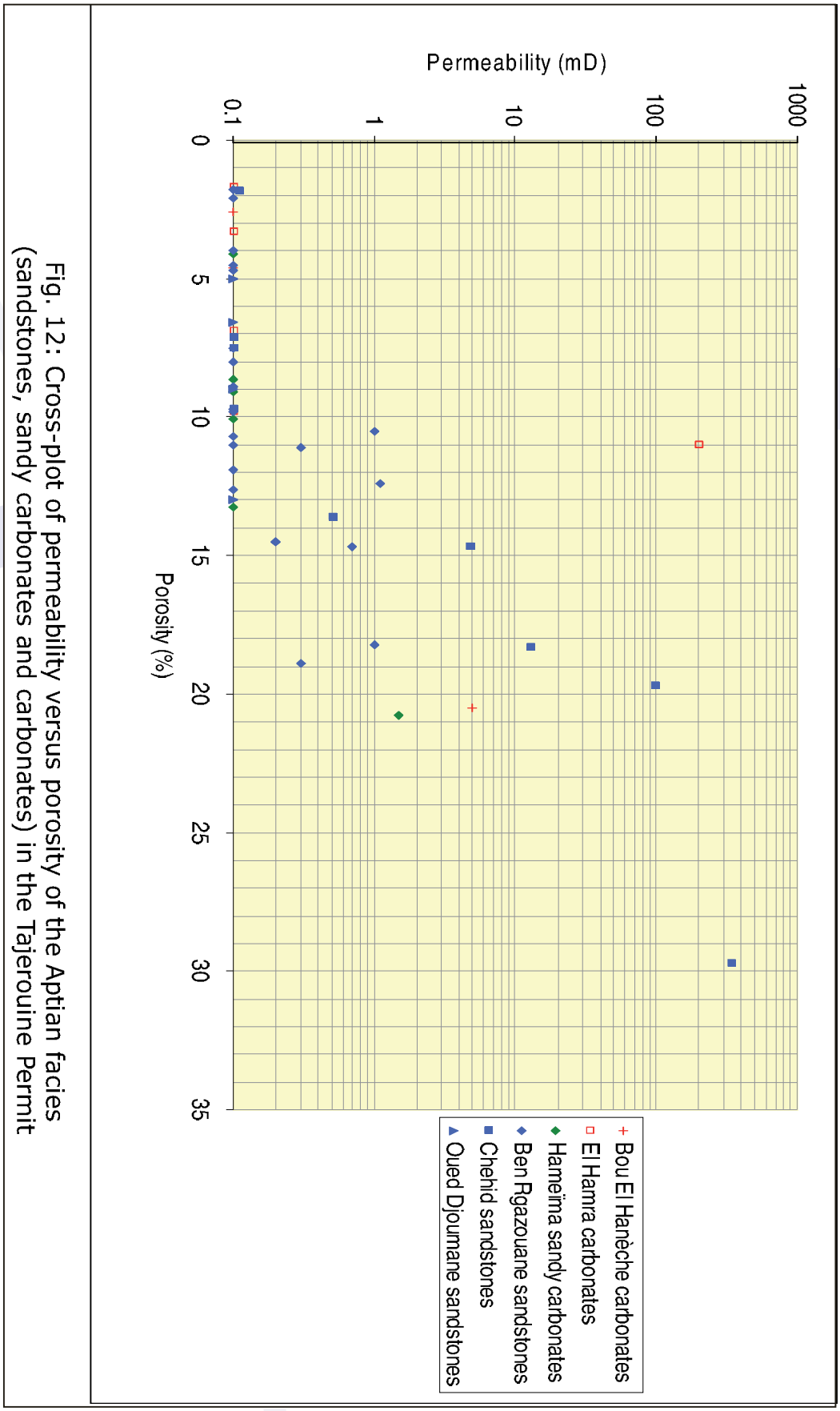

Fig. 12: Cross-plot of permeability versus porosity of the Aptian facies (sandstones, sandy carbonates and carbonates) in the Tajerouine Permit

C/ Conclusions and recommendations

On the whole, the porosity-permeability quantitative study could provide only an idea about the changes of pore spaces in relation with facies and lithologies. It means that pore spaces change in geometry and volume when Aptian series change in facies. In fact, the analysed facies consist of sandstones, carbonatic sandstones, sandy carbonates, dolomitised limestones, dolomites (Fig. 12).

The absolute measured values of porosity or permeability are not really consistent with the reality of the visible pores (Plate 5) in these different facies.

The most represented pores are certainly fractures (Plate 5, photos A and B) which are obvious in the whole studied sections particularly in Jebel Bou El Hanèche, Jebel Djerissa, Jebel Hameïma, Jebel Semmama, Jebel El Hamra etc.

All these sectors are more or less closed to the Kalaa-Khasba graben.

At least, some of the fractures are associated to the main faults responsible of the graben opening. It would be important to establish a relative chronology of the fracturing versus certain important events such as diagenesis, fluids migration, folding, genesis of traps etc.

Concerning the sandy facies, most of the analysed samples show variable sedimentary characters mainly concerning the (grain size) and the hardness. The latter is under the control of diagenetic modifications, especially cementation. Petrographic studies may certainly provide interesting data about the relationship between the primary texture - porosity and the porosity-permeability evolution versus diagenesis.

In addition, solution cavities identified in the carbonatic facies in the southern part of the Permit (in Jebel Bou El Hanèche, J. Djerissa, J. Hameïma, J. El Hamra and J. Semmama) suggest an improvement of the petrophysical characteristics and the reservoir properties by diagenetic modifications such as solution, dolomitisation, dedolomitisation processes.

V/ ORGANIC MATTER ANALYSES INTERPRETATION AND MAIN POTENTIAL SOURCE ROCKS IN THE TAJEROUINE PERMIT

A/ In Aptian series

In Aptian (Hamada equivalent, Serdj and Hameïma Formations) and Albian series (Fahdene Formation), dark-grey to black coloured marlstones, limestones and argillaceous limestones have been analysed. The organic carbon content of Aptian facies appears generally very low. In fact, all the studied samples mostly collected (in outcrop conditions) from the Hamada Formation equivalent in Jebel Bou El Hanèche, show very low Total Organic Content; the T.O.C does not exceed 0.15%.

However, within the Hameïma Formation equivalent in the Jebel Chehid, the studied samples corresponding to dark-grey to black argillaceous

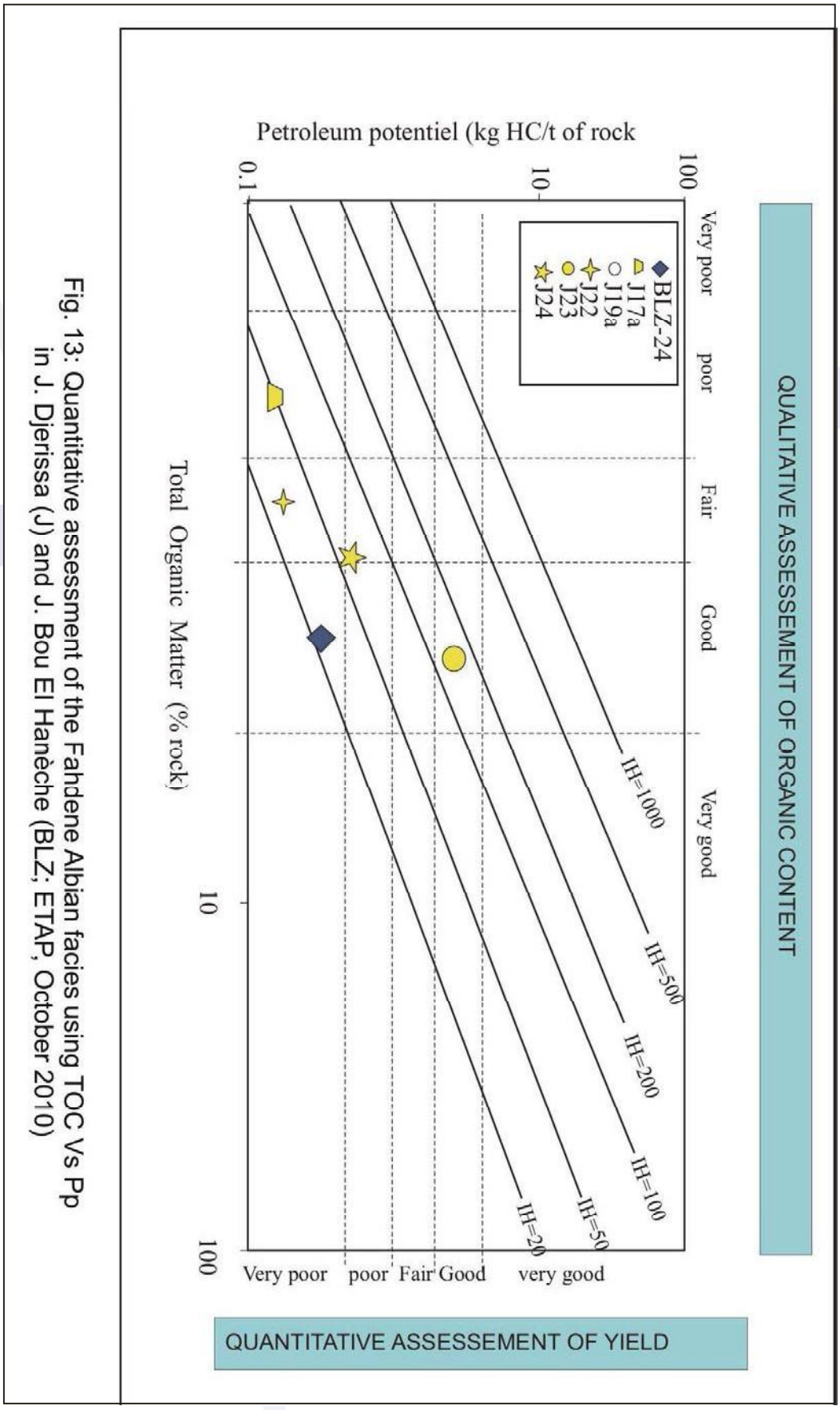

Fig. 13: Quantitative assessment of the Fahdene Albian facies using TOC Vs Pp in J. Djerissa (J) and J. Bou El Hanèche (BLZ; ETAP, October 2010)

Plate 6

Photo A : Organic-rich platy argillaceous limestones of the lower Fahdene Formation. The Jebel Djerissa section

Photo B : Argillaceous limestone layers showing pyrite crystals. The Jebel Chehid CH section

limestones containing floating pyrite crystals (Plate 6, photo B), show a relatively higher T.O.C content (near 0.5%).

B/ In Albian series

In the Albian Fahdene "black shales", the Total Organic Content is obviously higher. The studied facies which were sampled from the lower part of the Fahdene Formation in Jebel Djerissa and Bou El Hanèche, mainly consist of dark-grey to black laminated to "sub-platy" argillaceous limestones. The highest values of T.O.C (2 %) were sampled from the first black platy argillaceous limestones of the Fahdene Formation in Jebel Djerissa (Plate 6, photo A).

Concerning the whole studied samples, the Total Organic Carbon values which range from 0.4 to 2% deal with a poor to good content (Fig. 13).

On the basis of S2 values ranging from 0.11 to 1.43mg HC/g rock, the source rock is interpreted as poor to fair (Fig. 19; ETAP Report, October 2010).

The low Hydrocarbon Index ranging from 17 to 198mg HC/g T.O.C and the low Oxygen Index averaging 87mg CO^2/ g T.O.C (Fig. 14) suggest an advanced stage of maturity and/or a bad organic matter preservation

C/ Conclusions and recommendations

As classically known, the Fahdene black-coloured sub-platy to platy argillaceous limestones constitute the main source rocks. However, the high maturity to the over-maturity of the Fahdene organic matter sampled from the Djerissa and Jebel Bou El Hanèche sections could be local and particular to this area. Hydrothermal diagenesis identified in the Aptian carbonates of Jebel Djerissa (Adjali-Aissaoui, 1990) could be due also to a hydrothermal heat flow responsible of the over-maturity of the Albian organic matter in this area. To check with the maturity stage of the organic matter, a more generalised study has to be carried out in other sectors of the Tajerouine Permit such as in Jebel Chehid, Jebel Ben Rhazouane, Oued Djoumane and Jebel El Hamra outcrops.

On the other hand, additional organic matter analyses have to be undertaken on Aptian and older dark-grey to black-coloured facies (particularly argillaceous limestone and marlstone facies).

VI/ SUMMARY AND CONCLUSIONS

From the northern part to the southern part of the Tajerouine Permit, the lithostratigraphic study associated to the surveyed sections correlations show clear variations in terms of thickness, facies, deposition environments and reservoir properties. The proposed ramp model and the identified paleogeographic domains could be confirmed and completed by seismic interpretations.

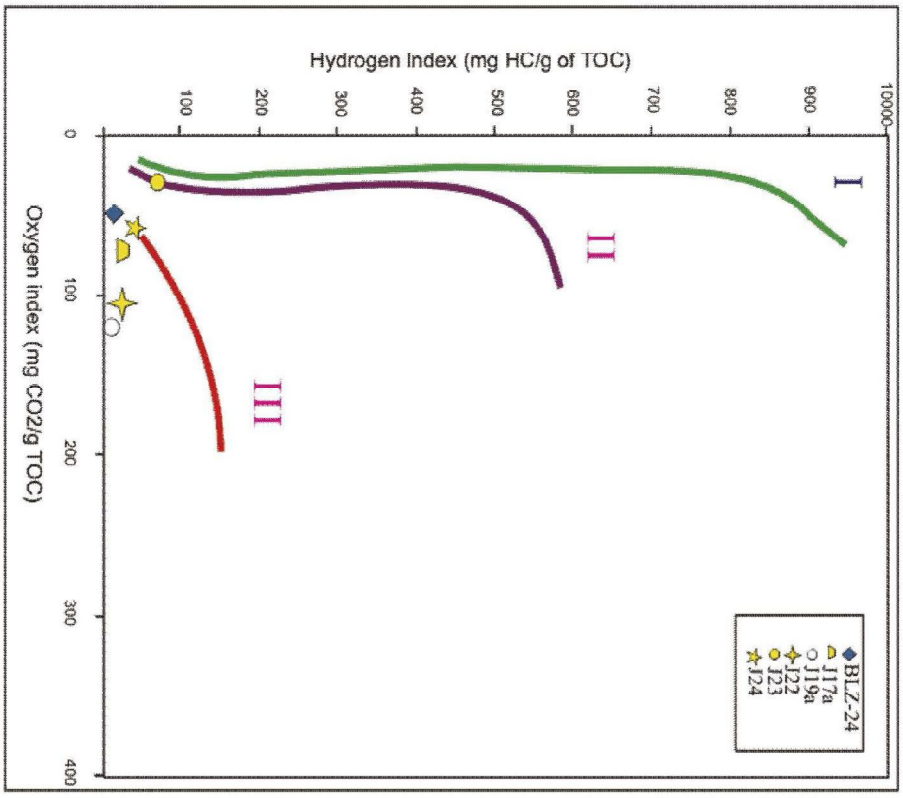

Fig. 14: Diagram IH/IO showing the organic matter type of the Fahdene Albian facies in Jebel Jerissa (J) and Jebel Bou El Hanèche (BLZ) (ETAP, October 2010)

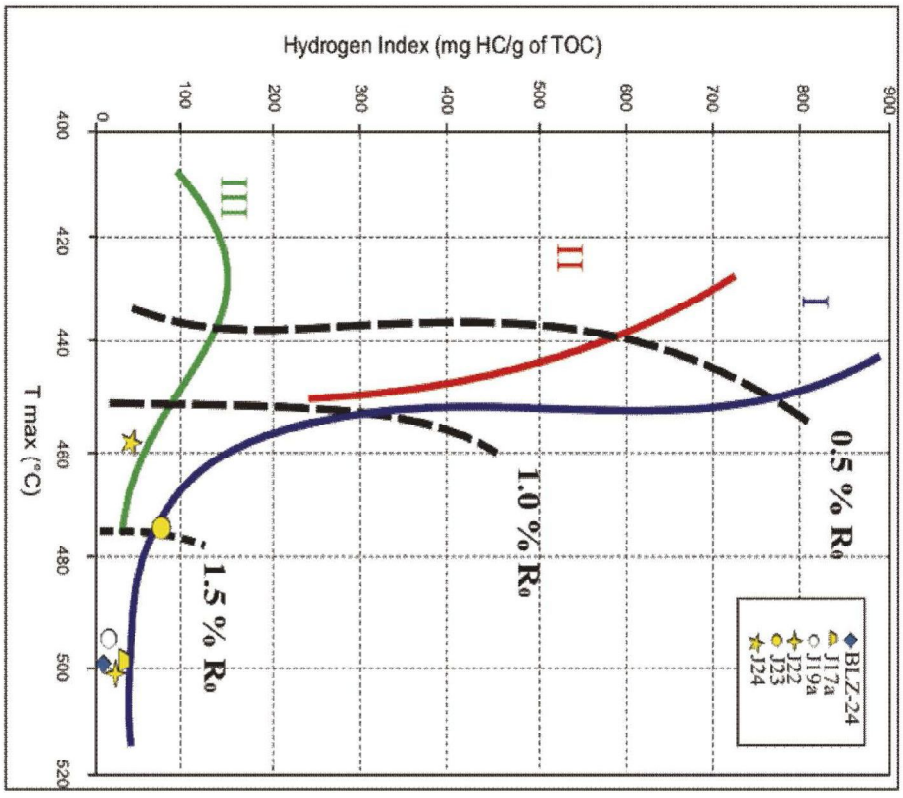

Fig. 15: HI vs Tmax diagram of the Fahdene Albian facies in J. Jerissa (J) and J. Bou El Hanèche (BLZ), showing the organic matter type and the maturity stage (ETAP, October 2010)

- Within the northern part of the Tajerouine Permit, sandstones are clearly more represented. The Jebel Ben Rhazouane - Jebel Chehid sector constitutes a relatively shallow marine environment propitious to the deposition of frequent and thick (metric to plurimetric) sandy lensoid bodies. Toward the Jebel Chehid, the deposition environment which appears more proximal is favourable to the sedimentation of porous and permeable sandstones with good petrophysical properties.

However, the porosity and permeability of the sand bodies appear controlled by diagenetic modification processes, as shown by the variable hardness of sandstones.

On the other hand, the identification of Aptian organic-rich facies (to be confirmed) could provide a supplementary interest to this area. In addition, the overlying Fahdene black-shales also constitute potential source rocks.

Toward the West, the subsiding which preferentially appears active neighbouring the relatively depressed area of Oued Djoumane, could be also favourable to the deposition of organic-rich facies during the Early Cretaceous interval. Some preliminary observations of outcrops located between Oued Djoumane and Jebel Ben Rhazouane area are promising in that subject.

Concerning the reservoir aspects in the Oued Djoumane area, the highly fractured and relatively thick lensoid silty and sandy bodies intercalated within the claystones could also constitute good reservoirs.

- Within the southern part of the Tajerouine Permit, the fractured carbonates of the Serdj and Hameïma Formations could constitute potential reservoir rocks.

Despite the low values of measured porosity and permeability, the visible high density of fractures and the obvious frequent vuggy pores in these carbonates provide a supplementary interest to these carbonates in terms of potential reservoir rocks.

According to subsurface studies, the Douleb and Semmama fields (about 50Km to the South of Jebel Bou El Hanèche - Jebel Djerissa area) producing oil from Aptian carbonates, exhibit similarities in terms of pore types. Dolomitisation processes (ETAP studies, 2003, 2006) tend to transform the primary fine-grained black limestones into porous coarse-grained dolosparitic material in which intercrystal and vuggy pores could be well developed.

The high density of fracturing, obvious in all the studied outcrops, particularly in Jebel Bou El Hanèche, could insure most of pore types connection.

Concerning source rocks, in addition to the Fahdene “black shales” which are classically considered as the best, more organic-rich facies, Early Cretaceous (Aptian or older) to Upper Cretaceous in age (Cenomanian-Turonian; Zagrarni et al., 2008) or Campanian-Maastrichtian (Negra et al., 1991) could be also, at least locally potential, such as in relatively depressed areas (half grabens to grabens, for example).

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