

Facies Analysis of Triassic Formations of the Hassi R'Mel in Southern Algeria Using Well Logs: Recognition of Paleosols Using Log Analysis

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Abstract: Well logs are essential in the study of geological formations, in terms of taking into account the nature and the structure of the formations, as well as the sedimentary processes. Qualitative and quantitative interpretations of well logs respond to a sedimentologic need as well as the establishment of lithological columns, according to the response to logging tools.

In this study, electrofacies have been defined by manual well-log analysis of ten surveys of Triassic formations in the Hassi R'Mel area of Algeria. The data thus obtained were then matched with sedimentary facies defined by core analysis.

The results obtained during the facies analysis made it possible to define ten electrofacies (sands, shale, dolomite, and evaporite, as well as the presence of andesite and clay). The model obtained by the Petrolog software was also developed and tested on other wells. A semi-automatic data processing was then carried out on seven other wells.

Our aim is to highlight the added value of this integrated regional-scale to reservoir-scale approach in identifying near-field exploration potential and additional recovery opportunities in producing reservoirs. Based on this aim, we emphasise the following points using our facies modelling: (1) improved definition of deposition within and between reservoirs, (2) development of regionally sedimentological models for reservoir intervals (the Hassi R'Mel Formations), and (3) recognition of paleosols from well log analysis and controls on reservoir architecture and their links to the Triassic Province of Algeria.

Keywords: Logging, paleosols, reservoirs, modeling, facies, Hassi R'Mel, Sahara.

1. INTRODUCTION

The Hassi R'Mel region is located at the western end of the Algerian Triassic Province [1] and is situated on the north western margin of a Triassic basin (Fig. 1). Today it constitutes a north-south trending anticlinal Mesozoic dome structure. It is one of the largest hydrocarbon reservoirs in the world.

Using well log analysis, this study aims to characterize, as a first step, the succession order of the various facies of the Triassic formations to help clarify the environments under which the various deposits were laid down. Applying the results obtained from faciological analysis and the data records of available well log analysis resulted in the definition of 8 facies at the level of the formations at Hassi R'Mel wells: sand, shaley sand, slightly shaley, dolomite, shaley dolomite, dolomite slight shaley and dolerite.

The objective of this study was to perform a sequential facies analysis starting from Triassic well log records available in the Hassi R'Mel area, with the aim of defining the facies in terms of lithology, texture, structure, and paleosols. A manual facies analysis made it possible to define the different electrofacies, and then the use of log

analysis software allowed the establishment of a quantitative lithological column. In addition, the results obtained by the facies analysis allowed correlations of the well logs in the Hassi R'Mel field to characterize the vertical layout of the various facies encountered, in order to have an idea of the geometry of the sedimentary bodies as well as the nature of the depositional environments [2].

Well-log analysis is used to calibrate electrofacies with sedimentary facies (Fig. 2), and to infer electrofacies associations and depositional environments directly from well logs. On the density and porosity neutron logs, 0% Nphi corresponds to 2.70 g/cm³ Rhob with the Rhob curve increasing to the right of the log and the curve increasing to the left. Negative polarity (Nphi curve on the right of the Rhob curve), positive polarity (Rhub curve on the right of the Nphi curve) and neutral polarity (superimposed Rhob-Nphi curves) were defined in this way. From the study of the conventional well logs (GR, Rhob, Nphi, and sonic logs) calibrated by cores, six electrofacies are defined as characterizing the main sedimentary facies of the Hassi R'Mel sandstone environments (Table 2 and Fig. 3). With conventional well logs, it is not possible to match one facies with an electrofacies; in practice, one electrofacies may correspond to an association of facies or one electrofacies may be interpreted only within a combination of electrofacies. These six electrofacies have been defined and validated from a study of cores and well logs based

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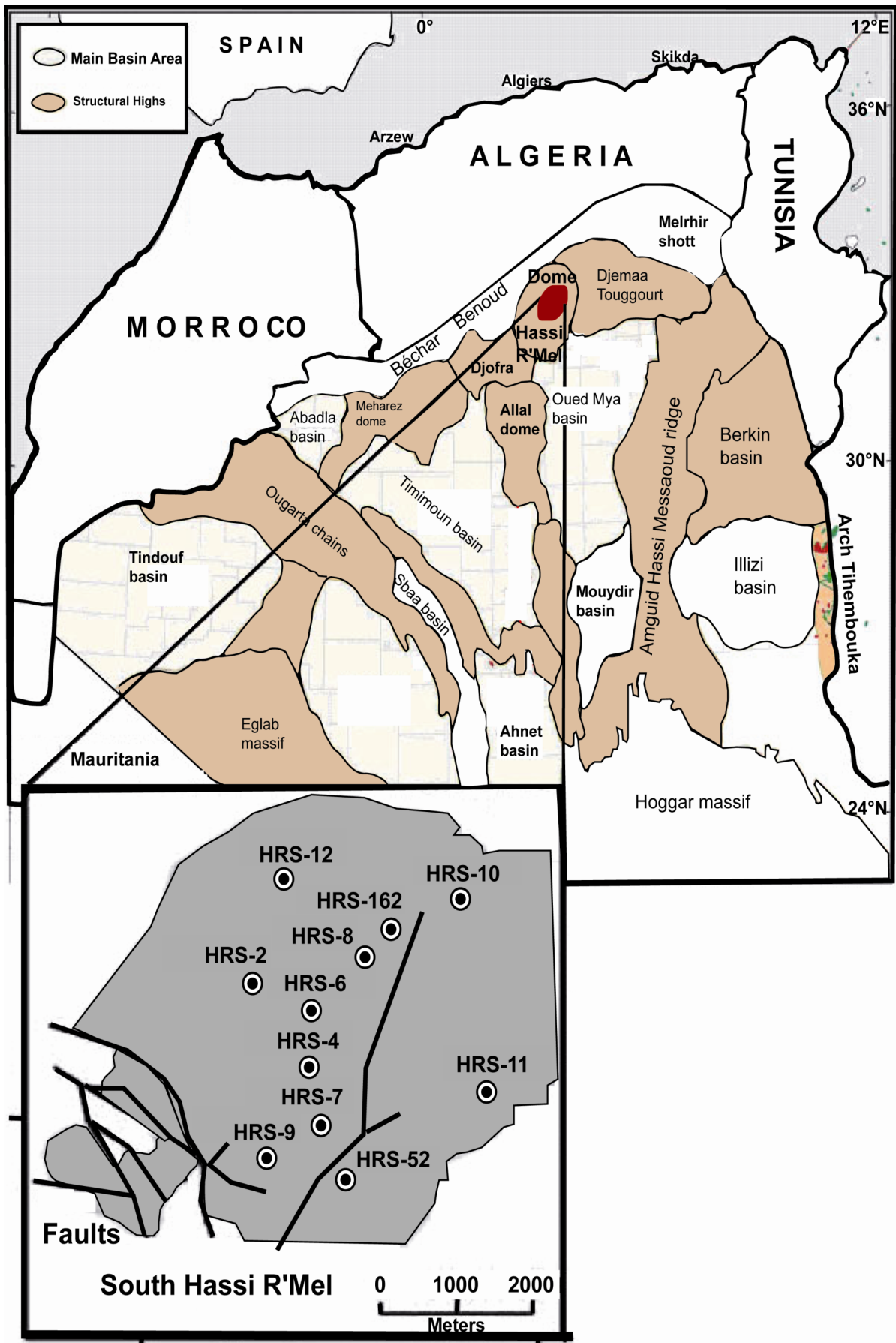


Fig. (1). Field location of the Southern Hassi R'Mel.

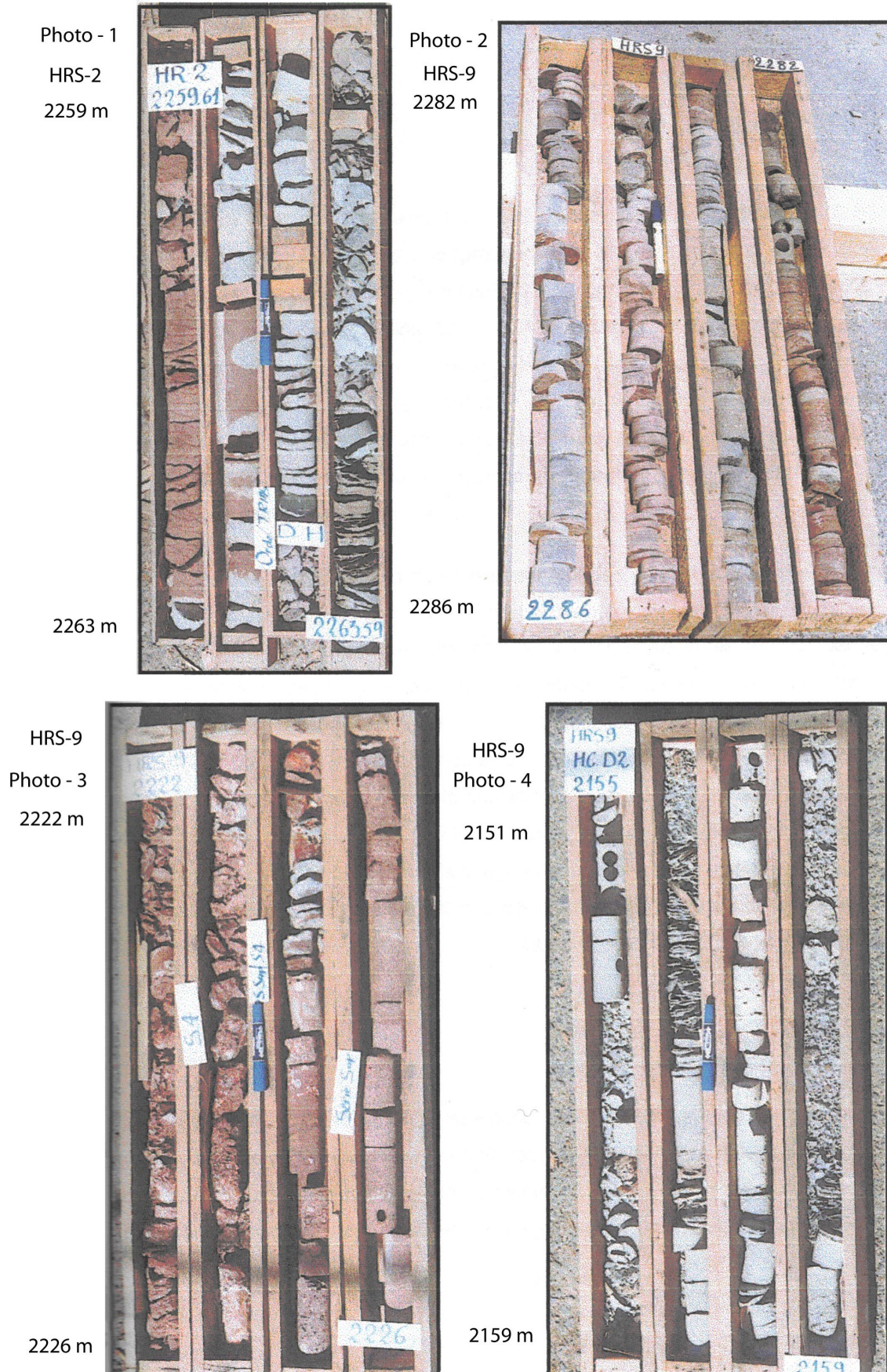


Fig. (2). Core Photos for the Wells: HRS-2 and 9 (memories of engineers: Zeggane F. and Chikhi Z., 2000).

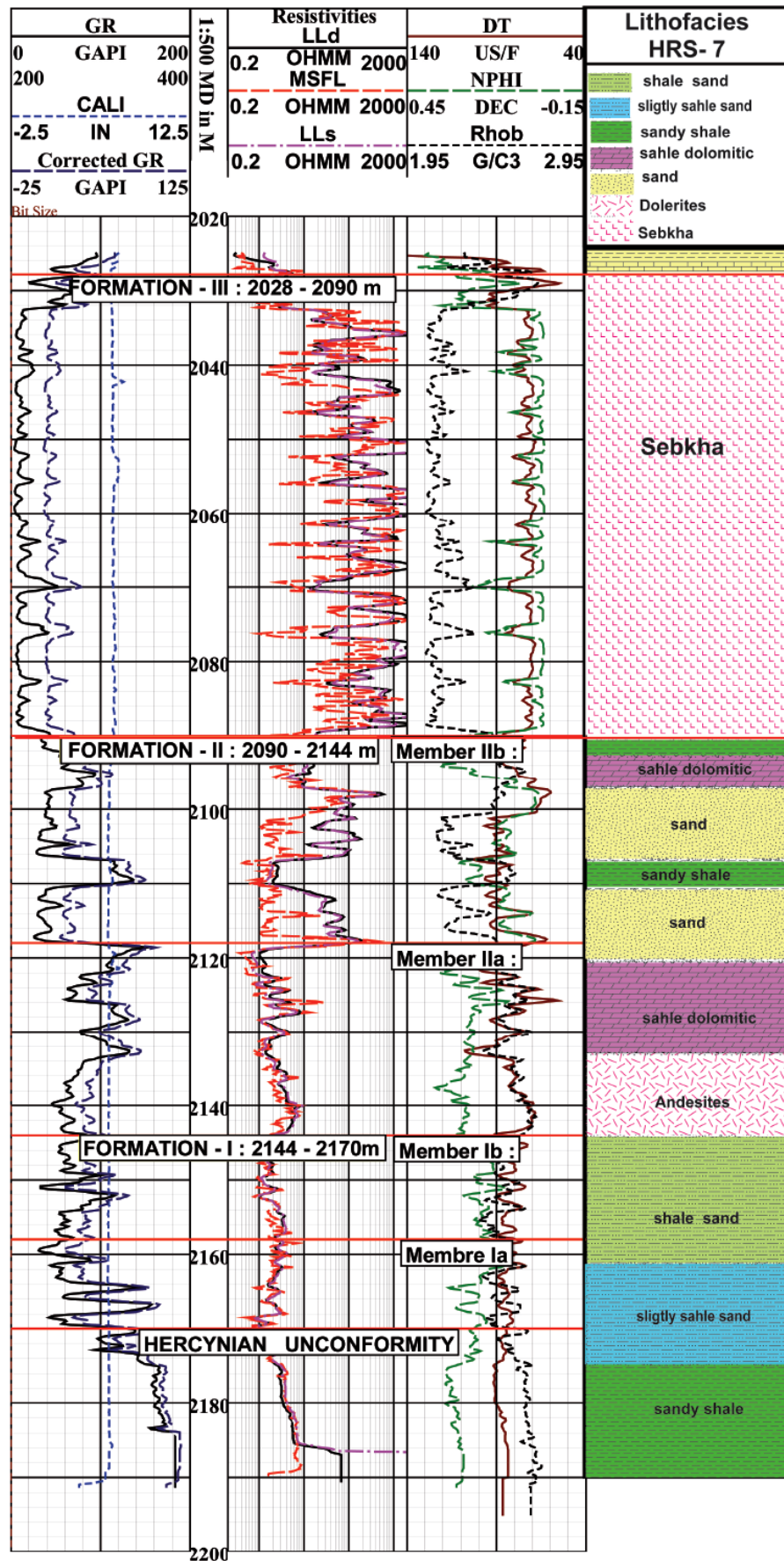


Fig. (3). Manual analysis of the lithofacies from the Hassi R'Mel Southern Triassic.

on 12 wells. The distinction between fluvial and sub-aqueous channels is also difficult with only conventional well log information [3]; only their association with floodplain or lacustrine deposits will allow an interpretation. Floodplain and lacustrine deposits are characterized by the electrofacies. Lacustrine environments differ from floodplain environments in having more positive polarity electrofacies and smoother curves. The flood deposits or sub-lacustrine flood deposits are characterized by the associated electrofacies. Paleosols can be easily recognized from well logs (Fig. 4). All these electrofacies can be recognized if the thickness of the facies associated is larger than the vertical resolution of these well logs (30 to 50 cm for conventional logs).

2. GEOLOGICAL SETTING

The Hassi R'Mel field is located in Algeria, between the longitudes 2°55' and 3°00' East and the latitudes 33°15' and 33°45' North, approximately 50 km south of Laghouat (Fig 1). It is located at an altitude of about 760 m and extends 80 km in a north-south direction and 60 km east-west. The discovery of gas with condensate in the well Hrs-1 [4], the excellent quality of the reservoir and its apparent continuity contributed to the development of exploration in the area; other wells were thus drilled in the north of the field (Bordj Nili; wells NL1 through NL5). The sandstones retain their good reservoir characteristics but are structurally lower and therefore dry or invaded by water. Toward the northeast, wells Lg1, Ph1, and Pg1 revealed poor reservoir quality, as did the AF wells to the south.

To the north of the Hassi R'Mel region, superficial formations are constituted of Senonian or Turonian sediments. To the south, the Mio-Pliocene continental outcrops and forms hamadas. The sedimentary series are quite relatively thick in the north (Bordj Nili) where the Paleozoic is complete. In the structurally high areas, the Mesozoic sedimentary rocks lie directly on the eroded palaeosurface. The Post-Hercynian erosion was the most prominent on the roof of the Tilrhemt (Li 3), where the sedimentary rocks were completely removed and the Triassic formations rest directly on the basement.

It is found at the intersection of two principal axes of the unconformity surface. The first one corresponds to the northern extension of the Hoggar-Idjerane M'zab ridge with a slight curve toward the west. The second, oriented east-west and including the high areas of Tilrhemt and Djemaa, is probably the northeastern extension of the buried relief of the Anti-Atlas [4]. The structure of Hassi R'Mel decreases to the north toward the southern Atlas flexure and is extended to the southwest by the small Djebel Bissa anticlinal structure and to the south by the Southern Hassi R'Mel. It is limited to the south by the Oued Mya depression and to the east by the Djemaa Touggourt zone [5-7].

Beneath the Hercynian unconformity, the primary terrains are in the form of a vast anticlinorium in the middle of successions are constituted of quartzites identical to those of the Cambrian Hassi Messaoud formations. The Ordovician is composed of quartzites and mudstone-quartzite alternations, the Silurian is made of shaley sands and the Devonian is principally argillaceous. The Ordovician, Silurian and Devonian form concentric rings

around a Cambrian core. In contrast, the Carboniferous, clastic at the base and carbonated at the top, is only present in the northwest (Bordj Nili) and transgresses the underlying series [8, 9].

3. METHODOLOGY OF THE FACIES ANALYSIS

We analyzed a set of available well log data, primarily principal conventional well logs, namely bulk density (R_{hob}), neutron porosity (Nphi), sonic porosity (DT), and resistivity (R_t). The use of photoelectric effect (Pef) and spectral Gamma (U, Th, and K) tools makes it possible to specify the nature of the Lithology. The facies analysis [10-13] can be carried out in two stages. The first stage consists of establishing a lithological column starting from one or more reference wells where all the facies are present [14]. The second stage consists of the use of suitable software for computer processing. In the case of this study, the objective is to specify the nature of the depositional environments [15] as well as the spatial extent of the sandy bodies. The facies analysis, carried out from basic conventional tools, namely R_{hob}, Nphi, DT, total radioactivity (GR), and Pef, can integrate several facies of an electrobed [16, 17], because of their weak vertical resolution (30 to 50 cm).

The stages of this analysis can be summarized in the following way,

- 1) Reading of the raw values and controlling the recordings, taking into account:
 - a) Control reliability of the tools used in the recordings,
 - b) Control effects due to the environment (effect of washout, bad borehole condition, etc.),
 - c) Flushing fluid used, standard of mud (effect of barite, etc.),
 - d) Checking and in-depth retiming of the curves.
- 2) Choice of the date of interpretation, taking into account:
 - a) Taking cores in homogeneous beds of electrofacies, according to the well log responses,
 - b) The choice of beds showing the same well log characteristics,
 - c) Reading the raw values and establishing cross-plots, which reflect the true matrix.
- 3) Facies analysis study:
 - a) Recognition of lithology starting from the neutron-density and sonic-density cross plots [18, 19].
 - b) In the case of the manual analysis, the spacing of these well log curves being taken into account for a better delineation of the lithology.

The interpretation of the density (R_{hob})-neutron porosity (Nphi) cross plot used the limestone scale where 0% porosity corresponds to a density of 2.70 g/cc with the density increasing toward the right and porosity increasing toward the left [20]. The combination of the density, neutron porosity and the photoelectric effect curves, in addition to the gamma ray, sonic, and resistivity curves, makes it possible to identify the Lithology [21]. The interpretation of spacing between the two curves led us to introduce the concept of polarity of Electrofacies [22], where one can distinguish the following possibilities:

(i) Electrofacies have a positive polarity, where the R_{hob} curve is on the right of the Nphi curve, which can indicate the presence of clay, anhydrite or dolomite. The lithology is

then distinguished by the Rhob, Nphi, DT and GR (API) values;

(ii) Electrofacies have a negative polarity, where the Rhob curve is to the left of the Nphi curve, characterizing a sandy facies, and the presence of gas, or halite;

(iii) Electrofacies have a neutral polarity, where the Rhob and Nphi curves are superimposed, corresponding to limestone or a mixture between electrofacies with positive and negative polarity.

Differentiation is then done by the analysis of other well log data (e.g. GR, DT, and Pef).

Detection of the presence of gas was done through the examination of the various visible deviations on the established cross-plots, which can be one of three types [20-22]:

- (i) Standard effect 3: the neutron tools, sonic and density tools are simultaneously affected,
 - (ii) standard effect 2: only porosity neutron and the density tools are affected,
 - (iii) Standard effect 1: only the porosity neutron, density or sonic, is affected.
- 4) Study by analysis of the depositional environments and the sedimentary systems:
 - a) Selection of the types of electrosequences in each well,
 - b) Recognition and study of the nature of the electrosequence types according to the well log responses (positive or negative sequence, rhythmicity and amplitude).
 - c) Definition of a sedimentary system characteristic of a type of sediment genesis; fluvial, coastal, etc.
 - d) Control of information: careful reading of the log headers regarding drilling and well conditions
 1. Checking the tool calibration using the Schlumberger charts.
 2. Checking the reliability of the logs by comparison of the repeated section (repeat section) and the principal section (main log).

Exclusion of significant washout zones: If the tools' pads are not firmly in contact with the wall of the hole, the tool will record the characteristics of the drilling mud and not those of the formation. The recordings are also inaccurate for tools with pads offset in the case of a deep washout with limited vertical extent. The caliper indicates the possible presence of washouts. However the undermined zones within a formation can have a particular lithological significance (e.g. the presence of uncompacted clays, friable sands, etc.).

- 5) Checking for the influence of mud on the various tools:

The presence, for example, of barite in mud returns unusable information on the Pef log: the Pef of barite being 260 B/E, the response of other minerals will be masked. Moreover, as it is the case in many studied surveys, the presence of KCl in mud disturbs the response of the instruments measuring the total natural radioactivity (GR* or NGS*).

- 6) Checking the depth correlation of the various recordings:

The elasticity of the cable, frictions due to the roughness of the hole, etc., can cause the curves to shift (relative to each other), and it is then advisable to readjust them in depth.
- 7) Control of the recording speed:

For the lithological tools, a speed lower than 10m/minute is usually recommended; for a sampling interval of 3cm; the resolution is then 20cm.

This speed is shown on the recordings by ticks, where each tick accounts for one minute that appears in the right and left edges of the document.

Fig. (3) shows an example of well log processing [23] carried out on a Hassi R'Mel well show the facies contacts obtained after this process.

4. FACIES ANALYSIS

Within the Hassi R'Mel Field, alternations of fine- to coarse-grained continental terrigenous facies with some interbedded dolomites were observed (Fig. 2). Ten main facies are described: four shale facies, six sandy facies and three dolomite facies (Table 1). The facies survey provides insight into depositional processes on the basis of the sedimentary structures [24, 25] and can be interpreted in terms of hydrodynamic regimes [26, 27]. The physical parameters of sandy facies are described in Table 1 and the facies codes are modified from [28-30].

In the Southern Hassi R'Mel, the Triassic rocks are characterized by alluvial fan deposits and contain dolomitic paleosols which are particularly well-developed at the top. The more proximal facies association is characterized by channel facies and debris-flow deposits. The more proximal, continental environment of the sands is characterized by mixed debris-flow and mainly stream-flood deposits, paleosols, and less developed floodplains [30]. The stream-flood deposits are characterized by sandy and gravelly bed-load-dominated deposits and could be attributed to braided channels. The lacustrine deposits observed within the Triassic section suggest a shallow lacustrine environment. The bioturbated mudstones attributed to lacustrine deposits are less than 10 m thick and contain evidence of a period of emergence with a paleosol formation [30].

The study of the facies obtained from core analysis, carried out on the level of the Triassic formations of Southern Hassi R' Mel, required the core analysis available at the laboratory of Sonatrach (Algiers), and combination of the differed well log data: the Gamma Ray, the Neutron and the sonic log, their fittings in sequences and their vertical and side evolutions. The study of the sedimentary figures observed in the sediments, representing the hydrodynamic and physical conditions of the medium of sedimentation was also taken into account. The facies met (Photo-2 of board 1) have well Hrs-9, (Fig. 2) Interval: 2282 to 2286m), show:

- a) Clean sandstones and argillaceous sandstones at the base;
- b) An argillaceous matrix on the level of the sandstones, the base of the sequences; A small percentage of cement in the sandstones and absence of thorough quartzification;

Table 1. Characterizations of Well Logs from the Various Facies of the Southern Hassi R' Mel Triassic Formations

	Rhob-Phin (Variation)	< Rhob < (g/cc)	< Phin < (%)	< DT < (μ s/ft)	< GR < (API)	Lithology Coloured
Halite	high	2.04 - 2.24	-0.01 - 0.10	68 - 75	0.0 - 13	Blue
Shale halite	low	2.10 - 2.35	0.01 - 0.25	79 - 86	10 - 53	Magenta
Sand	high	2.11-2.60	-0.04 - 0.26	59 - 108	10 - 102	Yellow
Low sand shale	without	2.33-2.58	0.13 - 0.23	66 - 99	30 - 64	Blue sky
Shaley sand	without	2.38-2.66	0.13 - 0.15	61 - 105	44 - 139	Light green
Shaley dolomite	high	2.40-2.79	0.22 - 0.36	68 - 105	42 - 134	orange
Sandy shaley dolomite	low	2.54 - 2.79	0.08 - 0.28	55 - 80	45 - 114	Purple
Slightly sandy shaley dolomite	low	2.58 - 2.79	0.12 - 0.19	59 - 74	35 - 114	Garnet
Sandy shale	high	2.38-2.67	0.19 - 0.34	77 - 108	90 - 171	Dark green
Andesites	high	2.44 - 2.67	0.20 - 0.36	68 - 94	45 - 65	red

- c) Importance of the sandstones compared to clays in the series T1 - T2. The fluvial series is characterized primarily by the volume of sand they contain and the natural resources which are associated (water, oil, coal and loggings mineral. Photograph - 2).
- d) Red clays (Photo-1 of the Hrs-2 well, interval: 2263.5 with 2259.6m), in centimetric layers with decimetric to metric at the top of the sequences; this aspect corresponds to a quite medium, on the flood plain. Joints argillaceous, centimetric, brown red, probably corresponding to periods of decantation during stops of currents; brown red clays silto-sand spreaders in decimetre benches on metric, pseudo-brecciated texture, abundant in also at the end of the sequences, thus marking periodize draining. Photo -1.
- e) Salt (saliferous) is presented in massive benches, of pink colour, with inter beds of clay grey black, sometimes dolomitic; characterizing an evaporitic sedimentation, lagunaire, under hot and even arid climate; Clays with anhydrite, grey black with dark or green grey dark, injected anhydrite, characterizing a sedimentation in edge of the evaporitic salted lagoon, where the water section is almost permanent, but under influence of silico clastic ends coming from the exondes grounds with flat relief. Photo - 3. Hrs-9.

5. APPLICATION OF MANUAL FACIES ANALYSIS FOR THE HASSI R'MEL ROCKS

The lithology is determined through the use of specific diagrams that compare the behavior of the electrobeds against the standard mineralogical poles by using an iteration process between different lithological diagrams, such as:

- a) The detection of heterogeneous formations (brecciated, cracked, vesicular zones, etc.), for example, the analysis of sonic-density and neutron-sonic cross plots in which the sound transit time is the shortest, a phenomenon develops to the right of the zones;
- b) The detection of the presence of gas through the examination of the various visible deviations on the established cross-plots [31]: (i) standard effect 3: the

neutron tools, sonic and density tools are simultaneously affected, (ii) standard effect 2: only porosity neutron and the density tools are affected. (iii) Standard effect 1: only the porosity neutron, density or sonic, is affected.

- c) The availability of high-resolution tools allows the integration of textural and structural data through high-resolution logging data such as dip logging (SHDT), or imaging (FMS, UBI), allowing one to distinguish very small sedimentary structures.

The use of facies analysis, starting from the well log data for the Triassic rocks of the Hassi R'Mel, was first done by hand after the examination of the representative electrobeds; iteration between the lithologic diagrams (Rhob vs Nphi, Rhob vs DT, Fig. 4) made it possible to define the principal lithology and also to recognize the lithology. Lithology fluctuate between the end points: sandstone, clay and dolomites, and, in certain cases, dolerites. Calculating the lithologic columns (using the Petrolog software) allowed for an analysis of the available data and thus made it possible to generalize the model of all of the wells in the study area. The results obtained are compared with those from the core analysis. The initial manual analysis of the Southern Hassi R'Mel Hrs-2, 4, 6, 8, 9, 10, 11, 12 and 162 wells showed the existence of the following facies:

A. The sandstone-like facies:

All of the **sandstone-like facies** have an elevated radioactivity, greater than 10 API. The sands are characterized by electrofacies with negative polarity (Rhob curve to the left of the Nphi curve) and by points located to the right of the sands in the neutron-density and sonic-density cross-plots (Fig. 4). They can have considerable amounts of potassic feldspars; thus, the GR increases appreciably. In the case of very porous facies and aquifers, the resistivity of the sandstones is weak to very weak. The **slightly shaley sands** have a slightly negative or slightly positive polarity. They are deviated to the right of the sandstones (or the quartz pole in the direction to the right of shale (Fig. 4, Table 1). They are represented by a clear green color. The **shaley sandstones**, with positive polarity and average spacing of the Rhob-

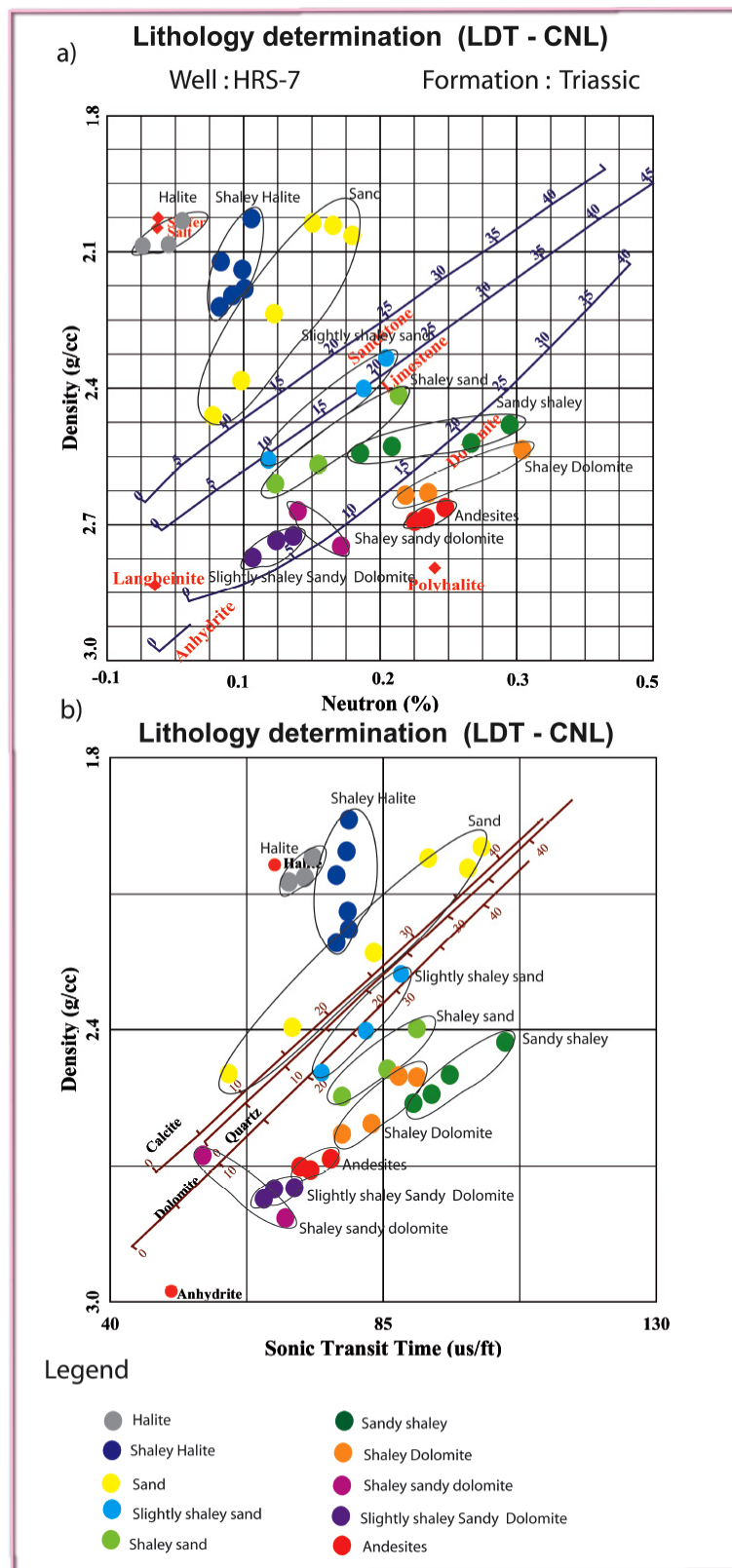


Fig. (4). Lithology determination from cross plots LDT/CNL and LDT/BHC. HRS-7.

Nphi curves, are characterized by a higher radioactivity than the sandstones and are deviated toward a clay pole close to the theoretical Illite pole (Fig. 4, Table 1). They are represented by a sky blue color.

B. Dolomitic facies:
Shaley dolomites, with average to elevated radioactivity are represented by electrofacies with positive polarity with widely spaced Rhob-Nphi curves. Their points are deviated toward the clay pole

(Fig. 4, Table 1). **Shaley sandy dolomites**, with positive polarity, cluster to the right of the sandstone line and radioactivity is uncommonly high: up to 150 (API).

C. Slightly shaley sandy dolomites:

These are present in the Hrs-12 well, have weak to average radioactivity and are represented by electrofacies with positive polarity with a wide spacing of the Rhob-Nphi curves. Their values are slightly deviated toward the clay pole on the ND and SD cross-plots and they are brown in color (Fig. 4, Table 1).

D. Shale facies:

They are characterized by high radioactivities (greater than 110 API), electrofacies with positive polarity, and a wide spacing of the Rhob-Nphi curves.

E. Sandy or dolomitic clays:

These are characterized by values deviated from the clay pole toward the sandstone or dolomite pole (Fig. 4, Table 1), represented by a dark green color.

F. Andesites:

They are characterized by radioactivities which vary from 54 to 105 API and a positive polarity with a wide spacing of the Rhob and Nphi curves. Their values are deviated toward the clay pole (Fig. 4, Table 1), and they are represented by a red color. However, to distinguish them from shaley dolomites, a shale cutoff was added.

G. Evaporite facies:

The higher formation corresponds to the evaporites and is primarily made up of halite to clays. This facies exhibits a natural radioactivity that is from 0 to 13 API, a neutron porosity that varies from - 1 to 0%, a density that varies from 2.04 to 2.14 g, a wide negative spacing of the neutron and density curves, and resistivity values from low to high. The gamma ray curve is not very strong because of the gamma ray tool spacing, which is higher than the thickness of the thin layers of clay (Fig. 4, Table 1).

The results of the manual study made on the basis of the cross-plots made it possible to obtain a manual log for well Hrs-7 of the Southern Hassi R'Mel (Fig. 3).

The paleosols correspond to the evolution of the basins, marked by events that close the sequences on different levels [8]. The electrofacies of the Triassic formations correspond to deposition events having specific logging characteristics.

6. AUTOMATIC FACIES

After having established the manual facies analysis and having checked its reliability by comparison with both the lithological well log data of the wells and the drilling, we used the PETROLOG program [23] to process the well log data, using these 4 entry parameters: radioactivity, total density, the transit time, and neutron porosity.

The facies interpretation made by the PETROLOG software, applied especially in the case of complex lithology, initially consists of defining the groups of dots representing each clean facies. Each of these groups represents the 10 litho-types described in this study (Table 2). Each group is identified by a standard color and is stored in the memory (e.g. as "Facies 1", "Facies 2", etc.).

After these data have been processed, the software provides the results in lithological terms for all of the formations crossed by the survey in accordance with the response of the well log tools given to the entry (Table 3). An example of the outputs for Hrs-7 is given in Fig. (5).

7. ELECTROFACIES AND ENVIRONMENT DEPOSITS

The various sedimentary features are well described [7] and are quite varied: mottling, shrinkage cracks, root traces, polyhedral structures (slickolites) and the ferruginous cementation of Liesegang rings. In the Saharan Triassic section, the context is very different; one finds the same features but some are different: silcrete, gypcrete, calccrete.

Table 2. List of the 10 Lithological Classes with the Porosity Variations and Clay Content

N°	LITHOLOGY	N°	LITHOLOGY
1	Halite	1	Halite
2	Shale halite	2	Halite + shale
3	Sandy shale	3	Sand shale < 40 % of sand
4	Shaley dolomite	4	Shaley dolomite < 40 % of dolomite
5	Sandy shale dolomite	5	Sandy shale dolomite Shale > 40 % et < 60 % of shale
6	Low sandy shale dolomite	6	Low sandy shale dolomite
7	Sand	7	Sand < 10 % Nphi > 10 % Nphi
8	Shaley sand	8	Shaley sand < 40 % of shale
9	Low sandy shale	9	Low sandy shale < 40 % of shale
10	Andesites	10	Andesites > 40 % of shale

Table 3. Well Log Input Parameters of the Petrolog Software

Generate LITHO column - HRS-7.LIC										
Primary Log				Conditional Logs						LITHO
Name	Lgcl	Min	Max	DT	4	Rhob	5	NPhi	6	
				Min	Max	Min	Max	Min	Max	
GR	2	0.00	13.00	68.00	75.00	2.04	2.14	- .01	0.10	
GR	2	10.00	102.00	59.00	108.00	2.11	2.60	- .04	0.26	
GR	2	30.00	64.00	69.00	99.00	2.33	2.58	0.13	0.23	
GR	2	44.00	139.00	61.00	105.00	2.38	2.66	0.13	0.15	
GR	2	42.00	134.00	68.00	105.00	2.40	2.79	0.22	0.36	
GR	2	45.00	114.00	55.00	80.00	2.54	2.74	0.08	0.28	
GR	2	35.00	114.00	59.00	74.00	2.58	2.79	0.12	0.19	
GR	2	90.00	171.00	77.00	108.00	2.38	2.67	0.19	0.34	
GR	2	45.00	65.00	68.00	94.00	2.44	2.67	0.20	0.36	

Litho Column

Pip Column

Zone 1 Start depth = 1975.000
 Zone 1 End depth = 2195.000
 Current Zone = 1 Total Zones = 1

<input type="button" value="Proceed"/>	<input type="button" value="Cancel"/>	<input type="button" value="Unit = M"/>	<input type="button" value="Help"/>
<input type="button" value="Goto zone"/>	<input type="button" value="Add / del / mod / zn"/>	<input type="button" value="Save master"/>	<input type="button" value="get Master"/>

In the literature [15], the proposed models are very diverse for the Hassi R'Mel, and one can recognize several models of sequences [2] of various scales which are of the second, third, and fourth order. The models suggested are very diverse, but are defined only by the gamma ray curve. The models of recognized formations for the wells of Southern Hassi R'Mel are primarily formations with siliciclastic fill, formations with volcanic sediment filling and formations with evaporitic shale filling representing sebkhah deposition.

The top of the sequences is represented by unconformities, which are modifications related to the pedogenesis and which are not characterized in the old models.

In this work, we characterized these pedogenetic features by their well log responses, namely: GR, Nphi, DT, sonic

signal, overall density, Rhob and resistivity, to make a comparative analysis of these results on the scale of all the features encountered in the wells not studied. This will make it possible to find these features starting from their well-log signature with an aim of better analysis of cores in the Triassic formations of Hassi R'Mel.

7.1. Well Log Responses of the Paleosols of the Fourth Order, at the Top of Formation I (Hrs-7)

The analysis of the unconformities of the second order in member I.B of formation I at well HRS-7 is represented by small paleosols with mottling, dessications and a small dolomite levels. Formation I is capped by a clay crust (argillan) complex [8].

The analysis of the well log responses obtained from the paleosols of the Hrs-7 well, at the top of formation I, made

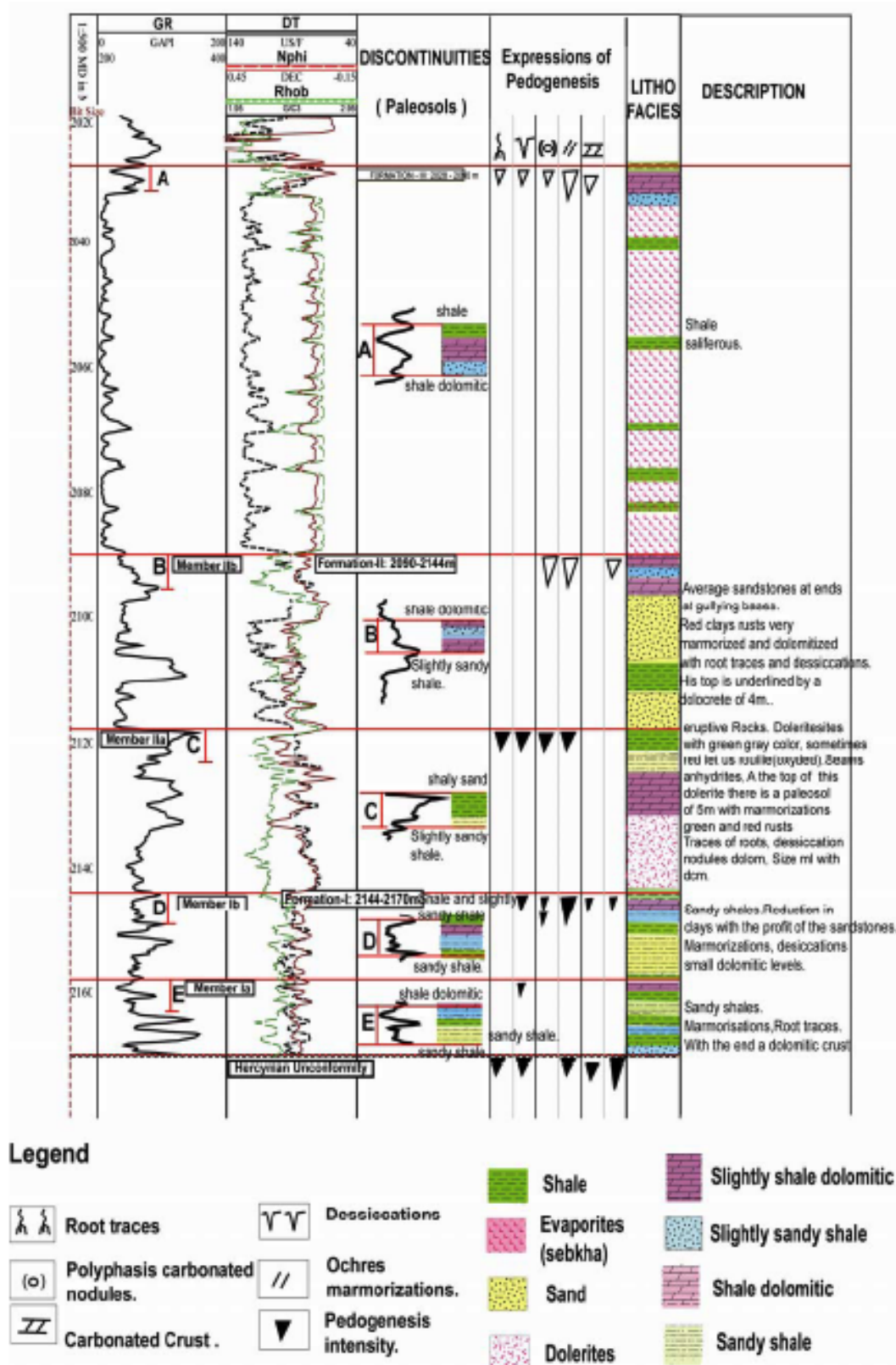


Fig. (5). Application of automatic data processing on the HR'mel wells using Petrolog Example from HRS 7 well;

starting from the unconformity (Fig. 6a, Hrs-7), shows an evolution from sandy facies at the base (evidenced at the unconformity by Aeolian sand) upward to an clayey dolomite (evidenced by pedogenetic nodules). The facies

analysis also shows a vertical evolution of facies from the base, represented by a slightly shaley sandstone facies (Fig. 6a, Hrs-7) to a shaley dolomite facies at the top, capped by clay with a radioactivity of about 96 API.

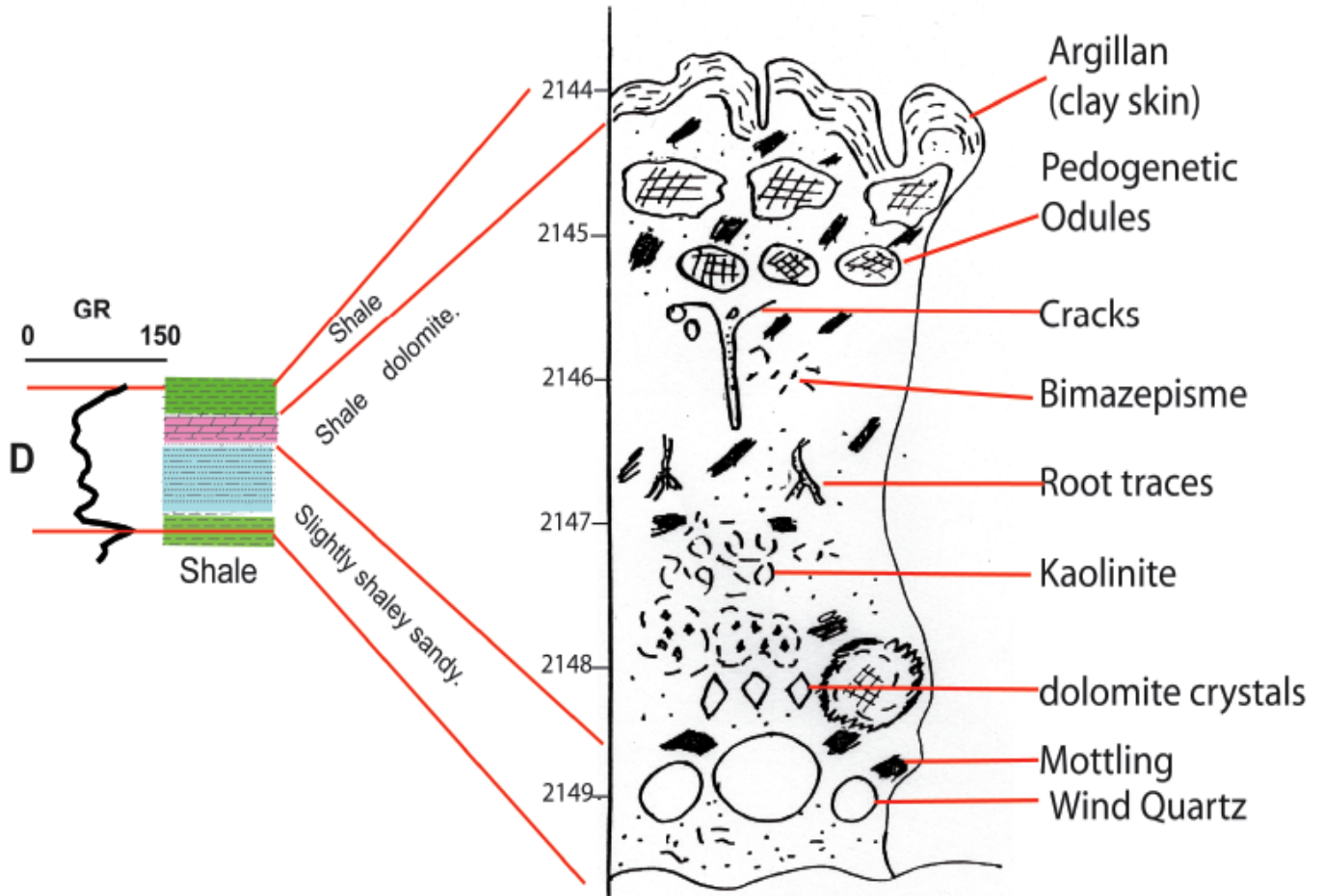


Figure 6a. Well log responses of paleosol (dolocrete)

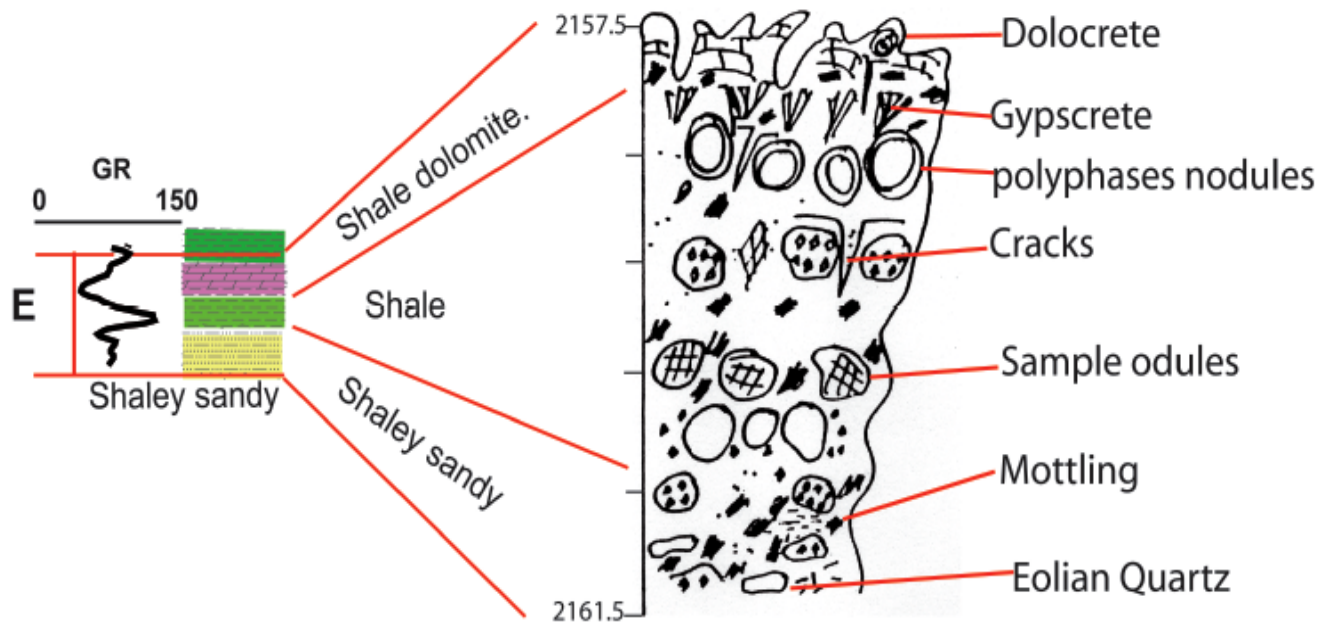


Figure 6b. Well log responses of paleosol (gypscrete).

Fig. (6). (a) Well log responses of the dolocrete paleosols; (b) Well log responses gypscrete paleosols.

7.2. Well Log Responses of the Third Order, at the Top of the Second Member of Formation I-(Hrs-7)

The analysis of the unconformities of the fourth order [8], (Fig. 6b) at the top of Triassic formation I from the HRS-7 well, shows that the first expressions of the pedogenesis are in the clays, with the presence of newly formed kaolinite, a bimazépism corresponding to the reorientation of clay minerals, a red rust mottling, root traces and desiccation. The evolution continues by giving rise to small dolomite crystals which structure into simple pedogenetic nodules to become polyphased coalescent nodules (Fig. 6b), topped by a small gypseus incrustation (gypcrete), upon which a dolcrete layer marks the end of the first sequence of the third order.

The analysis of the well log responses obtained from the paleosols of the Hrs-7 well, (Fig. 6b, Hrs-7) at the top of the second member of formation I, also shows an evolution of facies starting at the base with Aeolian sand, recognized by analysis of thin sections, at the third order discontinuity at the top of the second member and evolving to dolomite facies (dolcrete). Gypcrete occurs just below the dolcrete. The lithological results obtained from the facies analysis also show a vertical evolution of facies, with the base represented by Aeolian sand and grading upward to a shaley dolomite facies at the top with a radioactivity of 70 API (Fig. 6).

The well log responses recorded at the base of this unconformity have a radioactivity GR(API) level of 56 API, a neutron porosity of $\Phi_N = 18\%$, a transit time for the sonic signal $\Delta_t = 85$ ($\mu\text{s}/\text{ft}$), an overall density $\rho_b = 2.44$ (g/cc) and a resistivity $R_t = 2.60$ Ωmm . At the top of this unconformity, the readings recorded are: GR(API) = 69(API), $\Phi_N = 19.5\%$, $\Delta_t = 84.5$ ($\mu\text{s}/\text{ft}$) and $\rho_b = 2.48$ (g/cc) and a resistivity $R_t = 2.25$ Ωmm .

The well log responses of the paleosols to the roof of the formations of the Hrs-9 (Fig. 7) well can be summarized as follows:

Formation III: $24 < \text{GR} < 75$; $9 < R_t < 160$; $2.50 < R_{\text{hob}} < 2.75$; $0.30 < \text{Phin} < 0.08$; $57 < \text{Dt} < 93$.

Formation II: $33 < \text{GR} < 95$; $0.14 < \text{Phin} < 0.33$; $2.33 < R_{\text{hob}} < 2.60$; $70 < \text{DT} < 87$.

Formation I: $40 < \text{GR} < 80$; $4 < R_t < 13$; $2.57 < R_{\text{hob}} < 2.46$; $0.16 < \text{Phin} < 0.20$; $75 < \text{Dt} < 86$.

Finally, changes of facies and thicknesses affect these levels layers characterized by variabilities, in petrophysical terms that are more or less significant. To this end, in future, the prospect researches must be centered mainly with the Formations II which prove to be sandy or shaly sandy.

8. CROSS SECTIONS OF THE HASSI R'MEL WELLS

With an aim of establishing a study of the lateral facies variations in the Hassi R'Mel field, starting from the south toward the north and from the east to the west, three cross sections were generated starting from the well-log data coupled with core descriptions for some of the available wells. The temporal calibrations of the stratigraphic units were carried out starting from published palynologic data and the results of cores analyses provided by Nedjari and Ait Ouali [5]. This allowed correlations on a field scale at Hassi

R'Mel. The database used includes the analysis of reports from Sonatrach and the development and research center as well as results obtained by students from the USTHB and FTSGAT in Bab Ezzouar. In addition, the database included work by [23, 4], publications by Nedjari and Ait Ouali in the Triassic province in Algeria, and the results from work in the Zarzâitine area [11].

The analysis of the facies and electrofacies as well as the vertical evolution of the stratigraphic units and the analysis of their vertical arrangement made it possible to establish the lateral variation of the facies. The erosion of stratigraphic units and the lithostratigraphic models established, starting from the well log data and the results of available thin sections show that periods of fluvial, playas and sebkha sedimentation during the Triassic were intermingled with periods of non-deposition. This allowed the development of a more or less intense pedogenesis and formed unconformities of varying importance, and which will be used for a scaled sequential cutting erosion principle [24]. The lithographic sequences correspond to environmental sequences and members or formations of the third, fourth and fifth order. Therefore, to build the geometry of the deposit systems of the Hassi R'Mel field, three cross sections were established: NW-SE (Transect II-II), NE-SW (Transect III-III) and NE-SE (Transect V-V). To establish the cross section correlations, common data were chosen for the entire site. We used the paleosols encountered at the tops of formations I, II and III, as is customary in this region.

Transect: II-II: Extension of the reservoirs in members II.a and II.b are characterized by a thinning in the second order sequence of the well Hr-52 (NW) toward the Hr-23 well, passing through the Hr-55 well (NE). Conversely, the units thicken from the Hr-30 well to the Hr-10 well (Fig. 8). The electrofacies association of Formation I and II are characteristic of lag deposits and channels. The facies within these channel environments cannot be distinguished using classical well-logs. The distinction between stream flood and subaqueous channels is also difficult with only classical well-log informations; only their association with floodplain or lacustrine deposits will allow an interpretation. Floodplain and lacustrine deposits are characterized by the electrofacies of Formation I or II (Figs. 8-10). Lacustrine environments differ from floodplain environments in having more positive polarity electrofacies and smoother curves. The sebkha deposits are characterized by the electrofacies of Formation III.

Transect: III-III: Reservoirs of the second order sequences thin from the Hr-81 well (NW), to the well Hr-23 and thicken from this well to the well Hr-52 (SW). A horst can be seen in Hrs-12, Hrs-2 and Hr-52 (Fig. 9). The electrofacies association of Formation I and II are characteristic of lacustrine deposits, fluvial deposits and channels, the sebkha deposits can be recognized by the electrofacies of Formation III.

Transect: V-V: An apparent horst is seen in wells Hr-10, Hrs-6 and Hrs-4 and a graben in wells Hrs-4, Hrs-7 and Hrs-11 (Fig. 10). The thickness of the members II.a and II.b increases in the horst and decreases in the graben. These electrofacies have been defined and validated from a study of core and well-logs based on these wells.

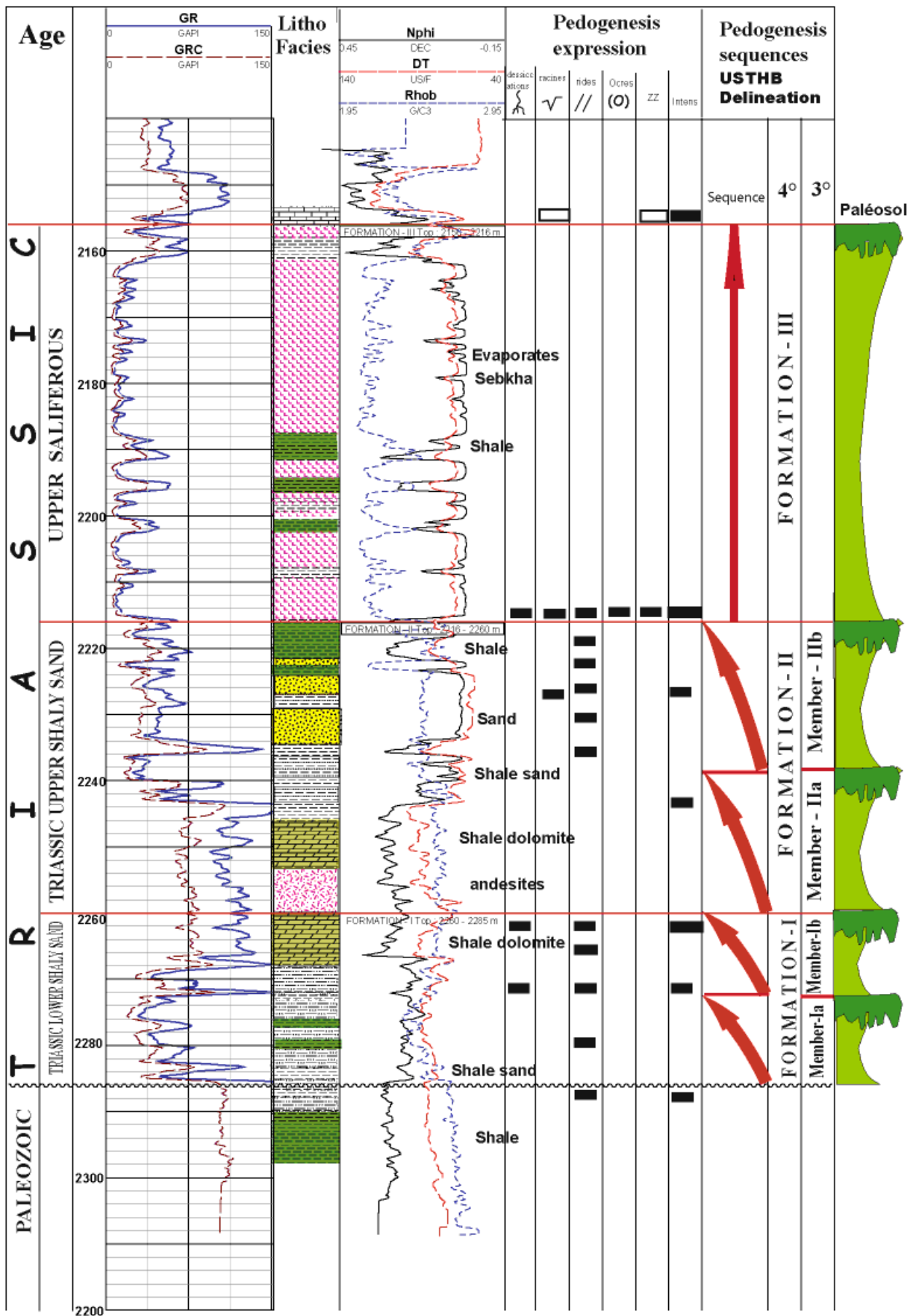


Fig. (7). Models of second, third, fourth sequences order and facies of Well Hrs-9.

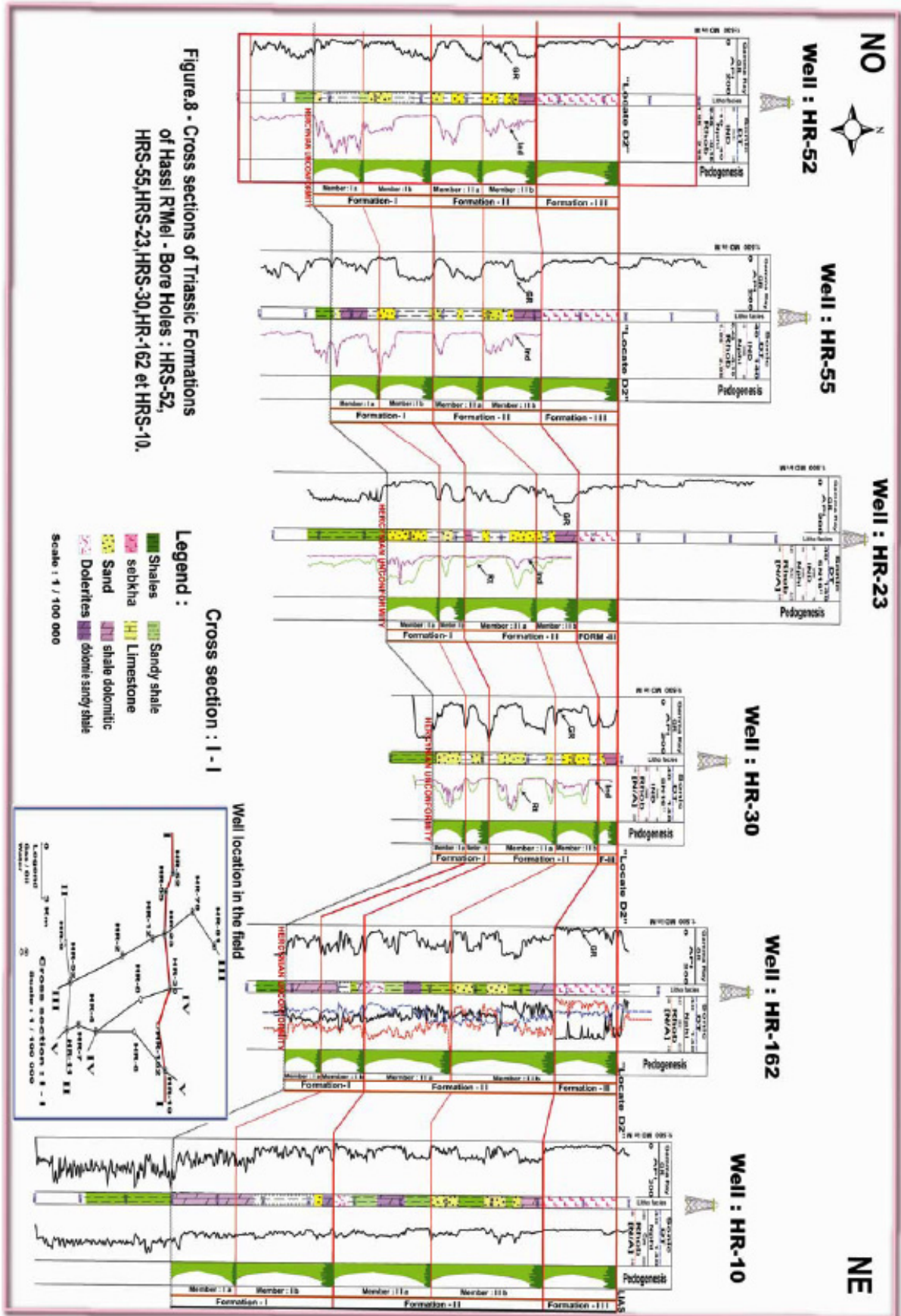


Fig. (8). Transect: I - I (NO-NE: cross section of the wells HR-52, 55, 23, 30, 162, 10;

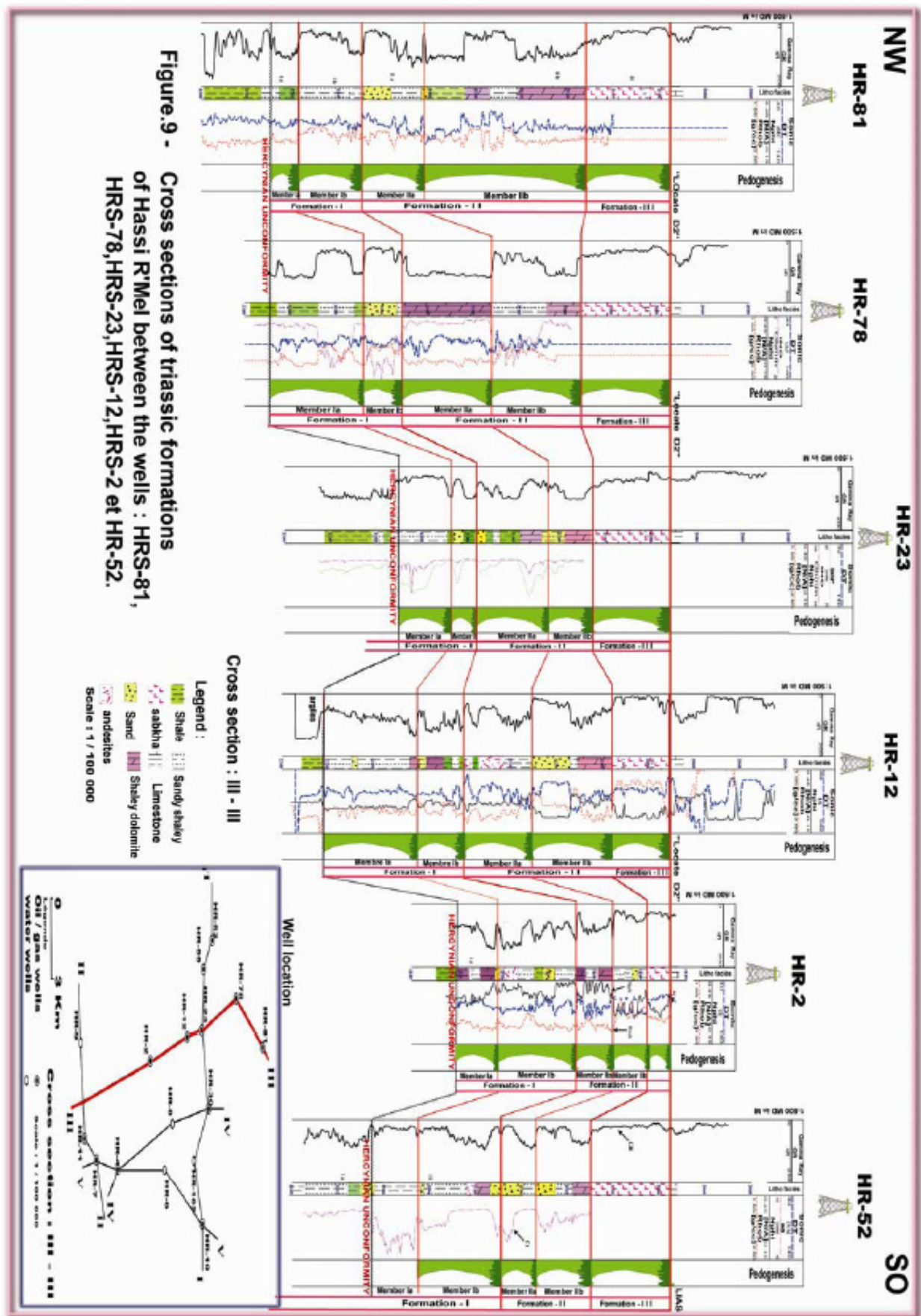


Fig. (9). Transect: III -III (NO-SO): cross section of the wells HR-81, 78, 23, 12, 2, 52.

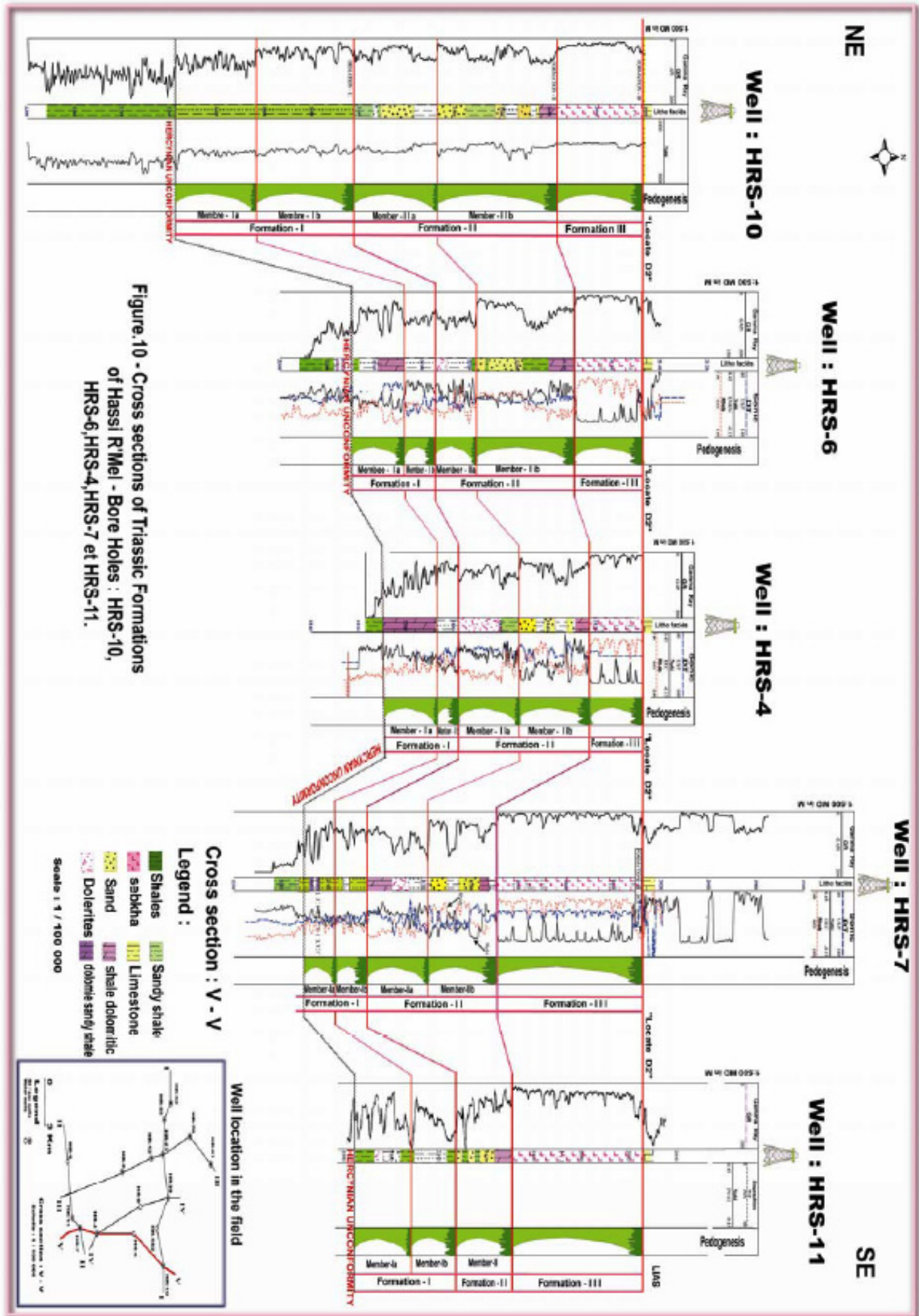


Fig. (10). Transect: V - V (NE-SE): cross section of the wells HR-10, 6, 4, 7, 11.

Paleosols can be easily recognized from well-logs (Figs. 8-10) at the top of Formations.

All these electrofacies can be recognized if the thickness of the facies associated is larger than the vertical resolution of the well-logs (30 to 50 cm for classical logs).

9. DISCUSSION AND CONCLUSIONS

The manual and computerized facies analysis of southern, northwestern and northern Hassi R'Mel data from the Triassic Algerian Province reveals the various facies present in the studied zone.

The computed results made it possible to create a reliable lithological model on all of the studied surveys. The comparison between the results obtained and the core analysis (the Hassi R'Mel sandstones were cored in only a very few wells) showed a similarity between the various rock types identified in the well logs and recognized in the core analysis. This method has the following advantages over the traditional approaches. First, the recognizer method effectively identifies lithofacies using well-log data. Lithofacies may be identified automatically and objectively using this process. Second, the system may be more accurate than the faciologic analysis approach where geological variation is complex, and the expert knowledge of geologists is needed to be utilized.

Currently, the model is being used on new wells with the aim of testing its possible extension to a wider field in order to integrate the new lithology that appear into the model (e.g. evaporites, dolomitic sandstone) in the east of the Triassic province. The goal will be to quantitatively define all of the existing rock types in the Triassic Algerian Province.

The facies analysis by well-log analysis helped to distinguish three formations from the Hassi R'Mel Triassic, each one characterized by a unique lithological suite. The first, formation I, is primarily shaley and the second consists of sandy facies alternating with shaley facies (sandy and/or dolomitic) or with sandy shale facies. It is important to note alternations of sandy beds with shaley or dolomitic beds within formations I and II. The dolomite facies have very heterogeneous resistivity curves. The evaporites are generally localized in the top of certain wells located in the south (comprising several tens of meters in thickness) and are absent in certain wells. The shaley facies are generally represented by dolomites and sandy clays. In conclusion, facies analyses can be effective only if an abundance of data is available for study. The manual faciologic analysis makes it possible to define the first elements of studies in order to approach the quantitative facies analysis. Thus, this facies analysis carried out with a maximum of well log records helped to obtain results with a very high degree of accuracy. However, the latter could have been improved if the spacing of the neutron curves and density had been considered in the well log conditions of the parameters (which is a limitation of the software): the software can take into account only five parameters:

Natural total radioactivity Gamma Ray (GR), neutron porosity (Nphi) density (Rhob), transit time of the sonic signal in the rock (DT), and spacing of the neutrons and density curves. Thus, faciologic analysis can be effective only if a variety of data as large as possible exists.

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