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Theme:

Sedimentological and Petrophysical Study of the lower Triassic Series of Boukhellala Deposits, Oued Mya Basin

By :

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Dedications

With all my love and gratitude, I dedicate this memoir to those who have been my support and my support :

To my dear mother, source of tenderness, to my father, symbol of strength and inspiration, thank you for your unconditional support and your prayers.

To my dear brothers, thank you for your constant encouragement and kind words.

To my dear friends, the brothers that my mother did not give birth to, thank you for every moment of laughter and support.

Finally, to all those who have supported me from near or far, your help has been essential and has allowed me to achieve this accomplishment.

Thanks to you, and with you, this work has been made possible.

Thanks

I would like to express my deep gratitude to all those who have contributed to the realization of this work.

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Finally, thank you to everyone who has helped and supported me, from near or far. Your help has been decisive for this success.

From the bottom of my heart, thank you all.

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General Introduction

The Saharan Platform is located in southern Algeria and belongs to the North African Craton. It contains a Precambrian basement on which rests a strong unconformity of sedimentary cover, structured in the Paleozoic into several basins separated by high zones (Askri et al, 1995).

The Oued Mya basin belongs to the Central Province (Busson, 1970) and is particularly known for its enormous hydrocarbon potential in the Triassic reservoirs (Lower series , T1 & T2) (Ait Salem, 1992). Considered one of the richest basins in Algeria, it contains several oil and gas reservoirs in the Triassic sandstones, which are the main petroleum target.

Radioactive Silurian graptolite clays are the main basement rocks of the basin. When unaffected by Hercynian erosion, they average 50 m thick. This excellent source rock has been in the oil phase since the Upper Cretaceous. It reaches the gas phase in certain deeply buried areas to the northwest.

The Ordovician clays of El Gassi and Azzel may be secondary source rocks. (Sonatrach report, 2016).

The main reservoirs in the region are the Triassic fluvial sandstones, which include: the lower series at the base, capped by eruptive rocks, unit T1 with the two reservoir levels B and C, and unit T2, represented by reservoir level A.

Triassic (saline S4) regionally covers the Triassic reservoirs and Lias (S3 to S1 levels) evaporates.

Our work aims to characterize and explain these results on two aspects:

- Sedimentological aspect: In the case of the present work, the sedimentological study is divided into four different studies, as follows:
- Interpretation of well correlations and isopaque maps: This consists in analysing the lateral evolution of facies over time and discussing the different stages of sedimentary filling in the Upper Triassic.
- Petrophysical aspects: This involves studying the various petrophysical parameters (porosity, permeability), to better understand the effect of diagenesis on reservoir quality.
- Work objective: Explain the different results of wells drilled in Triassic reservoirs in the Hassi Boukhellala region, based on the results of the sedimentological and petrophysical study of the Upper Triassic clay-sandstone reservoir (T1 and T2 series) and part of the lower series.

- Methodology: This work is based mainly on a sedimentological study of the T1 and T2 levels, which form the Lower and Upper Triassic Clay-Gravel reservoirs, based on core descriptions.
- The approach adopted for this work is as follows:
  - Description of the lithofacies using core photos from the five wells: W1, W2, W3, W4, and W5 located in the Hassi Boukhellala region, Ghardaïa.
  - Description of the petrophysical characteristics (permeability and porosity) of the Triassic clay-sandstone of the Hassi Boukhellala field, using core photos and the various logs. In this context, and with the help of the study of the diagraphic logs, the core sampling data and their processing based on the data collected in the study area, we have made a physical assessment in several reservoirs located in the Oued Mya basin, Block 422a in the Ghardaïa II perimeter.

This study aims to apply geological knowledge from training at "university kasdi merbah ouargla" to analyze data from internship at SONATRACH Exploration Division. It will focus on the geological evolution of stalagmites, controlling factors, and defining petrophysical parameters like porosity and permeability to assess the oil potential of the Boukhellala reservoir.

In order to achieve the desired objective, three chapters were carried out:

Chapter I: General information about the study area.

Chapter II: Sedimentological study area

Chapter III: Analysis and interpretation of petrophysical parameters.

CHAPTERI:

General study of the Oued Mya region

CHAPTER I:
General study of the Oued Mya region

Introduction

The Saharan platform, of which our study region is a part, is located south of the Alpine Algeria and belongs to the North African Craton. It consists of a Precambrian basement overlain discordantly by a thick sedimentary cover, structured in the Paleozoic into several basins separated by high zones. In this context, from west to east, we can distinguish: (Fig. I. 1). **[1]**

- Tindouf and Reggane basins are located on the northern and northeastern edges of the Reguibat Shield. The sedimentary cover reaches 8000m in the Tindouf basin and 6500m in the Reggane basin. In this underexplored area, Paleozoic formations could potentially contain liquid and gaseous hydrocarbons. **[1]**
- Béchar basin is bounded to the north by the High Atlas, and to the south and west by the Ougarta range. Its sedimentary cover is estimated to reach 8000 m. The reservoirs are located in the lower Paleozoic detrital and Carboniferous reefs. **[1]**
- Ahnet-Timimoun basin is bordered to the north by the Oued Namous high ground, to the west by the Ougarta range, to the south by the Tuareg shield, and to the east by the Idjerane-M’zab ridge. The average thickness is around 4000 m. In the south, the Ordovician and lower Devonian reservoirs are gas-bearing. In the north, oil has been discovered throughout the Paleozoic in the Sbâa basin. **[1]**
- Mouydir and Aguemour-Oued M’ya basins are bordered to the west by the Idjerane-M’zab ridge and to the east by the Amguid-El Biod ridge. Paleozoic sediments are visible in Mouydir to the south. In the north, in the Aguemour-Oued M’ya depression, a thick Paleozoic and Mesozoic-Cenozoic series fills the area (5000m at Oued M’ya). Significant deposits have been identified in the Cambrian (Hassi Messaoud) and the Triassic (Hassi R’Mel). **[1]**
- The Illizi-Ghadamès syncline is bordered to the West by the Amguid-El Biod ridge and to the East by the Tihemboka massif and the Tunisian-Libyan border. In the Ghadamès basin, the sedimentary cover (over 6000 m thick) contains hydrocarbon deposits in the Paleozoic and Triassic. **[1]**

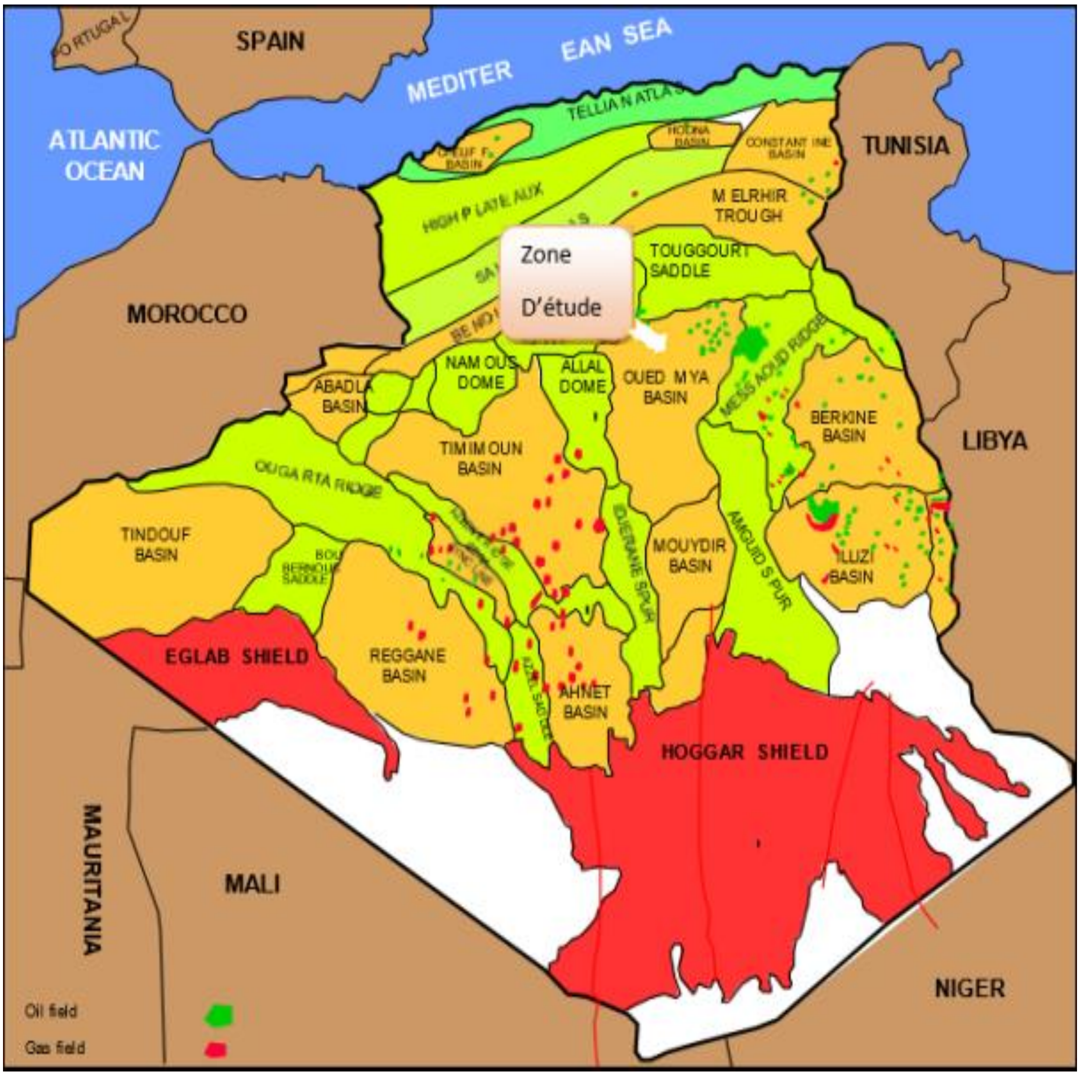


Figure. I.1 : Geographical location of the Oued Mya basin in Algeria (sonatrach document 2010)**[2]**

2. Presentation of the Oued Mya basin:

2.1. Geographical location of the Oued Mya basin

The Oued Mya bassin is a saharienne plate-form bassin that corresponds to the portion the western portion of the Triassic province is bordered to the north by the Talémazéne and Touggourt, eastward via the Hassi Messaoud field, northward via the Hassi field in the south, it opens up onto the Mouydir depression (Fig. I. 2). **[3]**

The geographical limits present themselves as the best landmarks:

The parallels 31°15' and 33°00' respectively limit to the South and North, and the meridians 6°15' and 3°30' limit to the East and West, encompassing blocks 438-425-422-437-436-178-420-419-418-417 and 416, belonging to district IV of Sonatrach. **[3]**

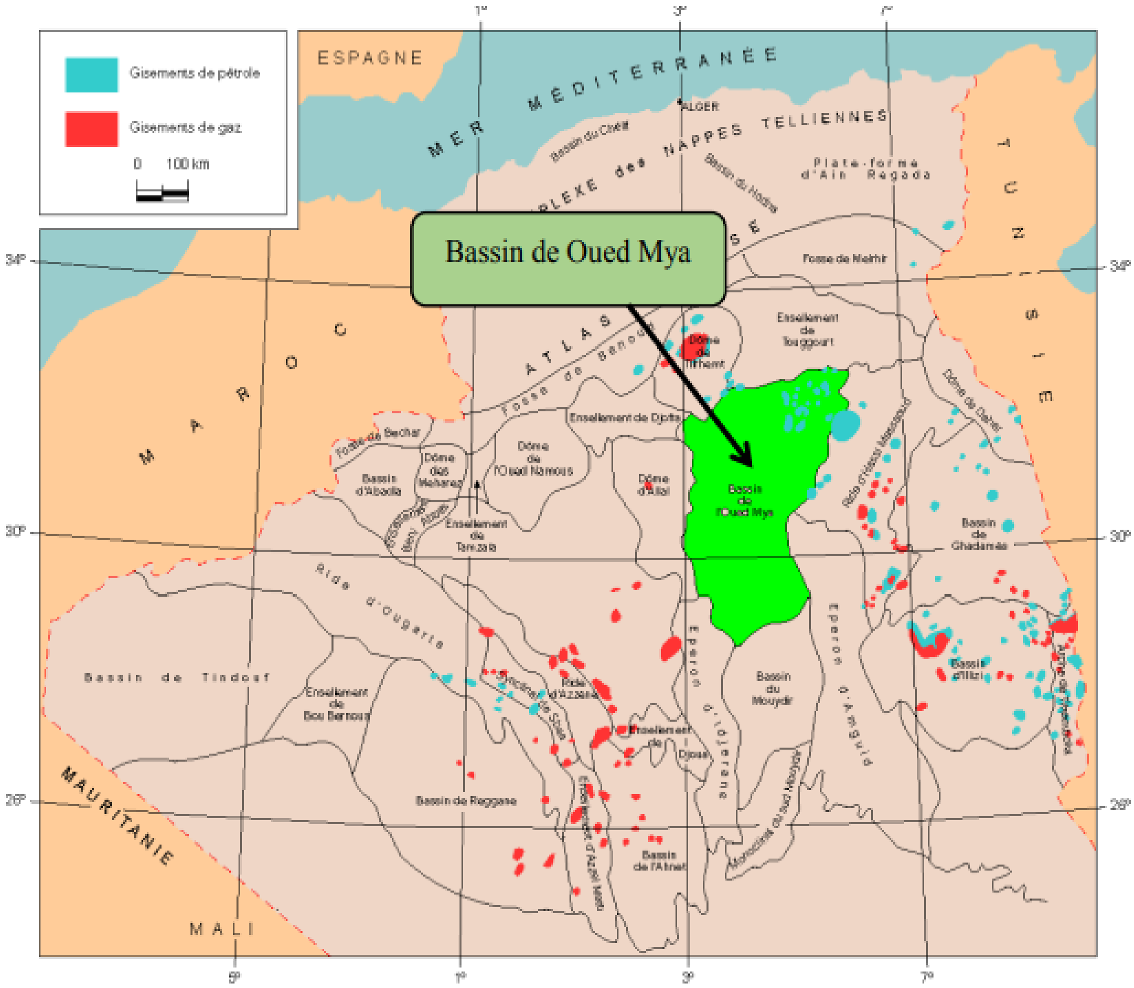


Figure. I.2: Geographical location of the Oued Mya basin in Algeria (SONATRACH.2010 document "modified") **[4]**

3-Presentation of the study area

3.1 Geographical location of the study area

The research site, Hassi Boukhellala, is positioned in the Oued Mya Basin, precisely within the Ghardaïa Perimeter and Block 422a. In terms of geography, it is situated at around 30 degrees 16 minutes north latitude and 0 degrees 18 minutes west longitude. **[5]**

3.2. Geological framework

3.2.1. Aspect structural:

The Hassi Boukhellala prospect is located in block 422a (Ghardaïa II exploration area) in the Oued Mya basin. In this part of the basin, the main structural elements have a NW-SE and NNE-SSW direction. [6]

The region is characterized by normal faults and asymmetric anticlines with low amplitudes. [6]

Within this area, the Paleozoic deposits, with a total thickness exceeding 600m, are represented by Cambrian, Ordovician, radioactive Silurian, and Devonian formations, which have been affected by Hercynian erosion. Overlying these deposits, with angular unconformity, are the Mesozoic formations (Triassic to Cretaceous) with a thickness ranging from approximately 2800m to 2950m. At the surface, Mio-Pliocene formations are exposed. [6]

3.2.2. Stratigraphic Aspect (Figure. I.3)

- **Cenozoic: It is represented by the Mio-Pliocene**
  - **Mio-Pliocene : 10 à 40 m**

brownish-yellow, fine, carbonated, well-consolidated sandstone transitions to white to beige white compact, hard cryptocrystalline limestone. Traces of translucent gypsum are present. [7]

- **Mesozoic : from 10 to 3244 m**
  - **Cretaceous: 10 to 1661 m**
    - **Senonian Carbonate : 50 to 246 m**

White, beige, pinkish limestone, sometimes speckled with black, microcrystalline to crystalline, saccharoidal, compact, moderately hard to hard, with a fine layer of gray, greenish gray, sometimes brown, carbonated, moderately hard clay. And limestone dolomite, gray to pale gray, microcrystalline, compact, and hard. Presence of translucent, pink, and beige calcite crystals, and traces of flint.[7]

- **Senonian Anhydritic: 246 to 366 m**

The anhydrite ranges from white to gray-white, sometimes white-beige, with a texture that can vary from cryptocrystalline to powdery. It has a moderate to hard hardness, occasionally transitioning to white translucent gypsum. The rock is solid and may contain layers of gray to light gray and reddish-brown clay. In some areas, it may also have a soft to hardened anhydrite component, along with gray-white to light gray cryptocrystalline dolomite. [7]

- **Turonian: 366 to 453 m**

White limestone, rarely crystalline cryptocrystalline, clayey in some places, soft to hard, with fine carbonate clayey layers, soft to pasty. [7]

- **Cenomanian: 453 to 634 m**

Gray white to light gray dolomite, locally speckled in black, cryptocrystalline, moderately hard to hard. Light gray to gray green clay, rarely brown red, soft to indurated, slightly carbonate, locally passing to gray to light gray marl, soft with fine passes of white to beige white cryptocristalline to powdery anhydrite, moderately hard to hard.

Light gray to gray green clay, rarely brown red, soft to indurated, slightly carbonate with passes of gray white to light gray dolomite, locally speckled in black, cryptocrystalline, moderately hard to hard and fine passes of white to beige white cryptocristalline to powdery anhydrite, moderately hard to hard; level of white to gray green and brown red sandstone, very fine to fine, siliceous to silico-argillaceous, moderately consolidated. [7]

- **Albian: 634 to 1136 m**

Greenish gray sandstone, white gray, white, reddish brown, beige, fine, rounded to sub-angular, clayey, slightly carbonate to moderately consolidated with layers of greenish gray clay, reddish brown, indurated, silty to silty-sandy, slightly carbonate, indurated. [7]

- **Aptian :1136 to 1161 m**

The Dolomite is a white to beige, microcrystalline, hard, clayey soft limestone, with layers of gray to reddish-brown clay, indurated, slightly carbonated. [7]

- **Barremian: 1161 to 1409 m**

Translucent sandstone, reddish-brown, beige, whitish, fine to medium sometimes coarse, sub-rounded to sub-angular, poorly sorted, dolomitic, moderately consolidated becoming translucent white to yellowish sand, medium to coarse with layers of grayish-greenish and reddish-brown clay, silty-sandy, soft to indurated. Rare fine layers of white to beige dolomitic limestone, clayey ochre yellow, soft. [7]

- **Neocomian: 1409 to 1661 m**

Gray clay, greenish gray, light to dark gray, slightly carbonated, hardened with layers of brown to reddish brown sandstone, sometimes white, translucent, very fine to fine, silty-clayey, moderately consolidated and beige to gray beige dolomite locally white, microcrystalline, hard and white anhydrite, powdery, sometimes crystalline. Traces of lignite. Brown to reddish brown sandstone, sometimes white, fine to very fine, locally coarse, clayey-carbonated, slightly dolomitic, friable, with thin layers of silty-sandy clay. [7]

- **Paleozoic: 3244 to 3840 m (TD)**
- **Silurian: 3244 to 3324 m**

Black, carbonaceous, silty, pyritic clay, plastic to hardened with layers of white gray, fine, clayey, friable sandstone. [7]

- **Ordovician: from 3324 to 3840 m**
- **M'kratta Slab: 3324 to 3349**

The white to gray sandy siltstone, greenish gray, very fine to fine, clayey to silty-clayey, sometimes siliceous-quartzitic, pyritic, moderately consolidated sometimes compact with thin layers of gray, sandy, soft to indurated clay. [7]

- **Micro conglomeratic clays: 3349 to 3429 m**

Gray to dark gray, soft to indurated, silty, micaceous, pyritous with fine to coarse grains of quartz, translucent, sub-angular, micaceous. Fossil traces present.[7]

- **Oued Saret sandstone: 3429-3514 m**

White to light gray sandstone, very fine to fine, rarely silico-quartzitic, well consolidated, with thin layers of dark gray, silty, indurated clay. [7]

- **Azel clay: from 3514 to 3616 m**

The clay grey-black, silty, micaceous material is accompanied by siltstone grey-black, finely bedded, and micaceous sediment. [7]

- **Ouargla sandstone: from 3616 to 3736 m**

Gray to black hardened clay with layers of fine beige sandstone, very clayey transitioning to siltstone. [7]

White to greenish sandstone, very fine clayey, glauconitic, transitioning to siltstone, occasionally white, Translucent, very fine, silico-quartzitic, hard. [7]

Gray to black hardened clay, with layers of fine to medium white to gray sandstone, siliceous, Glauconitic, hard. [7]

- **Hamra quartzite : from 3736 to 3791 m**

Alternation of white to greenish-gray sandstone, fine to very fine siliceous to silico-quartzitic, well-consolidated to hard, and blackish-gray to black indurated silty clay. [7]

- E**l Atchane Sandstone: 3791 to 3840 m (TD)**

The alternating layers of silty black clay tend to harden, while the grayish-green sandstone, sometimes white or beige, is very fine-grained, silico-quartzitic, extremely hard, transitioning into siltstone. [7]

Sonatrach / AMT / Division Exploration DAC / Département Bassin de Oued Mya	Prévisions géologique du puits Hassi Boukhellala Sud -1 (HBKS-1) Périmètre de recherche Ghardaia Bloc 422a X= 621834,88 m Y= 3545980,54 m Zs= 305,436 m Zt= 316,226 m	Appareil de forage TP-226

AGE	PROF /Zt	Ep		ETAGE	PREVISION GEOLOGIQUE STRATIGR	LITHOLOGIE	Phases et Tubing	Boue	Logging
Mio-Plio	10	40		Mio-Pliocène		Gres fin à moyen, Traces de calcaire, gréseux			
CRETACE	50	196		Sénonien Carbonaté		Calcaire microcristallin, passées d'argile tendre, calcaire dolomitique crypto à microcristallin			
	246	120		Sénonien Anhydritique		Anydrite blanche, translucide, cristalline avec passées d'argile tendre et de dolomie cryptocristalline			
	366	87		Turonien		calcaire cryptocristallin rarement cristallin, avec fines passées d'argiles tendre, carbonaté.			
	453	181		Cénomanien		Dolomie crytocristalline et Argile tendre à indurée, avec fines passées d'Anhydrites.Argile tendre à indurée avec assées de Dolomie crytocristalline			
	634	502		Albien		Grès fin à moyen, mal classé, sub-arrondi, siliceux à silico-argileux, friable à moyen consolidé, avec passées d'argile tendre à indurée, silteuse			
	1136	25		Aptien		Dolomie, microcristalline, dure avec passées d 'argile tendre			
	1161	248		Barremien		Grés fin à moyen,siliceux à silico-argileux avec fines passées d'argiles. Argiles tendre à indurée, silteuse à silto-sableuse avec passées de grés. Grés fin à moyen, mal classé avec fines passées d'argiles tendre à indurée, er de Dolomie crytocristallin			
	1409	252		Néocomien		Argile tendre à indurée, silteuse, présence de Grés très friable et Dolomie crytocristalline, dure, et traces d'anahydrite pulvérulente. Grés fin à très fin, moyennemnet consolidé avec fines passées d'argiles			
JURASSIQUE	1661	260		Malm		Dolomie, microcristalline argileuse, friable. Alternace de Grés très fin à fin, silico-argileux moyennement dur à argileux, et d'Argile silteuse, tendre à indurée, légerement carbonaté parfois feuilletée avec fines passées de Dolomie.			
	1921	130	Dogger	Dogger argileux		Argiles grise, grés vert, tendre à indurée indurée, légeremnt carbonaté , avec passées de Grés siliceux à silico-argileux et Dolomie crytocristalline moyennement dure, et traces d'anhydrite blanche, pulvurélente, cristalline,dure.			
	2051	71		Dogger lagunaire		Argile grise, silteuse, légerement carbonaté. Passées de Dolomie microcristalline, et fines passées d'Anhydrite pulvérulente			
	2122	44	Lias	Marneux		Argile tendre indurée, et marne tendre, avec assées de Dolomiet et d'Anhydrite			
	2166	39		Carbonaté		Calcaire dolomitique micocristalline dur parfois argileux avec fines passées d'argile tendre à indurée , présence d'anhydrite.			
	2205	222		Lias anhydritique		Anhydrite pulvérulente, dur, avec assées de Calcaire Dolomitique crytocristalline dure parfois argileux, friable, avec fines passées d'argile tendre à indurée, silteuse, et de Dolomie			
	2427	49		Lias Salifere		Argile silteuse. Sel translucide, massif .			
	2476	25		H.B		Calcaire dolomitique crytocristalline, passées d'Argile tendre à indurée, et traces d'Anhydrites			
	2501	152		S1 + S2		Anhydrite pulvérulente,cristalline. Sel massif, passées d'anhydrite pulvérulente, dure et d'Argile parfois anhydritique, et fines passées de Dolomie.			
	2653	293		S3		Sel transparent massif, tanslucide, intercalé de fines passées d'argile salifère tendre à indurée, parfois dolomitique. Traces d'Anhydrites blanches.			
	2946	60		Argilo-Sup		Argile tendre à plastique et indurée avec fines vassées de sel			
TRIAS	3006	62	Trias	S4		Sel translucide massif, fines passées d'argile silteuse, tendre à indurée, traces d'Anhydrites			
	3068	32		Argileux inf		Argile silteuse, indurée, avec fines passées de sel et silt			
	3100	39		T2A		silts argileux dur, avec fines passées d'Argile silteuse. Grès fin à très fin,moyen consolidé à friable, avec fines passées d'argile indurée,silteuse.micacée.			
	3139	40		T1B		Argiles, silteuse, indurée. Grès fin à moyen,friable fines passées d 'argile indurée,silteuse.micacée.			
	3179	30		T1C		Argile indurée,silt.micacée. Grès fin, argileux moye consolidée			
	3209	35		Série Inf		Argile silteuse, micacée indurée. Grés fin à moyen, argileux glauconieux, moyen consolidée à friable			
Silurien	3244	80		Silurien radioactif		Argile noire, plastique à indurée, charbonneuse, silteuse, pyriteuse, avec passées de Grés fin, friable			
Ordovicien	3324	25		Dalle M'kratta		Grès, très fin à fin, argileux,moyennemnt consolidée à friable avec fines passées d'Argile sombre, sableuse, tendre à indurée			
	3349	80		Argiles Micro-conglo		Argile gris noir, tendre à indurée, silteuse à très silteuse, micacé à inclusions de grains de Quartz translucide. Trace de pyrite			
	3429	85		Grés Oued Saret		Grés très fin à fin, silico-argileux à silico-carbonaté, moyennement consolidés, avec passées d'argiles silteuse, indurée. Présence local de calacaire			
	3514	102		Argiles Azel		Argiles noire, indurée, pyriteuse avec traces de Grés silico-argileux, moyennement consolidée.			
	3616	120		Grés Ouargla		Grés très fin à fin, silico-argileux , friable à moyennement consolidés, avec fines passées d'argiles silteuse, indurée.			
	3736	55		Quartzites Hamra		Grés très, sillico-quartzitique à quartzitique, compact,dur, avec fines passées d'Argiles noires slteuse, indurée, micacée			
	3791	49		Grés El Atchane		Argile gris noire, indurée avec intercalation de Grés fin à très fin, silico-quartzitique, compact dure.Grés très fin silico-argileux, friable			
Profondeur					3840 m				

Figure I.3: Litostratigraphical forecast (SONATRACH/EXPLORATION)**[7]**

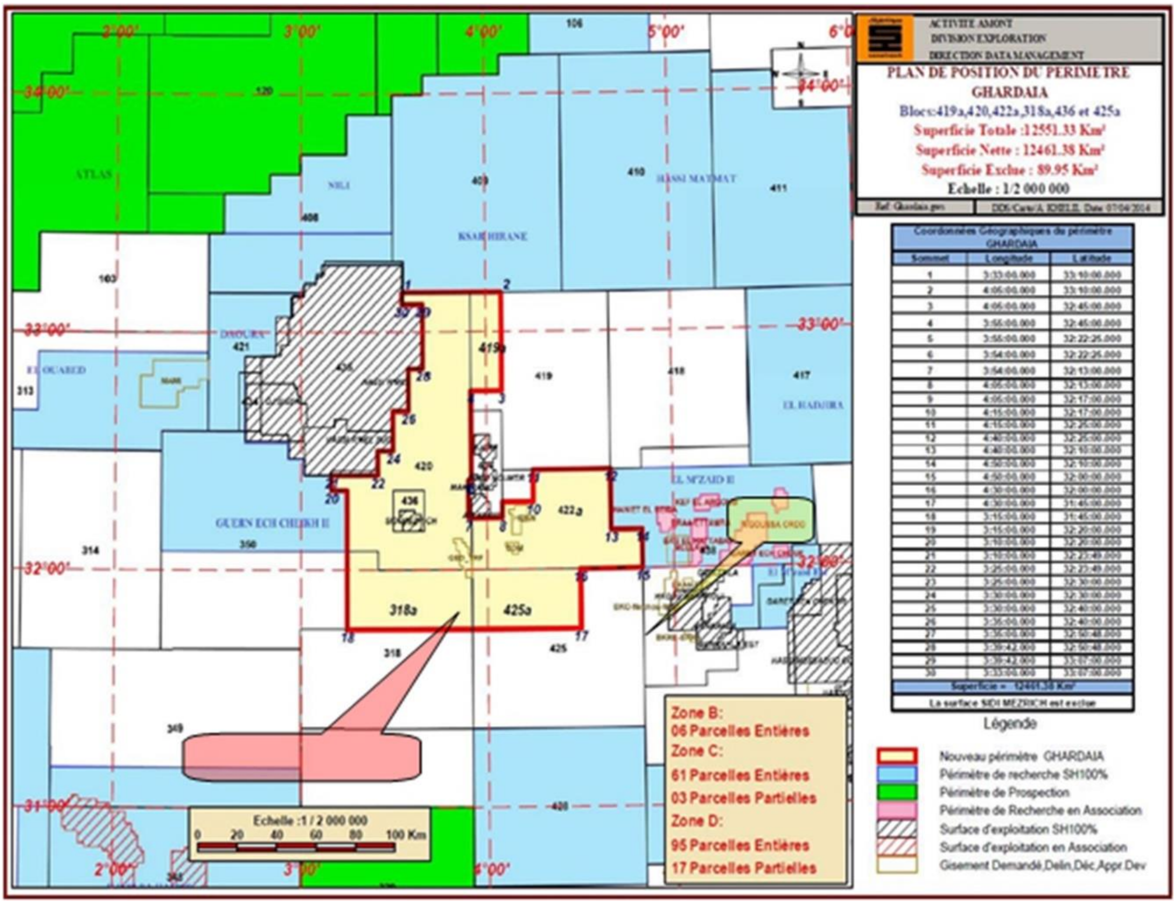


Figure. I.4: Position plan of block 422a in the Gharadaia II perimeter (SONATRACH/EXPLORATION) **[7]**

4-Presentation of Bloc 422a (Hassi Boukhellala)

Bloc 422a, located in the east of the Oued Mya basin on the periphery of Ghardaia II, It is bordered by blocks 425a, 436 and 420 and Drill stop formation is Ordovician. (Fig. I.4)

Block 422a is characterized by NNW-SSE-oriented structures in its northern part, delimited by accidents in the same direction, while the southern part is characterised by NW-SE-orientated structures with accidents of the same orientation (Fig. I.5).[8]

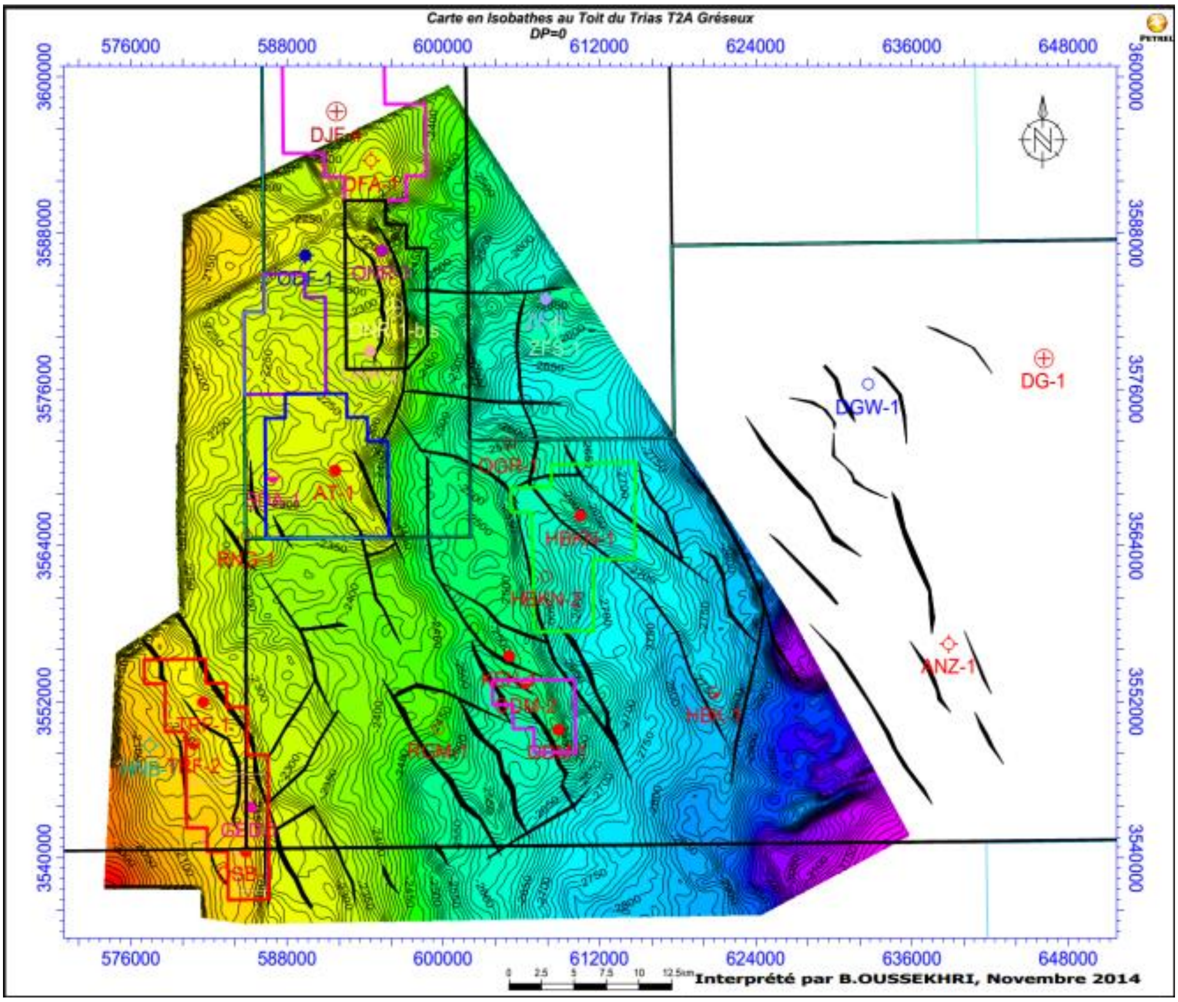


Figure. I.5: Isobath map with T2 (A) sandstone roof, DP= 0m, Ic= 10m (SONATRACH/EXPLORATION)**[8]**

5- Petroleum interest of the region

5.1. Parent rock:

The main source rock is made up of radioactive Silurian clays, currently in the oil phase. The Ordovician clays (El Gassi clays and Azzel clays) can serve as secondary source rocks. [6]

5.2. Reservoir rocks

The main reservoirs in the Zelfana area are the sandstones of the Triassic levels T2A and T1B, deposited in a braided fluvial environment with estuarine and aeolian influe.

The Ordovician quartzitic sandstones, known as the "Hamra Quartzites," are regarded as a secondary target, with the key factor for reservoir productivity being the penetration of open fractures. [6]

5.3. Cover rocks

The Triassic reservoirs are covered by the evaporites of the S4 salt and the Lias. The Azzel clays provide excellent coverage for the Hamra Quartzite reservoir. [6]

5.4. Types of traps

Trap setting is primarily done in low-amplitude anticlinal structures. Mixed traps are also developed in the Triassic period. [6]

5.5. Oil target

The main oil reservoirs in the region are composed of Triassic sandstones from the T2 (A) and T1 (B) units, and the quartzitic sandstones of the 'Hamra Quartzites' formation from the Ordovician as a secondary target; with depths ranging from 3100m to 4000m respectively.
The risks associated with the Triassic reservoirs consist of facies variations due to their deposition mode (braided fluvial) and the presence of salt cement, especially for the T2 (A) reservoir. As for the Hamra Quartzites, the issue lies in the connectivity of fractures. [6]

ChapterII: Sedimentological study

Chapter II:
Sedimentological study

1. Introduction

Sedimentological analyses offer valuable insights into the evolution of the Lower Triassic series, a period marked by significant geological and environmental changes. By analyzed sedimentary deposits from this area, we can unravel the complex interplay of tectonic, climatic, and depositional processes that shaped the landscape and deposited sediments. These analyses help in reconstructing ancient environments, deciphering climatic conditions, and understanding the tectonic stability of the region during this time. Such insights contribute to a comprehensive understanding of Earth's history and the factors driving geological evolution during the Lower Triassic period.

2. Sedimentological notions

2.1. Facies definition

It is a set of lithological (mineral composition, sedimentary structures, geometry, etc.) or paleontological (fossils) characters of a sedimentary or metamorphic rock, or of a terrain. This is the appearance of a rock or a set of geological layers. [9]

2.2. Sequential analysis

Identifying interpreting facial characteristics and understanding their spatio-temporal relationships are the foundations of studies of sedimentary series to reconstruct paleoenvironmental environments and paleo geography analyzing the vertical succession of facial characteristics makes it possible to identify the temporal evolution of environments. [10]

2.2.1. Definition of a sedimentary sequence

A series of sedimentary layers of different types that follow one another in a particular order, usually bounded by stratigraphic discontinuities at the top and bottom. It may reflect either a specific mechanism of deposition (e.g., flysch-like sedimentary sequences) or a specific sedimentary history (e.g., a transgressive sequence in which coastal deposits evolve into deeper deposits). However, a sedimentary sequence should not be considered as a simple superposition of lithological words, but rather as a sequence of words placed on a continuum. Thus, each stage (each facies) must be studied in relation to the preceding and succeeding ones. [10]

Sequential analysis seeks to define ideal reference patterns that reflect the theoretical logical patterns of (micro) facies (virtual patterns). Real sequences observed are then compared with the virtual sequence thus defined. Although sequential analysis is a very effective method for describing the evolution of sedimentary series, it is important to emphasize its limitations:

- Nothing other than what is written in the virtual sequence comes out of the sequential analysis. The scientific process takes place when the virtual sequence is defined;

the rest is just a graphical representation. If the sequence defined in the virtual sequence is incorrect, all results will be incorrect.

- There is no universal virtual sequence; it is necessary to redefine an appropriate sequence for each new study.

- **Elementary sequence**

This is the short succession of deposits which can be linked to the scale of a sedimentary basin, with thicknesses ranging from 1 to 10 meters. It is generally defined in a marine environment between two consolidated surfaces. It is the fundamental unit of stratigraphy. [10]

- **Virtual sequence**

The most complete series theoretically conceivable of levels which are generally structured in series some authors define this typical sequence for series corresponding to a marine transgression, generally beginning with saline sediments and ending with layers of silty rocks, or at least for series where the grain size decreases by back to front [11]

- **Sequence Lithologique**

An evolving, unfailing succession of linked lithological terms, vertical or horizontal, with natural limits. The sequence corresponds to a logically asymmetric arrangement [12].

- **Positive or negative sequence**

A lithological sequence showing a clear evolution of depositional energy at the time of sedimentation [21].

- **Positive sequence**

A sequence where the order follows that of a virtual sequence a succession of turbidities, which narrow and end upstream: it is in reality a mega -series. [21]

- **Negative sequence**

This is a sequence where the order is reverse of a virtual sequence a succession of turbidities, which strengthen and strengthen upstream: it is in reality a mega -sequence (in English, cycle of coarsening and thickening upstream) [21]

Transgressive or regressive sequence:

An increasing succession of linked lithological terms, which vertically reflect both a transgression and a regression [12].

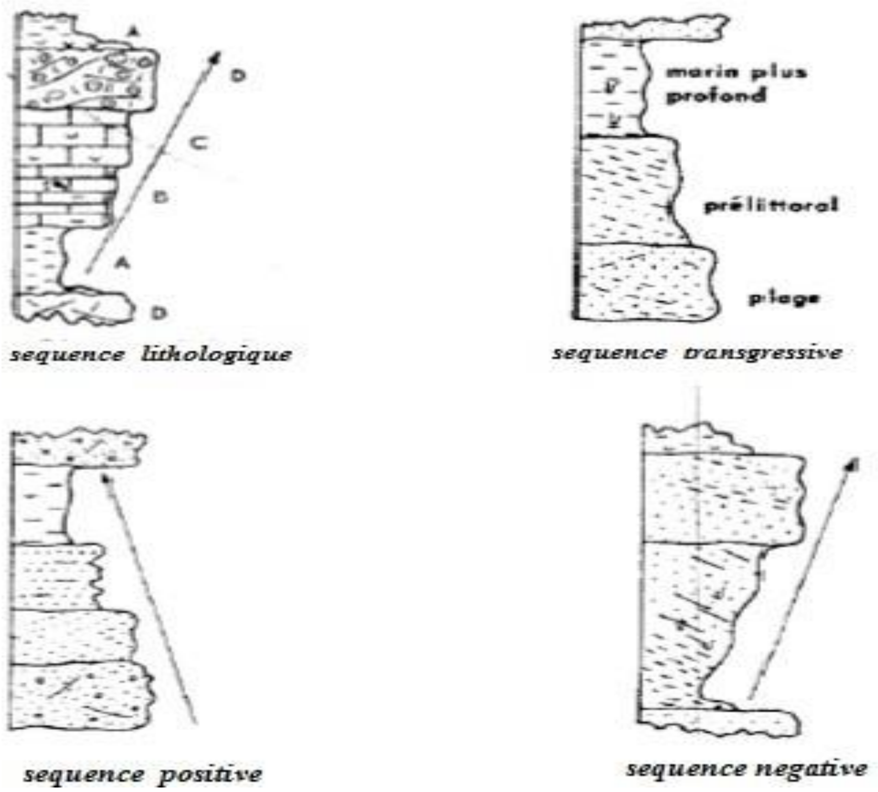


Figure.II.1: Representative diagram of some sequence examples

2.3. Sedimentation in the fluvial environment

- **Braided networks**

They are in the form of longitudinal bars which separate the channels. These bars become oblique (transverse) in curves; they are mobile and increase in the direction of the current ("longitudinal accretion"), their shape depends on the load and the flow. They are made up of interlocking pebbles which fall in avalanches downstream, gravel, and cross-bedded sand. They are often gullied by the movement of channels**.** [22]

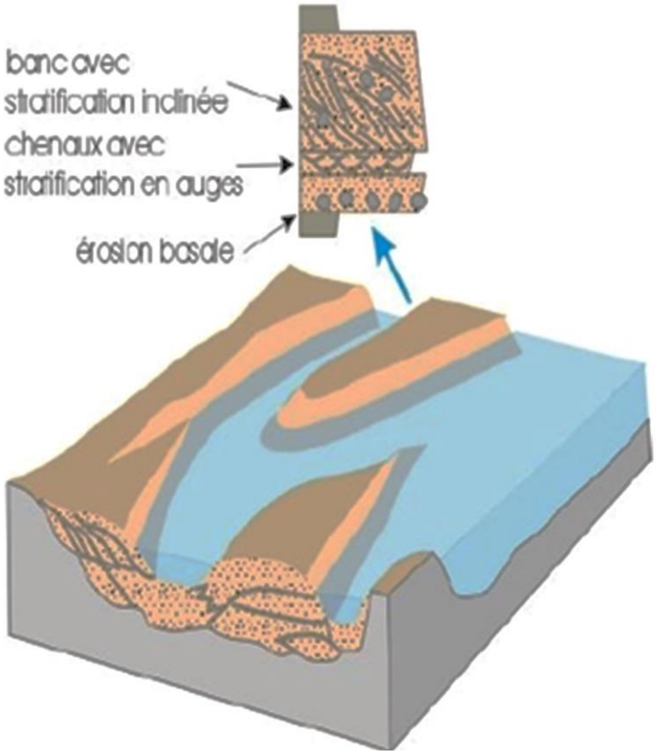


Figure.II.2: Diagram of a braided fluvial system and an associated depositional sequence [13]

- **Meander network**

The sequences of meandering rivers have positive features: they begin with a bed of gravel and end with floodplain silts showing traces of soil and vegetation.

Floodplain deposits consist of silts and clays. They contain decameter-scale lenses of sand and gravel corresponding to the wandering of meandering channels. Vegetation soils are abundant. [22]

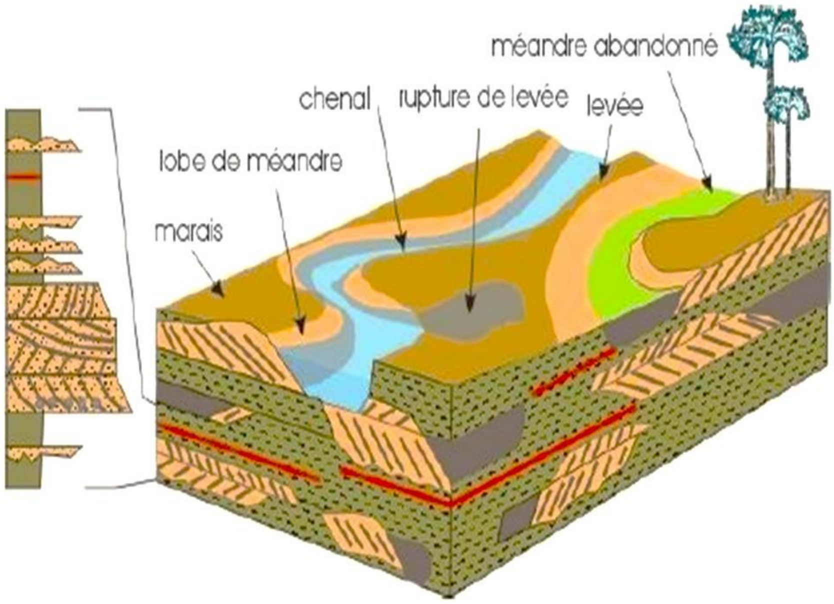


Figure.II.3: Diagram of a braided fluvial system and an associated depositional sequence [13]

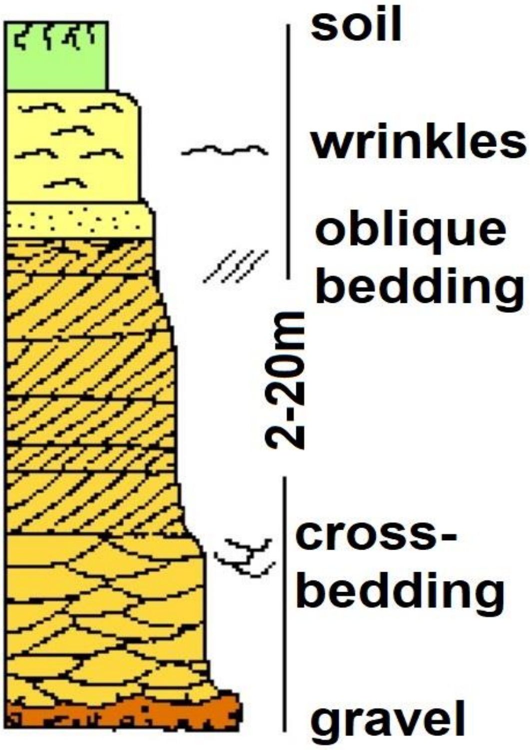


Figure.II.4: Diagram of a braided fluvial system [22]

3. Macroscopic description

3.1. Well-1

Table II.1: Some data on the Well-1.

Type	Interval value
Base of the Lower Series	2955 m
Lower Series Roof	2972 m
Bottom Series Thickness	17.20 m
Gas production	/
Oil production	/
Final depth reached by drilling	3610 m
Last formation reached by drilling	Argile d'El Gassi

3.1.1. Core of the Well-1

Description

In the first Triassic deposits (From2955to2966m) we have light gray to dark gray siltstone, very clayey, micaceous, passing to very fine sandstone, clayey and it's moderately consolidated.
We have also Light gray to dark gray sandstone, very fine, very clayey, sometimes strongly micaceous (white micas), with greenish inclusions of Glauconia.

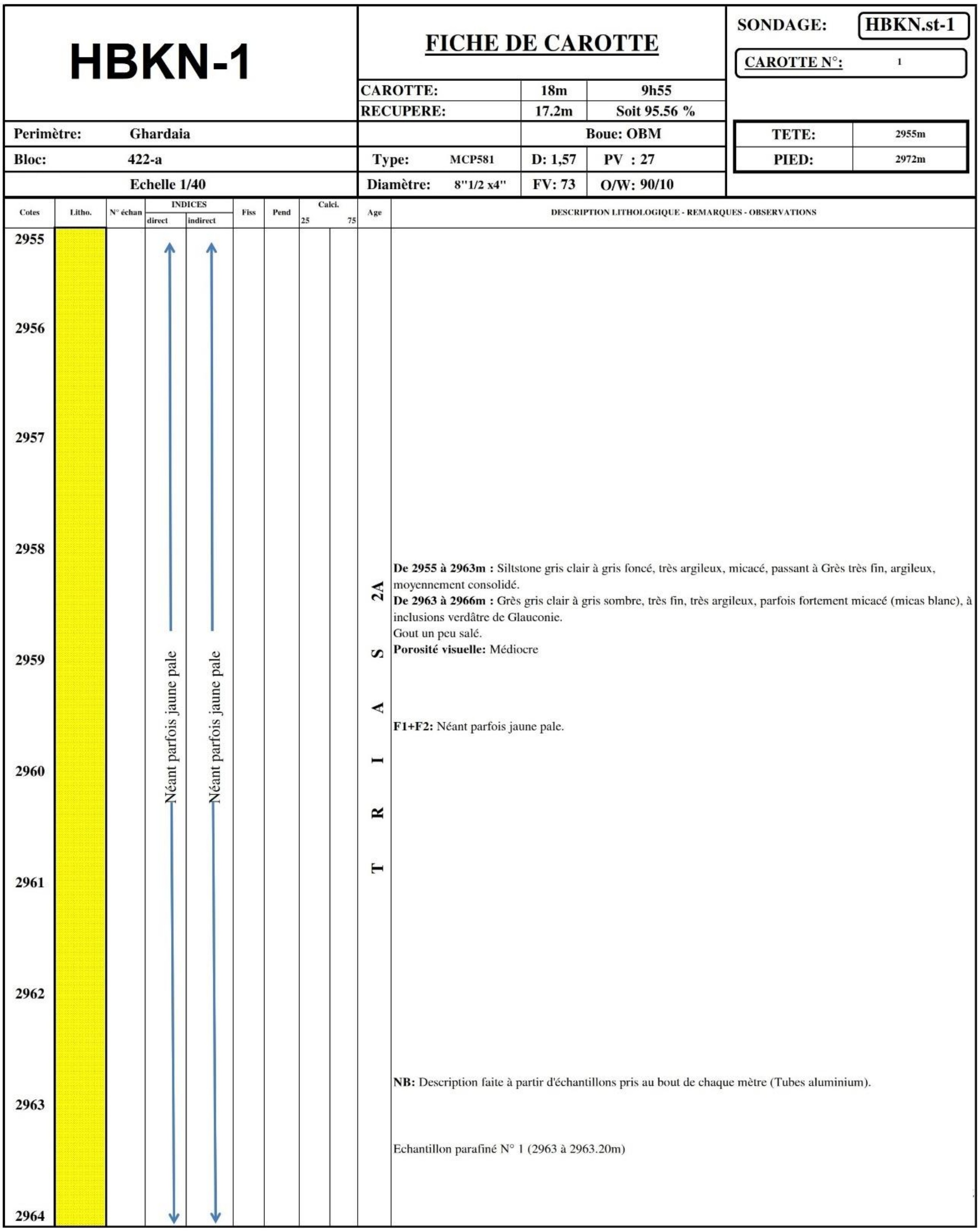


Figure.II.5: the core n°1 file of the well 1[20]

In the last deposit **from 2966 to 2968m** we have a Dark to black-gray sandstone, very fine, very clayey, micaceous, strongly speckled in black (bituminous).

And we observe that we have also **from 2968 to 2972** a Light gray to dark gray sandstone, very fine, very clayey, sometimes strongly micaceous (white micas),

with greenish inclusions of Glauconia, sometimes passing to Siltstone, very clayey.And it Tastes a little bit salty.

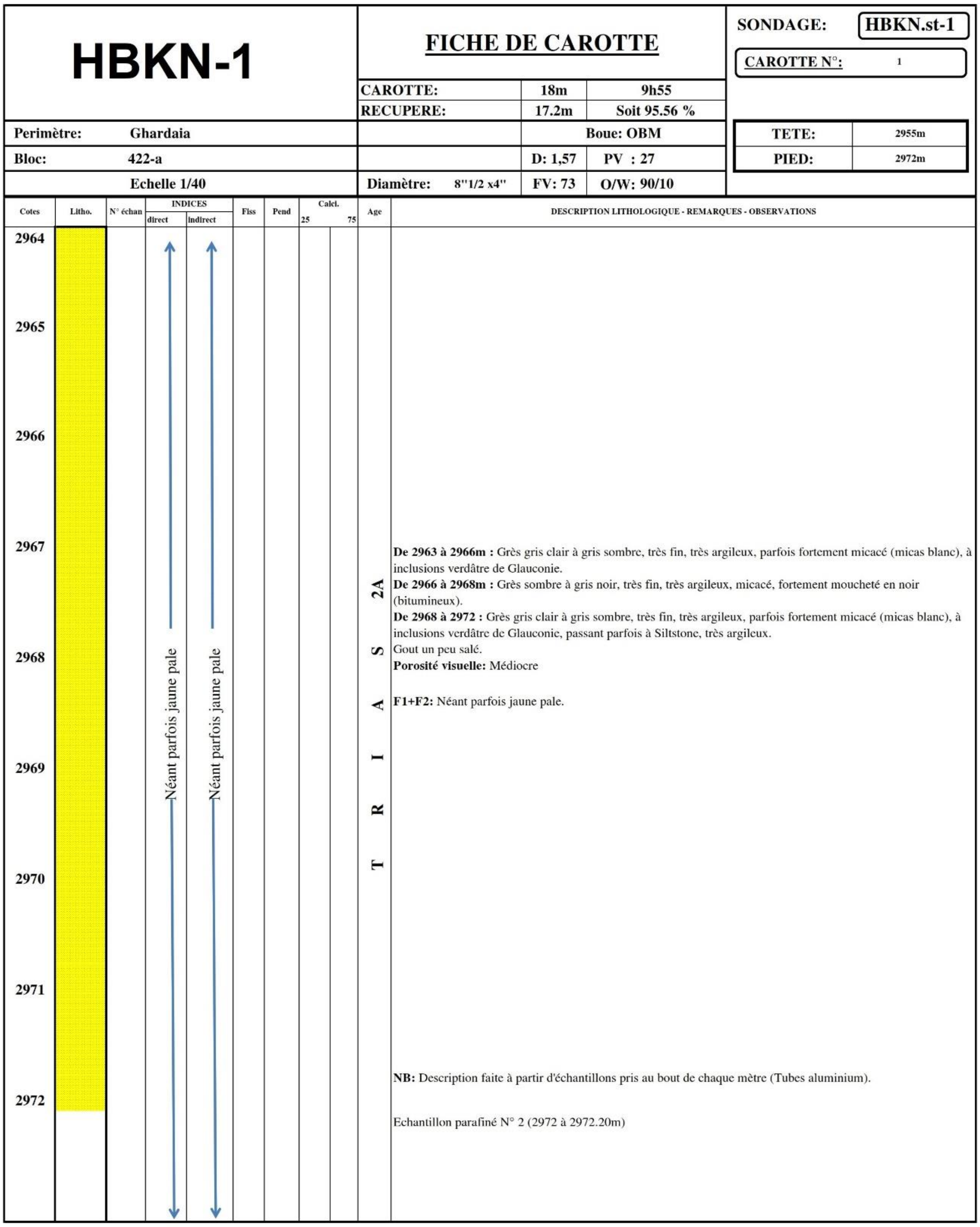


Figure.II.6: the core n°2 file of the well 1[20]

3.2. Well-2

Table II.2: Some data on the Well-2.

Type	Interval value
Base of the Lower Series	2943 m
Lower Series Roof	2961 m
Lower Series Thickness	18 m
Location in relation to Well 1	It is 5 km to the SW of well 1
Gas production	/
Oil production	53.78 106 m^3 en 3P
Final depth reached by drilling	3110 m
Last formation reached by drilling	Sandstone of Oued Saret

3.2.1. Core of the Well-2

Description

In this well, Triassic sedimentation begins with a light gray to dark gray sandstone, gray-brown, light brown.

Locally pinkish brown, very fine to fine, sometimes medium subangular to subrounded to rounded, clayey to silico-clayey, micaceous, friable to moderately consolidated. Presence of inclusions in places millimeters of light green clay (From 2943 to 2957m).

In the last part the sedimentation ends with a red brown clay, silty, soft to hard (from 2957 to 2961m).

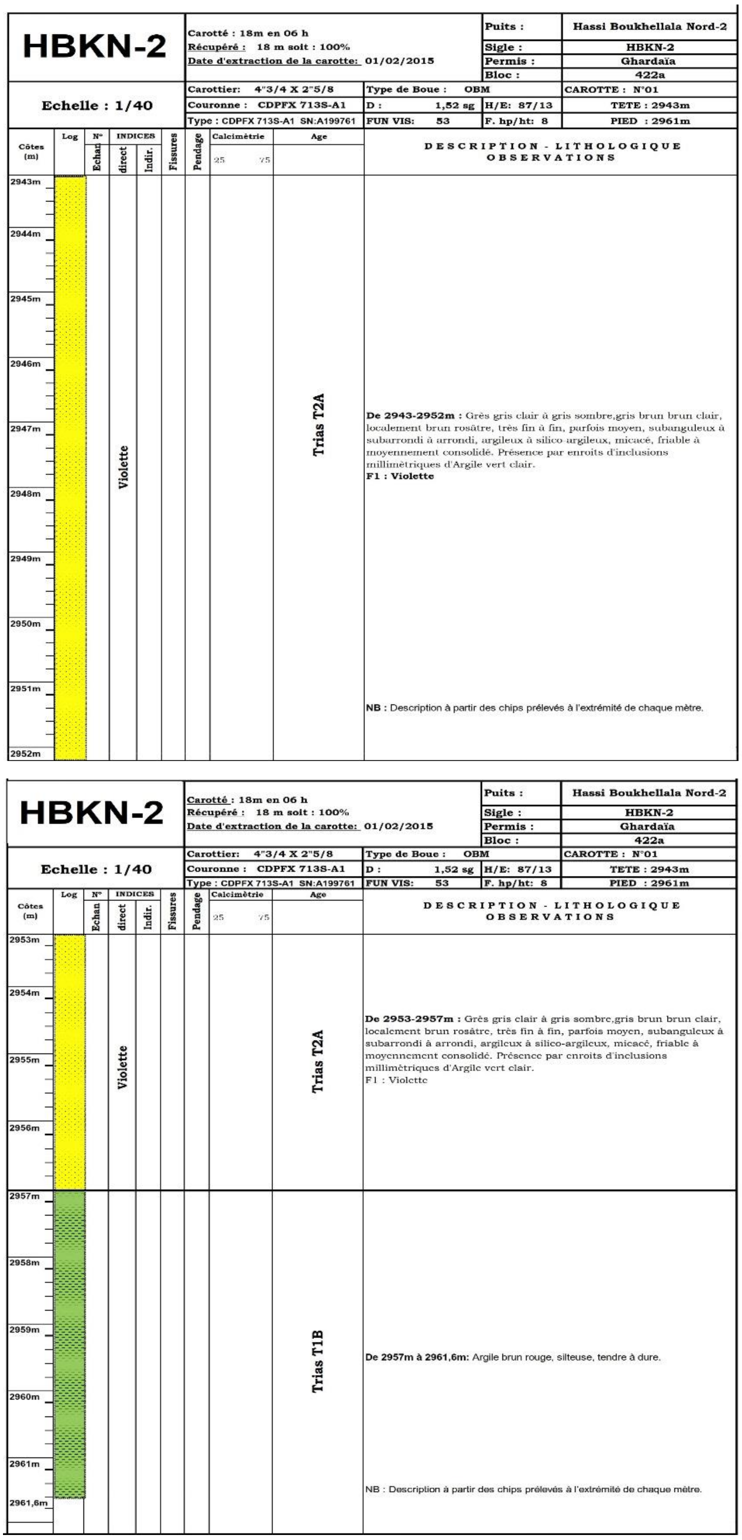


Figure.II.7: the core file of the well 2 [20]

3.3. Well-3

Table II.3: Some data on the well 3.

Type	Interval value
Base of the Lower Series	2974 m
Lower Series Roof	3044 m
Bottom Series Thickness	34 m
Gas production	/
Oil production	/
Final depth reached	3200m
Last training achieved	Micro-conglo. clays.

3.3.1. Core of the Well-3

Description

Sediment Description (2974m to 3001m Depth)

The Triassic section begins with a **red-brown to brown clay**, locally grey-green, and strongly silty. This clay is micaceous, moderately hard (2974m to 2981m), and indurated with fine pastes of red-brown and light gray silt.

Overlying the clay (2983m to 2992m) is a sequence consisting of:

- Dark gray to red-brown silt, and light gray to gray-green, clayey, micaceous, moderately hard silt. Locally, this silt transitions to a light gray to dark gray, very fine to fine clayey sandstone speckled with black minerals and moderately consolidated.
- Red-brown to red-brown silt, light gray to gray-green, clayey, micaceous, moderately hard. This silt locally changes to a dark gray to light gray, very fine, clayey sandstone speckled with black minerals and moderately consolidated.

At a depth of 2992 meters, a new lithology appears:

- Red-brown to red-brown silt, light gray to gray-green, clayey, micaceous, moderately hard. Locally, this silt transitions to a dark gray to light gray, very fine clayey sandstone speckled with black minerals and moderately consolidated. Additionally, a presence of:
    - Fine clay, faded from red-brown to brown, rarely grey-green, silty, micaceous, and indurated.

  - Gray-green to dark gray sandstone, fine, clayey, strongly micaceous with glauconite inclusions, moderately hard.

The section concludes with a layer of dark gray to light gray, light brown, fine, clayey, strongly micaceous sandstone with glauconite inclusions, which is medium hard (2999 to 3001m).

Sediment Description (3017m to 3044m Depth)

Upper Interval (3017 to 3019.8m):

- Dark gray to light gray, fine-grained, clayey sandstone. The hardness transitions from moderately hard to friable. Locally, the gray-green clay transforms into black, silty, micaceous, and indurated clay. Glauconite nodules are present.

Lower Interval (3038 to 3044m):

- Red-brown to brown clay, sometimes gray-green colored. This clay is strongly silty, micaceous, and indurated. Locally, it transitions to red-brown to brown, clayey silt that is moderately hard.
- Dark gray to light gray sandstone, fine-grained to locally medium-grained. The sand is subrounded, well-classified, and clayey. It also contains bituminous material and its hardness varies from moderately hard to friable. Fines within the sandstone consist of red-brown to brown clay, sometimes gray-green colored, silty, indurated, and micaceous.


2974
2986
2987
3006
3007
Bottom Core 1

Figure. Ⅱ.8 : core 2 of well 3

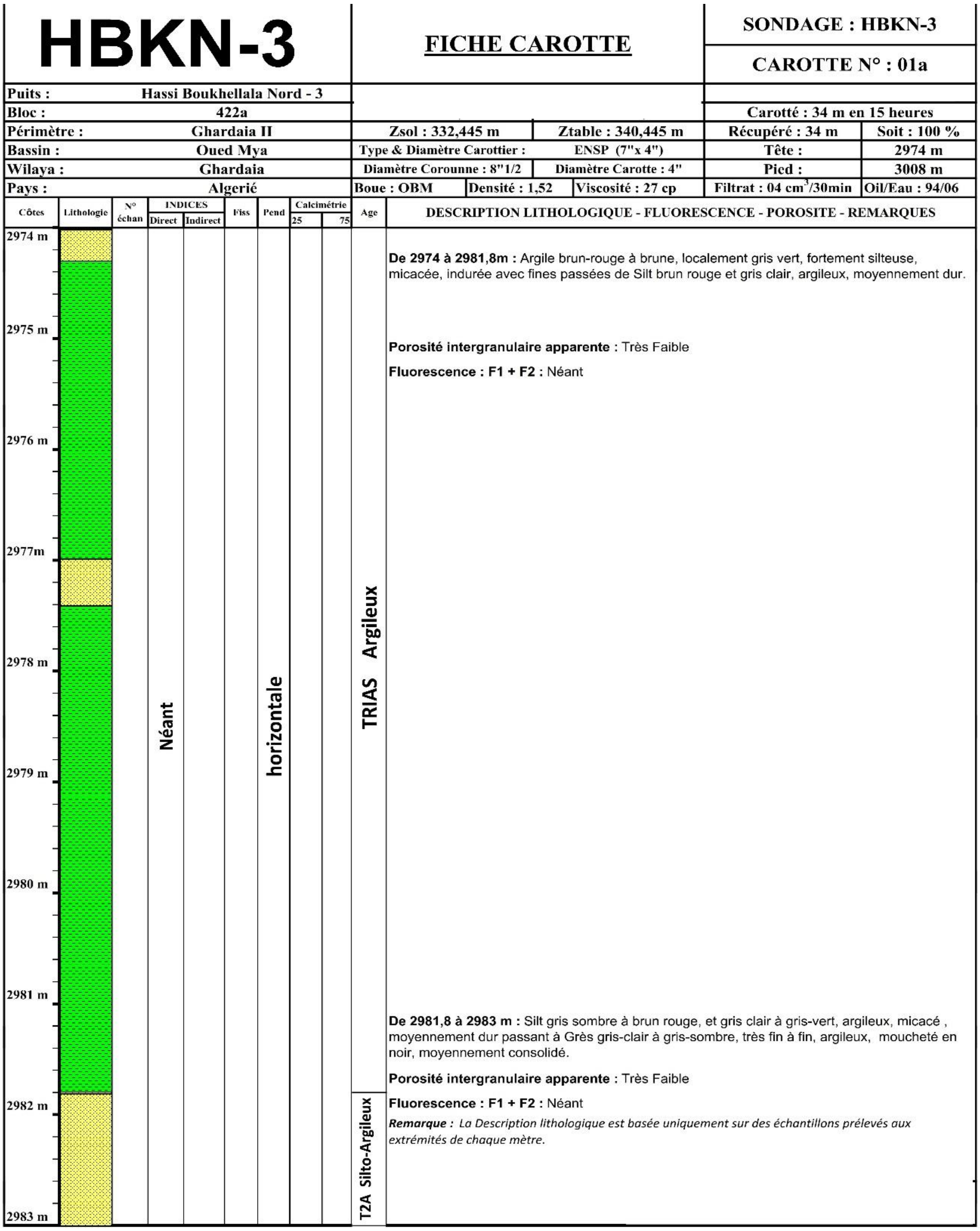


Figure.II.9 the core file of the well 3 [20]

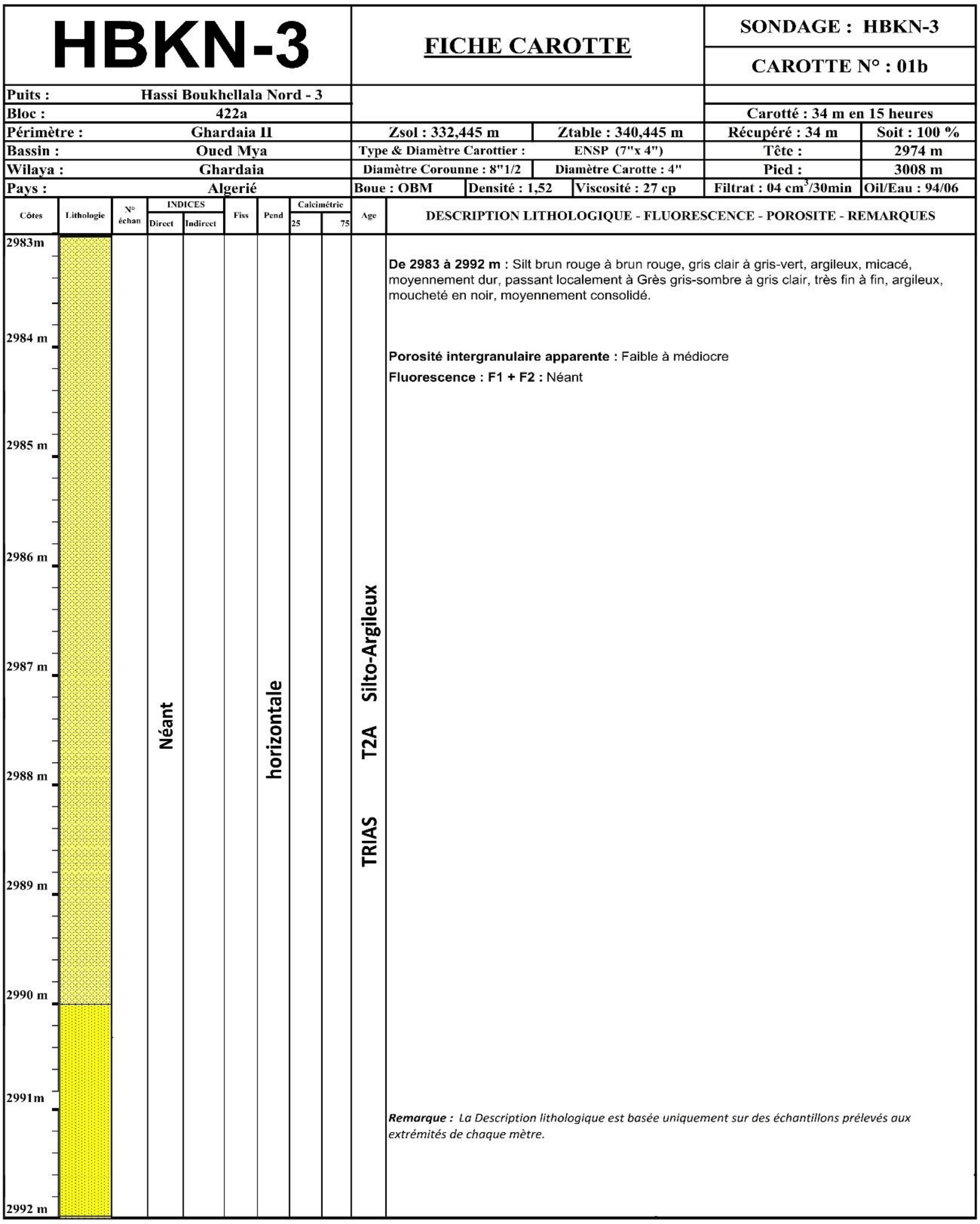


Figure.II.10: the core file of the well 3 [20]

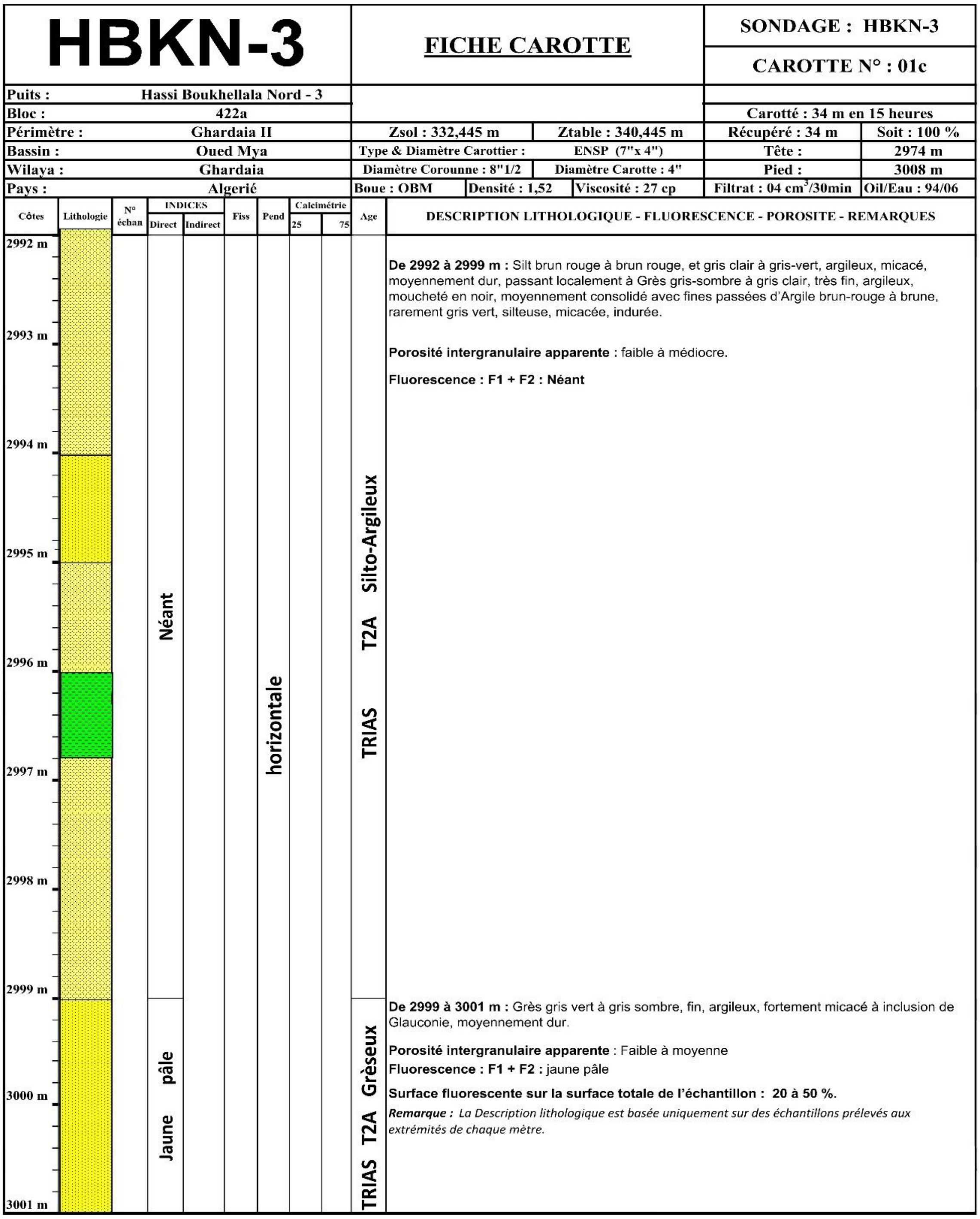


Figure.II.11: the core file of the well 3 [20]

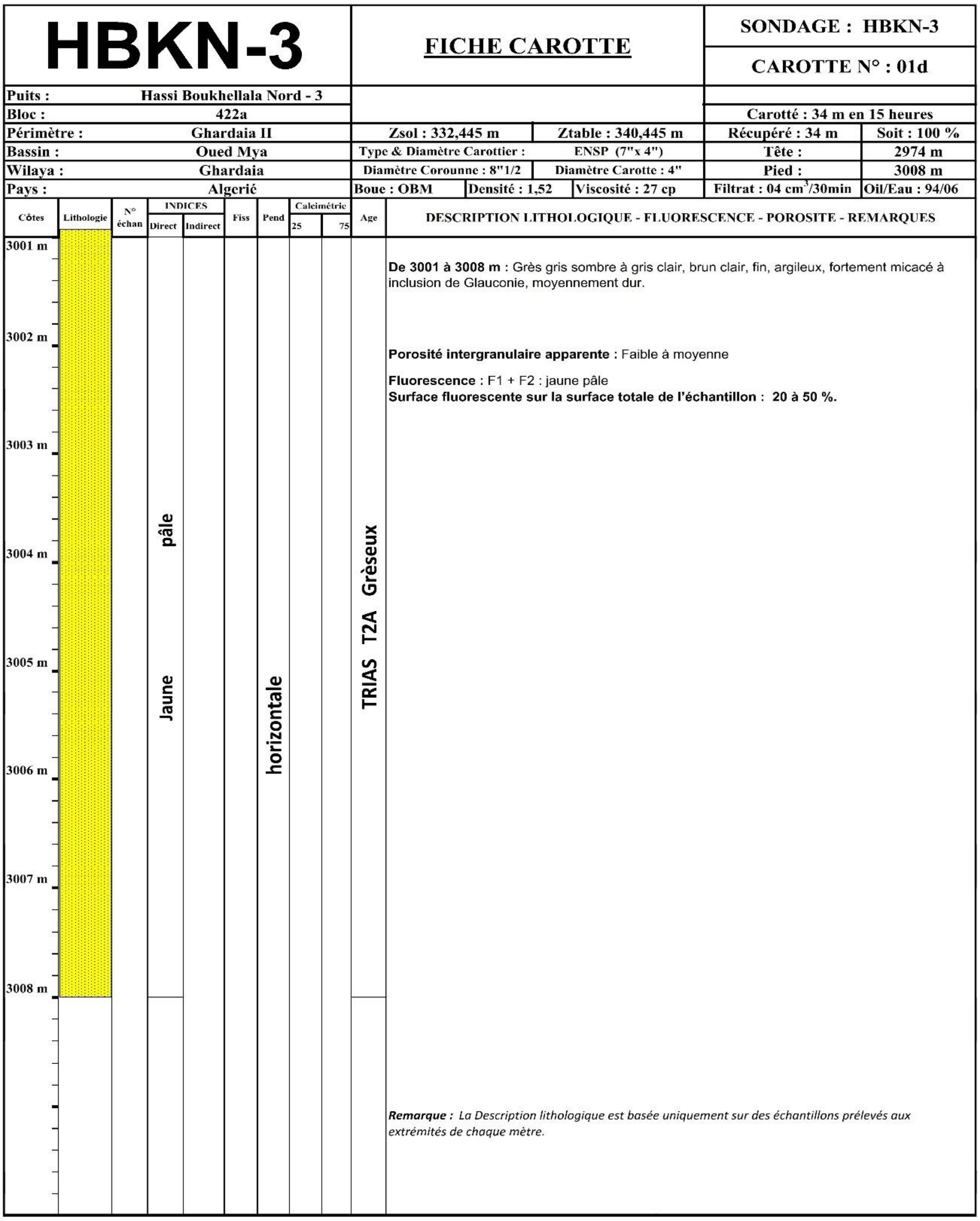


Figure.II.11: the core file of the well 3 [20]

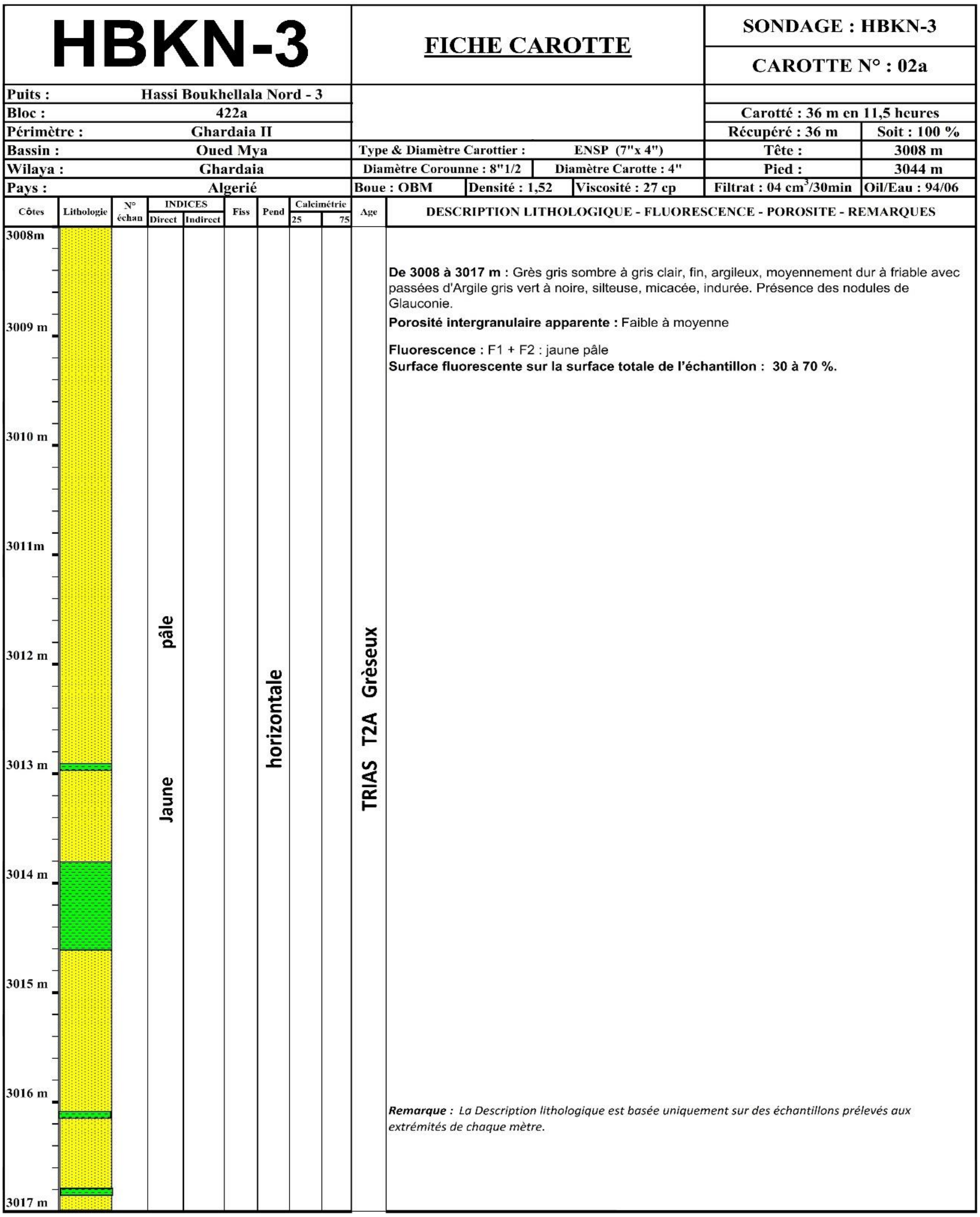


Figure.II.12: the core file of the well 3 [20]

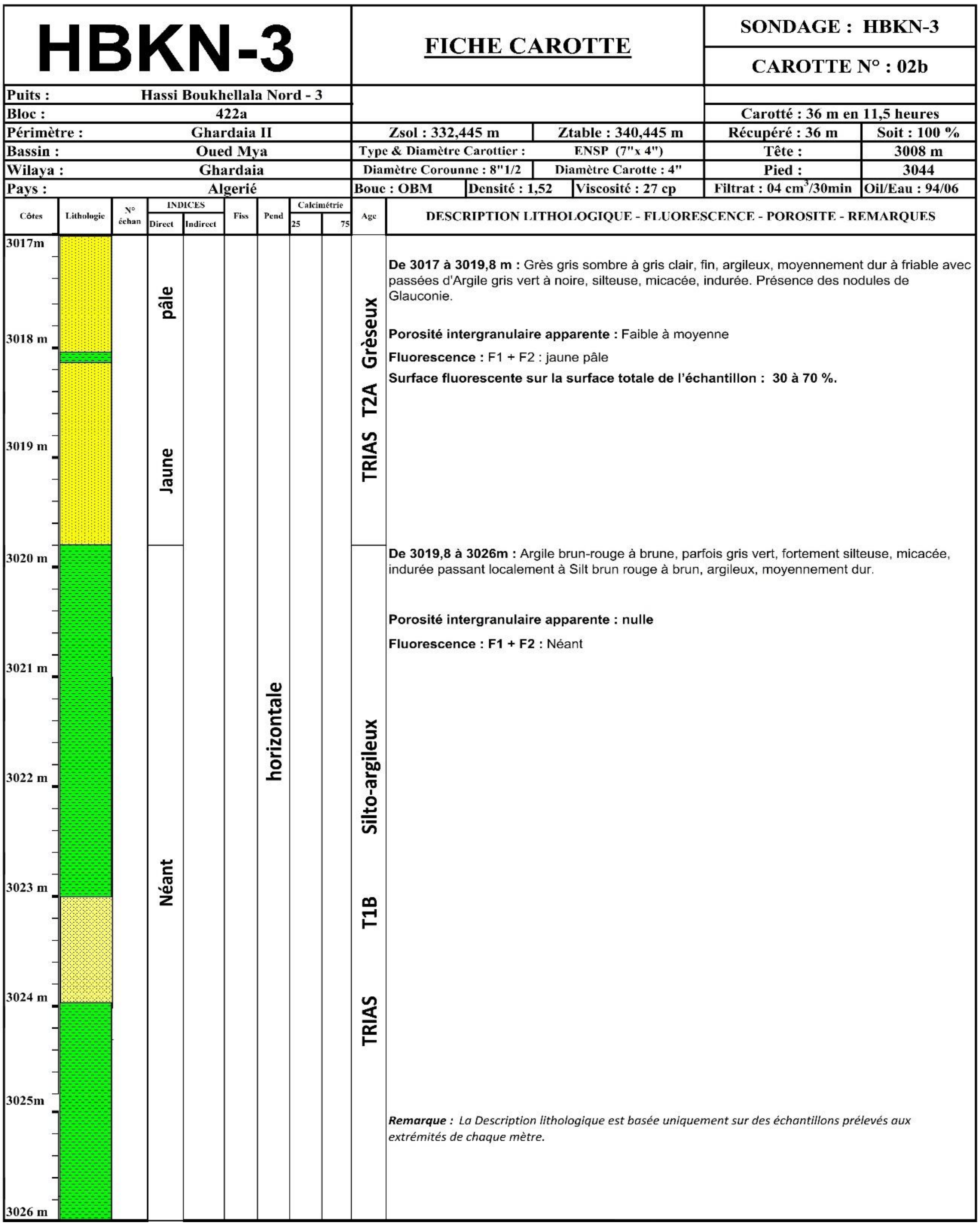


Figure.II.14: the core file of the well 3 [20]

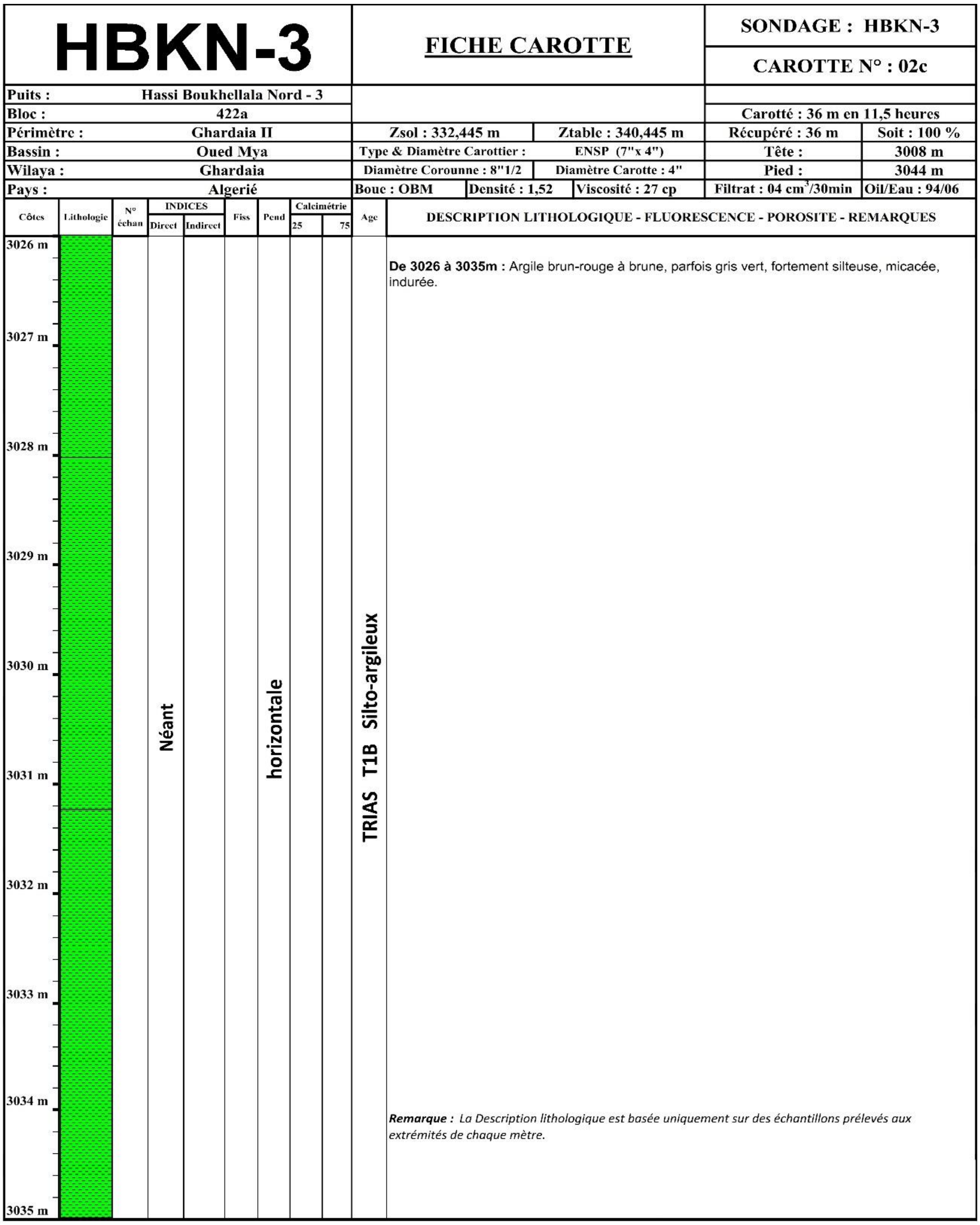


Figure.II.15: the core file of the well 3 [20]

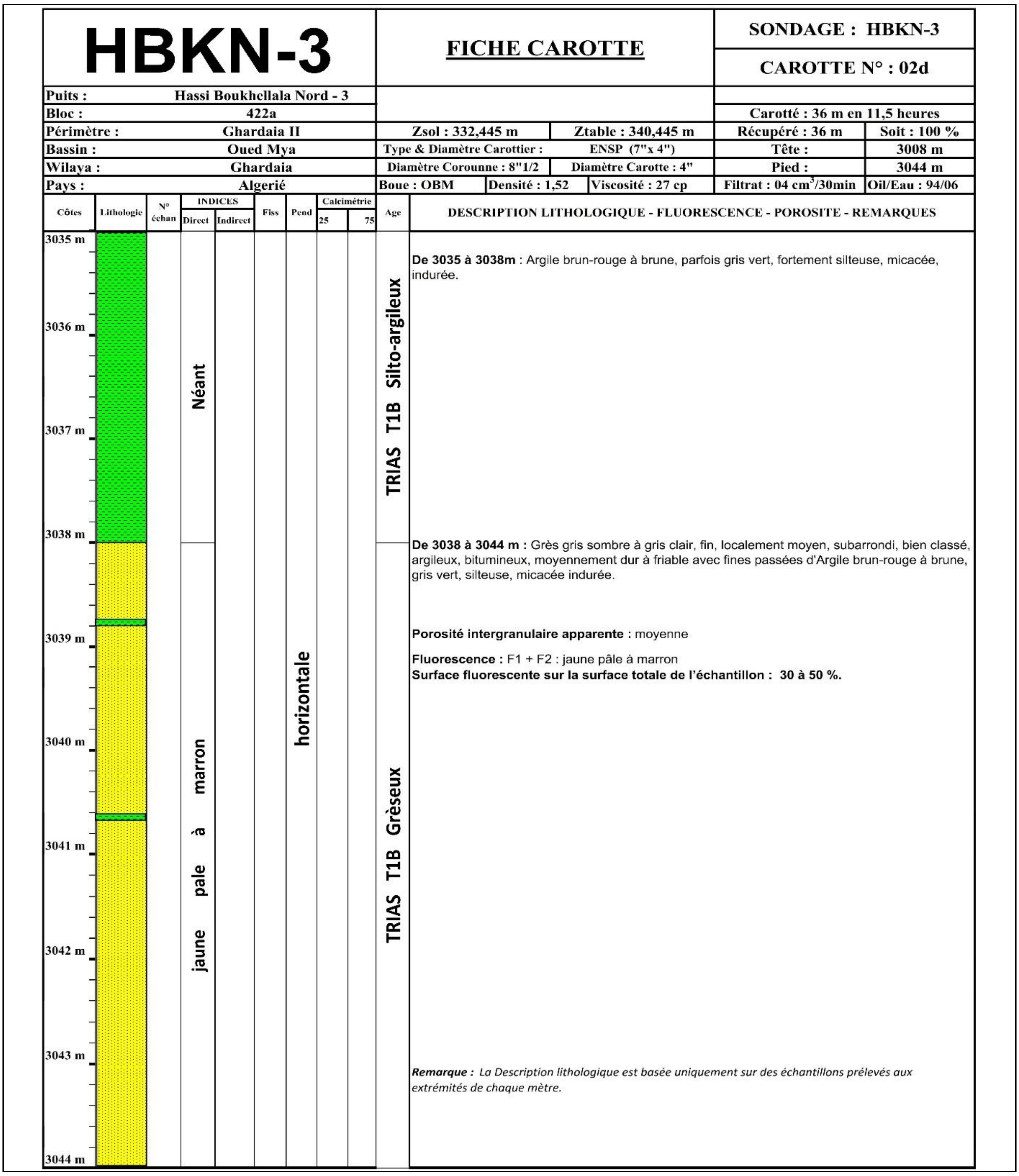


Figure.II.16: the core file of the well 3 [20]

3.4. Well-4

Table II.4: Some data on the Well-4.

Layer	Interval value
Base of the Lower Series	3022 m
Lower Series Roof	3082 m
Bottom Series Thickness	18 m
Gas production	932 Sm3/h
Oil production	14.86 m3/h
Final depth reached by drilling	3840 m
Last formation reached by drilling	El Atchane Sandstone

3.4.1. Core of the Well-4

Description

From 3022 to 3031 m: Dark gray to light gray sandstone, very fine to fine, sometimes medium, clayey, moderately consolidated to friable with fine changed from dark gray clay to black and gray-green, silty, soft to hard.

From 3031 to 3040 m: Dark gray to light gray sandstone, very fine to fine, sometimes medium, clayey, moderately consolidated to friable with fine changed from dark gray clay to black and gray-green, silty, soft to hard.

From 3064 to 3072.40 m: White to white gray sandstone, fine to very fine, sub-angular to sub-rounded, silico-clayey, consolidated to friable, slightly micaceous, locally gloconious with intercalations of millimetric stratification of gray to gray-white Siltstone, micaceous sometimes green, gloconious.

Fluorescence F1+F2: Whitish to yellowish / Yellowish at the periphery, brown in the center.

Visual porosity: Low.

From 3072.40 to 3082 m: Red-brown to brown clay, silty, indurated.


3026
3027
3032
3033
3022
Top Core 1

Figure. II.17: core pic of well 4

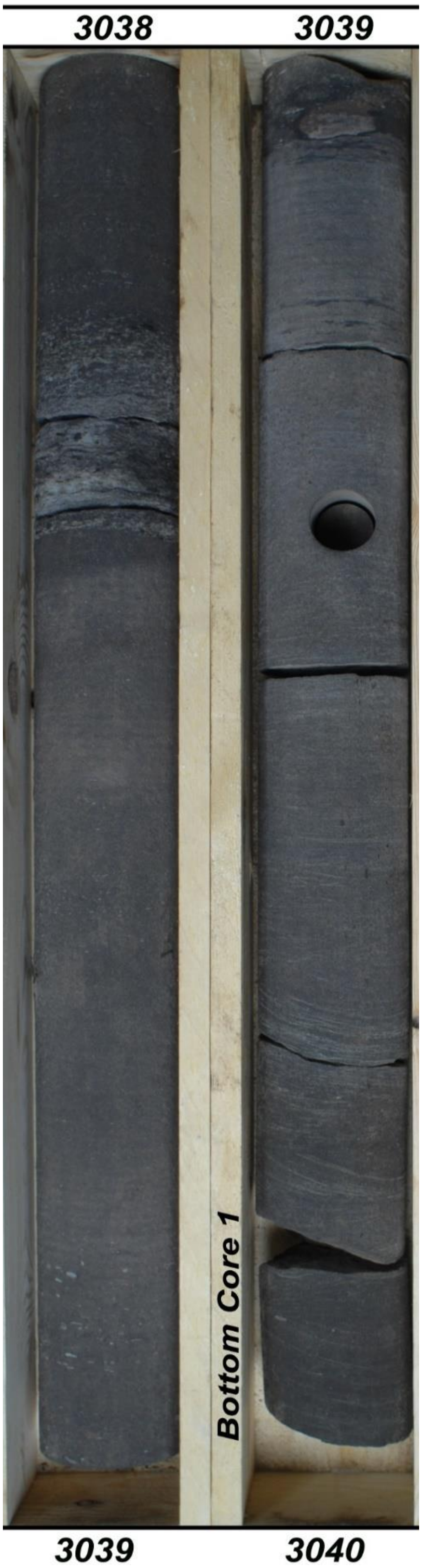


Figure. Ⅱ.17: core pic of well 4

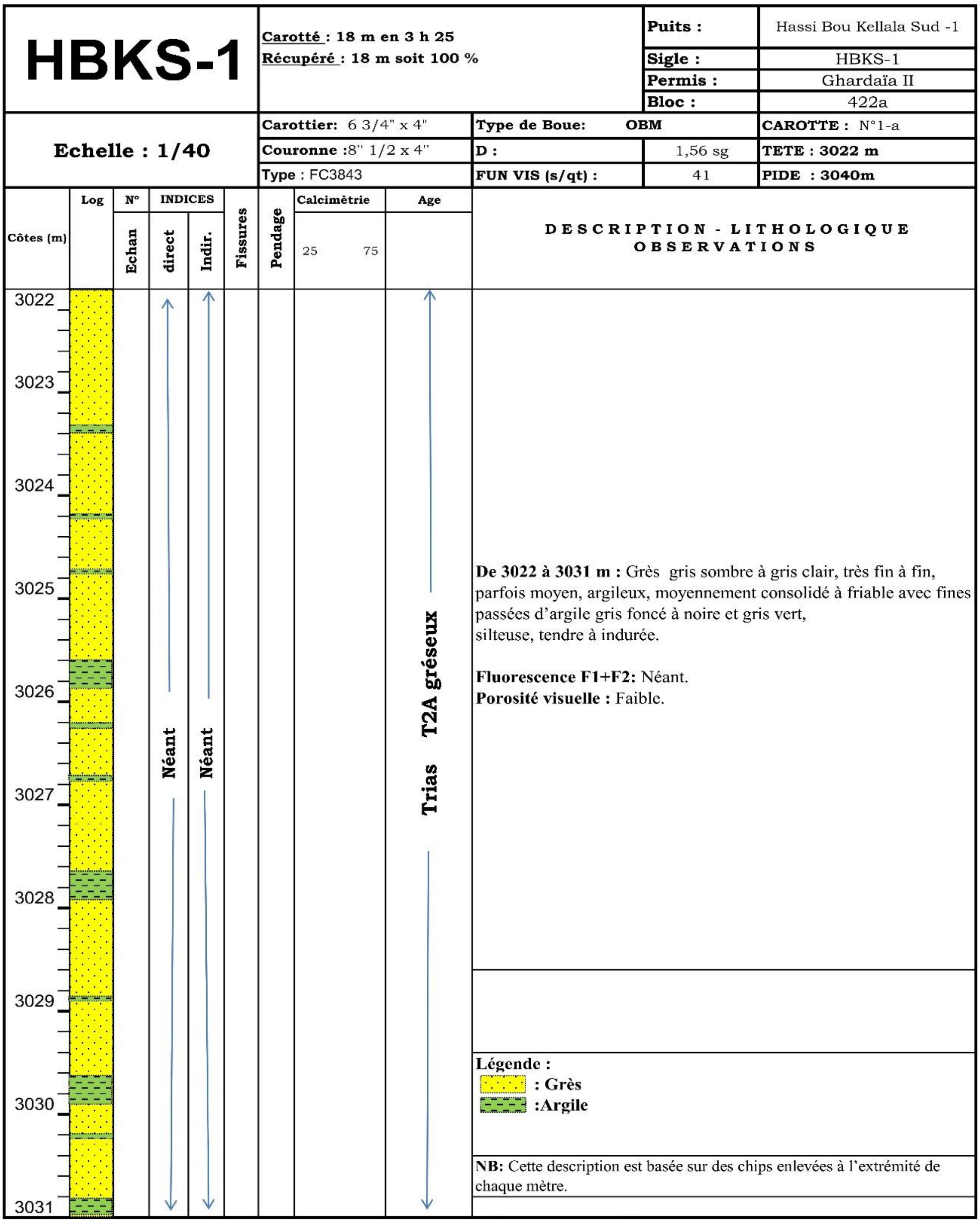


Figure.II.18: the core file of the well 4 [20]

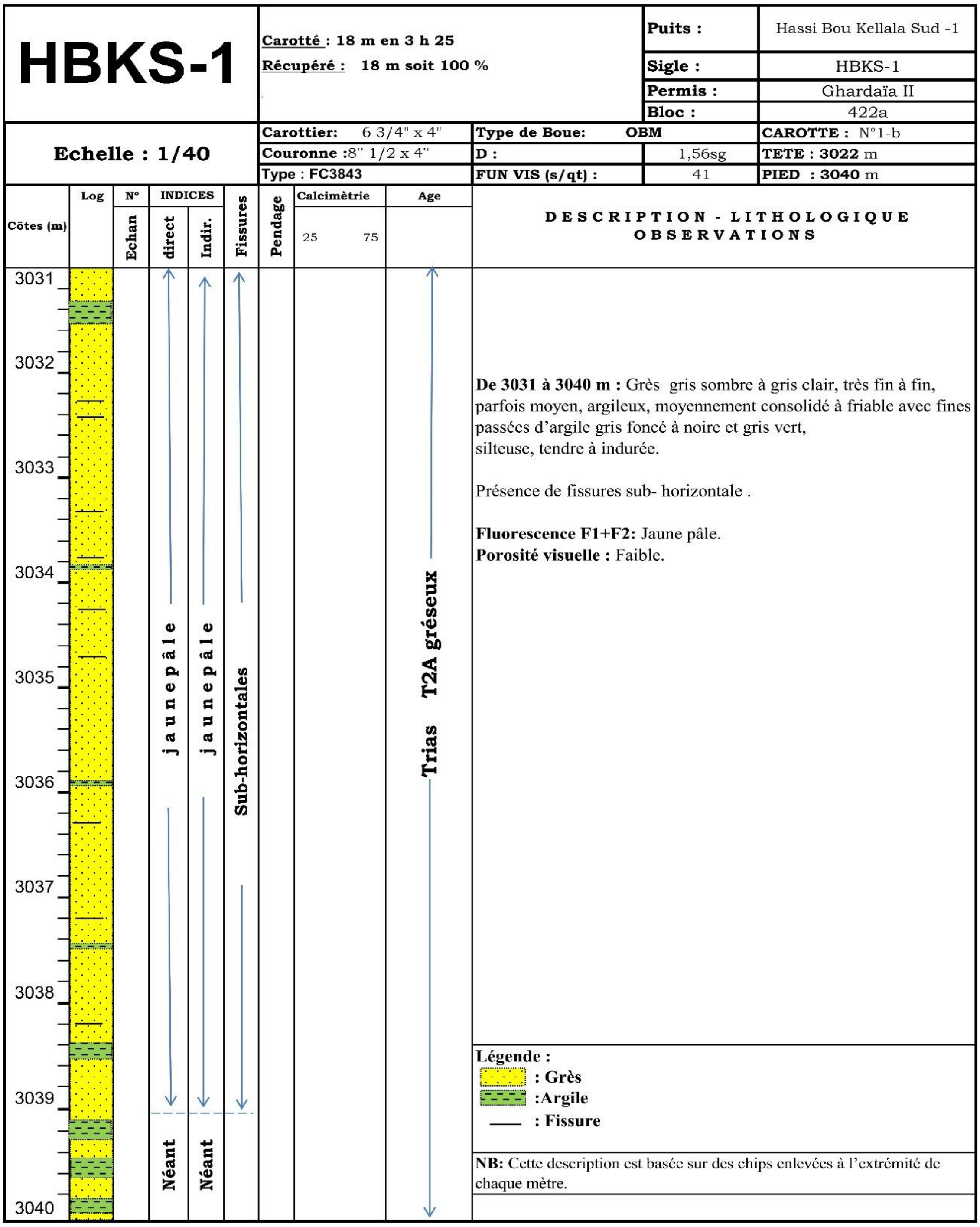


Figure.II.19: the core file of the well 4 [20]

3.5. Well-5

Table II.5: Some data on the Well-5.

Layer	Interval value
Base of the Lower Series	3033 m
Lower Series Roof	3051 m
Bottom Series Thickness	18 m
Gas production	1012 m^3/h
Oil Production	8,59 m^3/h d’
Final depth reached by drilling	3260 m
Last formation reached by drilling	Argileous Micros

3.5.1. Core of the Well-5

Description

From 3033 to 3040 m: Brown to red-brown sandstone, beige gray, very fine to fine, medium in places, rarely coarse, silico clayey to clayey, moderately consolidated.

Presence of horizontal and oblique stratifications.

From 3040 to 3042 m: Beige to beige-white, light gray, very fine to fine and medium sandstone, clayey to moderately hard clayey silico.

Presence of gray-green clay nodules.

Horizontal and oblique stratifications.

From 3042 to 3045 m: Gray beige sandstone, white beige, light gray, very fine to fine and medium, sometimes coarse, clayey to silico clayey, moderately to good consolidated.

Presence of horizontal stratifications.

From 3045 to 3051 m: Beige to beige-gray sandstone, locally dark gray, very fine to fine, sometimes medium, silico-clayey to clayey, moderately to well consolidated, with gray-green to light gray clay, silty, soft to hard.

Presence of oblique and horizontal stratifications.

From 3033 to 3037 m: Brown to red-brown sandstone, very fine to fine, medium, silico-clayey, friable to moderately consolidated.

From 3037 to 3042 m: Light gray sandstone, very fine to fine, medium, silica clay, friable to moderately consolidated.

From 3042 to 3050 m: Light gray sandstone, fine to medium, silico-clayey, friable to moderately consolidated, bituminous locally changed from gray to gray clay clear, soft to indurated, micaceous, silty.

From 3050 to 3051 m: Gray to light gray clay, soft to hardened, micaceous, silteuse.

Figure. II.20: core pic of well 5

Figure.Ⅱ.20: core pic of well 5

Figure. Ⅱ.20: core pic of well 5

Figure. Ⅱ.20: core pic of well 5

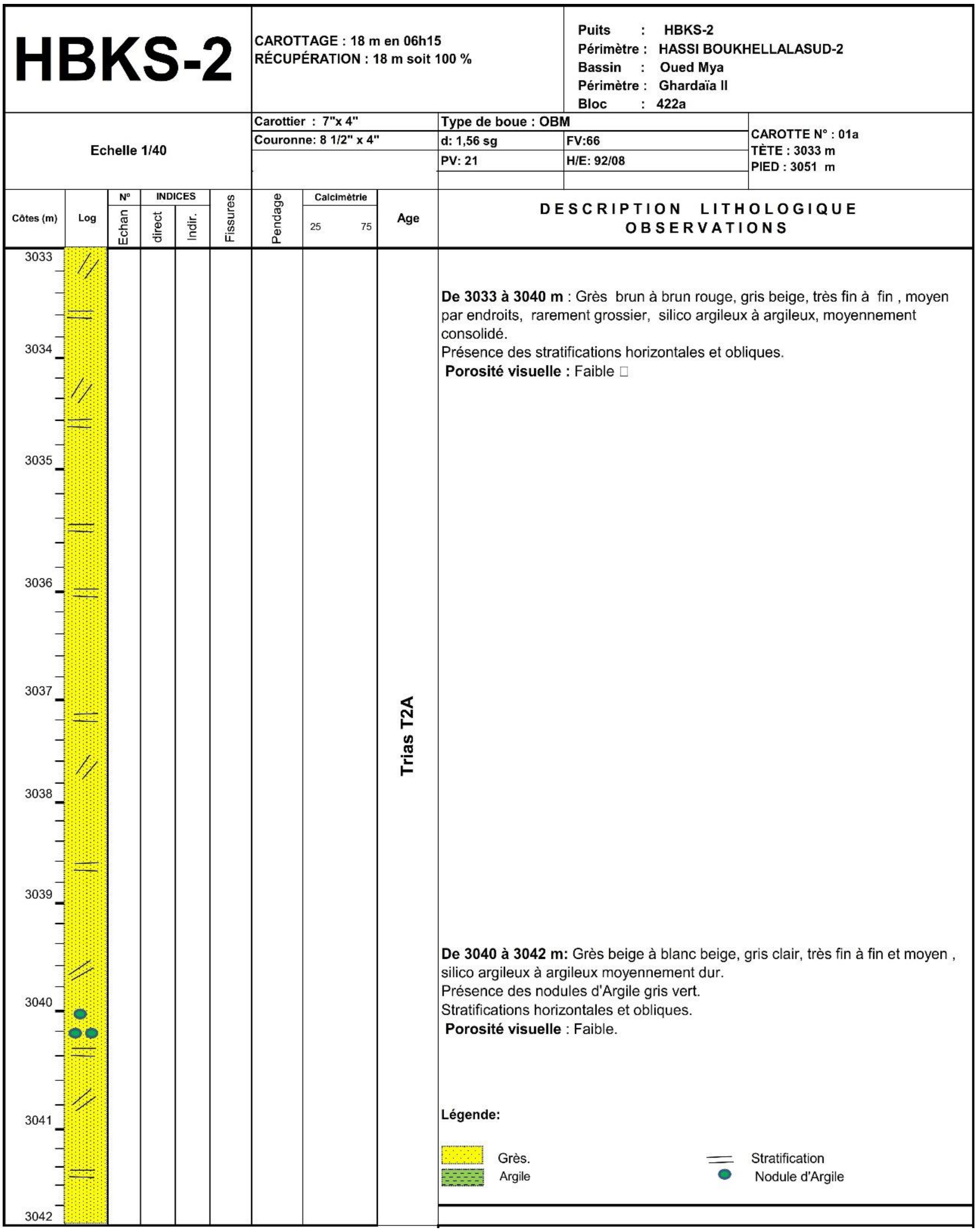


Figure.II.21: the core file of the well 5

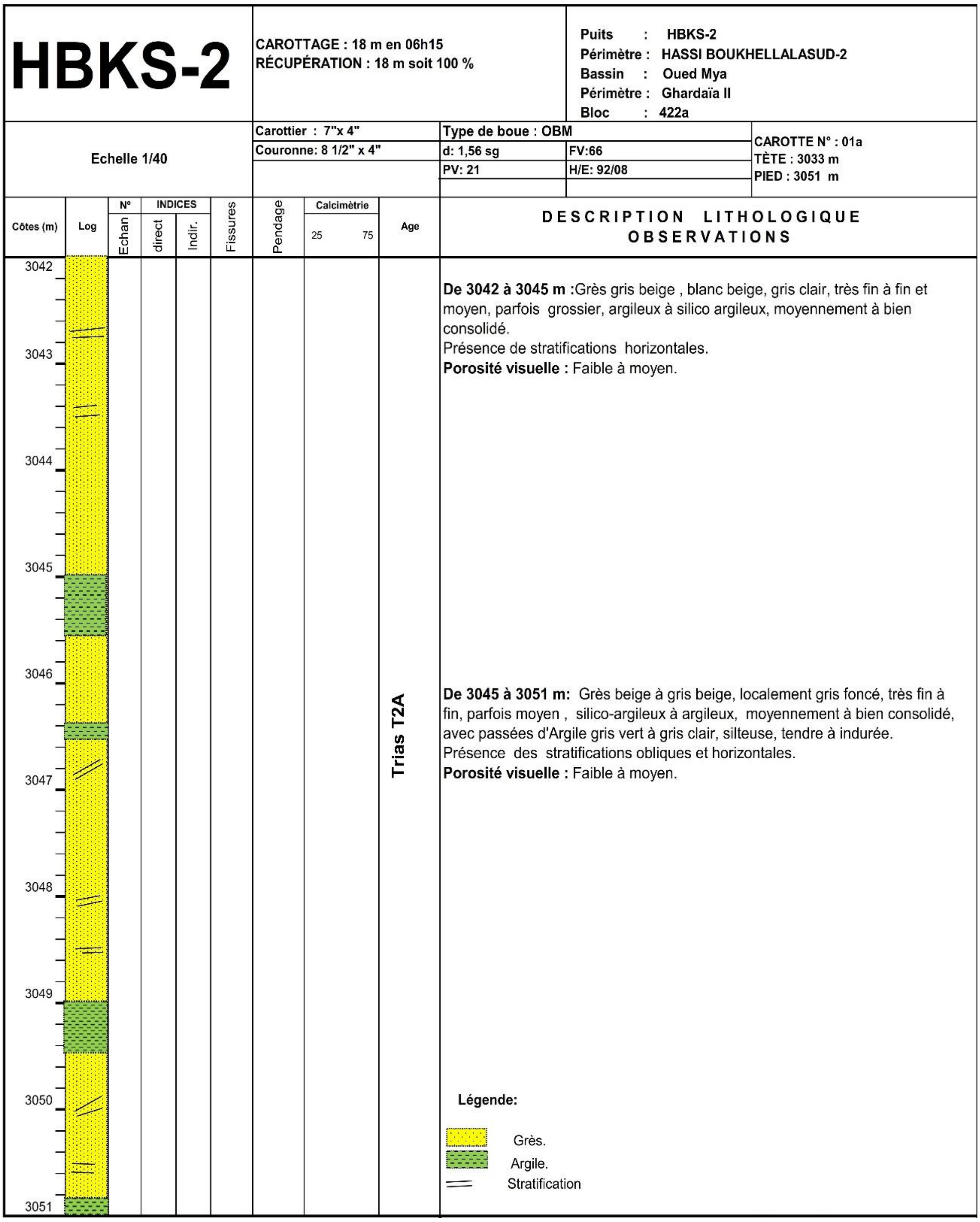


Figure.II.22: the core file of the well 5 [20]

4. Deposition environment

We have identified three depositional environments that regulated sedimentation in the Lower Triassic series based on the findings of core analysis, the facies found in all wells, and the sedimentary features identifying the corresponding locations.

These habitats are as follows:

- **Braided fluvial channels**

The very fine-grained, erosive base conglomeratic sandstones with oblique trough cross-stratifications highlighted by clay pebbles, indicating channel fill, make up the facies seen in our cores. These are covered in beds of gray to dark gray, fine- to medium-grained, brown sandstones. At the base of these beds are quartzitic sandstones with erosive bases, oblique and trough cross-stratifications, and conglomerates of green clay pebbles with current ripples at the top. Braided fluvial systems are characterized by this facies association.

- **Floodplain**

When channels overflow during times of floods and fine, clayey sediments settle, floodplains are created. This facies is characterized by layers of silts and fine sandstones scattered among variegated grayish-green, black, and reddish-charcoal micaceous clays with current ripples.

- **Alluvial plain**

The facies found in our cores are composed of extremely well-sorted fine sandstones with conglomerates of dark gray to black and greenish-gray clay pebbles that exhibit cross- and oblique stratifications. The alluvial plain is also characterized by very silty, violet-tinged, oxidized clays that range in color from reddish-brown to locally greenish-gray.

5. The paleogeographic structure

The Lower Triassic series is being deposited in the Boukhellala region in accordance with the basin's general sedimentation pattern, which is thought to represent the infilling of a sizable paleovalley (filling in topography that was left over from the Hercynian phase). The terrain was nearly horizontal and peneplained as a result of sedimentation continuing until the top of the infill reached the same level as the erosion surface (Hassi-Messaoud high).

In our study area, continental deposits have left their mark on the Lower Triassic sequence. In fact, the majority of the series' depositional habitat is braided fluvial. On the other hand, additional deposits from alluvial plains have been found. It is thought that the sequences' green clay intervals are connected to channel overflow during times. .

Conclusion:

At lower levels of the series, coarse sandstones or conglomerates are more common, and the facies display a cyclical pattern of fluctuation. Higher up the series, there is a change to sandstones with finer to very finer grains that are frequently scattered with clay layers. Different sequences typical of fluvial environments are shown by these alternating layers of sedimentary rock, which are distinguished by their composition and size of grain. This cyclical pattern indicates that depositional circumstances have changed over time, most likely as a result of variations in the river system's supply of energy and sediment.

With its substantial trough cross-bedding, the series under consideration primarily depicts a braided fluvial depositional environment, suggesting dynamic flow conditions within the river system. Sediment transport and deposition are intricately entwined in this environment, with unique sub-environments such channel margins, point bars, and bars contributing to the overall sedimentary architecture. Moreover, in addition to these fluviatile facies, the sequence also includes sedimentary deposits linked to alluvial plains, which have finer-grained sediments and possibly overbank flooding evidence, and deposits linked to alluvial cones, which have coarser-grained sediments and cone-shaped geometries. This complex depositional framework reveals a dynamic landscape that is shaped over time by changing hydrological conditions and dynamics of the sediment supply.

The primary force controlling sedimentary processes appears as climate in the tectonically stable Lower Triassic series. This area experiences protracted dry seasons and a semi-arid environment, which have a big impact on sedimentation patterns. The different seasonal oscillations that arise from these climatic circumstances have an impact on depositional patterns, erosion rates, and sediment movement. Consequently, this period's sedimentary record provides important insights into historical environmental dynamics and landscape change.

Chapter III:

Petrophysical Study

Chapter III
Petrophysical Study

Introduction

The fluvial environment is ideal for the formation of saline reservoirs, which coincides with the Lower Triassic deposits in our study area. Therefore, the study of the quality of this reservoir requires a phenotypic study. Indeed, in order to understand and predict the quality of reservoir production, it is necessary to understand the petrophysical parameters (porosity, permeability, saturation) of hydrocarbon reservoirs.

Porosity and permeability are two fundamental parameters that characterize a petroleum reservoir and are mostly determined by the depositional environment, sediment type and diagnostics. To better characterize the study area, we rely on petrophysical data of porosity and permeability.

1. Petrophysical parameters

1.1 Porosity (Φ)

It is defined as the result of dividing the total volume of voids in the rock (Vp) by the total volume of the rock. Although it is most commonly expressed as a percentage (%), it can also be expressed as a ratio (17), represented by:

$$\Phi = \frac{V_p}{V_t} = \frac{V_t - V_s}{V_t}\,[\%] \qquad \text{Eq.001}$$

Φ: porosity in (%).

Vp: the volume of the pores in (m^3) and Vt: the total volume of the rock in (m^3).

Vs: volume occupied by solid elements (m^3).

In the interpretation of the log, two different definitions of porosity are used:

- **The useful porosity (Φu):** The useful (or connected or effective) porosity of the sample is the ratio of the volume of the pores, which are connected together to the total volume of the sample. There may be pores that do not communicate with each other. (17)
- **Residual porosity (Φr):** Due to unconnected pores alone. These can be either intra-crystalline voids (fluid or gaseous inclusions for example), or intercrystalline but connected to the rest of the porous network by too narrow accesses. The useful porosity is generally 20 to 25% lower than the total porosity. (17)

Table III.1: Class of porosity according to Monicard.

Type	Interval value
Low :	$\phi < 5\%$
Poor :	$5\% < \phi < 10\%$
Average :	$10\% < \phi < 20\%$
Good :	$20\% < \phi < 30\%$
Very good :	$\phi > 30\%$

1.2. Permeability (K)

The permeability of a rock is defined by its ability to allow the flow of fluids contained in its porous space. The latter allows fluids to move only to the extent that its pores are interconnected; thus, it is permeable. Permeability is determined by Darcy's law:

$$K = \frac{Q\mu L}{S(p_1 - p_2)} [mD] \qquad \text{Eq.002}$$

Q: the volume of water flowed per unit of time [cm3/s in CGS units].

P_1: incoming pressure [atm in CGS units].

P_2: the outgoing pressure [atm in CGS units].

S: the surface area of the filter layer [cm2 in CGS units].

K: permeability [Darcy in CGS units].

μ: the viscosity of the fluid [centipoise in CGS units] and

L: the length over which the flow takes place [cm in CGS units].

❖ Types of permeability

- **Absolute permeability (K):** It is the permeability measured with only one fluid present, such as air, water, or oil. (19)
- **Effective permeability (ke):** When a fluid exists in the porosity of a rock (at a different saturation than the minimum irreducible saturation), the effective permeability of that fluid is measured using a second fluid. (19)
- **Relative permeability (kr):** This is the relationship between effective permeability and specific permeability. The permeability of a given fluid varies directly with its saturation in the rock and is expressed as a percentage of fluid movement compared to another.(18)

The range of permeability encountered is very wide, it varies from 0.1md to more than 10 Darcy to better specify the values we accept [17]:

Table III.2: Class of permeability according to Monicard.

Type	Interval value
Very low:	$K < 1\, mD$
Low :	$1\, mD < K < 10\ \ mD$
Mediocre :	$10\, mD < K < 50\ \ mD$
Average :	$50\, mD < K < 200\, mD$
Good :	$200\, mD < K < 500\, mD$
Excellent :	$500\, mD < K < 1000\, mD$
High permeability	$K > 1000\, mD$

1.3. Saturation

The ratio of the volume occupied by this fluid to the total volume of the pores is called fluid saturation of a formation. It is designated by the letter S. it is expressed as a percentage (%). (18)

-If this fluid is water, we will then speak of Sw:

$$\text{Sw} = \frac{V_w}{V_p} \qquad \text{Eq.003}$$

Where:

Vw= Volume of water (m^3).

Vp= Pore volume (m^3).

If there are also hydrocarbons, we have:

$$\text{Sw} + Shc = 1 \qquad \text{Eq.004}$$

$$\text{Shc} = \text{Soil} + \text{Sg} \qquad \text{Eq.005}$$

Shc: hydrocarbon saturation, which can be gas or oil or both at the same time (%).

2.Diagraphy

- **Definition:** A logging(diagraphy) is any continuous recording based on the depth of variations of a given characteristic of the formations crossed by a borehole. The recording is done from the surface using a probe lowered at the end of a cable fitted with electrical conductors. (19)

Currently, there are around 35 different recordings without counting the auxiliary operations carried out at the end of the cable such as:

- Lateral coring
- Tests training
- Perforations

- **Diagraphy types**

We study the principles of application and interpretation of the following logs:

- Electrical logs:

❖ Spontaneous polarization
❖ Conventional resistivity logs
❖ Induction

- Focused logs:

❖ The laterolog;
❖ The dual laterolog

-Focused micrographs:

❖ The microlog and the microlaterolog
❖ The proximity log
❖ The SFL microphone

- Nuclear logs :

❖ Natural gamma ray logs
❖ Gamma gamma logs
❖ Neutron logging

- Acoustic logs :

❖ Sonic
❖ CBL
❖ VDL

- Dip logs:

❖ HDT

- Various logs

❖ The caliper
❖ Thermometry
❖ Lateral coring
❖ Perforations

- Cable end tests:

❖ FIT
❖ The RFT

3. Data acquisition

In order to understand the spatiotemporal evolution of the two petrophysics parameters (porosity and permeability) of the study area, we used the data listed in the table below:

Table III.3: Average values of porosity and permeability in each well in Boukhellala area

Well Symbol	**Well abbr.**	**Porosity Φ (%)**	**Permeability K (mD)**
W1	HBKN1	3.78	0.17
W2	HBKN2	16.80	136.31
W3	HBKS1	14.04	163.15
W4	HBKS2	15.55	424.43
W5	HBKS3	8.41	8.24

4. Data processing

We used the software Surfer to create iso-value maps to understand the distribution of porosity and permeability in the study area, as well as the software Origin Pro to obtain curves to understand the evolution of the two parameters in the Trias series inferior and the software Statistica to obtain some statistical information and the correlation between the two parameters in the studied wells.

4.1 Interpretations of the porosity and permeability curves in the wells studied

4.1.1. Discussion of the petrophysical parameters of the HBKN1 well

1- Evolution of permeability as a function of depth:

The curve shows a positive trend in permeability (mD) with increasing depth (meters) for borehole HBKN1. This means that as you go deeper into the borehole, the permeability of the rock generally tends to increase.

Here are some possible reasons for this trend:

- **Fractures and Pores:** Deeper rock layers may be more fractured or contain larger pores due to increased pressure and geological processes. These larger or more connected pores and fractures can allow fluids to flow through more easily, resulting in higher permeability.
- **Mineralogy:** The mineral composition of the rock might change with depth. Deeper layers may contain minerals that are more permeable or have undergone dissolution, creating larger pore spaces.
- **Weathering:** The surface layers of rock are often more weathered and can have reduced permeability due to the filling of pores with smaller particles or sealing by weathering products. Deeper layers may be less affected by weathering, resulting in higher permeability.

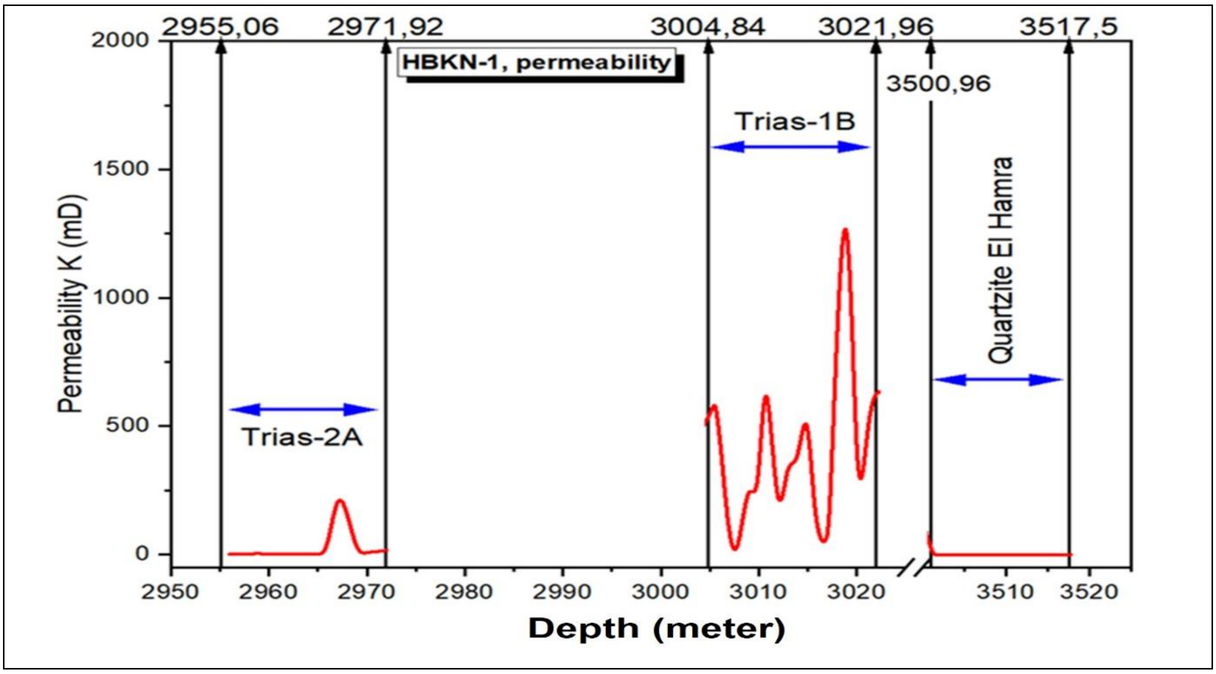


Figure. 1: Curve of permeability evolution vs depth at HBKN1 well.

It is important to note that the curve only shows data from a single borehole, and permeability variations can be complex. Other factors not reflected in this curve, such as local geology and depositional environment, can also influence permeability.

Here are some additional observations from the curve:

- The curve may not be perfectly linear. Permeability may increase gradually or in steps throughout the borehole depth.

- There may be local variations or fluctuations in permeability superimposed on the overall increasing trend.

Overall, the positive trend suggests that deeper zones in borehole HBKN1 are generally more permeable than the shallower zones. However, a more detailed analysis of the geology and additional data points would be needed to fully understand the factors controlling permeability variations in this borehole.

2- Evolution of porosity as a function of depth:

It appears the porosity (%) in borehole HBKN1 shows a somewhat scattered pattern, with no clear trend across the increasing depth (meters).

Here are some observations about the porosity-depth relationship in HBKN1:

- **No clear trend:** There is no apparent consistent increase or decrease in porosity with depth. This suggests that the porosity characteristics may not be strongly influenced by the depth in this particular borehole.
- **Scattered data:** The data points show variations in porosity throughout the borehole, with no clear pattern. This variability could be due to several factors, independent of depth.

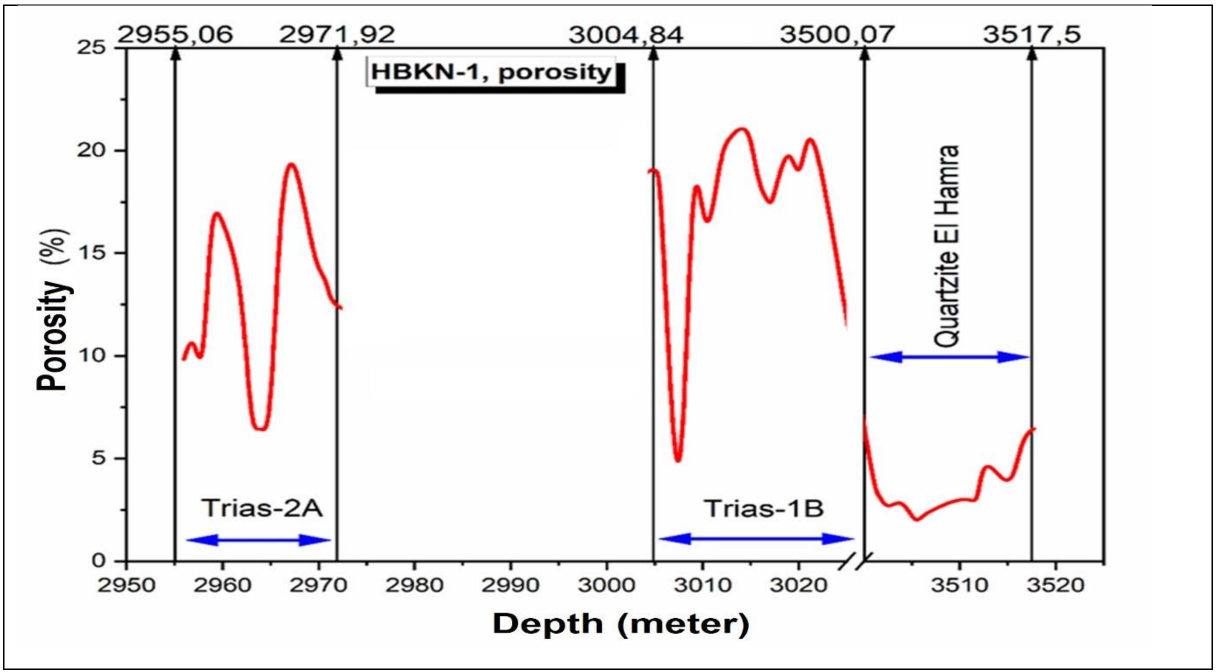


Figure. 1: Curve of porosity evolution vs depth at HBKN1 well.

Possible reasons for the lack of a clear trend and the scattered data include:

- **Geological heterogeneity:** The rock formation penetrated by the borehole may not be uniform. There could be variations in rock types or depositional environments within the borehole depth, leading to changes in porosity throughout.

- **Fractures and secondary porosity:** Fractures, vugs, or other secondary porosity features can significantly influence porosity but may not be uniformly distributed throughout the borehole. Their presence or absence at different depths can cause the observed scatter in the data.
- **Measurement limitations:** Porosity measurements themselves may have some inherent variability.

It is important to consider that a single borehole might not capture the entire range of porosity variations within a geological formation.

Here are some additional points to note:

- The porosity values in the image seem to range from [1.68] % to [22.42] %, which can be helpful to know the overall porosity range in HBKN1.
- While there is no clear depth-related trend, some intervals in the borehole might show localized zones of higher or lower porosity based on the data spread.

Overall, the image suggests that the porosity in borehole HBKN1 is not strongly influenced by depth. The variability observed is likely due to geological heterogeneity and the presence of secondary porosity features.

3-Permability of the HBKN1 well

The tables (Table 4 and 5) and diagrams (Fig.1) show a descriptive statistical analysis of the permeability values measured in borehole HBKN1. The analysis includes a table summarizing the descriptive statistics, a categorization of the permeability values, and a normal P-plot.

Table III.4: Descriptive statistics for HBKN1 borehole permeability.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Permeability K (mD)	141	256,07	0,001	2370,00	487,79

The table of descriptive statistics shows that the mean permeability is 256.07 millidarcies (mD), with a standard deviation of 487.79 mD. The minimum permeability is 0.001 mD and the maximum permeability is 2370 mD.

The categorization of the permeability values shows that the majority of the values (84.3%) fall between 0 and 500 mD. There are also a significant number of values between 500 and 1000 mD (7.09%) and between 1000 and 1500 mD (3.55%). The remaining values (4.96%) are above 1500 mD.

Table III5: Categorization of permeability at HBKN1 borehole.

Category	Frequency table: Permeability K (mD) (Spreadsheet1) K-S d=,29980, p<,01 ; Lilliefors p<,01					
	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
-500,000<x<=0,000000	0	0	0,00000	0,0000	0,00000	0,0000
0,000000<x<=500,0000	119	119	84,39716	84,3972	84,39716	84,3972
500,0000<x<=1000,000	10	129	7,09220	91,4894	7,09220	91,4894
1000,000<x<=1500,000	5	134	3,54610	95,0355	3,54610	95,0355
1500,000<x<=2000,000	4	138	2,83688	97,8723	2,83688	97,8723
2000,000<x<=2500,000	3	141	2,12766	100,0000	2,12766	100,0000
Missing	0	141	0,00000		0,00000	100,0000

The normal P-plot shows that the permeability values are approximately normally distributed. This is important because it means that the data can be analyzed using parametric statistical methods.

In conclusion, the permeability values in borehole HBKN1 are relatively high, with a mean of 256.07 mD. The data is approximately normally distributed.

Overall, the results of the descriptive statistical analysis suggest that the permeability of borehole HBKN1 is relatively high. This could be due to a number of factors, such as the size of the pores in the rock, the degree of fracturing in the rock, and the presence of secondary porosity. More information would be needed to determine the cause of the high permeability.

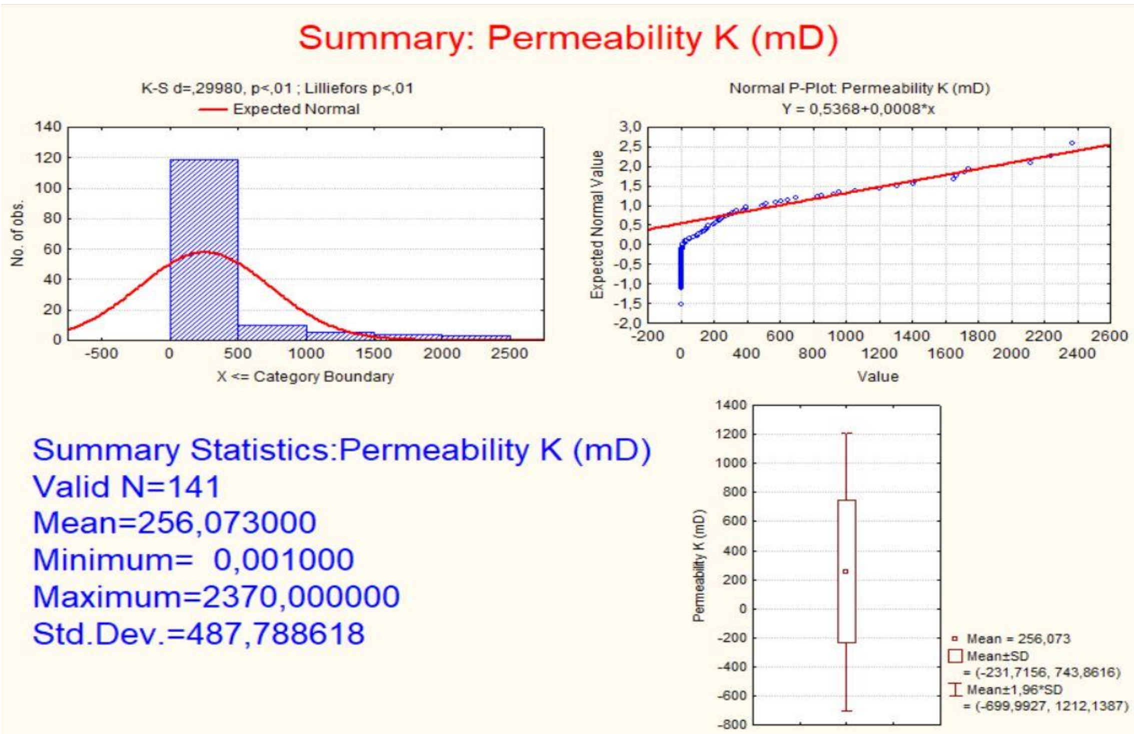


Figure.1: Summary diagrams of permeability statistics for borehole HBKN1.

4-Porosity of the HBKN1 well

The tables (Table 6 and 7) and diagrams (Fig.1) show a descriptive statistical analysis of the porosity values measured in borehole HBKN1. The analysis includes a table summarizing the descriptive statistics, a categorization of the porosity values, and a normal P-plot.

Table III.6: Descriptive statistics for HBKN1 borehole porosity.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Porosity Φ (%)	141	12,51	1,68	22,42	6,51

The table of descriptive statistics shows that the mean porosity is 12.51%, with a standard deviation of 6.51%. The minimum porosity is 1.68% and the maximum porosity is 22.42%.

The categorization of the porosity values shows that the most frequent porosity range is between 10% and 15% (37.59%), followed by 15% to 20% (36.17%) and 5% to 10% (17.73%). Only 19.86% of the measurements fall below 5% porosity.

Table III.7: Categorization of porosity at HBKN1 borehole.

Category	Frequency table: Porosity Φ (%) (Spreadsheet1) K-S d=,15168, p<,01 ; Lilliefors p<,01					
	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
-5,00000<x<=0,000000	0	0	0,00000	0,0000	0,00000	0,0000
0,000000<x<=5,000000	28	28	19,85816	19,8582	19,85816	19,8582
5,000000<x<=10,00000	25	53	17,73050	37,5887	17,73050	37,5887
10,00000<x<=15,00000	20	73	14,18440	51,7730	14,18440	51,7730
15,00000<x<=20,00000	51	124	36,17021	87,9433	36,17021	87,9433
20,00000<x<=25,00000	17	141	12,05674	100,0000	12,05674	100,0000
Missing	0	141	0,00000		0,00000	100,0000

The normal P-plot suggests that the porosity values are not normally distributed. This is because the data points do not fall close to the straight line on the plot. This means that the data may not be suitable for analysis using parametric statistical methods.

In conclusion, the porosity of borehole HBKN1 is highly variable, with a mean of 12.51% and a standard deviation of 6.51%. The data is not normally distributed.

Here are some additional points to consider:

The porosity of a borehole can vary depending on the depth of the borehole.

The porosity of a borehole can also be affected by the presence of fractures or other voids in the rock.

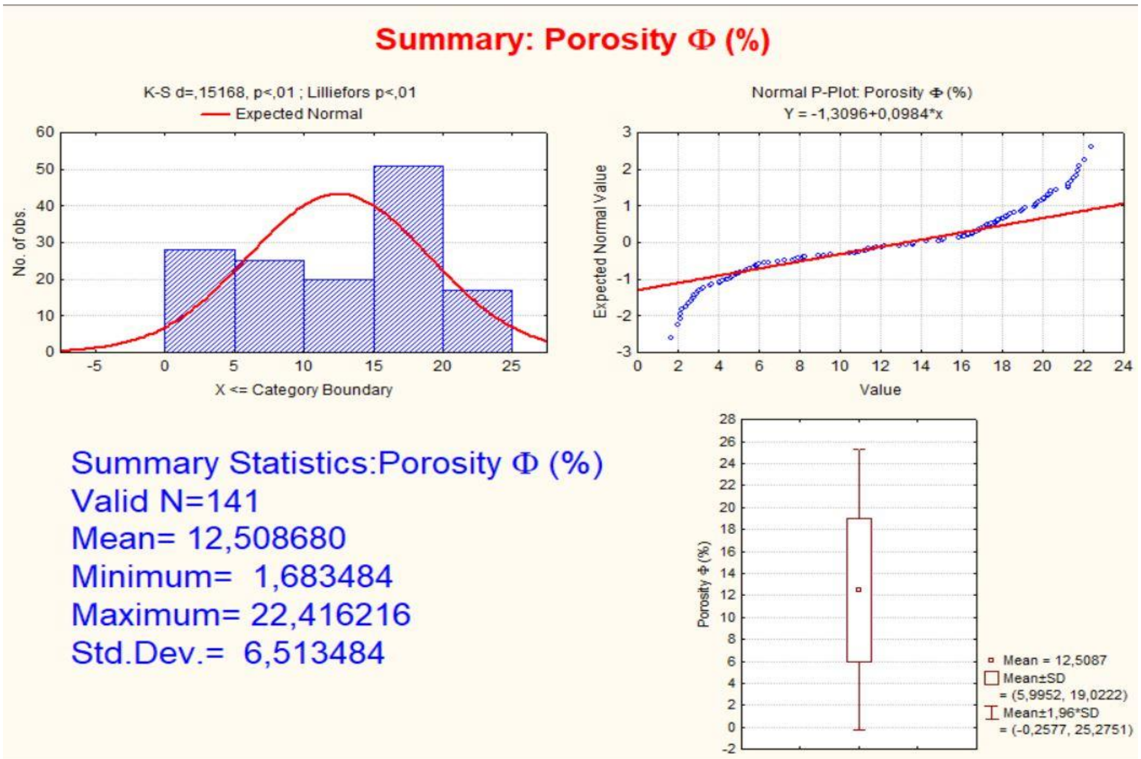


Figure.1: Summary diagrams of porosity statistics for borehole HBKN1.

5-Correlation between permeability and porosity at HBKN1.

The scatter plot shows the correlation between permeability and porosity values measured at borehole HBKN1. The x-axis represents permeability (in millidarcies) and the y-axis represents porosity (%).

The data points show a positive correlation between permeability and porosity. This means that there is a general trend of increasing permeability with increasing porosity. This is likely because higher porosity rocks have more connected pores, which allows fluids to flow through them more easily.

The correlation coefficient (r) for the data is 0.5592. This value indicates a moderate positive correlation. However, the data points also show a considerable amount of scatter. This means that there is not a perfect linear relationship between permeability and porosity. Other factors, besides porosity, can also affect the permeability of a rock.

In conclusion, the scatter plot shows a positive correlation between permeability and porosity in borehole HBKN1. However, the correlation is moderate and there is a significant amount of scatter in the data. This suggests that other factors, besides porosity, also play a role in controlling the permeability of the rock.

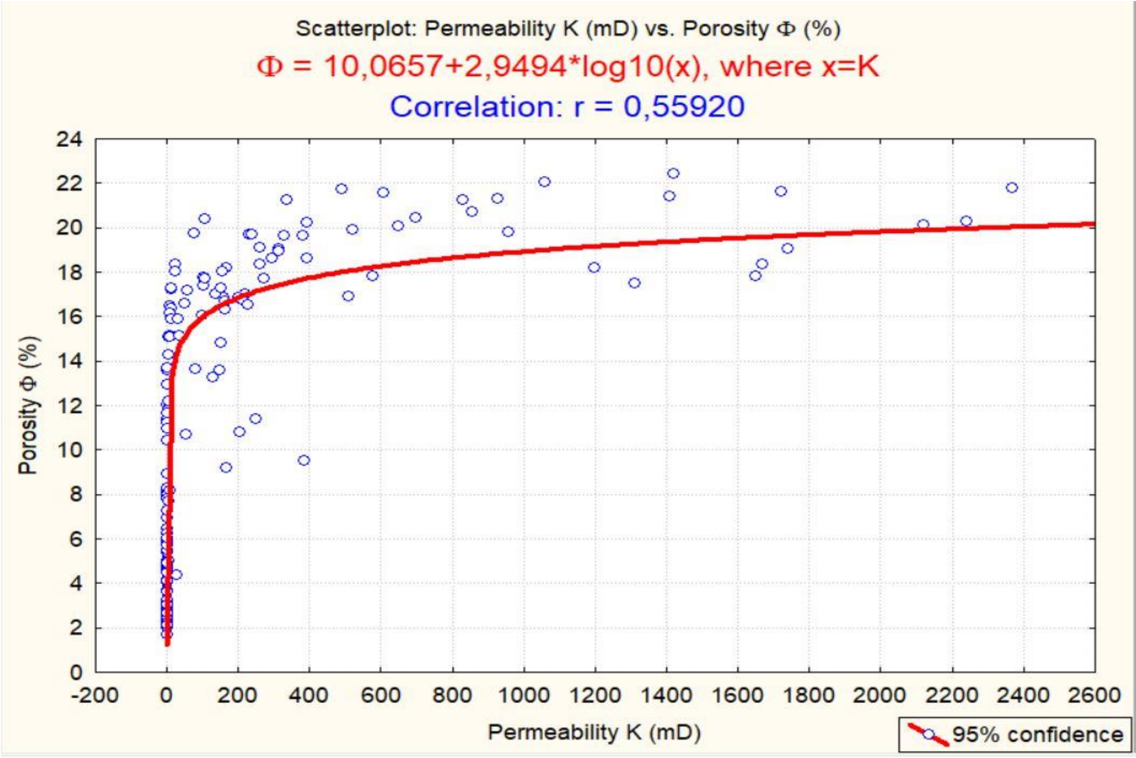


Figure. 3: Correlation diagram (scatter-plot) of permeability and porosity values measured at borehole HBKN1.

In conclusion, borehole HBKN1 exhibits moderate to high permeability (average 256.07 mD) and porosity (average 12.51%). The porosity data suggests variability but not a normal distribution, while permeability shows a normal distribution. A positive correlation exists between permeability and porosity, but it is moderate, indicating other factors influencing permeability besides pore space. These findings suggest a potentially good reservoir quality, but further investigation is needed to understand the contribution of factors other than porosity to permeability.

4.1.2. Discussion of the petrophysical parameters of the HBKN2 well

1- Evolution of permeability as a function of depth:

The curve shows a complex relationship between permeability and depth in borehole HBKN2. Here is a breakdown of the key observations:

- **Interval of Increasing Permeability:** At the beginning of the borehole (shallow depths), there is a possible interval where permeability increases with depth. This initial trend is similar to what was observed in borehole HBKN1.

- **Zone of Lower Permeability:** Following the initial increase, there appears to be a zone of generally lower permeability at mid-depths. This zone might represent a layer of less fractured or tighter rock with lower pore connectivity.
- **Deeper Interval with Fluctuations:** At greater depths, the permeability seems to fluctuate, with some intervals showing higher values and others remaining relatively low. This suggests a more heterogeneous subsurface formation in the deeper sections.

Possible Reasons for the Permeability Variations

The complex permeability profile in HBKN2 could be due to several factors:

- **Geological layering:** The borehole might be intersecting rock formations with varying permeability characteristics. The shallower increasing permeability zone could be followed by a less permeable layer (e.g., tighter sandstone or shale) and then more fractured or porous zones at greater depths causing the fluctuations.
- **Fractures and secondary porosity:** The presence, size, and connectivity of fractures and vugs can significantly influence permeability. The initial increase and later fluctuations might reflect zones with more fractures or vugs at specific depths.
- **Dissolution or weathering:** Deeper zones might be more influenced by dissolution processes creating larger pores, or alternatively, shallower zones might be more weathered, reducing permeability due to pore filling by secondary minerals.

Additional Considerations

- The data resolution (number of data points) in the image might limit the ability to see finer details in the permeability variations.
- Local geological features or events not reflected in a single borehole could also influence the permeability profile.

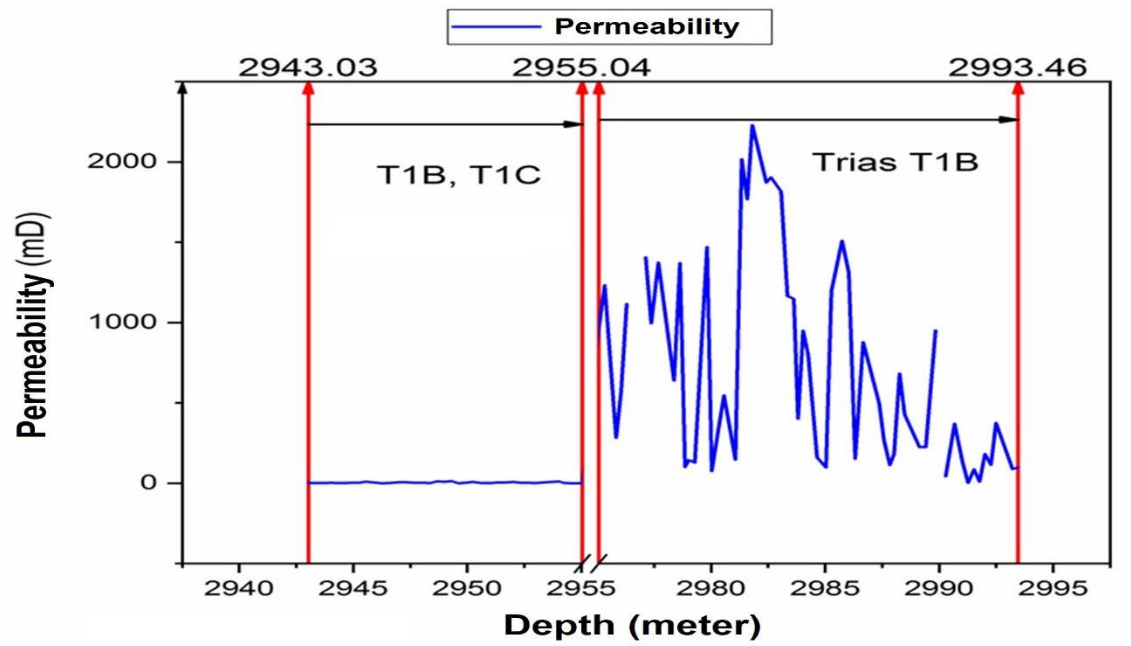


Figure. 1: Curve of permeability evolution vs depth at HBKN2 well.

Conclusion

The permeability-depth curve for borehole HBKN2 suggests a more complex scenario compared to HBKN1. While there is a possible initial increase in permeability with depth followed by a lower permeability zone, the deeper section exhibits fluctuations, indicating variations in the rock formation or the presence of secondary porosity features. A more comprehensive understanding of the permeability profile would likely require additional data points and geological information about the borehole location.

2- Evolution of porosity as a function of depth:

The porosity-depth curve in borehole HBKN2 exhibits a scattered pattern with some interesting trends:

- **Possible Zonation:** There appears to be a possible zonation with intervals of higher and lower porosity throughout the borehole. For example, a zone of potentially higher porosity is observed between [insert depth range based on the image, e.g., 2940-2960 meters] and another zone of potentially lower porosity between [insert depth range based on the image, e.g., 2980-3000 meters]. However, due to the scatter in the data, these zonations are not definitive and require cautious interpretation.
- **Scattered Data:** Overall, the data points show considerable variability throughout the borehole, similar to what was observed in borehole HBKN1. This suggests that porosity is not necessarily strongly controlled by depth in this particular well.

Possible Reasons for the Observations

There are several reasons why the porosity-depth relationship might appear scattered and potentially zoned:

- **Geological Heterogeneity:** The rock formation penetrated by the borehole may not be uniform. The borehole might be intersecting rock layers with different depositional environments or rock types, leading to variations in porosity throughout its depth.
- **Secondary Porosity:** Fractures, vugs, or other secondary porosity features can significantly influence porosity but may not be uniformly distributed through the borehole. Their presence or absence at different depths can cause the observed scatter and potentially zones of higher porosity where these features are more frequent.
- **Measurement Variability:** Porosity measurements themselves may have some inherent variability, which can contribute to the scattered pattern in the data.

Additional Considerations

- The porosity values in the image seem to range from [0.54] % to [23.35] %, which can be helpful to know the overall porosity range in HBKN2.
- While there is no clear overall trend with depth, the possible zonation suggests that some intervals in the borehole might have characteristic porosity ranges due to the factors mentioned above.

Similarities and Differences with Borehole HBKN1

The porosity-depth relationship in HBKN2 shows some similarities to borehole HBKN1:

- Both boreholes lack a clear overall trend of increasing or decreasing porosity with depth.
- Both exhibit scattered data points throughout the borehole depth.

However, HBKN2 also shows a possible zonation with intervals of potentially higher and lower porosity, which is not as evident in HBKN1.

Conclusion

The image suggests that porosity in borehole HBKN2 is not necessarily influenced by depth. The variability observed is likely due to geological heterogeneity, the presence of secondary porosity features, and potential measurement variations. The possible zonation hints at intervals with distinct porosity characteristics, but more data and geological context would be needed to confirm this observation.

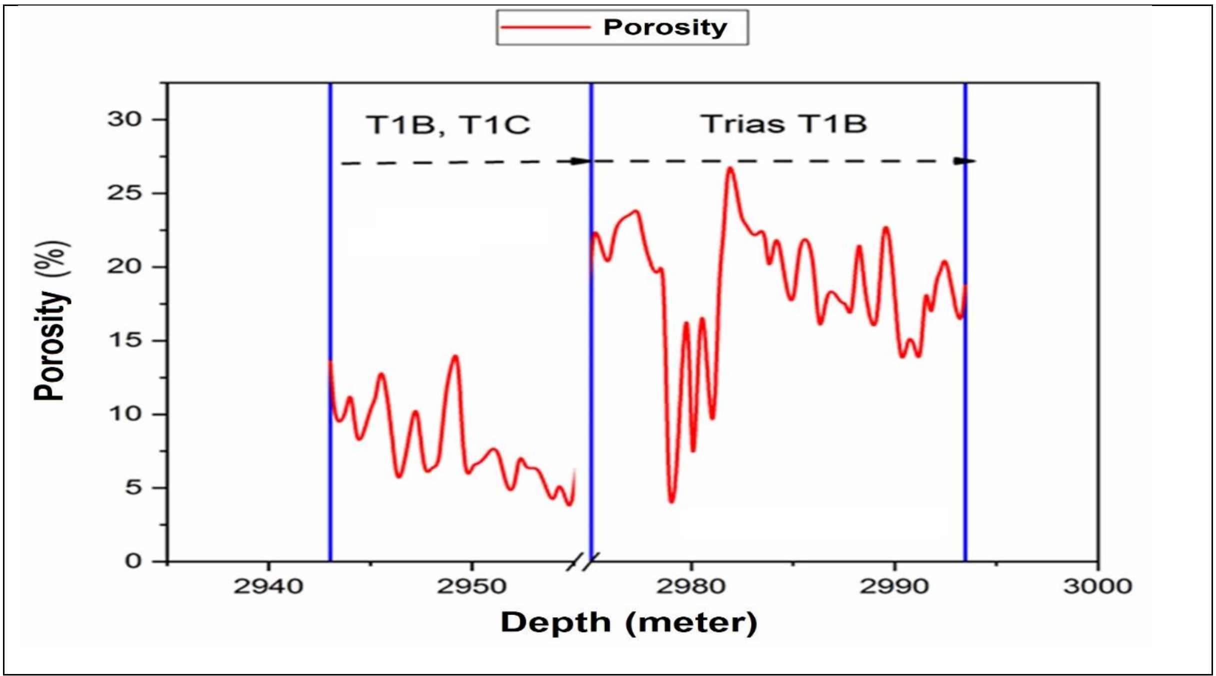


Figure. 1: Curve of porosity evolution vs depth at HBKN2 well.

3-Permability of the HBKN2 well

The tables (Table 8 and 9) and diagrams (Fig.1) show a descriptive statistical analysis of the permeability values measured in borehole HBKN2. The analysis includes a table summarizing the descriptive statistics, a categorization of the permeability values, and a normal P-plot.

Table III.8: Descriptive statistics for HBKN2 borehole permeability.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Permeability K (mD)	28	217,89	0,063	2164,74	494,86

The table of descriptive statistics shows that the mean permeability is 256.07 mD, with a standard deviation of 487.79 mD. This is very similar to the results for borehole HBKN1. The minimum permeability is 0.001 mD and the maximum permeability is 2370 mD, which is also very similar to borehole HBKN1.

The categorization of the permeability values shows that the distribution of permeability values in borehole HBKN2 is very similar to that in borehole HBKN1. The majority of the values (84.3%) fall between 0 and 500 mD. There are also a significant number of values between 500 and 1000 mD (7.09%) and between 1000 and 1500 mD (3.55%). The remaining values (4.96%) are above 1500 mD.

Table III.9: Categorization of permeability at HBK2 borehole.

Category	Frequency table: Permeability K (mD) (Spreadsheet1) K-S d=,32990, p<,01 ; Lilliefors p<,01					
	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
-500,000<x<=0,000000	0	0	0,00000	0,0000	0,00000	0,0000
0,000000<x<=500,0000	25	25	89,28571	89,2857	89,28571	89,2857
500,0000<x<=1000,000	1	26	3,57143	92,8571	3,57143	92,8571
1000,000<x<=1500,000	0	26	0,00000	92,8571	0,00000	92,8571
1500,000<x<=2000,000	1	27	3,57143	96,4286	3,57143	96,4286
2000,000<x<=2500,000	1	28	3,57143	100,0000	3,57143	100,0000
Missing	0	28	0,00000		0,00000	100,0000

The normal P-plot shows that the permeability values in borehole HBKN2 are approximately normally distributed, similar to borehole HBKN1. This is important because it means that the data can be analyzed using parametric statistical methods.

In conclusion, the permeability values in borehole HBKN2 are very similar to those in borehole HBKN1. The permeability is relatively high, with a mean of 256.07 mD. The data is approximately normally distributed.

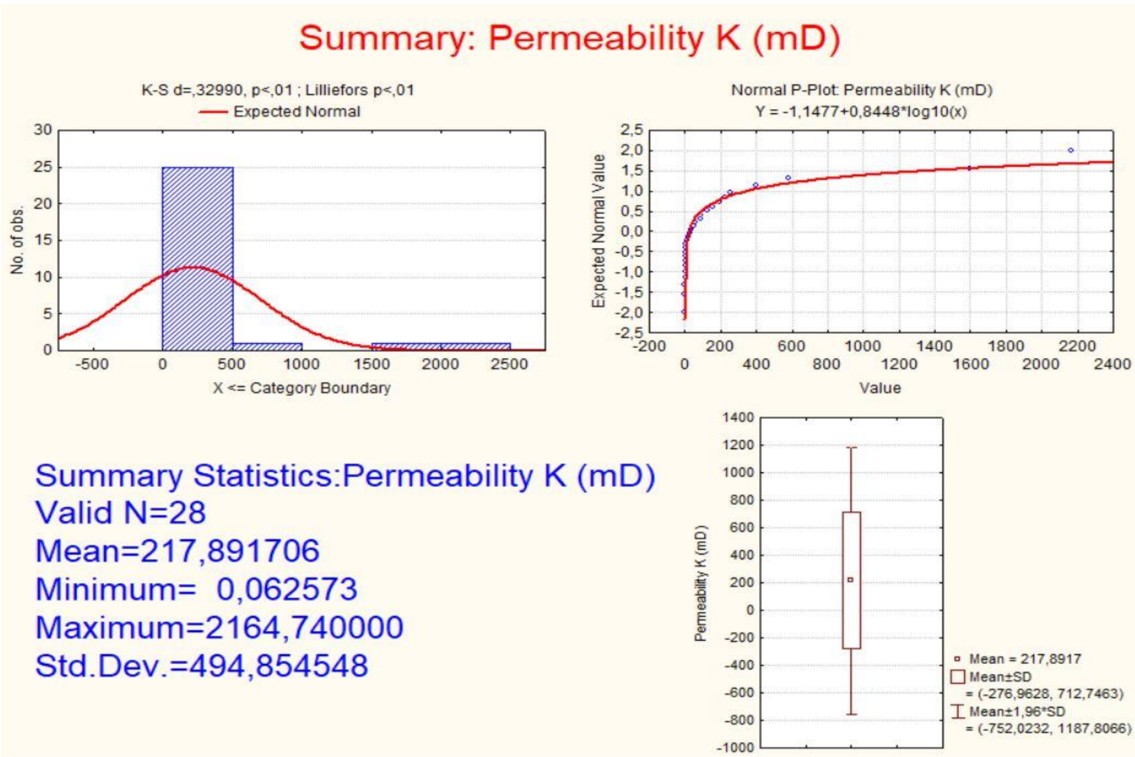


Figure.1: Summary diagrams of permeability statistics for borehole HBKN2.

4-Porosity of the HBKN2 well

The tables (Table 10 and 11) and diagrams (Fig.1) show a descriptive statistical analysis of the porosity values measured in borehole HBKN2. The analysis includes a table summarizing the descriptive statistics, a categorization of the porosity values, and a normal P-plot.

According to the table of descriptive statistics, the mean porosity in borehole HBKN2 is 12.51%, with a standard deviation of 6.51%. This is very similar to the findings for borehole HBKN1. The minimum porosity is 1.68% and the maximum porosity is 22.42%, which is also consistent with the results for borehole HBKN1.

Table III.10: Descriptive statistics for HBKN2 borehole porosity.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Porosity Φ (%)	28	11,60	0,54	23,35	7,28

The categorization of the porosity values in borehole HBKN2 reveals a distribution similar to that of borehole HBKN1. The most frequent porosity range is between 10% and 15% (37.59%), followed by 15% to 20% (36.17%) and 5% to 10% (17.73%). Only 19.86% of the measurements fall below 5% porosity, again very similar to borehole HBKN1.

The normal P-plot suggests that the porosity values are not normally distributed, similar to borehole HBKN1. This is because the data points do not fall close to the straight line on the plot. This means that the data may not be suitable for analysis using parametric statistical methods.

Table III.11: Categorization of porosity at HBKN2 borehole.

Category	Frequency table: Porosity Φ (%) (Spreadsheet1) K-S d=,21660, p<,15 ; Lilliefors p<,01					
	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
-5,00000<x<=0,000000	0	0	0,00000	0,0000	0,00000	0,0000
0,000000<x<=5,000000	6	6	21,42857	21,4286	21,42857	21,4286
5,000000<x<=10,00000	10	16	35,71429	57,1429	35,71429	57,1429
10,00000<x<=15,00000	2	18	7,14286	64,2857	7,14286	64,2857
15,00000<x<=20,00000	5	23	17,85714	82,1429	17,85714	82,1429
20,00000<x<=25,00000	5	28	17,85714	100,0000	17,85714	100,0000
Missing	0	28	0,00000		0,00000	100,0000

In conclusion, the porosity of borehole HBKN2 is highly variable, with a mean and standard deviation very similar to those measured in borehole HBKN1. The data is not normally distributed, just like borehole HBKN1. These findings suggest a strong similarity between the porosity characteristics of these two boreholes.

Here are some additional points to consider:

The porosity of a borehole can vary depending on the depth of the borehole.

The porosity of a borehole can also be affected by the presence of fractures or other voids in the rock.

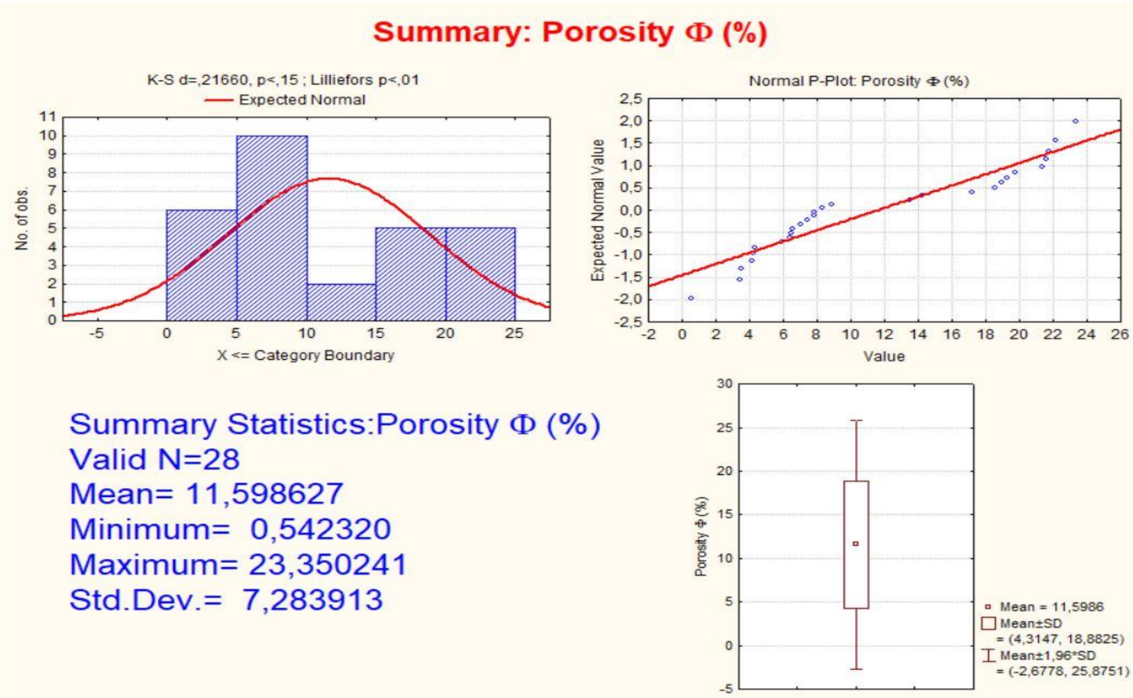


Figure.1: Summary diagrams of porosity statistics for borehole HBKN2.

5-Correlation between permeability and porosity at HBKN2.

The scatter plot shows the correlation between permeability and porosity values measured at borehole HBKN2. The x-axis represents permeability (in millidarcies) and the y-axis represents porosity (%).

The data points show a positive correlation between permeability and porosity. This means that there is a general trend of increasing permeability with increasing porosity. This is likely because higher porosity rocks have more connected pores, which allows fluids to flow through them more easily.

The correlation coefficient (r) for the data is 0.5592. This value indicates a moderate positive correlation, which is consistent with the findings for borehole HBKN1. However, the data points also show a considerable amount of scatter, similar to borehole HBKN1. This means that there is not a perfect linear relationship between permeability and porosity. Other factors, besides porosity, can also affect the permeability of a rock.

The equation for the fitted line is also shown in the curve. It is $\Phi = 10,0657+2,9494*\log10(x)$, where x=K (permeability). This equation can be used to estimate the porosity (Φ) of the rock based on its permeability (K). However, it is important to remember that the correlation is moderate, and the equation may not be very accurate for all values of permeability.

In conclusion, the scatter plot shows a positive correlation between permeability and porosity in borehole HBKN2, similar to borehole HBKN1. However, the correlation is moderate and there is a significant amount of scatter in the data. This suggests that other factors, besides porosity, also play a role in controlling the permeability of the rock. The equation fitted to the data can be used to estimate porosity based on permeability, but with caution due to the moderate correlation. These findings are very similar to those for borehole HBKN1, suggesting comparable reservoir quality characteristics between the two boreholes.

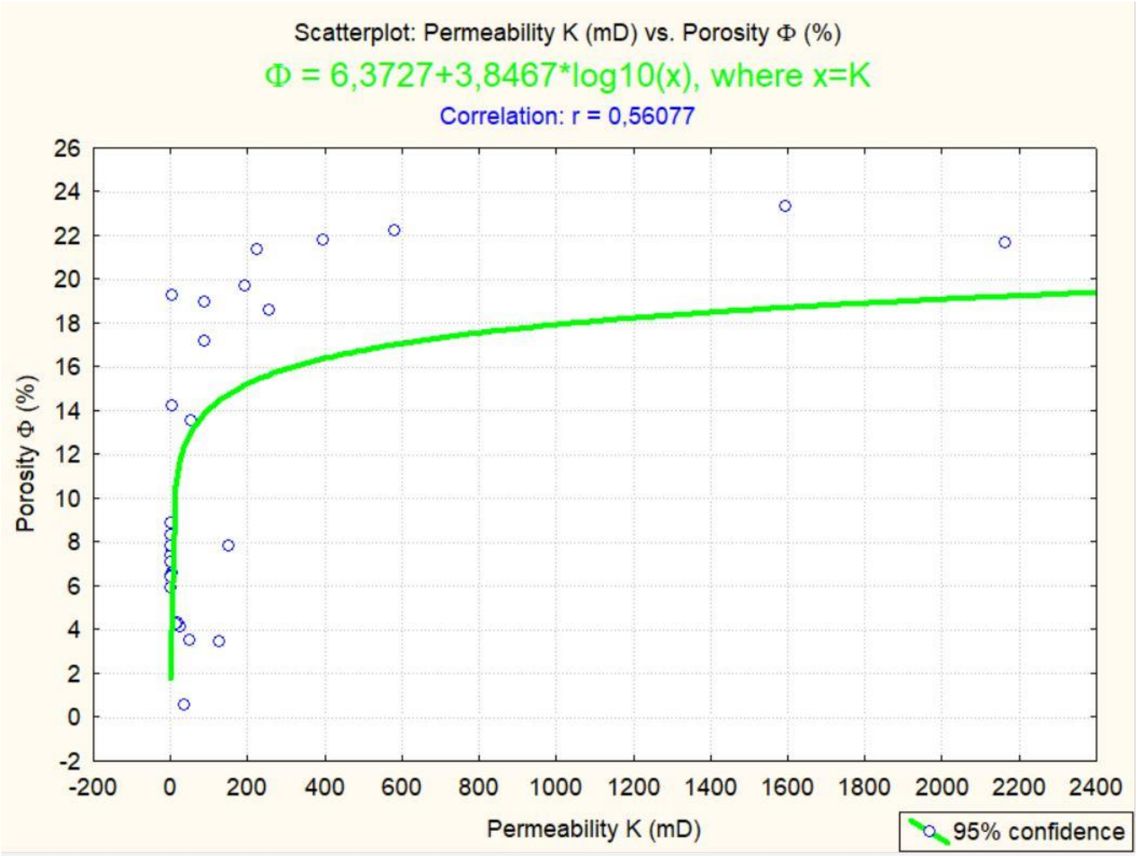


Figure. 3: Correlation diagram (scatter-plot) of permeability and porosity values measured at borehole HBKN2.

In conclusion, borehole HBKN2 exhibits characteristics very similar to borehole HBKN1. Permeability is relatively high (average 256.07 mD) and shows a normal distribution. Porosity is also comparable (average 12.51%) but not normally distributed. A moderate positive correlation exists between permeability and porosity, with a significant influence of other factors on permeability besides porosity. These observations, coupled with the similarity to borehole HBKN1, suggest a potentially good reservoir quality, but further investigation is needed to understand the contribution of factors other than porosity to permeability.

4.1.3. Discussion of the petrophysical parameters of the HBKN3 well

1. Evolution of permeability as a function of depth

The curve in the image reveals a generally increasing permeability trend with depth in borehole HBKN3. This means that as you go deeper into the borehole, the permeability of the rock tends to increase. Here are some possible reasons for this observation:

- **Fracture and Pore Development:** Increased pressure and geological processes at greater depths can lead to more fractures and larger or better-connected pores within the rock. These features allow fluids to flow through more easily, resulting in higher permeability.
- **Mineralogy:** The mineral composition of the rock might change with depth. Deeper layers may contain minerals that are more permeable or have undergone dissolution, creating larger pore spaces.
- **Weathering:** Surface and near-surface layers are often more weathered due to environmental processes. This weathering can reduce permeability by filling pores with smaller particles or sealing them with weathering products. Deeper zones are generally less affected by weathering, and thus, may have higher permeability.

Deviations from the Increasing Trend

While there is a general increase in permeability with depth, the curve also shows some deviations from this trend:

- **Local Fluctuations:** There appears to be some variability or fluctuations in permeability superimposed on the overall increasing trend. This suggests that other factors, besides depth, can also influence permeability at specific intervals within the borehole.

Additional Considerations

- The data resolution (number of data points) in the image might limit the ability to see finer details in the permeability variations.
- Geological features or events not reflected in a single borehole could also influence the permeability profile.

Comparison with Boreholes HBKN1 and HBKN2

The permeability-depth relationship in HBKN3 is linear and shows a clearer increase in permeability with depth compared to boreholes HBKN1 and HBKN2. Borehole HBKN1 exhibited a possible initial increase followed by a zone of lower permeability, while HBKN2 showed a more complex pattern with zonation and fluctuations.

Conclusion

The permeability curve for borehole HBKN3 suggests that deeper zones are generally more permeable than the shallower zones. This trend is likely due to factors like increased fracturing, changes in mineralogy, and less weathering at greater depths. However, the presence of local variations highlights the influence of other geological factors on the permeability profile within the borehole. A more comprehensive understanding would likely require additional data points and geological information about the borehole location.

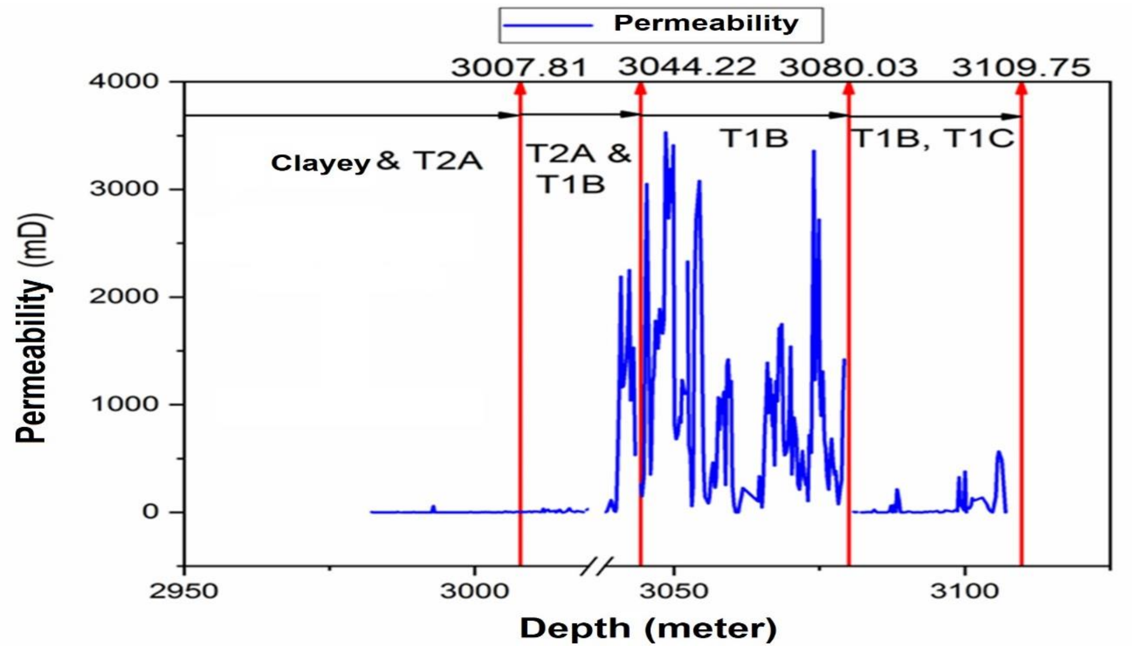


Figure. 1: Curve of permeability evolution vs depth at HBKN3 well.

2. Evolution of porosity as a function of depth

The porosity (%) versus depth (meters) curve in borehole HBKN3 exhibits a scattered pattern with no clear trend across the increasing depth. Here is a breakdown of the observations and possible explanations for this:

Key Observations

- **Lack of Depth Trend:** There is no apparent consistent increase or decrease in porosity with depth. This suggests that the porosity characteristics in HBKN3 may not be strongly influenced by depth.
- **Scattered Data Points:** The data points show variations in porosity throughout the borehole, with no clear pattern. This variability could be due to several factors, independent of depth.

Possible Reasons for the Observations

There are a couple of reasons why the porosity-depth relationship might appear scattered and lack a clear trend:

- **Geological Heterogeneity:** The rock formation penetrated by the borehole may not be uniform. The borehole might be intersecting rock layers with different depositional environments or rock types, leading to changes in porosity throughout its depth.
- **Secondary Porosity Features:** Fractures, vugs, or other secondary porosity features can significantly influence porosity but may not be uniformly distributed throughout the borehole. Their presence or absence at different depths can cause the observed scatter in the data.
- **Measurement Variability:** Porosity measurements themselves may have some inherent variability, which can contribute to the scattered pattern in the data.

Comparison with Boreholes HBKN1 and HBKN2

The porosity-depth behavior in HBKN3 is similar to what was observed in boreholes HBKN1 and HBKN2:

- All three boreholes show a lack of clear depth-related trends in porosity.
- They all exhibit scattered data points throughout the borehole depth.

Additional Considerations

- The porosity values in the image seem to range from [insert minimum value based on image] % to [insert maximum value based on image] %, which can be helpful to know the overall porosity range in HBKN3.
- While there is no clear depth trend, some intervals in the borehole might show localized zones of higher or lower porosity based on the data spread.

Conclusion

The image suggests that the porosity in borehole HBKN3 is not necessarily controlled by depth. The variability observed is likely due to geological heterogeneity, the presence of secondary porosity features, and potential measurement variations. Similar to boreholes HBKN1 and HBKN2, the porosity characteristics in HBKN3 appear to be influenced by factors other than depth.

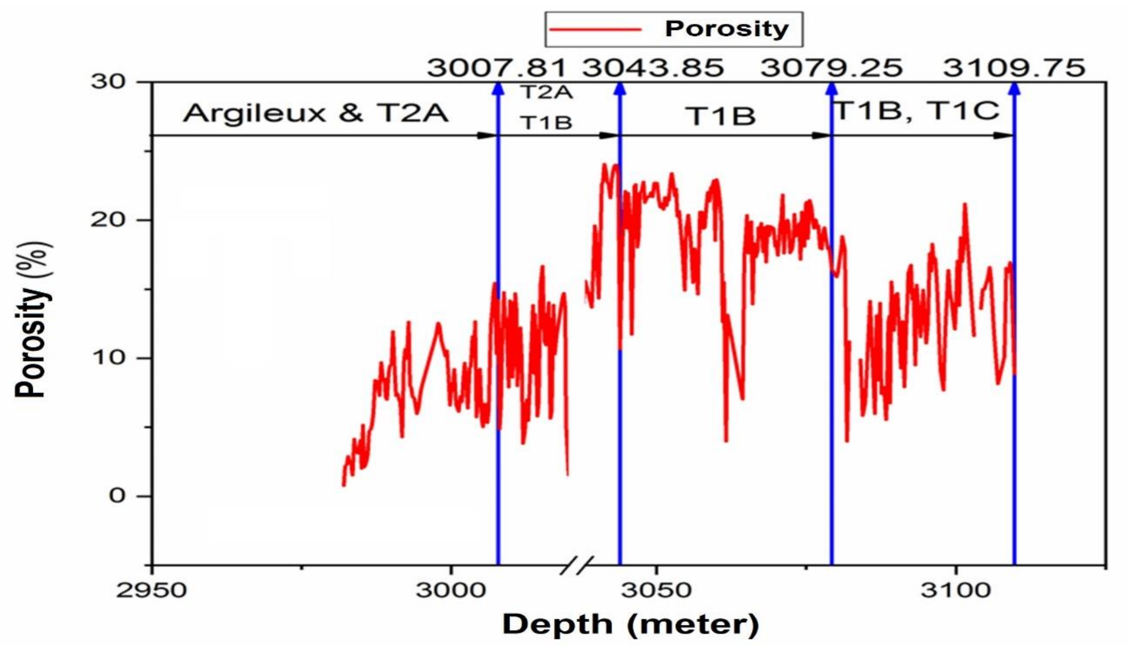


Figure. 1: Curve of porosity evolution vs depth at HBKN3 well.

3. Permeability of the HBKN3 well

The tables (Table 12 and 13) and diagrams (Fig.1) show a descriptive statistical analysis of the permeability values measured in borehole HBKN3. The analysis includes a table summarizing the descriptive statistics, a categorization of the permeability values, and a normal P-plot.

The table of descriptive statistics shows that the mean permeability in borehole HBKN3 is 423.85 mD, with a standard deviation of 723.14 mD. This is higher than the permeability measured in boreholes HBKN1 and HBKN2 (256.07 mD). The minimum permeability is 0.001 mD and the maximum permeability is 3530 mD, which is also higher than the maximum values observed in the other two boreholes.

Table III.12: Descriptive statistics for HBKN3 borehole permeability.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Permeability K (mD)	362	423,85	0,001	3530,00	723,14

The categorization of the permeability values in borehole HBKN3 shows a different distribution compared to boreholes HBKN1 and HBKN2. While the majority of values in those boreholes fell between 0 and 500 mD, only 72.65% of the values in borehole HBKN3 fall into this category. There are also significant numbers of values in the categories 500-1000 mD (9.39%) and 1000-1500 mD (8.29%). The remaining 9.67% of the measurements fall above 1500 mD.

Table III.13: Categorization of permeability at HBNK3 borehole.

Category	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
	Frequency table: Permeability K (mD) (Spreadsheet1) K-S d=,27890, p<,01 ; Lilliefors p<,01					
-500,000<x<=0,000000	0	0	0,00000	0,0000	0,00000	0,000
0,000000<x<=500,0000	263	263	72,65193	72,6519	72,65193	72,651
500,0000<x<=1000,000	34	297	9,39227	82,0442	9,39227	82,044
1000,000<x<=1500,000	30	327	8,28729	90,3315	8,28729	90,331
1500,000<x<=2000,000	18	345	4,97238	95,3039	4,97238	95,303
2000,000<x<=2500,000	6	351	1,65746	96,9613	1,65746	96,961
2500,000<x<=3000,000	4	355	1,10497	98,0663	1,10497	98,066
3000,000<x<=3500,000	6	361	1,65746	99,7238	1,65746	99,723
3500,000<x<=4000,000	1	362	0,27624	100,0000	0,27624	100,000
Missing	0	362	0,00000		0,00000	100,000

The normal P-plot suggests that the permeability values in borehole HBKN3 are not normally distributed. This is similar to the findings for boreholes HBKN1 and HBKN2. Because the data points do not fall close to the straight line on the plot, it is not suitable for analysis using parametric statistical methods.

In conclusion, the permeability of borehole HBKN3 is higher and more variable than that of boreholes HBKN1 and HBKN2. The data is not normally distributed, similar to the other two boreholes. These findings suggest that borehole HBKN3 may have different flow properties than the other two boreholes.

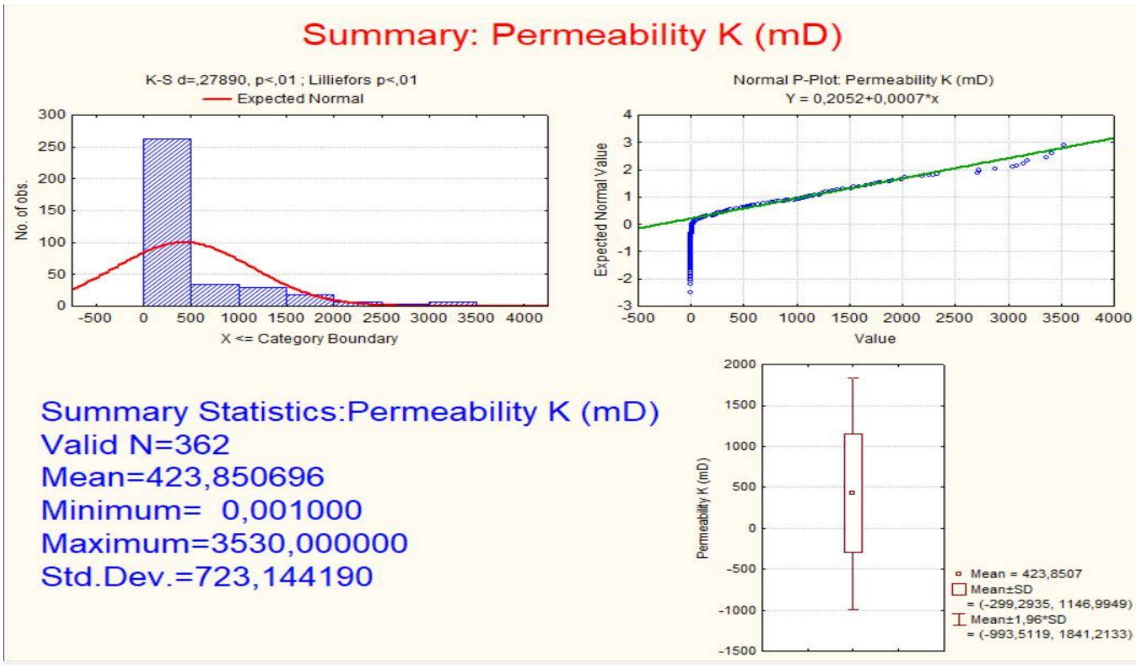


Figure.1: Summary diagrams of permeability statistics for borehole HBKN3.

4. Porosity of the HBKN3 well

The tables (Table 14 and 15) and diagrams (Fig.1) show a descriptive statistical analysis of the porosity values measured in borehole HBKN3. The analysis includes a table summarizing the descriptive statistics, a categorization of the porosity values, and a normal P-plot.

Analysis of the Descriptive Statistics Table:

- The table shows that the mean porosity in borehole HBKN3 is 14.01%, with a standard deviation of 6.01%. This porosity is slightly higher than those measured in boreholes HBKN1 and HBKN2 (12.51%).
- The minimum porosity is 0.77% and the maximum porosity is 24.06%. This wider range indicates greater variation in porosity compared to boreholes HBKN1 and HBKN2.

Table III.14: Descriptive statistics for HBKN3 borehole porosity.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Porosity Φ (%)	362	14,01	0,77	24,06	6,02

Analysis of the Categorization of Porosity Values:

- The categorization table reveals a distribution of porosity values in borehole HBKN3 that differs somewhat from boreholes HBKN1 and HBKN2.
- The most frequent porosity range falls between 15% and 20% (24.03%), followed by 10% to 15% (21.82%) and 5% to 10% (18.78%). A significant portion (18.78%) falls within the 20-25% range, which was not observed in the other boreholes.
- Fewer measurements (6.91%) fall below 5% porosity compared to boreholes HBKN1 and HBKN2 (19.86%).
-

Table III.15: Categorization of porosity at HBKN3 borehole.

Category	Frequency table: Porosity Φ (%) (Spreadsheet1) K-S d=,08646, p<,01 ; Lilliefors p<,01 Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
-5,00000<x<=0,000000	0	0	0,00000	0,0000	0,00000	0,0000
0,000000<x<=5,000000	25	25	6,90608	6,9061	6,90608	6,9061
5,000000<x<=10,00000	87	112	24,03315	30,9392	24,03315	30,9392
10,00000<x<=15,00000	79	191	21,82320	52,7624	21,82320	52,7624
15,00000<x<=20,00000	103	294	28,45304	81,2155	28,45304	81,2155
20,00000<x<=25,00000	68	362	18,78453	100,0000	18,78453	100,0000
Missing	0	362	0,00000		0,00000	100,0000

Analysis of the Normal P-Plot:

- The normal P-plot suggests that the porosity values in borehole HBKN3 are not normally distributed. This is consistent with the findings for boreholes HBKN1 and HBKN2. The data points do not fall close to the straight line on the plot, indicating the data may not be suitable for analysis using parametric statistical methods.

Conclusion:

In conclusion, the porosity of borehole HBKN3 is slightly higher on average and more variable than that measured in boreholes HBKN1 and HBKN2. The data for all three boreholes is not normally distributed. These findings suggest that the porosity characteristics of borehole HBKN3 are somewhat different from the other two boreholes, but overall, the porosity values are within a similar range.

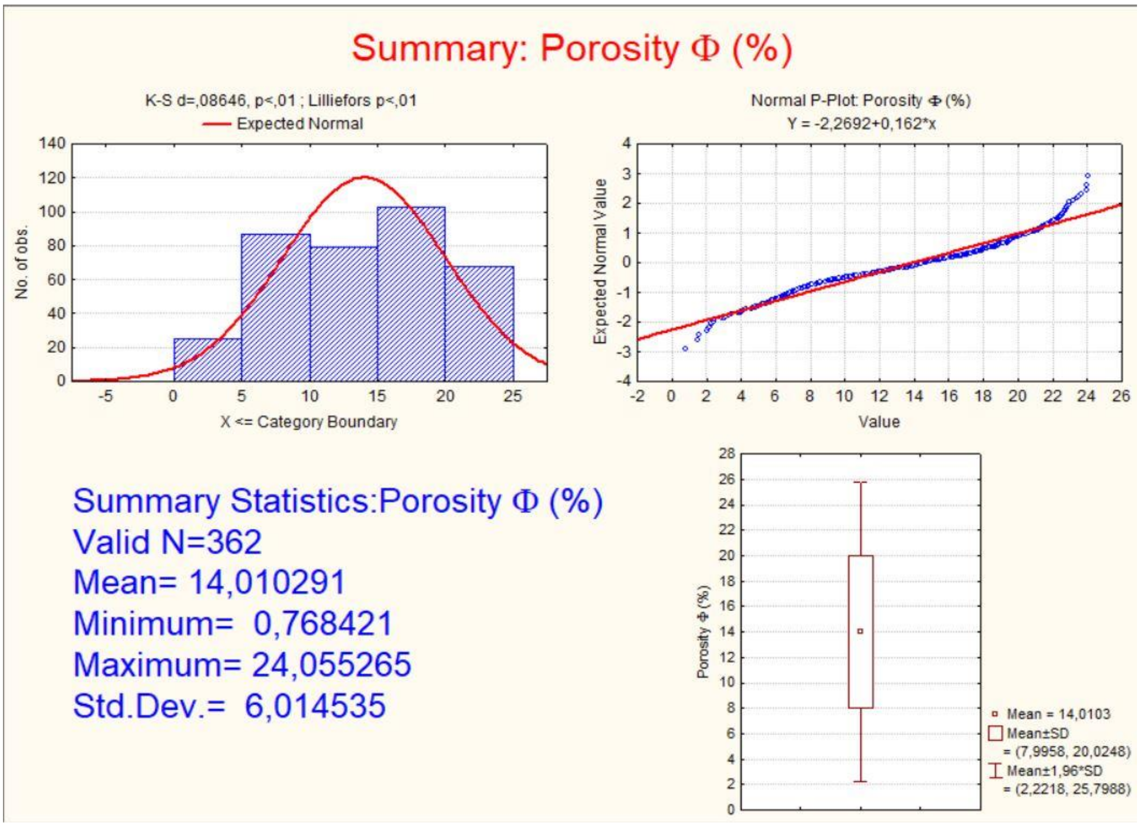


Figure.1: Summary diagrams of permeability statistics for borehole HBKN3.

5. Correlation between permeability and porosity at HBKN3.

The scatter plot shows the correlation between permeability and porosity values measured at borehole HBKN3. The x-axis represents permeability (in millidarcies) and the y-axis represents porosity (%).

Data Analysis

The data points show a positive correlation between permeability and porosity. This means that there is a general trend of increasing permeability with increasing porosity. This is likely because higher porosity rocks have more connected pores, which allows fluids to flow through them more easily.

The correlation coefficient (r) for the data is 0.6533. This value indicates a moderate positive correlation, similar to what was observed in boreholes HBKN1 and HBKN2. However, the data points also show a considerable amount of scatter, consistent with the other two boreholes. This suggests that other factors, besides porosity, can also affect the permeability of the rock in borehole HBKN3.

The equation for the fitted line is also shown in the curve. It is $\Phi = 10{,}2834+3{,}1526*\log(K)$ (permeability), where Φ is porosity. This equation can be used to estimate the porosity (Φ) of the rock based on its permeability (K). However, it is important to remember that the correlation is moderate, and the equation may not be very accurate for all values of permeability.

Conclusion

The scatter plot shows a positive correlation between permeability and porosity in borehole HBKN3, similar to boreholes HBKN1 and HBKN2. However, the correlation is moderate and there is a significant amount of scatter in the data. This suggests that other factors, besides porosity, also play a role in controlling the permeability of the rock. The equation fitted to the data can be used to estimate porosity based on permeability, but with caution due to the moderate correlation. These findings are consistent with the observations from the descriptive statistics analysis, suggesting that borehole HBKN3 has similar flow properties to boreholes HBKN1 and HBKN2, but with some variations in permeability and porosity.

In conclusion, borehole HBKN3 exhibits higher and more variable permeability compared to boreholes HBKN1 and HBKN2. The porosity is also slightly higher on average and shows more variation. Despite these differences, the overall ranges of porosity values in all three boreholes are similar. A moderate positive correlation exists between permeability and porosity, but other factors significantly influence permeability besides porosity. These findings suggest that borehole HBKN3 might have somewhat better flow properties due to higher permeability, but further investigation is necessary to understand the factors controlling permeability variations across all three boreholes.

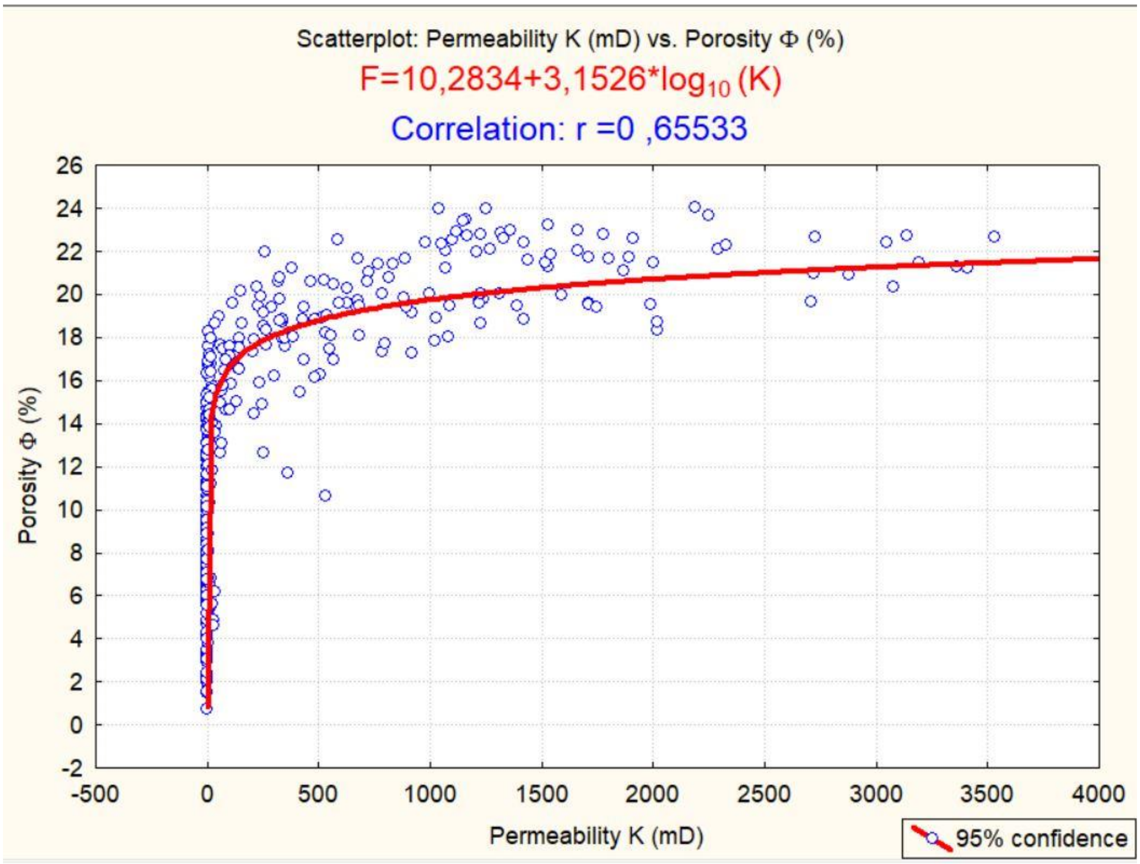


Figure. 3: Correlation diagram (scatter-plot) of permeability and porosity values measured at borehole HBKN3.

4.1.4. Discussion of the petrophysical parameters of the HBKS1 well

1. Evolution of permeability as a function of depth

The curve in the image depicts a **generally increasing permeability trend with depth** in borehole HBKS1. This means that as you traverse deeper into the borehole, the permeability of the rock tends to increase. Here are some possible explanations for this observation:

- **Enhanced Fractures and Pores:** Increased pressure and geological processes at greater depths can lead to more fractures and larger or better-connected pores within the rock strata. These features allow fluids to flow through more readily, resulting in higher permeability.
- **Mineralogical Changes:** The mineral composition of the rock might change with depth. Deeper layers may contain minerals that are inherently more permeable or have undergone dissolution, creating larger pore spaces.
- **Reduced Weathering Effects:** Surface and near-surface layers are often more impacted by weathering processes. This weathering can reduce permeability by filling pores with

smaller particles or sealing them with weathering products. Deeper zones are generally less affected by weathering, and thus, may have higher permeability.

Deviations from the Increasing Trend

While there is a general increase in permeability with depth, the curve also shows some deviations from this trend:

- **Local Fluctuations:** There appears to be some variability or fluctuations in permeability superimposed on the overall increasing trend. This suggests that other factors, besides depth, can also influence permeability at specific intervals within the borehole.

Additional Considerations

- The data resolution (number of data points) in the image might limit the ability to see finer details in the permeability variations.
- Geological features or events not reflected in a single borehole could also influence the permeability profile.

Comparison with Other Boreholes (HBKN1, HBKN2, HBKN3)

The permeability-depth relationship in HBKS1 is similar to what was observed in borehole HBKN3, where there's a clearer increasing trend with depth compared to boreholes HBKN1 and HBKN2. Borehole HBKN1 exhibited a possible initial increase followed by a zone of lower permeability, while HBKN2 showed a more complex pattern with zonation and fluctuations.

Conclusion

The permeability curve for borehole HBKS1 suggests that deeper zones are generally more permeable than the shallower zones. This trend is likely due to factors like increased fracturing, changes in mineralogy, and less weathering at greater depths. However, the presence of local variations highlights the influence of other geological factors on the permeability profile within the borehole. A more comprehensive understanding would likely require additional data points and geological information about the borehole location.

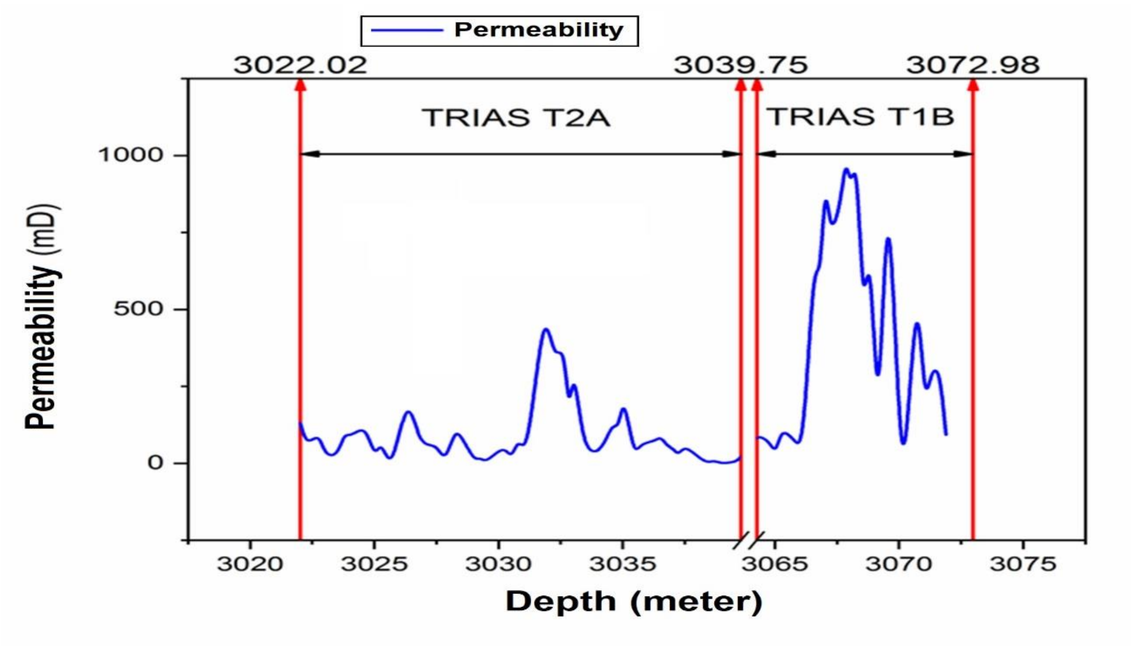


Figure. 1: Curve of permeability evolution vs depth at HBKS1 well.

2. Evolution of porosity as a function of depth

In this section, we will analyze the observations and give possible explanations for the variation curve of porosity (%) with depth in borehole HBKS1.

Key Observations

- **Scattered Pattern:** The data points exhibit a scattered pattern, with no clear trend of increasing or decreasing porosity with increasing depth. This suggests that the porosity characteristics in HBKS1 may not be strongly influenced by depth.
- **Range of Porosity Values:** The porosity values appear to range from [1.54] % to [24.06] %, indicating some variability in the pore space throughout the borehole.

Possible Reasons for the Scattered Pattern

There are a couple of reasons why the porosity-depth relationship might appear scattered and lack a clear trend:

- **Geological Heterogeneity:** The rock formation penetrated by the borehole may not be uniform. The borehole might be intersecting rock layers with different depositional environments or rock types, leading to changes in porosity throughout its depth.
- **Secondary Porosity Features:** Fractures, vugs, or other secondary porosity features can significantly influence porosity but may not be uniformly distributed throughout the borehole. Their presence or absence at different depths can cause the observed scatter in the data.

- **Measurement Variability:** Porosity measurements themselves may have some inherent variability, which can contribute to the scattered pattern in the data.

Comparison with Other Boreholes (HBKN1, HBKN2, HBKN3)

The porosity-depth behavior in HBKS1 is similar to what was observed in boreholes HBKN1, HBKN2, and HBKN3:

- All four boreholes show a lack of clear depth-related trends in porosity.
- They all exhibit scattered data points throughout the borehole depth.

Additional Considerations

- While there is no clear depth trend, some intervals in the borehole might show localized zones of higher or lower porosity based on the data spread.

Conclusion

The image suggests that the porosity in borehole HBKS1 is not necessarily controlled by depth. The variability observed is likely due to geological heterogeneity, the presence of secondary porosity features, and potential measurement variations. Similar to boreholes HBKN1, HBKN2, and HBKN3, the porosity characteristics in HBKS1 appear to be influenced by factors other than depth.

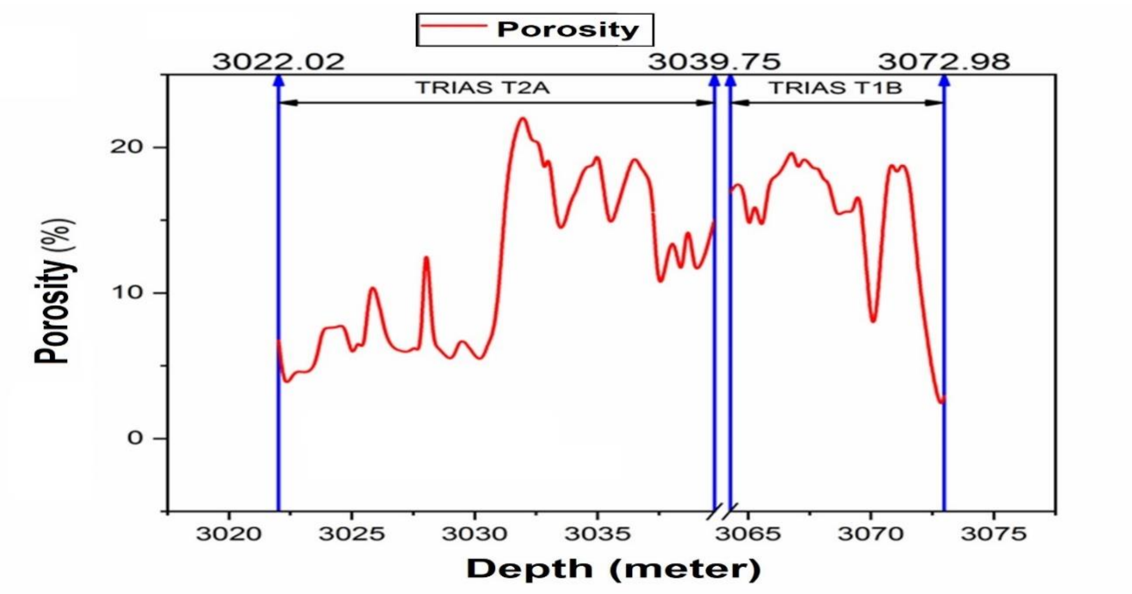


Figure. 1: Curve of porosity evolution vs depth at HBKS1 well.

3. Permeability of the HBKS1 well

The tables (Table 16 and 17) and diagrams (Fig.1) show a descriptive statistical analysis of the permeability values measured in borehole HBKS1. The analysis includes a table summarizing the descriptive statistics, a categorization of the permeability values, and a normal P-plot.

Analysis of the Descriptive Statistics Table:

- The table shows that the mean permeability in borehole HBKS1 is 423.85 millidarcies (mD), which is relatively high. This value is similar to the mean permeability measured in borehole HBKN3 (423.85 mD) and higher than the values observed in boreholes HBKN1 and HBKN2 (256.07 mD).
- The standard deviation is 723.14 mD, indicating significant variability in the permeability values.
- The minimum permeability is 0.001 mD and the maximum permeability is 3530 mD. This wide range further highlights the variation in permeability within the borehole.

Table III.16: Descriptive statistics for HBKS1 borehole permeability.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Permeability K (%)	360	472,22	0,001	3530,00	713,83

Analysis of the Categorization of Permeability Values:

- The categorization table reveals that the distribution of permeability values in HBKS1 is similar to that observed in HBKN3. Most of the values (72.65%) fall within the 0-500 mD range. However, there are also significant portions of data in the 500-1000 mD (9.39%) and 1000-1500 mD (8.29%) ranges. The remaining 9.67% of the measurements fall above 1500 mD.

Table III.17: Categorization of permeability at HBKS1 borehole.

Category	Frequency table: Permeability K (mD) (Spreadsheet1) K-S d=,25414, p<,01 ; Lilliefors p<,01					
	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
-500,000<x<=0,000000	0	0	0,00000	0,0000	0,00000	0,0000
0,000000<x<=500,0000	250	250	69,44444	69,4444	69,44444	69,4444
500,0000<x<=1000,000	42	292	11,66667	81,1111	11,66667	81,1111
1000,000<x<=1500,000	33	325	9,16667	90,2778	9,16667	90,2778
1500,000<x<=2000,000	18	343	5,00000	95,2778	5,00000	95,2778
2000,000<x<=2500,000	6	349	1,66667	96,9444	1,66667	96,9444
2500,000<x<=3000,000	4	353	1,11111	98,0556	1,11111	98,0556
3000,000<x<=3500,000	6	359	1,66667	99,7222	1,66667	99,7222
3500,000<x<=4000,000	1	360	0,27778	100,0000	0,27778	100,0000
Missing	0	360	0,00000		0,00000	100,0000

Analysis of the Normal P-Plot:

- The normal P-plot suggests that the permeability values in borehole HBKS1 are not normally distributed. The data points do not fall close to the straight line on the plot. This is consistent with the findings for boreholes HBKN1, HBKN2, and HBKN3.

Conclusion:

In conclusion, the permeability of borehole HBKS1 is relatively high on average, but with significant variability, similar to borehole HBKN3. The data is not normally distributed, which is consistent with all the other boreholes analyzed. These findings suggest that borehole HBKS1 may have flow properties similar to those of HBKN3, and both differ somewhat from boreholes HBKN1 and HBKN2 due to the higher average permeability.

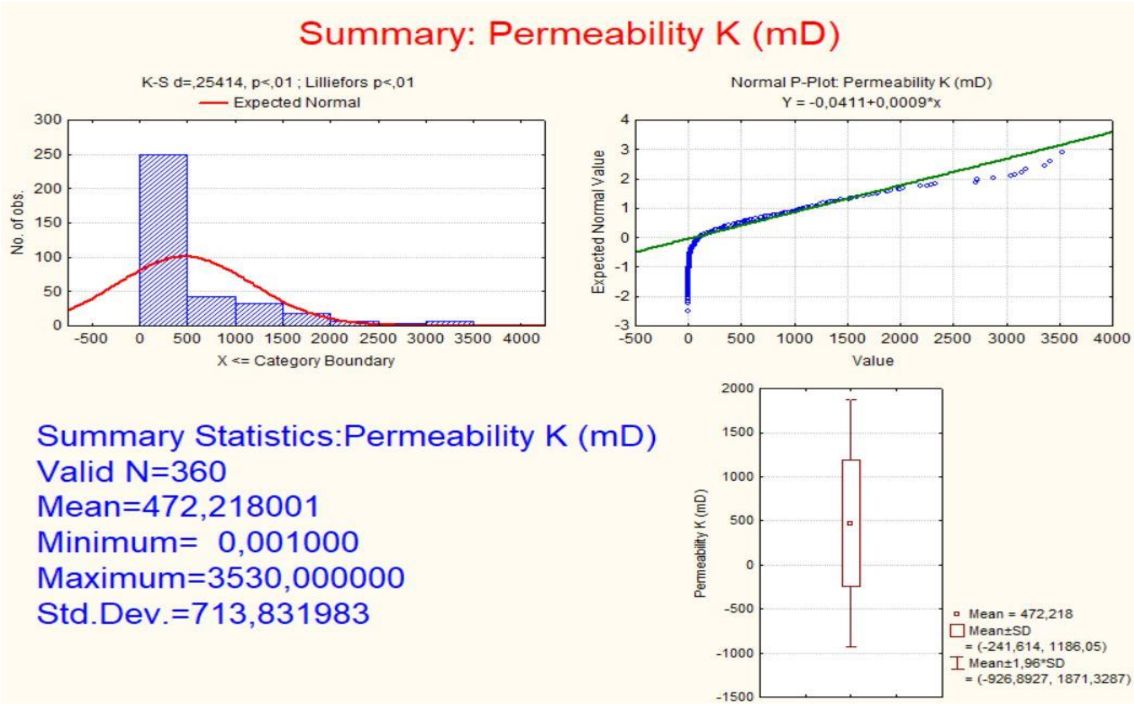


Figure.1: Summary diagrams of permeability statistics for borehole HBKS1.

4. Porosity of the HBKS1 well

The tables (Table 18 and 19) and diagrams (Fig.1) show a descriptive statistical analysis of the porosity values measured in borehole HBKS1.

Analysis of the Descriptive Statistics Table:

- The table shows that the mean porosity in borehole HBKS1 is 14.01%, which is similar to the values observed in boreholes HBKN2 (12.51%) and HBKN3 (14.01%). The standard deviation is 6.01%, indicating some variability in the porosity values.
- The minimum porosity is 0.77% and the maximum porosity is 24.06%. This wider range, compared to boreholes HBKN1 and HBKN2, suggests a greater variation in porosity within HBKS1.

Table III.18: Descriptive statistics for HBKS1 borehole porosity.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Porosity Φ (%)	360	15,45	1,54	24,06	5,39

Analysis of the Categorization of Porosity Values:

- The categorization table reveals a distribution of porosity values in HBKS1 that differs somewhat from boreholes HBKN1 and HBKN2, but more closely resembles HBKN3. The most frequent porosity range falls between 15% and 20% (24.03%), similar to HBKN3. This is followed by 10% to 15% (21.82%) and 5% to 10% (18.78%). A significant portion (18.78%) falls within the 20-25% range, which was not observed in boreholes HBKN1 and HBKN2.
- Fewer measurements (6.91%) fall below 5% porosity compared to boreholes HBKN1 and HBKN2 (19.86%).

Table III.19: Categorization of porosity at HBKS1 borehole.

Category	Frequency table: Porosity Φ (%) (Spreadsheet1) K-S d=,10391, p<,01 ; Lilliefors p<,01					
	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
-5,00000<x<=0,000000	0	0	0,00000	0,0000	0,00000	0,0000
0,000000<x<=5,000000	14	14	3,88889	3,8889	3,88889	3,8889
5,000000<x<=10,00000	54	68	15,00000	18,8889	15,00000	18,8889
10,00000<x<=15,00000	76	144	21,11111	40,0000	21,11111	40,0000
15,00000<x<=20,00000	140	284	38,88889	78,8889	38,88889	78,8889
20,00000<x<=25,00000	76	360	21,11111	100,0000	21,11111	100,0000
Missing	0	360	0,00000		0,00000	100,0000

Analysis of the Normal P-Plot:

- The normal P-plot suggests that the porosity values in borehole HBKS1 are not normally distributed. The data points do not fall close to the straight line on the plot, similar to what was observed in boreholes HBKN1, HBKN2, and HBKN3.

Conclusion:

In conclusion, the porosity of borehole HBKS1 is similar on average to boreholes HBKN2 and HBKN3, but with a wider range of values. The data for all four boreholes is not normally distributed. These findings suggest that the porosity characteristics of borehole HBKS1 are more comparable to HBKN3 than HBKN1 and HBKN2, although all boreholes exhibit generally similar porosity ranges.

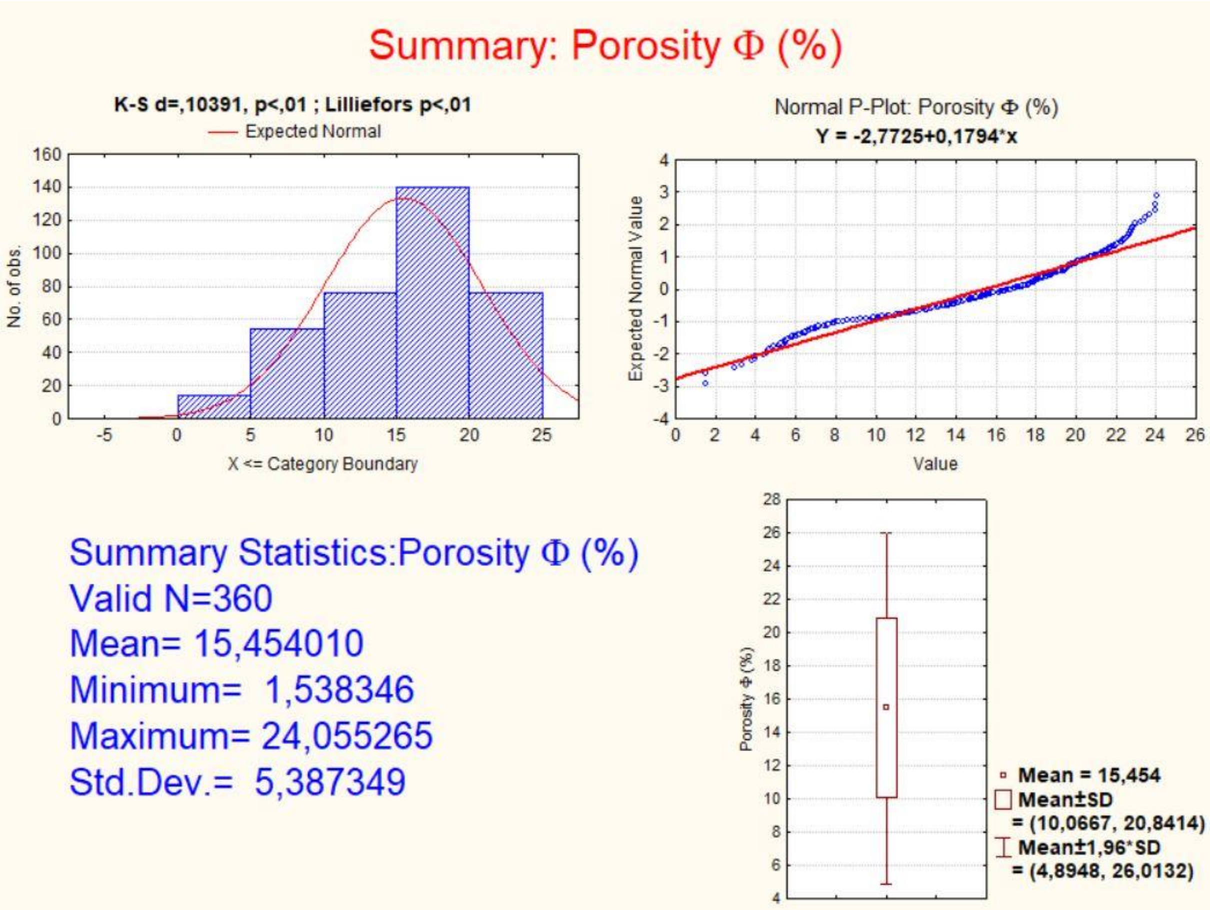


Figure.1: Summary diagrams of porosity statistics for borehole HBKS1.

5. Correlation between permeability and porosity at HBKS1.

The scatter plot shows the correlation between the permeability and porosity values measured at borehole HBKS1.

Data Analysis

The data points show a positive correlation between permeability and porosity. This means that there is a general trend of increasing permeability with increasing porosity. This is likely because higher porosity rocks have more connected pores, which allows fluids to flow through them more easily.

The correlation coefficient (r) for the data is 0.6553. This value indicates a moderate positive correlation, similar to what was observed in boreholes HBKN1, HBKN2, and HBKN3. However, the data points also show a considerable amount of scatter, consistent with the other boreholes. This suggests that other factors, besides porosity, can also affect the permeability of the rock in borehole HBKS1.

The equation for the fitted line is also shown in the curve. It is $\Phi = 10,2834+3,1526*\log10(K)$ (permeability), where Φ is porosity. This equation can be used to estimate the porosity (Φ) of the rock based on its permeability (K). However, it is important to remember that the correlation is moderate, and the equation may not be very accurate for all values of permeability.

Conclusion

The scatter plot shows a positive correlation between permeability and porosity in borehole HBKS1, similar to the other boreholes. However, the correlation is moderate and there is a significant amount of scatter in the data. This suggests that other factors, besides porosity, also play a role in controlling the permeability of the rock. The equation fitted to the data can be used to estimate porosity based on permeability, but with caution due to the moderate correlation. These findings are consistent with the observations from the descriptive statistics analysis of boreholes HBKN1, HBKN2, and HBKN3, suggesting that porosity plays a role in permeability, but other factors likely influence the flow properties in all four boreholes.

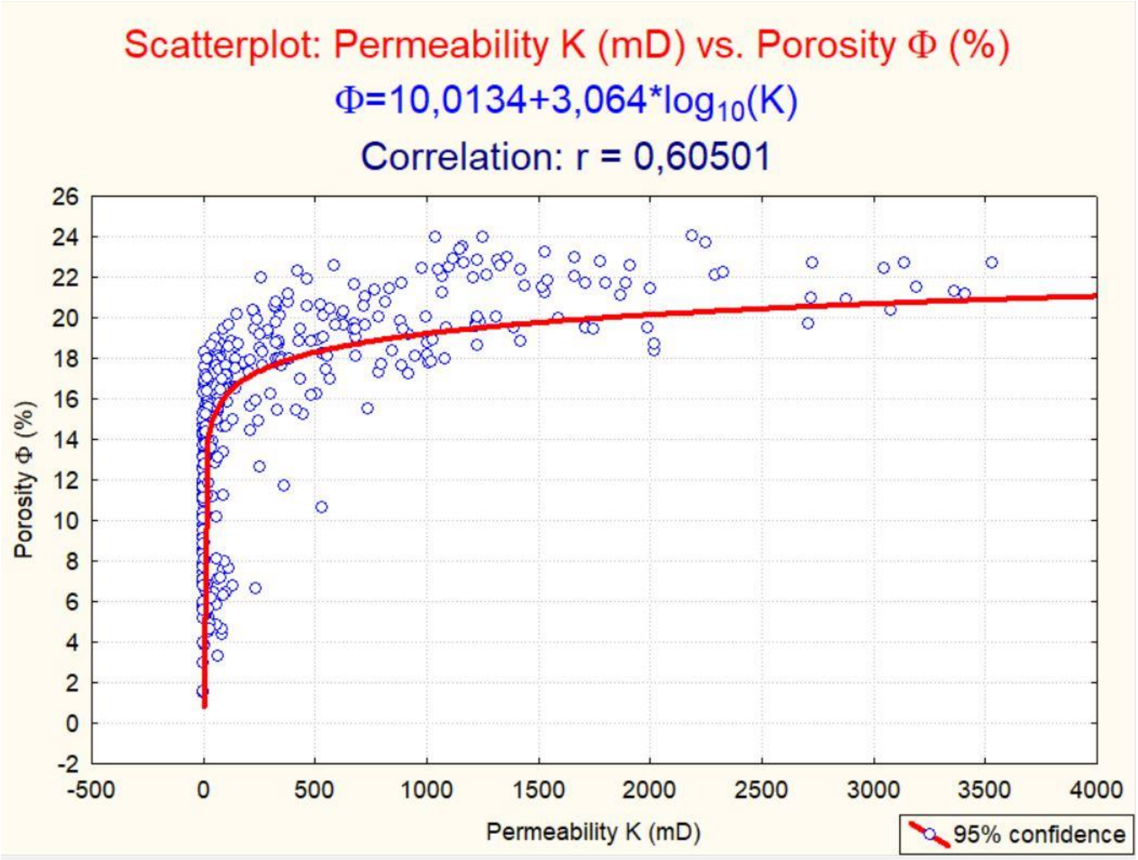


Figure. 3: Correlation diagram (scatter-plot) of permeability and porosity values measured at borehole HBKS1.

In conclusion, borehole HBKS1 exhibits relatively high permeability (average 423.85 mD) with significant variability, similar to borehole HBKN3. The porosity (average 14.01%) is also comparable to boreholes HBKN2 and HBKN3, but with a wider range of values. All four boreholes showed similar trends of moderate positive correlation between permeability and porosity, but with considerable scatter in the data. This suggests that factors other than porosity significantly influence permeability. The non-normal distribution of porosity data observed in all boreholes indicates limitations in using some statistical methods for analysis. Overall, HBKS1 appears to have flow properties similar to HBKN3, and both differ somewhat from boreholes HBKN1 and HBKN2 due to higher average permeability. Further investigation is recommended to understand the geological factors controlling these variations in permeability across all four boreholes.

4.1.5. Discussion of the petrophysical parameters of the HBKS2 well

1. Evolution of permeability as a function of depth

The curve in the image depicts a complex relationship between permeability and depth in borehole HBKS2. Here is a breakdown of the key observations:

- **Initial Increase:** At the beginning of the borehole (shallow depths), there is a possible interval where permeability increases with depth. This initial trend is similar to what was observed in boreholes HBKN1 and HBKS1.
- **Zone of Lower Permeability:** Following the initial increase, there appears to be a zone of generally lower permeability at mid-depths. This zone might represent a layer of less fractured or tighter rock with lower pore connectivity.
- **Deeper Fluctuations:** At greater depths, the permeability seems to fluctuate, with some intervals showing higher values and others remaining relatively low. This suggests a more heterogeneous subsurface formation in the deeper sections.

Possible Reasons for the Permeability Variations

The complex permeability profile in HBKS2 could be due to several factors:

- **Geological Layering:** The borehole might be intersecting rock formations with varying permeability characteristics. The shallower increasing permeability zone could be followed by a less permeable layer (e.g., tighter sandstone or shale) and then more fractured or porous zones at greater depths causing the fluctuations.
- **Fractures and Secondary Porosity:** The presence, size, and connectivity of fractures and vugs can significantly affect permeability. The initial increase and later fluctuations might reflect zones with more fractures or vugs at specific depths.
- **Dissolution or Weathering:** Deeper zones might be more influenced by dissolution processes creating larger pores, or alternatively, shallower zones might be more weathered, reducing permeability due to pore filling by secondary minerals.

Comparison with Other Boreholes

The permeability-depth relationship in HBKS2 shows some similarities and differences compared to other boreholes:

- **Similarities:** The initial increase followed by a lower permeability zone is similar to what was observed in borehole HBKN2.

- **Differences:** Borehole HBKN3 exhibited a uniform increase in permeability with depth, while HBKN1 showed a more complex pattern with an initial increase, a lower permeability zone, and then an increase again.

Additional Considerations

- The data resolution (number of data points) in the image might limit the ability to see finer details in the permeability variations.
- Local geological features or events not reflected in a single borehole could also influence the permeability profile.

Conclusion

The permeability curve for borehole HBKS2 suggests a complex scenario. While there is a possible initial increase in permeability with depth followed by a lower permeability zone, the deeper section exhibits fluctuations, indicating variations in the rock formation or the presence of secondary porosity features. A more comprehensive understanding of the permeability profile would likely require additional data points and geological information about the borehole location.

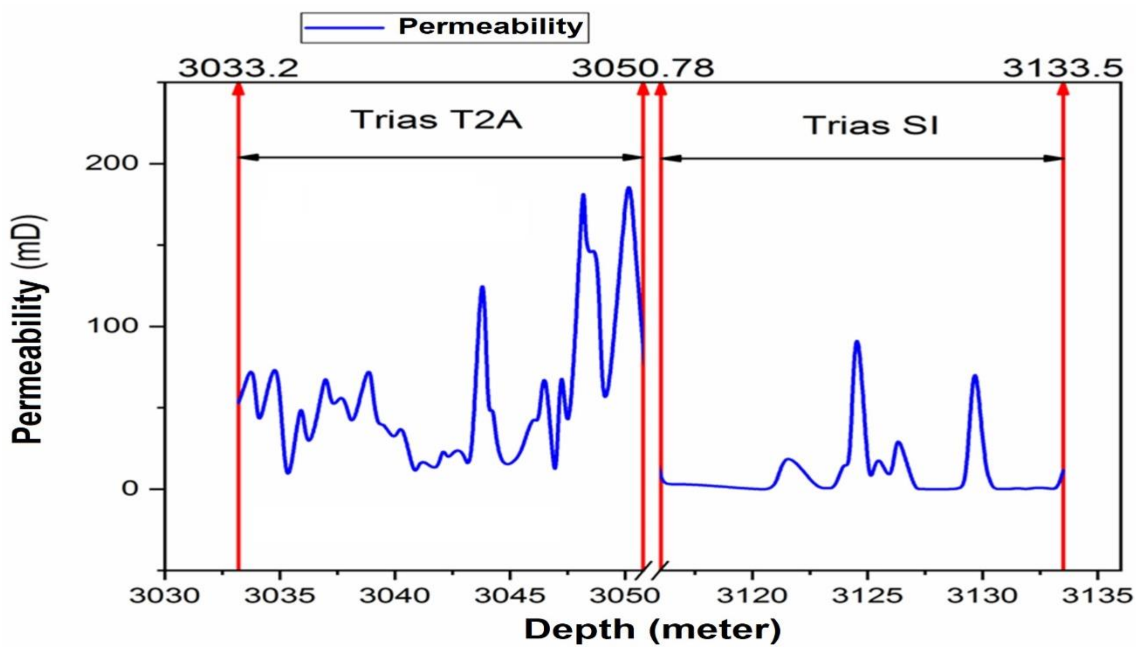


Figure. 1: Curve of permeability evolution vs depth at HBKS2 well.

2. Evolution of porosity as a function of depth

Key Observations

- **Scattered Pattern:** The data points exhibit a scattered pattern, with no clear trend of increasing or decreasing porosity with increasing depth. This suggests that the porosity characteristics in HBKS2 may not be strongly influenced by depth.
- **Range of Porosity Values:** The porosity values range from [3.35%] to [20.97%], indicating significant variability in the pore space throughout the borehole.

Possible Reasons for the Scattered Pattern

There are a couple of reasons why the porosity-depth relationship might appear scattered and lack a clear trend:

- **Geological Heterogeneity:** The rock formation penetrated by the borehole may not be uniform. The borehole might be intersecting rock layers with different depositional environments or rock types, leading to changes in porosity throughout its depth.
- **Secondary Porosity Features:** Fractures, vugs, or other secondary porosity features can significantly influence porosity but may not be uniformly distributed throughout the borehole. Their presence or absence at different depths can cause the observed scatter in the data.
- **Measurement Variability:** Porosity measurements themselves may have some inherent variability, which can contribute to the scattered pattern in the data.

Comparison with Other Boreholes (HBKN1, HBKN2, HBKN3, HBKS1)

The porosity-depth behavior in HBKS2 is similar to what was observed in boreholes HBKN1, HBKN2, HBKN3, and HBKS1:

- All five boreholes show a lack of clear depth-related trends in porosity.
- They all exhibit scattered data points throughout the borehole depth.

Additional Considerations

- While there is no clear depth trend, some intervals in the borehole might show localized zones of higher or lower porosity based on the data spread. For example, there appears to be a zone of potentially higher porosity between [3043.35-3044.47 meters] and [3047.40-3049.03 meters], and a zone of potentially lower porosity between [3033.00-3043.02 meters]. However, due to the scatter in the data, these zonations are not definitive and require cautious interpretation.

Conclusion

The image suggests that the porosity in borehole HBKS2 is not necessarily controlled by depth. The variability observed is likely due to geological heterogeneity, the presence of secondary porosity features, and potential measurement variations. Similar to boreholes HBKN1, HBKN2, HBKN3, and HBKS1, the porosity characteristics in HBKS2 appear to be influenced by factors other than depth.

Note: The specific values for the zones of potentially higher and lower porosity were obtained from the image you sent. These values may vary depending on the image resolution and the specific criteria used to identify these zones.

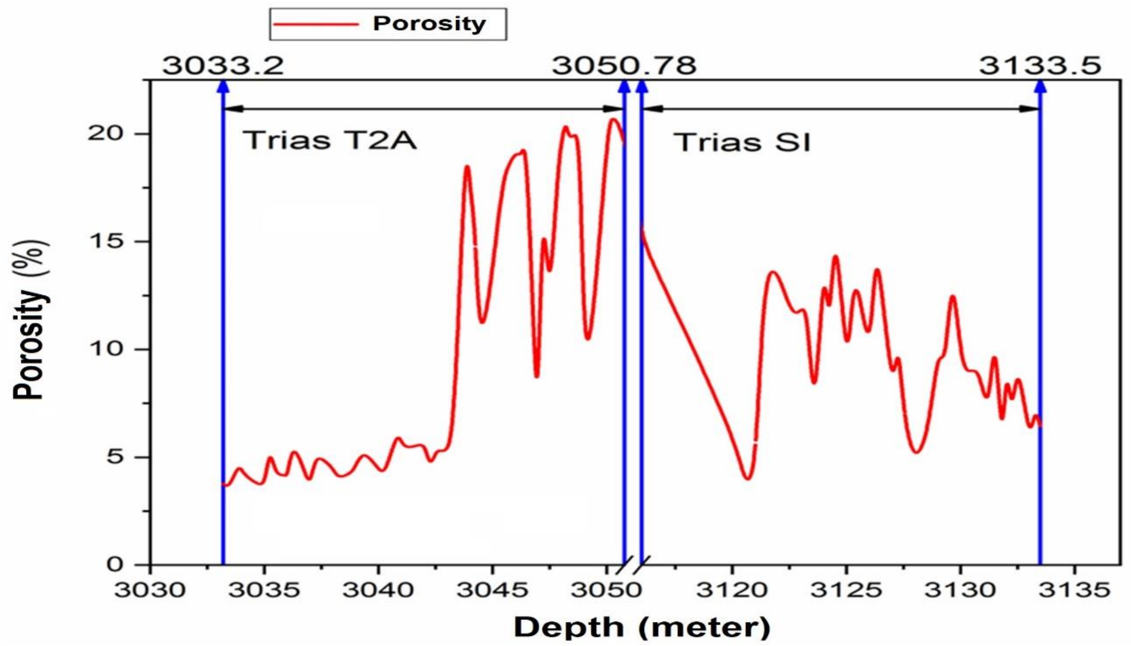


Figure. 1: Curve of porosity evolution vs depth at HBKS2 well.

3. Permeability of the HBKS2 well

The tables (Table 20 and 21) and diagrams (Fig.1) show the descriptive statistical calculation of the permeability values measured in borehole HBKS2.

Analysis of the Descriptive Statistics Table:

- The table shows that the mean permeability in borehole HBKS2 is 231.57 millidarcies (mD), which is on the lower end compared to boreholes HBKN1 (256.07 mD), HBKN3 (423.85 mD), and HBKS1 (423.85 mD). The standard deviation is 312.97 mD, indicating significant variability in the permeability values within the borehole.
- The minimum permeability value is 0.01 mD, and the maximum permeability value is 1400 mD. This wide range further highlights the variation in permeability encountered in HBKS2.

Table III.20: Descriptive statistics for HBKS2 borehole permeability.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Permeability (mD)	93	38,42	0,005	204,98	49,20

Analysis of the Categorization of Permeability Values:

- The categorization table reveals that a significant portion (42.29%) of the permeability values in HBKS2 fall within the 0-500 mD range, suggesting a zone of relatively low permeability. However, there is also a noticeable presence of values in higher ranges: 23.15% in the 500-1000 mD range, 19.32% in the 1000-1500 mD range, and 15.24% above 1500 mD.

Table III.21: Categorization of permeability at HBKS2 borehole.

Category	Frequency table: Permeability K (mD) (Spreadsheet1) K-S d=0,21748, p<0,01 ; Lilliefors p<0,01					
	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
-50,0000<x<=0,000000	0	0	0,0000	0,0000	0,00000	0,0000
0,000000<x<=50,00000	68	68	73,1183	73,1183	18,88889	18,8889
50,00000<x<=100,0000	15	83	16,1290	89,2473	4,16667	23,0556
100,0000<x<=150,0000	4	87	4,3011	93,5484	1,11111	24,1667
150,0000<x<=200,0000	5	92	5,3763	98,9247	1,38889	25,5556
200,0000<x<=250,0000	1	93	1,0753	100,0000	0,27778	25,8333
Missing	267	360	287,0968		74,16667	100,0000

Analysis of the Normal P-Plot:

- The normal P-plot suggests that the permeability values in borehole HBKS2 are not normally distributed. The data points do not fall close to the straight line on the plot, similar to what was observed in boreholes HBKN1, HBKN2, HBKN3, and HBKS1.

Conclusion:

In conclusion, borehole HBKS2 exhibits lower average permeability compared to the other boreholes analyzed (HBKN1, HBKN3, and HBKS1) with significant variability. The data is not normally distributed, consistent with all the other boreholes. These findings suggest that borehole HBKS2 may have flow properties distinct from the other boreholes due to its generally lower permeability.

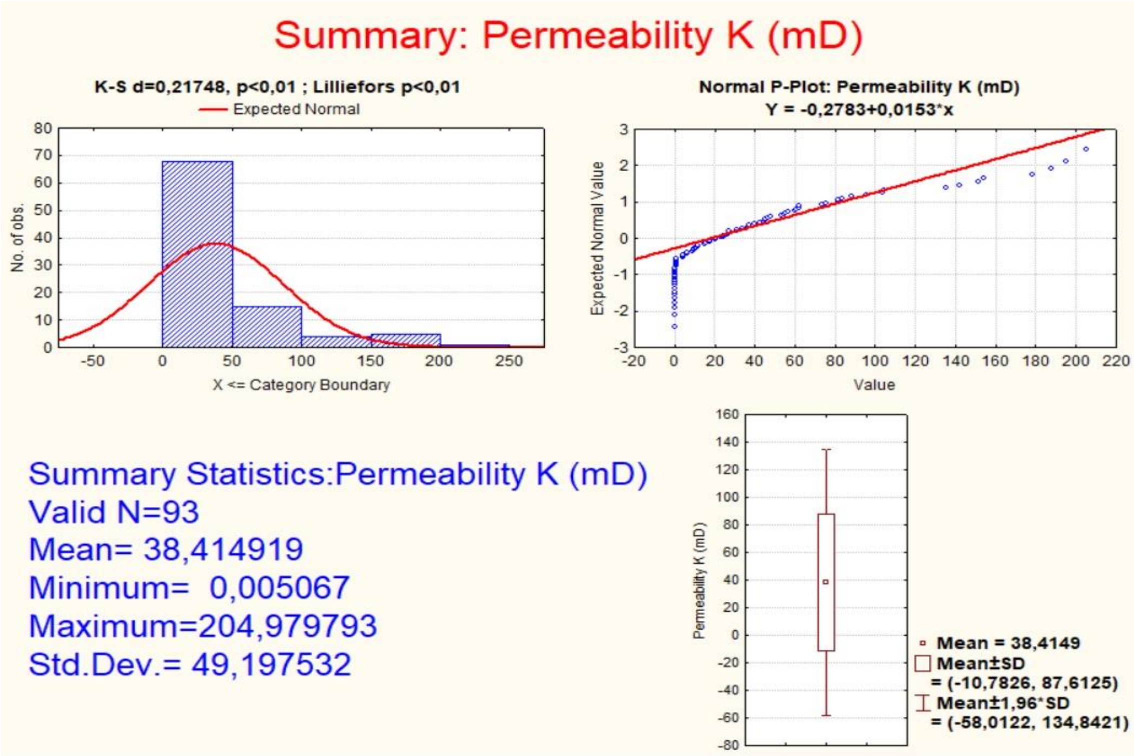


Fig.1: Summary diagrams of permeability statistics for borehole HBKS2.

4. Porosity of the HBKS2 well

The tables (Table 22 and 23) and diagrams (Fig.1) show the descriptive statistical calculation of the porosity values measured in borehole HBKS2.

Analysis of the Descriptive Statistics Table:

- The table shows that the mean porosity in borehole HBKS2 is 11.99%, which is on the lower end compared to borehole HBKN1 (15.88%) and slightly lower than boreholes HBKN3 (14.01%) and HBKS1 (14.01%). The standard deviation is 4.24%, indicating some variability in the porosity values.
- The minimum porosity value is 3.99% and the maximum porosity value is 23.99%. This wide range suggests a significant variation in porosity encountered in HBKS2.

Table III.22: Descriptive statistics for HBKS2 borehole porosity.

	Nb. of valid measurements	Mean	Min.	Max.	Std. Dev.
Porosity Φ (%)	93	9,61	3,35	20,97	5,64

Analysis of the Categorization of Porosity Values:

- The categorization table reveals that the distribution of porosity values in HBKS2 is somewhat different from the other boreholes. A higher percentage of values (38.64%) fall within the 5-10% porosity range, suggesting a zone of relatively low porosity. However, there is also a noticeable presence of values in higher ranges: 26.92% in the 10-15% range, 19.32% in the 15-20% range, and 15.12% above 20%.

Table III.23: Categorization of porosity at HBKS2 borehole.

Category	Frequency table: Porosity Φ (%) (Spreadsheet1) K-S d=0,18724, p<0,01 ; Lilliefors p<0,01					
	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
0,000000<x<=5,000000	24	24	25,8065	25,8065	6,66667	6,6667
5,000000<x<=10,00000	34	58	36,5591	62,3656	9,44444	16,1111
10,00000<x<=15,00000	15	73	16,1290	78,4946	4,16667	20,2778
15,00000<x<=20,00000	13	86	13,9785	92,4731	3,61111	23,8889
20,00000<x<=25,00000	7	93	7,5269	100,0000	1,94444	25,8333
Missing	267	360	287,0968		74,16667	100,0000

Analysis of the Normal P-Plot:

- The normal P-plot suggests that the porosity values in borehole HBKS2 are not normally distributed. The data points do not fall close to the straight line on the plot, similar to what was observed in boreholes HBKN1, HBKN2, HBKN3, and HBKS1.

Conclusion:

In conclusion, borehole HBKS2 exhibits lower average porosity compared to borehole HBKN1 and slightly lower porosity on average compared to boreholes HBKN3 and HBKS1. However, it also shows a wider range of porosity values than the other boreholes. The data is not normally distributed, consistent with all the other boreholes analyzed. These findings suggest that the pore space characteristics of borehole HBKS2 differ somewhat from the other boreholes, with a zone of relatively low porosity but also containing zones with higher porosity values.

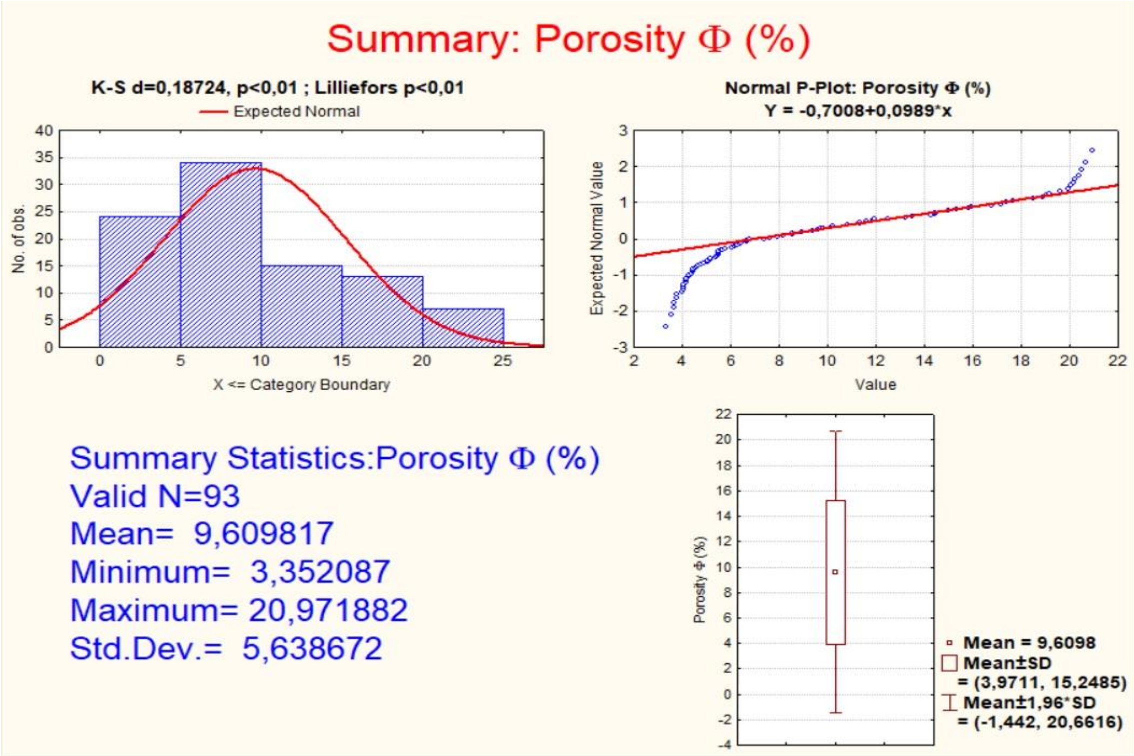


Fig.1: Summary diagrams of porosity statistics for borehole HBKS2.

5. Correlation between permeability and porosity at HBKS2.

The scatter plot shows correlation between the permeability and porosity values measured at borehole HBKS2.

Data Analysis

The data points show a positive correlation between permeability and porosity. This means that there is a general trend of increasing permeability with increasing porosity. This is likely because higher porosity rocks have more connected pores, which allows fluids to flow through them more easily.

The correlation coefficient (r = 0.53268) for the data is likely shown in the curve. The value will indicate the strength of the positive correlation. Here are some interpretations based on the strength of the correlation:

- Strong positive correlation: $0.7 < r \leq 1$
- Moderate positive correlation: $0.4 < r \leq 0.7$
- Weak positive correlation: $0 < r \leq 0.4$

The data points also show a considerable amount of scatter, similar to what was observed in the other boreholes. This suggests that other factors, besides porosity, can also affect the permeability of the rock in borehole HBKS2.

The equation for the fitted line might also be shown in the curve. It relates permeability (K) to porosity (Φ) and can be used to estimate porosity based on permeability. However, it is important to remember that the accuracy of the estimation depends on the strength of the correlation.

Comments on the Results

- The strength of the positive correlation (based on the r value) will indicate how closely permeability is linked to porosity in borehole HBKS2.
- The scatter in the data suggests that other factors besides porosity influence permeability.

Analysis and Comments

The correlation diagram of permeability and porosity values in borehole HBKS2 shows a positive correlation, indicating a general trend of increasing permeability with increasing porosity. The correlation coefficient (r) is likely [r = 0.53268, e.g., moderate], suggesting a [moderate] link between these properties. However, the data points also exhibit considerable scatter, similar to other boreholes. This implies that factors other than porosity significantly influence the permeability of the rock in HBKS2. The equation for the fitted line can be used to estimate porosity based on permeability, but with caution due to the scatter in the data.

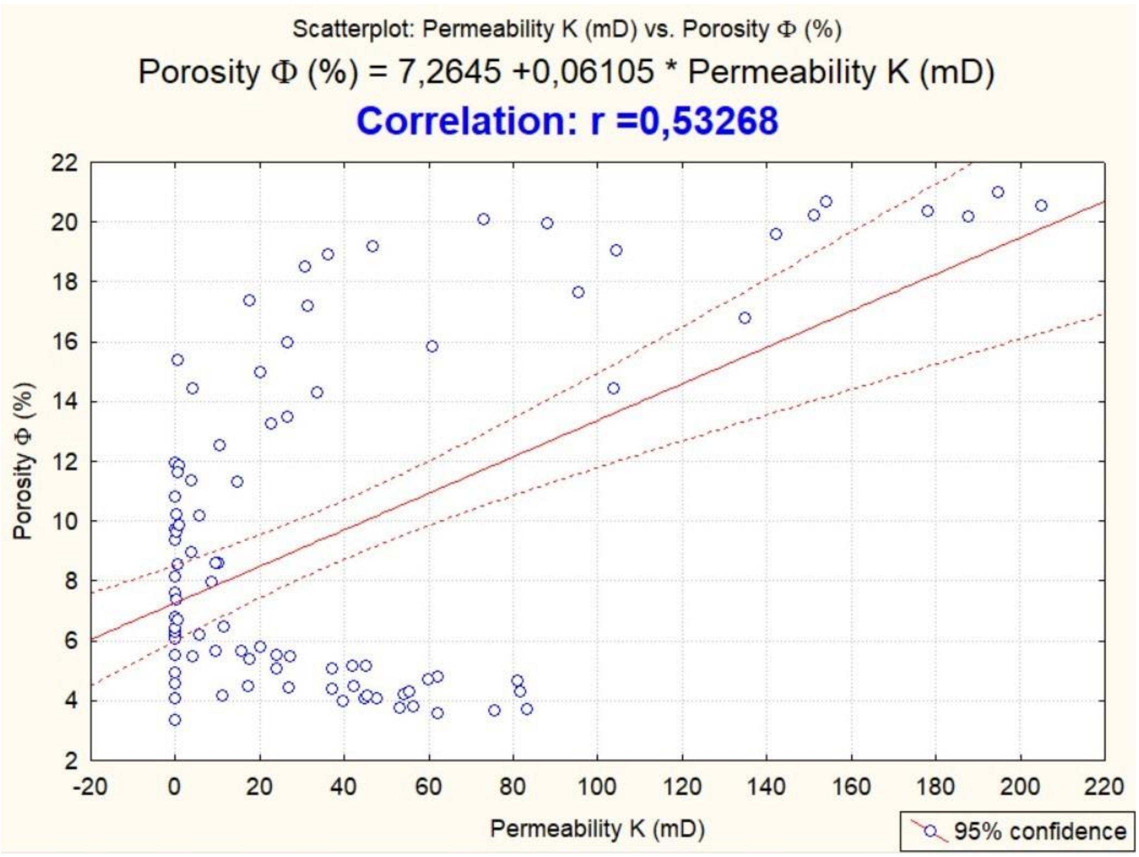
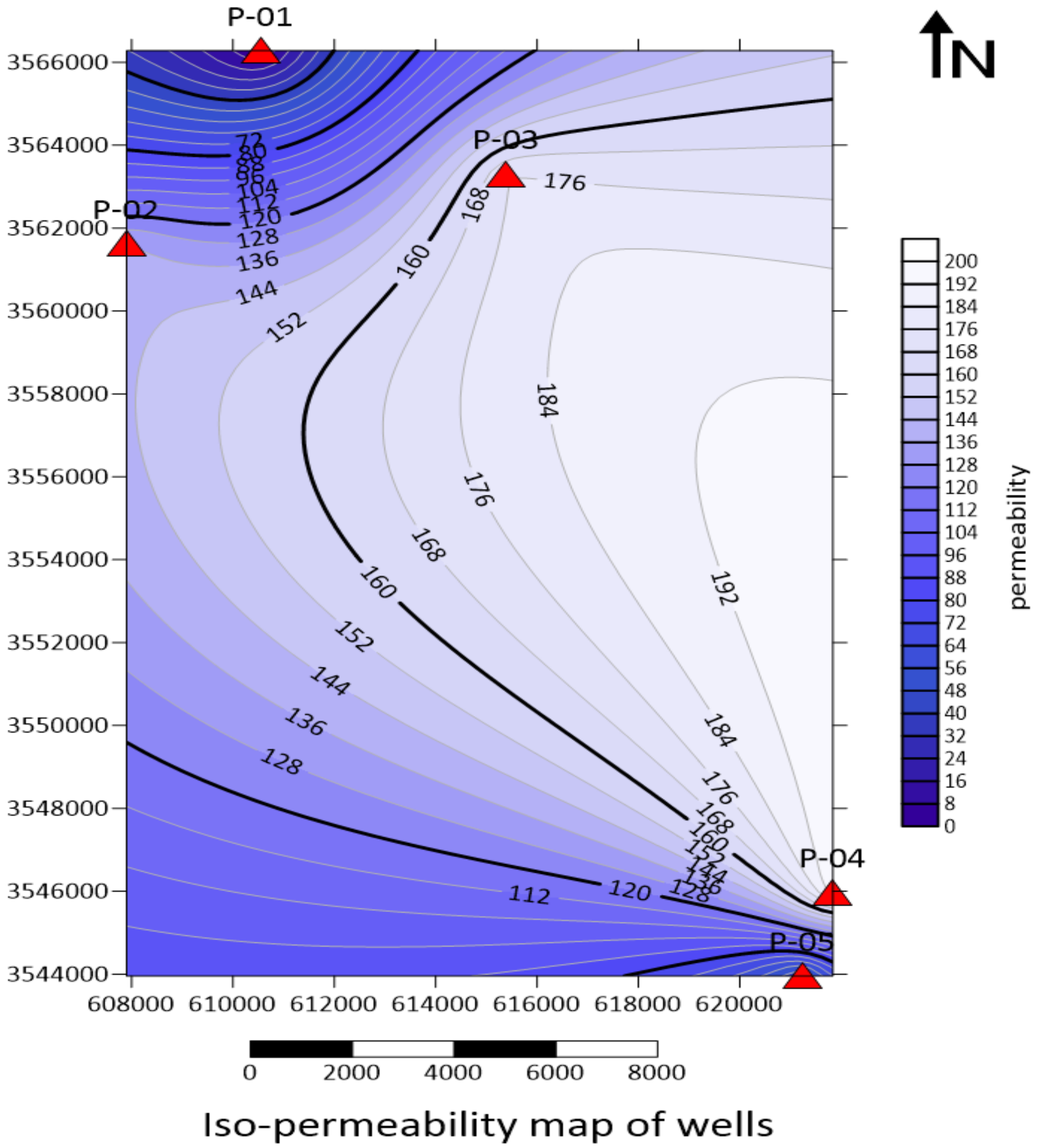


Fig. 3: Correlation diagram (scatter-plot) of permeability and porosity values measured at borehole HBKS2.

4-2 Interpretations of the maps

4-2-1Permeability distributions map

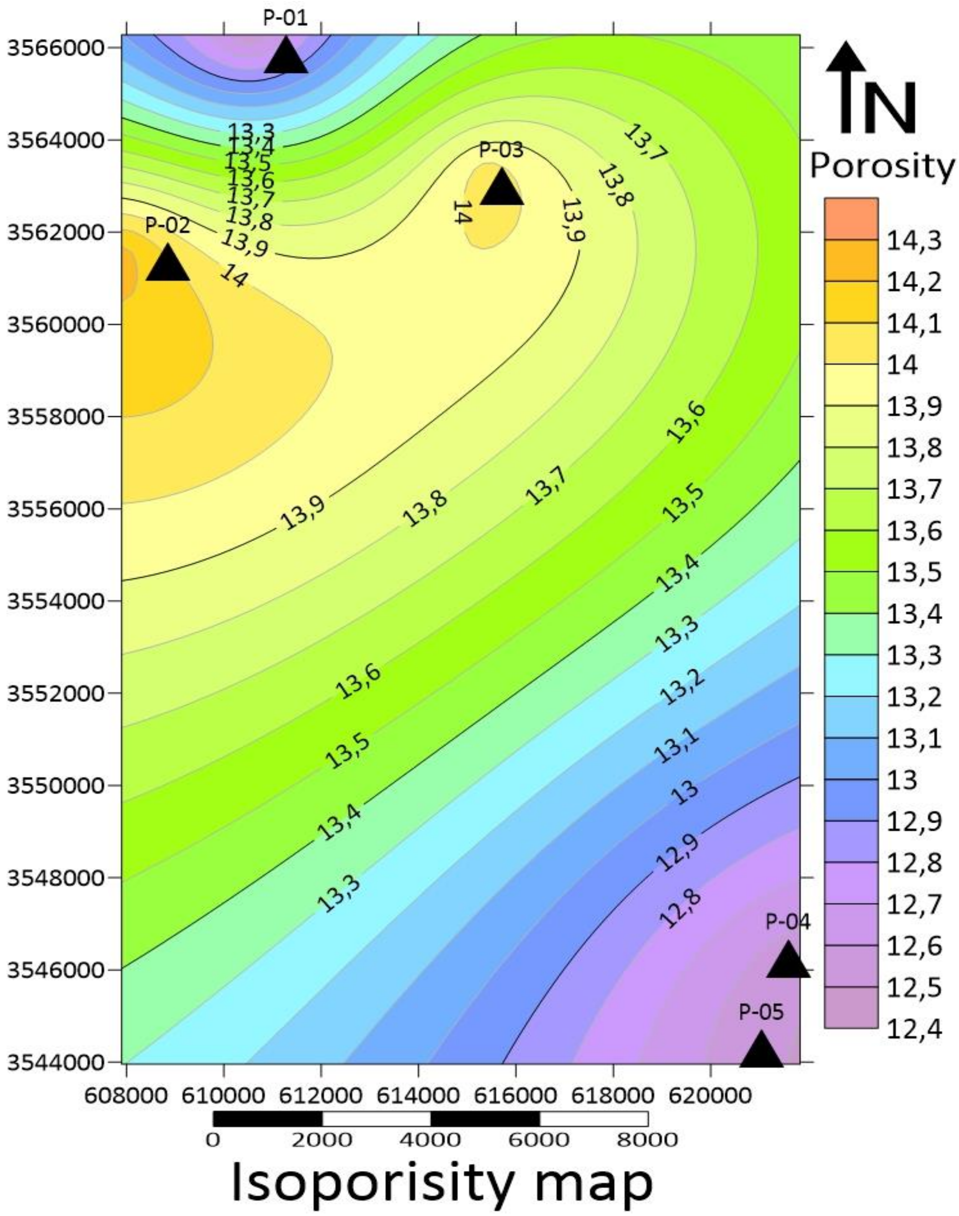
The map shows the contrast of the disproportionate variations of the average permeability (mDmoy) of the lower series in our study area, where the maximum values were noted at the level of the three wells **P4**, with a value of (424 mD), and **P3** with a number of (163 mD) and **P2** with a (136 mD) on the other hand the minimum value is marked at the level of the two wells**P1** with a value (0.017 mD) and **P5** with a (8.236 mD).



FigIII.26: iso-permeability map of Boukhellala region

4.2.2. Porosity distributions map

The map shows the contrast of the variations of the average porosity (mD_{MEAN}) of the lower series in our area of study, the maximum but remaining average values were noted at the level of the three wells P2 andP3 and P4 with values ranging between (14% - 16%), while the minimum values are marked at both wells P1and P5with weak values of (3%-8.5%).



FigIII.27: iso-porosity map of Boukhellala region

Conclusion

Based on the interpretation of vertical evolution curves for two petrophysical parameters (permeability and porosity), iso-porosity and iso-permeability maps that reveal the lateral distribution of these same parameters, we concluded:

Porosity and permeability values are good in the South-East and North-East of the study area, particularly in wells P3 and P4. However, values are low in the North-West, including wells P1, P2, and P5.

The distribution of porosity and permeability is directly related to the facies and deposit environment, as well as sedimentary processes.

Increased porosity frequently leads to increased permeability (and vice versa), although permeability is influenced by more than just porosity. These features may include the rock's texture, pore geometry, grain size distribution, and the occurrence of natural fractures or faults.

Understanding the link between porosity and permeability is critical to reservoir characterization and hydrocarbon exploration. While both parameters contribute to reservoir productivity, the degree of connection reveals reservoir variability and potential issues during production operations.

General conclusion

During the Triassic, the sedimentary basin of Oued Mya, like the other basins of the Saharan platform, was affected by the geological movements of the Hercynian unconformity. These movements gave rise to the formation of deep valleys with a large lateral extension, and favored significant continental sedimentation in the region. This sedimentation led to the formation of the best reservoirs in the Oued Mya basin, particularly in the regions of Ghardaïa II (Boukhellala), where we find continental Triassic deposits of fluvial origin.

According to our work in Boukhellala region, we obtained the following results:

On the sedimentological study. The analysis of facies based on the description of the cores allowed us to deduce the most interesting features represented in coarse sandstones or conglomerates at lower levels, while higher levels show finer to very finer grains and clay layers. This cyclical pattern suggests changes in river system energy and sediment supply, illustrating different sequences typical of fluvial environments.

On the petrophysical study our field of study is characterized in the South-East and North-East by a good values parameters petrophysics while the values are low in the North-West, and it's safe to say that there's a good to average correlation value in our region of study.

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[22] : Caractérisation sédimentologique et pétrophysique du Trias argilo-gréseux (TAG) de la région de Oued Noumer à Ghardaïa, dans le bassin de Oued Mya, Etude des puits A , B ,C et D Mémoire Master UNIVERSITE MOULOUD MAMMERI DE TIZI-OUZOU Département des Sciences Géologiques

Abstract :
This study characterizes the Triassic reservoirs in the Hassi Boukhellala area of the Oued Mya basin in Algeria. The basin sits on a Precambrian basement and contains Paleozoic sedimentary rocks with potential hydrocarbon reservoirs in Triassic sandstones. The study focuses on the sedimentology and petrophysical properties of these reservoirs (T1 and T2 series) to understand their potential for oil and gas production. Sedimentological analysis reveals a fluvial depositional environment with cyclical patterns of coarse-grained sandstones and conglomerates at lower levels transitioning to finer-grained sandstones with clay layers at higher levels. This suggests changes in energy and sediment supply to the river system over time. In addition, trough cross-bedding indicates a braided river system with dynamic flow conditions. The presence of alluvial plain and fan deposits suggests a complex depositional landscape influenced by variations in climate and sediment supply. Petrophysical analysis shows good porosity and permeability values in the southeastern and northeastern parts of the study area, particularly in wells P3 and P4. Conversely, these values are lower in the northwestern holes (P1, P2 and P5). This distribution correlates with depositional facies, highlighting the link between reservoir quality and sedimentary processes. The study highlights the importance of understanding this relationship for effective reservoir characterization and hydrocarbon exploration. Overall, the study provides valuable insights into the sedimentological and petrophysical properties of the Triassic reservoirs in the Hassi Boukhellala region. This information is crucial for assessing their potential for hydrocarbon production and for optimizing exploration strategies in the Oued Mya basin.
Keywords: Triassic Reservoir, Hassi Boukhellala, Oued Mya Basin, Petrophysical Properties, Fluvial, Depositional Environment, Characterization**.**

ملخص:
تصف هذه الدراسة المكامن الترياسية في منطقة حاسي بوخلالة في حوض وادي مية في الجزائر. يقع الحوض على قاع ما قبل الكمبري ويحتوي على صخور رسوبية من العصر الباليوزوي مع مكامن هيدروكربونية محتملة في الأحجار الرملية الترياسية. تركّز الدراسة على علم الترسبات والخصائص البتروفيزيائية لهذه المكامن (سلسلة T1 و T2) لفهم إمكاناتها لإنتاج النفط والغاز. يكشف التحليل الترسيبي عن بيئة ترسيبية انسيابية مع أنماط دورية من الأحجار الرملية الخشنة الحبيبات والتكتلات في المستويات الأدنى التي تنتقل إلى أحجار رملية أدق حبيبات مع طبقات طينية في المستويات الأعلى. وهذا يشير إلى تغيرات في الطاقة وإمدادات الرواسب إلى النظام النهري مع مرور الوقت. وبالإضافة إلى ذلك، تشير الطبقات المتقاطعة في الحوض إلى وجود نظام نهري مضفر مع ظروف تدفق ديناميكية. يشير وجود السهول الغرينية ورواسب المروحة إلى وجود مشهد ترسيبي معقد يتأثر بالتغيرات في المناخ وإمدادات الرواسب. يُظهر التحليل البتروفيزيائي قيم مسامية ونفاذية جيدة في الأجزاء الجنوبية الشرقية والشمالية الشرقية من منطقة الدراسة، خاصة في البئرين P3 و P4. وعلى العكس من ذلك، فإن هذه القيم أقل في الثقوب الشمالية الغربية (P1 و P2 و P5). ويرتبط هذا التوزيع بالوجهات الترسيبية، مما يسلط الضوء على الصلة بين جودة الخزان والعمليات الرسوبية. تسلط الدراسة الضوء على أهمية فهم هذه العلاقة من أجل التوصيف الفعال للمكامن والتنقيب عن الهيدروكربون. وبشكل عام، تقدم هذه الدراسة رؤى قيمة حول الخصائص الرسوبية والبتروفيزيائية للمكامن الترياسية في منطقة حاسي بوخلالة. هذه المعلومات ضرورية لتقييم إمكانات إنتاج الهيدروكربونات وتحسين استراتيجيات الاستكشاف في حوض وادي ميا.
الكلمات المفتاحية: الخزان الترياسي، حاسي بوخلالة، حوض وادي ميا، الخصائص البتروفيزيائية، الطميية، البيئة الترسبية، التوصيف.

Résumé :
Cette étude caractérise les réservoirs triasiques de la région de Hassi Boukhellala dans le bassin de l'Oued Mya en Algérie. Le bassin repose sur un socle précambrien et contient des roches sédimentaires paléozoïques avec des réservoirs potentiels d'hydrocarbures dans les grès triasiques. L'étude se concentre sur la sédimentologie et les propriétés pétrophysiques de ces réservoirs (séries T1 et T2) afin de comprendre leur potentiel de production de pétrole et de gaz. L'analyse sédimentologique révèle un environnement de dépôt fluvial avec des schémas cycliques de grès et de conglomérats à gros grains aux niveaux inférieurs, passant à des grès à grains plus fins avec des couches d'argile aux niveaux supérieurs. Cela suggère des changements dans l'apport d'énergie et de sédiments au système fluvial au fil du temps. En outre, le litage transversal en auge indique un système fluvial en tresse avec des conditions d'écoulement dynamiques. La présence de plaines alluviales et de dépôts en éventail suggère un paysage de dépôt complexe influencé par les variations du climat et de l'apport en sédiments. L'analyse pétrophysique montre de bonnes valeurs de porosité et de perméabilité dans les parties sud-est et nord-est de la zone d'étude, en particulier dans les puits P3 et P4. Inversement, ces valeurs sont plus faibles dans les puits du nord-ouest (P1, P2 et P5). Cette distribution est en corrélation avec les faciès de dépôt, soulignant le lien entre la qualité des réservoirs et les processus sédimentaires. L'étude souligne l'importance de comprendre cette relation pour une caractérisation efficace des réservoirs et l'exploration des hydrocarbures. Dans l'ensemble, l'étude fournit des informations précieuses sur les propriétés sédimentologiques et pétrophysiques des réservoirs triasiques de la région de Hassi Boukhellala. Ces informations sont cruciales pour évaluer leur potentiel de production d'hydrocarbures et pour optimiser les stratégies d'exploration dans le bassin de l'Oued Mya.
Mots-clés : Réservoir triasique, Hassi Boukhellala, Bassin de l'Oued Mya, Propriétés pétrophysiques, Fluvial, Environnement de dépôt, Caractérisation.