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MASTER THESIS

Speciality: HYDROCARBON GEOLOGY

The impact of Borehole Imaging (OBMI and UBI)
in the oilfield BBK in the Hassi Berkine
Field

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DEDICATION

Alhamdulillah, All praise is due to Allah, for granting me the strength, patience, and guidance to reach this important milestone in my life.

I would like to dedicate this work to my amazing parents for their endless support, boundless love, and relentless encouragement, which have been fundamental in all things I have managed to do. Sacrifices made, advice given, and belief in me which you had, made it possible for me to move on this journey and this makes me forever grateful to you.

To my two beloved sisters, Your kindness, support, and belief in me have been a constant source of motivation. Thank you for always being there, for your patience, and for standing by me through every step of this journey.

To the soul of my late grandfather HOUCINE, You may no longer be with us, but your memory lives on in my heart. Your wisdom and values continue to inspire me every day. I dedicate this work to your everlasting presence in my life.

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This work is a testament to all of you, with heartfelt gratitude and endless love. Thank you for being the pillars of my life and for always believing in me.

-Laouamen Tayeb Said-

DEDICATION

In the name of Allah, the Most Gracious, the Most Merciful. With deep gratitude, I dedicate this work to the people whose presence, guidance, and support have contributed to my academic and personal journey.

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-Khammar Aymen Malik Bey-

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Abstract

In this modest contribution to reservoir characterization, we explore the Hassi Berkine BBK field within Algeria's Berkine Basin using OBMI and UBI borehole imaging tools. These techniques provide valuable insights into the field's sedimentary structures, fracture systems, and borehole stability. By carefully combining electrical and acoustic imaging data, we aim to better understand subsurface heterogeneity and support more accurate geological interpretations. The findings may help inform improved reservoir models and contribute, in a small way, to more effective hydrocarbon development strategies.

Keywords: borehole Images, OBMI, UBI, combining electrical and acoustic imaging data.

ملخص

في هذه المساهمة المتواضعة في توصيف المكامن، نستكشف حقل حاسي بركين كـ ضمن حوض بركين بالجزائر باستخدام أدوات تصوير الآبار اوبي ووي. توفر هذه التقنيات رؤى قيمة حول التركيبات الرسوبية للحقل، وأنظمة الصدعات، واستقرار الآبار. من خلال الجمع الدقيق لبيانات التصوير الكهربائي والصوتي، نهدف إلى فهم أفضل لتباين باطن الأرض، ودعم تفسيرات جيولوجية أكثر دقة. قد تساعد هذه النتائج في تحسين نماذج المكامن، وتساهم، ولو بشكل طفيف، في استراتيجيات أكثر فعالية لتطوير الهيدروكربونات.

الكلمات المفتاحية : اصور الآبار، اوبي، اوي، تجمع بين بيانات التصوير الكهربائي والصوتي..

Résumé

Dans cette modeste contribution à la caractérisation des réservoirs, nous explorons le champ BBK de Hassi Berkine, dans le bassin de Berkine en Algérie, à l'aide des outils d'imagerie de forage OBMI et UBI. Ces techniques fournissent des informations précieuses sur les structures sédimentaires, les systèmes de fractures et la stabilité des forages du champ. En combinant soigneusement les données d'imagerie électrique et acoustique, nous cherchons à mieux comprendre l'hétérogénéité du sous-sol et à optimiser les interprétations géologiques. Ces résultats pourraient contribuer à l'amélioration des modèles de réservoir et, dans une moindre mesure, à l'élaboration de stratégies plus efficaces d'exploitation des hydrocarbures. **Mots Clés:** Images de forage, OBMI, UBI, combinant des données d'imagerie électrique et acoustique.

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In the face of escalating global energy demands, the precise characterization of hydrocarbon reservoirs has become critically important. High-resolution borehole imaging techniques have emerged as essential tools, providing detailed insights into reservoir features that directly influence fluid dynamics and hydrocarbon extraction efficiency. Specifically, Oil-Base MicroImager (OBMI) and Ultrasonic Borehole Imager (UBI) logging technologies have proven highly effective in identifying and characterizing subtle geological attributes such as sedimentary bedding, fracture networks, and fine-scale heterogeneities. The Hassi Berkine Complex, operated by Groupement Berkine, is among Algeria's leading onshore hydrocarbon-producing regions. The Hassi Berkine South (HBNS) field, discovered in January 1995, is strategically located approximately 200 km southeast of the prolific Hassi Messaoud field, within the intracratonic Berkine Basin on the Saharan Platform. Its rapid development, led by Anadarko Petroleum in Blocks 403 and 404, achieved initial oil production in early 1995, quickly ramping up to a capacity of 75,000 bbl/day. The reservoir's complex architecture, comprising Triassic sandstones structurally segmented by salt-induced growth faults and stratigraphic variations, underscores the necessity of advanced borehole imaging for optimized reservoir management. The OBMI logging tool employs microresistivity sensors mounted on multiple pads to capture high-resolution electrical images of the borehole wall, covering extensive azimuthal sectors of up to

80The combined application of OBMI and UBI provides a comprehensive analytical framework, leveraging electrical and acoustic data synergy to significantly enhance petrophysical evaluation, structural mapping, and fracture characterization. This study focuses on the interpretation of OBMI and UBI logs from a selected BBK well, with targeted objectives to:

- Accurately delineate reservoir heterogeneity by mapping sedimentary facies and identifying precise stratigraphic boundaries.
- Identify and thoroughly characterize both natural and drilling-induced fractures, determining their orientations, distribution, and apertures.
- Analyze borehole stability indicators, such as breakouts and washouts, to infer in-situ stress orientations and magnitudes.
- Integrate detailed image-derived structural data with traditional log and core analyses to refine geological models, thus optimizing reservoir management strategies.

By adopting advanced interpretation workflows and integrating multiple imaging techniques, this research will deepen the understanding of Hassi Berkine reservoir architectures, promoting improved decision-making in drilling, completion, and overall production efficiency in one of Algeria's premier hydrocarbon assets.

CHAPTER 1

PRESENTATION OF THE Hassi Berkine REGION

1.1 Introduction

The Hassi Berkine Field, encompassing the Bir Berkine (BBK) and Bir Berkine Nord (BBKN) sectors, is a significant hydrocarbon accumulation within Algeria's Berkine Basin. Discovered in the mid-1980s, this field has been pivotal in Algeria's oil production landscape, contributing substantially to the nation's energy output. The field's development has been marked by collaborative efforts between Sonatrach and international partners, leading to extensive exploration and production activities.

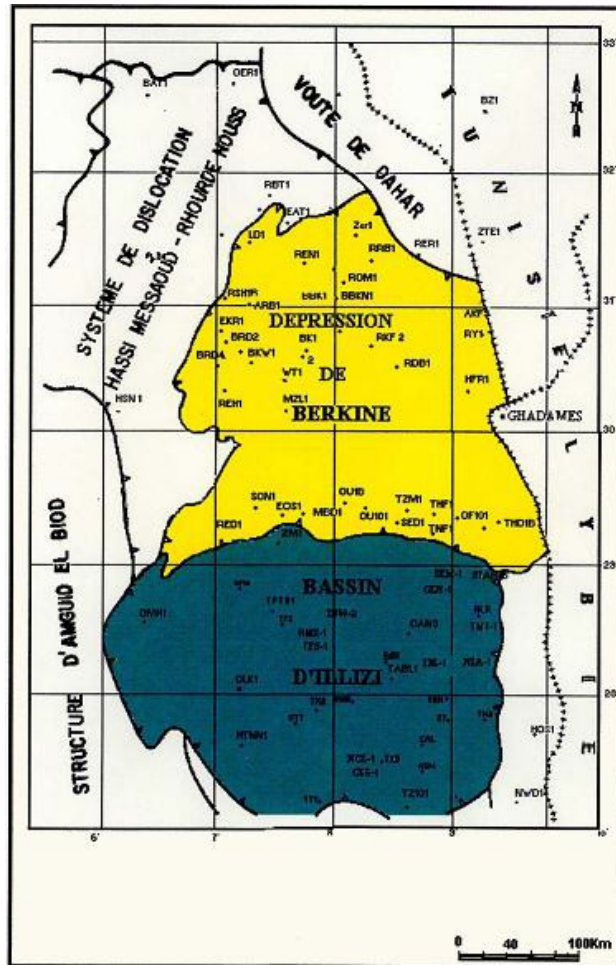


Figure 1.1: Geographic location of the Berkine Basin[5]

1.2 Geographical Location

The Berkine Basin is situated in the eastern Erg of the Algerian Sahara, between latitudes 29° N and 34° N and longitudes 5° E and 10° E, to the east of the Hassi Messaoud, Rhourde El Baguel, and Rhourde Nouss fields. It extends across three countries: its western portion lies in Algeria, its eastern sector in Libya, and its

northern fringe in southern Tunisia. From a geological standpoint, the Berkine Basin is an intracratonic basin (WEC, 2007) situated in the northeastern sector of the Saharan platform. It encompasses a total area of 102 395 km². The limits of the Berkine Basin are defined by:

- • **the Tunisian and Libyan national borders to the east**
- • **the Illizi Basin to the south**
- • **the Dahar Dome to the north**
- • **the Hassi Messaoud area to the west**

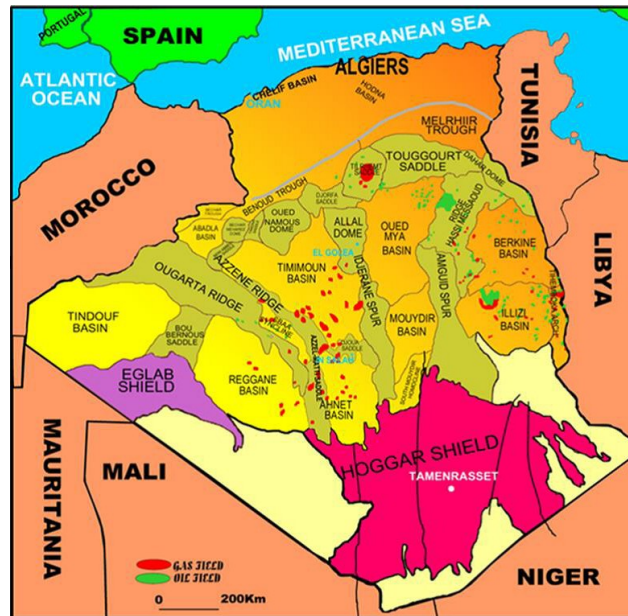


Figure 1.2: Map of the Sedimentary Basins of the Saharan Platform[2]

1.3 Geographical Framework

1.3.1 Regional Tectonic Setting

The Berkine Basin is a major hydrocarbon-bearing depocentre situated within the Triassic–Ghadames Province of the northern African intracratonic platform. It is structurally delineated by several key tectonic elements:

- **Northern Boundary** The Dahar Dome, a prominent uplifted structure.
- **Eastern Boundary** The Tihemboka Arch and the Tunisian–Libyan border, marking a transition into the Pelagian Basin.
- **Southern Boundary** The Illizi Basin hinge line, a structural flexure separating deeper subsidence zones.

- **Western Boundary** The Hassi Messaoud–Amguid structural axis, a long-lived basement high influencing sediment distribution.

This basin represents a broad cratonic sag that developed during Mesozoic rifting associated with the breakup of Pangea and the opening of the Neo-Tethys Ocean. The sedimentary succession reaches up to 7,000 m in thickness, encompassing strata from Cambrian basement rocks to Tertiary cover, recording multiple phases of subsidence, erosion, and tectonic reactivation.

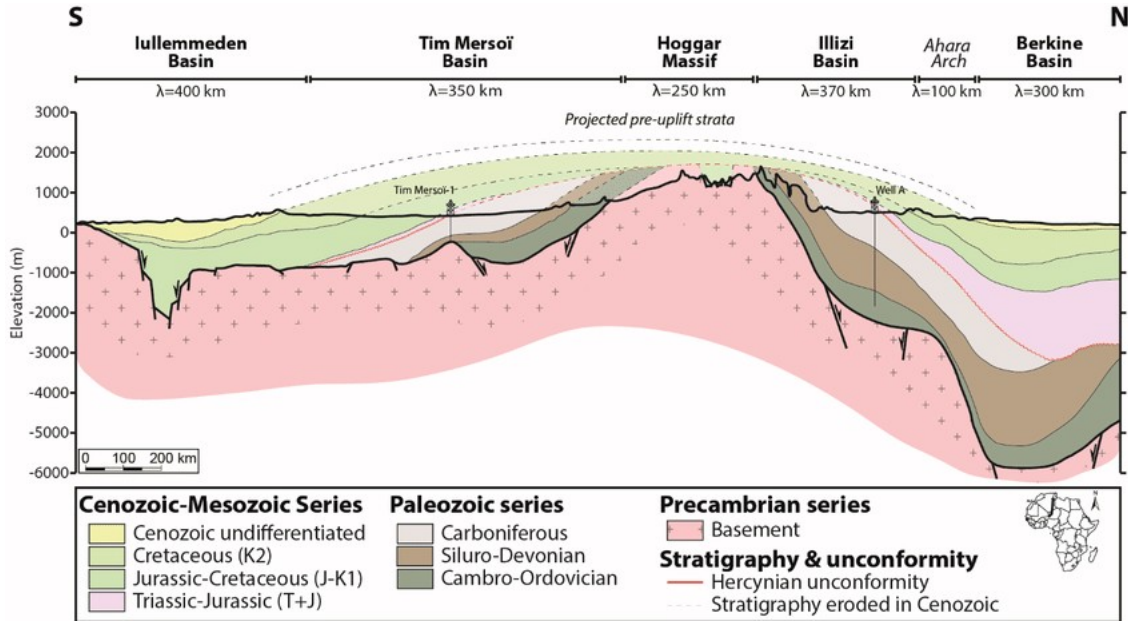


Figure 1.3: Regional Geological Cross-Section from the Iullemmeden Basin to the Berkine Basin, Algeria from [3]

1.4 Stratigraphic Framework and Basin Evolution

1.4.1 Basement and Paleozoic Succession

- **Basement Composition** The basin overlies Precambrian metamorphic and igneous rocks of the West African Craton, which were locally uplifted during the Pan-African orogeny (Late Proterozoic, 600 Ma). Paleozoic Sedimentation:
- **Cambrian–Ordovician:** Fluvial to shallow-marine sandstones and shales, deposited in a stable passive margin setting.
- **Silurian:** Deposition of the Tanezzouft Formation, a globally significant hot shale rich in organic matter (TOC up to 12%) , serving as the primary source rock for hydrocarbons.

- **Devonian–Carboniferous:** Mixed carbonate-clastic sequences, influenced by Hercynian orogenic events (300 Ma), leading to regional uplift and erosion.
- **Permian** Continental red beds and localized fluvial deposits, marking arid conditions prior to Mesozoic rifting.

1.4.2 Triassic–Jurassic "TAGI" Sag Basin (Syn-Rift Phase)

- **Tectonic Context:** Middle to Late Triassic extension linked to Neo-Tethyan rifting created a broad intracratonic sag.
- **Reservoir Unit:** The Triassic Argilo-Gréseux Inférieur (TAGI) Formation consists of fluvial-lacustrine sandstones (thickness: 50–200 m), exhibiting high porosity (15–25%) and permeability (100–1000 mD), making it the primary hydrocarbon reservoir.
- **Seal Mechanism:** Overlying halite-dominated evaporites (Upper Triassic) form an effective regional seal, though halokinetic diapirism and growth faults locally disrupt continuity.

1.4.3 Mesozoic–Cenozoic Post-Rift Cover

- **Jurassic:** Mixed carbonate-shale sequences, with localized sabkha evaporites enhancing seal capacity.
- **Cretaceous:** Aptian evaporites provide additional sealing.
- **Albian–Cenomanian:** fluvial-deltaic sandstones act as secondary reservoirs.
- **Alpine–Pyrenean compression:** (30 Ma) reactivated basement structures (e.g., Tihemboka Arch), creating subtle structural traps and modifying hydrocarbon migration pathways.

1.5 Structural Architecture and Hydrocarbon Trapping Mechanisms

1.5.1 Salt Tectonics and Fault Systems

- **Salt-Related Deformation:** Triassic evaporites facilitated diapirism, rollover anticlines, and growth faults, compartmentalizing reservoirs.
- **Fault Block Segmentation:** The basin is divided into 1–3 km displacement fault blocks, with structural relief (10–50 m) controlling hydrocarbon distribution.

1.5.2 Petroleum System Elements:

The petroleum system in the Berkine Basin is characterized by well-defined source rocks, effective migration pathways, and diverse trapping mechanisms. The primary source rock is the Silurian Tanezzouft Shale, which is rich in Type II kerogen and exhibits a high hydrocarbon potential with hydrogen index (HI) values ranging from 300 to 600 mg HC/g TOC. A secondary, though less significant, source is found within the Devonian mudstones. Hydrocarbon generation reached its peak during the Late Cretaceous to Tertiary period, approximately 80 to 30 million years ago, driven by progressive burial and increased thermal maturity. The generated hydrocarbons migrated through a combination of vertical pathways, primarily along faults and fractures, and lateral migration within carrier beds, particularly the Ordovician sandstones, which provided efficient conduits due to their high porosity and permeability. Trapping mechanisms in the region include both structural and stratigraphic styles. Structural traps are predominantly represented by faulted anticlines and salt-cored domes, resulting from tectonic activity and halokinesis. On the other hand, stratigraphic traps often occur where sandstone reservoirs pinch out against low-permeability evaporitic seals, effectively retaining hydrocarbons within the reservoir.

1.6 Economic Significance and Exploration Challenges:

The Berkine Basin contains major oil fields such as Hassi Berkine and Ourhoud, with recoverable reserves exceeding 1 billion barrels. However, exploration faces key challenges, including reservoir heterogeneity from fluvial deposition, trap complexity caused by salt tectonics, and the critical timing between hydrocarbon charge and trap formation. These factors reflect the basin's complex geological evolution and define both the risks and opportunities for further exploration.

1.7 Stratigraphy of HBNS (Hassi Berkine North/South):

The stratigraphic succession in the Hassi Berkine North/south (HBNS) field is representative of the Berkine Basin's intracratonic setting and spans from the Precambrian basement up to Tertiary cover, with the most productive interval being the Lower Triassic TAGI Formation.

1.7.1 Basement and Paleozoic Units

The foundation of the region is formed by Precambrian crystalline basement rocks, often uplifted and faulted. The Paleozoic sedimentary cover comprises a thick sequence (up to 6000 m), including:

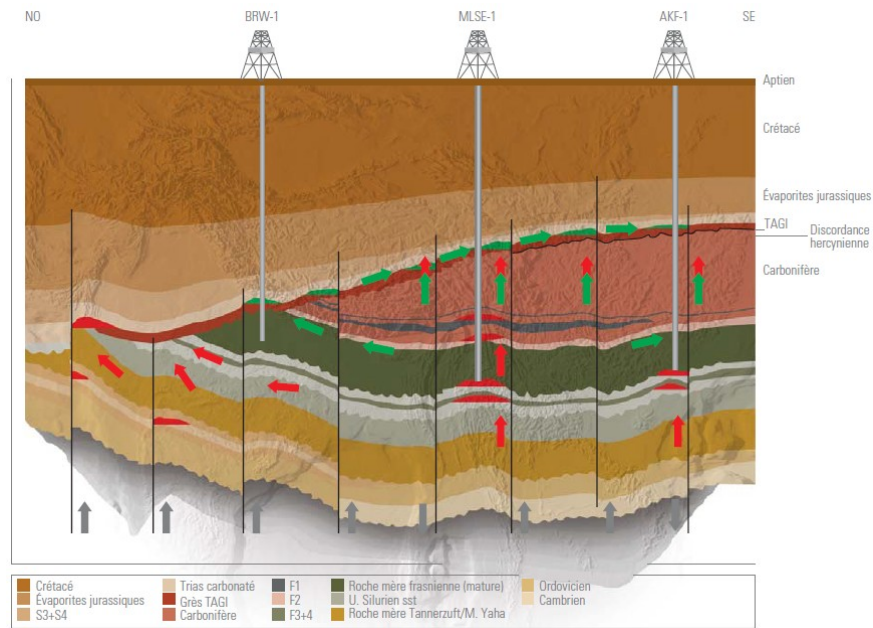


Figure 1.4: Map of the Sedimentary Basins of the Saharan Platform[5]

- **Cambrian:** Quartzites and conglomeratic sandstones, averaging 300 m thick, resting directly on the basement.
- **Ordovician:** Alternating clays and sandstones with quartz layers.
- **Silurian (Tanezzuft Shale):** Characterized by organic-rich, fossiliferous black shales, serving as a principal regional source rock, with an average thickness of 600 m.
- **Devonian (Siegenian to Frasnian):** Multiple levels of fine to medium sandstones and silty clays, with several distinct reservoir horizons (notably levels C, D, E, F, and G in the Siegenian), showing variable thickness and facies heterogeneity. The Hercynian orogeny caused significant uplift and erosion, particularly affecting the upper Paleozoic units.

1.7.2 Mesozoic Units

- **Triassic (TAGI Formation):** Represents the main reservoir in the region. These are fluvial, fine to medium, silicified sandstones (average thickness 20 m in BBK/BBKN, but up to >100 m elsewhere), often with excellent porosity and permeability. The TAGI is locally reduced due to Hercynian erosion. Overlying the TAGI are thick sequences of halite and anhydrite (Triassic salt), acting as highly effective evaporitic caprock, ensuring robust hydrocarbon trapping.
- **Jurassic to Cretaceous:** Comprised mainly of extensive sequences of shales, carbonates, dolomites, and anhydrites. While regionally significant, these

intervals do not serve as productive reservoirs within the BBK/BBKN fields.

1.7.3 Cenozoic Cover

The Cenozoic (mainly Mio-Pliocene) is represented by sandy and clayey deposits with minor carbonates and dolomites, reaching thicknesses of around 200 m. These have little reservoir potential but contribute to basin burial and overburden.

1.7.4 Reservoir Relevance

- **The TAGI** sandstones (Triassic) and Siegenian sandstones (Lower Devonian) are the principal reservoirs. Their quality is controlled by original facies, diagenetic overprint, and significant fault compartmentalization due to regional tectonics. The thick Triassic evaporites provide excellent structural and stratigraphic trapping conditions.
- **Siegenian reservoirs** are encountered at depths of 3460–3560 m, displaying porosities from 9–19% and permeabilities from 1 to 30 mD. Oil accumulations are light, with densities between 0.81–0.82 g/cm³ (39.5–42° API).

1.8 Oil Interest in the Hassi Berkine Field

1.8.1 Introduction

The Hassi Berkine Field holds significant strategic importance in Algeria's oil sector. Operated by Groupement Berkine, a joint venture between Sonatrach and international partners including Occidental Petroleum Corporation (24.5%), Eni S.P.A. (12.25%), and TotalEnergies (12.25%), the field has been a major contributor to the country's oil production. Since its inception, the partnership has produced over 1.7 billion barrels of gross oil and liquids. The field's production peaked in 2026, with an expected operational lifespan extending until 2043, accounting for approximately 3% of Algeria's daily oil output.

1.8.2 Hydrocarbon Potential of the Berkine Basin and HBNS

The Berkine Basin has proven to be one of Algeria's most productive petroleum provinces. HBNS is strategically positioned over a structurally complex zone influenced by salt tectonics, regional unconformities, and multiple source rock intervals. Oil discoveries in HBNS are concentrated along:

- **Pre-existing** structural highs (often uplifted during the Hercynian or Alpine phases).
- **Growth fault** systems associated with Triassic salt movement.

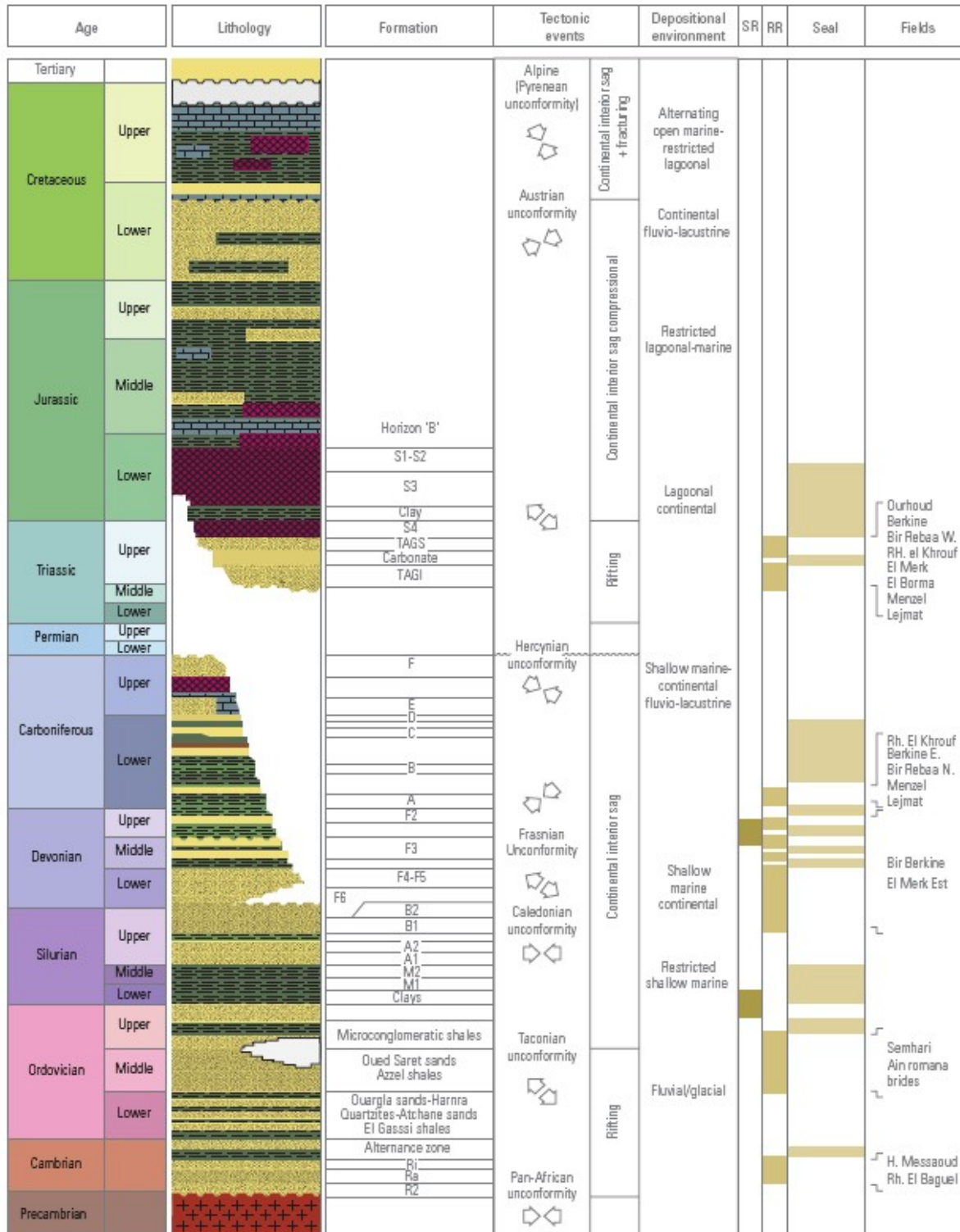


Figure 1.5: Stratigraphy of Hassi Berkine[5]

- **Unconformity** surfaces, acting both as migration pathways and trap boundaries. Hydrocarbons in the HBNS field are generated predominantly from the Silurian Tanezzuft Formation, an organic-rich black shale. Migration is primarily vertical through faults and fractures, with lateral migration along porous strata such as Ordovician and Triassic sandstones.

1.8.3 Petroleum System Overview :

Element	Description
Source Rock	Silurian Tanezzuft Shale (TOC: 5–12%, Type II kerogen)
Reservoirs	TAGI sandstone (main), Ordovician and Devonian sandstones (secondary)
Seal Rocks	Triassic evaporites (halite and anhydrite), Jurassic shales
Trap Types	Structural (fault blocks, salt domes), Stratigraphic (pinch-outs, unconformities)
Migration Pathways	Faults, unconformities, and carrier beds

Table 1.1: Main petroleum system elements of the Berkine Basin.

1.9 Principal Source Rocks in the Berkine Basin

The most important source rock in the Berkine Basin is the Silurian Tanezzuft Shale, with additional contributions from Devonian and Ordovician organic-rich intervals. These source rocks were deposited under anoxic marine conditions that favored the preservation of organic matter.

Silurian Tanezzuft Shale

- **Age:** Llandovery–Wenlock (Early to Middle Silurian)
- **Environment:** Deep marine, anoxic bottom waters
- **Organic Content:** Total Organic Carbon (TOC) ranges from 4% to 12%
- **Kerogen Type:** Type II (Oil-prone), with Hydrogen Index (HI) of 300–600 mg HC/g TOC
- **Thickness:** Can exceed 100 meters in the central basin
- **Importance:** Recognized as the primary source rock for oil and gas in the HBNS field and much of North Africa

Devonian Source Rocks

- Found within the Frasnian–Famennian black shales
- Typically contain Type II/III kerogen, capable of generating mixed oil and gas
- TOC values average 2–6%
- Generally considered secondary in terms of hydrocarbon contribution

Ordovician Shales

- Present in some deeper sections but less widespread
- TOC values usually below 3%
- Kerogen Type III (gas-prone), and thermally mature only in the deepest depocenters

1.9.1 Geochemical Characteristics and Maturity

The geochemical evolution of the Berkine Basin source rocks is driven by burial history, heat flow, and tectonic reactivation. Several geochemical parameters are used to evaluate their maturity and hydrocarbon generation potential:

- **Vitrinite Reflectance (Ro):** Tanezzuft Shale: Typically between 0.7% and 1.2% Ro, indicating mature to late-mature oil generation window
- **Tmax (from Rock-Eval pyrolysis):** Values between 430°C and 460°C, supporting oil-prone maturity levels
- **Biomarkers:** Abundant pristane/phytane ratios <1, and the presence of C29 steranes, confirm anoxic marine origins

1.9.2 Thermal Evolution and Timing of Generation

Thermal modeling indicates that peak oil generation from the Tanezzuft Shale occurred during the Late Cretaceous to Early Tertiary, coinciding with maximum burial depths and elevated geothermal gradients. The following stages characterize its evolution:

- **Early Maturation (Jurassic–Early Cretaceous):** Onset of kerogen transformation under increasing burial
- **Main Oil Window (Late Cretaceous):** Maximum hydrocarbon generation, particularly under high heat flow zones near structural highs
- **Late Maturation (Paleogene):** Oil generation slows as kerogen becomes depleted and enters wet gas window

1.9.3 Migration and Accumulation Pathways

Once expelled, hydrocarbons migrated vertically and laterally into structural and stratigraphic traps:

- Vertical migration through faults and fractures, particularly near salt diapirs and Hercynian uplift zones
- Lateral migration along porous carrier beds (e.g., Ordovician and Triassic sandstones)
- Timing of expulsion is closely aligned with trap formation, enhancing hydrocarbon preservation in the TAGI and Ordovician reservoirs

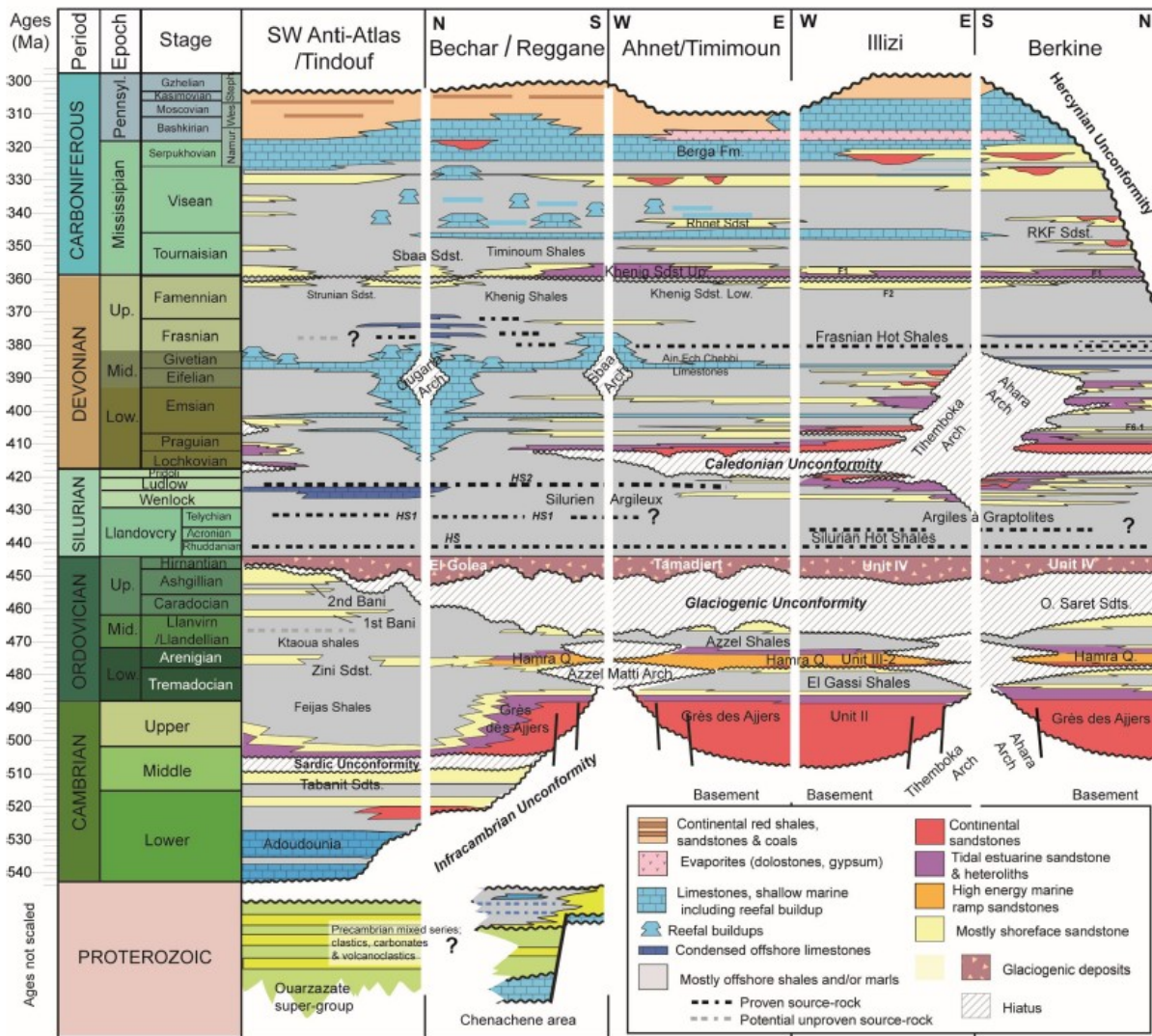


Figure 1.6: Chronostratigraphic chart on the scale of the Algerian Saharan basins (Alnaft study, realized by Beicip-Franlab).[4]

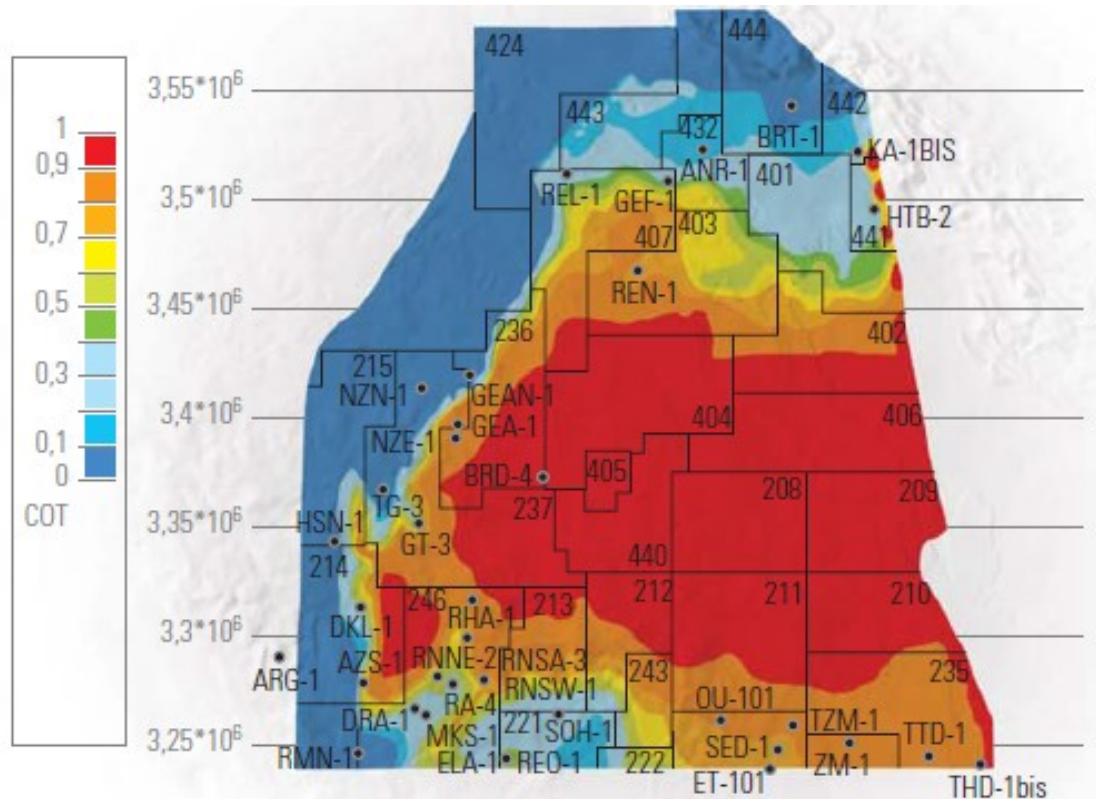


Figure 1.7: Silurian maturity map.[5]

1.10 Conclusion

The Hassi Berkine field, strategically located within the prolific Berkine Basin, represents a key hydrocarbon province in Algeria. The region's complex geological history, shaped by multiple tectonic and sedimentary events from the Precambrian to the Cenozoic, has fostered the development of high-quality reservoirs and effective seals. The Paleozoic succession, particularly the Silurian Tanezzuft Shale, acts as a major source rock, while the Triassic TAGI and Devonian Siegenian sandstones serve as the principal reservoirs, benefiting from significant facies heterogeneity and structural compartmentalization.

The discovery and subsequent development of the field have been driven by intensive exploration and delineation efforts, revealing substantial oil reserves, light crude characteristics, and robust trapping mechanisms provided by overlying evaporites. The evolution of source rocks and migration pathways within this tectonically active setting has contributed to the accumulation and preservation of significant hydrocarbon volumes.

Overall, the geological framework and petroleum system elements of the Hassi Berkine field underscore its strategic importance and continuing potential for hydrocarbon exploration and production in the Berkine Basin.

CHAPTER 2

imaging Purpose and Methodology

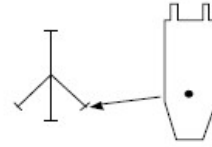
2.1 Introduction (History of Imaging)

The historical development of borehole imaging tools represents a transformative progression in the field of subsurface geological characterization, particularly in the context of hydrocarbon reservoir evaluation. Early efforts in structural interpretation relied on mechanical dipmeter tools, such as the Continuous Dipmeter (CDM), introduced in 1956, and the High-Resolution Dipmeter Tool (HDT), developed in 1968. These tools used mechanical arms and compasses to estimate bedding dip and azimuth, but their performance was constrained by friction, borehole irregularities, and low measurement resolution. The shift to solid-state electronics in the early 1980s marked a significant leap forward, exemplified by the Stratigraphic High-Resolution Dipmeter Tool (SHDT), which could deliver up to 28 dip measurements per bedding plane, vastly enhancing data density and reliability. A major technological breakthrough came with the introduction of Schlumberger's Formation MicroScanner (FMS) in 1986, an electrical imaging tool equipped with 27 button electrodes on two pads. The FMS not only retained dipmeter functionality but also enabled detailed imaging of the borehole wall. The subsequent four-pad version, released in 1988, increased borehole coverage to approximately 40%. In 1991, Schlumberger introduced the Formation MicroImager (FMI), a tool incorporating four arms, each with two pads, with a total of 192 microelectrodes. This enabled coverage of up to 80% of an 8-inch borehole wall and vertical resolution as fine as 0.2 inches (5 mm), setting a new industry standard for high-resolution borehole imaging. However, the use of FMI was limited in oil-based mud (OBM) environments due to the non-conductive nature of the fluid. To address this, ultrasonic tools such as the Ultrasonic Borehole Imager (UBI) were developed, which utilize high-frequency acoustic pulses to generate amplitude and transit-time images, independent of mud conductivity. While these tools provided robust imaging in OBM wells, their lithological interpretability was lower than resistivity-based imagers. In response, the Oil-Based MicroImager (OBMI) was launched in 2000, specifically engineered to operate in OBM using AC volt-

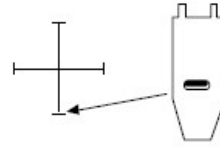
age to record microresistivity contrasts with vertical resolution equivalent to FMI. The OBMI offers borehole wall coverage ranging from 32% to 42%, depending on hole diameter, and is capable of resolving fine structural details such as fractures, bedding, and sedimentary structures. Today, borehole imaging tools like FMI, OBMI, and UBI are routinely integrated with orientation measurement devices such as the General Purpose Inclinometry Tool (GPIT), which uses triaxial magnetometers and accelerometers to correct for tool rotation, azimuthal drift, and borehole deviation, ensuring accurate structural reconstruction. The advancement of these tools has enabled not only precise geological and structural interpretations but also enhanced integration with core, seismic, and petrophysical datasets. Moreover, the emergence of automated image processing, supported by machine learning algorithms, now facilitates the extraction and classification of geological features such as fractures, dissolution pores, and bedding structures, thus transforming borehole imaging from a purely qualitative method into a quantitatively robust tool for reservoir characterization, particularly in geologically complex settings like presalt carbonates and fractured reservoirs.

Mechanical Systems

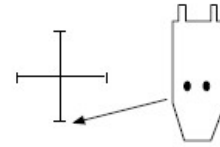
CDM 1956
Continuous Dipmeter



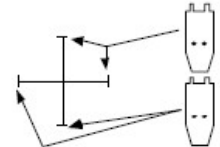
HDT 1968
High Resolution Dipmeter

**Solid State Systems**

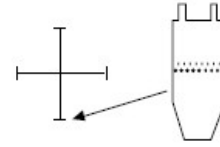
SHDT 1982
Stratigraphic Dipmeter



FMS (2 Pad) 1986
Formation Micro Scanner



FMS (4 Pad) 1988
Formation Micro Scanner



FMI (8 Pad) 1991
Formation Micro Imager

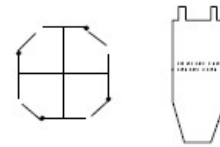


Figure 2.1: Evolution of Borehole Imaging and Dipmeter Tools
[10]

2.2 Types of Imaging Tools

2.2.1 Micro-Resistivity Imaging

Operating Principle Micro-resistivity imaging tools function by applying a focused electrical current through button electrodes pressed against the borehole wall. The FMI, for instance, has 192 buttons arranged across 8 pads, capturing variations in the formation's microresistivity. These variations are converted into

grayscale or color images that reflect lithological contrasts, such as those caused by bedding, fractures, or diagenetic features. Button data are corrected for tool speed, button response uniformity, and EMEX (focusing current) variations, then statically and dynamically normalized to enhance image clarity.

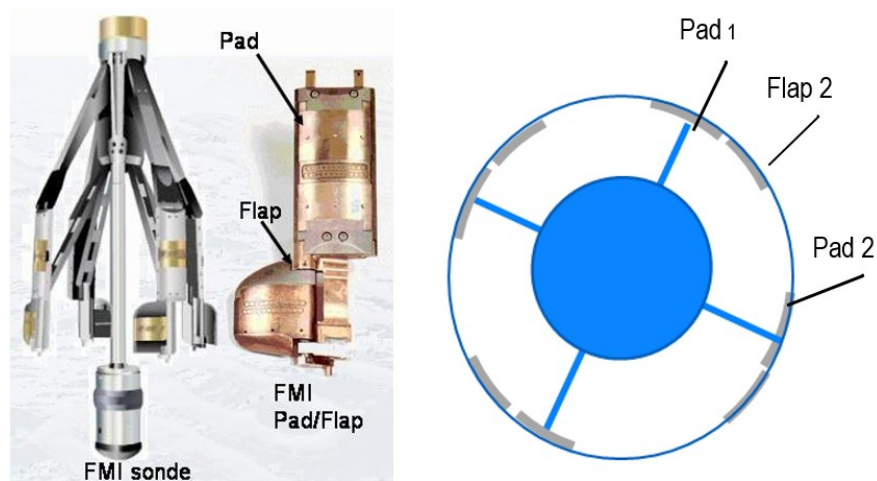


Figure 2.2: FMI Tool Structure: Pads and Flaps and downhole view [8]

Applications

These tools are extensively used for:

- Bedding and sedimentary structure analysis
- Fracture detection and characterization
- Fault identification
- Image-based dip computation
- Lithological mapping
- Net-to-gross and facies analysis

Advantages

Micro-resistivity tools offer:

- High vertical resolution (~ 5 mm)

- Broad resistivity dynamic range (0.2 to $>10,000$ ohm-m)
- Resistance to borehole rugosity
- Compatibility with conductive muds
- Extensive coverage (up to 80% in 8" holes)

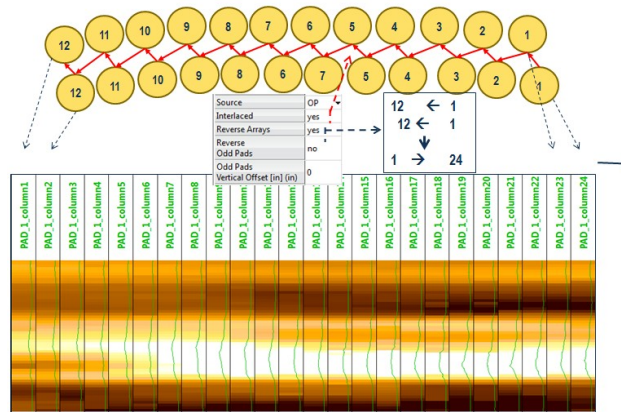


Figure 2.3: FMI Pad Button Array and Image Data Configuration [8]

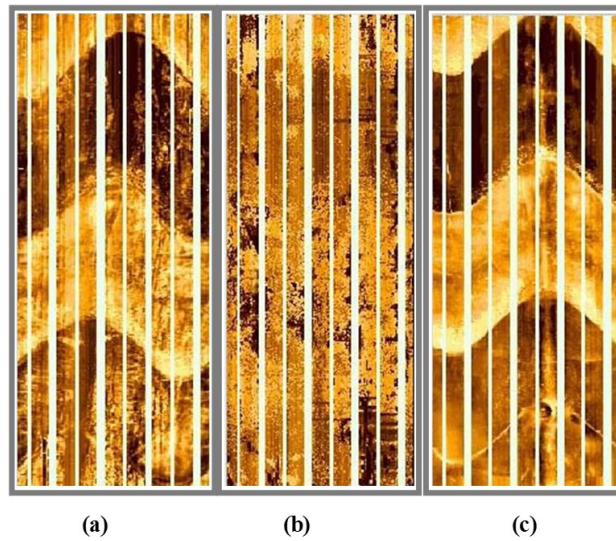


Figure 2.4: FMI image log comparison in (a) water based mud, (b) oil based mud, and (c) conductive oil-based mud (Tehrani et al., 2001). [11]

2.2.2 Ultrasonic Imaging

Operating Principle UBI tools emit ultrasonic pulses from a rotating transducer. The amplitude and travel time of reflected waves from the borehole wall are recorded. Transit time data reveal borehole geometry and ovalization, while amplitude data map acoustic impedance contrasts that correlate with lithological and structural features.

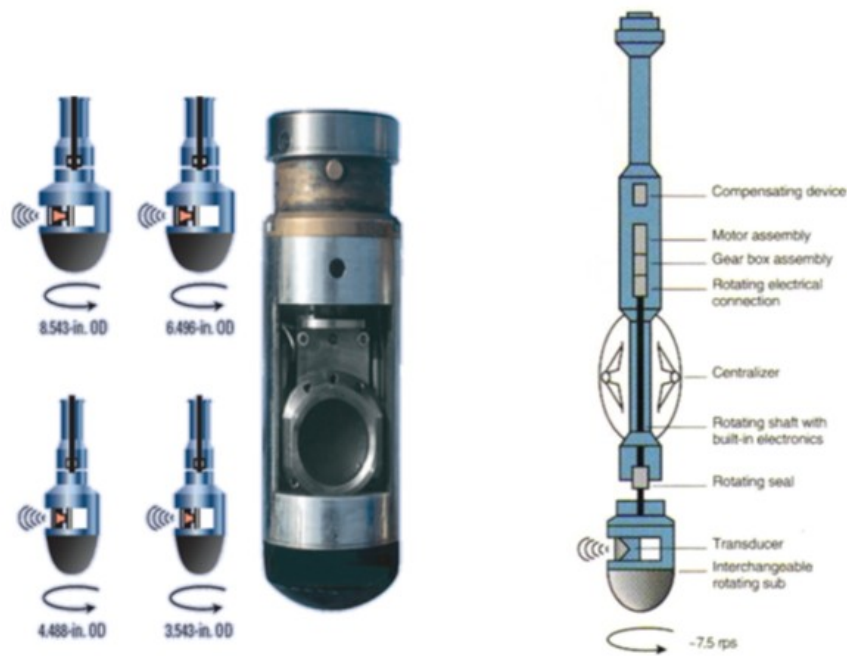


Figure 2.5: UBI Transducers and UBI tool sketch
[8]

Applications

UBI tools are suited for:

- Fracture detection in OBM environments
- Borehole shape and breakout analysis
- Geomechanical stress interpretation
- Fault and bedding plane visualization

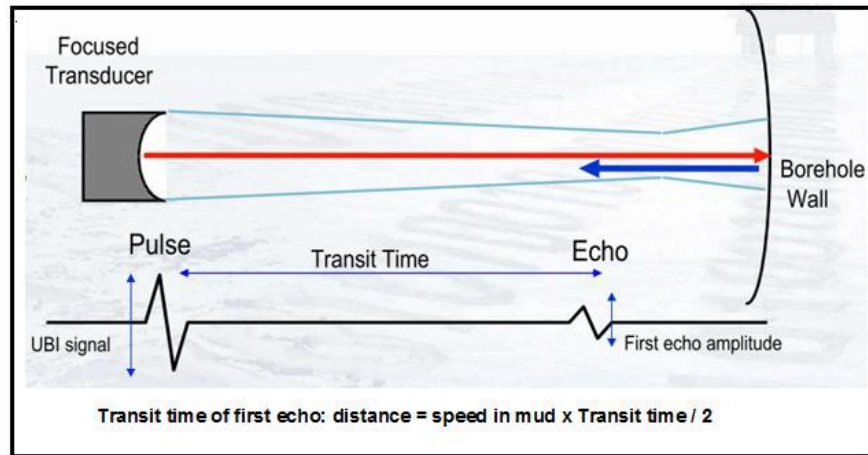


Figure 2.6: Principle of Ultrasonic Borehole Imaging (UBI): Transit Time and Echo Measurement

[8]

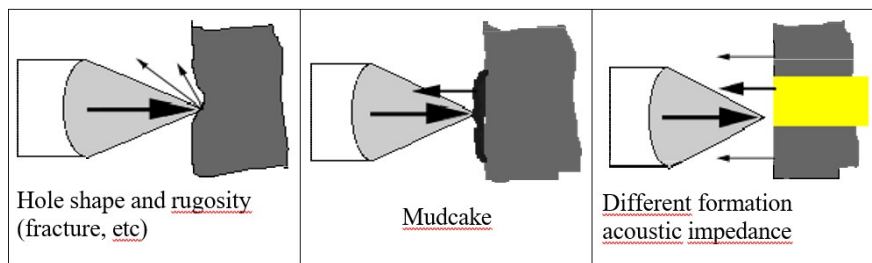


Figure 2.7: Acoustic Imaging Signal Responses to Borehole Conditions

[8]

Advantages

- Full 360° borehole coverage
- Good performance in non-conductive muds
- Effective in identifying breakouts, vugs, and tool eccentricity
- Resilient to mud type, borehole condition, and tool decentralization

2.2.3 Imaging Probes

Key imaging tools include:

- FMI (Formation MicroImager): 192 electrodes, conductive muds

- OBMI (Oil-Based MicroImager): designed for OBM, 40 buttons
- UBI (Ultrasonic Borehole Imager): acoustic imaging for OBM
- FMS (Formation MicroScanner): older resistivity imaging tool with up to 64 electrodes

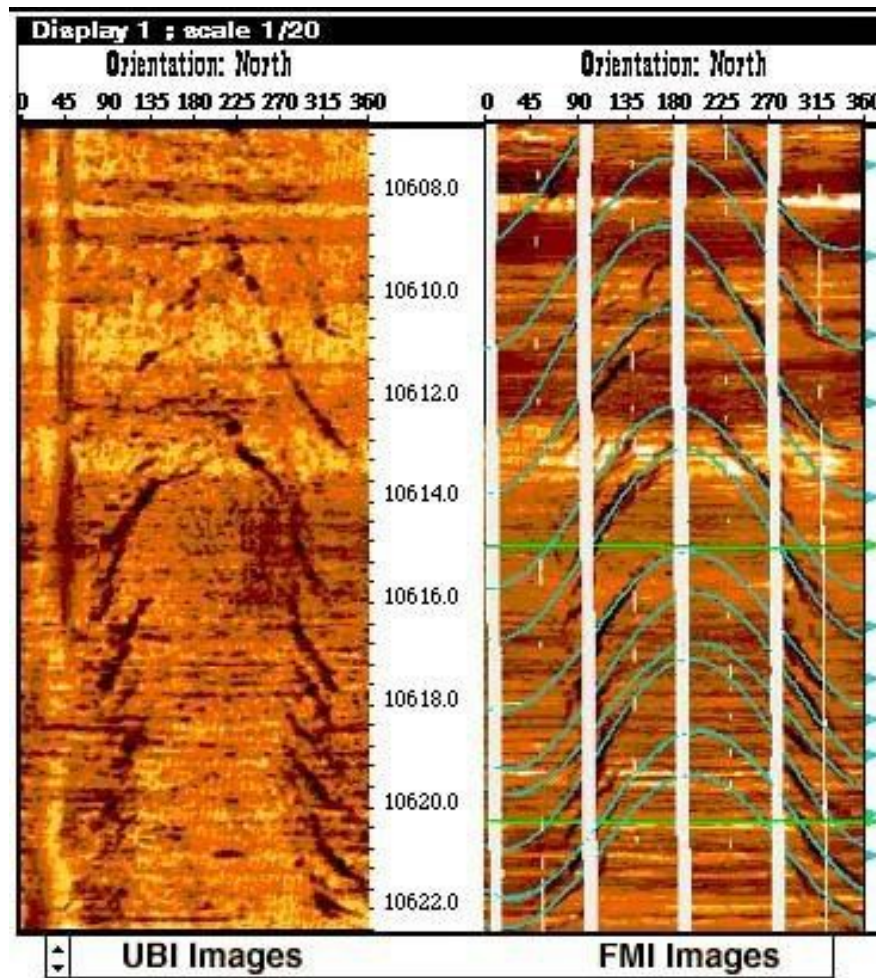


Figure 2.8: Comparison between ultrasonic and electrical imaging logs, showing the significantly greater detail with electrical imaging.

[8]

OBMI offers $\sim 32\%$ coverage in 8" boreholes and is often combined with UBI for dual-mode imaging. UBI's amplitude and radius images assist in identifying breakout patterns and borehole stability features.

2.3 Required Equipment

Accurate borehole imaging relies not only on the imaging tool itself but also on a suite of auxiliary equipment essential for data acquisition, orientation, and image quality. These auxiliary devices ensure that the measurements reflect the true geometry and geological structures intersected by the borehole. This section details the principal equipment required to achieve precise borehole image logging.

2.3.1 Gamma Ray Tool

The Gamma Ray (GR) tool is a fundamental component of borehole imaging suites. It measures the natural gamma radiation emitted by subsurface formations, primarily from isotopes of potassium-40, uranium, and thorium. These radioactive elements are typically concentrated in clay-rich and shale layers, making the GR log a powerful lithological discriminator.

Purpose in Borehole Imaging

In the context of borehole imaging, the GR tool serves as a lithological discriminator and stratigraphic reference. Shale-rich intervals tend to emit higher gamma radiation, resulting in elevated GR readings, whereas cleaner formations like sandstones, limestones, and dolomites exhibit lower values. This contrast allows geoscientists to:

- Identify lithological boundaries
- Recognize depositional cycles
- Highlight stratigraphic sequences
- Detect shale markers used in well-to-well correlation

Integration with Imaging Tools

Gamma Ray logs are frequently plotted alongside borehole images (e.g., FMI or UBI) to provide lithostratigraphic context for observed structural or sedimentary features. Their integration is particularly useful in:

- Facies classification: GR profiles support the interpretation of resistivity or acoustic textures in the image by linking high gamma responses to clay content and sedimentary environments.
- Dip picking workflows: GR curves are used to assist the interpreter in choosing intervals with consistent bedding responses for dip orientation analysis.
- Image calibration: GR logs may serve as references during depth matching and normalization of image data, ensuring alignment between logs and structural events.

Illustrative Example

Figure 23 shows a composite track of Gamma Ray curves correlated with a high-resolution FMI image. Notice how intervals with elevated GR values coincide with laminated, low-resistivity zones on the image—typically indicative of shales or silty beds. In contrast, clean sandstones or carbonates show bright resistive responses with corresponding low GR readings.

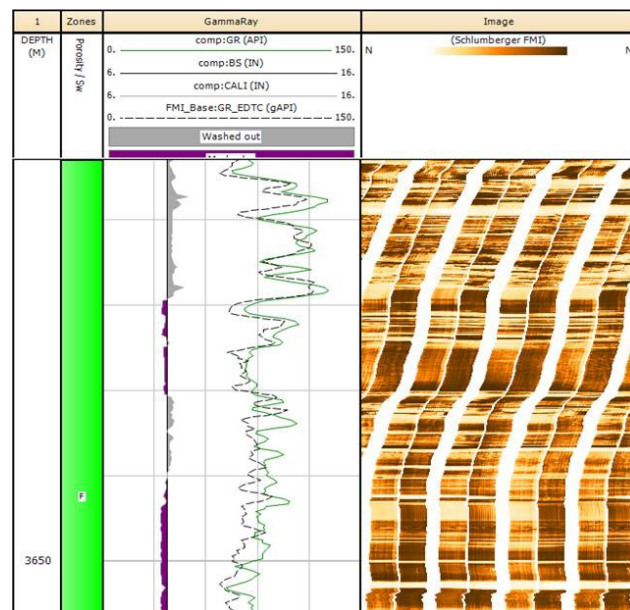


Figure 2.9: Gamma Ray and FMI Image Correlation Panel
[9]

2.4 Image Development

Image processing involves:

- Loading DLIS data into software (e.g., GeoFrame, Techlog)
- Performing inclinometry QC
- Speed correction using accelerometer data (BorEID module)
- Button equalization and EMEX correction
- Static normalization (entire image scaled to a resistivity range)
- Dynamic normalization (1-ft windows enhance local contrast)
- Interpretation and dip picking (BorView)

Processed data can be calibrated with SFL or LLS resistivity logs for quantitative analysis. The BorScale module allows resistivity matching, useful in sand count and fracture aperture analysis.

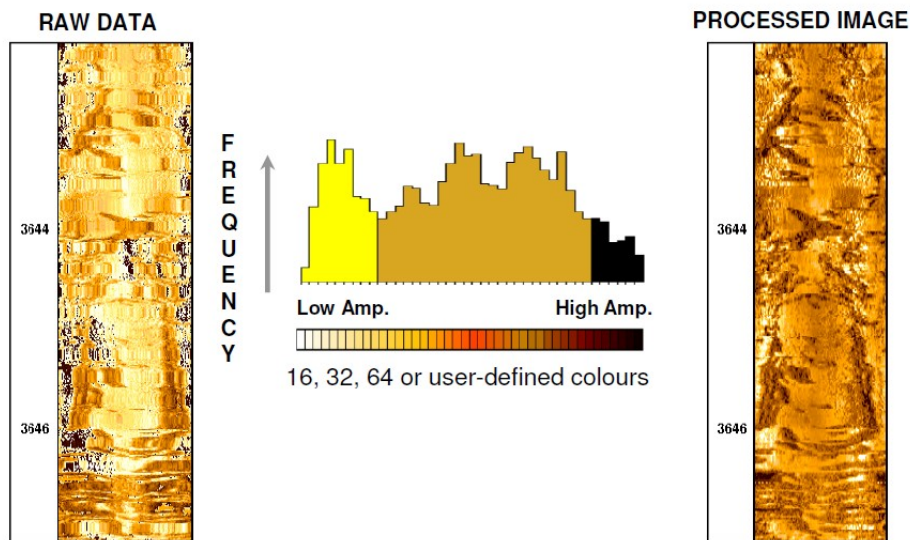


Figure 2.10: Static and Dynamic Normalization of Borehole Image Data [8]

2.5 Image Classification

The quality of borehole images is a critical factor in determining the scope and reliability of geological interpretations. Imaging tools, whether resistivity-based (FMI, OBMI) or ultrasonic (UBI), are subject to several factors that influence the clarity, coverage, and consistency of the images produced. Image classification enables geoscientists to evaluate the integrity of the image data before engaging in structural, sedimentological, or petrophysical analyses. Classifications are typically divided into three categories based on image fidelity, tool contact, borehole conditions, and overall interpretability.

2.5.1 Class 1: Excellent Image

Class 1 image is the highest-quality borehole image, characterized by:

- High vertical and azimuthal resolution, clearly resolving fine-scale features such as thin beds, stylolites, minor fractures, and bioturbation textures.
- Excellent pad-to-wall contact throughout the logged interval, ensuring continuous data acquisition with minimal to no missing button traces.
- Uniform tool orientation and rotation, leading to highly stable azimuthal referencing. This enables the accurate computation of dip azimuths and structural orientation.
- Minimal electrical or acoustic noise, resulting in well-contrasted images with high signal-to-noise ratios.
- Effective image normalization, allowing for clear distinction between lithological units, fluid-filled features, and conductive or resistive anomalies.

Class 1 images are suitable for advanced and quantitative interpretations including:

- Fracture aperture measurement

- Sedimentary facies characterization
- Computation of fracture density and porosity
- Image-based net-to-gross evaluation
- Sequence stratigraphy and paleocurrent studies

2.5.2 Class 2: Good Image

Class 2 images represent a medium quality that still allows for substantial geological interpretation. Features include:

- Moderate tool decentralization or minor standoff issues, leading to occasional button dropout or reduced resolution in some azimuthal sectors.
- Localized image artifacts such as noise streaks or discontinuous signal from one or more pads.
- Slight degradation in contrast or resolution that may obscure fine features but still preserves the visibility of major bedding, fractures, and structural trends.
- Acceptable inclinometry and azimuth referencing, albeit with some corrections needed during processing.

These images are generally acceptable for:

- Structural dip analysis and fault interpretation
- Primary fracture detection and orientation clustering
- Coarse facies discrimination (e.g., distinguishing between massive and laminated units)
- Identifying major unconformities and bedding planes

While Class 2 images do not support high-precision measurements (e.g., aperture, porosity estimates), they remain useful for regional structural and depositional analysis.

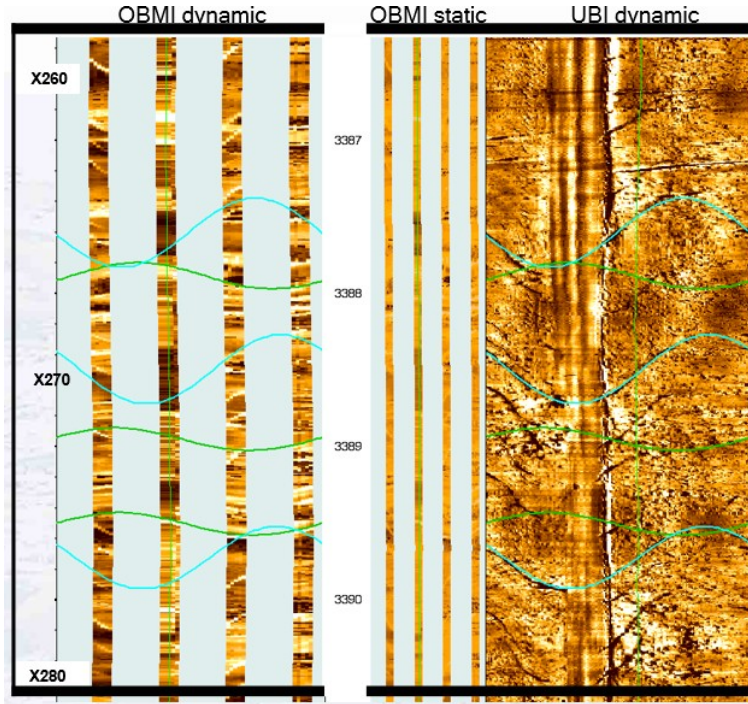


Figure 2.11: Comparative visualization of OBMI and UBI borehole image logs under dynamic and static normalization modes

[8]

2.5.3 Class 3: Poor Image

Class 3 images exhibit significant quality degradation and are limited in their interpretive value. Characteristics include:

- Poor pad contact due to borehole enlargement (washouts), extreme rugosity, or tool decentralization. These lead to loss of electrode or acoustic coupling.
- High noise levels resulting from poor signal-to-noise ratio, electrical interference, or tool instability.
- Missing data or large unmeasured zones due to dead buttons, faulty sensors, or severe standoff.

- Erratic tool rotation, making azimuthal orientation unreliable or unusable.
- Poor borehole conditions (e.g., cavings, spiraling) that prevent tool stabilization.

Class 3 images are generally limited to:

- Identification of major faults or zones of structural deformation
- Delineation of intervals of interest for re-logging or intervention
- General stratigraphic correlation using auxiliary logs (e.g., Gamma Ray)

Despite their limited use in high-resolution interpretation, Class 3 images can still provide qualitative insights when combined with other well log data or core samples.

Image classification, therefore, is an essential step in ensuring that the level of interpretation matches the quality of available data, thereby improving the robustness and accuracy of subsurface geological models.

2.6 Imaging Applications

2.6.1 Tectonic Applications

Borehole imaging tools play a crucial role in tectonic interpretation by providing high-resolution images of the borehole wall. These images enable geoscientists to detect, characterize, and classify fractures, faults, and structural fabrics that are key to understanding in-situ stress regimes, fracture systems, and reservoir compartmentalization. This section outlines the key aspects of tectonic applications: fracture detection, interpretation, and classification.

Fracture Detection and Analysis

Fracture detection using borehole imaging tools relies on the recognition of sinusoidal patterns on unwrapped borehole wall images. These patterns arise due to

the intersection of planar geological features (like fractures) with the cylindrical borehole geometry.

Electrical imaging tools (e.g., FMI, OBMI) use micro-resistivity contrasts to reveal conductive (dark) or resistive (bright) features.

Acoustic imaging tools (e.g., UBI) capture differences in acoustic impedance across the borehole wall to highlight features such as tensile fractures, breakouts, and petal-centerline fractures.

Natural fractures usually appear as continuous sinusoids with distinct resistivity or acoustic contrast, while induced fractures often display symmetric and repetitive patterns parallel to the direction of maximum horizontal stress.

Sinusoid characteristics such as dip, azimuth, amplitude, and wavelength allow analysts to infer fracture orientation and inclination using tools like Techlog.

Vertical fractures commonly intersect bedding planes and may cross the full circumference of the borehole.

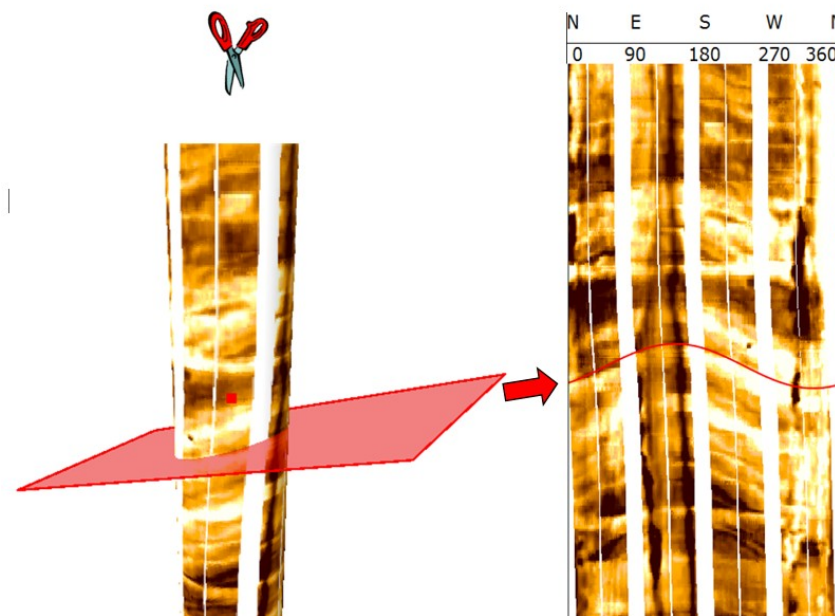


Figure 2.12: Sinusoidal Fracture Patterns in Borehole Imaging
[8]

Fracture Interpretation

Fracture interpretation extends beyond visual detection and involves determining the geological nature and physical state of the identified features:

Continuity: Continuous sinusoids typically suggest persistent fractures, while irregular, discontinuous features may represent localized deformation or cemented/jointed zones.

Orientation: Determined through dip and azimuth calculations, orientation reflects the structural regime and can be used to correlate fractures across multiple wells.

Aperture Estimation: Fracture aperture is a critical parameter for assessing flow potential. For FMI tools, fracture aperture can be estimated quantitatively using the Luthi and Souhaite equation based on the resistivity contrast and image.

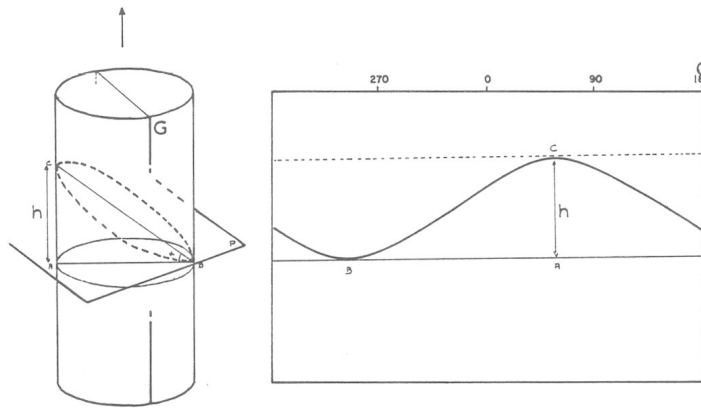


Figure 2.13: Geometric Relationship Between Planar Features and Sinusoidal Traces in Borehole Imaging

[11]

However, OBMI and UBI tools in non-conductive muds have limited aperture quantification ability due to lower resolution and tool sensitivity.

Fractures with high resistivity often correspond to open features in non-conductive muds, while low-resistivity signatures may indicate conductive (mud-filled) or mineralized fractures depending on mud system properties.

Fracture Classification

Fractures observed in borehole imaging are generally categorized based on their genesis, aperture, and electrical response:

By Origin:

- Natural fractures: Often tectonic in origin, show irregular distribution, high angle dips, and may control reservoir flow.
- Induced fractures: Created during drilling or hydraulic stimulation, usually aligned with the minimum horizontal stress.
- Polygonal (syneresis) fractures: Related to chemical or mechanical dewatering, typically appearing braided or "chicken-wire" in texture.

By Aperture:

- Open fractures: Highly conductive in water-based muds, or resistive in oil-based muds depending on mud and formation properties. They enhance reservoir permeability.
- Closed (healed) fractures: Often mineralized and less likely to transmit fluids.
- Vuggy fractures: Show solution-enlarged textures and may reflect enhanced secondary porosity.

By Electrical/Acoustic Character:

- Conductive fractures: Appear dark in resistivity images and indicate fluid or mud-filled features (typically open in water-based mud).
- Resistive fractures: Appear bright in oil-based muds; can be either open or mineralized, requiring combined acoustic/electrical interpretation for certainty.

Fracture Identification From Borehole Images

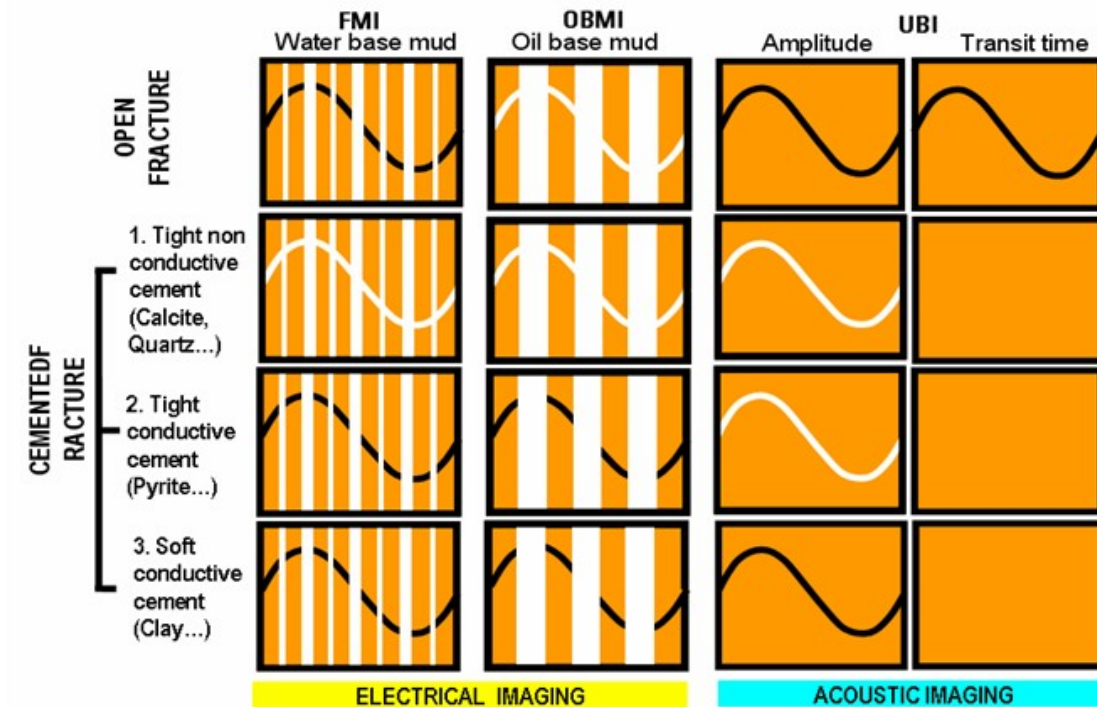


Figure 2.14: Comparison of Fracture and Cement Detection in Electrical and Acoustic Borehole Imaging: FMI, OBMI, and UBI Log Responses to Open and Cemented Fractures [8]

2.6.2 Types of Fractures

A. Natural Open Fractures

Natural open fractures are primary structural discontinuities formed through tectonic or diagenetic processes. In borehole images, particularly in resistivity-based tools such as FMI or OBMI, they appear as clean, continuous sinusoidal traces with high contrast against the surrounding matrix. In oil-based mud environments, these fractures typically exhibit a resistive signature, indicating that the fracture is unfilled with conductive drilling fluids and thus likely open. Their consistent geometry and orientation across depth intervals reflect their tectonic origin and mechanical coherence.

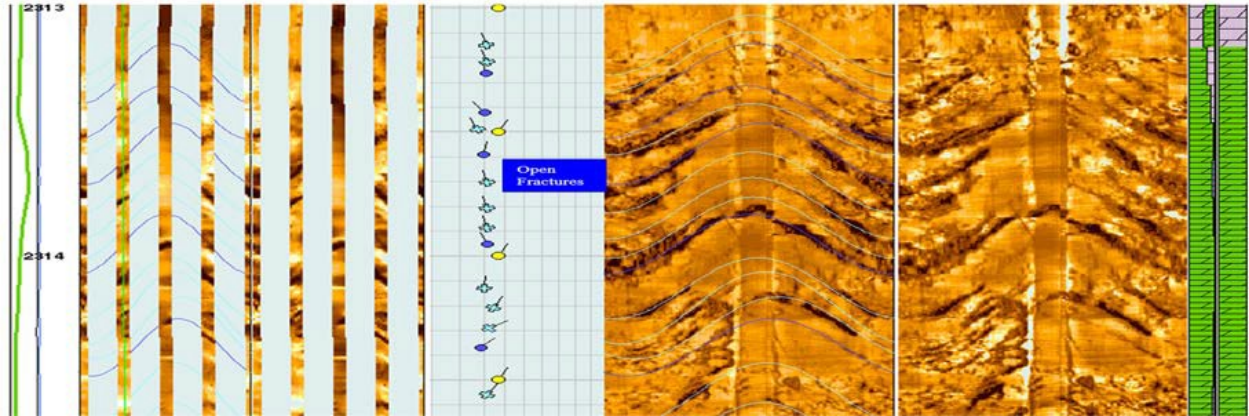


Figure 2.15: UBI image illustrating continuous open fractures
[8]

2.6.3 Fracture Aperture Estimation

Fracture aperture estimation is a critical parameter for assessing the permeability potential of fractured reservoirs. In high-resolution FMI images, aperture is inferred from the resistive width of the sinusoidal feature. Wider resistive zones correspond to larger apertures, assuming consistent mud resistivity and formation properties. However, image-derived apertures must be calibrated against physical measurements—such as core data or ultrasonic borehole images (UBI)—to improve accuracy, especially in complex lithologies or variable mud conditions. In UBI data, amplitude and travel time variations can be used to estimate aperture via borehole wall geometry reconstructions.

2.6.4 Fracture Density in Horizontal Wells

In horizontal or highly deviated wells, fracture density analysis becomes essential for evaluating the productivity potential of tight or fractured reservoirs. Fracture density is generally quantified as the number of identified fractures normalized per 10 or 100 meters of logged interval. This statistical approach provides an estimate of the intensity and spacing of fracture systems, which is critical in horizontal wells where fluid flow is largely controlled by intersected fracture networks. Image logs allow consistent and repeatable quantification of these features, reduc-

ing uncertainty in reservoir connectivity models.

2.6.5 Image and Dip Orientation

Dip and azimuth data extracted from bedding planes, fractures, and structural surfaces are visualized using a suite of geospatial analysis tools:

- Tadpole plots provide depth-wise dip tracking.
- Rose diagrams summarize azimuthal fracture or bed orientation distributions.
- Stereonets enable 3D structural interpretation by projecting dip data into lower-hemisphere plots.

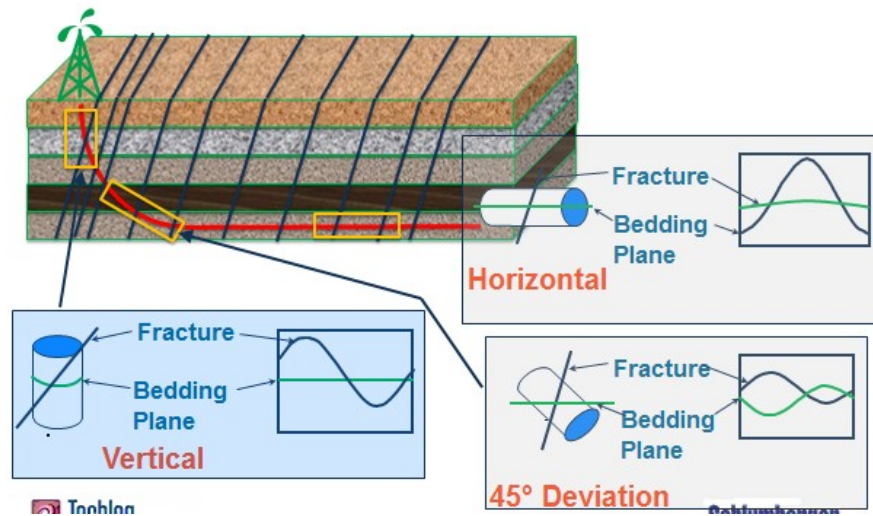


Figure 2.16: Effect of Wellbore Deviation on Fracture and Bedding Plane Sinusoid Representation in Borehole Images

[8]

These orientation tools help identify dominant fracture sets, fold geometries, and fault kinematics. Their use supports structural mapping, regional tectonic analysis, and the estimation of in-situ stress directions, especially when integrated with borehole breakout and drilling-induced fracture data.

Fault Identification

Faults in borehole images are recognized by abrupt changes in bedding dip, offset layers, or disrupted and discontinuous sinusoids. They may also be associated with drag features, shear gouge, or zones of deformation, often marked by intense micro-fracturing. The identification of such features is vital in structurally complex reservoirs, where fault-related compartmentalization can impact production strategies. Faults can be further characterized by analyzing dip scatter, stratigraphic displacement, and local changes in image texture or resistivity response.

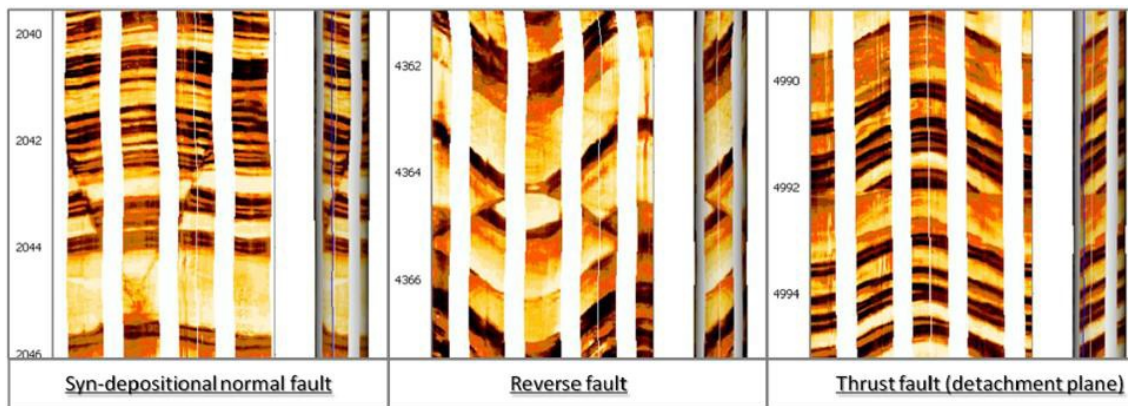


Figure 2.17: Normal, reverse and thrust faults as observed on high-resolution image logs [bor]

2.6.6 Sedimentological Applications

Borehole imaging is a powerful tool for facies analysis in both clastic and carbonate systems. It allows the visualization of sedimentary structures such as:

- Cross-bedding
- Ripple marks
- Graded bedding
- Massive sands
- Bioturbation textures

These features, visible due to resistivity or acoustic contrast, help reconstruct the depositional environment, energy regime, and paleogeography. For instance, inclined laminae suggest high-energy channels, while bioturbated zones may indicate low-energy or oxygen-rich settings.

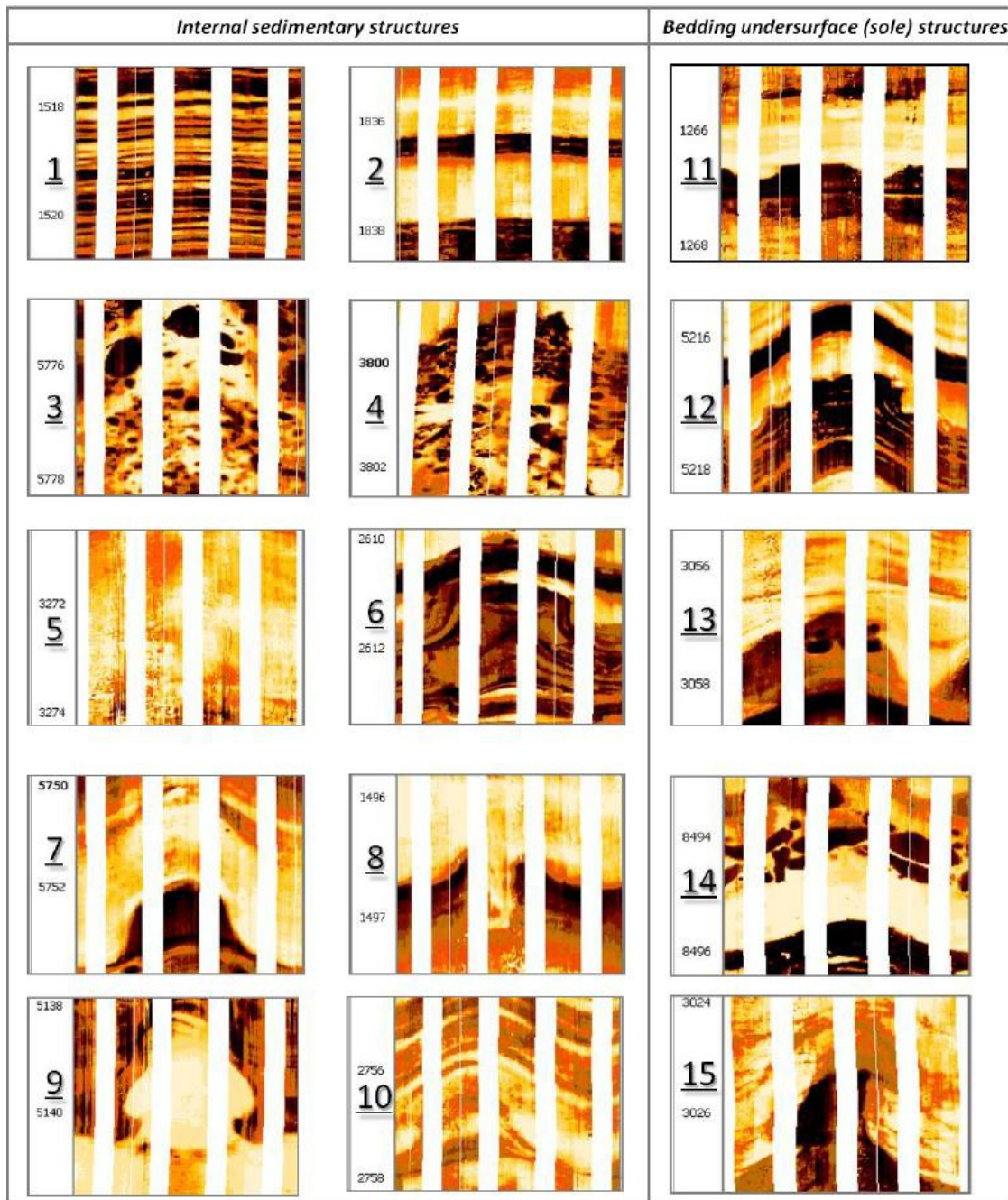


Figure 2.18: Sedimentary structures observed on the high-resolution borehole image logs [bor]

2.6.7 Paleocurrents

In the absence of core data, image-based analysis of cross-laminations or climbing ripples provides estimates of paleocurrent direction. The azimuth of these inclined features is extracted and aggregated to infer the transport direction of sediments at the time of deposition. This information is particularly valuable for reconstructing sediment dispersal systems and guiding stratigraphic correlations.

2.6.8 Diagenetic Applications

Borehole images allow the identification of diagenetic overprints that influence reservoir quality. Features commonly recognized include:

- Stylolites, appearing as irregular high-resistivity seams with zigzag textures
- Cemented nodules and concretions, characterized by discrete resistive or acoustic anomalies
- Vugs, visible as rounded or irregular cavities with distinct signatures depending on their connectivity and fill

Diagenetic structures influence porosity, permeability, and mechanical behavior. Recognizing these features supports carbonate reservoir modeling by helping define zones of enhanced storage or flow resistance.

2.6.9 Reservoir Evaluation Applications

Imaging logs contribute directly to reservoir evaluation by enabling:

- Net-to-gross estimation, using bed boundary dips to delineate productive from non-productive intervals
- High-resolution porosity profiling, through textural resistivity variations correlated with core porosity measurements

- Fracture network modeling, where dip, orientation, and aperture data feed into 3D simulation grids for flow prediction

These applications enhance the geoscientist's ability to characterize reservoir heterogeneity, optimize well placement, and reduce uncertainty in reserve estimation.

2.7 Contributions of Imaging to Reservoir Evaluation

Borehole imaging is a transformative tool in reservoir evaluation, providing high-resolution visualization of geological features directly from the borehole wall. It allows for detailed structural and sedimentological interpretations, supports stress analysis, and enhances the construction of depositional and structural models. This section presents the main interpretative contributions of imaging to reservoir analysis, including dip interpretation, stratigraphic evaluation, stress characterization, and stereographic visualization.

2.7.1 Basics of Dip Interpretation

When a planar geological surface intersects the cylindrical geometry of a borehole, it generates a characteristic sinusoidal pattern on unwrapped image logs. These sinusoids are defined by their amplitude and wavelength, which are directly related to the dip magnitude and dip azimuth of the intersecting surface.

Dip is calculated using trigonometric relationships, typically expressed as:

Accurate dip determination requires precise depth alignment, orientation calibration using GPIT (inclinometry), and well-centered imaging acquisition. The computed dip data form the basis for sedimentary and structural interpretation of the reservoir.

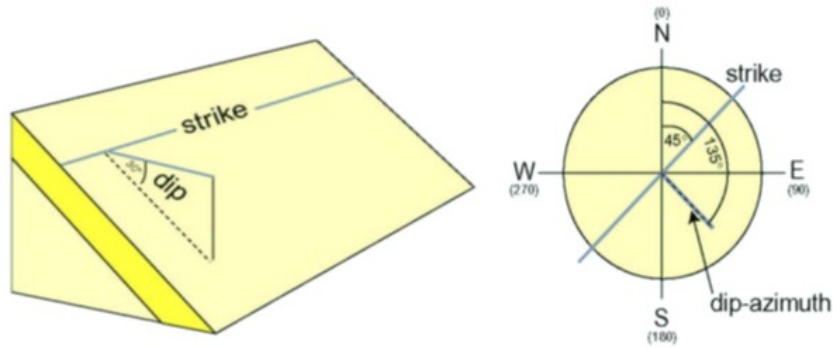


Figure 2.19: Dip magnitude & dip azimuth
[6]

2.7.2 Structural Dipmeter Interpretation

Structural dip interpretation involves identifying clusters or groupings of dips that suggest tectonic deformation such as folding, tilting, or faulting. Sudden changes in dip direction, magnitude, or scatter may indicate the presence of fault planes, fold limbs, or drag structures near displacement zones.

These interpretations are crucial for:

- Constructing cross-sections and structural contour maps
- Identifying fault blocks and stratigraphic offsets
- Estimating structural dip and assessing trap integrity

In structurally complex areas, consistent variations in dip across depth intervals help define fault geometries, unconformities, and thrust planes.

2.7.3 Sedimentary (Stratigraphic) Interpretation

Borehole imaging significantly enhances the understanding of depositional processes and stratigraphy. Dips extracted from sedimentary features provide directional and structural information used to interpret sediment transport systems and depositional settings.

Dip Orientation

A consistent dip azimuth throughout a stratigraphic interval often reflects a unidirectional depositional current. This pattern is typical of turbiditic fans, fluvial channels, or deltaic foresets. In contrast, bidirectional or radial dip patterns may represent tidal influences or distributary systems.

Dip Classification

Based on geometry and distribution, dips are classified into:

- **Parallel Dips:** Indicate horizontal or gently inclined bedding typical of low-energy deposition.
- **Cross-Bedding:** Refers to inclined laminae within sets, produced by migration of bedforms in high-energy settings (e.g., dunes or channels).
- **Convoluted Bedding:** Deformed layers resulting from soft-sediment deformation such as slumping or loading.

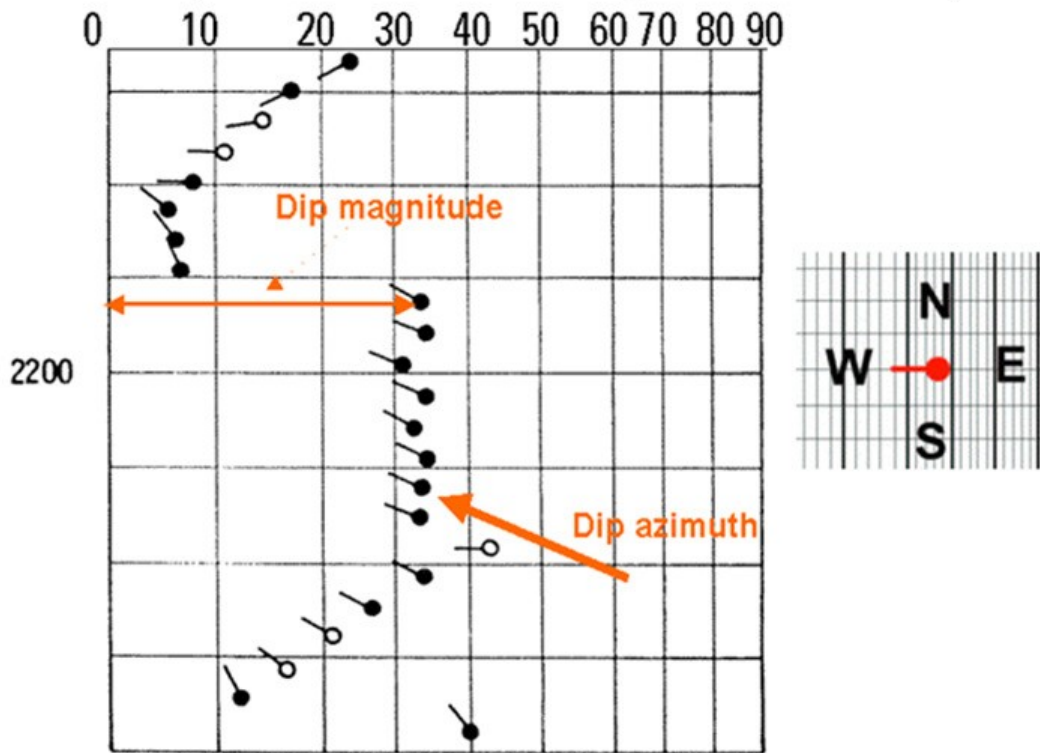
Such classifications help reconstruct depositional environments and recognize sedimentary processes like traction, suspension, or gravity flows.

Dip Grouping

Dips are grouped into stratigraphic packages based on consistent dip orientation, magnitude, and structural context. These dip packages correspond to individual depositional episodes, and their stacking patterns are used to identify:

- Parasequences
- Systems tracts (e.g., lowstand, highstand)
- Sequence boundaries

Grouping dips is a key method in sequence stratigraphy, aiding in the subdivision of the reservoir into genetically meaningful units.



[6]

Figure 2.20: Dip presentation

2.7.4 Dip Interpretation

Integrated dip interpretation involves correlating dip patterns with other logs such as gamma ray (GR) and resistivity curves. For example:

- Increasing dip angle and GR may indicate upward fining sequences.
- Dip azimuth changes with resistivity trends can reflect channel migration or lateral facies transitions.

This multi-log approach enables detailed facies modeling, helps map reservoir heterogeneity, and supports depositional environment reconstructions.

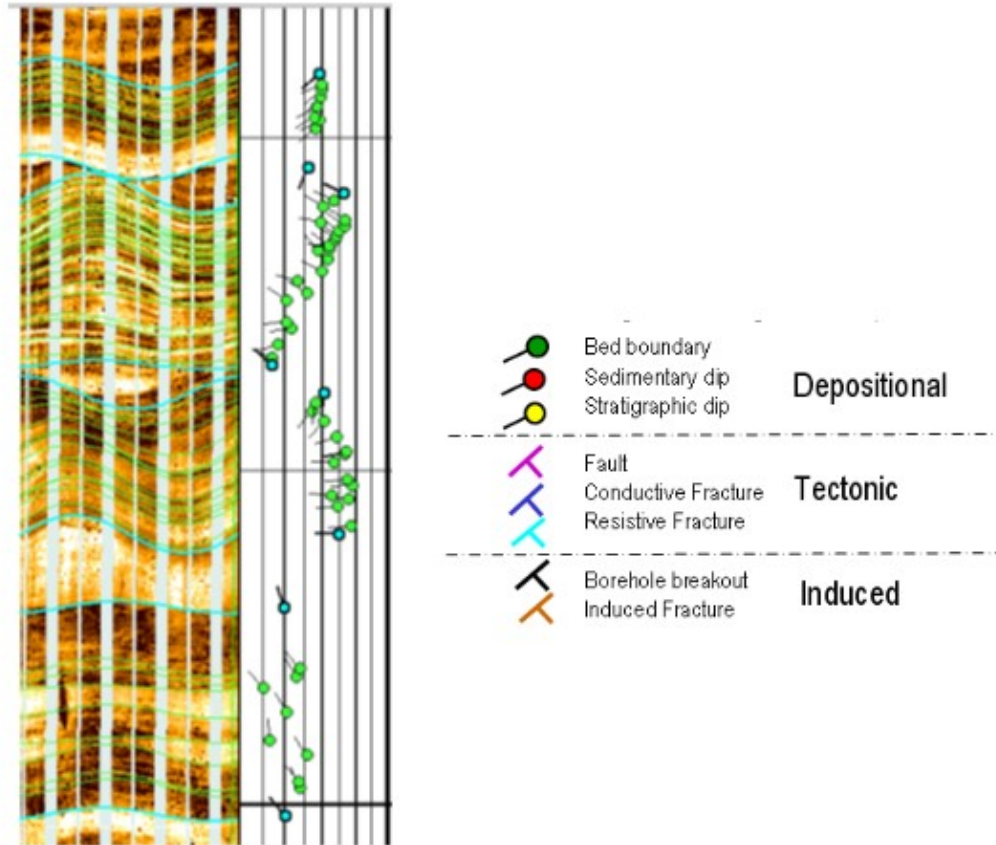


Figure 2.21: Dip classification
[3]

2.7.5 Stress Analysis (Breakouts)

Imaging logs also capture features formed during drilling, such as borehole breakouts and drilling-induced fractures (DIFs), which are directly related to the in-situ stress field.

Breakouts occur due to compressive failure of the borehole wall and appear as elongated dark bands on ultrasonic or resistivity images. They form parallel to the minimum horizontal stress direction (σ_{Hmin}).

DIFs appear as symmetric conductive or resistive features, oriented perpendicular to the maximum horizontal stress (σ_{Hmax}).

Analyzing the orientation and frequency of these stress-induced features provides critical insights into:

- Stress anisotropy

- Fault reactivation risk
- Wellbore stability planning

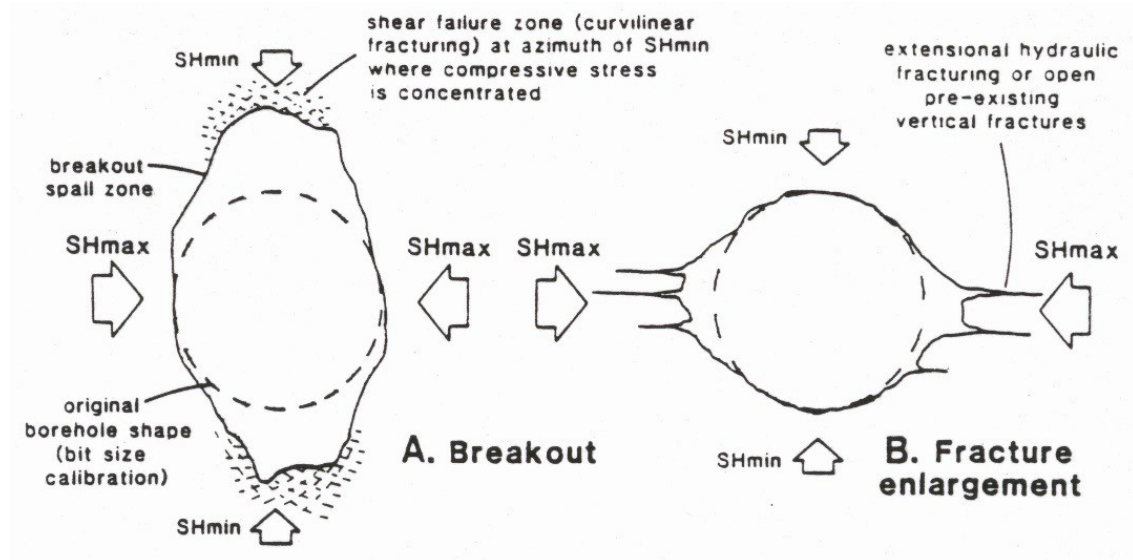


Figure 2.22: Borehole failure in two modes: (A) breakout, and (B) induced fractures (Contreras and Gamero, 2000).

[bor]

2.7.6 Stereonet

Stereonet plotting is a graphical technique used to visualize the spatial orientation of planar geological features, such as bedding planes, fractures, and faults. Each dip and azimuth measurement is represented as a point on a lower hemisphere polar plot, allowing for the recognition of:

- Fracture sets and families
- Fold axes and limb geometries
- Paleostress directions

When applied to fracture analysis, stereonets help identify the dominant structural trends and guide decisions in well planning, fracture stimulation, and reservoir connectivity modeling.

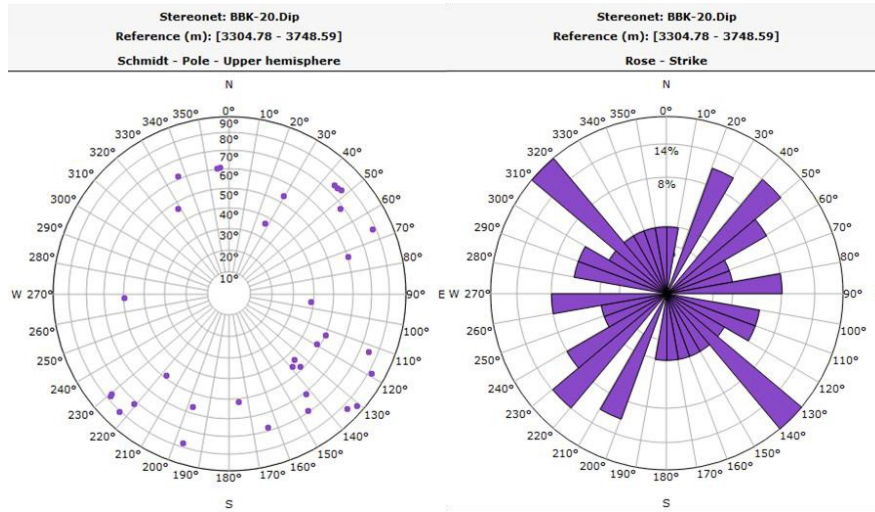


Figure 2.23: Stereonet and Rose Diagram of Fracture Orientations
[per]

2.8 Conclusion

Borehole imaging has emerged as an indispensable technique in modern geoscience, revolutionizing the way subsurface geological structures and reservoir characteristics are interpreted. The development of advanced tools such as the Formation MicroImager (FMI), Oil-Based MicroImager (OBMI), and Ultrasonic Borehole Imager (UBI) has significantly enhanced the resolution and accuracy of down-hole data acquisition, providing geoscientists with continuous, high-definition visualizations of the borehole wall. These tools enable the direct observation of critical geological features, including fracture systems, bedding planes, faults, stylolites, sedimentary structures, and diagenetic textures. They allow for the precise measurement of dip and azimuth, identification of open and closed fractures, and assessment of in-situ stress directions through borehole breakouts and drilling-induced fractures. In sedimentological analysis, borehole images reveal cross-bedding, ripple marks, bioturbation, and stratigraphic discontinuities that are essential for facies interpretation and depositional environment reconstruction. Moreover, imaging contributes directly to reservoir characterization by supporting net-to-gross estimation, identifying flow-contributing fracture networks, and

enabling high-resolution porosity evaluation. The integration of borehole images with core data, wireline logs, and seismic interpretation enhances the accuracy of structural and stratigraphic models, facilitating more informed decisions in exploration, development, and production. In summary, borehole imaging bridges the gap between qualitative geological insight and quantitative reservoir evaluation. It delivers unparalleled value by improving structural mapping, supporting sedimentological and diagenetic analyses, and refining reservoir models. As exploration targets become more complex, the role of imaging technologies in unlocking subsurface potential continues to grow, making them essential tools for the success of modern hydrocarbon exploration and field development strategies.

CHAPTER 3

case of study

3.1 Introduction

The integration of high-resolution borehole imaging technologies, particularly the Oil-Based MicroImager (OBMI) and the Ultrasonic Borehole Imager (UBI), has significantly enhanced the precision and reliability of geological interpretations in subsurface exploration. These tools provide complementary datasets: the OBMI records micro-resistivity variations allowing detection of sedimentary and structural features in oil-based mud environments, while the UBI measures acoustic amplitude and radius, enabling accurate identification of fractures and borehole deformation. Their combined application is particularly valuable in vertical wells where direct observation of formation structure, facies, and stress indicators is essential for reservoir evaluation and geomechanical modeling.

In this chapter, we analyze and interpret image log data acquired in wells BBK-16 and BBK-20, drilled in the Bir Berkine Basin—a tectonically stable region in the Algerian Sahara characterized by multi-cycle sedimentation and significant hydrocarbon accumulations. Both wells penetrated stratigraphic intervals ranging from the Triassic to the Devonian, including key reservoir units such as the TAGI and indicators of structural discontinuities like the Hercynian Unconformity.

The main objectives of this chapter are:

- To delineate structural dip zonation and assess tectonic tilting.
- To characterize fracture populations and their implications on in-situ stress.
- To interpret sedimentary structures and paleocurrent trends.
- To classify depositional environments and facies using advanced image log processing.

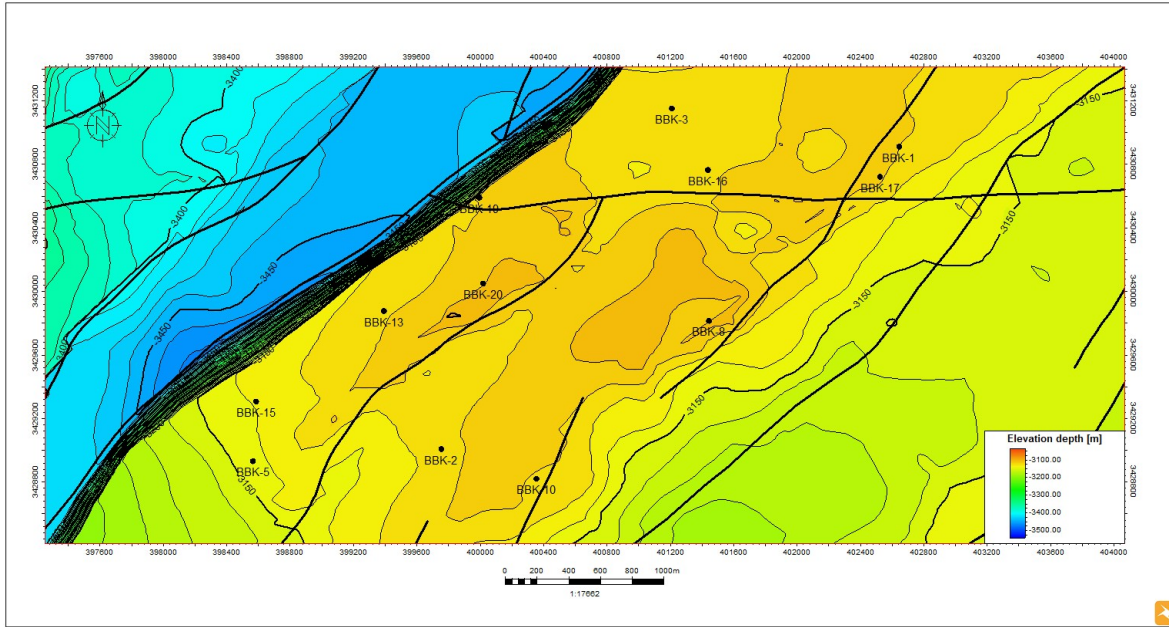


Figure 3.1: Structural map at the level of the Hercynian Discontinuity
[13]

3.2 Well Locations and Geological Setting

The wells examined in this study, BBK-16 and BBK-20, are strategically positioned within the Bir Berkine Basin, a significant Paleozoic sedimentary basin situated in the eastern Algerian Sahara. The Bir Berkine Basin represents a structurally stable depression bounded by major geological features such as the Rhourde En Nouss structural axis to the west and the Ahara–El Ouar uplift toward the south, which separates it from the adjacent Illizi basin. These wells were specifically drilled within the Bir Berkine North area, an important hydrocarbon-rich province characterized by extensive Paleozoic to Mesozoic sedimentation cycles. Geographically, well BBK-16 is located at coordinates latitude $31^{\circ} 00' 30.35''$ N and longitude $07^{\circ} 58' 02.35''$ E, while well BBK-20 is situated approximately northeast within the same field, precisely positioned at UTM coordinates $X = 400018.264$ m, $Y = 3430045.486$ m. The proximity of these two vertical wells allows for effective comparative geological and reservoir characterization, particularly with respect to structural continuity, stratigraphic correlation, and reservoir compartmental-

ization. Their strategic positioning within this basin enhances the accuracy and relevance of the geological interpretations derived from borehole imaging data, thereby supporting robust subsurface modeling efforts.

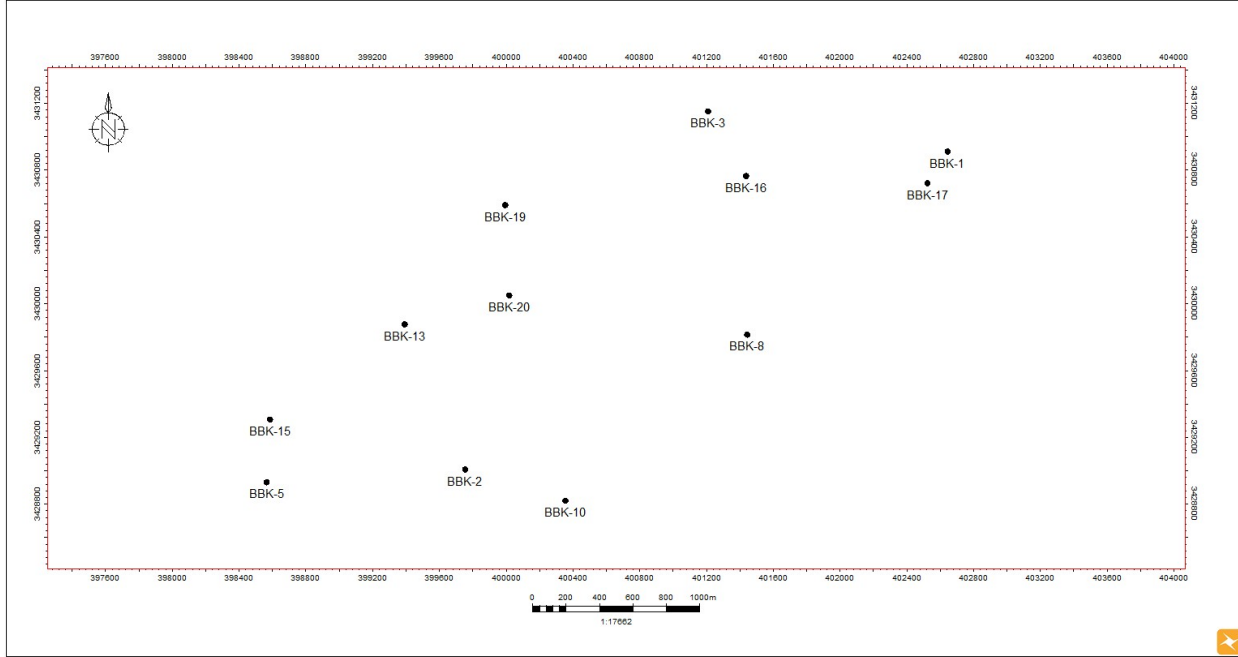


Figure 3.2: Wells position plan
[13]

3.3 Methodology and Acquisition Details

In this study, high-resolution borehole imaging data were acquired in wells BBK-16 and BBK-20 using a combination of Oil-Based MicroImager (OBMI) and Ultrasonic Borehole Imager (UBI) tools. Particular attention was paid to ensuring optimal logging conditions, tool selection, and quality control to guarantee the reliability of subsequent geological and geomechanical interpretations.

3.3.1 Tools and Logging Conditions

OBMI & UBI Tool Specifications

Oil-Based MicroImager (OBMI):

FORMATION	LITHOLOGY	TOPS MD (m)
TRIAS ARGILEUX	Shale, Evaporites	-
TRIAS CARBONATE	Carbonates, Shale & Evaporites	3224
T.A.G.I.	Sandstones	3298
FRASNIAN (HERCYNIAN UNCONFORMITY)	Shale	3317
GIVETIAN	Shale, Siltstone	3369
EIFELIAN	Shales, Siltstones	3398
EMSIAN	Shale	3430
SIEGENIAN	Shale, Siltstones & Sandstones	3479
NIVEAU C	Siltstones, Sandstones & Shale	3508
BASE C		3556
NIVEAU D	Siltstones, Sandstones & Shale	3567
BASE D		3587
NIVEAU E	Siltstones, Sandstones & Shale	3603
BASE E		3625
NIVEAU F	Shale, Siltstone	3656
NIVEAU G	Siltstones, Sandstones	3699
GEDINNIAN	Sandstones	3788

Figure 3.3: Formation tops (well BBK-16) Provided by SONATRACH-DP
[14]

Formations	Tops MD (m)	OBMI		UBI	
Trias argileux.	3210		3225m		3301m
Trias carbonate	3250				
TAGI	3338			3373m	
DH (Frasnian)	3351				
Givetien	3377				
Effelien	3394			3470.5	
Emsien	3430				
siegenien	3484				
Gedinien	3728			3752.5m	
TD	3756				
			3756m		

Figure 3.4: Formation tops (well BBK-20) Provided by SONATRACH-DP
[15]

- Measurement principle: Four pad-mounted micro-resistivity electrodes generate a 5-pixel-wide, oriented resistivity image of the borehole wall (0.4/×0.4/ pixel size).
- Vertical resolution: ~1.2 inches (three pixels)
- Depth of investigation: 0.5 inches for small objects; ~3.5 inches for invasion front
- Resistivity range: 0.2 to $> 10\,000\,\Omega\cdot\text{m}$ (quantitative to $\pm 20\%$ over 1–10 000 $\Omega\cdot\text{m}$)
- Maximum logging speed: 3 600 ft/hr (1 100 m/hr)
- Operating environment: Oil-based muds up to 1.4 g/cm³; downhole $T \leq 160^\circ\text{C}$; $P \leq 20$ kpsi

Ultrasonic Borehole Imager (UBI):

- Measurement principle: Rotating focused transducer emits ultrasonic pulses; echo amplitude and transit time are recorded to yield amplitude and radius images.
- Frequencies/modes: 250 kHz (0.4 vertical sampling) or 500 kHz (0.2/ sampling)
- Vertical resolution: 0.2–1.0 inches depending on mode and logging speed
- Azimuthal resolution: 1° sampling, full 360° coverage
- Maximum logging speed: 2 125 ft/hr (650 m/hr) in 250 kHz mode
- Operating environment: Compatible with water- and oil-based muds (WBM ≤ 15.9 lb/gal; OBM ≤ 11.6 lb/gal); $T \leq 177^\circ\text{C}$; $P \leq 20$ kpsi

3.3.2 Well BBK-16 Logging Parameters

- Interval logged: 3 196–3 907 m MD (711 m total)
- Drilling fluid: Oil-based mud, density 1.20 g/cm³
- Bit size: 6 in.
- Borehole deviation: <2° (max 2.0° at 3 725.3 m); vertical, ensuring full orientational reference.
- Log QC (OBMI/UBI): Rated A–B (Very Good to Good)
 - Pad-lift-off flags <5% of interval
 - Saturation and signal strength within tool tolerances
 - Accelerometer/magnetometer cross-plots showing complete, centered rotations

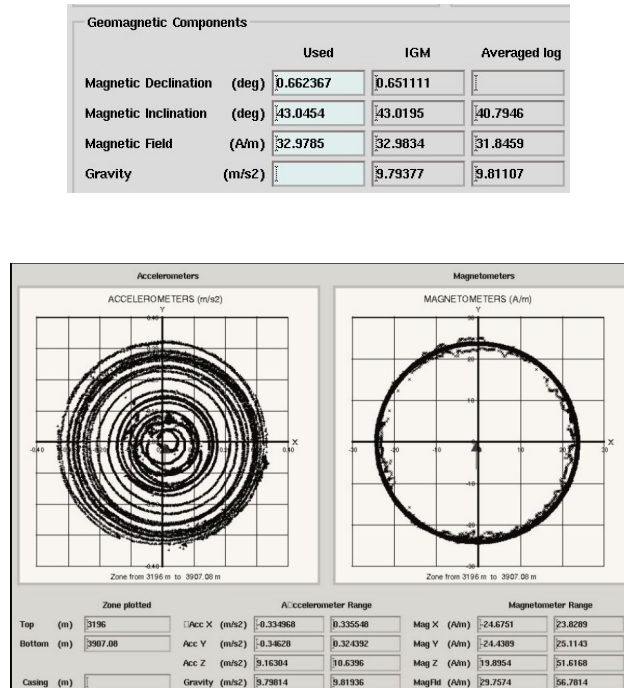


Figure 3.5: Accelerometer and Magnetometer Cross Plots Confirming Tool Rotation and Vertical Well Orientation(BBK-16)

[4]

3.3.3 Well BBK-20 Logging Parameters

- OBMI interval: 3 225–3 756 m MD (531 m)
- UBI intervals: 3 301–3 373 m and 3 470.5–3 752.6 m (combined 354 m)
- Drilling fluid: Same OBM formulation; continuous monitoring
- Bit size: 6 in.
- Borehole deviation: Max 1.98° at 3 511.3 m; near-vertical geometry
- Log QC (OBMI/UBI): Rated B–C (Good to Moderate)
 - Localized pad lift-off and signal flags between 3 286–3 338 m
 - UBI breakouts across multiple intervals
 - Quality checks confirming accelerometer/magnetometer data integrity.

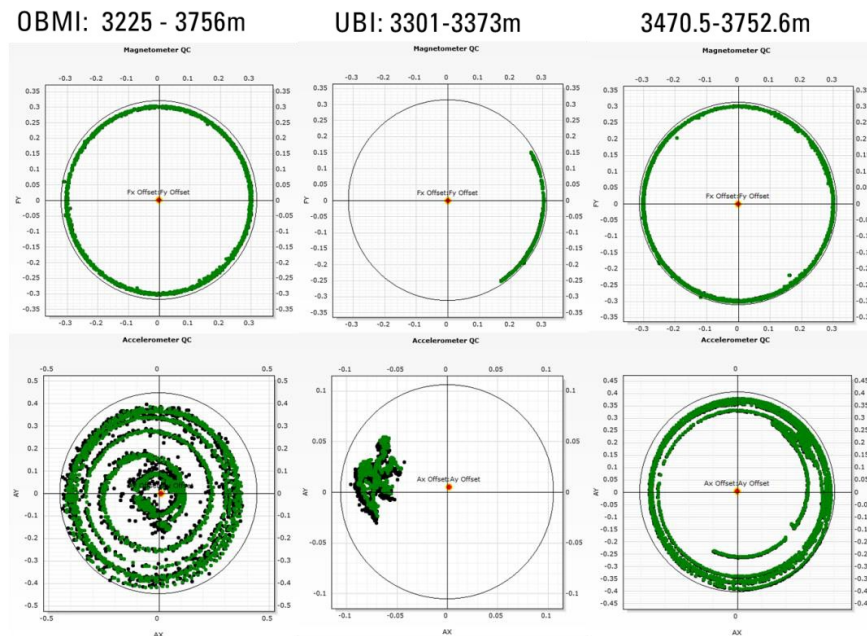


Figure 3.6: Accelerometer X-Y (right) and magnetometer X-Y-axis (left) cross-plots (BBK-20)

[15]

3.4 Key Takeaways:

- **1.Tool selection and calibration:** OBMI and UBI parameters were chosen to balance resolution, depth of investigation, and mud compatibility.
- **2.Hole conditions:** Both wells were logged in sub-vertical sections with minimal tortuosity, ensuring high confidence in image orientation.
- **3.Quality control:** Rigorous LQC flagging, cross-plot verification, and pad-contact monitoring maintained data quality ratings of A–B (BBK-16) and B–C (BBK-20).

3.5 Structural Interpretation

3.5.1 Structural Dip Zonation

Structural dips were derived from low-angle planar features, typically shale bedding or laminations within sandstones.

- **BBK-16:** A single structural dip zone (3 196–3 907 m) with a consistent azimuthal trend of N133° (SE) and an average magnitude of 2.6°.
- **BBK-20:** Also showed a singular structural zone with a dip of 2.7° toward N122.5°, reflecting regional tilting.

No major faults were imaged. However, the Hercynian Unconformity is clearly recognized in both wells (3 317 m in BBK-16, ~3 351 m in BBK-20), marked by abrupt changes in resistivity, acoustic fabric, and open-hole responses.

3.5.2 In-situ Stress and Borehole Deformation

Borehole breakouts and drilling-induced fractures were primarily interpreted from UBI amplitude images. Their orientation provides direct evidence of horizontal stress directions in vertical wells.

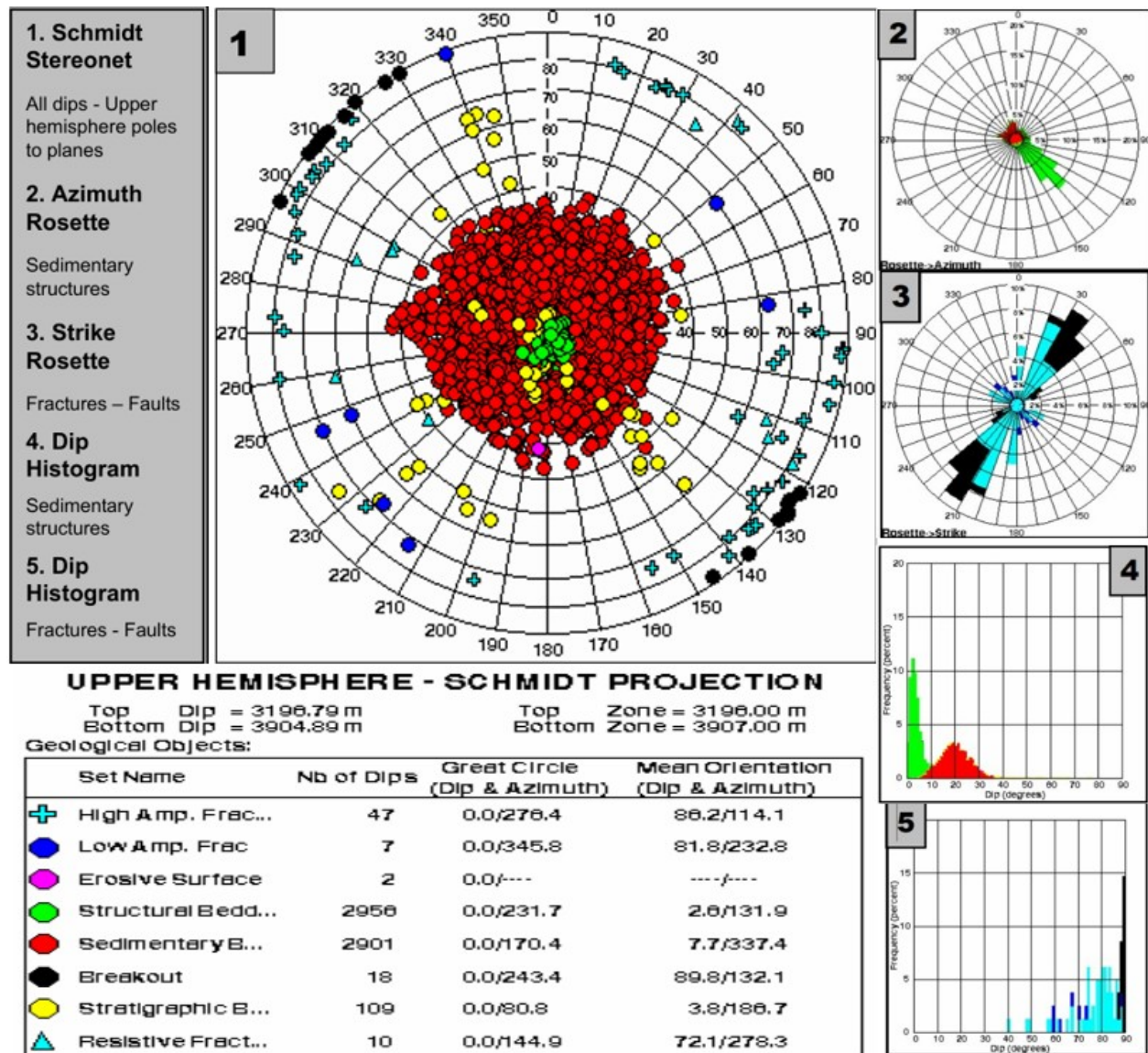


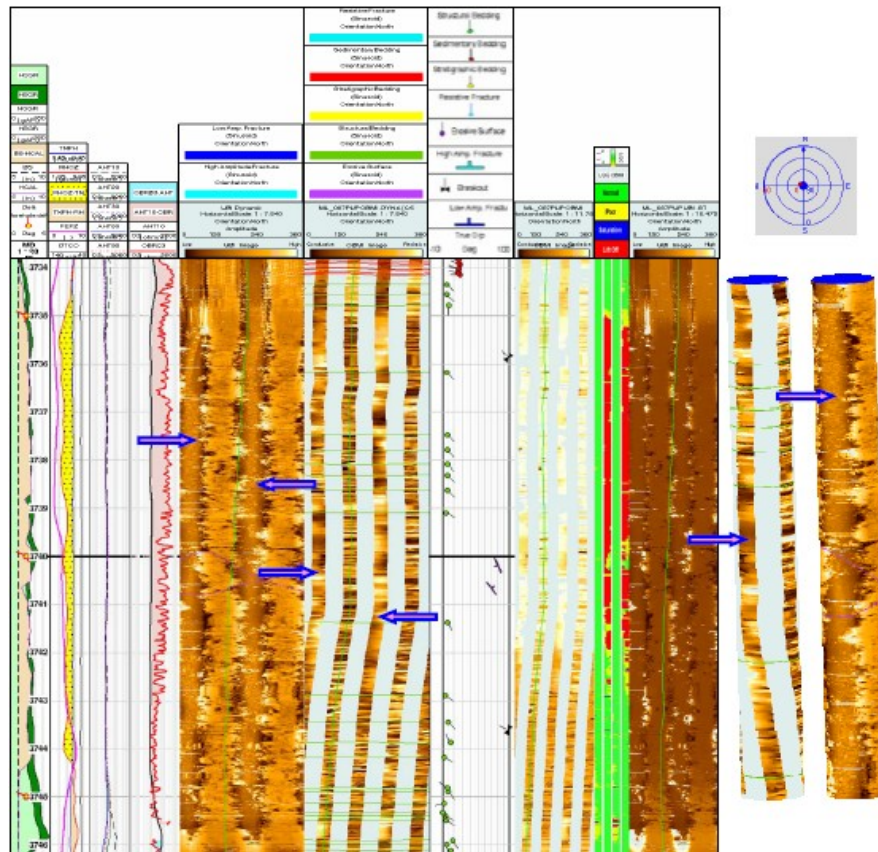
Figure 3.7: Dip statistics from OBMI-UBI Image analysis (well BBK-16)

[4]

BBK-16:

- Breakouts oriented NE–SW (N040°) indicating the minimum horizontal stress (σ_h) direction.
- Inferred maximum horizontal stress (σ_H) direction: NW–SE.

Breakout observed on the UBI image and partially on the OBMI image as two blurred, fuzzy traces. Poor pad contact suspected from the red colour on two of the OBMI pads is an indication of breakouts (see OBMI LQC flag in Track 9).



As the well is vertical, the strike of borehole breakout represents the direction of in-situ minimum horizontal stress.

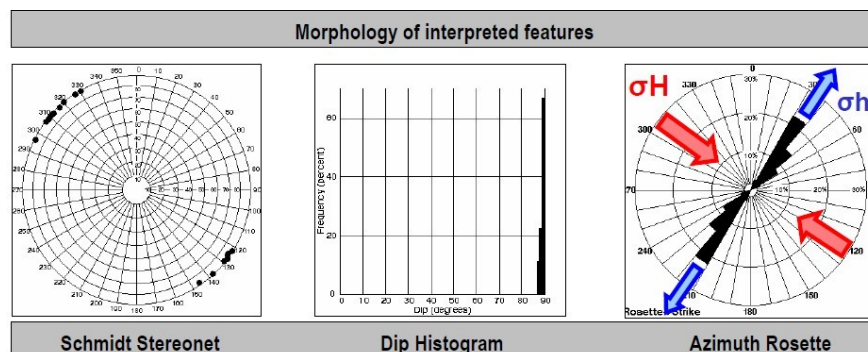


Figure 3.8: Borehole Breakout from OBMI & UBI image analysis (BBK-16)
[4]

BBK-20:

- Similar NE–SW breakout trend.
- Induced fractures aligned NW–SE, confirming the regional compressive regime.

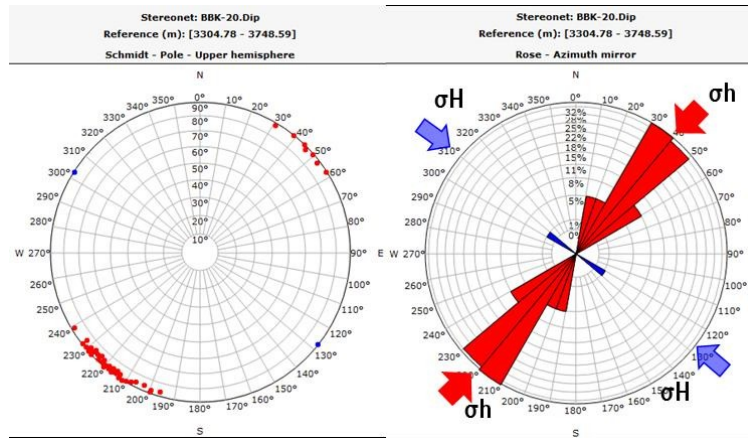


Figure 3.9: Borehole breakouts and induced fracture orientation (well BBK-20)
[15]

3.5.3 Fracture Characterization

Fracture detection was conducted through manual sinusoid fitting and amplitude/radius analysis.

BBK-16:

- 54 total fractures: 7 low amplitude (potentially open, NW–SE); 47 high amplitude (closed, NE–SW).
- Fractures are discontinuous and primarily intersect shaly intervals, reducing their reservoir permeability potential (rated D).

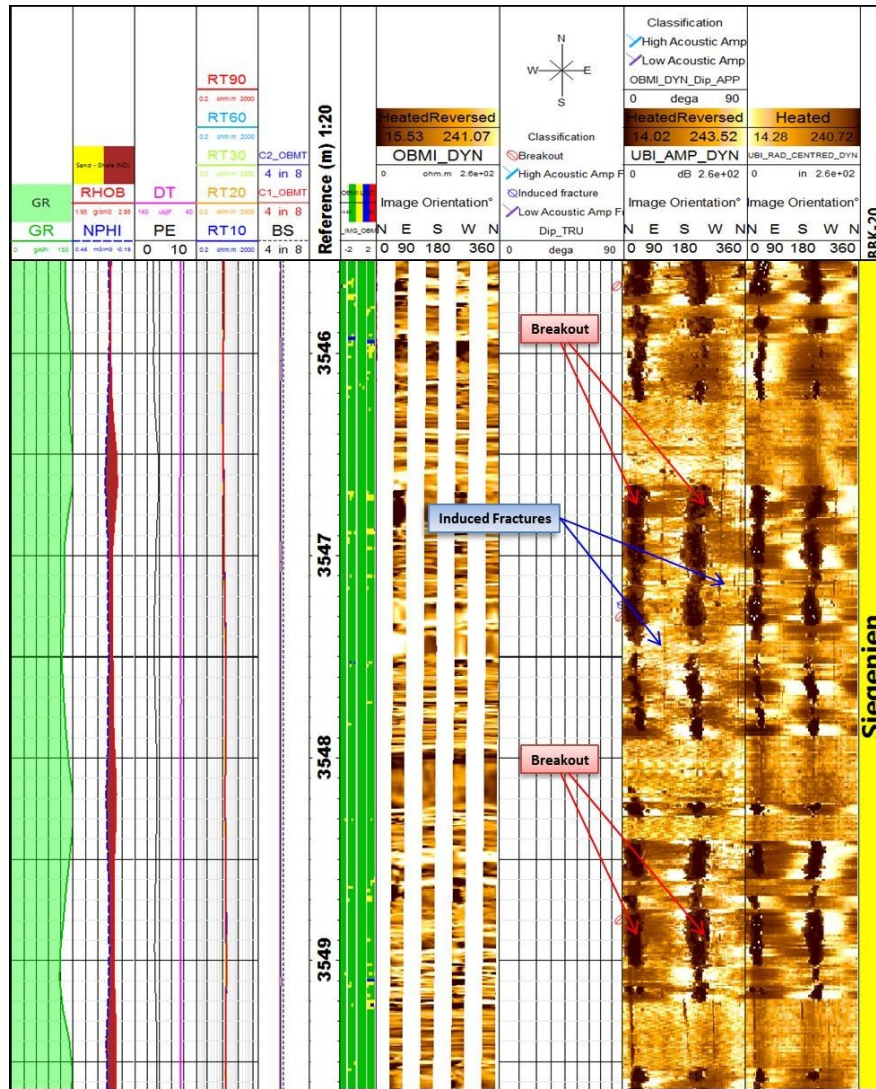


Figure 3.10: Borehole Breakouts identified from UBI images (BBK-20)
[15]

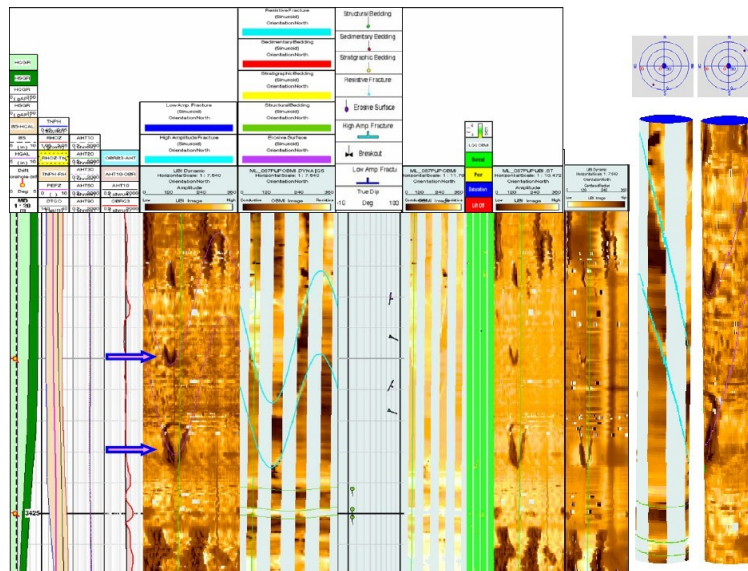


Figure 3.11: Low Acoustic Amplitude Fractures (UBI) & Resistive Fractures (OBMI) (BBK-16)
[14]

Low Acoustic Amplitude Fracture (strike signs) striking NNE-SSW. Fracture dip magnitude is 70 deg. Fractures are possibly partially open since they are visible on the UBI centred radius image (last track). The fracture appears as a resistive (bright) sinusoid on the OBMI image (triangle tadpoles).

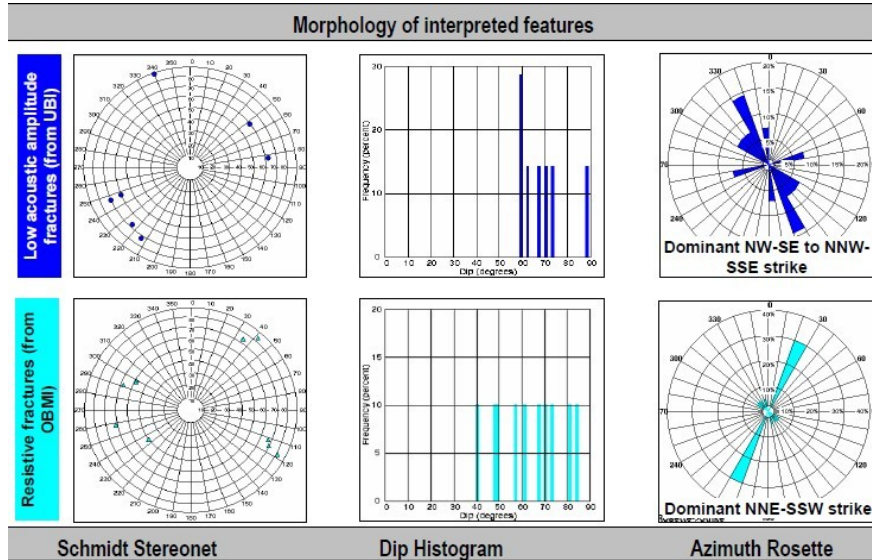


Figure 3.12: High Acoustic Amplitude Fractures from UBI image analysis (BBK-16)

High Acoustic Amplitude Fractures (cyan tadpoles) striking mainly NW-SE. Fracture dip magnitude is 70 deg. Fractures are closed (sealed with a material having a higher acoustic properties than the surrounding rock, as these fractures appear bright on the UBI image). These fractures appear as resistive (white) on the OBMI image.

BBK-20:

- 34 low amplitude (scattered strikes); 3 high amplitude fractures (NE-SW).
- Open fractures were identified where features coincided in both UBI amplitude and radius images.

3.6 Sedimentological and Facies Analysis

Image logs enabled identification of various bedding types, paleocurrent indicators, and depositional features.

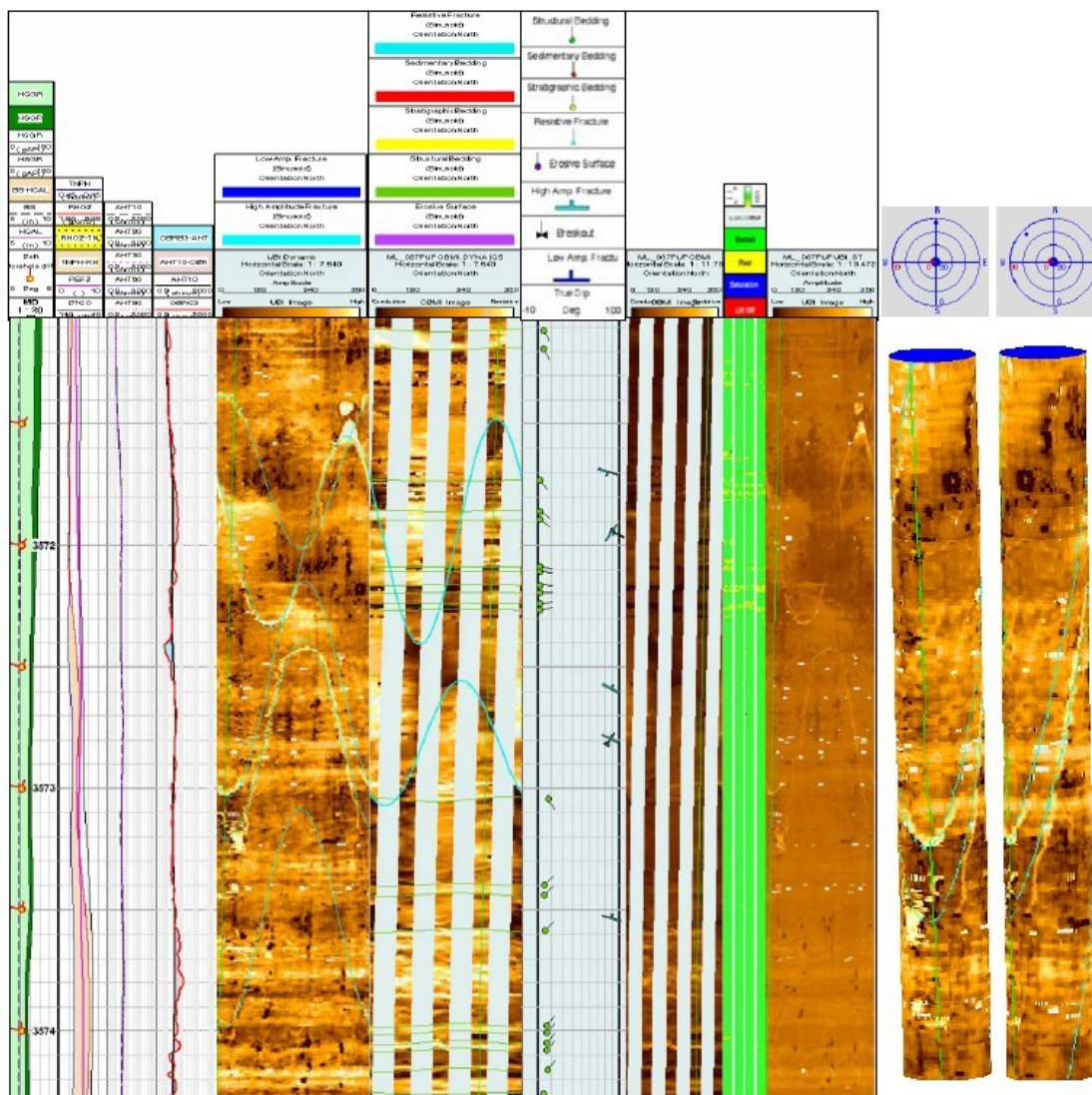


Figure 3.13: Low acoustic amplitude fracture statistics from UBI image (BBK-20)

[15]

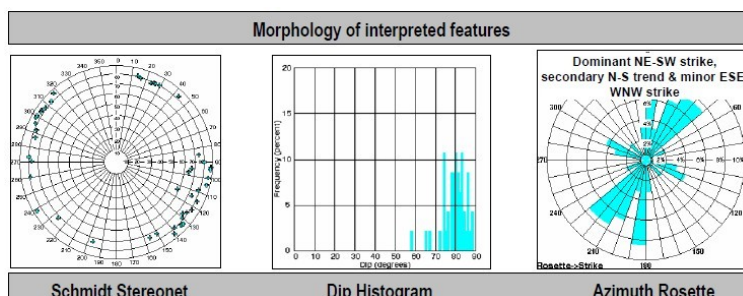


Figure 3.14: High acoustic amplitude fracture statistics from UBI (BBK-20)

[15]

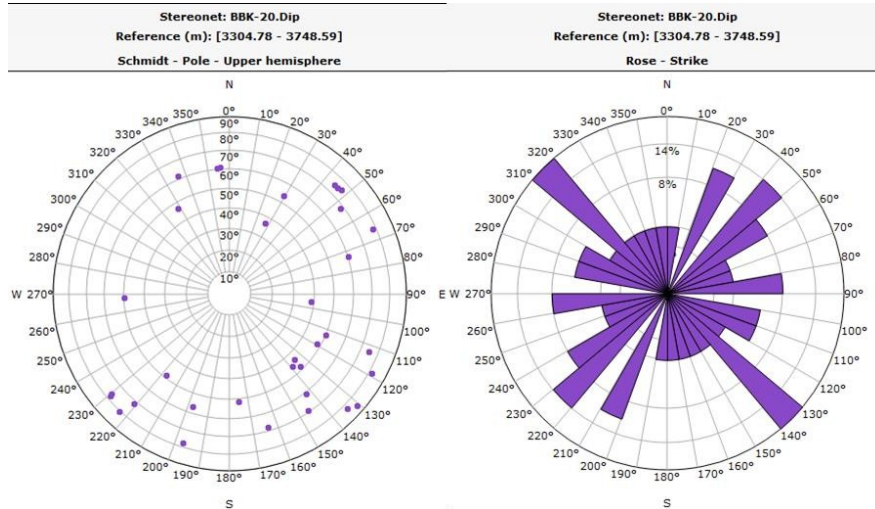


Figure 3.15: Sedimentary bedding from OBMI & UBI image analysis (BBK-16)
[15]

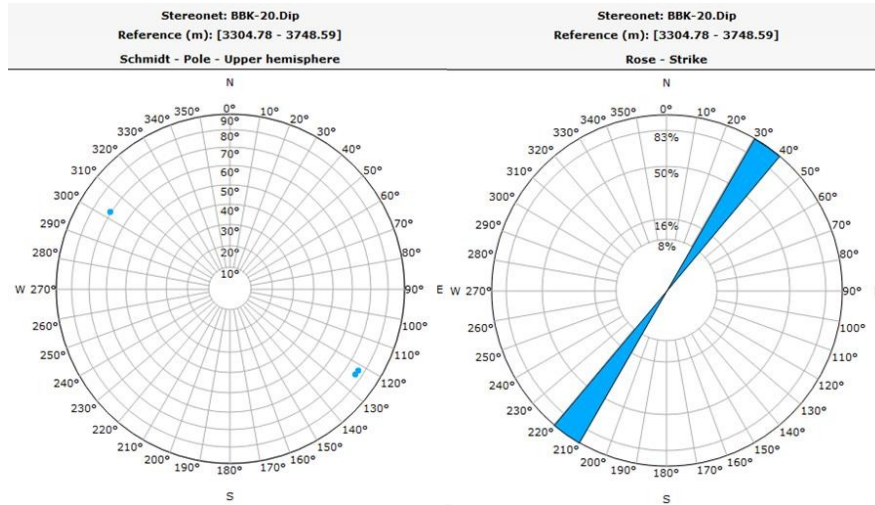
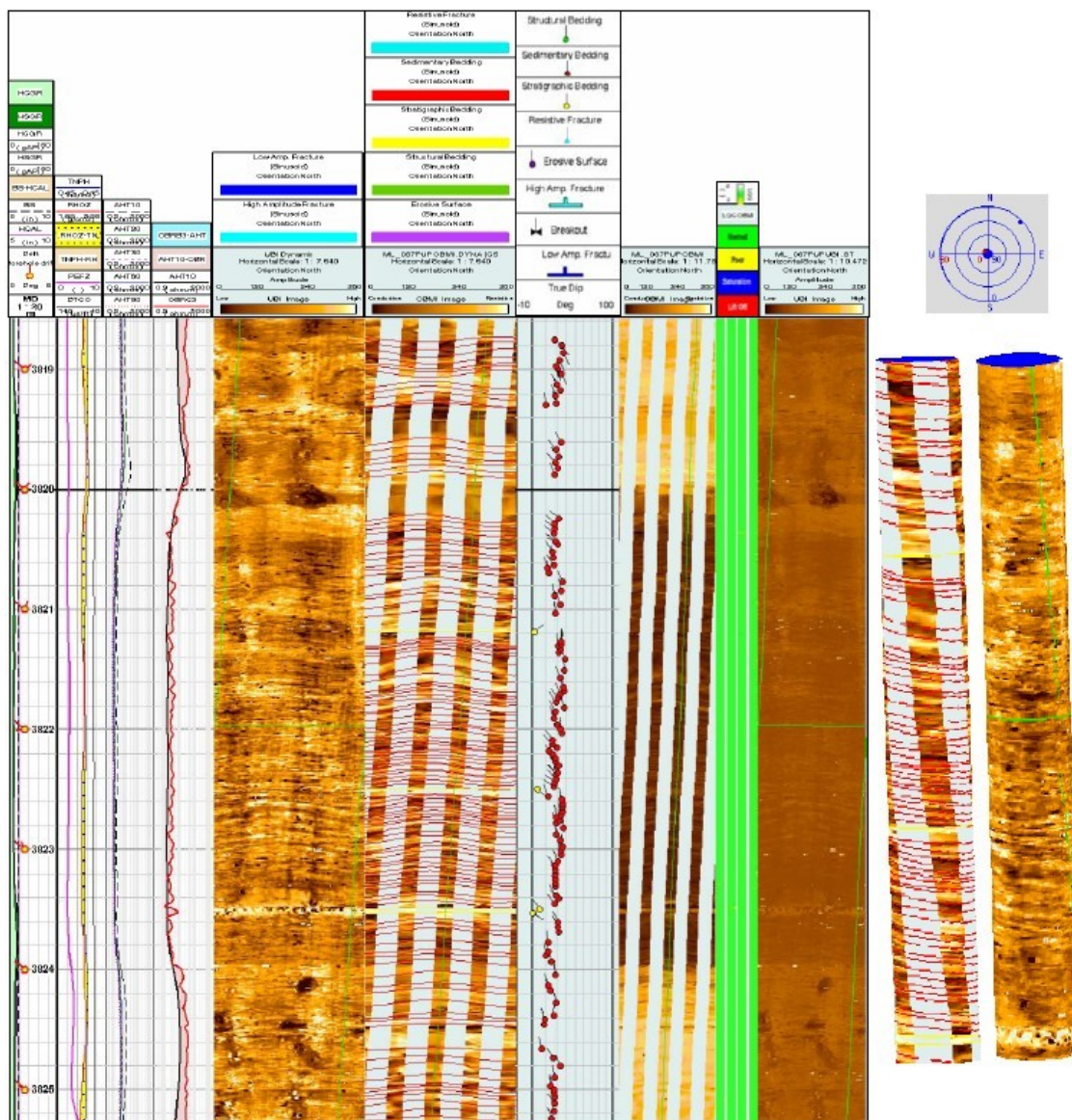


Figure 3.16: High acoustic amplitude fracture statistics from UBI
[15]

3.6.1 BBK-16

- 2 901 sedimentary dips and 109 stratigraphic dips.
- Paleo-flow in the Gedinnian predominantly NNW–WNW (meandering and estuarine systems).
- In TAGI: fluvial systems with SE flow direction.

Sedimentary beds (cross-bedding, red tadpoles) with a north-westward dip az-



imuth. Dip magnitude range from 10 to 30 degrees.

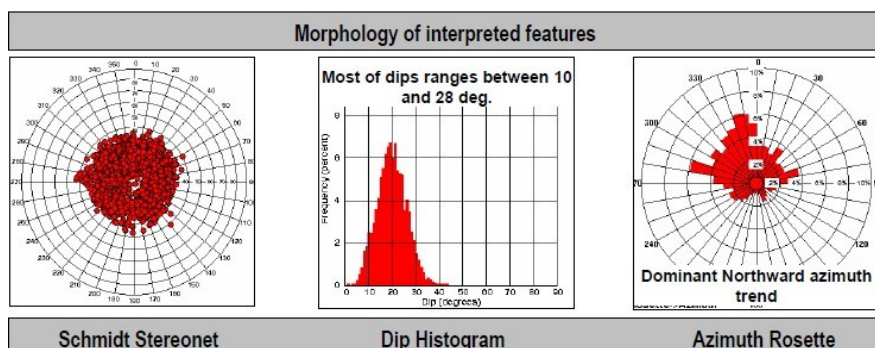


Figure 3.17: Sedimentary bedding from OBMI & UBI image analysis

3.6.2 BBK-20

A comprehensive facies analysis using Sandspect, Sand Counting, and IPSOM (Techlog modules):

Formation	Environment	Paleo-flow Direction
Gedinian	Stacked fluvial channels	NW & SW
Siegenian	Deltaic to shallow marine	SE
Emsian	Offshore marine	Undefined
Effelian/Givetian	Lower shoreface	SE (weak signal)
Frasnian	Marine	Variable
TAGI	Braided fluvial	SE
Trias Argileux	Tidal-channel influenced	Bidirectional: NW & SE

Table 3.1: Main facies, environment and paleo-flow directions for the studied formations.

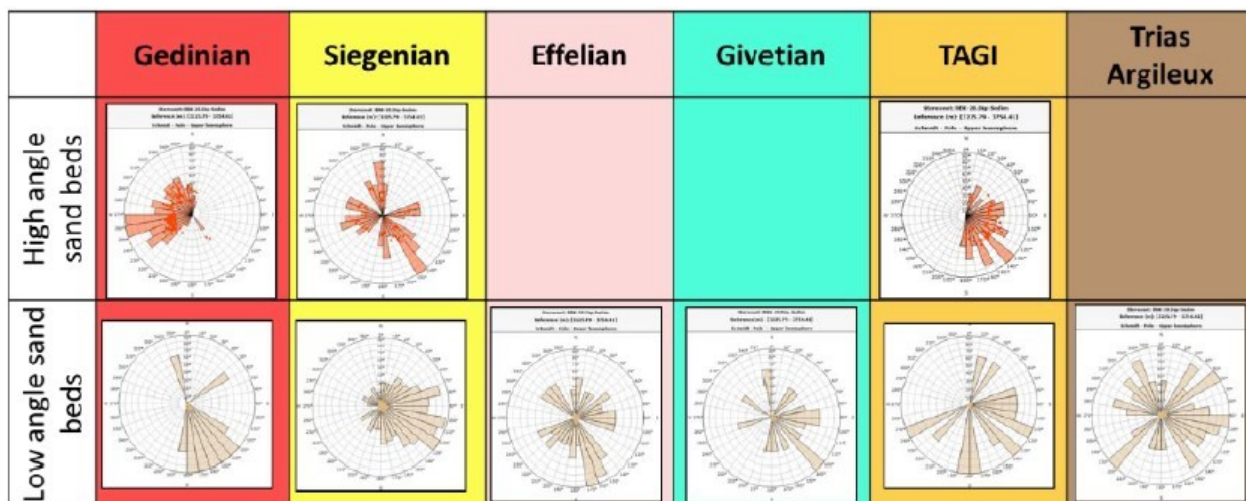


Figure 3.18: Paleocurrent orientation
[15]



51

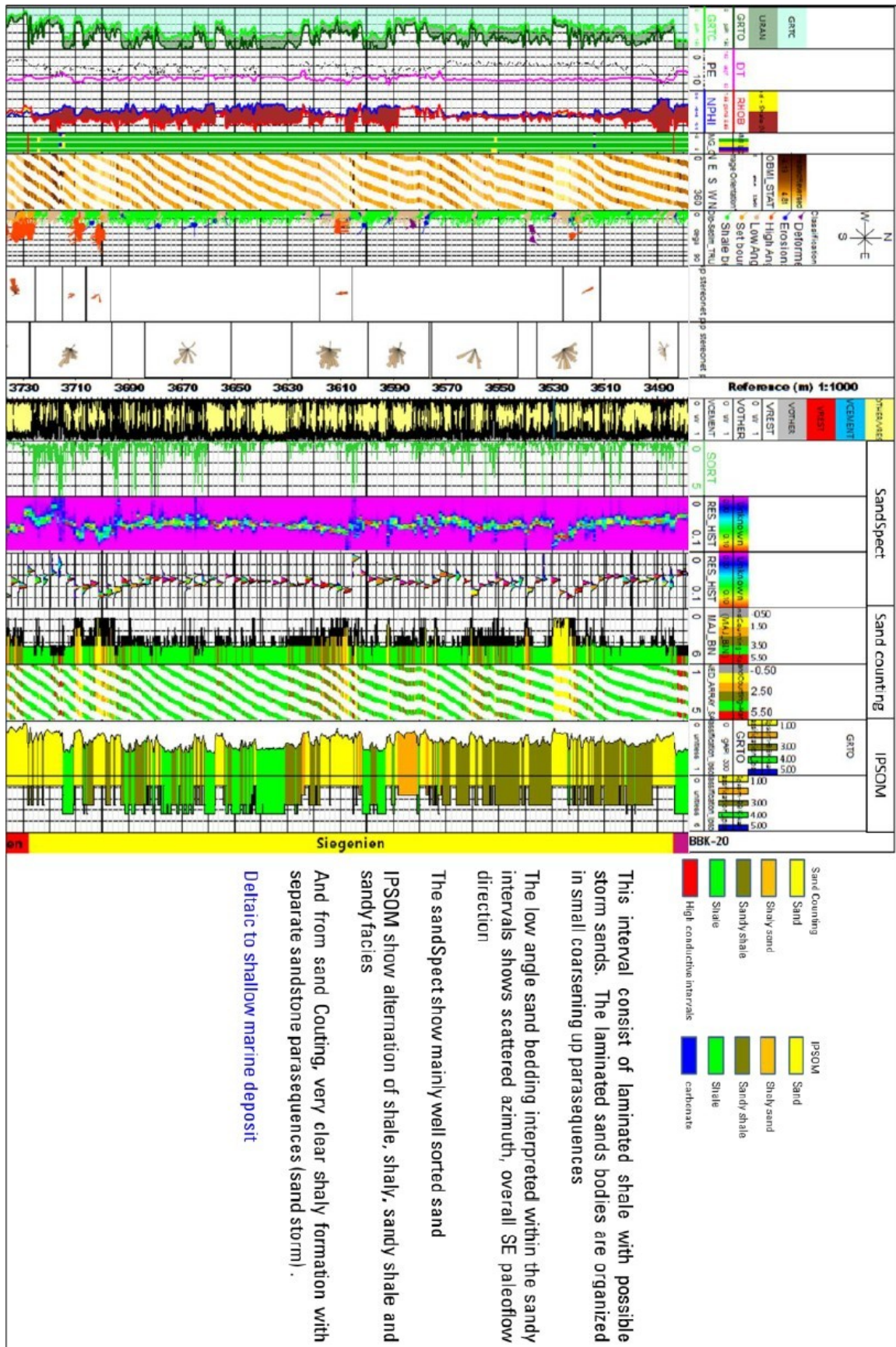


Figure 3.20: Sedimentology analysis 3728–3485 m
[15]

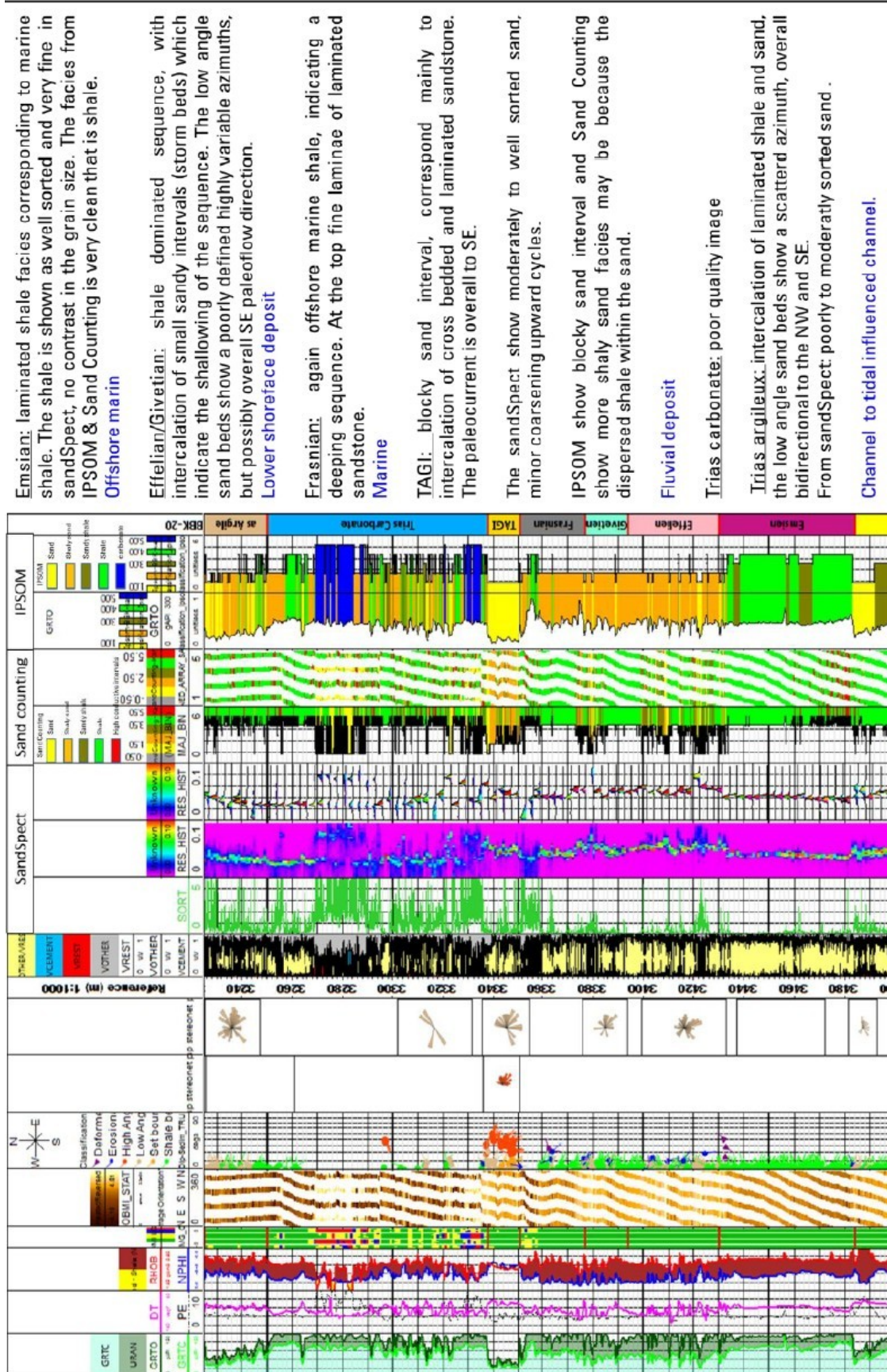


Figure 3.21: Sedimentology analysis 3485–3225 m
[15]

3.7 Conclusion

The integration of OBMI and UBI imaging in wells BBK-16 and BBK-20 has yielded a high-resolution geological characterization of subsurface intervals in the Berkine Basin. Both wells display a single structural dip zone with gentle southeast tilting, aligned with regional tectonic trends. The presence of the Hercynian Unconformity was confirmed and spatially correlated between wells.

Fracture analysis revealed a predominance of sealed, high acoustic amplitude fractures with low potential for enhanced permeability. Breakout orientations and induced features established a consistent σ_H direction of NW–SE, affirming the regional compressive stress regime.

Sedimentological analysis highlighted fluvial-dominated deposition in the Gedinian and TAGI, transitioning to marine and deltaic environments upward. The application of image-based facies interpretation tools (Sandspect, IPSOM) in BBK-20 further allowed detailed mapping of sorting, bedding architecture, and reservoir body delineation.

The combined OBMI-UBI approach demonstrated its critical value in both structural and sedimentological interpretations, particularly in the absence of core data, and provides a solid foundation for reservoir modeling and future development planning in the Bir Berkine region.

General Conclusion

The integration of advanced borehole imaging technologies, specifically OBMI and UBI, has proven invaluable in the geological characterization of the Hassi Berkine field within the Berkine Basin. These tools have enabled detailed analysis of sedimentary structures, fracture networks, and borehole stability, leading to a better understanding of reservoir heterogeneity and compartmentalization. By providing high-resolution data on both natural and induced features, OBMI and UBI have improved the accuracy of structural and sedimentological interpretations, which are critical for effective reservoir modeling and management.

The findings of this study demonstrate that the combination of electrical and acoustic imaging enhances the identification of key geological features, supporting optimized drilling, completion, and production strategies. Ultimately, the use of borehole imaging contributes to more efficient hydrocarbon exploitation and helps reduce exploration and production risks, underscoring its vital role in modern reservoir evaluation and development.

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