

Seismic tectono-stratigraphy of fluvio-deltaic to deep marine Miocene silicoclastic hydrocarbon reservoir systems in the Gulf of Hammamet, northeastern Tunisia

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Abstract Most of hydrocarbon accumulations within the Gulf of Hammamet foreland basins in eastern Tunisia are reservoirized within the Upper Miocene Birsa and Saouaf sandstones. It is the case of Birsa, Tazarka, Oudna, Baraka, Maamoura, Cosmos and Yasmine fields. These sandstones constitute oil and gas fields located on folded and faulted horst anticline highs and described as varying from shoreface to shallow marine and typically exhibit excellent reservoir quality of 30 to 35% porosity and good permeability from 500 to 1100 md. In addition, the fracturing of faults enhanced their reservoir quality potential. However, due to the lack of seismic stratigraphic studies to highlight depositional environment reservoir characterization and distribution, petroleum exploration faces structural and stratigraphic trap types and remains on targeting only high fold closures with limited reserve volumes of hydrocarbons. As an example of the Birsa concession case, syn-sedimentary tectonic structuring and geodynamic evolution during Middle to Upper Miocene Birsa reservoir sequences have guided the distribution of depositional environment of sandstone channel systems around horst and grabens by E-W, NE-SW and N-S strike slip flower faults controlling the subsidence distribution combined with the eustatic sea level variations. Seismic sequence stratigraphy study of

Miocene Birsa reservoir horizons, based on the analysis and interpretations of E-W and N-S 3D selected regional lines that were compared and correlated to outcrops and calibrated by well data, permitted to highlight the basin configuration and sequence deposit nature and distribution. Sedimentary infilling of the basin from Langhian Ain Ghrab carbonate to Serravallian Tortonian Birsa and Saouaf sandstone and shale formations is organized in four third-order seismic sequences, limited by regional erosional toplap, onlap and downlap unconformity surfaces and by remarkable chronostratigraphic horizons of forced and normal erosive lowstand and highstand system tracts separated by transgressive and maximum flooding surfaces. Reconstructed sedimentary paleo-environment distribution vary from deltaic fluvial proximal deposits in the northern part of the high central Birsa horst to a delta front and prodelta coastal and shelf shore face and shore line channelized deposits in the surrounding borders of grabens. Distal deposits seem to be distributed from upper to lower slope fans and probably to the basin floor on the flanks of the subsiding grabens. Synthetic predictive paleogeographic depositional reservoir fairway map distribution of Lower, Middle and Upper Birsa sandstone reservoirs highlights four main domains of channelized superposed and shifted reservoirs to explore.

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Introduction

The Birsa oil field was discovered in 1976 by Shell Company. Hydrocarbon was encountered in Middle Serravallian Miocene sandstones defined as Lower Birsa and Upper Birsa Sandstone (Ben Brahim 1991). Several oil and gas fields discovered within the Gulf of Hammamet are reservoirized in

Birsa Formations sandstone such as Baraka, Dougga, Yasmine, Tazarka (Ben Brahim 1991; Jeddi et al. 2001, 2004) and others (Fig. 1).

The Birsa Block is located in the northeastern part of the gulf of Hammamet bordered to the north and the south, respectively, by the Tazarka and Oudna oil field concessions (Fig. 1). The first well Birsa-1 (Bir-1) drilled in the concession encountered 180 m gross sand of Birsa Formation and flowed in a production test 478 barrels per day of 26° API gravity oil and 1.34-mm cfd of gas with 1"choke. Birsa-2 (Bir-2) and Birsa-3 (Bir-3) flowed respectively 2634 barrels per day of 31°API gravity oil and 900 mm cfdg and 456 barrels per day of 31° API gravity oil.

This work consists on a tectonic analysis and seismic stratigraphy study of Middle to Upper Miocene horizons of Birsa reservoirs in the Birsa concession calibrated to surrounding outcrops and well data. It aims to highlight the basin tectonic configuration and the sequence patterns and distribution with different systems tracts within the sandstone reservoirs.

In this work, we will first try to replace these formations in their lithostratigraphic position according to a review of the bibliographic and new data to correlate between onshore and offshore sections.

Petroleum systems setting and exploration plays

The petroleum systems in the area of the Gulf of Hammamet are represented by Cretaceous Bahloul, Mouelha and Fahdene Albian-Turonian Formations source rocks (Gaaya and Ghenima 1998) with Upper Cretaceous Campanian-Maastrichtian Abiod Formation reservoirs and Eocene Ypresian Boudabbous Formation source rocks with Lower Eocene and Miocene reservoirs (Klett 2000) (Fig. 2).

The exploration plays existing in the area are as follows:

- The Upper Cretaceous fractured limestone: (Abiod Fm.) in Miocene folds and thrust Blocks sealed by Paleogene El Haria shales and charged from Albian source during Plio-Pleistocene (Klett 2000) (MMR-1, MMR-E1 & ZNN-1) (Figs. 1 and 3)
- A similar play is provided by fractured limestone (Boudabbous Fm.) sealed by late Eocene shales Souar Fm. (Belli & El Menzah) (Brehm 1993; Touati et al. 1994)
- Middle Miocene marine limestone (Ain Grab Fm.) in Miocene folds or faulted blocks, sealed by marine

Fig. 1 Gulf of Hammamet study area Birsa petroleum block location tectonic map (ETAP 1998, modified)

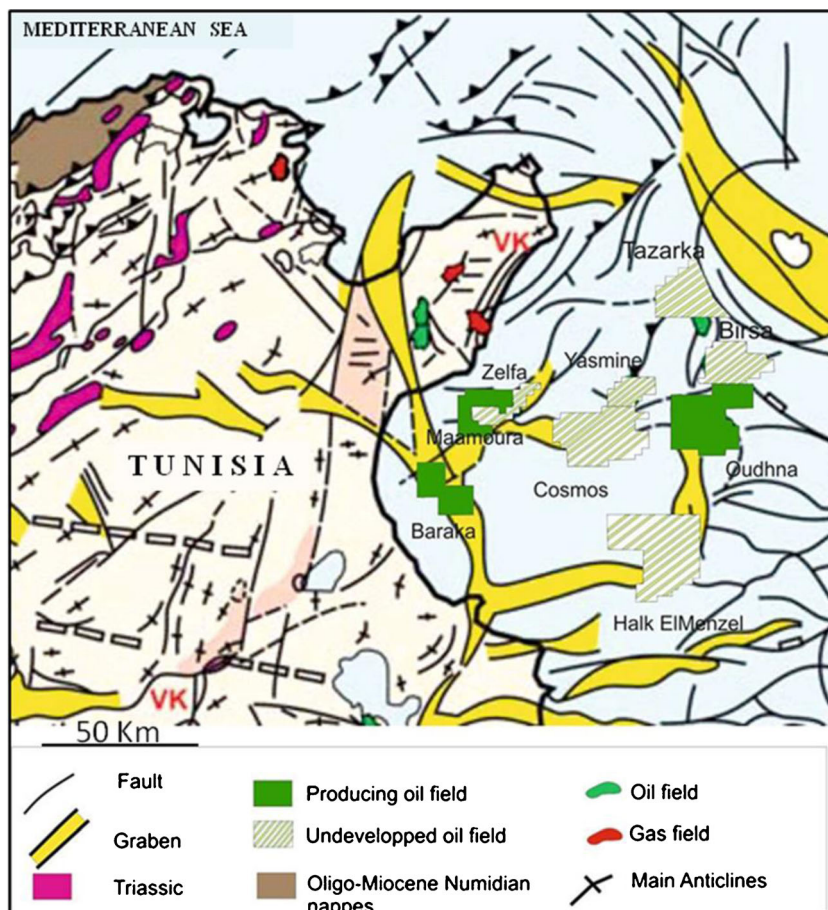
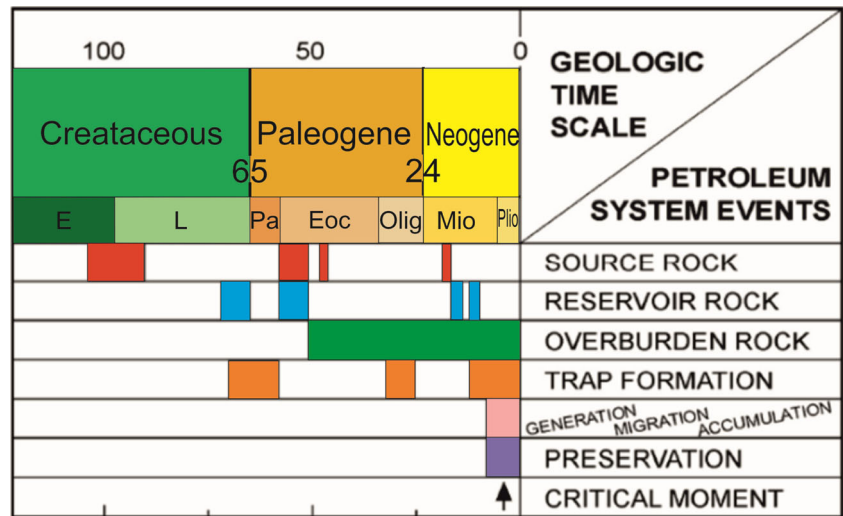


Fig. 2 Petroleum system chart of Gulf of Hammamet (Klett 2000)



Mahmoud shales and charged from Albian source and/or locally by Eocene sources (MMR-1 & HLK) (Ben Brahim 1991; Jeddi et al. 2001, 2004).

- Birsa and Saouaf sandstone reservoirs sealed by intraformational shaly intervals (Ben Brahim 1991; Jeddi et al. 2001, 2004) in OUD-1, COS-1... & BRK-1, BRK-SE1, ZFA1) (Figs. 1 and 3).

Source rocks

The Albian-Cenomanian-Turonian has been traditionally referred to the Fahdene Formation (Fig. 3). Marls and shales of the Fahdene Formation are laterally equivalent to the Zebbag Formation in the south and reefal carbonates of Bordj Cedria to the west on Cap Bon (Saidi et al. 1989; Klett 2000, Mejri et al.

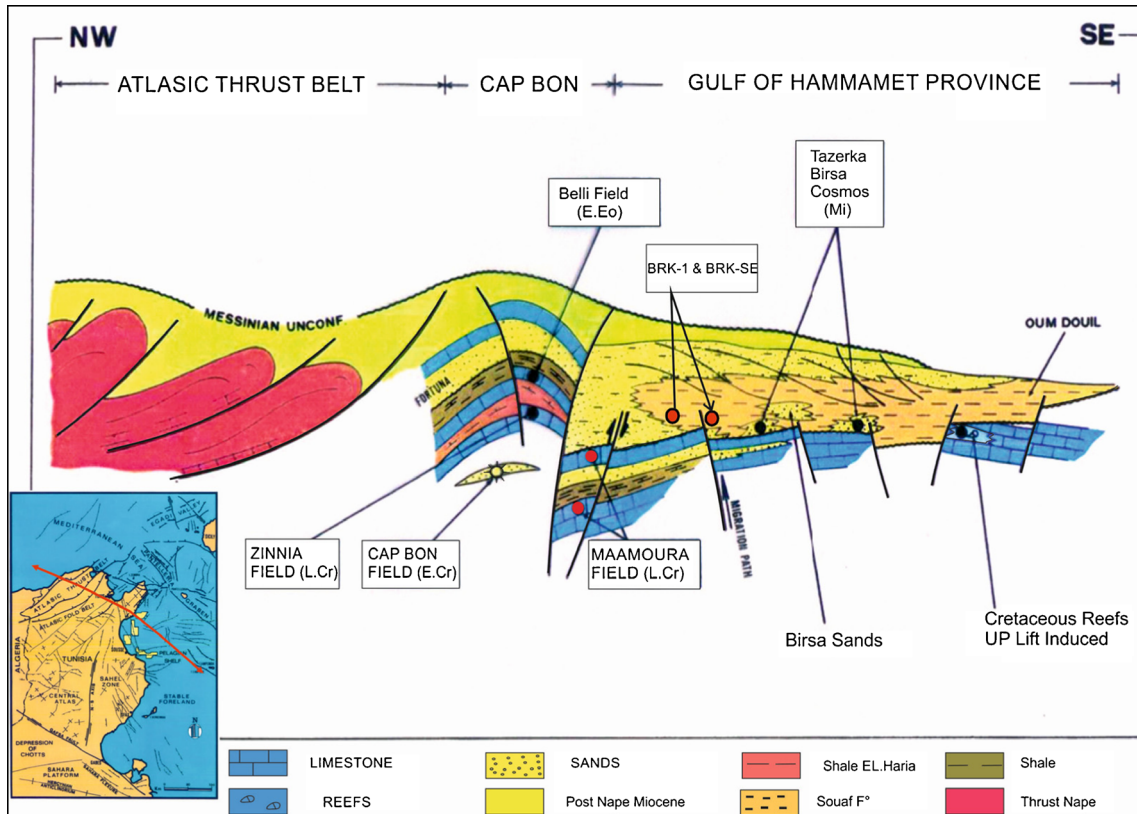


Fig. 3 Regional geoseismic section showing petroleum system and trap types in the Gulf of Hammamet

2006). It is evident then that significant temporal and spatial variations exist in response to regional and localized tectonics.

These levels are confirmed source rocks of several oil and gas fields in the Sahel region and the Gulf of Gabès in eastern Tunisia. Lower Eocene Boudabous Formation shales are also a confirmed source of rocks of several oil fields in eastern Tunisia and in the Cap Bon area. Miocene petroleum oil fields in the Gulf of Hammamet are obviously resourced by Cretaceous and Eocene source rocks.

Reservoirs

Most hydrocarbon accumulations within the Gulf of Hammamet are found within the Mid-Upper Miocene Birsa Formation sandstone, such as at Dougga, Tazerka, Oudna, Birsa, Cosmos and Yasmin fields Tazerka (Ben Brahim 1991; Jeddi et al. 2001, 2004). These sandstones are described as varying from being shore face to marine and typically exhibit excellent reservoir quality (Bédir et al. 2015) in addition to the fracturing of faults that affected the most anticline traps (Fig. 3).

Seals

Several clay packages constitute a seal for Cretaceous and Tertiary reservoirs represented by Cenomanian and Senonian shales and Paleocene El Haria and Eocene Souar shale Formation.

For the Birsa sand reservoirs, seal is provided by the Upper Oum Dhoul and Saouaf clays (Ben Brahim 1991; Bédir et al. 1996; Klett 2000; Jeddi et al. 2001, 2004 and Gharsalli et al. 2013).

For the Middle and Upper Miocene reservoirs, the petroleum system Chart of the Gulf of Hammamet highlights a migration and trapping timing of critical moments from Upper Miocene/Quaternary compressional events (Klett 2000). Therefore, Miocene reservoir traps had been already structured when they have been filled by expulsion and migration of hydrocarbons from source rocks (Middle Cretaceous Fahdene and Lower Eocene Boudabous) (Figs. 2 and 3).

Traps

All the hydrocarbon traps in the Miocene petroleum system are only structural traps of hinges of anticlines which reduce the potentialities of exploration of this confirmed and proven system.

Geo-tectonic setting

Cenozoic and Miocene tectonic events had been induced in northeastern Tunisia in the Cap Bon Peninsula, the Gulf of Hammamet and the Saouaf basin complex inheritate and syndimentary structuring especially during deposition of

fluvio-deltaic silicoclastic deposits of Miocene carbonate and sandstone reservoirs that are distributed around faulted blocks, folds and synclines and grabens.

The Birsa concession is located in the northeastern part of the gulf of Hammamet bordered to the north by the Tazarka oil field concession and to the south by the Oudna oil field concession (Figs. 1 and 3). Mesozoic and Cenozoic lithostratigraphy and tectonic structures show that the gulf of Hammamet is in continuity with the western Cap Bon peninsula.

The Gulf of Hammamet is located in a foreland inverted basin back to the fold belt over a thrust arc extending from NE-SW of the northern Tunisian Atlas to the Sicily channel and southern Italy (Craig 2010) (Fig. 4). The Birsa concession is located in the foreland basin area back to the inverted foreland basin (ADX, 2013).

The subsurface tectonic map of the Tunisian eastern margin (Bédir 1995; Bédir et al. 1996) shows the existence of tectonic blocks delimited by first-order master strike slip flower fault corridors trending N90–120 and N160–180 (Fig. 1). Second-order NE-SW faults are connected to the first-order faults as “R strike slip Riedels”, which take place in the major NE-SW fold Anticline during compressive Upper Cretaceous and Tertiary events.

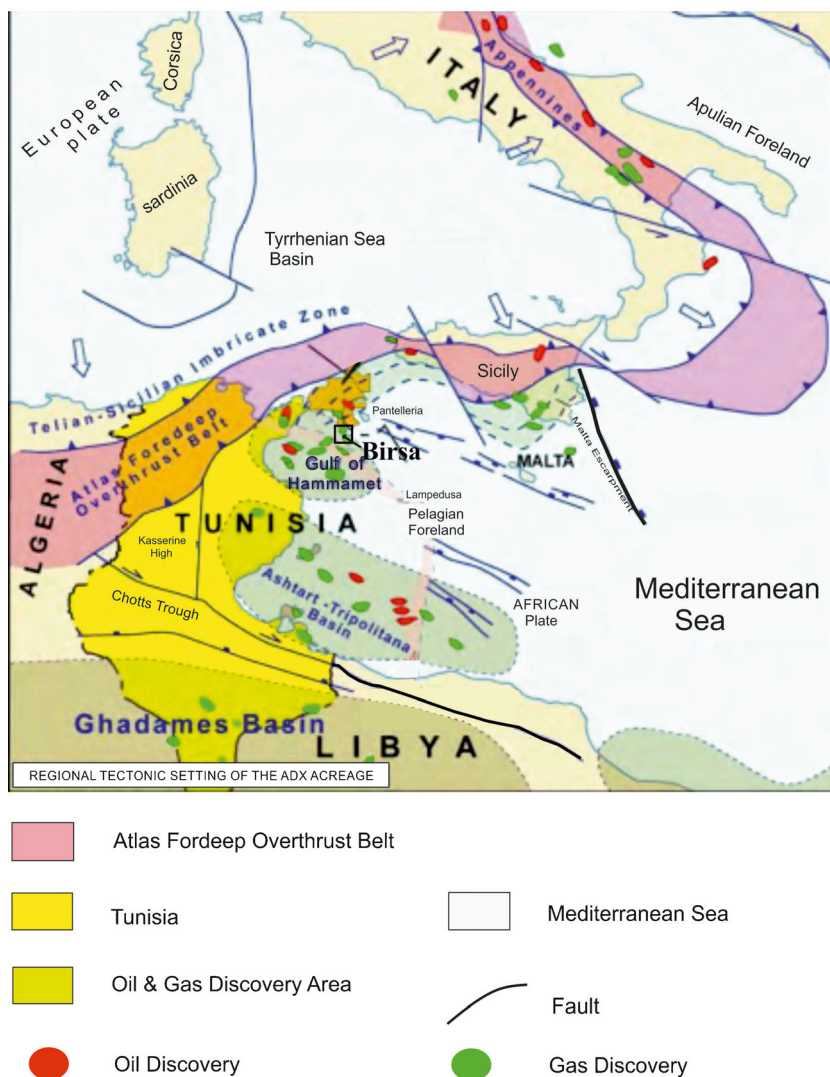
The NE-SW Jebel Abderrahmane anticline occupies the most part of the Cap Bon peninsula and offers an important analogue structure for Neogene deposit outcrops for the gulf of Hammamet subsurface structures (Figs. 1 and 3).

This area presents a succession of NE-SW multi-kilometric anticlines and synclines (Fig. 1). It shows the oldest series exposed in the area pertaining to the Middle Eocene argillaceous Souar Formation (Burolet 1956). This NE-SW dissymmetrical structure presents a southeast more subsiding syncline during Miocene and Plio-Quaternary (Abbes 1983; Ben Salem 1992; Bédir et al. 1996). It is affected by several radiant faults starting from the centre. These faults are in Majority N50 normal, N70, N130 and N160 sinistral and N90 dextral strike-slip (Burolet 1956; Ben Salem 1992; Bédir et al. 1996).

The Cap Bon and the Gulf of Hammamet area had experienced major regional tectonic events marked by a Mesozoic distensive stresses in Triassic-Jurassic, Early Cretaceous and Middle Cretaceous rifting (Bédir et al. 1992; Ben Salem 1990, 1992; Bédir 1995; Bouaziz et al. 2002; Zouaghi et al. 2009; Melki et al. 2011) and Upper Cretaceous, Eocene, Lower and upper Miocene and Plio-Quaternary in versions and compressions (Ben Salem 1992; Bédir et al. 1992; Bédir 1995; Bédir et al. 1996; Bouaziz et al. 2002; Khomsi et al. 2006; Khomsi et al. 2009; Melki et al. 2011; Gharsalli et al. 2013).

These events had reactivated the inherited E-W, NE-SW and N-S Master fault corridors in transtensional and transpressional movements resulting to the actual structuring of the Cap Bon and Gulf of Hammamet in Neogene grabens and in NE-SW anticline sand synclines (Ben Frajani et al. 1990; Bobier et al. 1991; Ben Salem 1992; Bédir et al.

Fig. 4 Tectonic and Birsa block study area location map and associated oil and gas fields (dark box) (Craig 2010)



1996; Bouaziz et al. 2002; Patriat et al. 2003; Zouaghi et al. 2011; Melki et al. 2011).

Geo-stratigraphic and sedimentologic setting overview

In this section, an overview of the sedimentary depositional systems of these Middle to Upper Miocene series and their sequence deposit organization in the surrounding outcrop analogues as in the Gulf of Hammamet wells are presented before proceeding to the seismic stratigraphic study in the next part.

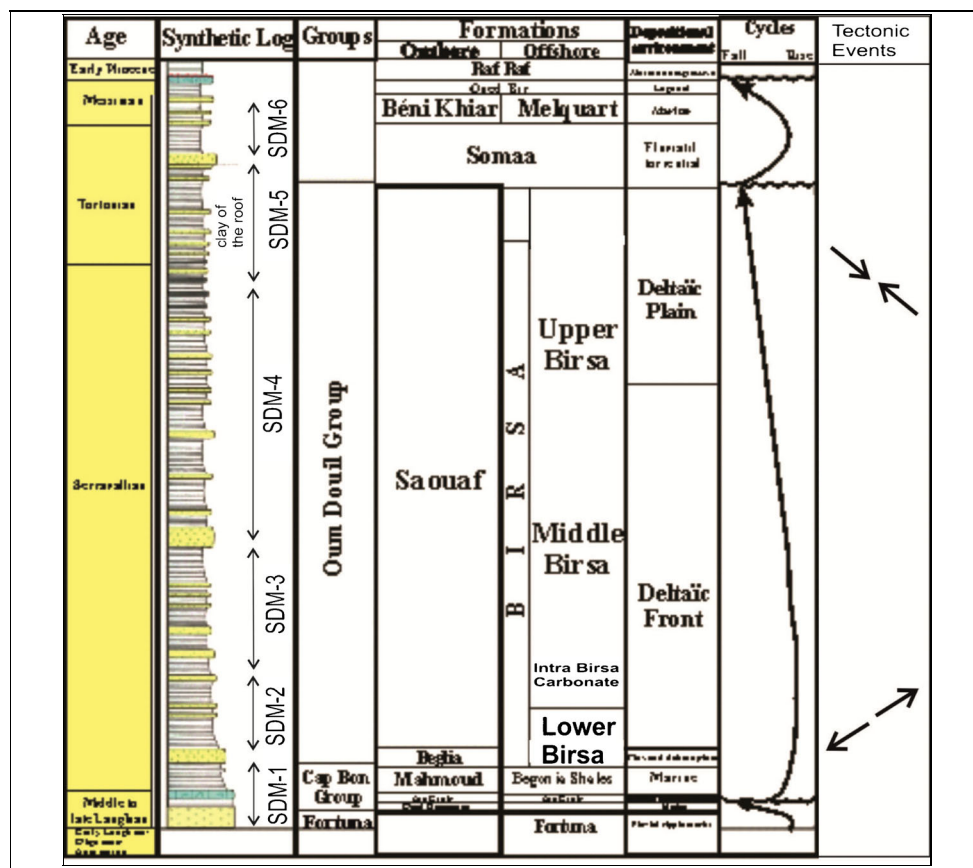
Several geologic works had been carried out in the Miocene outcrops in the Jebel Abderrahmane in the Cap Bon and Saouaf basin according to the biostratigraphic, sedimentologic, palaeontologic, palynologic, sequence and seismic stratigraphy and structural geology studies (Burolet 1956; Salaj et al. 1970; Robinson 1971; Biely et al. 1972; Robinson and Wiman 1976; Colleuil 1976; Fournié 1978, Ben Ismail-Latrache 1981;

Abbès 1983; Tayech 1984; Méon et al.1986; Mahjoub et al. 1989; Bédir and Tlig 1992 and 1993; Ben Salem 1990,1992; Bédir 1995; Hooyberghs 1995; Bédir et al. 1996; Hooyberghs et al.1999; Jeddi 2001; Patriat et al. 2003; Mannai-Tayech 2006, 2009; Gharsalli et al. 2013; Bédir et al. 2015).

This opportunity offers an important way to study the analogue deposits of the Birsa reservoirs by establishing a sedimentologic, stratigraphic and tectonic studies according to a modern high-resolution integrated sequence stratigraphic and seismic sequence stratigraphy analyses calibrated to petroleum well data.

The Middle and Upper Miocene synthetic stratigraphic column of the onshore and offshore northeastern Tunisia includes several formations (Fig. 5), corresponding from the base to the top: Aïn Grab, Mahmoud (Begonia Shales) Formations (Langhian), Beglia (Lower Birsa) (Serravallian) (Besème and Blondel 1989), Saouaf Formations (Middle and Upper Birsa and Upper Oum Douil Group) (Serravallian-Early Tortonian), Somaâ Formations (Tortonian) and the Beni khiar (Melquart

Fig. 5 Onshore-offshore lithostratigraphic Miocene chart of the Cap Bon and Gulf of Hammamet showing lateral equivalent formations and Birsa sand position (in Gharsalli et al., modified, 2013)



Formations (Messinian) (Colleuil 1976; Bismuth 1984; Besème and Kamoun 1988).

The sequence stratigraphic, sedimentology and environmental deposit study of the Miocene Jebel Abderrahmane analogue outcrops had led in previous works (Bédir et al. 1992, 1993; Bédir 1995; Bédir et al. 1996; Jédi et al. 2001, 2004; Bédir et al. 2012; Gharsalli et al. 2013) to identify the sequence deposits and the space-lateral distribution of the sandstone reservoir lowstand and highstand system tracts around the flanks of the anticline in the Cap Bon Peninsula.

This study around the Jebel Abderrahmane anticline had highlighted six third-order sequences (Bédir et al. 1996; Gharsalli et al. 2013) from SDM 1 to SDM 6 that ranged from Langhian Ain Ghrab to Tortonian Somaa Formations (Figs. 6 and 7). These results help to understand the Miocene sandstone depositional system around similar anticline sand synclines in the Gulf of Hammamet. The sandstone reservoirs of Béglia and Saouaf Formations which correspond to the Lower, Middle and Upper Birsa sandstones in the Gulf of Hammamet (Gharsalli et al. 2013; Bédir et al. 2015) and their shale seal packages show a regional extension accompanied by environment deposit and thickness variations.

Middle Miocene lowstand and highstand reservoir and seal system tract deposits progress from the southeastern high deltaic plain anticline axis to the northeastern pro and front delta of the Jebel Abderrahmane flanks (Bédir et al. 1996; Gharsalli

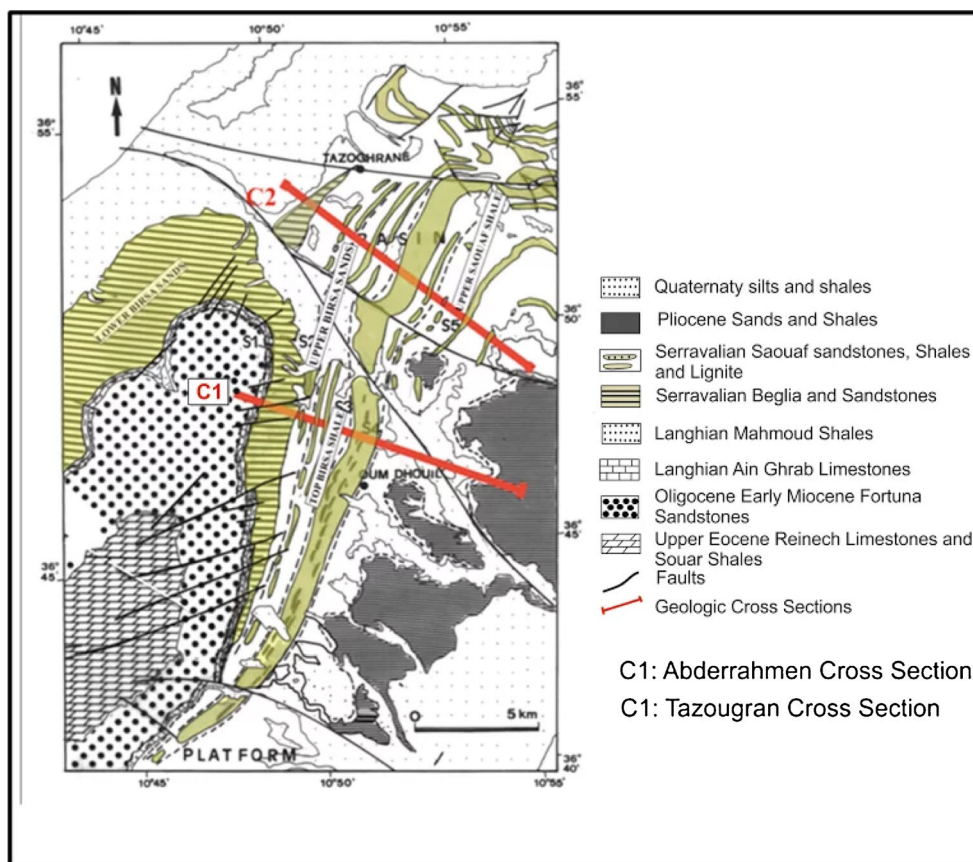
et al. 2013) (Figs. 6 and 8, C1 to C5 cross sections). This distribution highlights the large extension of the sandstone reservoirs with changes in thickness and sedimentologic facies as grain sizes coarsening and richness in shales (Bédir et al. 1996; Gharsalli et al. 2013). These changes occur from the Abderrahmane anticline high axis deltaic fluvial plain of Béglia Formation to the pro and delta front deposits in Tazoghane subsiding graben and Hammamet trough (Bédir 1995; Bédir et al. 1996; Gharsalli et al. 2013) (Figs. 6 and 8).

This correlation integrates the El Oudiane-1, Zinnia-1, Maamoura-1, Yasmine-2 and Birsa-5 petroleum wells, corresponding to the northern part of gulf of Hammamet. It extends from the eastern flank of the Jebel Abderrahmane anticline to the eastern end of the northern Hammamet zone and crosses a number of master corridor faults trending NW-SE, E-W, N-S and NE-SW (Fig. 9).

Onshore-offshore Miocene sequence deposit correlations

E-W lithostratigraphic correlation of Miocene Formations between Cap Bon onshore area and the Gulf of Hammamet offshore well data has been established in order to precise the different reservoir sand seal equivalences and extension based on sequence stratigraphic characters (Fig. 9). Paleogeographic and environmental locations both in the outcrops and the

Fig. 6 Jebel Abderrahmane geologic cross sections location map showing Miocene lithostratigraphic formations, sequence deposit distribution and Birsa reservoir equivalent position (Ben Salem 1990 and Bédir et al. 1996, modified)



petroleum wells are very comparable because of the similar inherited high position of the folded platform in the Miocene.

The main results of this correlation is the regional extension of the Middle Miocene Formation deposits, and the correspondence of the sandstone reservoir equivalents that of on-shore Béglia and Saouaf Formations and offshore Lower, Middle and Upper Birsa (Fig. 9).

The regional extension of reservoir sequence thickness variations detected already in outcrops is confirmed here along this correlation, Béglia sandstone sand overlying shales are matching well with the Lower Birsa sandstone sand the overlying shales, and they correspond to the sequence deposits and seismic sequence SDM 2 (Figs. 6, 7, 8, and 9).

On the other hand, Middle and Upper Birsa sandstone sand overlying Top Upper Birsa shales correspond to the Lower and Middle Saouaf sandstones and shales, and they constitute the SDM 3 sequence (Figs. 6, 7, 8, and 9), whereas the so-called Mahmoud shales (Shell denomination) (Ben Brahim 1991) correspond to the Upper Saouaf shales and the so-called Béglia sandstones of Shell denomination correspond to the Lignite and sandstone sequence SDM 4 of Upper Saouaf Formation (Figs. 6 and 9).

The clay package overlying the Lignite sequence is the “Clay of Roof” (Abbès et al. 1981; Abbès 1983) of SDM 5 of the Upper Saouaf Formation. The overlying sandstone sand conglomerates correspond to the Somaa Formation (Colleuil 1976 and Ben

Salem 1992), which represent the SDM 6 lowstand system Tract. Birsa well correlations from the central horst structure to the northern and southern grabens present the lateral and vertical organization of Miocene deposits from Ain Ghrab carbonate Formation to Lower, Middle and Upper Birsa sandstone reservoirs showing the oil and gas levels encountered by these wells (Fig. 10). This correlation calibrates well the Birsa reservoir levels with the onshore analogue and presents the same lateral extension with thickness variation sand fault pattern affecting these levels.

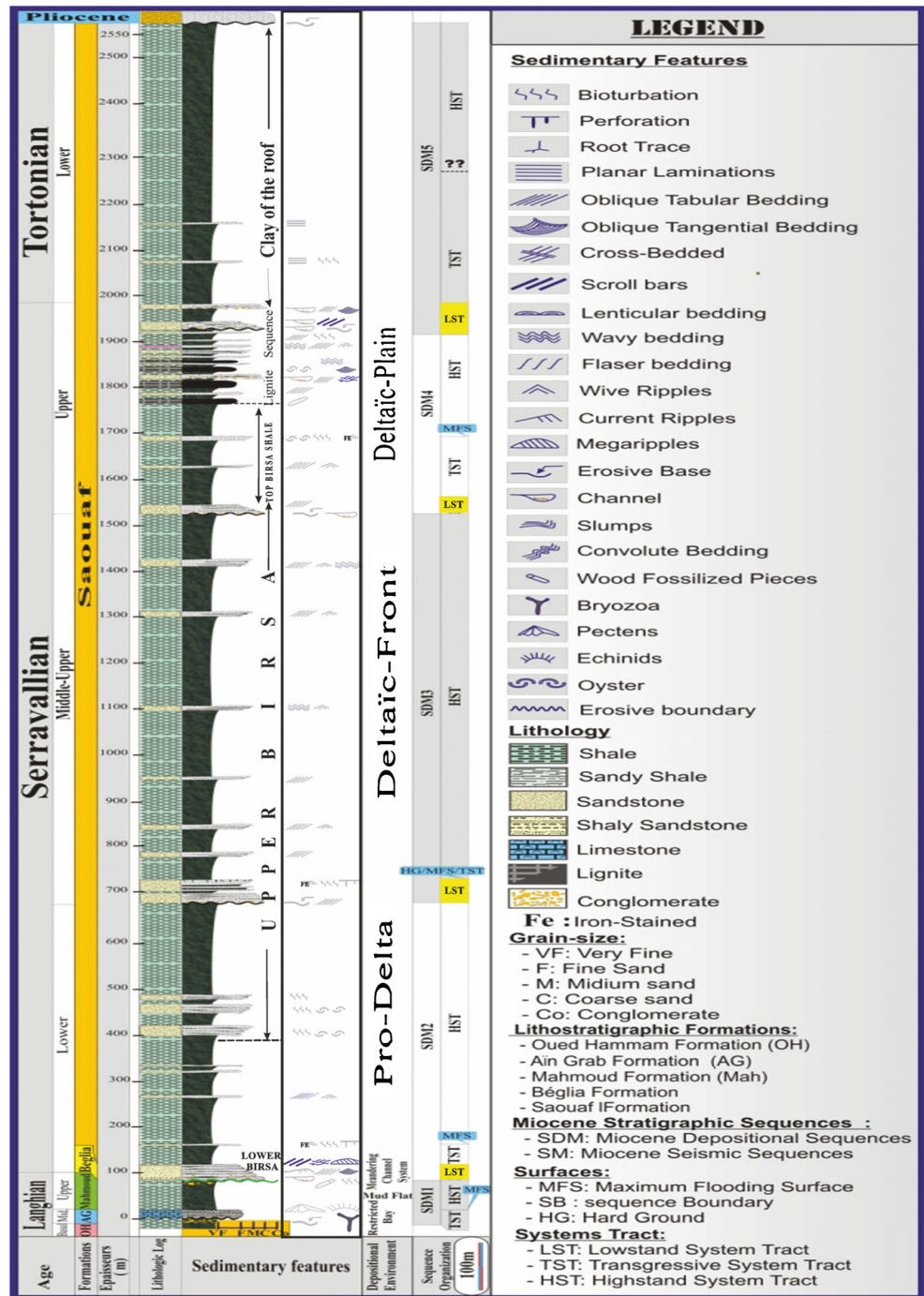
Data sets and methods

Seismic

3D reflexion seismic acquisition has concerned an offshore surface area of 2976 km² in the Birsa concession (Fig. 1). The seismic grid comprises about 820 inlines and 820 cross lines with a space interline of 50 m. The seismic used frequency ranged from 40 to 100 Hz. The total vertical resolution reaches 6.5 s two-way travel time wave and corresponds to an average of 8770 m of depth with average velocity of 2700 m/s.

In this paper, we detailed two seismic stratigraphic cross line sections (A and B) and two seismic stratigraphic inline sections (C and D) (Fig. 11) that summarize and synthesize the depositional system tract environments and geometries of the three

Fig. 7 Sequence lithostratigraphic and environment depositional of Miocene of Jebel Abderrahmane (logc1) showing Birsa reservoir equivalent deposit position in the Cap Bon outcrops (Gharsalli et al. 2013, modified)



Birsa reservoir sequences according to the Birsa basin structuring.

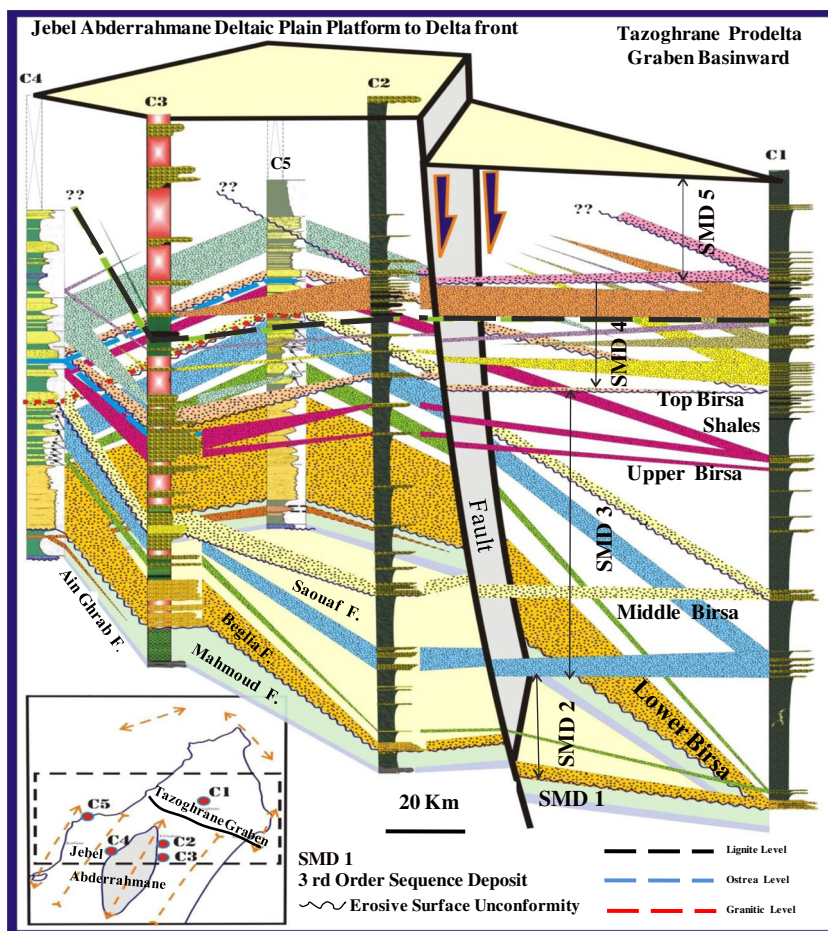
These lines were also selected to cross the maximum number of wells within the concession (Bir-1, 2, 3, 4, 5 and 6) in order to fully correlate the seismic with the well data and undertake the most reliable seismic stratigraphic analysis to identify and highlight seismic sequence boundaries and system tract horizons of Middle to Upper Miocene.

The seismic analyses have been interpreted in SMT Kingdom 8.7 workstation. The interpreted 3D seismic

processing is under Society of Exploration Geophysicists (SEG) normal polarity and zero phase which means an increase in impedance produces a negative amplitude reflection (trough). In all seismic lines presented in the paper, positive amplitudes are in black colour whereas negative ones are in red.

In the study area, seismic constant average interval velocities of the Miocene reflectors is 2790 m/s, and the average vertical resolution between two successive Miocene reflector horizons varies from 15 to 23 m. This resolution permits to identify the

Fig. 8 3D diagram representation of geologic cross section correlations of Miocene analogue Birsa sandstone sequence reservoirs and seal distribution in the Cap Bon (Gharsalli 2006, modified)



second- and third-order seismic stratigraphic sequence system tracts and boundaries, but in some areas, such as deformed and faulted zones, the quality of the seismic decreases.

Seismic and sequence stratigraphic analyses and interpretations are based on horizon reflection terminations and external pattern geometries and configurations which are indicative of depositional system tracts types, eustatic sea level changes and sedimentary environments according to the theoretical sequence deposit system tracts and boundaries as developed in Memoir 26 of the American Association of Petroleum Geology Bulletin (Vail et al. 1977; Mitchum et al. 1977; Sangree et al. 1977; Mitchum 1985; Haq et al. 1987, 1988) and sequence seismic stratigraphy concepts especially in silicoclastic environments (Vail et al. 1987; Van Wagoner et al. 1988 and Vail et al. 1991; Galloway 1989a, b; Gardner et al. 1996; Hardenbol et al. 1998; Homewood et al. 2002; Catuneanu 2002, 2003, 2006).

Depositional sedimentary environment maps of Miocene Birsa sandstone reservoirs are extracted and established from seismic sedimentologic attributes, on shore analogues and well data and seismic tectonic analyses.

As the studied Miocene deposits in this area are from shallow to deep marine silicoclastic environments varying from shelf continental margin to deep marine basin and constitute a reservoir targets, we have also used several shallow and deep marine

clastic sequence stratigraphy systems around the world, with known hydrocarbon reservoir characteristics (Chapin et al. 1994; Mahaffie et al. 1994; Gardner et al. 1996, Richards et al. 1998; Catuneanu 2002, Sharnugam 2003; Catuneanu 2006; Slatt et al. 2007; Shew et al. 2007; Weimer et al. 2007; Bouma et al. 2007).

Evolutionary sequence and seismic stratigraphy concepts and nomenclature have been applied for genetic sequence boundaries, system tracts and seismic configurations facies and geometry to match paleogeographic and deposit environment reconstructions.

Interest will be mostly focused on low stand and transgressive sandstone sequence horizons for the reservoir distribution target with detailed research of downlapping progradational and onlap/toplap features in delineating the high sand slopes of the basin that are not yet explored targets up to now.

Results

Birsa block tectonic structuring

Isochronous structural maps of top Lower Birsa and Upper Birsa horizons (Figs. 12 and 13) show that the Birsa concession presents a NE-SW anticline bounded by E-W and N-S

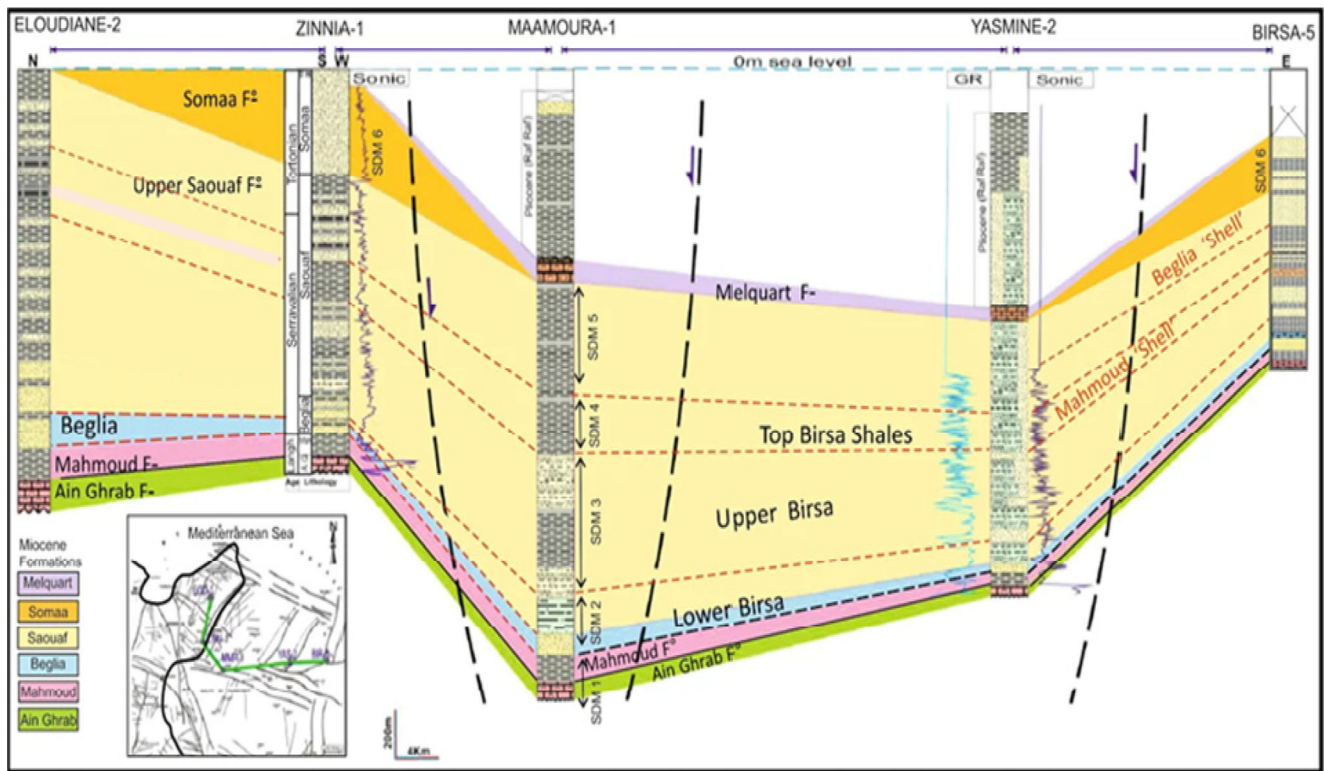


Fig. 9 E-W well correlations of updated Miocene lithostratigraphic formations and related Birsa sandstone sequence deposit distribution from Jebel Abderrahmane to the Gulf of Hammamet (Gharsalli 2006, modified)

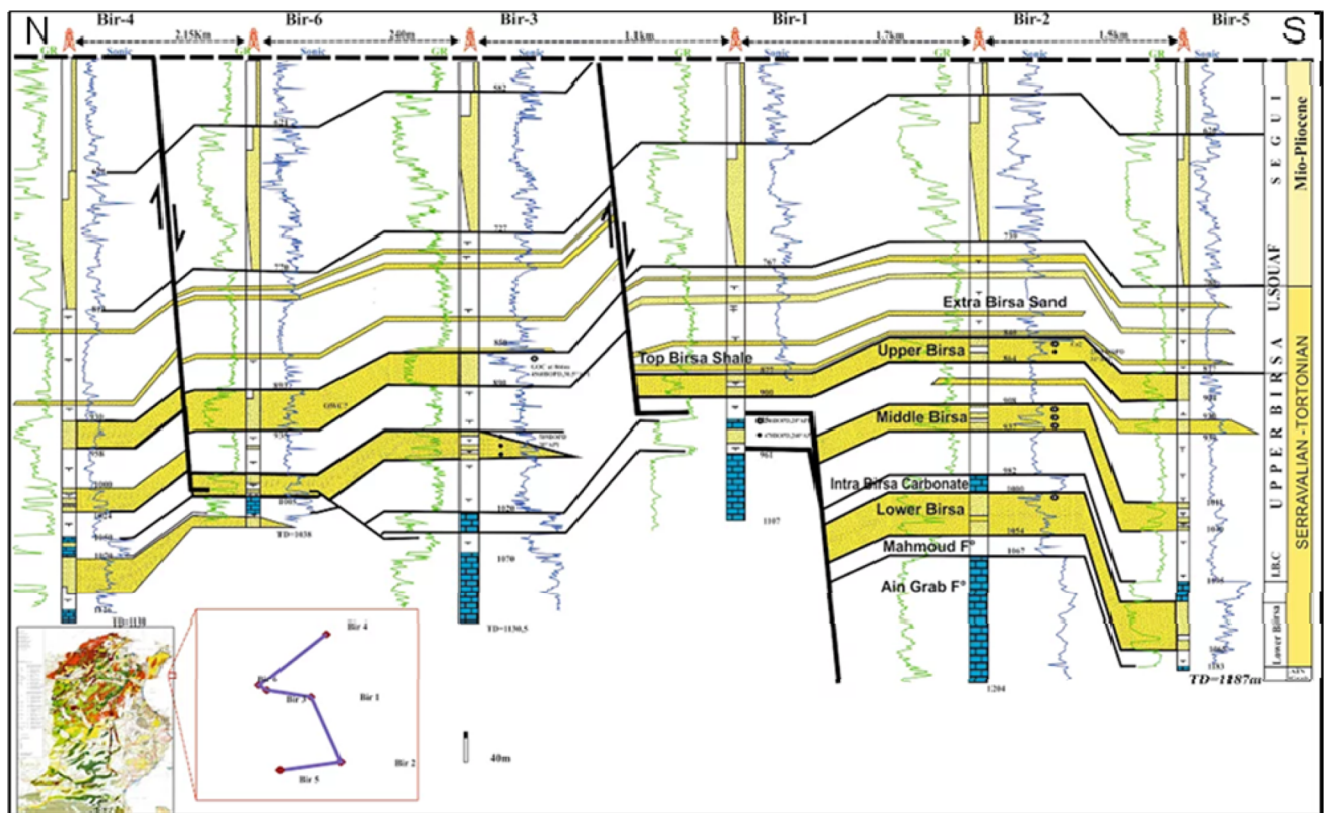
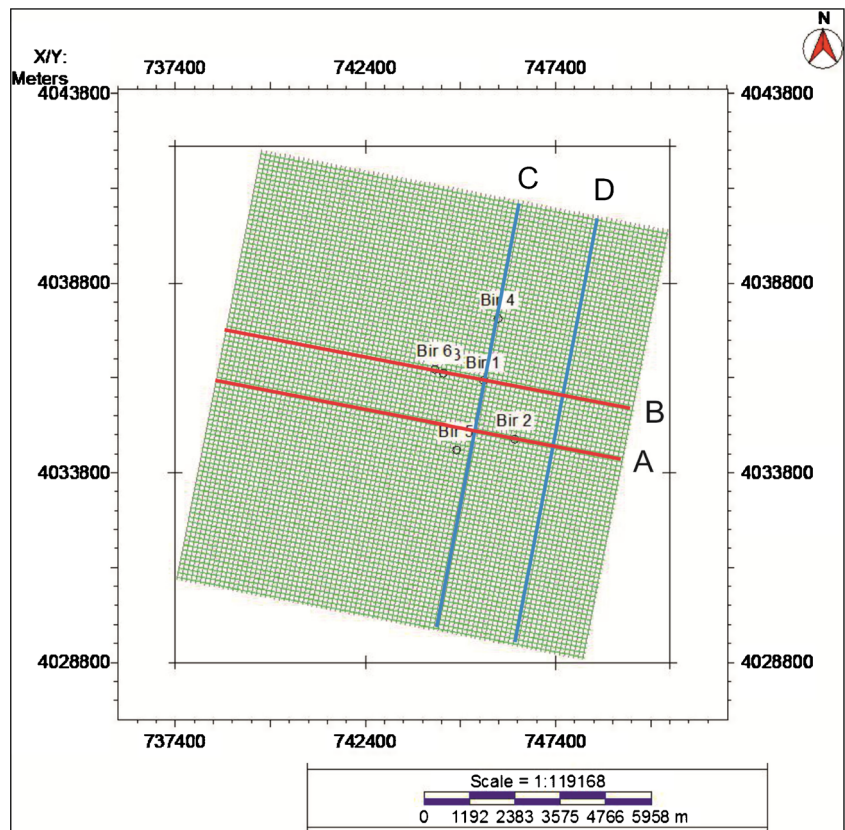


Fig. 10 North-South Miocene reservoir Birsa well correlations showing distribution of lower middle and upper Birsa sandstone reservoirs around Birsa 1A and Birsa 2 bis faulted central horst to northern and southern grabens and sandstone levels in the top Birsa shales (Shell Exploration 1988, modified)

Fig. 11 3D grid of seismic inlines, cross lines and well location map of Birsa block with selected and presented lines



faults. These faults have been reactivated in transpressive movements during the latest Tortonian and Quaternary NW-SE compressions.

The tectonic frame work is an Inherited Mesozoic deep-seated Master faults directed N-S, E-W and NE-SW. Middle to Upper Miocene Langhian-Serravallian distensive event had

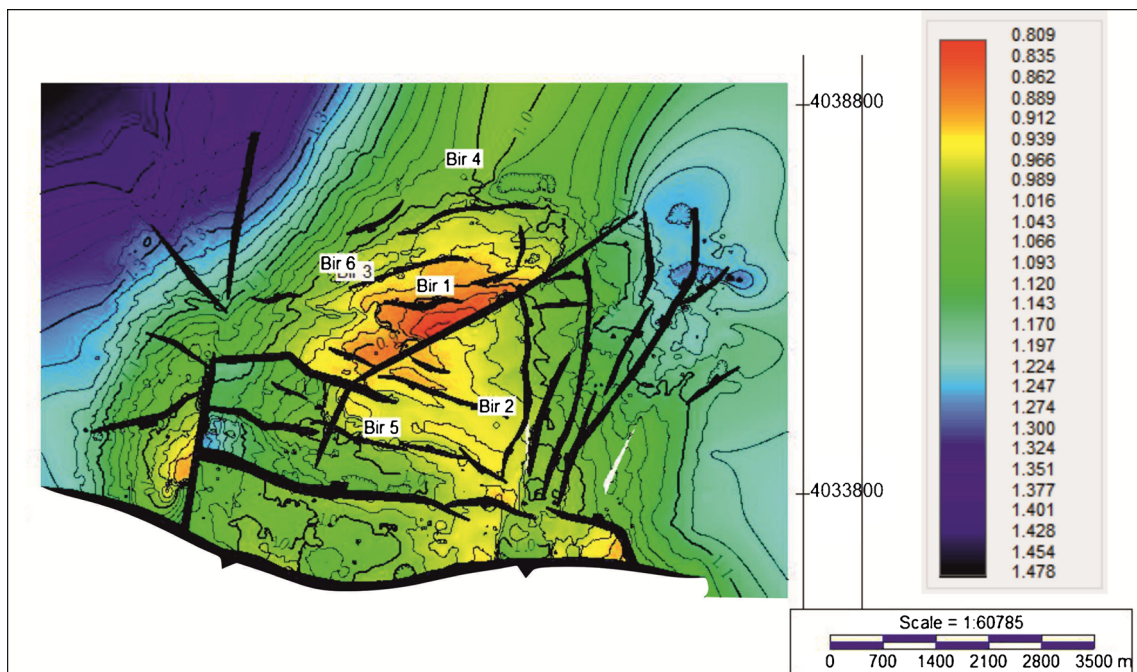


Fig. 12 Top Lower Birsa isochron time structure map (25 ms interval contours) showing faulted central horst anticline and surrounding eastern, western, southern and northern grabens

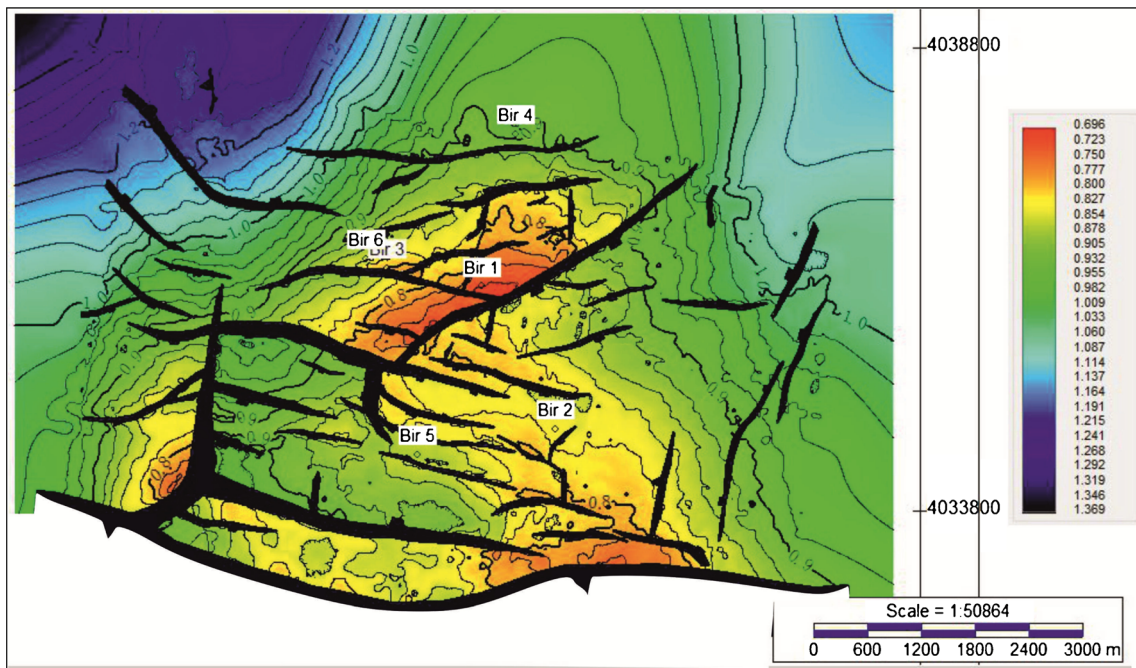


Fig. 13 Top Upper Birsa isochron time structure map (25 ms interval contours) showing faulted central horst anticline and surrounding eastern, western, southern and northern grabens

opened lateral eastern, western, northern and southern grabens synchronously to Mahmoud, Lower, Middle and Upper Birsa deposits sealed by top Birsa shales.

This structuring was also a strike slip rhomb basin where NE-SW horst of Birsa represented a P Riedel formed by transtensive E-W dextral master faults, whereas N-S master faults opened limitroph grabens to the East and to the West (Fig. 14).

All these tectonic basin structuring have been reactivated by Upper Miocene Tortonian Atlasic compressive regional

stress event resulting to a transpressive reactivations of the fault framework inducing the folding of the central Birsa horst in a right lateral drag fold and reverse fault movements (Fig. 15).

Syn-sedimentary tectonic structuring and geodynamic evolution of Middle to Upper Miocene Birsa reservoir sequences has guided the depositional systems around horsts and grabens by the subsidence and eustatic sea level controlling the accommodation (Gharsalli et al. 2013).

Fig. 14 Upper Miocene Birsa tectonic model showing compressive regional stress direction and transpressive ramified flower structure faults associated with drag folded central horst

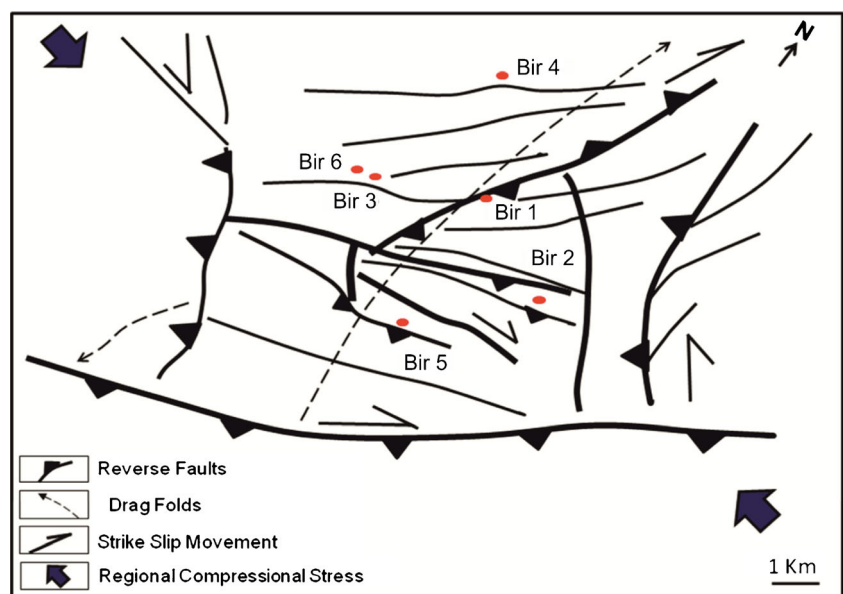
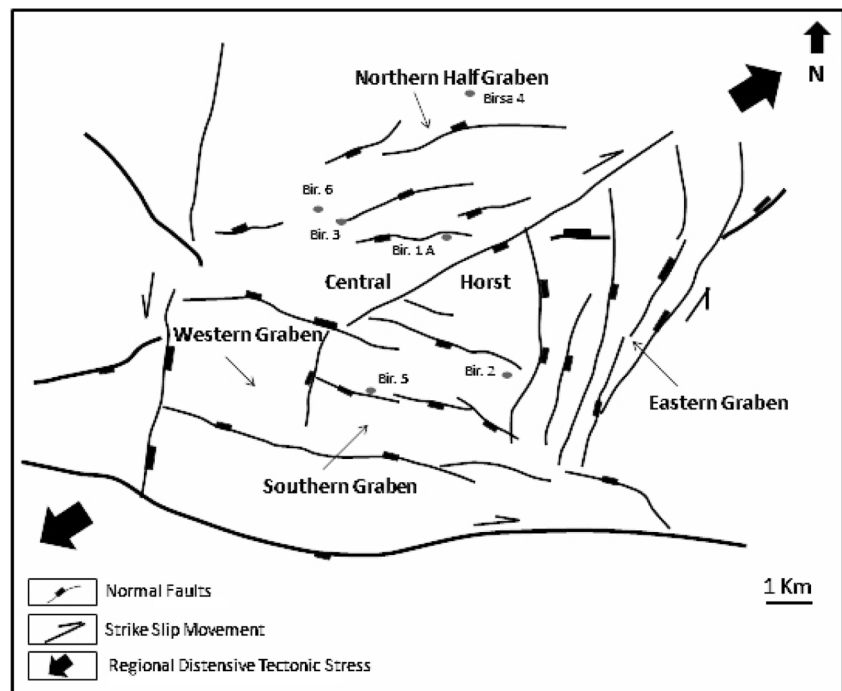


Fig. 15 Tectonic basin structuring of Birsa block during Middle Miocene Birsa reservoir deposition showing faulted central horst and surrounding graben sand regional extensional stress



Therefore, the seismic stratigraphic study and the depositional system tracts distribution will be intimately related to this tectonic structuring. Birsa well positions are drilled on high central Horst area and at the limit of its borders, so these sedimentary environment deposits are from shallow marine deltaic plain to prodelta. We expect that over the horst area and towards the graben subsiding zones, the environments should be more deepened.

This study interests the Middle and Upper Miocene deposits especially the Langhian Ain Grab and Mahmoud Formations and Serravallian-Tortonian Béglia and Saouaf Formations (Burolet 1956), with a focus on offshore Birsa equivalent (Béglia and Saouaf Formations) reservoir sandstones on the basis of combination of several analysis tools, namely sedimentology, facies analysis, sequence stratigraphy, seismic reflection stratigraphy and wire line logging. The application of these tools allowed us to identify the third-order depositional and seismic sedimentologic sequences, with their associated system tracts and parasequences and specify the depositional environments from facies characteristics and correlate the major stratigraphic surfaces and the tectonic events with platform to basin reservoir distribution.

Regional and clear seismic markers horizons picked are the Top Upper Middle Miocene Ain Ghrab horizon (TAG), the Base and Top Lower Birsa Serravallian sandstone horizons (BLB and TLB), the Intra-Birsa Serravallian intra-Carbonate (IBS), the Base and Top of Middle Birsa sandstone horizons (BMB and TMB) and the Base and the Top of Upper Birsa sandstone horizons (BUB and TUB).

Basin tectonic structuring and seismic sequence stratigraphy

Southern block of Birsa 2–Birsa 5 well E-W seismic cross line A

Basin configuration

Middle to Upper Miocene seismic horizons of this cross line have been calibrated by Birsa 2 well and by the other inline intersections. Seismic interpretation and precise seismic stratigraphy analysis of Middle to Upper Miocene horizons from top A in Ghrab to top Birsa shale horizons highlight the basin structuring of Birsa concession along this direction (Fig. 16). The Birsa 2 well is located on a horst structure with reduced Miocene and Birsa sandstone reservoir sequences in comparison to the eastern and western graben structures where these sequences are more developed (Fig. 16).

Middle Miocene Langhian to Upper Miocene Serravallian period that correspond to the Ain Ghrab, Mahmoud and Birsa Formation deposits has experienced distensive tectonic regime which created a central horst structure bounded by two eastern and western grabens. The horst and graben structures had been induced and limited by the strike slip flower faults directed N-S along this seismic section (Fig. 16).

This syn-sedimentary structuring had distributed the sequence deposits of the Lower, Middle and Upper Birsa sandstone reservoir sand shale seals around a high horst depositional environment and a subsiding graben depositional environment. Furthermore, during Upper Miocene Tortonian

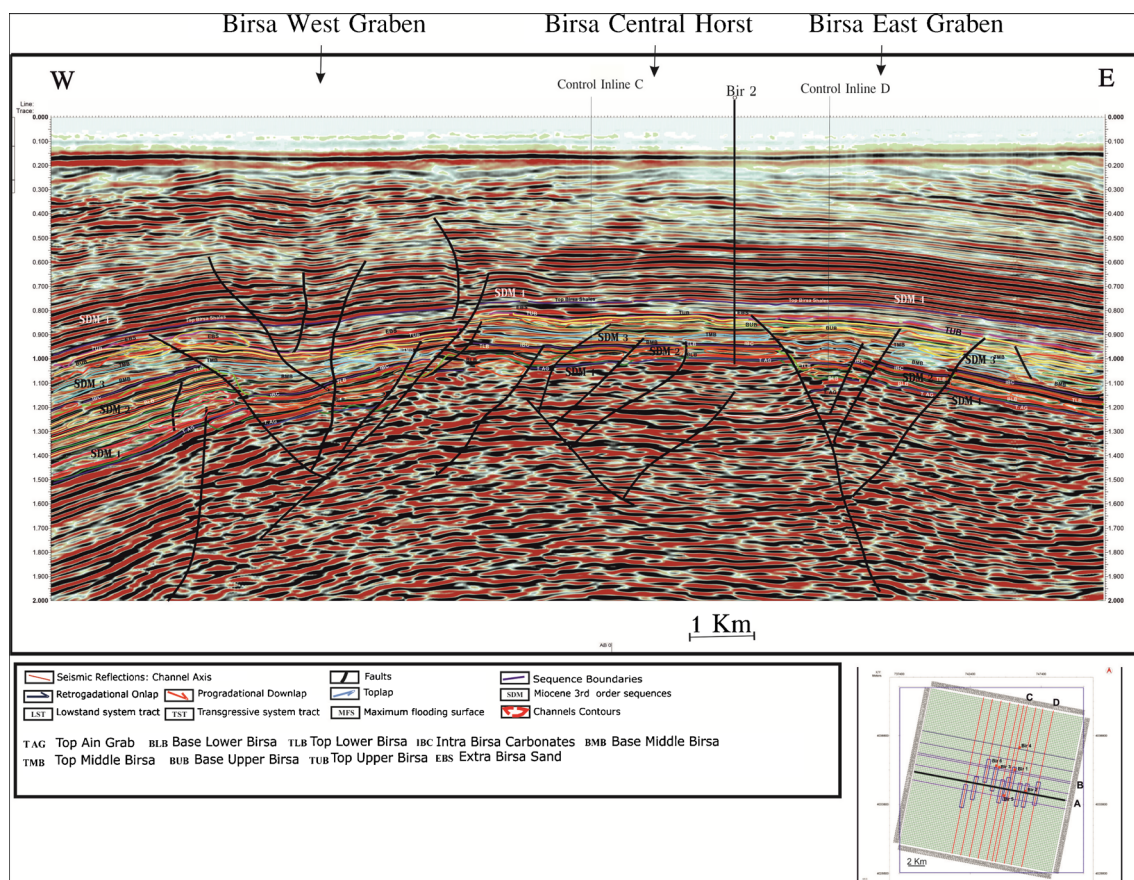


Fig. 16 3D Seismic structural and stratigraphic E-W cross line A

period and Quaternary one, all this structuring had been compressed and folded by transpressive fault movements and drag folds. For Birsa reservoir faulting point of view, the central horst prospect structure of Birsa 2 well is affected by normal faults at the level of Lower and Middle Birsa horizons but with low throw (Fig. 16) and does not play a role of seal faults, whereas the Upper Birsa horizons are not affected by these faults and are sealing this fault system.

Isochron time structure maps of top Lower Birsa and top Upper Birsa horizons (Fig. 17) show the faults framework that affects these horizons and enables to follow the basin configuration of the Birsa Block with the seismic stratigraphic results and to establish the reservoir depositional fairway maps.

Seismic horizon configurations and depositional environment distribution

Seismic stratigraphy analysis of Miocene horizons had concerned essentially the Lower, Middle and Upper Birsa sandstone reservoirs. This entire Birsa reservoir section is organized in two main third-order seismic sequences: SDM 2 for Lower Birsa and SDM 3 for Middle and Upper Birsa (Figs. 16 and 18).

These sequences present basal toplap unconformities with the underlying sequences respectively with the top sequence of SDM 1 (Mahmoud Shales Formation) and the top of sequence SDM 2 of Lower Birsa intra-carbonate shales. Base lap terminations of the SDM 2 and SDM 3 basal system tract horizons exhibit downlap or onlap seismic reflection terminations (Fig. 18).

Each sequence of Lower, Middle and Upper Birsa horizon reservoirs starts at the base by downlap or onlap horizons of lowstand system tracts and terminate a titstop by a toplap transgressive and maximum flooding condensate section surface overlain by highstand system tract of shales (Fig. 18). This organization is well conformable to the regional onshore and offshore sequence deposits of Miocene. Lowstand system tracts correspond respectively to the Lower and Middle Birsa sandstones whereas Upper Birsa sandstones represent a transgressive system tract of sequence SDM 3.

These lowstand prograding and transgressive retrograding sandstones represent the main hydrocarbon reservoirs of the Birsa concession as well as the other gulf of hammamet oil and gas miocene fields (Figs. 1 and 3).

Transgressive and MFS surfaces are marked by gradational and retrogradational onlap and toplap horizon sand correspond to the top surface of the LST sandstones marked in

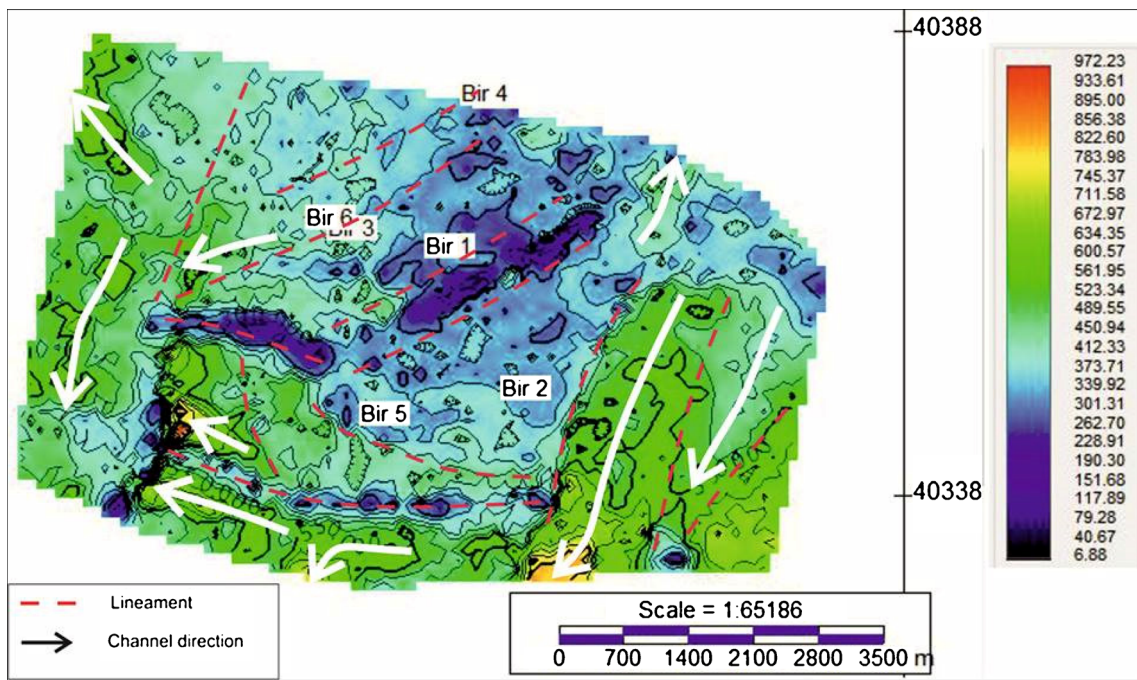


Fig. 17 Top Base Lower Birsa-Top Lower Birsa (Lower Birsa) isopach time map (25 ms interval contours) showing thickening channel directions from high Birsa horst to the surrounding shelf slope grabens as well as along grabens

outcrops as in the well cutting by a rich ferruginous bioturbated surface that indicate a hard ground and as top of sedimentation related to the maximum sea level flooding of the

platform, whereas high stand system tracts (HST) correspond to the shale deposits that overlie the transgressive and MFS surfaces on the tops of the LST sandstone reservoirs (Fig. 18).

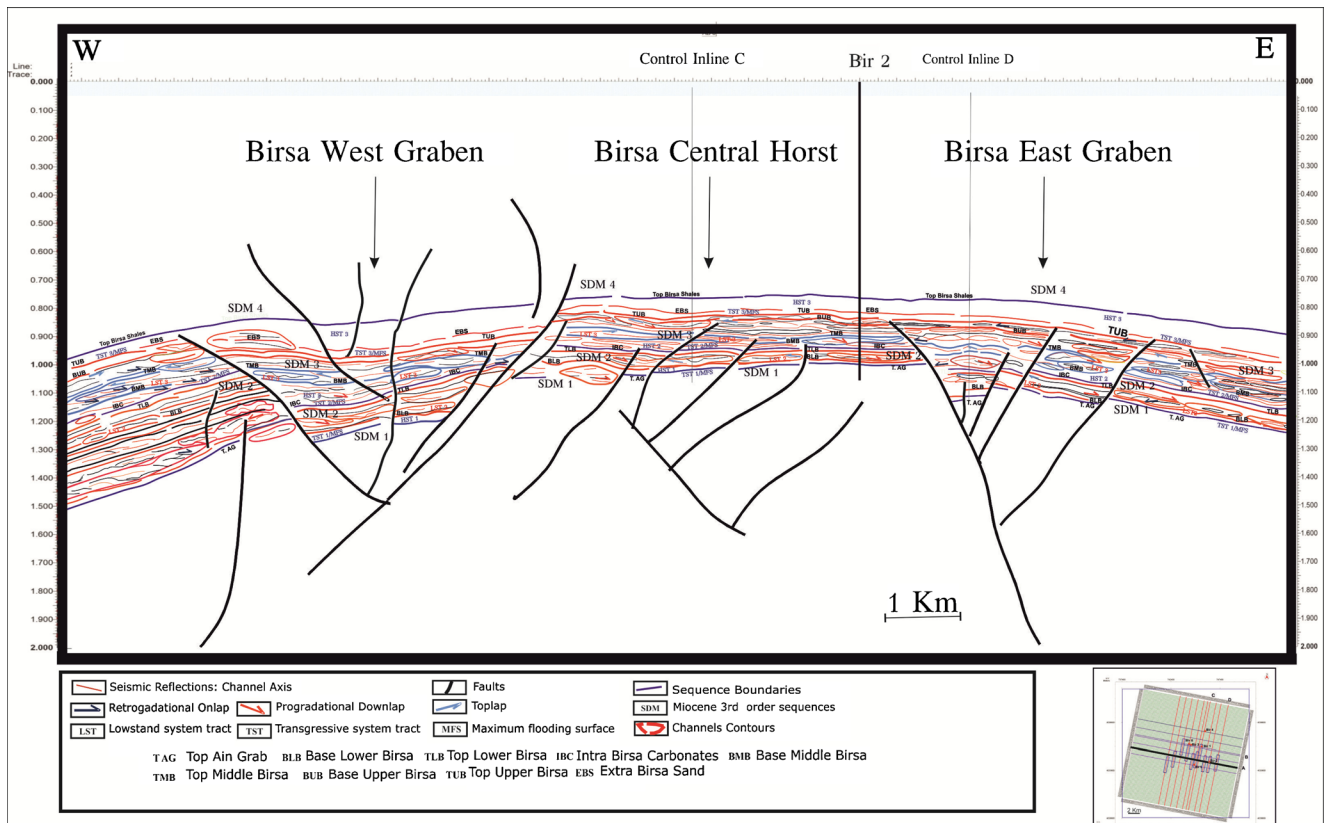


Fig. 18 Seismic structural and seismic stratigraphic section of E-W cross line A

As a conclusion, the downlap LST system tracts and the onlap TST system tracts of sandstones are the main sandstone reservoirs of Birsa Formation and the HST are their shale seals.

Lower Birsa configurations and depositional environment distribution

Lower Birsa sequence corresponding to SDM 2 is well bounded at the base and to the top by unconformity surfaces (Fig. 18). The base and top reflectors are area in red negative phase. The basal reflection presents good to fair continuity with high to low amplitude; it lies unconformable on the Mahmoud Formation shale top horizons according to a top lap erosive surface (Figs. 16 and 18). This figure is well recognized in the Jebel Abderrahmane analogue section of Miocene.

Top Lower Birsa horizon presents high amplitude and good continuity also to the eastern and western graben basins (Fig. 18). External horizon configuration is marked by a lateral extended lenticular channelization presenting an average width varying from 100 m to 1 km or more (see horizontal seismic line scale). Each major channel is composed by a smaller distributary channel sand levees (Figs. 16 and 18).

On the central Birsa well 2 horst, Lower Birsa sequence is thinner than the eastern and western grabens. This thickness change is accompanied by a change of configurations (Figs. 16 and 18). This is attested by internal configurations inside the channels that are marked by parallel, sigmoid and shingled horizons on the horst structure whereas shingled, sheets and probably mounded lobes of turbidites appear laterally in the eastern and western grabens (Figs. 16 and 18).

These seismic reflection attributes and pattern configurations calibrated to the outcrops analogues and well cuttings data indicate a silicoclastic sedimentary environments of deposits marked by middle to high hydrodynamic energy extending from fluvial deltaic plain shoreface on the high horst blocks (distributaries concave up channels sand levees, parallel and shingled features of upper slope fan) to deeper shelf of delta front and prodelta slope zones with possibility to reach a deep basin floor turbidities domain in the centre of subsiding grabens (convex up channels, sheets and mounded lobes of mid to lower slope).

The LST downlap direction along this E-W cross line indicates progradations from the central horst platform to eastern and western subsiding graben basins. Also, other perpendicular N-S directions exist and will be highlighted by the inline seismic sections. Lower Birsa time isopach map (Fig. 17) confirms the central horst structure thinning directed NE-SW during Lower Serravallian with reduced deposits in comparison to the bounding graben structures to the East, to the West and to the South where Lower Birsa, horizon packages show more thickness deposits with sandstone channels

thickening directions (Fig. 17). Extending from the central horst to the shelf slope borders of subsiding grabens and also along inside grabens.

Middle Birsa configurations and depositional environment distribution

Middle Birsa sandstone sand shale horizons correspond to SDM 3. They are well delineated at the base and the top by a toplap and downlap configurations (Figs. 16 and 18). They exhibit continuous reflections of positive black phases with high to Middle amplitude on the central horst structure (Fig. 17). These continuity and amplitude of reflection change laterally to the eastern and western subsiding grabens due to the changes of deposit sediments of shaly and sandy enrichments between high deltaic platform and basin slopes (Figs. 16 and 18).

External horizon configuration in the central horst is marked by parallel patterns enveloped by a concave up and convex up channel structures. This channelization becomes very frequent and multistory to the subsiding slopes of the eastern and western grabens (Figs. 16 and 18).

The channels have a width of hundreds of metres reaching a kilometre or more (see horizontal Seismic line scale). Each major channels composed by a story smaller channels and levees (Figs. 16 and 18).

On the central Birsa well 2 horst Middle Birsa sequence is thinner than the eastern and western grabens. This thickness change is accompanied by a change of external and internal configurations (Figs. 16 and 18).

Internal configurations inside the channels are marked by mainly parallel, sigmoid and shingled horizons on the horst structure where as shingled, sheet sand mounded lobes appears strongly developed laterally in the eastern and western graben slopes (Figs. 16 and 18).

Seismic reflection attributes configurations calibrated to the outcrop analogues, and well cutting data indicate a deposit marked by middle to high hydrodynamic energy extending from shelf deltaic area to delta front deposits on the high horst blocks (distributaries channels and levees, parallel and shingled features) to deeper prodeltaic slope zones and a deep basin floor turbidite domain in the centre of subsiding grabens (convex up channels, sheets sand lobes).

In the Jebel Abderrahmane outcrop analogue, ball structures, debris flow sand turbidite sedimentary structures of slope fan domain had been documented (Bédir et al., 1993, 1996) in the Lower Saouaf sandstones equivalent to offshore Middle Birsa sandstones. Thus, the sedimentary environment deposit of Middle Birsa sequence which corresponds to the Lower Saouaf delta front and prodelta formation in onshore analogue deposits is deeper Marine deposits than Lower Birsa sediments and extends from the high Birsa central horst delta

front to prodelta higher and lower slope to the eastern and western grabens.

The LST downlap direction along this E-W cross line indicates progradations from the central horst platform to eastern and western subsiding graben basins. Horst and graben channel structures present E-W longitudinal axis, so channel axis should be in N-S direction.

This seismic stratigraphy reconstruction of Middle Birsa sandstones and shales is matching to the isopach time map of these system tracts (Fig. 19) which highlights thickening channel progradational directions from the high central horst to the western, eastern and southern graben borders and also along inside these grabens.

Upper Birsa configurations and depositional environment distribution

Upper Birsa sandstone horizons are unconformably lying and sealing the Middle Birsa ones. They are less affected by the Lower and Middle Birsa fault system and are in general sealing this latter (Figs. 16 and 18).

These horizons correspond to the end system tract of SDM 3 as transgressive deposits as marked by onlap configurations from the eastern and western flanks of the Birsa central horst (Figs. 16 and 18). These horizons are well delineated at the base and the top by a toplap and onlap terminations.

The top reflection of Upper Birsa is a negative red phase in contrast with the overlain shales; it exhibits continuous reflection with high amplitude on the central horst structure (Figs. 16 and 18). The basal reflection is represented by

positive black phase with good to fair continuity and high to medium variable amplitude.

The Upper Birsa horizon package is thinner than Middle Birsa one. These horizons present some difficult picking in the areas of syn-sedimentary faults and of facies changes. External horizon configuration in the central horst is marked by a concave up and convex up channel structures of hundred metres width. This channelization is extending laterally to the subsiding slopes of the eastern and western grabens (Figs. 16 and 18) but with low rate of subsidence due to the stopping of graben opening and the end of the distensive regime during this period.

These channels are less thicker and longer than those of Middle Birsa as they constitute transgressive deposits related to a sea level rise around the central horst platform.

Internal configurations inside the channels are marked by mainly parallel and sigmoid horizons on the horst structure whereas convex up channels, sheets and mounded lobes appear well developed laterally towards the eastern and western grabens slopes (Figs. 16 and 18).

These seismic reflection attributes pattern configurations calibrated to the outcrops analogues indicate a silicoclastic sedimentary environments marked by low to middle hydrodynamic energy extending from deltaic estuarian shore face to shelf prodeltaic deposits on the high horst blocks (distributaries channels and levees, parallel and sigmoid features) to deeper delta front and prodelta slope zones in the centre of subsiding grabens (convex up channels, sheets and lobes).

After these seismic characteristics, sedimentary environment of Upper Birsa sequence, which corresponds to the middle Saouaf prodelta and delta front formation in onshore

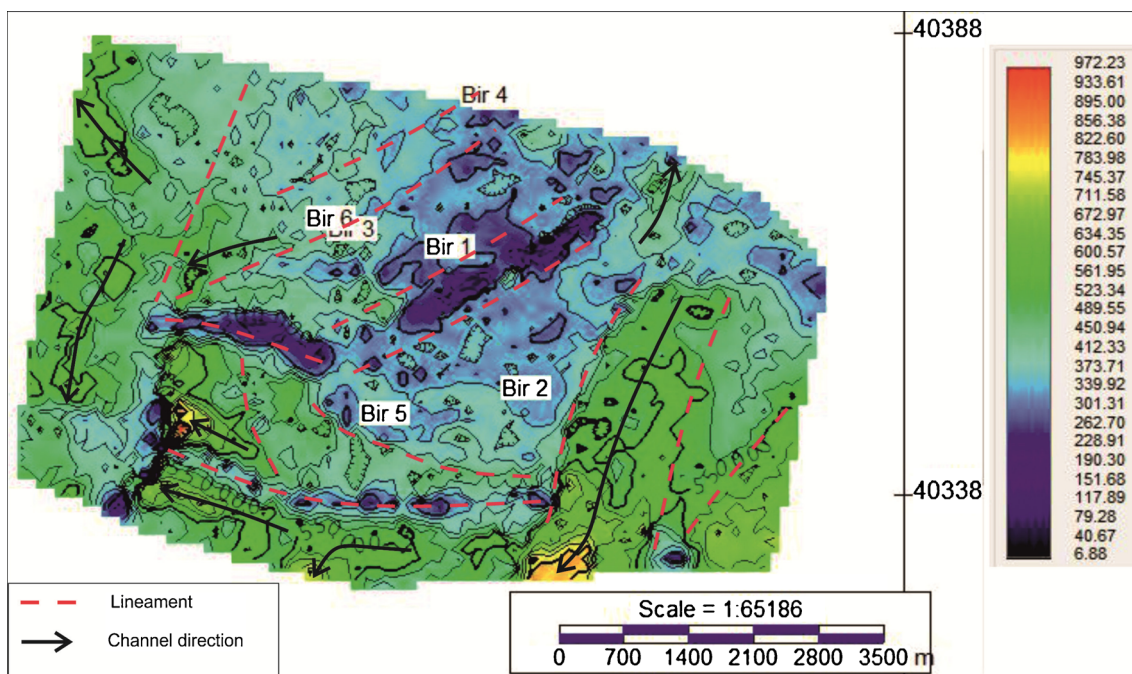


Fig. 19 Top Lower Birsa-Base Upper Birsa (Middle Birsa) isopach time map (25 ms interval contours) showing thickening channel directions from high Birsa horst to the surrounding shelf slope grabens as well as along grabens

analogue deposits, has more transgressive marine deposits than Middle Birsa sediments and extends from the high Birsa central horst deltaic shelf to prodelta slope to the eastern and western less subsiding grabens.

Some downlap configurations are detected on the central Birsa horst and to the western graben, indicating a west-to-east direction along this E-W cross line (Figs. 16 and 18). Horst and graben channel structures present E-W width axis.

Upper Birsa isopach time map shows thickening of deposit horizons along prograding channel directions (Fig. 20, dark arrows) from the central high horst to surrounding western and eastern borders and along the insides of eastern and western grabens controlled by syn-sedimentary faults as it was deduced by seismic stratigraphy attributes.

Northern block of Birsa 2-Birsa 1A wells

E-W seismic cross line B

Basin configuration

Cross line B crosses the northern part of the eastern Birsa graben to the east and the Birsa 2 and Birsa 1A central horst. The eastern Birsa graben continues from South to North along the N-S faults. Whereas to the west of the line, we observed a gentle fold flank deepening to the west and ending by a graben limited by N-S faults. This line is calibrated by Birsa 1A and Birsa 6 wells. Along this line, we recognize the northern

continuity of the central Birsa horst which is cut and collapsed to the south west by the NE-SW subvertical strike slip master fault (Fig. 21).

The eastern and western grabens are bordered by the same N-S faults detected on the southern part cross lines A and B that are well documented on the structure time maps of top lower and top Upper Birsa (Figs. 12 and 13). Normal faults affect the Lower and Middle Birsa reflectors on the central horst structure and in the eastern and western grabens where they are asyn-sedimentary faults. These faults are mainly sealed by top Upper Birsa horizons as well as on the central horst as in the grabens structures (Fig. 21).

As documented on the southern cross line A, Lower to Middle Birsa horizons exhibit thickness and seismic facies changes between the central horst platform and the bordering graben due to the syn-sedimentary opening of the latter and the play of normal faults (Fig. 21).

This tectonic control has important impact on the paleogeographic distribution and geometries on the sequence deposit system tracts of Birsa sandstone reservoirs.

Seismic horizon configurations and depositional environment distribution

Seismic stratigraphy analysis of Miocene horizons undertaken along this line shows similar sequence organization than the southern seismic line A. The entire Birsa reservoir section is organized in two main third-order seismic sequences: SDM 2 for Lower Birsa and SDM 3 for Middle and Upper Birsa

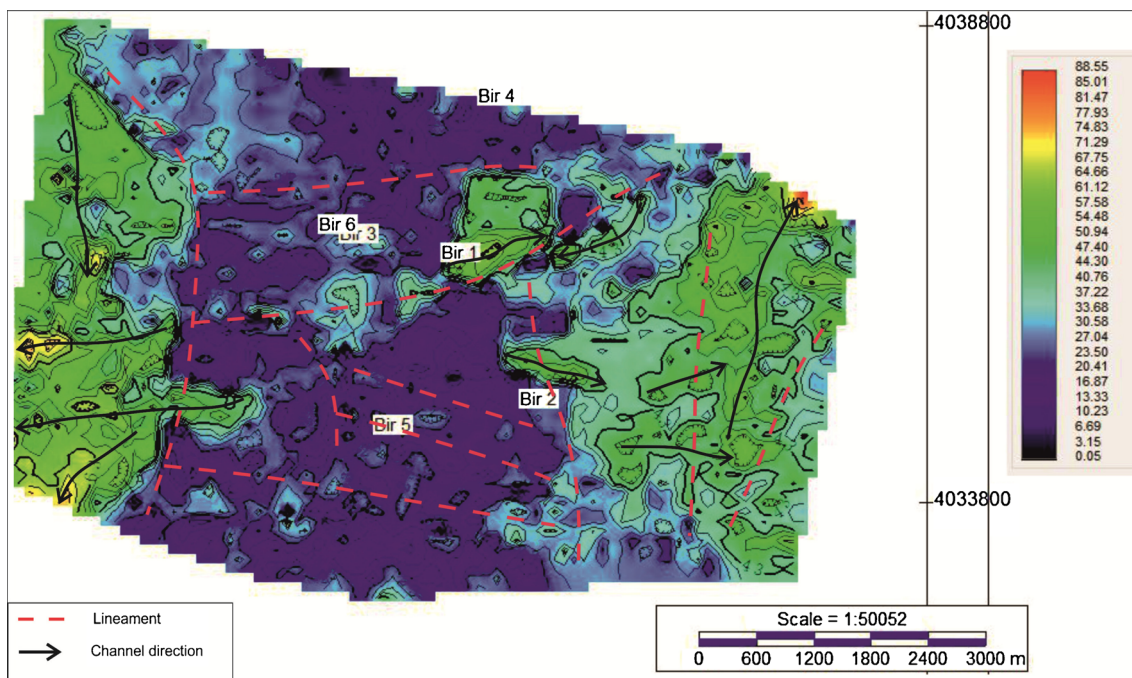


Fig. 20 Top Middle Birsa-Top Upper Birsa (Upper Birsa) isopach time map (25 ms interval contours) showing thickening channel directions from high Birsa horst to the surrounding shelf slope grabens as well as along grabens

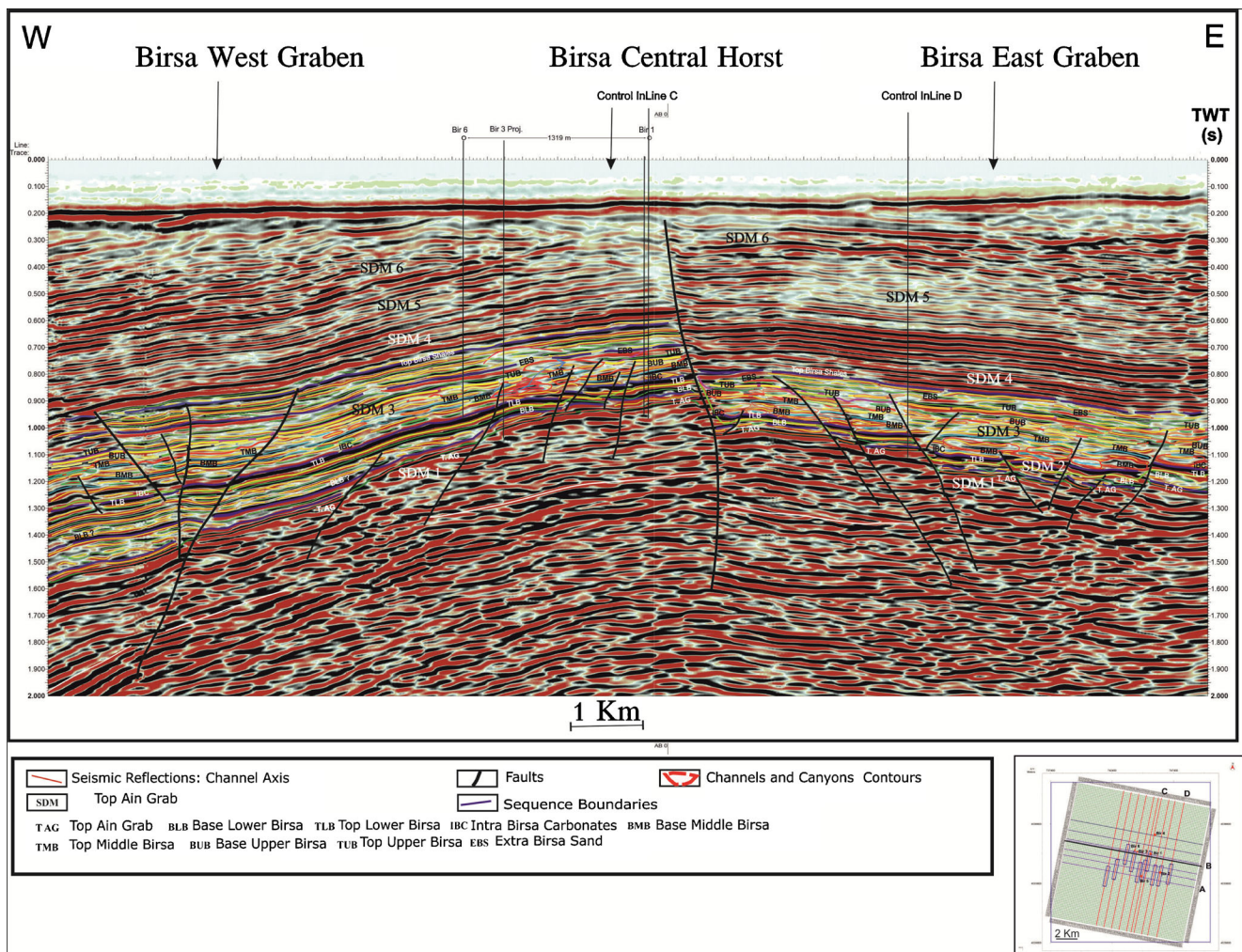


Fig. 21 3D Seismic structural and stratigraphic E-W cross line B

(Figs. 21 and 22). These sequences present basal toplap unconformities with the underlying sequences respectively with the top sequence of SDM 1 (Mahmoud Shales Formation) and the top of sequence SDM 2 of Lower Birsa intra-carbonate shales. Base lap terminations of the SDM 2 and SDM 3 basal system tract horizons exhibit downlap or onlap seismic reflection terminations (Figs. 21 and 22).

Each sequence of Lower, Middle and Upper Birsa horizon reservoirs starts at the base by downlap or onlap horizons of lowstand system tract sand and terminates at its top by a toplap transgressive and maximum flooding condensate section surface overlain by highstand system tract of shales (Figs. 21 and 22). Lowstand system tracts correspond respectively to the Lower and Middle Birsa sandstones, whereas Upper Birsa sandstones represent a transgressive system tract of sequence SDM 3.

Transgressive and MFS surface are marked by gradational and retrogradational onlap and toplap horizons and correspond to the top surface of the LST sandstones marked in outcrops as in the well cutting by a rich ferruginous

bioturbated surface that indicates a hard ground and as top of sedimentation related to the maximum sea level flooding of the platform, whereas highstand system tracts (HST) correspond to the shale deposits that overlain the transgressive and MFS surfaces on the tops of the LST sandstone reservoirs (Figs. 21 and 22).

Lower Birsa configurations and depositional environment distribution

Lower Birsa sequence corresponding to SDM 2 is limited at the base and to the top by unconformity surfaces (Figs. 21 and 22). Base and top reflectors are a red negative phase, and the basal reflection presents good to fair continuity with high to low amplitude. It lies unconformably on the Mahmoud Formation shale top horizons according a toplap erosive surface (Figs. 21 and 22). Top Lower Birsa horizon presents high amplitude and good continuity also to the eastern and western graben basin ward (Fig. 21). On the central Birsa well 2 horst, Lower Birsa sequences are thinner than the eastern and

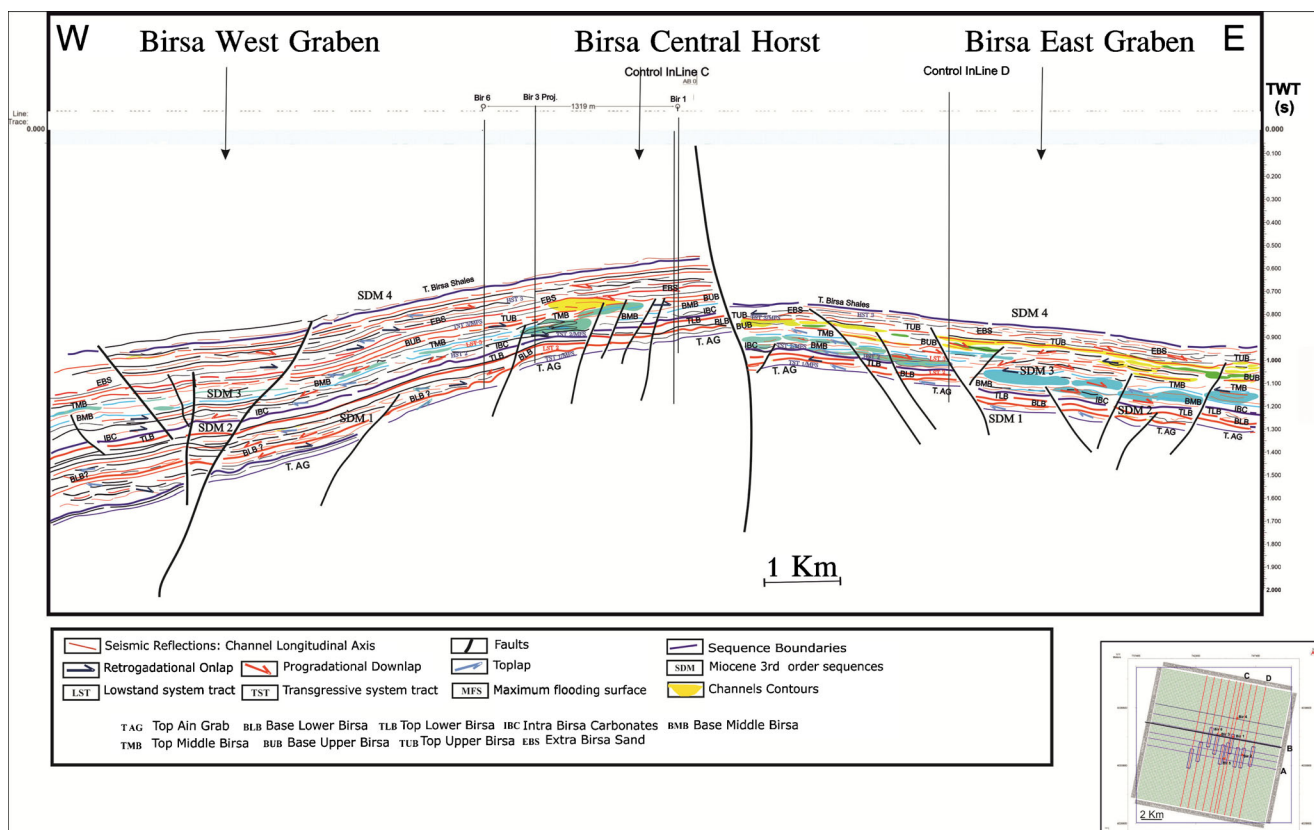


Fig. 22 3D Seismic structural and seismic stratigraphic section of E-W cross line B

western grabens and present parallel configurations (Figs. 21 and 22). To the eastern collapsed horst and graben, Lower Birsa horizon package becomes thicker and shows concave up and some convex up channel's configurations (Figs. 21 and 22).

External horizon configuration in the central Birsa well 1A is marked by parallel patterns that evolved quickly to a concave up and convex up channel, sigmoid and lobate structures to the slope of the western graben by successive syndimentary normal faults (Figs. 19, 21 and 22).

Internal configurations inside of the channels are marked mainly by parallel and sigmoid convex up geometries. The width of the channel extends from 100 m for the smaller ones to more than 1 km for the greater ones. Towards the collapsed eastern Birsa 2 well central horst block and eastern subsiding graben slope, the channel structures become more frequent and intensive with multistory patterns (Figs. 19, 21 and 22). These channels have lateral extension of hundreds of metres reaching a kilometre or more (see horizontal seismic line scale). Each major channel is composed by a story smaller channels and levees.

The general seismic facies becomes more transparent probably due to the lower slope fan position characterized by more shaly deposits (Figs. 21 and 22). Seismic reflection attributes pattern configurations calibrated to the outcrop analogues and well data indicate a silicoclastic sedimentary environments of

deposits marked by middle to high hydrodynamic energy extending from delta front deposits on the high horst blocks (distributaries channels and levees, parallel and sigmoid features) to deeper prodeltaic slope zones and a deep basin floor turbidite domain in the centre of subsiding grabens (convex up channels, sheets and lobes).

Thus, the sedimentary environment deposit of Middle Birsa sequence which corresponds to the Lower Saouaf prodelta and delta front formation in onshore analogue deposits is deeper in marine deposits towards the northern part of eastern Birsa graben than the western graben northern one zone. It shows extending from the high Birsa central horst delta front to prodelta higher and lower slope to the eastern and western grabens.

The LST downlap direction along this E-W cross line indicates progradations from the central horst platform to eastern and western subsiding grabens basins. Horst and graben channel structures present E-W width axis, and their length seems to be in a perpendicular N-S direction.

Upper Birsa configurations and depositional environment distribution

Upper Birsa sandstone horizons are unconformably lying and sealing the Middle Birsa ones by a toplap and onlap terminations. Apart a major horst and graben faults that bound the

Birsa concession structures and affect the Upper Birsa horizons, syn-sedimentary Lower and Middle Birsa faults are more less affected by Upper Birsa and sealed by its top horizons (Figs. 21 and 22).

These horizons correspond to the end system tract of SDM 3 as transgressive deposits are marked by onlap configurations from the eastern and western flanks of the Birsa 1A and Birsa 2 central horst (Figs. 21 and 22). These horizons are well delineated at the base and the top by toplap and onlap terminations.

Seismic attributes of top Birsa reflector present good continuity and high amplitude, whereas the basal one is less continued with high to low amplitude. Inside the Upper Birsa package, which is thicker to the eastern Birsa graben, reflection attributes are variables inside the channel's structures where continuity and amplitude variations reflect a variability in the sedimentary facies deposits (Figs. 20, 21 and 22).

External horizon configuration in the central horst is marked by a concave up and convex up channel structures of hundred metres width. This channelization is extending laterally to the subsiding slope of the eastern graben whereas to the western slope flank, Upper Birsa horizons are thinner than the eastern graben and do not present the intensive and frequent channelization as the eastern graben (Figs. 20, 21 and 22). On the central Birsa well 1A horst, Upper Birsa sequence is thin and becomes thicker to the collapsed Birsa 2 well horst.

Internal configurations inside the channels are marked by mainly parallel horizons on the central Birsa horst, whereas concave up and convex up channels, sheets and mounded lobes appear developed laterally towards the eastern grabens slope (Figs. 21 and 22).

These seismic reflection attributes pattern configurations calibrated to the outcrops analogues and well data indicate a silicoclastic sedimentary environments of deposits marked by low to high hydrodynamic energy extending from deltaic shore face deposits on the high horst blocks (distributaries channels and levees, parallel and sigmoid features) to deeper prodeltaic and delta front slope zones of the centre of eastern subsiding graben (convex up channels, sheets and lobes).

After these seismic characteristics of sedimentary environment deposits, Upper Birsa sequence is more marine transgressive than Middle Birsa sediments and extend from the high Birsa deltaic central horst to shelf delta front and prodelta slope to the eastern and western less subsiding grabens in comparison to the Lower Middle Birsa deposit sequences.

Downlap configurations detected to the eastern and western grabens suggest a progradation direction from the high central horst to the east and west (Figs. 20, 21 and 22). Also, some contrary downlap directions are documented on the eastern flank graben from east to east related to channel's deposition.

Northern block of Birsa 1A well and southern block of Birsa 2 well

N-S seismic inline C

Basin configuration

After the analyses and interpretations of E-W seismic lines, it is important to follow the basin configuration and seismic reflection patterns according N-S perpendicular position to match the previous interpretations. Logically, all the seismic sequence subdivisions and internal and external reflection patterns are the same in the N-S lines that strike E-W sections, but they are crossed from different angles. Nevertheless, some changes of lateral evolution and distributions along N-S direction will present new results for mapping and constructing the system tract distribution around the study area. Two seismic lines located from western to eastern parts of the Birsa structures will be presented across Birsa central horst and the eastern graben.

Seismic in line C crosses the Birsa concession structures along the N-S direction. It is calibrated by Birsa 1A and Birsa 4 wells and the other interpreted cross lines. This section shows the Birsa 1A well central horst high and the collapsed Birsa 2 well central horst to the southern line (Fig. 23).

To the southern part of this line appears a graben structure opened mainly during post-Ain Ghrab and Middle Birsa horizon deposits (Fig. 23). The central horst and the southern graben structures that affect the Miocene seismic horizons from Ain Ghrab to the Upper Birsa ones are limited by deep seated normal faults in flower strike slip structures.

The central horst Birsa 1A fault is oriented NE-SW as encountered on cross lines A and B and mapped at the top Lower and top Upper Birsa horizons (Figs. 12 and 13). The southern graben faults are oriented E-W to WSW-ESE, and the southern one presents the Southern border of the Birsa concession as mapped at the level of top Lower and Upper Birsa horizons.

To the northern part of the seismic section, the central Birsa horst flank evolves to tilted blocks of half grabens and grabens (Fig. 23). These faults are oriented ENE-WSW as mapped at the level of top Ain Ghrab and top Lower and Birsa horizons.

All these Middle to Upper Miocene (Langhian to Middle Serravallian) structures of horst and grabens have been reactivated by compressional events of Tortonian and Quaternary that has folded these structures and removed the flower structure faults in transpressive movements. This inline section highlights the basin structuring of the Birsa concession structures along the N-S direction. It confirms the central high horst and the northern tilted flank in half graben and graben structuring of the Lower, Middle and Upper Birsa sandstone reservoirs (Fig. 23).

In addition, it revealed a southern half graben and graben structure to the south of the central collapsed horst of Birsa 2–Birsa 5 wells (Fig. 23). The majority of faults affect the Ain Ghrab, Lower and Middle Birsa reservoirs and Upper Birsa

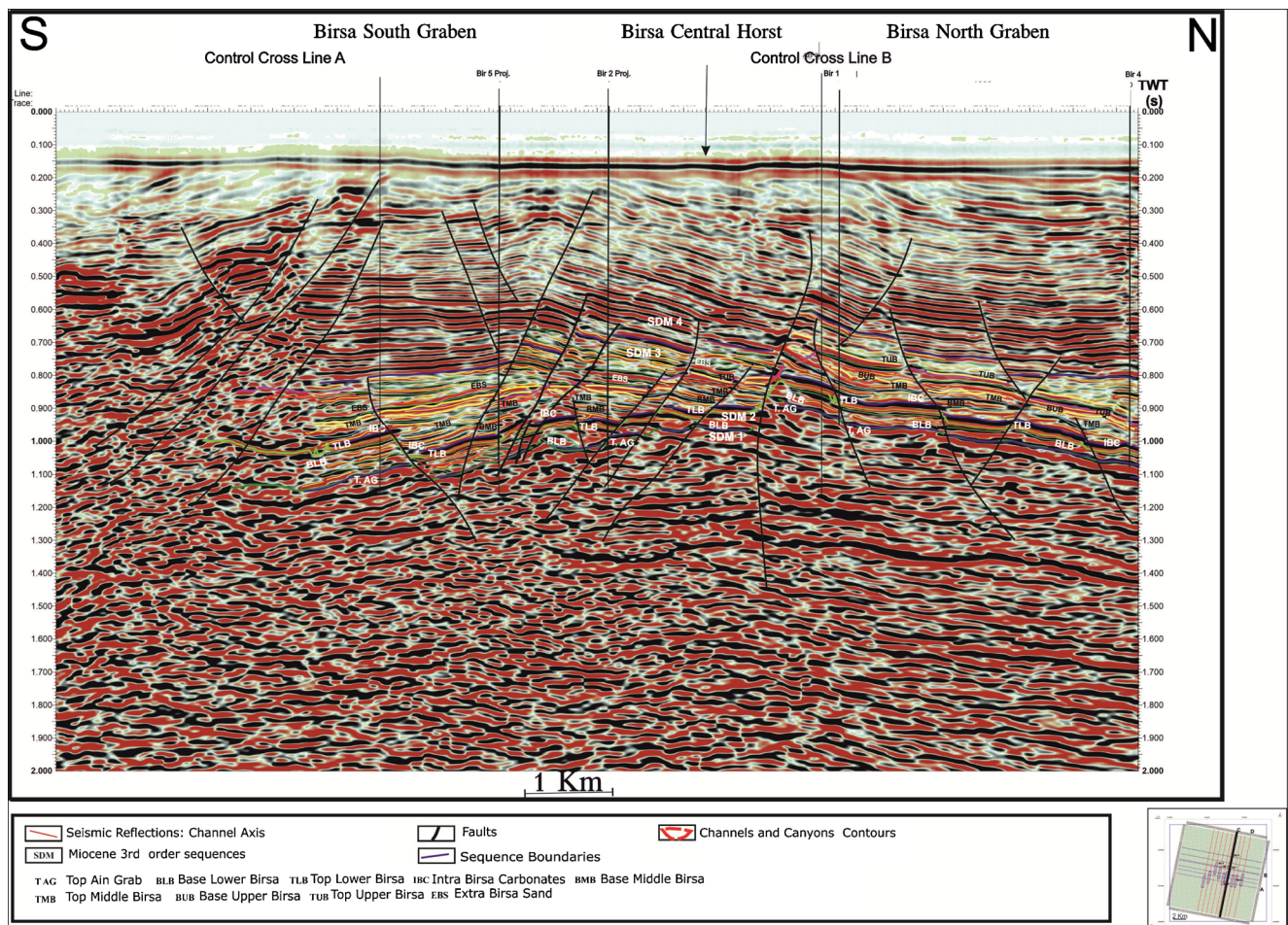


Fig. 23 3D Seismic structural and stratigraphic N-S in line C

reservoir. This basin structuring along the N-S direction and the Middle to Upper Miocene syn-sedimentary tectonics will guide and distribute the Birsa and stone sequences according different paleogeographic depositional systems as we had observed on the E-W direction by cross line seismic sections.

Seismic horizon configurations and depositional environment distribution

Despite the intensive faulting of Miocene horizons along this inline section, seismic stratigraphy analysis was possible for the good seismic resolution and marker horizons. It presents the same sequence organization and system tract terminations from Ain Ghrab to Upper Birsa horizons than the above studied cross line (Figs. 23 and 24) which is very logical because sequence deposits are of 3D dimensions and controlled by eustatic regional sea level variations.

Thus, the Birsa reservoir section is organized in two main third-order seismic sequences: SDM 2 for Lower Birsa and SDM 3 for Middle and Upper Birsa (Figs. 23 and 24). These sequences present basal toplap unconformities with the underlying sequences respectively with the top sequence of SDM 1

(Mahmoud Shales Formation) and the top of sequence SDM 2 of Lower Birsa intra-carbonate shales. Basal terminations of basal system tract horizons of the SDM 2 and SDM 3 exhibit downlap or onlap seismic reflection terminations. Each sequence of Lower, Middle and Upper Birsa horizon reservoirs starts at the base by downlap or onlap horizons of lowstand system tracts and terminate at its top by an onlap and toplap transgressive and maximum flooding condensate section surface overlain by highstand system tract of shales. Lowstand system tracts correspond respectively to the Lower and Middle Birsa sandstones, whereas Upper Birsa sandstones represent a transgressive system tract of sequence SDM 3.

Transgressive and MFS surface are marked by gradational and retrogradational onlap and toplap horizons and correspond to the top surface of the LST sandstones marked in outcrops as well as in the well cutting by a rich ferruginous bioturbated surfaces that indicate a hard ground and a stop of sedimentation related to the maximum sea level flooding on the platform. Highstand system tracts (HST) correspond to the shale deposits that overlain the transgressive and MFS surfaces on the tops of the LST sandstone reservoirs of SDM 1, SDM 2 and SDM 3 (Figs. 23 and 24).

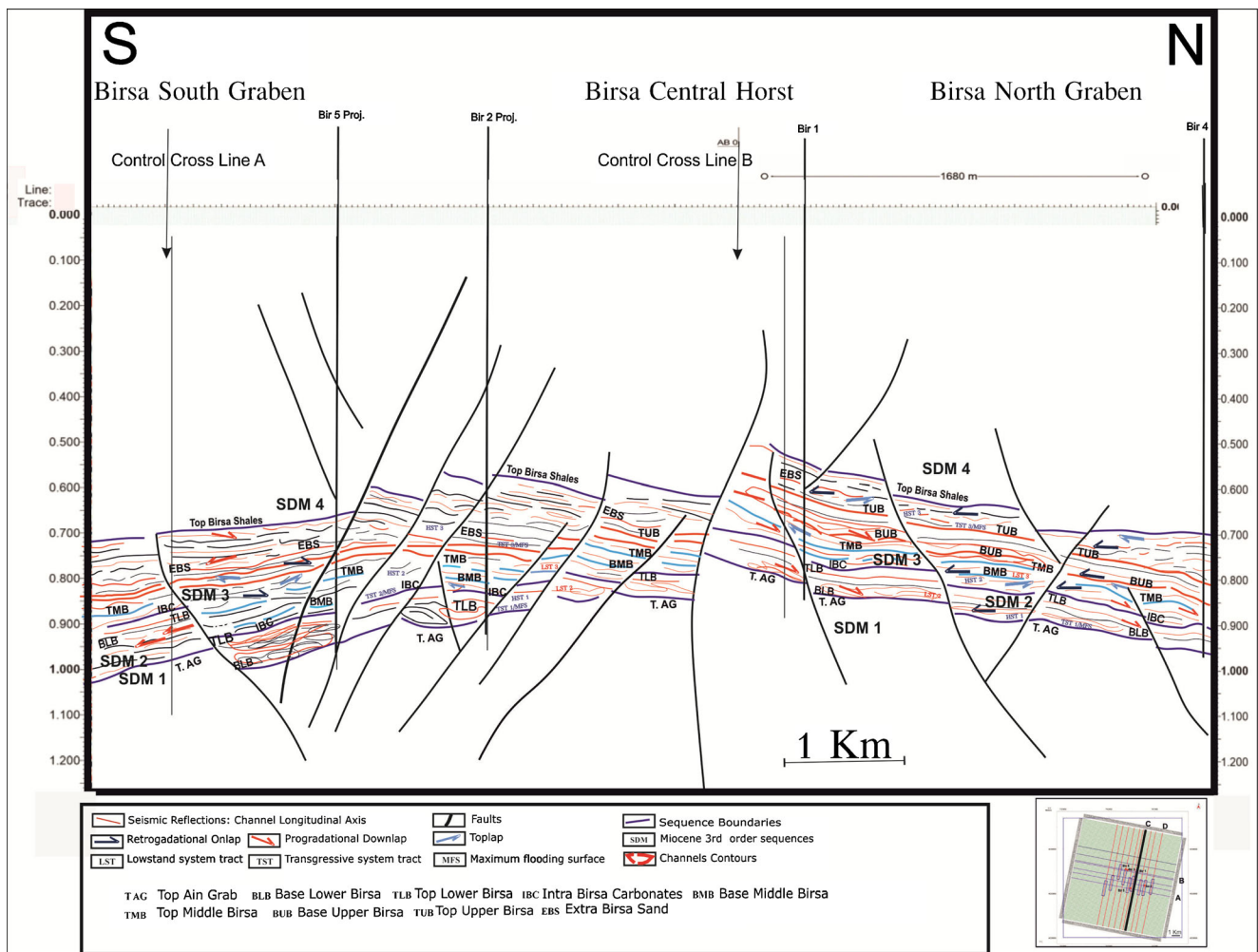


Fig. 24 3D Seismic structural and seismic stratigraphic section of N-S in line C

Lower Birsa configurations and depositional environment distribution

Lower Birsa sequence of SDM 2 is limited at the base by erosive unconformity surface and to the top by a toplap surface (Figs. 23 and 24). Base and top reflectors are a red negative phase, and the basal reflection presents lateral discontinuity with high to low amplitude. It lies unconformably on the Mahmoud Formation shale top horizons. Top Lower Birsa horizon presents high amplitude and good continuity from high central horst block to the northern and southern half grabens and grabens (Fig. 23).

On the central Birsa well 1A horst, Lower Birsa sequence is thinner than the southern half graben and graben. It shows basal channel sand sheets with sigmoid, shingled and concave up geometry, whereas top Lower Birsa horizon presents parallel configurations (Figs. 23 and 24).

To the northern half graben and graben, basal Lower Birsa horizon package stays with isopach thickness than the high central Birsa 1A horst and shows channel sand sheets with sigmoid, shingled and concave up geometry. Some downlap

terminations suggest a South to North Direction of progradation (Figs. 23 and 24). In contrast, top Lower Birsa horizon presents parallel configurations.

Towards the southern collapsed Birsa 2 well central horst and half graben and graben structures, Lower Birsa horizons present progressive increase of thickness. Seismic horizon configuration exhibits some canyon structures with stacked channel sand sheets with sigmoid, shingled and concave up and convex up lobate geometries (Figs. 18, 23 and 24). In the centre of the graben, major kilometric channels comprise stacked story channels that present lateral migration.

These seismic reflection attributes and pattern configurations indicate low-to-high hydrodynamic energy of Lower Birsa lowstand system tract related to a falling stage of sea level. These channelized deposits extend from fluvial deltaic plain on the high horst blocks (distributaries concave up channel sand sheets with sigmoid and shingled configurations) to deeper delta front and prodelta a slope zones of southern and northern half grabens and grabens.

Top Lower Birsa horizons present more continuous parallel configurations as they constitute the end of the sequence with

sea level rising before the intra-Birsa carbonate transgressive system tract of SDM 2.

Downlap progradational terminations from south to north on the Birsa northern flank and from north to south on the southern flank suggest a multi-directional progradational supplies around the Birsa horst high in comparison to the E W cross line results that highlighted an E-W progradational downlap from the central Birsa high horst (Figs. 18, 23 and 24).

These conclusions join the first cross line observations concerning Lower Birsa sequence as depositional sedimentary environments that extend from proximal fluvial and shoreface deposits on the Birsa horst high and prograde to the more distal shelf slope fan to the subsiding southern and northern grabens (Figs. 18, 23 and 24).

Middle Birsa configurations and depositional environment distribution

Middle Birsa sandstones and shale horizons of sequence SDM 3 present approximately similar thicknesses between the highest crest of central horst at Birsa 1A and the northern and southern flanks but show thickening in the centre of the southern part (Figs. 23 and 24). The base and top Middle Birsa sequence are marked by a toplap and downlap base lap configurations. They exhibit discontinuous reflections of positive black phases with high to middle amplitude (Fig. 23).

External horizon configurations from the central Birsa horst well 1A to the northern tilted blocks flank present sheets, sigmoid and lobate structures of a convex up channels indicating a distal middle to lower slope fan deposits (Figs. 23 and 24). To the central Birsa well 2 collapsed horst, seismic configurations are marked by parallel channelization with concave up geometries, indicating low to middle energy of proximal shore face deltaic shelf and/or upper slope fan.

Towards the southern tilted block, graben channel configurations present sheet structures and more convex up and lobate form sand shingled geometries, suggesting more distal deposits of middle to high energy of middle to lower slope fans. These channels have width varying from 200 m to 1 km and more (see horizontal seismic line scale) (Figs. 23 and 24). Seismic reflection attributes pattern configurations calibrated to the outcrop analogue sand well data that indicate deposits marked by low to high hydrodynamic energy extending from shelf delta front deposits on the high horst blocks (distributaries channels and levees, parallel and sigmoid features) to deeper prodeltaic slope zones and a deep basin floor turbidite domain in the centre of southern subsiding Birsa graben (convex up channels, sheets and lobes).

The LST downlap directional on this N-S inline indicates progradations from the central horst platform to northern and southern subsiding tilted grabens flank. Horst and graben channel structures present N-S width axis as they showed E-W axis on the E-W cross lines (Figs. 19, 23 and 24), so the

progradational directions seem to present multidirectional pathways around the paleo-high horst of Birsa.

Upper Birsa configurations and depositional environment distribution

Upper Birsa sandstone horizons are unconformably lying and sealing the Middle Birsa ones by a toplap and onlap terminations (Figs. 23 and 24). It presents a basal erosive surface. Along this N-S directed inline, Upper Birsa horizons present a clear thickening to the northern flank of Birsa central horst, whereas the southern flank is characterized by a constant thin package.

Upper Birsa horizons correspond to the end system tract of SDM 3 as transgressive deposits are marked by toplap and onlap configurations from the northern and southern flanks of the Birsa 1A and Birsa 2 central horst. These horizons are delineated at the base and the top by toplap and onlap configurations.

Seismic attributes of top Birsa reflector present good continuity and high amplitude, whereas the basal one is more less continued with high to low amplitude. From the Birsa 1A well horst to the sloped and tilted northern flank, base Upper Birsa sandstones show a kilometric channel configuration with a concave up and convex up forms and sigmoid geometry bodies that prograde towards the north (Figs. 23 and 24).

To the collapsed centre Birsa 2 well horst, the base of Upper Birsa horizons present an erosive surface and channel configurations with concave up and convex up forms, whereas Upper Birsa top sandstones show more continued and channelized parallel horizons (Figs. 23 and 24). Thus, we can conclude that the sedimentary environment deposit of Upper Birsa system tracts sequence which correspond to the middle Saouaf prodelta and delta front formation in onshore analogue deposits is more transgressive marine deposits than Middle Birsa sediment sand extend from the high Birsa central horst to shelf delta front and prodelta slope to the eastern and western less subsiding grabens (Fig. 20). Rarely, downlap terminations are detected on the upper border slope of northern flank of Birsa central horst on this inline but mainly onlap retrograding terminations around this horst from north to south and from south to north attesting of the transgressive character of Upper Birsa sandstones.

Eastern graben N-S border

Seismic inline D

Basin configuration

Inline D crosses the border of the eastern graben from north to south (Fig. 25). The northern and southern line seismic resolution is very bad due to the intensive faulting of horizons. Nevertheless, this line presents an NS configuration of the Birsa structures as it belongs to the eastern graben border flank.

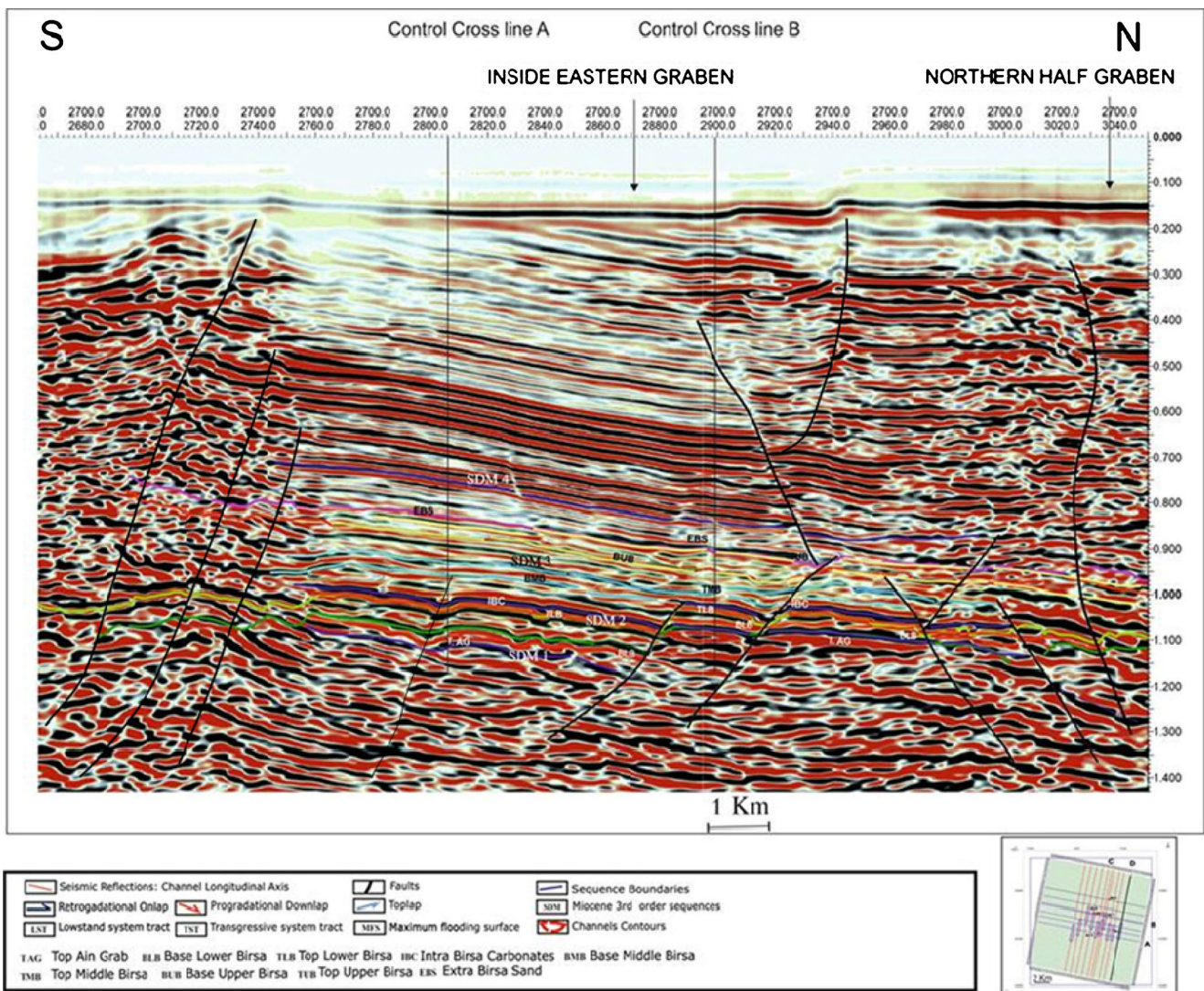


Fig. 25 3D Seismic structural and seismic stratigraphic section of N-S in line D

Miocene horizons are structured according to a global isopach section showing a tilted monocline to the south. This structure is affected by normal faults at the level of Ain Ghrab and Lower Birsa horizons that are in general sealed by the Upper Birsa ones (Fig. 25). Horst and half graben structures affect the Ain Ghrab and Lower to Middle Birsa horizons to the southern seismic section. The southern part of the line crosses the NE-SW Birsa 1A well fault of Birsa central horst and is bordered to the southern part by the E-W south Birsa fault.

This structuring confirms the presence of the eastern graben structure highlighted by the structural and seismic stratigraphic studies of E-W previous documented cross lines.

Seismic horizon configurations and depositional environment distribution

This line exhibits the same seismic sequence organization of the Middle to Upper Miocene horizons of three third-order

sequences SDM 1, SDM 2 and SDM 3 with the remarkable surface boundaries at the base and the top of these sequences (Fig. 25).

Nevertheless, this line highlights a different seismic horizon patterns and geometries for the three Birsa system tracts.

Lower Birsa

Lower Birsa horizons present a thicker package to the northern part of the southern horst and show at the base an important erosive base of canyon sand, a concave up and lobate channelization (Figs.18, 19, 20, 21, 22, 23, 24 and 25). Whereas on the horst structure, it exhibits more less thickness with sheet sand lobate channels (Fig. 25). Top Lower Birsa horizon presents, as usual, a good continuity and high amplitude due to the overlain intra-Birsa carbonate contrast and possibly hydrocarbon content.

Middle Birsa

Middle Birsa horizons show an isopach thickness along its north-south inline with seismic reflection high amplitude but discontinuity which reflects a variable hydrodynamic depositional energy. External configuration highlights parallel and sigmoid channelized deposits with concave up, convex up and lobate channels and sheets. Some vertical and lateral multistory channels migrating from north to south are well clear between Middle Birsa deposits and Upper Birsa ones along normal fault (Fig. 25).

Some rare downlap sigmoid features to the southern part of the line indicate a south to north progradations (Figs. 19 and 25). There are reflection terminations along this line which confirm that we are in perpendicular position of the sedimentary progradational supplies and in parallel position according to the onlap and toplap transgressive deposits.

These characteristics indicate that we are along the N-S eastern graben border slope in deep slope marine deposits of prodelta to lower slope environments. Sandstones and shales of this sequence could be distal turbidites.

Upper Birsa

Upper Birsa horizon package presents more thickness along this line and especially to the central and northern part of the eastern graben border (Fig. 25), whereas it thins to the south in a horst structure. The base and top of Upper Birsa horizons are of good continuity and variably low to high amplitude. They are channelized with large lateral kilometric extend (Figs. 20 and 25). Channels are of concave up geometry and exhibit a parallel configuration.

Along collapsed compartment of normal fault, a thick channel is formed overlying a Middle Birsa channel and showing a space lateral southern migration (Fig. 25). These characteristics suggest a low to middle variable hydrodynamic energy between shelf and upper to middle slope depositional domain.

Paleogeographic and depositional Birsa fair maps

Seismic stratigraphic study of the Middle to Upper Miocene horizons comprising the three Birsa sandstone reservoir deposits with their shale seals highlighted their sequence deposit system tracts distribution around the Birsa concession structures.

Based on the tectonic structuring and geodynamic evolution of this area of the Gulf of Hammamet and the isochron and isopach time maps of the three Birsa sandstone sequences, paleogeographic depositional environment reconstruction and reservoir fair maps have been tentatively established.

Lower Birsa

Tectonic structuring of the Birsa concession in central horst and surrounding grabens during the deposition of Lower Birsa lowstand deposits had induced a paleogeographic domains characterized by three main sedimentary environments.

The map presents a central deltaic plain with shallow marine fluvial channels prograding to the eastern, southern, western and northern shelf sand slopes of differentiated subsiding grabens (Fig. 26). Shelf to basin slope domains contain channel sand canyons of slope fan deposits. They present prograding directions from the deltaic plain to the surrounding shelf and slope and a contour directions along these slopes and grabens attested by downlap and onlap terminations.

This model suggests that the Lower Birsa sandstones progress from fluvial channelized sands as it is documented in the outcrop analogues and the Birsa wells drilled around the high platform central horst to a deeper marine channel and canyon deposits of slope fan sand turbidites.

According to this model, Lower Birsa sandstone deposits could present three types of reservoirs from fluvial deltaic channels to upper, middle and lower slope fan turbidites around the Birsa concession. Structural and stratigraphic traps of these reservoirs are existing around the horst and graben structures.

Middle Birsa

Middle Birsa sandstone depositional map is tectonically and paleogeographically characterized by the same Lower Birsa domains with difference in extension domain variations. As Middle Birsa sandstone sequence is related to a sea level rising in comparison to the Lower Birsa one, deltaic fluvial horst platform domain becomes more restricted whereas the shelf to slope domain is now more extended (Fig. 27).

This result is also improved by the prodeltaic and delta front deposits of the equivalent Lower Saouaf analogue outcrop and the seismic horizon configurations of the Middle Birsa around the concessions that suggest a more deep marine sandstones and shales of this sequence.

Shelf to slope fan deposits are of more frequent occurrence in Middle Birsa sequence with prograding directions to the subsiding grabens and also along their flanks from north to south and vice versa attested by the downlap, onlap and toplap terminations (Fig. 27). Similarly to the Lower Birsa deposits but with more accurate occurrence, Middle Birsa sandstone deposits present three types of reservoirs from very restricted area of fluvial deltaic channels to more frequent upper, middle, lower slope and basin floor fan turbidites around the Birsa concession. Existence of structural and stratigraphic traps at a level of these horizons offers a potential prospect around the horst and graben structures.

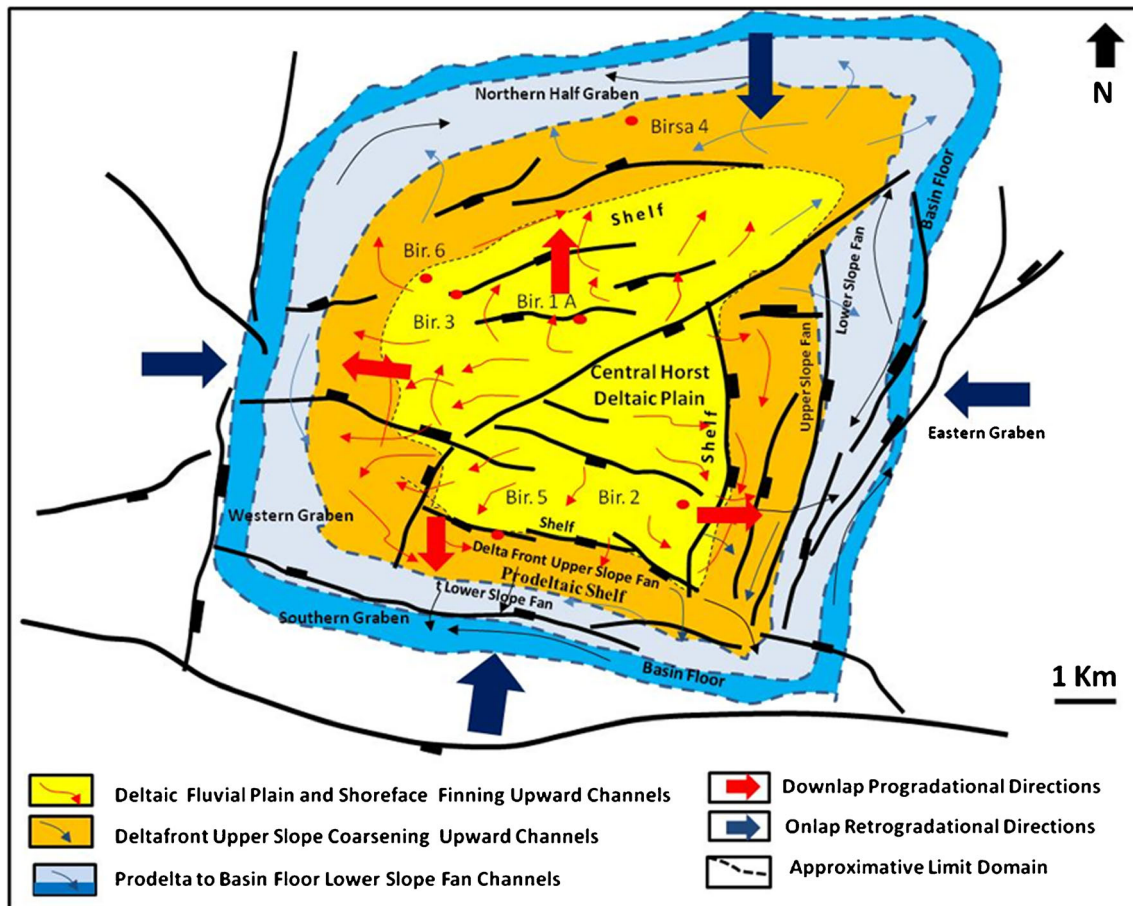


Fig. 26 Lower Birsa paleogeographic and depositional reservoir fair map

Upper Birsa

Upper Birsa depositional fair map resembles the Middle Birsa paleogeographic by means of the sedimentary environment domains of high deltaic channels to shelf and slope deeper marine fan deposits (Fig. 28). The different aspects with the previous map is that the paleogeographic limits and extension vary slightly as Upper Birsa sandstones and shales are the transgressive system tracts of the SDM 3 Middle Birsa sequence and the syn-sedimentary distensive tectonics during the deposition of Middle Birsa is stopping and sealed during Upper Birsa deposits.

So the shelf slope angle degree becomes more less accentuated in Upper Birsa and reduce the prograding deposits of slopes. These deposits are more uniform, isopach and extended around the concession than the Middle Birsa ones. They present a proven hydrocarbon reservoir with tidal to shore face and delta front sedimentary deposits as found in the Birsa well scores placed around the central high horst. So we can expect another deep water deposit sandstones on the border of the shelf and slope domains with more fine-grained turbidites according this reconstructed reservoir fair map.

Paleogeographic and depositional reservoir domains

The synthesis of depositional system tracts nature and distribution of Middle-Upper Miocene around the study area of Birsa basin shows globally the lowstand and transgressive clastic hydrocarbon reservoir repartition.

Tectonic structuring represented by the fault framework and the drag fold deformations of Miocene and Pliocene-Quaternary horizons has a great link with the system tract repartition and trap types. Particularly, the incised canyon and channel pathways with the differentiation from shelf to slope and lateral and vertical sedimentary and petrophysic characteristic reservoir variations.

Stratigraphic, structural and combined structural/stratigraphic traps are also present in the case of the Birsa horizons of the study area.

After the paleogeographic depositional maps of Lower, Middle and Upper Birsa horizon depositional systems, sandstone reservoir rocks present three domains of superposed systems from the fluvial tidal deltaic plain to shelf and slope domains and probably the basin floor one. These depositional domains are strongly linked to tectonic structures of horst and grabens limited by syn-sedimentary deep-seated normal

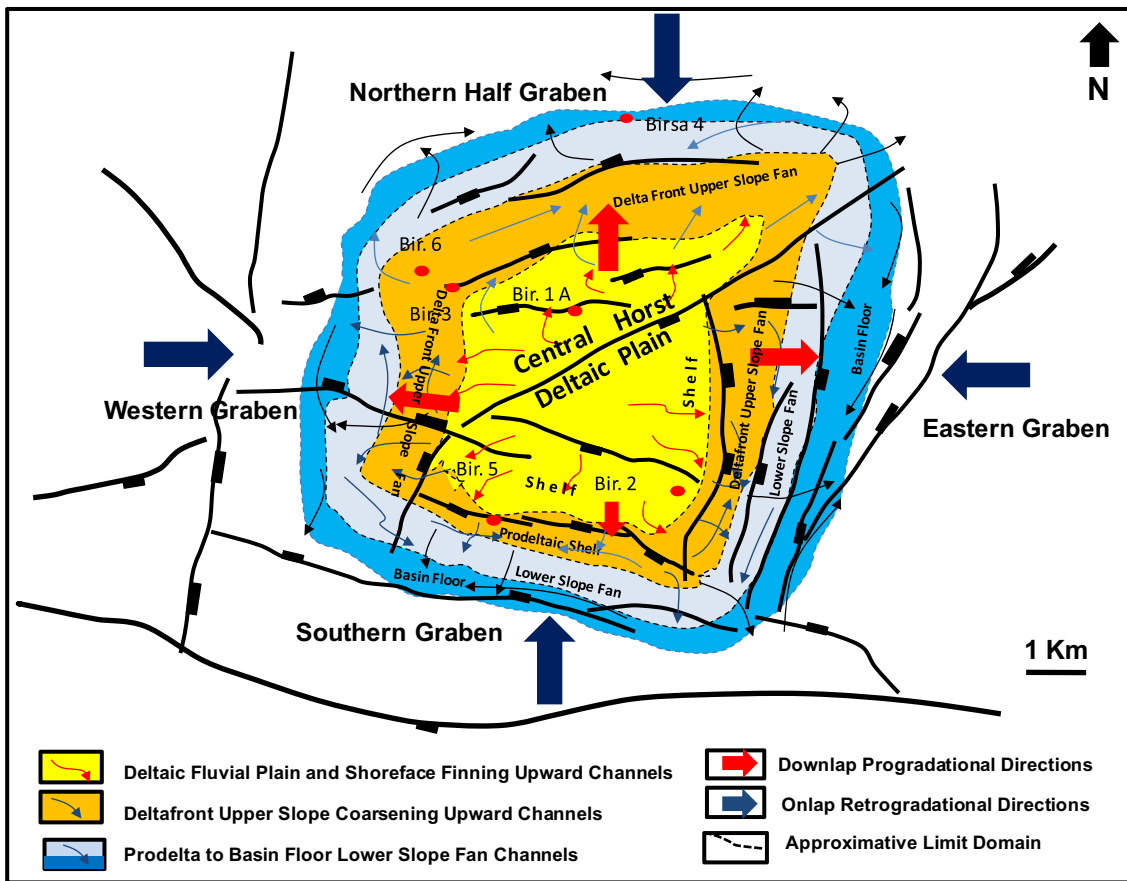
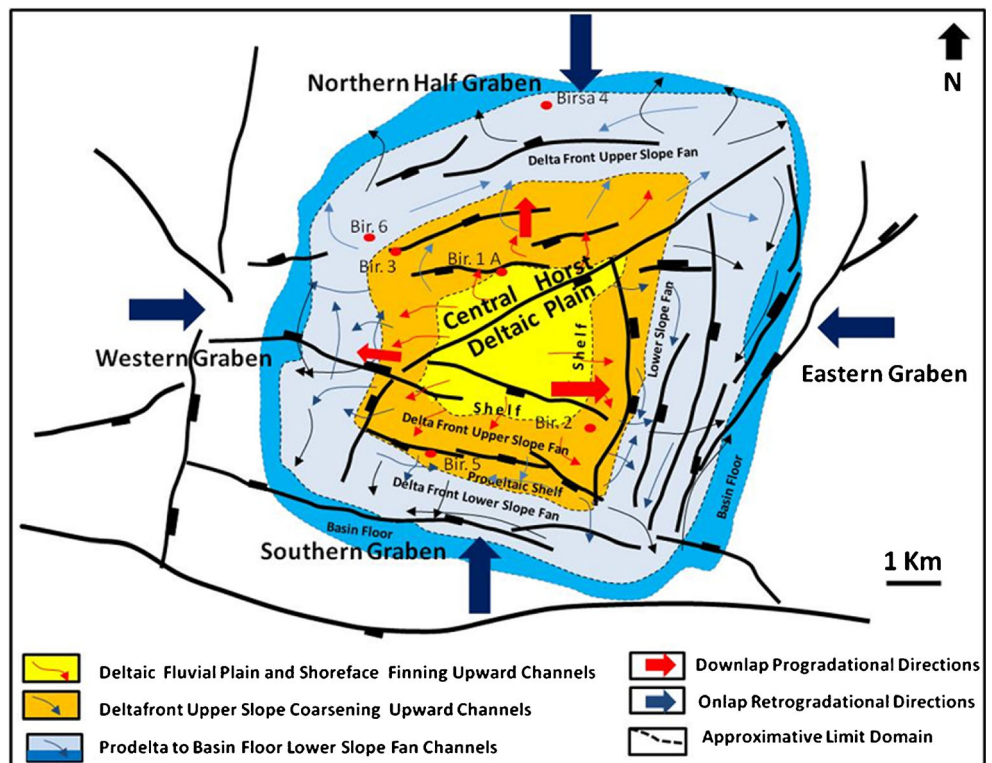


Fig. 27 Middle Birsa paleogeographic and depositional reservoir fair map

Fig. 28 Upper Birsa paleogeographic and depositional reservoir fair map



faults. The synthesized general depositional reservoir fair map of the four Birsa sandstone reservoirs (Fig. 29) highlights the following main results:

Fluvio-deltaic plain and shelf shallow marine reservoir system domain

This highest depositional domain has characteristics of a fluvio-deltaic plain comprising flood plain and incised valleys of fluvial and tidal distributary channels of sandstones and shales. These fluvio-deltaic channels are from amalgamated and/or braided types according to their lowstand or highstand stage origin.

To the border part of this domain in the border of the shelf, estuarian and prograding shore line and shore faces took place and deposited as well in lowstand sea level fall as in transgressive sea level rise.

These sandstones were drilled by Birsa 1A, Birsa 2 wells and Upper Birsa showing shallow marine tidal to estuarian sands whereas Birsa 4, 5 and 6 encountered deeper marine levels of shaly rich level sands (Lundin, 2005). They are located around the central horst, northern and southern flanks of the structure. These data are in concordance with the seismic stratigraphic results conducting this depositional domain prediction.

Effectively, this fluvio-deltaic domain is limited by surrounding coastal and shelf prograding domain where it is expected to have coastal shore line sands and shallow water shore face sands as it was encountered in Birsa wells.

Shelf shallow marine domain is occupied by prodelta deposits and positioned between the high horst border and graben slope. This domain interests the Lower and Middle Birsa reservoir sandstones as Upper Birsa ones. Therefore, we have a superposition of three sandstone reservoirs on the border of central Birsa horst structure.

Sandstone channels of fluvial, shore line and shore face deposits and delta front environments are good hydrocarbon reservoirs. In addition, this domain occupied an important surface of the Birsa concession and offers three superposed reservoir systems.

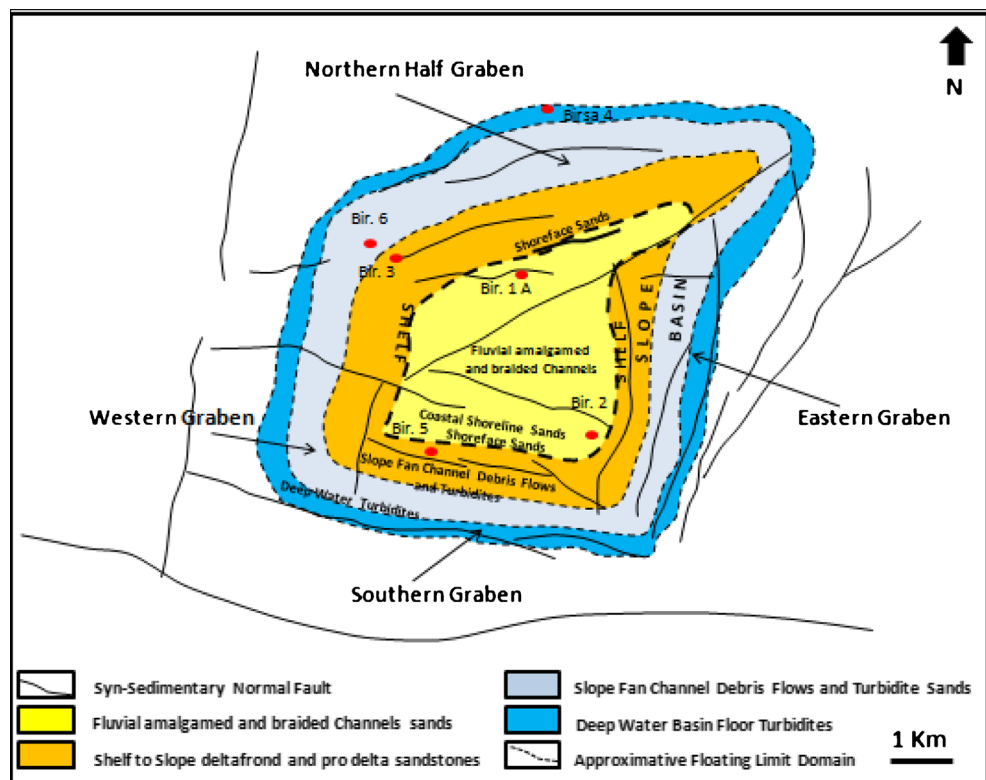
Shallow to deep marine slope reservoir system domain

This domain interests the three Birsa sandstone reservoirs; they are superposed on each other but with shifting of their domain limits (Figs. 26, 27 and 28). It coincides with the graben normal fault borders around the central horst (Fig. 29). It comprises upper and lower slope areas.

Birsa prograding channels and canyons slope fan deposits should suggest here a high and low-density turbidite system according to lowstand or highstand transgressive system tracts of Lower, Middle or Upper Birsa. These sandstone layers are intercalated by mudstones and pelagic marls of transgressive and highstand deposits.

These channel fans, sheets, lobes and levee deposits could be composed of debris flows, slumps, mass flows of fine or coarse sandstones, sands and siltstones as in the lower and

Fig. 29 General synthetic Birsa depositional reservoir fair map



upper Saouaf SDM 3 sequence in the Tazoghrane graben in the northeastern flank of Jebel Abderrahmane in the Cap Bon outcrops. Grain size finning and coarsening upward of these types of slope fan deposits are good reservoirs. As the first exposed deltaic to coastal shelf domain, this slope domain is extending around the Birsa concession and present important exploration surface.

Basin floor reservoir system domain

This domain has been suggested by seismic reflection configurations of convex up channels, sheets and lobes; it is placed preferably to the subsiding centres of eastern, western and Southern grabens at the level of Lower and Middle Birsa lowstand deposits and with less probability in Upper Birsa deposits to the subsiding eastern graben.

This type of domain which represents the final distal deep sea fan deposits presents a large and low-density turbiditic system composed of lobes and sheets. This domain is proposed in the Birsa concession paleogeographic reconstruction with accuracy and according the silicoclastic model characteristics and seismic configurations without any outcrop analogue or well data controls.

Synthesis and conclusions

Basin structuring and tectonic control

Seismic sequence stratigraphy study of Miocene Birsa reservoir horizons of the Birsa petroleum concession in the Gulf of Hammamet offshore basin, based on the analysis and interpretations of eight E-W and N-S selected lines matched by lithostratigraphic outcrops and calibrated by Birsa well data, had permitted to highlight the basin configuration of this concession and sequence deposit nature and distribution.

This area presents a NE-SW anticline bounded by E-W, NE-SW and N-S flower and vertical strike slip faults. The latter has been reactivated in transpressive movements during the latest Tortonian and Quaternary NW-SE compressions inducing the folding of the central Birsa horst in a right lateral drag fold and the reverse fault movements.

Birsa anticline was a horst structure during Middle to Upper Miocene (Langhian to Middle Serravallian) with reduced deposits surrounded by eastern, western, southern and northern flanked grabens where Lower Birsa, Middle Birsa and Upper Birsa reservoir horizons are thickening.

Syn-sedimentary tectonic structuring and geodynamic evolution of the Middle to Upper Miocene Birsa reservoir sequences has guided the depositional systems around horst and grabens by the subsidence and the accommodation space control interplaying with the regional eustatic sea level variations. Especially the faults that limit the central Birsa horst and

the surrounding grabens had played a major role in the paleogeographic sedimentary distribution of the sequence deposits of Middle to Upper Miocene.

Seismic sequence stratigraphy and reservoir lowstand system tracts

Middle to Upper Miocene sedimentary infilling of the basin from Ain Ghrab carbonate to Birsa and Saouaf sandstone and shale formation thickness is guided by the tectonic horst and graben structures. They show three third-order seismic sequences, limited by regional erosive toplap, onlap and downlap unconformity surfaces and by remarkable chronostratigraphic horizons of forced and normal erosive lowstand and highstand systems tracts separated by transgressive and maximum flooding surfaces.

Lower Birsa sandstones are the lowstand system tract of sequence SDM 2. Whereas Middle Birsa and Upper Birsa sandstones are respectively the lowstand and the transgressive system tracts of sequence SDM 3, the top Birsa shales are the highstand system tract of SDM 3.

Seismic reflection acoustic parameters of amplitude and continuity vary, respectively, from good and high to fair and low according to the nature and the position of deposit environments and facies changes. Seismic external and internal configurations of Birsa sandstones and shale system tracts exhibit around high horst and graben structures a channelized and leveed infillings extending from 100 m to more than a kilometre of width. They present a stacked single story and multistory types showing space lateral and vertical migrations along E-W and N-S directions. They show vertical concave up and convex up geometries, suggesting a proximal to distal shelf to slope position deposits.

Hydrodynamic energy of these deposits varies from low to middle and high, according to the external and internal configurations and acoustic parameters of continuity and amplitude.

These channels and levees show different directions of their dip and strike axis and present seismic horizon configurations from parallel to sigmoid and shingled progradations and sheets and lobes structures (Lakin 2013).

These characteristics suggest a sedimentary paleo-environment distribution extending from deltaic fluvial proximal deposits on the central Birsa high horst to a delta front coastal and shelf shoreface and shoreline deposits in the high borders of grabens. Distal deposits seem to be distributed from upper to lower slope fans and probably to the basin floor on the flanks of the subsiding grabens.

Progradational and supply directions of channels present multidirectional pathways since they transit from the high central horst and surround its flanks along E-W and N-S directions. These depositional environments are bounded by the major master faults that limit the horst and graben structures.

Depositional reservoir distribution domains

Synthetic predictive paleogeographic depositional reservoir fair maps distribution of Lower, Middle and Upper Birsa sandstone reservoirs, according to seismic stratigraphic study calibrated to well data and outcrop analogues and silicoclastic models, highlight four main domains of superposed and shifted reservoirs.

Deltaic horst domain with floodplain and incised valley of fluvial amalgamated and braided sandstone distributary channels occupies the central horst structure of the Birsa concession. Horst-graben border domain of shelf delta front occupied by coastal and shallow water estuarine prograding shoreline and shoreface sands. Slope domain of graben flanks marked by upper to lower progradational slope fan channels, canyons and levees composed by slides, slumps, low- and high-density turbidites, debris flows, mass flows, sandstones and conglomerates alternated by hemipelagic marls and probably central graben's basin floor domain containing distal lobes and sheets sandstone turbidites and longshore contourites.

The presented depositional model of Birsa deposits is concordant with the Birsa well sedimentology conclusions of core data and can explain the facies changes of sandstones and shaly units between these wells.

This reconstructed model predicts an important potential of Birsa sandstone reservoirs around the concession supported by structural/stratigraphic trap types. Some new prospects have been proposed in this study. They are mainly placed in the border of the faulted central horst and grabens.

New trap targets

These results had highlighted new potentialities of different platform-to-basin stratigraphic reservoir traps in the three Birsa sandstones and the importance to target these new depositional environment zones and sequence system tracts of lowstand deposits in the different depositional silicoclastic domains.

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