High-resolution sequence stratigraphy in basin reconnaissance: example from the Tarfaya Basin, Morocco

Axel Wenke,[1] Rainer Zühlke,[1] Haddou Jabour[2] and Oliver Kluth[3] introduce high-resolution sequence stratigraphy to basin reconnaissance in exploration for the Moroccan passive continental margin based on well log and 2D seismic data.

Increasing global demand of hydrocarbons (IEA, 2011) and the renewed interest in underdeveloped hydrocarbon-prone basins drive new ventures and require refined exploration strategies. The continental margin of southern Morocco with the Tarfaya-Laayoune Basin (TLB) clearly represents an example of such underexplored basins. Although sufficiently mature source rocks (Early Jurassic, Late Cretaceous, Paleogene) exist in the TLB (Davison, 2005, Sachse et al., 2011) as indicated by numerous oil/gas shows, previous exploration has not yielded commercially producing wells (Morabet et al., 1998, Davison, 2005). 2D seismic data have been acquired since 1959, especially in the early 1960s to late 1990s (El Mostaine, 1991, Wenke and Zühlke, 2011). However, data acquisition and processing has developed significantly, resulting in a strongly variable quality of seismic and well log data which are available for basin reconnaissance studies today.

Since its development over 35 years ago (Vail et al., 1977), the concept of sequence stratigraphy has evolved significantly and successfully reshaped exploration strategies – especially as far as lowstand systems tracts are concerned (Catuneanu et al., 2010).

This study establishes an operational basin reconnaissance approach which is based on the Exxon model and derivatives (Depositional Sequence II–IV, Accommodation Succession Method – Catuneanu, 2006, Neil and Abreu, 2009). It applies advanced seismic post-processing, filtering, and interpretation tools (ProMAX, OpendTect, Petrel) as well as well log pattern detection for high-resolution systems tract analysis in basin reconnaissance.

Geological setting

The continental margin of Morocco extends for nearly 3000 km from Tangier in the north to Lagouira in the south. The TLB covers the segment between the towns of Boujdour and Sidi Ifni (Figure 1), followed by the Dhakla and Souss basins to the south and the north respectively. The conjugate margin is the Nova Scotia margin of eastern Canada (Davison, 2005). Sediment source areas include the Anti-Atlas in the north, the Oued Drâa, Zag Basin, Reguibate Massif, and the West African Craton in the southeast (clockwise). The Tarfaya Basin (TB) and the Laayoune Basin (LB) are separated by a transfer fault which is followed by the Saguia el Hamra River.

The basin fill and evolution of the TLB was subject of several studies. An overview of existing publications is given in Hafid et al. (2008). The basin evolution includes six tectonic stages: i) rift and sag basin stage, ii) early drift stage, iii) mature drift stage, iv) mature drift stage with initial Atlasian compression, v) mature drift stage with peak Atlasian uplift and deformation, and vi) mature drift stage with decreasing Atlasian compression. The onset of pre-Atlantic rifting in the Southern Morocco area occurred in the Ufimian-Kazanian at approx. 260 Ma (Zühlke et al., 2004). The rift and sag basin stage includes four substages (sT1–sT4, Le Roy and Piquet, 2001) and lasted for approximately 70 mya until 190 Ma. Alluvial fan, fluvial, and evaporite deposition prevailed during this stage. Basalt flows related to the Central Atlantic Magmatic Province (CAMP) event are dated at 200 Ma (Davison, 2005). The rift basin stage terminated with a hiatus of approximately 13 mya (Hettangian-Pliensbachian, Zühlke et al., 2004).

The early drift basin stage shows clastic-carbonate ramps in the Toarcian followed by primarily carbonate ramps during the Bajocian to Callovian. Intra-shelf carbonate ramps and platforms developed during the Late Jurassic. The onset of the mature drift stage was associated with a major relative sea-level fall in the Late Tithonian to Early Valanginian with widespread subaerial exposure and karstification of the Jurassic shelf top (Vail et al., 1977). During the Berriasian to Early Valanginian, incised valleys linked

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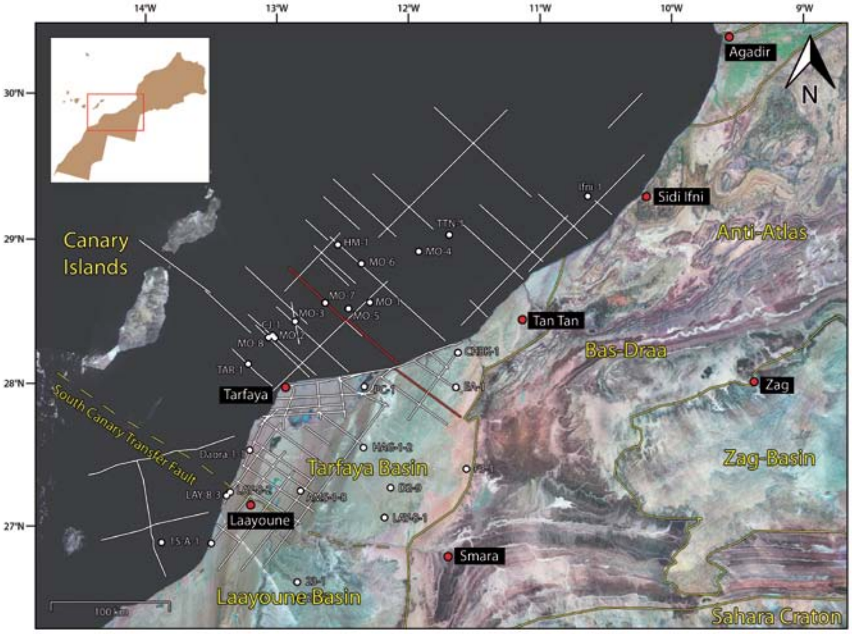

Figure 1 Basemap with study area, major tectono-stratigraphic units and well and seismic locations.

eastern source areas (Anti-Atlas, Reguibate) to delta systems at the inherited Late Jurassic slope. Shelf-wide deposition (inner, outer shelf top) returned in the Late Valanginian to Hauterivian. The main Early Cretaceous delta systems are the Tan Tan Delta in the northern TB and the Boujdour Delta in the LB. The subsequent development of the mature drift phase was dominated by salt flow and led to the development of prominent growth faults in the central and northern TB. They became inactive in Albian times. Lagoonal to open marine carbonate sedimentation prevailed during the Albian to Turonian (El Khatib et al., 1995). Initial Atlasian compression caused a moderate increase in sediment input during the Coniacian to Campanian, the time of maximum transgression. A shelf margin wedge developed during the Maastrichtian to Lower Oligocene concurrent with peak Atlasian uplift and deformation including a flexural uplift of the northwestern TB. Since the Late Oligocene erosion prevailed on the northern shelf top. Sediment input increased significantly and triggered major bypass to the basin as indicated by seismic reflector geometries.

Methods

Sequence stratigraphic modelling requires litho-, bio- and, chrono-stratigraphic data at basin scale. This frameset includes outcrop analysis, formation top evaluation in 28 wells, and interpretation of 10 2D on- and offshore seismic surveys (4084 km length, Figure 1). Basic seismic interpretation and well log pattern recognition was performed in Petrel (Schlumberger). Twenty-nine stratigraphic horizons have been mapped basin-wide.

Filter/Attribute	Line A	Line B	Line C
Low-cut (8-16 Hz)	-	+	-
Vertical Scaling	Zn = 1.1	-	-
Lateral scaling	Amp*c0 = 4,285.7	Amp*c0 =1,428.5	-
BG fast steering	Step out: 3/3 Filter step out 10/3	Step out: 3/3 Filter step out 10/3	Step out: 3/3 Filter step out 10/3
DSMF	Step out: 6	Step out: 6	Step out: 6
NSMF	-	+	-
Similarity	-	+	-
Average similarity	-	+	-
Conditional DSMF	-	Dipvar < c0 ? NSMF:DSMF	
FFT steering	+	+	+

Table 1 Filtering and noise reduction parameters.

Well sequence stratigraphy is based on hierarchical sediment stacking patterns in GR- or R-logs (Van Wagoner, 1990). Stacking patterns cover metre-scale 5th order to 50 to 250 m-scale 3rd order cycles. At well log and seismic scale, API peaks and trends have been interpreted as sequence boundaries (SB), maximum flooding (mfs), transgressive (ts) and flooding surfaces (fs), defining sequences, systems tracts, and parasequences (Figure 2).

2D sequence stratigraphy was performed with OpendTect SSIS (dGB). The basic concept of a sequence stratigraphic interpretation system (SSIS) is the auto-detection of all reflector traces (horizons) within user-defined intervals, usually 2nd order sequences, and their correct chronostratigraphic order (de Groot et al., 2010). Reflector traces (horizons) are analysed at sub-seismic resolution and tracked throughout the seismic volume within the limits of the manually defined interval boundaries (2D) or surfaces (cube).

Auto-detection of reflector traces requires a largely uniform seismic data set in terms of bandwidth, reflector amplitude, and noise reduction. The TLB seismic transect represents a composite from three individual lines: i) vibro-line, inner shelf, acquired in 1987 (Line A); ii) marine seismic line, inner to outer shelf, acquired in 1969 (Line B), iii) marine seismic line, outer shelf to middle slope, acquired in 1983 (Line C). The three lines are not directly connected (see Figure 1). Several filter and noise reduction procedures were initially performed including low frequency cuts (performed in ProMAX) and several OpendTect attribute and filter tools (Table 1). Figure 3 shows parts of the transect

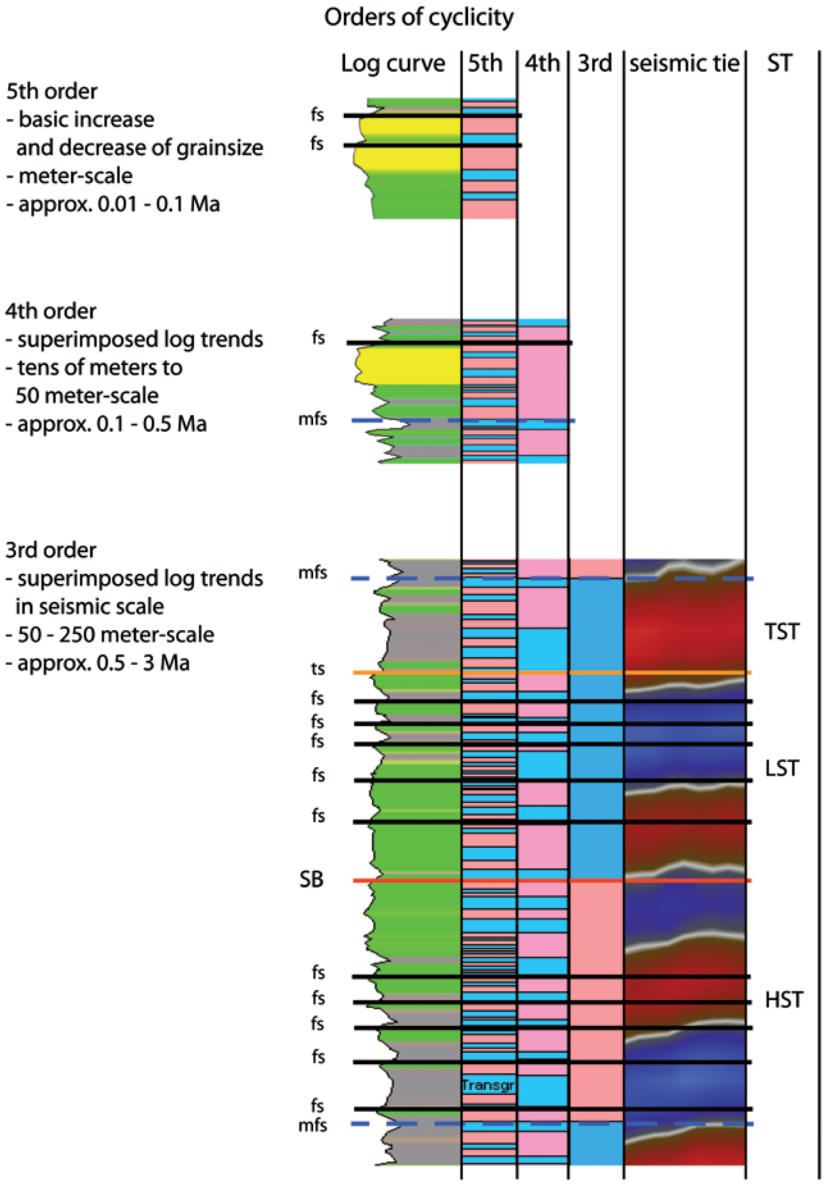

***Figure 2** Log pattern detection and sequence stratigraphy. Third order cycles in seismic scale.*

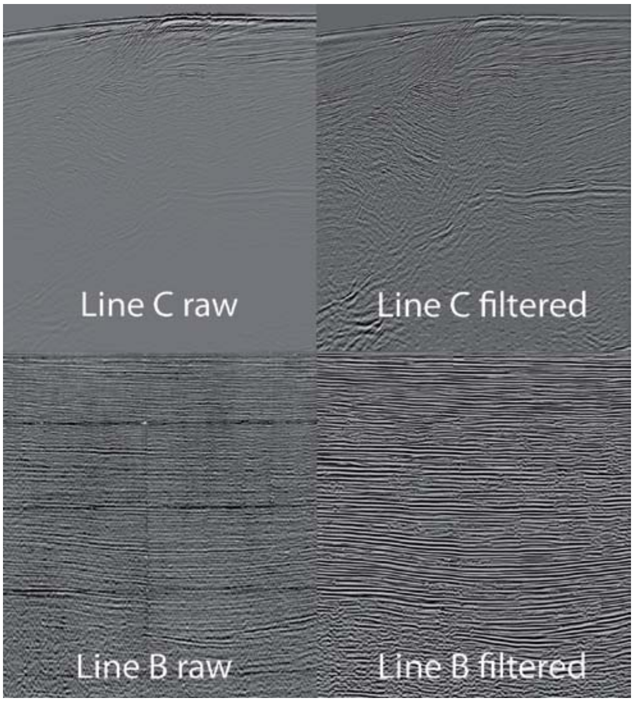

Figure 3 *Seismic filtering compared to raw data (see Table 1).*

before and after seismic filtering. In order to constrain the auto-detection of chrono-stratigraphic intervals to the litho-, bio-, and chrono-stratigraphic data available, the key seismic transect was subdivided into 17 units (Figure 4). Pre-defined interval boundaries represent at least 2nd order sequence boundaries spaced at approximately 10 mya.

SSIS offers five approaches described in detail by Catuneanu (2006). This study follows the Depositional Sequence II concept (Early/Late LST, TST, HST) which assures the most reliable results given the vintage seismic dataset. Based on reflector auto-detection, sequence and systems tract interpretation is manually performed. Results are a high-resolution 3rd order sequence and systems tract interpretation on each seismic line and a related base level curve. Outcrop studies, log pattern detection, and SSIS were integrated in the final model. A comparison of resolution of the three different approaches is illustrated in Figure 5.

Integrated outcrop-analogue, well, and seismic sequence stratigraphy provides a detailed model of the lateral migration and areal extent of depositional systems through time. Mud logs and organo-chemical data from outcrop samples (Sachse et al., 2011) allow identifying oceanic anoxic events (OAE) in the Meso-Cenozoic basin fill. The chronostratigraphic analysis of the basin fill (Wheeler plots, Figure 6) indicates progradation, aggradation, and retrogradation of depositional systems and their trajectories in time. The colour code applied follows the accommodation succession method (Neill and Abreu, 2009). It includes: i) the location and lateral migration of potential source rocks and reservoirs, e.g., reefal margins, delta fronts, shoreface sands, and lowstand fans, and ii) timing and areal extent of major unconformities in the basin fill.

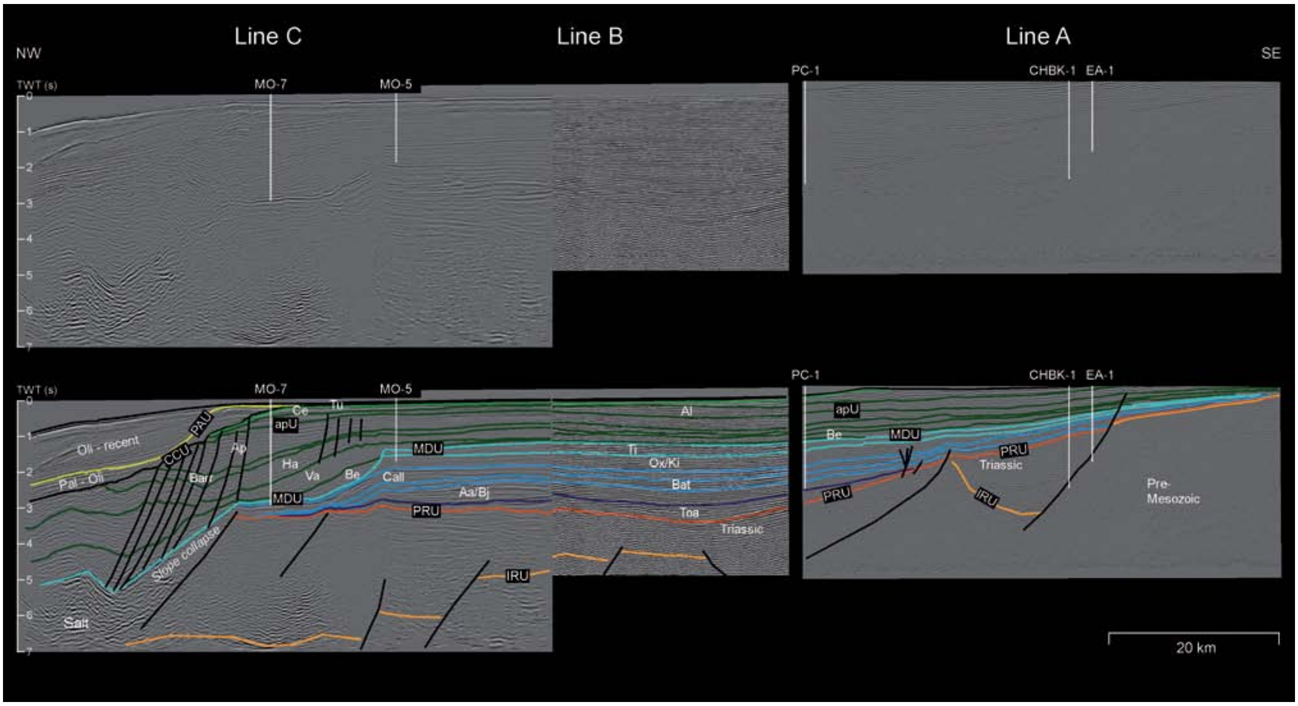

Figure 4 *Basic interpretation of the key transect in the northern TLB. Well positions are partly projected. Regional unconformities: IRU: Initial Rift Unconformity, PRU: Post Rift Unconformity, MDU: Mature Drift Unconformity, apU: Aptian Unconformity, CCU: Cenozoic Cretaceous Unconformity, PAU: Peak Atlasian Unconformity.*

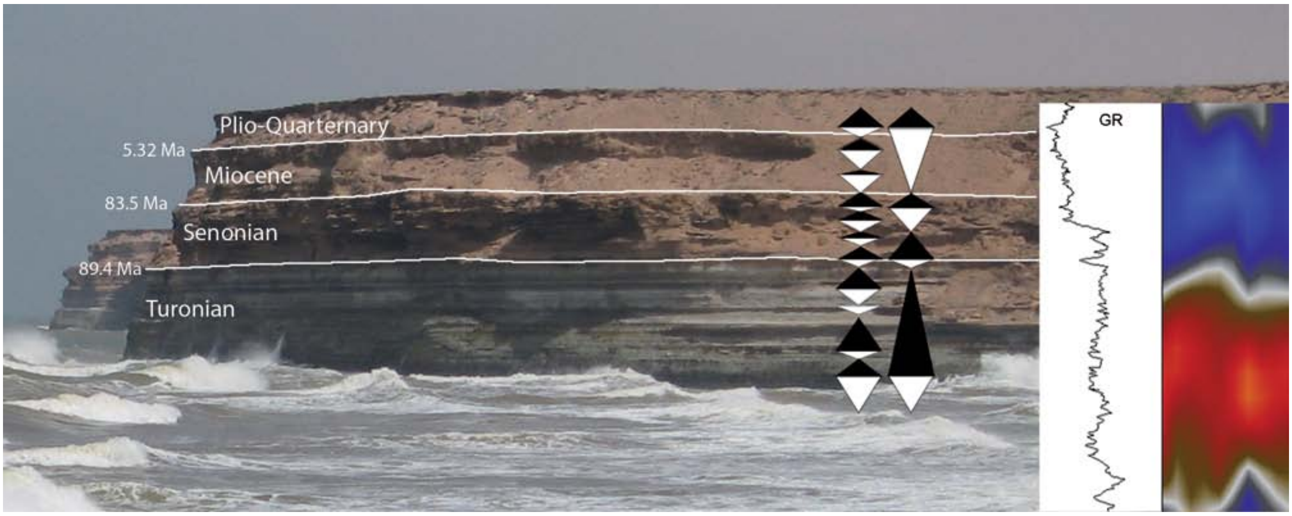

Figure 5 *Data resolutions compared in outcrop of Turonian black shales (Oued Ma Fatma).*

Well sequence stratigraphy

Four wells, two onshore and two offshore, are located on the seismic transect (Figure 4). The sequence stratigraphic well correlation is given in Figure 7.

Well log interpretation for EA–1 is based on R-logs for the Upper Jurassic, Lower and Upper Cretaceous. The well is located on the inner shelf and was drilled through a rift graben structure (Chebeika Graben) to the Paleozoic basement. The Triassic consists of stacked alluvial fans, fluvial channels, and alluvial plain sediments. A depositional/erosional gap covers the Early to Early Middle Jurassic. The Middle/Late Jurassic and Early Cretaceous succession is represented by alluvial/fluvial deposits. Although detailed bio-stratigraphic data are not available, seismic analysis, well log pattern detection, and sequence stratigraphic modelling in this study provide a sufficiently reliable subdivision of the basin fill. Twenty-three 3rd order sequences have been identified in the Mesozoic succession. No Cenozoic basin fill developed or has been preserved.

Well PC–1 is located at the recent coastline on the eastern flank of the Laayoune Depression, a depocentre on the inner to outer shelf. It contains the most continuous Jurassic succession of the northern TB. Toarcian to Callovian sequences were correlated by seismic interpretation. Sequence stratigraphic log pattern detection for the Callovian to Turonian has been performed on a γ-ray log. The Toarcian to Bajocian sequences include clastic-carbonate ramp deposits, the Bathonian to Tithonian ramp and platform carbonates. The Lower Cretaceous in PC–1 is represented by mainly fine clastic sediments with coarse clastic intercalations and includes an upper delta plain facies of the Lower Cretaceous Tan Tan Delta Complex. Delta development was terminated in the Late Aptian and followed by marine fine clastics of the Albian Aguidir Fm representing an inner to outer shelf environment. The Upper Cretaceous consists of mainly outer marine fine clastic sediments of an outer shelf to open marine area. The Coniacian to Quaternary successions did not develop or have not been preserved. Forty-two 3rd

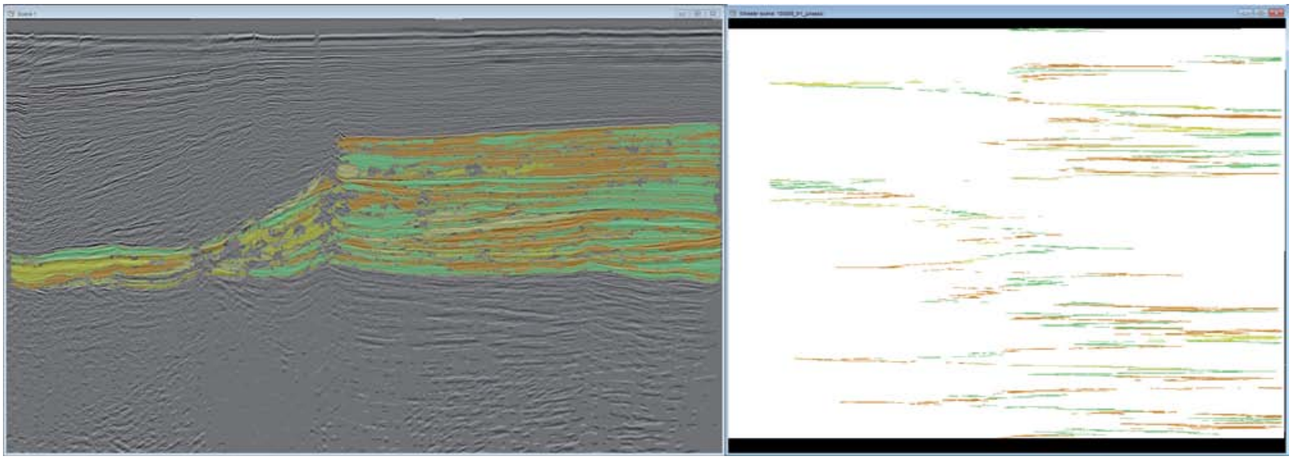

Figure 6 *Systems tract interpretation and chronostratigraphic diagram (Wheeler plot) of line C.*

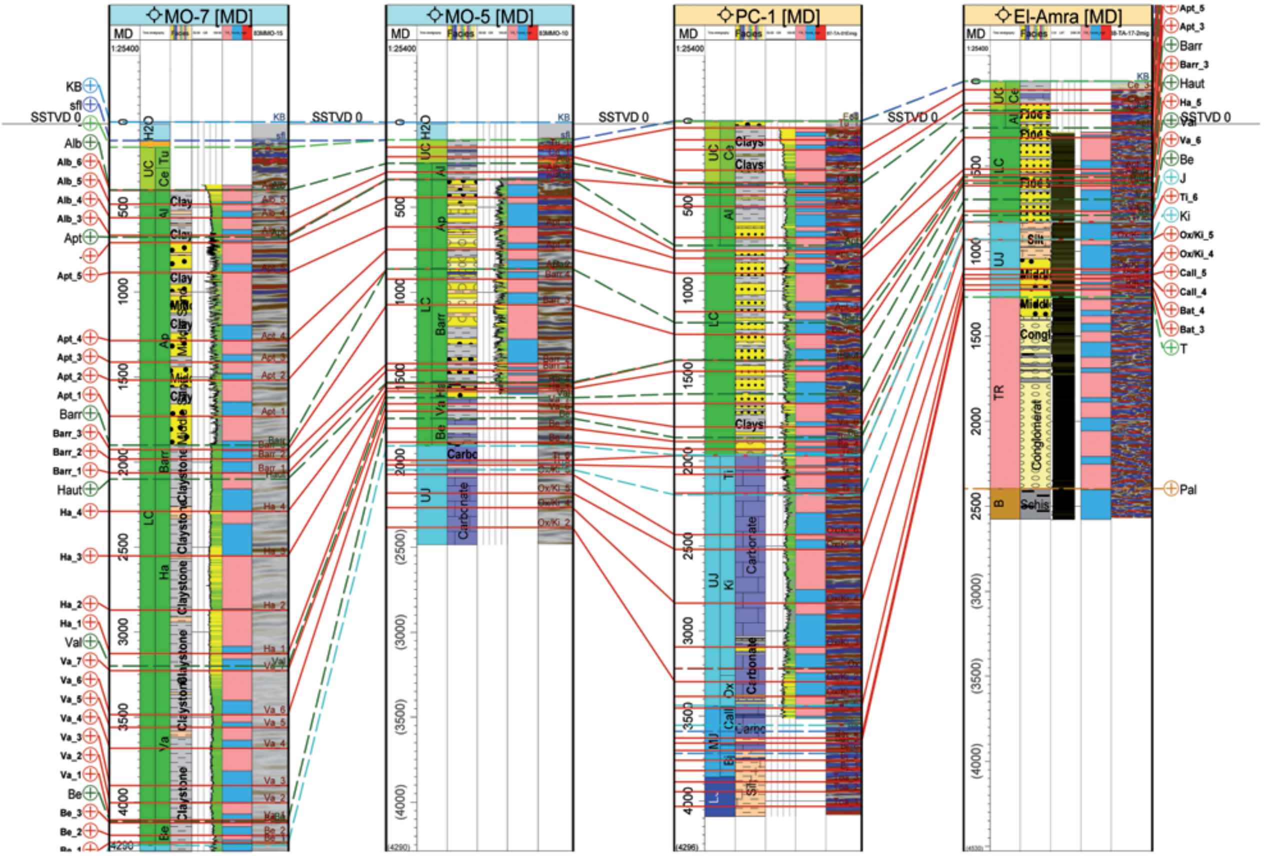

Figure 7 *Sequence stratigraphic well correlation in key transect (see Figure 4).*

order Early Jurassic to Late Cretaceous sequences have been recognized based on log pattern detection.

Well MO–5 was drilled to the Tithonian shelf margin. Well sequence stratigraphy covers the Barremian to Aptian for which a γ-ray log has been available. Late Jurassic, Berriasian to Hauterivian and Albian to recent sequences in the well correlation panel are based on seismic sequence stratigraphy. The Late Jurassic shows reefal carbonates (bryozoa, corals) with few fine clastic intercalations representing flooding surfaces. The earliest Cretaceous to Top Aptian basin fill consists of a large-scale coarsening upward trend of continuously prograding delta facies. Outer shelf to open marine fine clastics and carbonates characterize the Albian to Late Cretaceous. Coniacian to recent sediments are absent in this area. Twenty-five 3rd order sequences have been identified in the Late Jurassic to Late Cretaceous basin fill.

Well MO–7 is located in the recent shelf break area. Sequence stratigraphic log pattern recognition is based on a γ-ray log. MO-7 shows the most continuous Early Cretaceous succession with 3800 m thickness. The lowest units drilled are Tithonian calcareous siltstones of an undefined environment. Early Cretaceous sedimentation started after a major relative sea level fall in Late Tithonian/Early Berriasian. Initial sedimentation features coarse clastics overlain by fine lowstand clastic deposits of the basal fan area. The Lower Barremian succession in MO-7 includes fine-grained lower delta plain to upper slope environments. Deltafront sandstones constitute 60–65% of the Middle Barremian to Aptian succession. During the Early Albian the Tan Tan Delta became largely inactive and shallow marine to outer neritic conditions prevailed on the shelf top. The Albian sequences consist of outer shelf argillaceous to silty mudstones. The Upper Cretaceous succession of MO-7 has a thickness of 250 m and was deposited in an open marine shelf top and break environment. Twenty seven Early Cretaceous sequences have been identified in well MO–7.

Seismic sequence stratigraphy and northern Tarfaya base level curve

Figure 8 shows the integrated sequence stratigraphic interpretation (logs, seismic), Figure 9 further includes an illustration of the Meso-/Cenozoic tectonic stages and the distribution of potential reservoir formations of the transect. Coastal onlap against the Triassic occurs in the central shelf area west of the Chebeika Graben while Toarcian reflectors show prograding clinoforms in a basinward direction. Seven sequences have been interpreted in the Toarcian (Toa) interval, two of which (Toa 3/4) extend basinward to below the recent shelf break.

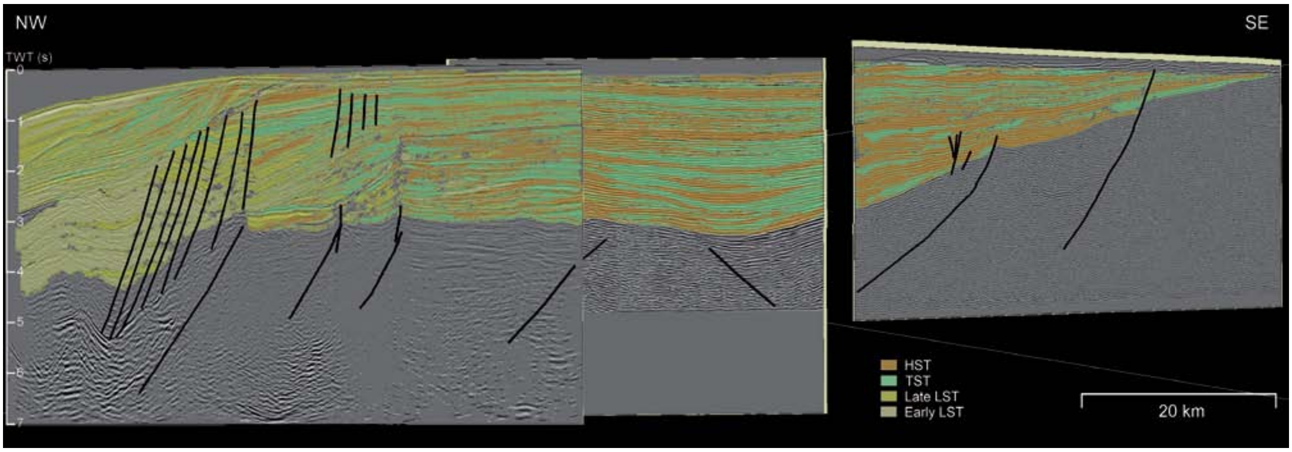

Figure 8 *High-resolution systems tract analysis of key transect (see Figure 4).*

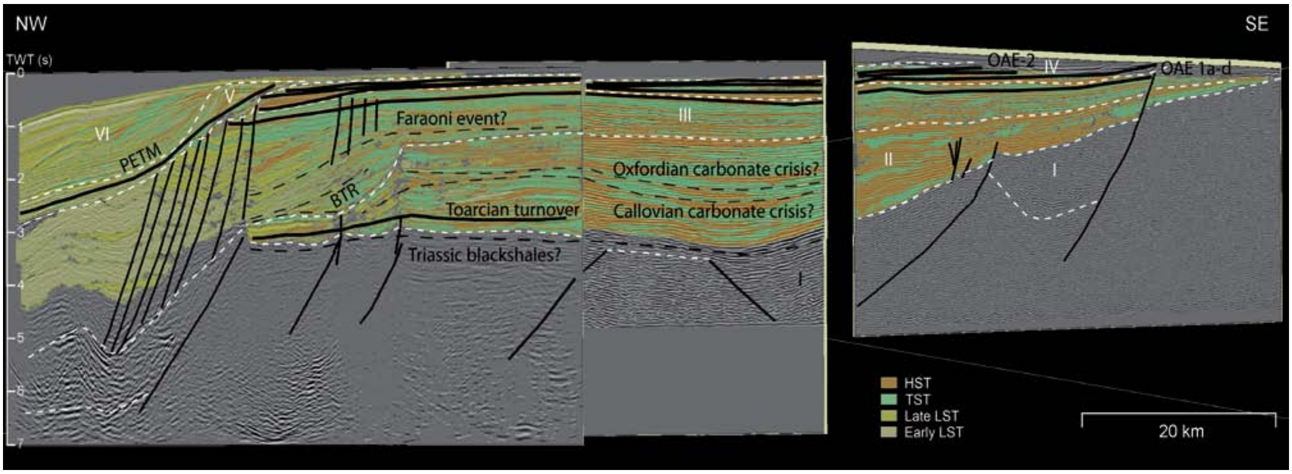

Figure 9 *Sequence stratigraphy and source rock distribution. Dashed white lines separate the tectonic stages (see text). Black lines: reflectors with potential source rock intervals. BTR: Berriasian Terrestrial Runoff, PETM: Paleocene-Eocene Temperature Maximum.*

Aalenian/Bajocian (Aa/Bj) reflector geometries indicate westward progradation of the shelf break for more than 20 km compared to its Toarcian position. Coastal onlap occurs against the Triassic rift halfgrabens in continentward position. At least six Aa/Bj sequences have been identified. The Callovian (Ca) sequences Ca 1–5 show predominant shelf aggradation with coastal onlap. Oxfordian/Kimmeridgian (Ox/Ki) reflectors do not show any specific large-scale progradation geometries. Selected features include i) an upward increasing thickness in line B, ii) retrogradation in the Kimmeridgian combined with, iii) strong eastward shift of coastal onlap. Because of the limited well and seismic data quality available, only seven sequences could be identified. During the Tithonian, the Late Jurassic shelf break again features progradation (Ti1–7). Shelf break and slope experienced a large-scale collapse in the Late Tithonian to Early Berriasian. The Top Jurassic reflector represents a major erosional unconformity, the Mature Drift unconformity. In total, 35 Jurassic sequences have been identified. The Berriasian to Valanginian is dominated by the Tan Tan Delta, which started to develop in front of the post-collapse slope of the Jurassic continental shelf.

The Berriasian delta covers seven reflectors at maximum which show onlap against the Jurassic slope and downlap towards the basin. Berriasian shelf reflector geometries show low-angle progradation on the middle to outer shelf. The Berriasian includes five sequences. Valanginian to Hauterivian reflectors show delta progradation. Stacked deep marine fans were deposited in the deep offshore until the Barremian before the depositional system started to retrograde in the Middle Hauterivian. Overall retrogradation continued until the Campanian. Aptian (Ap) thickness increases below the recent shoreline. Sequences Ap 1–4 are restricted to the outer shelf top. Sequences Ap 3–6 extend to the inner shelf top and show coastal onlap towards the continent. The Early Cretaceous includes 34 sequences.

In the northern TB, only the Cenomanian and Turonian intervals, comprising 4–5 reflectors in total without specific geometries, have been deposited or preserved on the middle shelf (Line A). The Late Cretaceous includes five sequences.

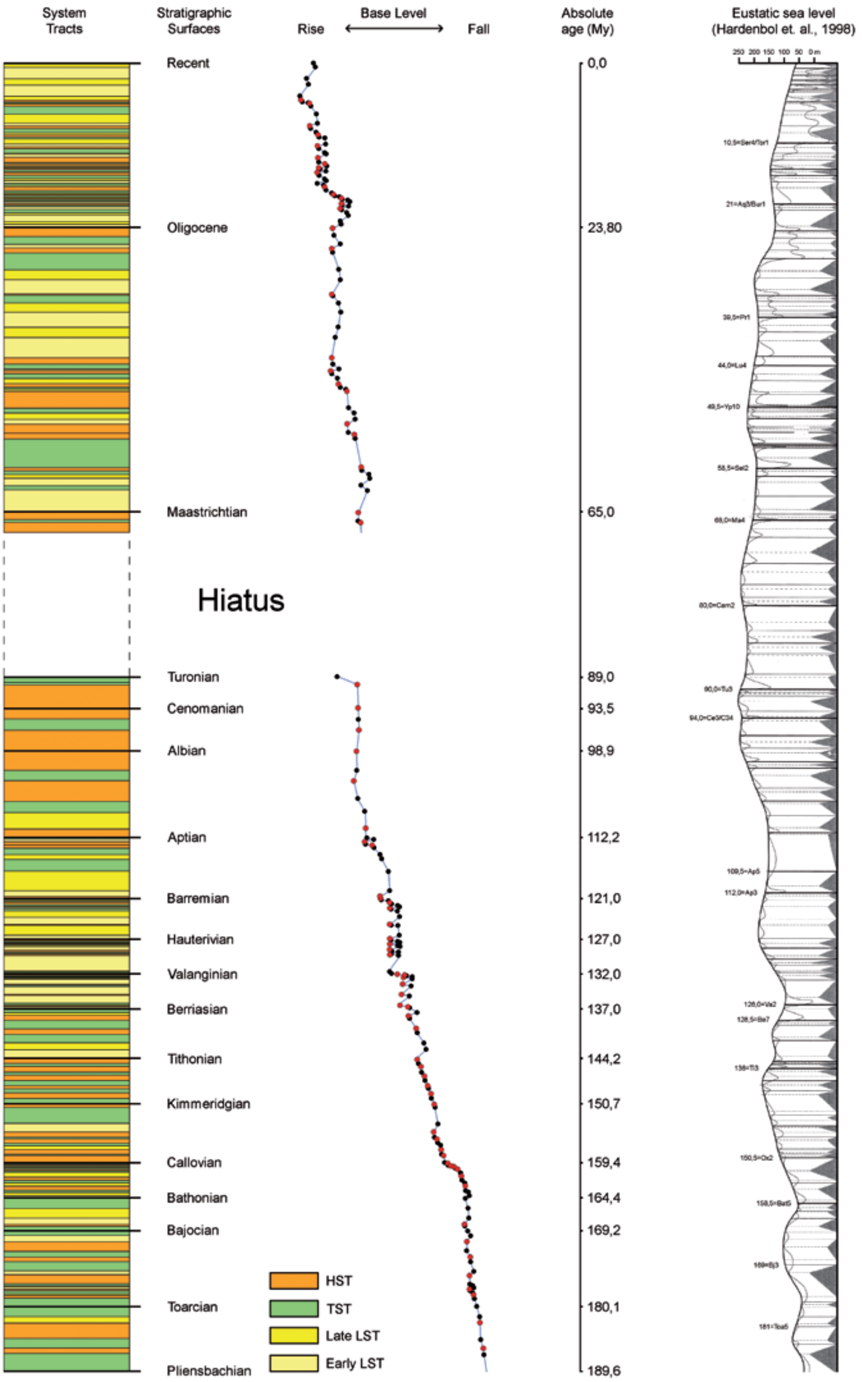

***Figure 10** Tarfaya base level curve vs. eustatic sea level curve (Hardenbol, 1998).*

The Cenozoic (except a Miocene succession of 10–15 m thickness) has not been deposited on the shelf or has been eroded and exists only west of MO-7. On the western part of Line C, the Cretaceous/Cenozoic boundary is developed as a major regional unconformity which cuts down to the Barremian succession at maximum. The Paleogene basin fill is restricted to a long-term lowstand wedge with 10 sequences in front of the Late Cretaceous shelf margin. In contrast to the Oligocene, shelf downstepping progradation characterizes the Neogene sequences. The Neogene time interval increases up to 2 s TWT at the northwestern end of Line C. Fifteen Neogene sequences have been interpreted. Additional sequences may have developed in basinward direction to the northwest of Line C.

The base-level curve resulting from high-resolution sequence stratigraphic interpretation covers the Toarcian

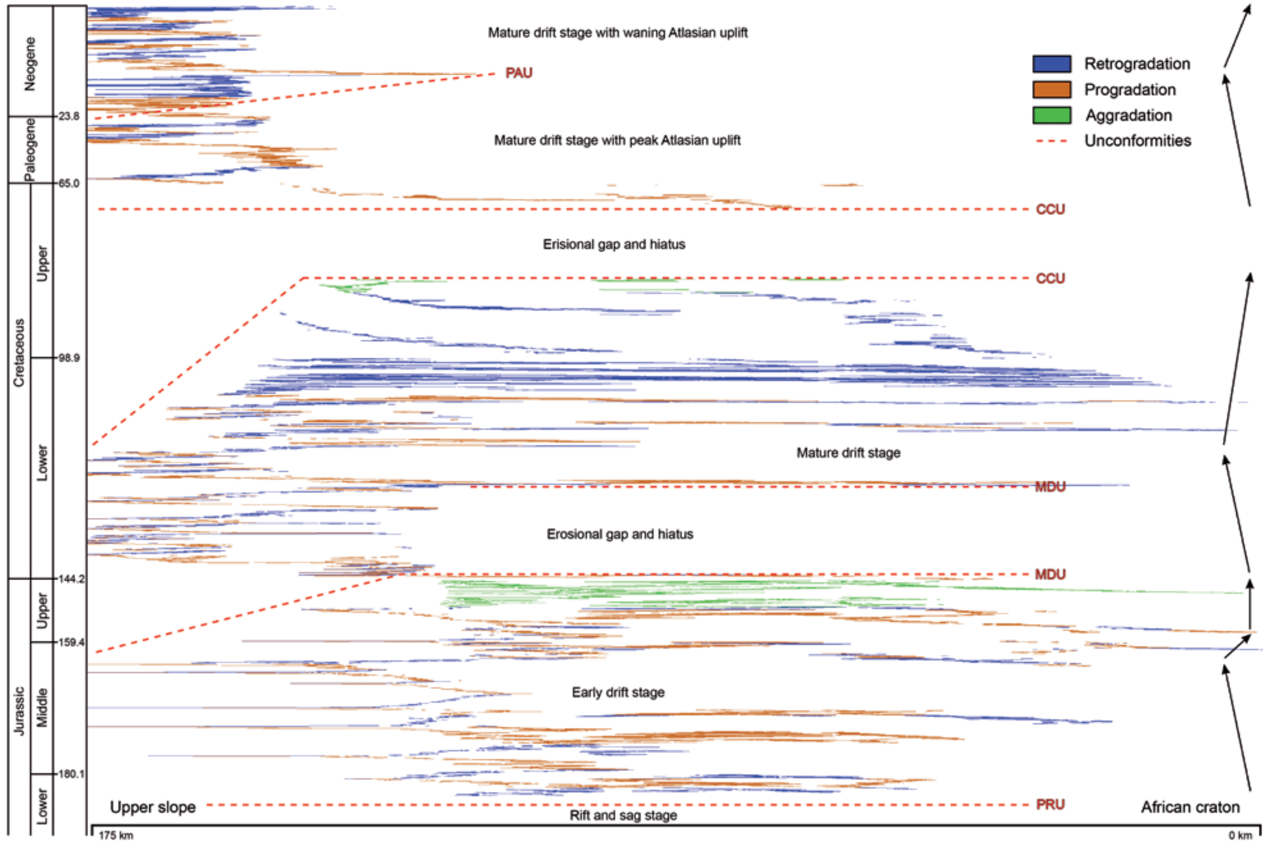

***Figure 11** Chrono-stratigraphic diagram with stages of basin development.*

to Holocene (Figure 10). Base-level is controlled by eustatic sea level, marine erosion depths and total subsidence. Base-level changes in the TB have been tentatively correlated to eustatic sea level changes as inferred from the sequence stratigraphy of European basins (Hardenbol et al. 1998). Long-term (2nd order) relative base level trends as interpreted in the TLB are largely comparable to eustatic sea-level changes on the Eurasian plate. Short-term (3rd order) relative base level changes (shorter than 3–5 Ma) indicate regional subsidence trends specific to the TLB.

Source rocks of the Tarfaya Basin

Subordinate hydrocarbon shows have been encountered in the Triassic of the TLB, but their origin is questionable. Intra-Triassic hydrocarbon shows have been tentatively attributed to Silurian and Devonian source rocks. Toarcian source rocks are well known from outcrops of the Western Tethys and Proto-Atlantic (Macgregor, 1994; Jenkyns et al., 2002). Hydrocarbons probably sourced from Late Triassic or Toarcian source rocks (ONAREP, 2003) have been discovered in the Cap Juby and MO–2 wells. Potential source rocks related to the Callovian and Oxfordian carbonate crises exist in the Essaouira Basin, where productive oil fields have existed since the 1970s (MacGregor, 1994). Lower Cretaceous source rocks in the TLB also occur in the Berriasian and Hauterivian (Faraoni event, ONAREP, 1985).

Aptian to Campanian oceanic anoxic events (OAE 1a-d, OAE 2, and OAE 3) are well developed in the TLB (e.g., Sachse, 2011). They show high TOC, but low maturity. Excellent oil-prone source rocks developed during the PETM event which have been recognized on- and offshore. They are mainly immature in shelf and slope areas, but are probably productive in the deep offshore.

High-resolution well sequence stratigraphy detection in combination with detailed organo-chemical well evaluation allows to allocate the (sequence) stratigraphic position of high organic-bearing strata. A correlation of literature data combining sequence stratigraphy and organo-chemistry with the presented well and seismic sequence stratigraphic frameset defines reflectors which may represent potential source rock formations. The stratigraphic position and local distribution of potential source rock facies on the seismic key transect are highlighted concurrent to tectonic stages in Figure 9. The distribution of anoxic events in the basin fill have been identified and correlated from literature, mud log descriptions, organo-chemical analyses (Kuhnt et al., 2005; Mort et al., 2008; Sachse et al., 2011) and outcrops samples.

Chrono-stratigraphic diagrams and distribution of source and reservoir formations

Figure 11 shows a chrono-stratigraphic diagram for the TB transect including times of progradation, aggradation, and retrogradation, also major unconformities and their correlative conformities. The distribution of source and reservoir facies is shown in Figure 12. Jurassic drift sedimentation started on top of an erosional unconformity which cuts into Triassic rift, post-rift, and sag basins and represents the Post-Rift Unconformity (PRU). The Jurassic ramp and platform system is bounded on top by the Mature Drift Unconformity (MDU) which marks the end of the early drift stage. While sedimentation continued in the deep offshore, a hiatus of up to 12 mya characterizes the outer and inner shelf top. Growth faults triggered by Early Cretaceous salt flow and large-scale shelf retrogradation during the Late Cretaceous led to the Cretaceous Combined Unconformity (CCU).

The uplift of the Western High Atlas started in the Late Oligocene and led to an increase in clastic input during the Neogene. The Peak Atlasian Unconformity (PAU) separates the Paleogene shelf margin wedge from Neogene bypass sedimentation.

The Early Jurassic clastic-carbonate ramp systems include six long-term progradation/shallowing-upward cycles until the Middle Callovian which is made visible in the chrono-stratigraphic diagram. Subsequent to three retrogradation/deepening-upward cycles in the Middle Callovian to Late Kimmeridgian, shelf aggradation prevailed during the Tithonian. Deposition successively shifted to the cratonward parts of the continental margin (central, inner shelf).

Between Hauterivian to Coniacian times, the continental shelf experienced major retrogradation, triggered by increasing accommodation space. In addition, sediment input sharply decreased, and the Tan Tan Delta became inactive by the Late Aptian to Early Albian. Initial deposition above the CCU includes Late Maastrichtian outer shelf deposits.

The Maastrichtian to Lower Oligocene is restricted to the NW part of the transect. After a progradation/retrogradation cycle, deposition took place in a very small area at the shelf break. Paleogene sediments may have been deposited on the shelf but were eroded in Late Oligocene.

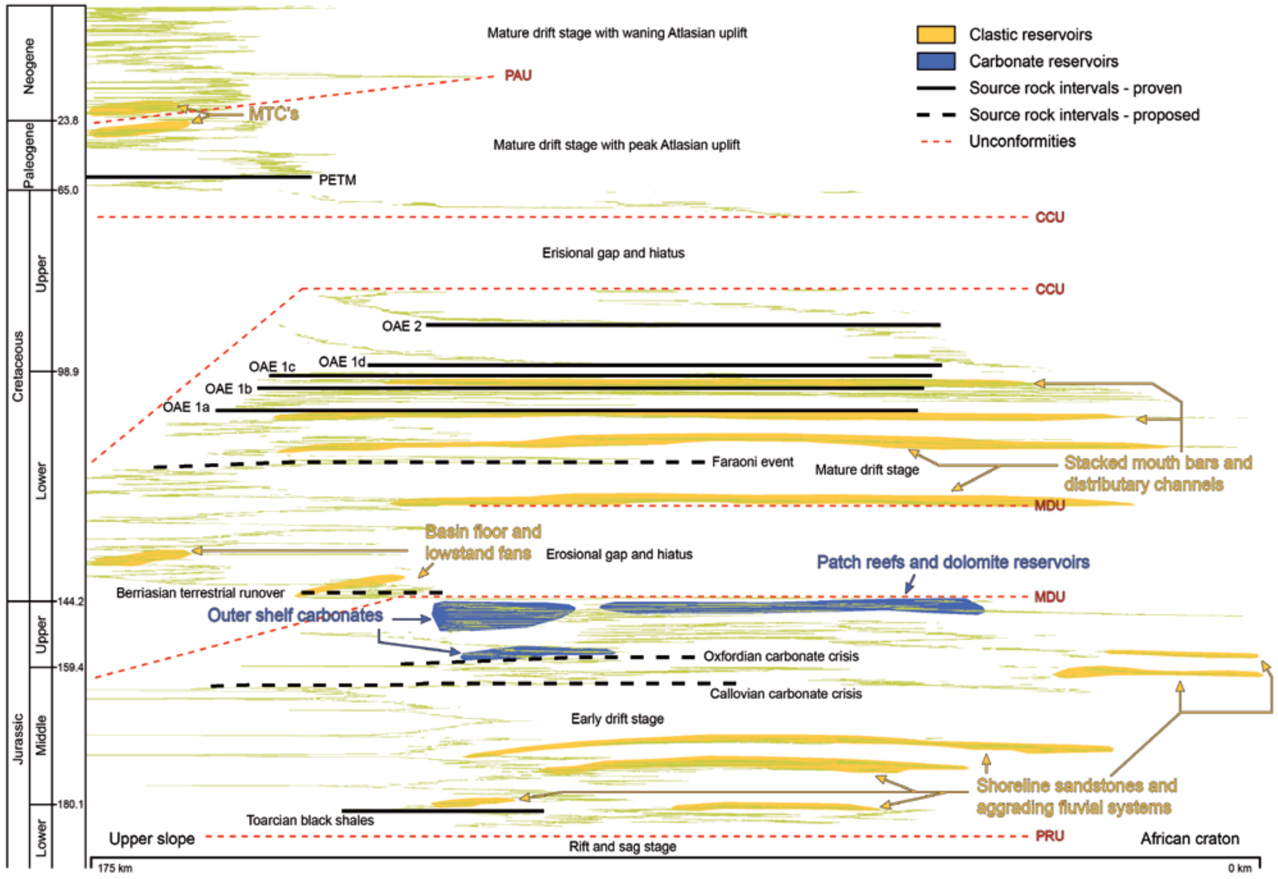

Figure 12 Chrono-stratigraphic diagram with highlighted source and reservoir facies distribution.

Retrogradation took place in the Middle Miocene, when clastic sediments were deposited on the shelf.

The illustration of potential source rock distribution was performed analogous to the sequence stratigraphic interpretation (cf. Figure 9).

Potential reservoir intervals include: i) Lower to Middle Jurassic: shoreline and shelf-top sandstones, and aggrading fluvial systems. Shoreline sandstones and aggrading fluvial systems retrograde cratonward related to a continuous eustatic sea-level rise while the distribution of shelf top sandstones extends in both basin and craton direction; ii) Kimmeridgian to Tithonian: reefal shelf margins, carbonate shelf top with karstification, fractured shelf-top dolomites. Shelf margin reservoirs are bounded to outer shelf regions while patch reef reservoirs and fractured dolomite reservoirs facies are mainly located in central and outer shelf areas; iii) Berriasian to Middle Valanginian: basin floor and lowstand fans, which are bounded to the Jurassic slope-collapse area; iv) Late Valanginian to Aptian: delta system incl. stacked mouth bars, distributary channels. They show wide extension across the shelf; v) Cenozoic: coarse-grained mass transport complexes, associated to the peak Atlasian uplift or the strong Serravalian eustatic sea level fall. These reservoirs are bounded to the deep offshore.

Major seal formations are i) Lower to Middle Jurassic mudstones; ii) Upper Cretaceous shales; and iii) Lower and Upper Miocene fine clastic deposits.

Conclusions

A high-resolution sequence stratigraphic model for the TLB has been developed from outcrop, well log, and 2D seismic data. The interpretation of 17 formation tops, well log pattern detection, and sequence stratigraphic analysis has enables the identification of 89 sequences in the Pliensbachian to Holocene basin fill. The resolution of this chrono-stratigraphic framework is so far unparalleled in the TB and similar continental margin basins. The approach allows a significantly improved assessment of the position and lateral shifts of reservoir and source rocks in under-developed basins and helps to develop new play scenarios.

Coniacian to Early Maastrichtian sequences of the northern TB (Wenke et al., 2011) have not been preserved. They were eroded following Oligocene flexural uplift. The Cenozoic basin fill features major depositional/erosional gaps, but is more continuous in the deep offshore, which has not been covered by the presented transect. Sequences have an average duration of 1.7 Ma. 4th order parasequence interpretation reaches reservoir scale. Thirteen potential source rock and 11 reservoir units have been identified. Regional unconformities in the TB can be traced to adjacent Moroccan continental margin segments (Agadir and Essaouira Basins to the north, Dakhla Basin to the south). They separate six stages of basin development. Above the rift basin, the Jurassic carbonate ramps and platforms are bounded by the basal PRU and the MDU. The Jurassic shelf contains 35 sequences. Potential source rocks include: i) Toarcian black shales (Toa 3/4) basinward of the prograding ramps, ii) Callovian slope and inner to outer shelf areas (Call 4/5), and Late Oxfordian outer shelf areas (Ox/Ki 3). Reservoir units occur in the Toarcian to Bajocian clastic highstand to early lowstand slope units and mass transport complexes. Karstified and dolomitized Tithonian outer to mid shelf carbonates represented further potential reservoirs.

The Early Cretaceous Tan Tan Delta Complex is bounded by the basal MDU and the Aptian Unconformity (apU) and contains 27 sequences. A relative sea level fall led to increased erosion of the continental source areas. The Berriasian Terrestrial Runoff (BTR) allowed the development of kerogen type-III source rocks in the Berriasian and Valanginian. Indications were found in well MO-7 (Ellouz et al., 1998). Further indications for the presence of Late Hauterivian source rocks (Ha 3/4) are known from the Cap Juby area. Potential reservoir formations developed in Berriasian shelf margin (toplapping units of Be 3/4) and Barremian to Aptian delta to shoreface environments. The Late Cretaceous of the TLB is bounded by the basal apU and the Cenozoic-Cretaceous unconformity (CCU). This unit includes six potential oil-prone source rocks, which are immature but may have unconventional potential (Sachse et al., 2011). The Paleogene shelf wedge geometry is bounded by the CCU and the PAU whose development is related to the uplift of the Western High Atlas.

Source rocks of the PETM event are part of the Pal2/Eoc1 sequences. Corresponding reservoir formations occur in Upper Oligocene (Oli 3) and Miocene mass transport complexes. They may represent interesting plays in the deep offshore salt province.

The integrated high-resolution sequence stratigraphy of this study presents a powerful tool for basin reconnaissance at an early stage of new venture exploration.

Acknowledgements

The first two authors are greatly indebted to ONHYM, Rabat, and RWE Dea, Hamburg. Seismic and well data for this study have been made available by ONHYM. The associated PhD project of the first author has been supported by RWE Dea. Seismo-stratigraphic and well-log interpretation has been performed with Petrel 2009 (Schlumberger), seismic systems tract analysis with OpendTect 4.0 SSIS (dGB Earth Sciences).

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