[PS]Seismic Expression of Low-Angle Clinoforms in Ancient Deltaic Systems: Implications for Stratigraphic Modelling*

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Abstract

Upper Miocene deltaic reservoir sands located in the Vienna Basin contain substantial remaining HC potential. Although the studied production unit has been extensively drilled, previous studies could not fully explain reservoir connectivity issues. The recognition of different scale heterogeneities in reservoir modelling studies is a prerequisite to understand fluid flow behaviour that supports optimal design and implementation of flooding patterns and subsequent EOR activities.

During the ongoing study detailed mapping of seismic signatures was carried out in the reservoir using Relative Acoustic Impedance (RAI) and Spectral Decomposition (SD). The attributes used enhance the expression of depositional elements at different scales and allow the identification of geologic patterns such as low-angle clinoforms and previously unrecognized morphological progradation/aggradation events. The seismically imaged morphological characteristics suggest an intricate reservoir facies distribution. The patterns observed might be linked to a fast and changing interplay between accommodation space and sediment supply, different feeders and/or source-shifting that are inferred to be acting over the deposition area. This complex scenario renders largely ambiguous a definition of flow units based on a purely lateral well-to-well log correlation.

It is concluded that a more accurate interpretation of flow units could be achieved using the aforementioned seismic attributes together with a classical stratigraphic modelling approach and available reservoir information. The value added with the use of these attributes certainly impacts the geological understanding during integrated multidisciplinary reservoir model workflows. At the subsequent study stage during dynamic simulation this may lead to improved understanding of the flow behaviour.

References

Boyles, M., and Boyd, D., 2009, Shoreline and shelf reservoir systems: Outcrop lessons for Exploration & Production (NW Colorado, USA). Nautilus Course handouts.

Bureau of Economic Geology. 1998, Optimizing hydrocarbon recovery from the Matzen Field, Vienna Basin, Austria. Phase 2b Project Review.

Chopra, S., and Marfurt, K.J., 2007, Seismic attributes for prospect identification and reservoir characterization: Geophysical Developments No. 11, EAGE.

Enge, H. D., and Howell, J.A., 2010, Impact of deltaic clinothems on reservoir performance: Dynamic studies of reservoir analogs from the Ferron Sandstone Member and PantherTongue, Utah: AAPG Bulletin v. 94, p. 139-161

Fuchs, R., and Hamilton, W., 2006, New depositional architecture for an old giant: The Matzen field, Austria, *in* J. Golonka and F. J. Picha, eds., The Carpathians and their foreland: Geology and hydrocarbon resources: AAPG Memoir 84, p. 205-219.
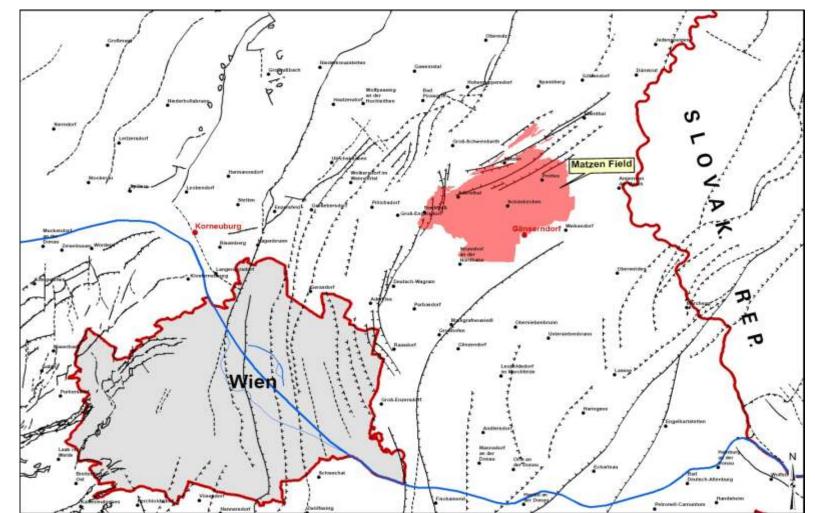
Møller, Lausen, O.R., 2009, Clinoform migration patterns of late Miocene delta complex in the Danish Central Graben; implications for sea-level changes: Basin Research No 2, EAGE, p. 704-720.

Seismic Expression of Low-Angle Clinoforms in Ancient Deltaic Systems: Implications for Stratigraphic Modelling

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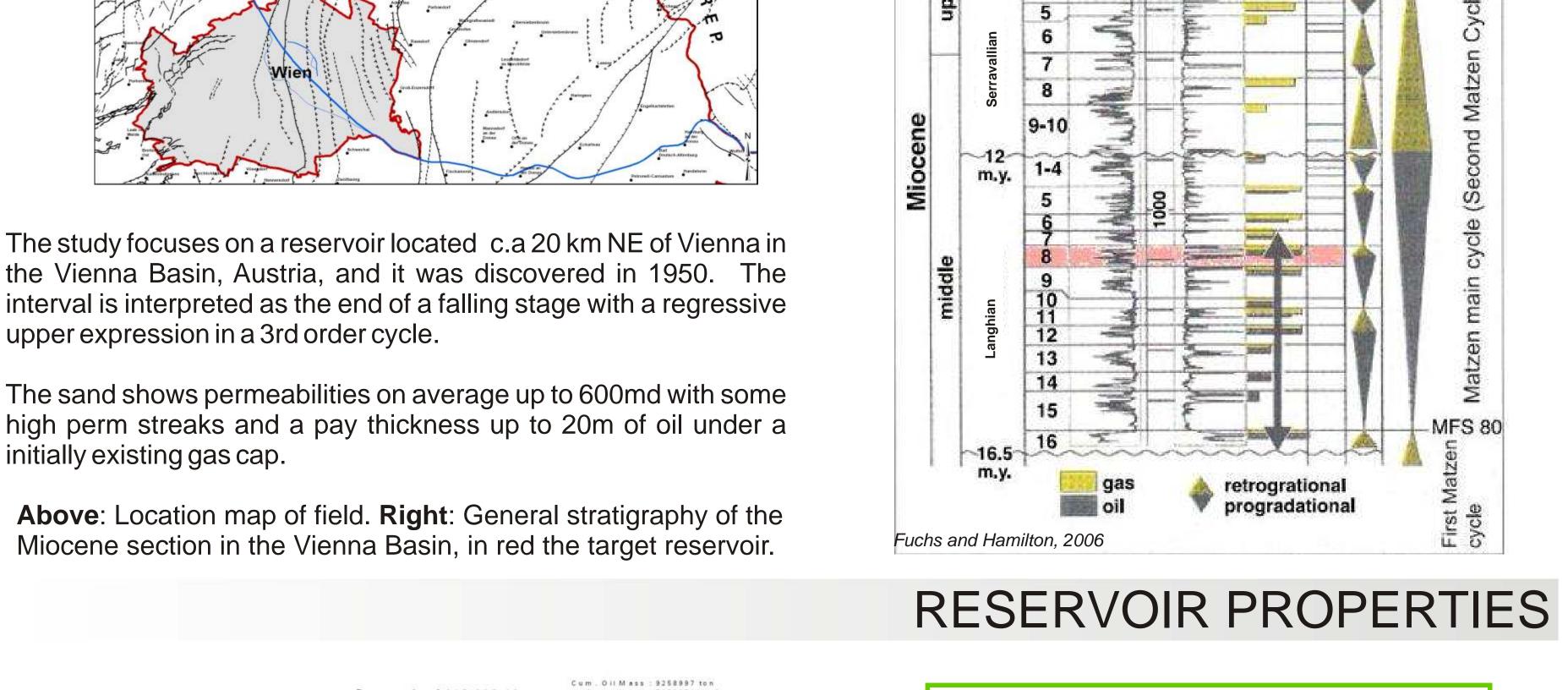** OMV Exploration & Production GmbH, Gänserndorf, Austria

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Upper Miocene deltaic reservoir sands located in the Vienna Basin contain substantial remaining HC potential. Although the studied production unit has been extensively drilled, previous studies could not fully explain reservoir connectivity issues. The recognition of different scale heterogeneities in reservoir modelling studies is a prerequisite to understand fluid flow behaviour that supports optimal design and implementation of flooding patterns and subsequent EOR activities. During the ongoing study detailed mapping of seismic signatures was carried out in the reservoir using Relative Acoustic Impedance (RAI) and Spectral Decomposition (SD). The attributes used enhance the expression of depositional elements at different scales and allow the identification of geologic patterns such as low angle clinoforms and previously unrecognized morphological progradation/aggradation events. The seismically imaged morphological characteristics suggest an intricate reservoir facies distribution. The patterns observed might be linked to a fast and changing interplay between accommodation space and sediment supply, different feeders and/or source-shifting that are inferred to be acting over the deposition area. This complex scenario renders largely ambiguous a definition of flow units based on a purely lateral well-to-well log correlation. It is concluded that a more accurate interpretation of flow units could be achieved using the aforementioned seismic attributes together with a classical stratigraphic modelling approach and available reservoir information. The value added with the use of these attributes certainly impacts the geological understanding during integrated multidisciplinary reservoir model workflows. At the subsequent study stage during dynamic simulation this may lead to improved understanding of the flow behaviour.

GEOLOGICAL SETTING

The study focuses on a reservoir located c.a 20 km NE of Vienna in the Vienna Basin, Austria, and it was discovered in 1950. The interval is interpreted as the end of a falling stage with a regressive upper expression in a 3rd order cycle.

The sand shows permeabilities on average up to 600md with some high perm streaks and a pay thickness up to 20m of oil under a initially existing gas cap.

Above: Location map of field. **Right:** General stratigraphy of the Miocene section in the Vienna Basin, in red the target reservoir.

Fuchs and Hamilton, 2006

RESERVOIR PROPERTIES

Left: Production profile of the studied reservoir. **Right:** Table with main reservoir parameters.

Key Reservoir Parameters		
Reservoir Pressure	80 - 130	bar
Permeabilities	300 - 1200	md
Porosity	25 - 30	%
Viscosities	5 - 25	cp
Mobility Ratio	3 - 8	[-]
VRR	50 - 100	%
Injectivity Index	5 - 25	m³/d/bar
Avg. FWHIP	10 - 90	bar

To date, some 9.9 million m³ of oil and 1.4 billion m³ of gas have been produced with a RF of ~38% (WC=96%, 19°API). The reservoir was developed by completing 340 producing wells in total. The waterflood concept is a peripheral injection pattern. Presently 99 wells are active and 9 of them are injector wells.

CORE DESCRIPTION

Several transgressive reworking features such: sharply-based bioclast, bioturbated sandstones with a basal *Glossifungites* firmground surface are interpreted as transgressive ravinement surface.

Phycosiphon, Scolicia, Zoophycus, Ophiomorpha, Planolites and *Cylindrichnus concentricus* document a marine character.

No evidence of subaerial exposure or crevasse channel/splay features argue against a delta plain environment as proposed by previous authors.
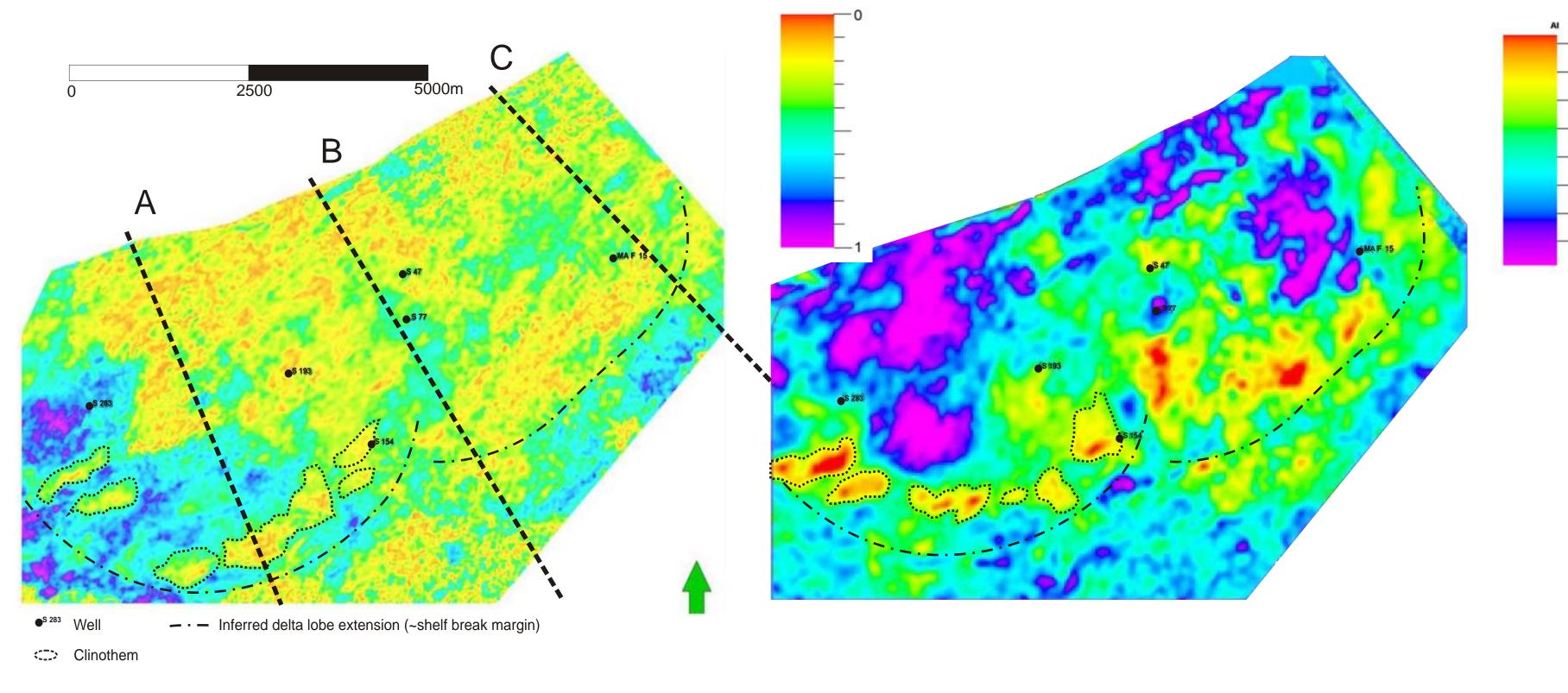
The depositional enviroment is interpreted as marine deltaic system with local evidences of a tidal influence and probably partly barrier shoreface system.

Sedimentary structures support a transgressive backstepping of the sediments with frequent transgressively reworked sand shoals/ridges interpreted to have been deposited during falling stage systems tract. Transgressive ravinement surfaces can be considered as amalgamated transgressive surfaces/sequence boundaries.

Incised features are recognized in the East, most likely tidal channel-shoal sandstones together with the fining-upward log signature that argue for a transgressive filling event. The repetition of transgressively reworked sandstones throughout the reservoir demonstrates high- frequency sea-level fluctuations.

SPECTRAL DECOMPOSITION AND RELATIVE ACOUSTIC IMPEDANCE

Left: Normalized Colored Spectral Decomposition (SD) at tunning frequency (50Hz). **Right:** Relative Acoustic Impedance (RAI). Notice the match of elongated shapes with high SD amplitude values and high values of RAI in the SW corner. Both images are time slices from flattened seismic at Top Reservoir and display well locations with core descriptions.

A Spectral Decomposition attribute provides a set of frequency slices around the horizon of interest and allows the interpretation of interference patterns such as thin-bed tuning associated with channels and deltas in plan view. These changes can be related qualitatively to the thickness of the imaged elements. Textures and patterns are indicative of geological processes *(Chopra and Marfurt, 2007)*. It is important to have a good understanding of the depositional environment prior to interpretation.

Colored Inversion applies an operator, O, in the frequency domain to a seismic trace to transform it into impedance. It is a fast method and therefore good for a first pass inversion. It also does not need a detailed initial model.
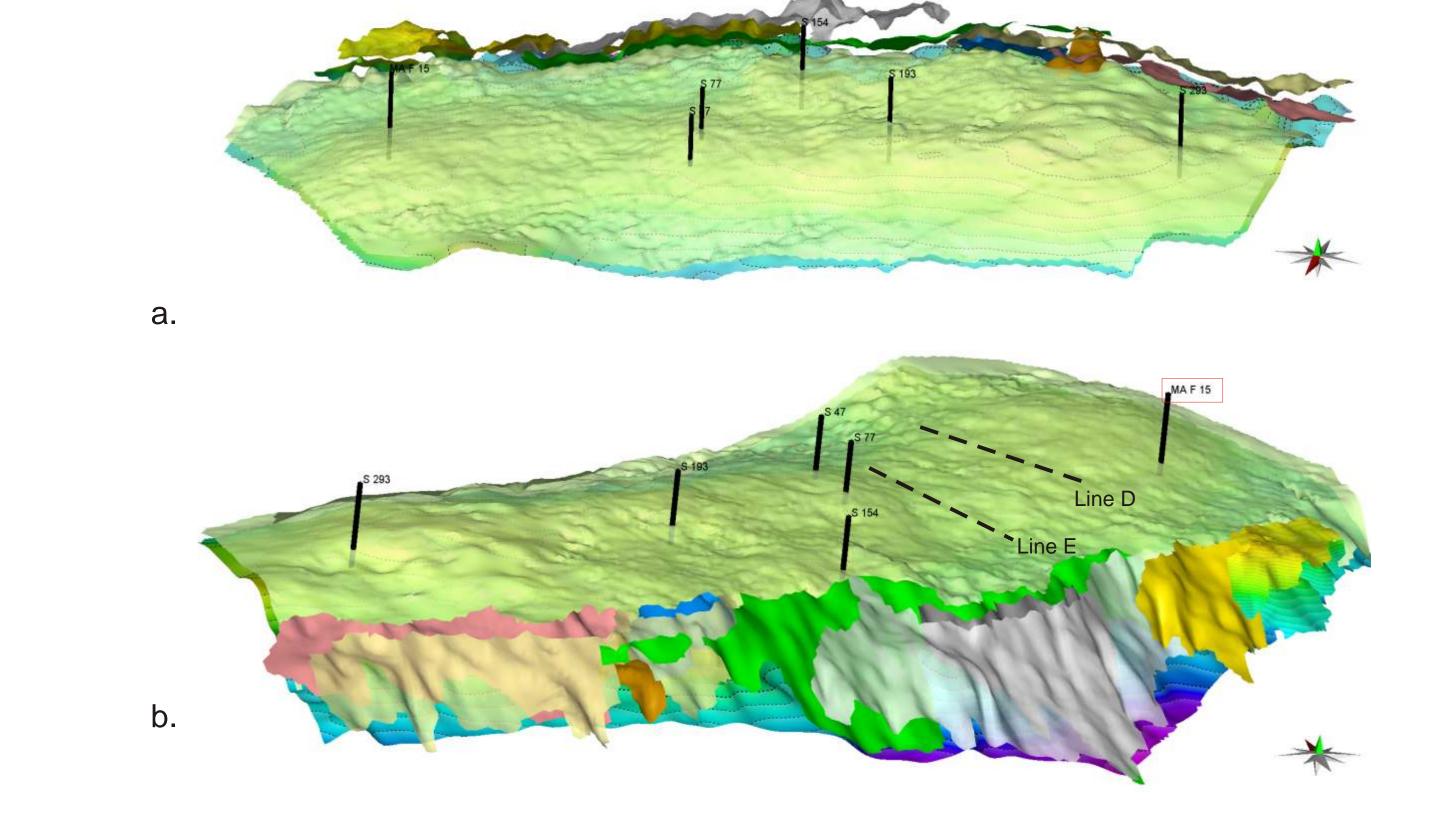
Impedance=Operator convolved with Seismic
The operator is -90° and spectral shaping.

1. A relation between Amplitude/Frequency spectra between well and seismic data is established.

2. These spectra are used to calculate an operator, which shapes the seismic spectrum to the well impedance spectrum.

3. This operator is combined with the 90° phase shift to create the Colored Inversion Operator.

4. This operator is convoluted with the seismic traces to compute the Relative Acoustic Impedance from reflectivity data.

Above: Dip Seismic Sections (plan view time slide SD attribute) at different locations in the reservoir. Notice the change in dip towards the east (from A, B and C).

SEISMIC ANALYSIS

The seismic used for interpretation is a pre-stack depth-migrated cube converted back to time. The interest area is cropped from the regional mega-survey. The cropped volume is 539 inlines and 658 crosslines with a sampling interval of 25.

The vertical resolution of this survey is app. 25 m. A detailed well to seismic tie in 3 wells resulted in the identification of zero-crossing events as the major reservoir bounding surfaces.
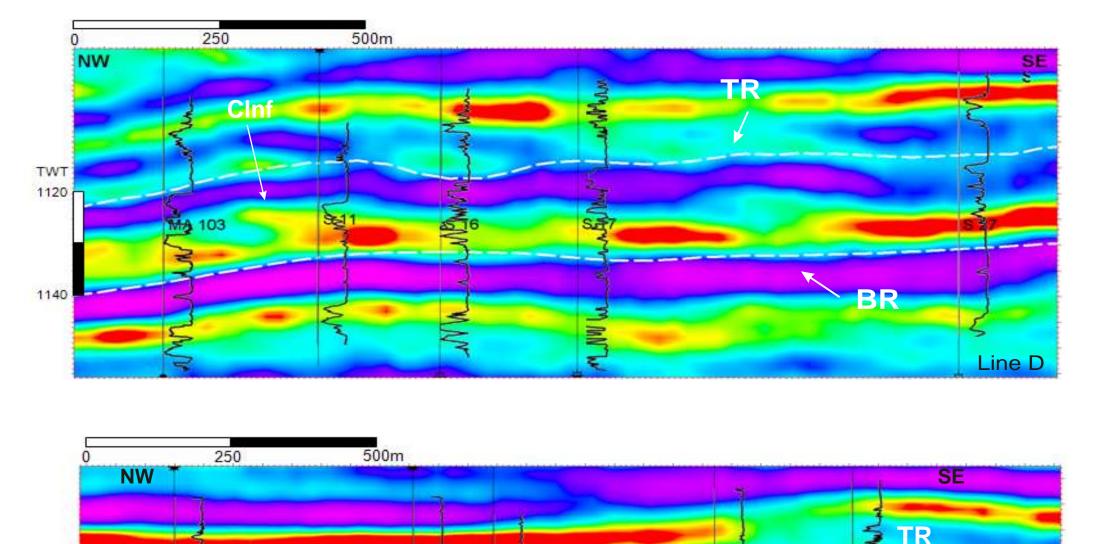
Several reservoir seismic events are mapped: Top Reservoir (TR), Base Reservoir (BR) and intra-reservoir reflections to define internal geometries. These intra-events are characterized by seismic facies such as parallel continuous, parallel discontinuous and sigmoidal type.
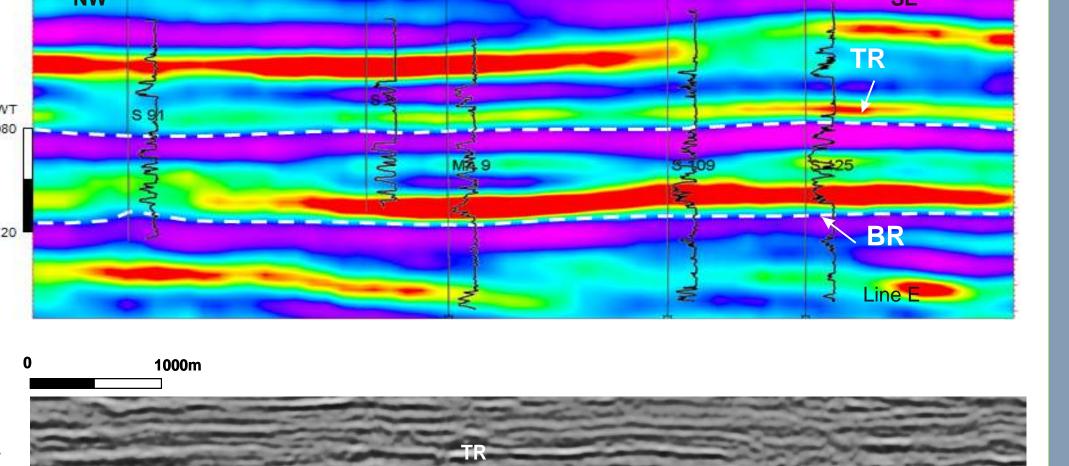
Resolving the complexity of the BR is only possible by enhancing the subtle geological changes with attributes like RAI. The seismic thickness of the section changes laterally.
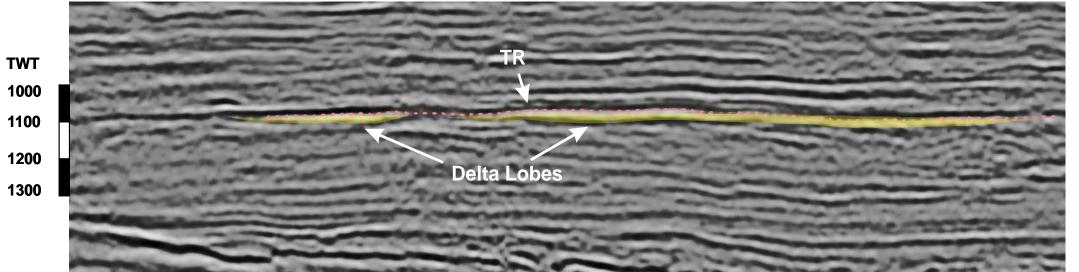
A thicker sequence is developed in the southern flank of the structure coinciding with the interpreted shelf margin of the prograding delta. Here, gently intra-clinothem expressions suggest the migration of the slope position indicated by the migration of the off lap break.

Right Top: RAI TWT sections (see figure left for location) a) exhibits the morphological expression of the clinoforms (Clnf) in the reservoir. Inclination varies from c.a 0.3° to 3° from well log correlations. b) Fining-upward incision features resolved by RAI.

Right Bottom: E-W Seismic section at the middle of the area highlighting the lateral offset of seismic events interpreted as delta lobes. The westernmost lobe appears to be disconnected from the multi-lateral stacked lobes in the East. Pressure data, not shown here, suggest a slight discontinuity between both regions. The western lobe develops the clinoform expressions which are identified in the RAI flattened time. The east lobe is interpreted to contain the prominent incision features identified both in core and well-log sections.
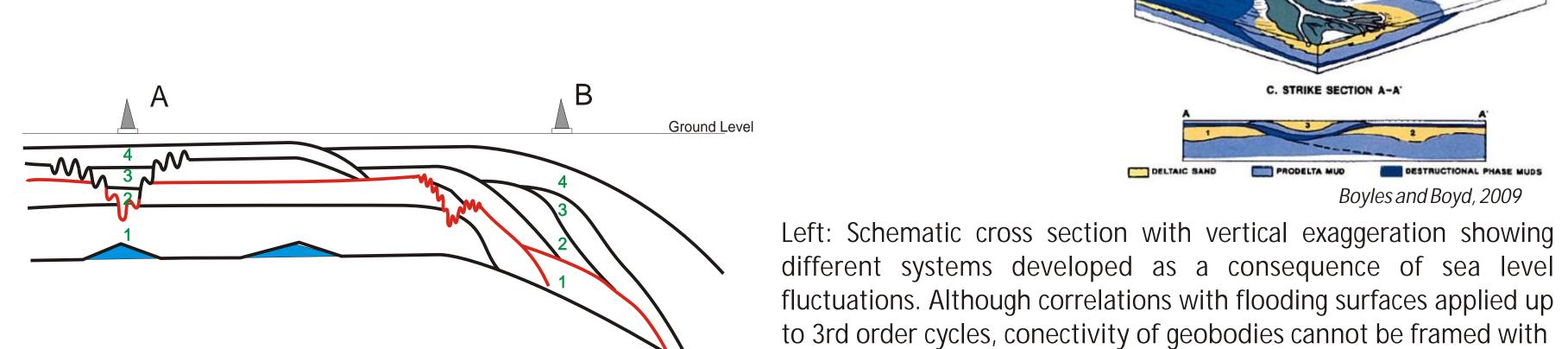
Above: a) Tilted plan view (from south to north) showing seismic elements. Both shallow and steeply dipping at the platform margin unravel the intricate coalescent architecture and lateral amalgamation of clinothems. Well locations show available core material. b) Oblique view showing the drapping nature of the seismic elements mapped. In red well MA F 15 with core description presented in previous section . Chronologically they develop from west to east reaching the maximum thickness where more accommodation space seems to be available for the sequence.

STRATIGRAPHIC MODELLING AND IMPLICATIONS

Stratigraphic modelling is a prerequisite for static reservoir building. Often due to dynamic simulation limitations models are upscaled and geological details are condensed. However architectural styles of the reservoirs are captured when a sound conceptual model is used in the correlations.

The reservoir was previously described as a fluvial dominated delta and it was correlated using the petrophysically defined sands that occurred at the same stratigraphic horizon relative to flooding surface datum. New seismic and re-interpretation of the available core material plus seismic attributes suggest a more complex system in which several delta lobes ranging between tide and fluvial dominated may be closely related.

The resulting concept used to correlate the main changes in accommodation depicts two delta lobes. These lobes could be the result of sediment source shifting related to the strike movement of the faults bounding the basin. The eastern lobe suggests a more fluvial-dominated nature (mouth bars) whereas the western one seems to be tide-influenced.
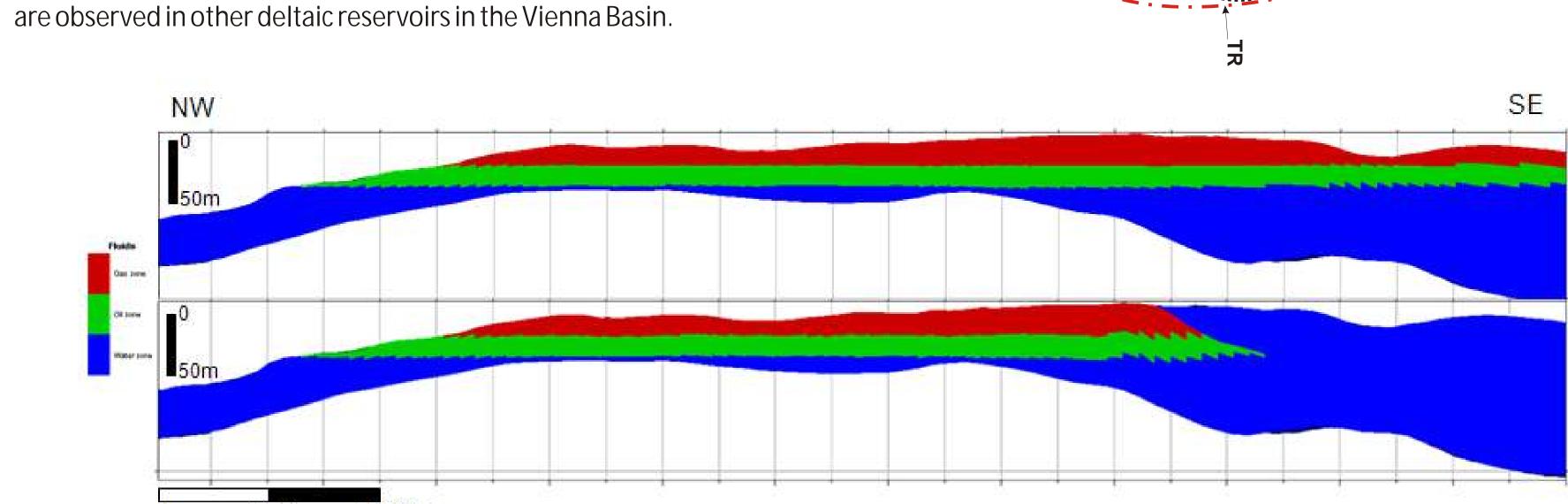
Right: a) Reservoir section showing the flooding surface subdivision (in blue *BGE, 1998*) compared with a more general approach wich follows the identification of major change in accommodation pattern (CAP) in the section. This CAP matches the intra-seismic zero crossing event in the reservoir. b) Conceptual depositional model for the study interval upper block diagram resembles the eastern delta lobe. The lower diagram depicts the interpretation for eastern lobes.

Boyles and Boyd, 2009

Left: Schematic cross section with vertical exaggeration showing different systems developed as a consequence of sea level fluctuations. Although correlations with flooding surfaces applied up to 3rd order cycles, conectivity of geobodies cannot be framed with these internal flooding surfaces.

Right: Schematic architecture of clinoforms coalescing along the shelf margin (black dotted line). Observe the intricate build-up of clinoforms in between TR and BR (red dotted lines); this pattern is observed in seismic lines with RAI used for detailed mapping. Clinothem features are traceble for distances up to 1 km. These coalescing patterns are observed in other deltaic reservoirs in the Vienna Basin.

Above: a) Simple case fluid distribution for gas and oil using lithostratigraphic correlation approach. Closure of the field is controlled by structural relief. b) Simple case fluid distribution using the mapped clinothems as a geometrical constraint to bring stratigraphic closure in the reservoir. Wells drilled in the most SE region confirm the absence of hydrocarbons.

Fluid distribution: Modelling fluid distribution on the periphery of the reservoir is a challenging task. Steeply dipping clinothems can add potential attic oil. Contrary, low-angle character may result in ineffective lateral seals and complicated rock type distribution that may affect the saturation distribution.

Correlation of geo-bodies: Geological features are enhanced by attributes and these seismic events can be incorporated into correlations with a reasonable velocity model. Lithostratigraphic correlations using flooding surfaces straight from well logs do not relate genetically to the ocurrence of seismic events. Incision features and prograding clinothems are not fully resolved in a 3D correlation scheme purely on well log basis due to log quality and the large or small number of observation points. Detailed seismic mapping supported by specific attributes and an accurate velocity model may help to achieve this task.

References:

Boyles, M. and Boyd, D. 2009, Shoreline & Shelf reservoir Systems: Outcroop Lessons for Exploration & Production (NW Colorado, USA). Nautilus Course handouts.
Bureau of Economic Geology. 1998, Optimizing Hydrocarbon Recovery from the Matzen Field, Vienna Basin, Austria. Phase 2b Project Review
Chopra, S. Marfurt K. J. 2007, Seismic Attributes for Prospect Identification and reservoir Characterization. Geophysical Developments No. 11. EAGE.
Enge, H. D and Howell. J. A. 2010. Impact of deltaic clinothems on reservoir performance: Dynamic studies of reservoir analogs from the Ferron Sandstone Member and Panther Tongue, Utah. AAPG Bulletin v. 94 pp 139-161
Møller, Jausen, O. R. 2009. Clinoform migration patterns of late Miocene delta complex in the Danish Central Graben: Implications for sea-level changes. Basin Research No 2. pp 704-720. EAGE
Fuchs, R. and Hamilton, W. 2006, New depositional architecture for an old giant: The Matzen field, Austria, in J. Golonka and F. J. Picha. eds., The Carpathians and their foreland: Geology and hydrocarbon resources: AAPG Memoir 84, p. 205 – 219.