Petroleum systems modelling as an exploration tool: from surface seismic acquisition to basin modeling; a case study from a periplatform basin in Northern Adriatic

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Petroleum systems modelling as an exploration tool: from surface seismic acquisition to basin modelling: a case study from a periplatform basin in Northern Adriatic

Gabriele Busanello[1*], Anna Del Ben[2] and Michele Pipan[2] investigate the still unproven thermogenic hydrocarbon potential of deep Mesozoic basins in the North Adriatic Sea and correlate the results with the sedimentary evolution of proven petroleum systems in the Central and South Adriatic.

Introduction

The Adriatic Sea hosts important historically explored hydrocarbon provinces. In the northern areas, the main sources of hydrocarbon productivity are from biogenic gas reservoirs located in Quaternary thick deltaic depositional systems related to the Apennine and Dinaric foreland domain. In addition, Mesozoic thermogenic oil plays were identified and exploited in the Southern areas. Herein, we use basin and petroleum systems modelling (BPSM) techniques to investigate the still unproved thermogenic hydrocarbon potential of deep Mesozoic basins in the North Adriatic Sea and to correlate the results with the sedimentary evolution of proven petroleum systems in the Central and South Adriatic, both in the Italian and Croatian offshore areas.

We used the regional CROP-M16 marine seismic profile in the eastern segment of the study area, where it cuts the western margin of the Dinaric carbonate platform and reaches the pelagic domain of the Umbria-Marche basin intersecting the Barbara isolated platform (Figure 1). We reprocessed the 2D seismic data set to obtain the correct dips and depths of the geological structures from a depth-migrated profile. During the interpretation phase, we integrated the information from profile CROP-M16 with the orthogonal CROP-M17B and C profiles that are intersecting the Alessandra-001 exploration well. The interpretation allowed a detailed analysis of the main lithological discontinuities and of the fault system. We used the interpreted features together with the petrophysical parameters inferred by the available wells in the area and by literature, for 2D petroleum systems modelling. Our simulation integrated the available information to produce a set of possible scenarios of basin development, with the objective to understand the maturation and migration of hydrocarbons.

Figure 1 The study area, bordered by the red rectangle, with position of wells (green points) used in this study. Position of Dinaric carbonate platforms and isolated Barbara carbonate platform (modified by Cazzini et al., 2015).

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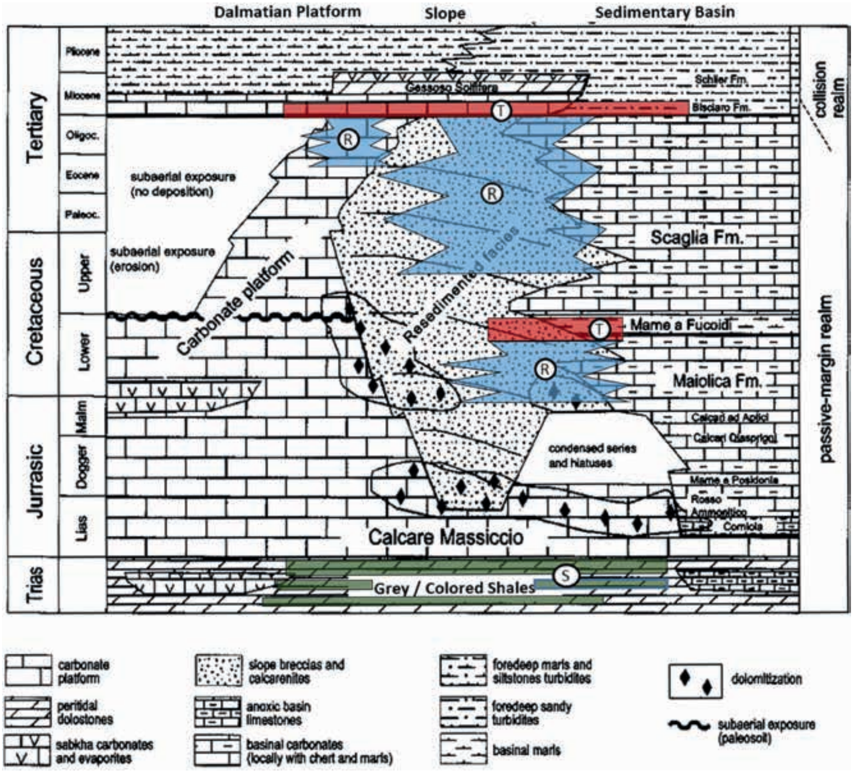

Figure 2 Conceptual entrapment model in the periplatform slope zone (after Murgia et al., 2004) in relation to the depositional environment. In grey the source rocks (S), in blue the reservoir (R), and in red the sealing formations (T).

Regional and petroleum geology

The hydrocarbon exploration of the Adria plate (Po Plain, Adriatic Sea, Apulia swell, and NE Ionian region) is based on large seismic reflection data sets and several calibration boreholes. Such information provides a good understanding of the main geological features and their geodynamic evolution since the Paleozoic period (Finetti et al., 1987).

Analysis and interpretation of the logs from a number of wells in Italian and Croatian waters confirmed that during Permian to Early Triassic (Anisian) time, the Tethyan rifting phase affected the current Adriatic area, which was covered by siliciclastic beds, limestones, and dolomites, interbedded by salt and gypsum deposits (Grandic et al. 2004). The area was part of the continental margin during the Mesozoic opening of Tethys, with deposition of the Carnian-Norian Dolomia Principale/ Burano Formations. The Burano evaporites (mainly salt and anhydrite) are present in the central and southern sectors of the Adriatic Sea (Mattavelli et al., 1991) and extend to the Italian peninsula onshore. In the Middle Liassic age, a new Tethyan rift phase caused the break-up of the previously unique carbonate platform. This phase generated the intra-platform pelagic domain of the Umbria-Marche/South Adriatic Basins, which were filled by a carbonate sequence of Cretaceous/ Paleogene age (Cati et al., 1987), and separated the Dinaric (also called Adriatic) and the Apulian carbonate platforms. At the end of the Late Cretaceous period, the Early Alpine compressive phase generated the Southern Alps and, successively, the Dinaric Chain, from Paleocene/Eocene, and the Apennine Chain, from the Oligocene period. These two opposite fronts gradually migrated toward the central axis of the Adriatic Sea (Channel et al., 1979). The deposition of a clastic sequence of Upper Eocene/Oligocene age was followed by the Lower Pliocene tilting of the current Adriatic foreland below and in front of the Apennine orogenic front. The foredeep basin was filled by Pliocene sub-horizontal clastic layers (CNR-PFG 1991) covered by a thick prograding Quaternary sequence. Picha (2002) postulated a late orogenic strike-slip faulting, along the Dinaric-Hellenic side of the peri-Adriatic region, and suggested an escape tectonics scenario.

Such a geological setting shows that the paleo-geographic relations between the fast accretion of the carbonate platforms and the basin deep-water environment contributed to the formation of periplatform clastics along their margins and to their petroleum potential in quality of reservoirs (Grandic, 2007). The relation between euxinic deposits (Ladinian-Carnian shales) and clastics (turbiditic calcarenite) represents the conceptual model for possible hydrocarbons migration into these periplatform sediment rocks and structural or stratigraphic traps (Figure 2) that we investigate herein.

Processing and interpreting seismic data

We reprocessed the CROP-M16 seismic profile, part of the Italian deep-crust exploration programme (CROP project, see Finetti et al., 2005), and reinterpreted it in the depth domain together with the intersecting CROP-M17B & C seismic profiles.

The CROP-M16 profile is a shallow-water 2D seismic line (water depth around 60 m) of the mid-90s CROP-MARE sub-project. The seismic acquisition was designed for deep crust illumination giving preference to the low end of the frequency bandwidth. The acquisition record length is 18 s. Shot and receiver intervals are 50 m and 25 m, respectively, and the maximum streamer offset is 4500 m (Bertelli et al., 2003). The processing sequence objective was to obtain an image of the subsurface in the depth domain that correctly represents the complex shape and positioning of the carbonate platform structures in relation to the turbiditic deposition in the sedimentary basin (Table 1).

The processing focused on reconstructing the velocity model for depth imaging, enhancing the signal-to-noise ratio, and regularizing the data through prestack common reflection surface (CRS) techniques before Kirchhoff prestack depth migration (KPSDM). Velocity analysis was carefully performed at different stages along the processing sequence.

The CROP-M16 seismic profile is oriented NE-SW and intersects the western margin of the Dinaric carbonate platform and the Barbara isolated platform. The CROP-M17B and C seismic profiles are mainly parallel to the Dinaric platform edge and perpendicular to CROP-M16 profile. Both directions present challenges and limitations in the illumination of the subsurface owing to the acquisition layout: lateral effects related to the steep carbonate flanks cannot be fully resolved by a 2D imaging condition. Iterations between velocity analysis, prestack Kirchhoff depth migrations, interpretation, and well calibration were performed to compensate for the 2D imaging limitations and to properly represent the steep dips of the carbonate flanks in the depth domain. Unfortunately, the CROP-M17B and CROP-M17C profiles were not available in raw data format, so we depth-converted the available stack profiles.

Processing step	Description
Navigation geometry merge and trace editing	Identifying and removing dead and bad traces, correcting for traces with reversed polarity
Source and receiver cable statics correction	Assigning the correct source and receiver nominal depth and compensating for cable steering effects
Coherent noise and direct arrival removal	Tau-p linear filtering technique to target event propagating at water-velocity
Random noise attenuation	Time- and spatial- windowed amplitude mean discrimination in different domains
Geometrical spreading and Inverse-Q compensation	Amplitude correction using a single regional velocity function and a single Q-attenuation value
Spiking deconvolution	Spectral broadening and wavelet stabilization
Targeted deconvolution designed in the offset domain	Removal of short-period reverberations owing to the shallow-water environment and to the high impedance contrast boundaries
Velocity analysis (stacking velocity)	First pass of velocity analysis with dedicated preconditioning
Data regularization through prestack common reflection surface (CRS)	CRS techniques bring dip structural information into time processing to improve the image focusing
Velocity analysis	Migration velocity analysis
Prestack Kirchhoff depth migration (KPSDM)	KPSDM imaging with cable length aperture
Velocity analysis	High-density manual velocity picking for stacking enhancement
Stacking	Stacking the final image including offset balance function
Poststack data conditioning	Poststack noise attenuation (dip filtering)

Table 1 Brief description of the 2D marine seismic profile processing sequence.

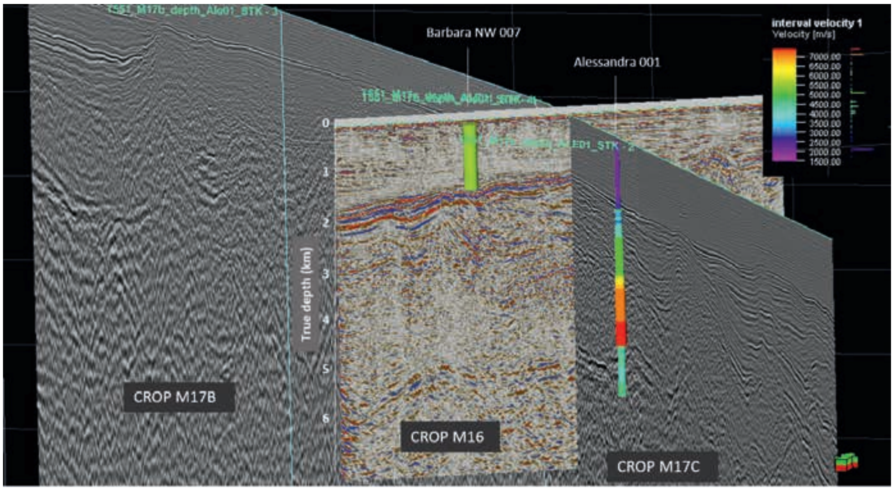

Figure 3 3D picture of CROP-M16, M17B and C profiles and the Alessandra 001 well used in this work for horizon interpretation. The colour bar refers to the interval velocity profile interpreted from Alessandra 001 (Bally et al., 1986).

The Alessandra-001 is a wildcat exploration well close to the CROP-M17C profile (1 km to the west) and it reaches a depth of 6037 m (see location map in Figure 1). The deepest formations are siltstone deposits of the Early Triassic, dated on the basis of palynological data. Interpretation of well logs provided a stratigraphic description, a log-velocity profile, and a temperature profile at the well location. Additional information used to calibrate the seismic velocity fields was also provided from Mattavelli et al. (1991), Finetti ed. (2005) and unpublished data recovered from velocity spectra analysed during the long experience of the Exploration Geophysics Group (EGG) in seismic processing and interpretation. Lithological information derived from the in-situ mud and core analyses allows a reliable and detailed stratigraphic characterization at the well location and it was used to populate the geological model in the next modeling phase.

Seismic interpretation in the depth domain of the CROP-M16 and CROP-M17B and C seismic profiles, calibrated by the Alessandra-001 well, provided the starting (time zero) geological framework to build the petroleum system model (Figure 3). The stratigraphic column at the well location allowed the correlation between the lithological properties and the interpreted layers, with a particular reference to the characterization of source, reservoir, and seal rocks. Vitrinite reflectance data are not available at the Alessandra-001 well, which does not show any evidence of oil in place: we interpreted such evidence as a consequence of the local structural high in the Permo-Trias formations reached at the well location. During the syn-rift phase, structural lows are likely to be depocentres for organic-rich sediments in the phase of early to complete maturity (Grandic et al., 2010).

Petroleum systems modelling

We performed 2D basin and petroleum systems modelling (BPSM) to evaluate the development of the petroleum system, burial history, and thermal evolution, as well as migration, accumulation, and preservation of hydrocarbons (Hantschel and Kauerauf, 2009) using the following steps:

A. Classification of the paleo-environment that allowed the deposition of the source rocks in the intra-graben Triassic synrift euxinic basins;
B. Reconstruction of the depositional environment that generated the slope-turbiditic periplatform sediments along the margin of the wide Dinaridic carbonate platforms;
C. Reconstruction of the burial history to assess the maturity of the source rocks and the generation and migration of hydrocarbon into the sedimentary basin.

Petroleum system models require geochemical and petrophysical characterization of the sedimentary formations in conjunction with boundary conditions (paleo-water depth, sediment-water interface temperature, and basal heat-flow). We used a petroleum systems modelling software to integrate all the available information (see Figure 4) to produce a set of possible scenarios in which the conditions of the petroleum system could have evolved in the last 250 Myr.

Building the basin and petroleum systems modelling

The interpreted horizons and faults in the depth domain were imported and gridded. Stratigraphic relationships, discontinuities and depositional hiatus need then to be assigned according to the

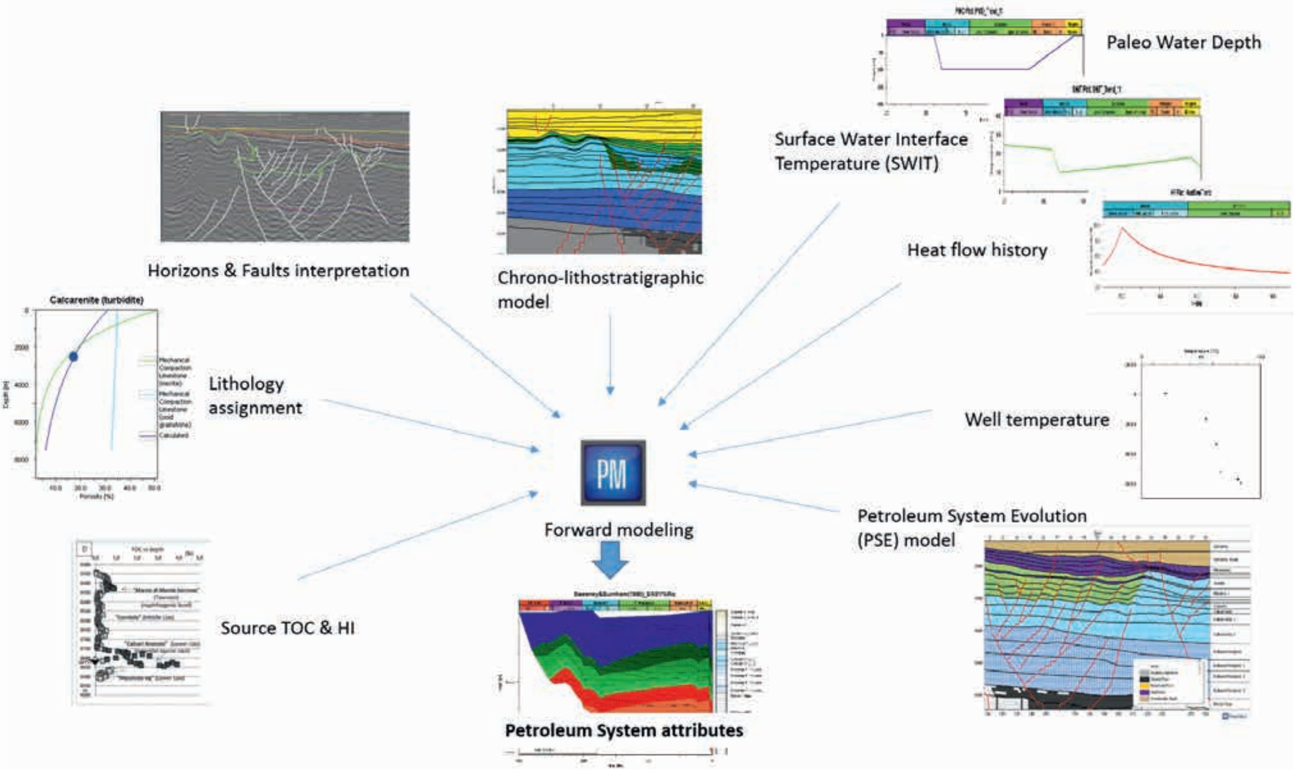

Figure 4 Petroleum systems simulation software workflow. The design of the geological model evolution and the definition of constraining boundary conditions are required to simulate the generation, migration, and accumulation of hydrocarbons.

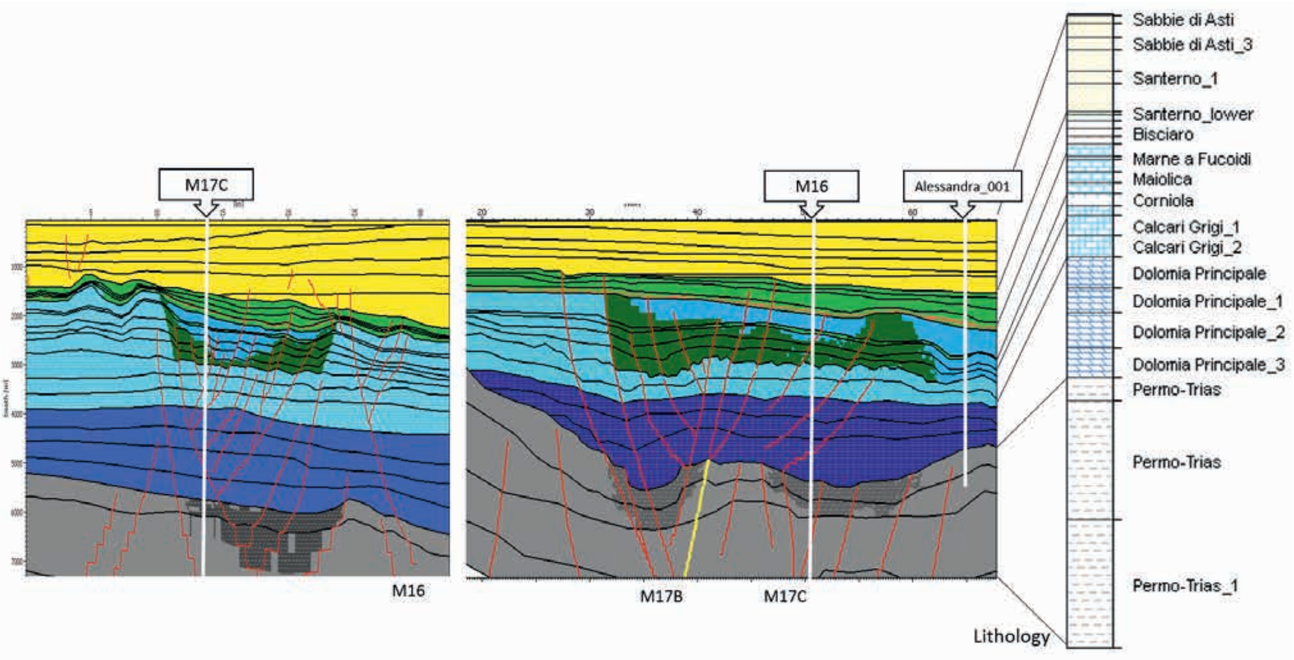

Figure 5 Depositional models for the two sections intersecting the sedimentary basin (CROP-M16 on the left and CROP-M17 on the right). The Alessandra_001 well, less than 1 km west of CROP-M17C, calibrates interpretation and model building. In green, the slope-turbiditic calcarenite facies assigned to the reservoir, and in dark grey the modelled source rocks: organic-rich shales in the Permo-Triassic structural lows.

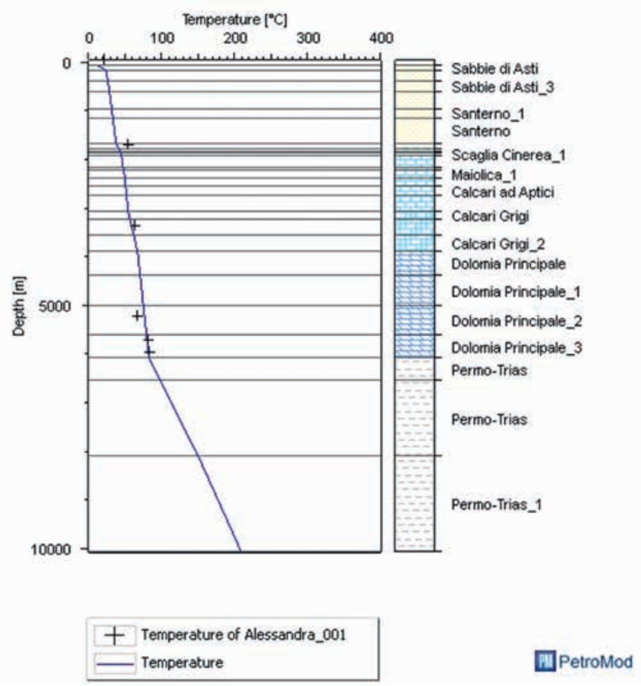

Figure 6 1D predicted temperature curve at the Alessandra 001 well location overlaid with the borehole temperature measurements.

conceptual depositional environment. Guided by the stratigraphy interpreted from the Alessandra-001 well, we assigned lithologies to each modelled layer and depositional time (in Myr) to each gridded layer: this step defines the initial chrono-lithostratigrahic framework. The interpreted fault systems were imported from the interpretation; the timing of their activity and properties were assigned in relation to the tectonical evolution history of the region. Such framework guided the reconstruction of the burial history of the sedimentary basin during the simulation, taking into account layers' thicknesses, time of depositions, and lithology (Figure 5).

The reservoir lithological composition was modelled based on real logs from the existing wells. The slope-turbiditic calcarenite composition was assigned adjusting the composition of limestone and grainstone to match the detected porosity (15% at 2250 m) and permeability (45 mD at 15% porosity) of the core samples analysed in the ISTRA_MORE 3 well as described in Grandic et al. (2010).

The properties to be assigned to the source rocks are hydrocarbon generation kinetics, original total organic carbon (TOC) and the hydrocarbon index (HI) values estimates for the source rocks. Considering that direct measurements of such parameters for source rocks characterization were not available from the well, we assigned the relevant values from different vitrinite reflectance analyses at existing interpreted wells in the region from the same Triassic anoxic limestone and siltstone that share similar depositional settings. Values of 3% original TOC and 700 mgHC/g HI for the hydrocarbon indicator are used in the simulation: such values agree with the references located in the Central-South Adriatic region that share a comparable depositional environment during the syn-rift phase. Pepper and Corvi (1995) Type-II-S was the kinetic reaction used to predict composition, masses, and phases of petroleum expelled from the Permo-Trias deltaic source rocks as shown by the organic geochemical data for Well Sparviero 1bis (Cazzini et al., 2015).

Boundary conditions and thermal calibration

Modelling the thermal history of a basin requires reconstructing the temperature over geologic time and across the basin (Peters et al. in press), for which specific boundary conditions must be estimated. They include sediment-water interface temperature

(SWIT), which can be derived from the paleo-surface temperature recalculated for the paleo-water depth, and the paleo-heat flow.

We designed paleo-water depth profiles according to the expected depositional environments at each defined geological interval. Along the 2D-profiles, from the shallow water associated with the carbonate platform, the Middle Liassic rift phase (230-180 Myr) saw the deposition of deep-water sediments in the basin area. At the end of Late Cretaceous, the Early Alpine compressive phase led to the Messinian erosional hiatus and then to the thick deltaic sedimentary sequence from the Pliocene.

The SWIT is calculated from the global mean temperature at sea level matrix (based on Wygrala 1989) and it is a function of the varying latitude of the area of interest at the time of deposition. In these simulations, this global mean surface temperature profile was then recalculated for paleo-water columns along the 2D model.

The heat flow profiles were calculated from the uniform stretching McKenzie crustal model parameterization, taking into account the timing of the rifting phase and then calibrated with the borehole temperature profiles available in the area. The modelled heat flow extracted at the well location correlated with the well temperature log and showed a reasonably good match (Figure 6).

Forward modelling simulation

The final phase of the BPSM is the forward modeling that performs calculations on the model to simulate the burial history, pressure and temperature variations, kerogen maturation, and hydrocarbon expulsion, migration, and accumulation through time. To run the forward modeling simulation, combined Darcy/Flowpath was selected.

We tested different simulation scenarios to validate the sensitivity of the following key parameters:

- The maturity of the source rocks in relation of the burial history: to evaluate the risks of falling out of the oil window;
- The compositional properties of the reservoir rocks to evaluate the sensitivity of the lithological sediments to the oil accumulation;
- Faults properties in relation to the hydrocarbon migration: the faults are known to play an important role in the migration of hydrocarbons either towards stratigraphic traps or provide a potential route for escape to the surface;
- The sealing properties of the sealing rocks: to assess the conditions linked to the hydrocarbons migration to the surface.

Results and conclusions

Considering the lack of calibration data in such an unexplored area, it is crucial to evaluate the sensitivity of the geological model to the boundary conditions. For example, available wells and log samples can be used to characterize the petrophysics of the formations and even a small number of direct measurements of temperature in the borehole or at the surface can be used to estimate the thermal history of the sedimentary basin. On the other hand, a good collection of data is available in the scientific literature, both in the Italian and Croatian waters, in areas with very similar sedimentary conditions. Correlation between source and reservoir rocks of existing petroleum systems in these basins was already successfully proven (Cazzini et al., 2015).

Figure 7 shows temperature and transformation ratio (TR) attributes overlaid on the burial history display. The transformation ratio of the reaction at the source rock indicates the converted mass fraction of the initial reactant with time: these depth profiles has been extracted in correspondence of the intersection between the CROP-M16 with CROP-M17 seismic profiles (see Figure 5).

The results from the modelling simulation and the scenarios evaluated during the sensitivity tests confirmed that the basin might present all the requirements for successful generation, migration, and accumulation of hydrocarbons. The turbiditic slope sediments on the flank of the carbonate platforms may have the right porosity to host the accumulation of hydrocarbon (Figure 8). The results further indicated that the system can eventually generate oil and gas, as shown by the time extraction diagrams of hydrocarbon generation through time (Figure 9), and the accumulations can preferentially occur in stratigraphic

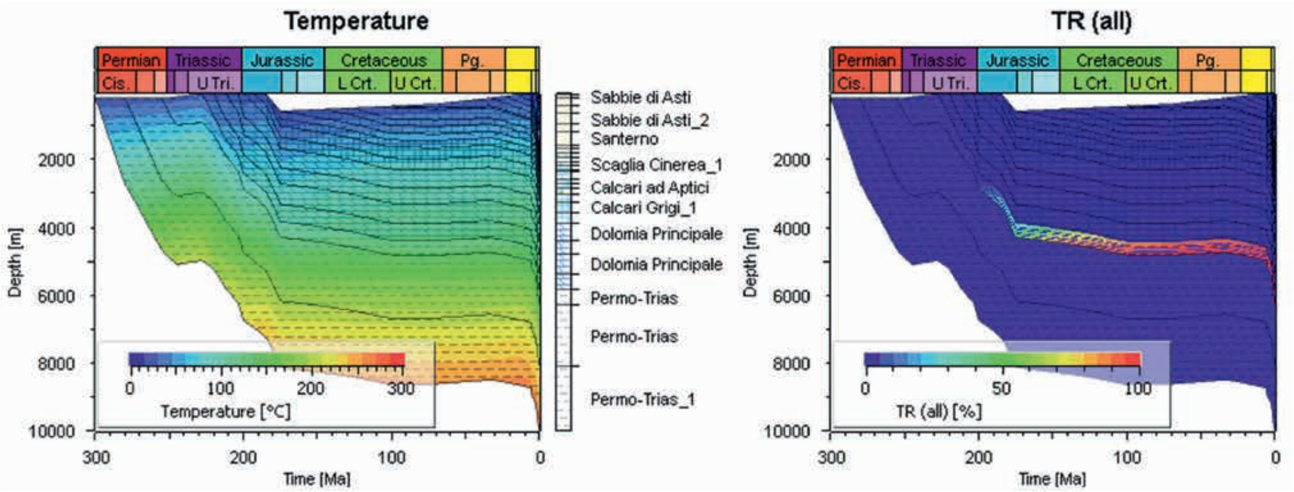

Figure 7 Petroleum system attributes overlaid on the burial history display at a profile located in correspondence of the sedimentary basin (intersection between the CROP-M16 with CROP-M17 profiles; see Figure 5). On the left temperature, and on the right the TR of the reaction at the source rock.

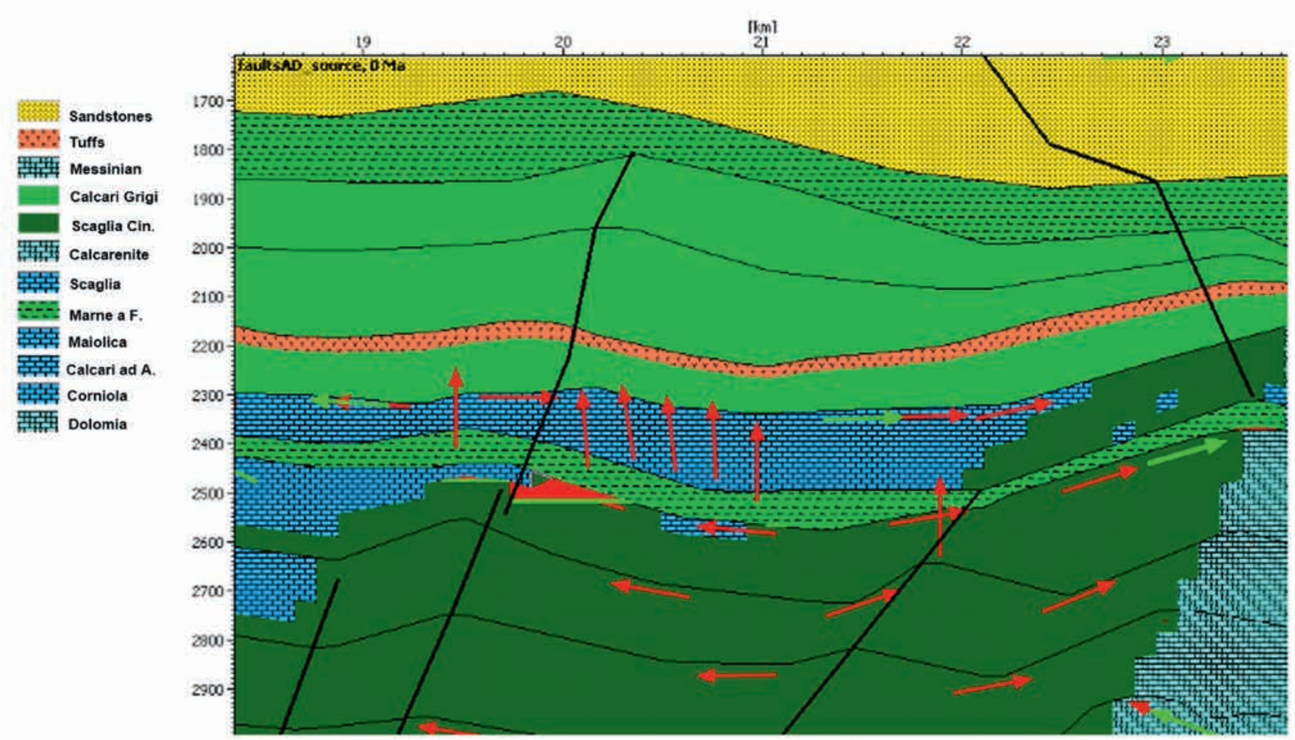

Figure 8 Display of a detail from the litho-stratigraphic model (at present day) with overlaid attributes from the Darcy/Flowpath simulation: in red attributes related to accumulation and migration of vapor, in green attributes related to accumulation and migration of liquid. Accumulations of liquid and vapour are visible in correspondence of stratigraphic traps and arrows indicate the migration pathways in the slope-turbiditic calcarenite reservoirs (in dark green).

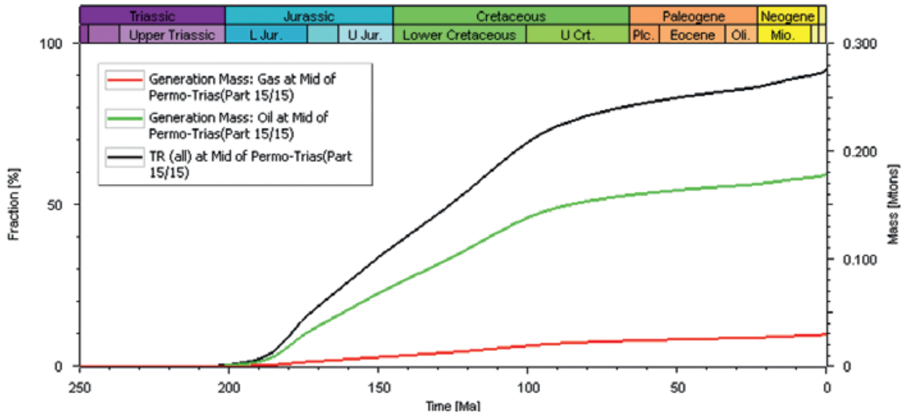

Figure 9 Generation curves for Type-II-S kerogen (Pepper and Corvi, 1995) from the time extraction-at a cell in the Permo-Triassic shales. In black the TR, in green the oil, and in red the gas express as fraction of the total generation mass.

closures owing to the presence of low-permeable calcareous sealing formations. From the sensitivity tests performed on the properties of the faults, it is possible to infer that the faults worked to conduct oil and gas into the upper stratigraphic units where it was trapped below the Cretaceous marly intervals.

The BPSM represents a valid tool to assess the hydrocarbon potential of the sedimentary basin. In this specific case study, the aim was to make a qualitative validation of such conditions for quantitative analysis, further integration with new seismic data, and borehole calibration required to be implemented into a 3D model.

Acknowledgments

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References

Bally, A. W., Burbi, L., Cooper, C. and Ghelardoni R. [1986]. Balanced sections and seismic reflection profiles across the central Apennines. *Memorie-Soceita Geologica Italiana*, **35**, 257-310.

Bertelli, L., Mazzotti, A. and Persoglia, S. [2003]. Planning, acquisition and processing of the CROP seismic data: a few comments. *Mem. Descr. Carta Geol. d'It. LXII*, 47-54.

Cati, A., Sartorio, D. and Venturini, S. [1987]. Carbonate platforms in the subsurface of the Northern Adriatic Area. *Memorie – Soceita Geologica Italiana*, **40**, 295-308.

Cazzini, F., Zotto, O. D., Fantoni, R., Ghielmi, M., Ronchi, P. and Scotti, P. [2015]. Oil and Gas in the Adriatic Foreland, Italy. *Journal of Petroleum Geology*, **38**, 255-279.

Channel, J.E.T., D'argenio, B. and Horvath, F. [1979]. Adria, the African Promontory, in Mesozoic Mediterranean Paleogeography. *Earth Science Reviews*, **15**, 213-292.

CNR-Progetto Finalizzato Geodinamica [1991]. Structural Model of Italy. *SELCA*, Firenze.

Finetti, I.R., Bricchi, G., Del Ben, A., Pipan, M. and Xuan, Z. [1987] .Geophysical study of the Adria Plate. *Memorie – Soceita Geologica Italiana,* **50**, 335-344.

Finetti, I.R. and Del Ben, A. [2005]. Crustal tectono-stratigraphic setting of the Adriatic Sea from new CROP seismic data. In: Finetti I.R. (ed), CROP Project: Deep seismic exploration of the Central Mediterranean and Italy, Atlases. in *Geoscience 1*, Elsevier, 519-547.

Grandic, S., Kratkovic, I., Kolbah, S. and Samarzija, J. [2004]. Hydrocarbon potential of stratigraphic and structural traps of the RavniKotari area – Croatia. *Nafta*, **55**, 311-327.

Grandic, S. [2007] Review of the hydrocarbon plays in the Croatian offshore and Periadriatic areas. *Nafta*, **58**(3), 146-158.

Grandic, S., Kratkovic, I., and Rusan, I. [2010]. Hydrocarbon potential assessment of the slope deposits along the SW Dinarides carbonate platform edge. *Nafta*, **61**(7-8) 325-338.

Hantschel, T. and Kauerauf, A.I. [2009]. *Fundamentals of Basin and Petroleum Systems Modeling*: Springer, Berlin, 476 p.

Mattavelli, L., Novelli, L., and Anelli, L. [1991]. Occurrence of hydrocarbons in the Adriatic basin. *Special Publication. EAPG,* **1**, 369-380.

Murgia, M.V., Ronchi, P. and Ceriani, A. [2004]. Dolomitization processes and their relationships with the evolution of an orogenic belt (central Apennines and periAdriatic foreland, Italy). In: R. Swennen, F. Roure and J. W. Granath, (Eds), Deformation, fluid flow, and reservoir appraisal in foreland fold and thrust belts. *AAPG Hedberg Series*, **1**, 277-294.

Pepper, A. S. and Corvi, P. J. [1995] .Simple kinetic models of petroleum formation. Part I: oil and gas generation from kerogen. *Marine and Petroleum Geology*, **12**(3), 291-319

Peters, K.E., Schenk, O., Hosford Scheirer, A., Wygrala, B. and Hantschel, T. [in press]: *Basin and Petroleum System of Conventional and Unconventional Petroleum Resources*. In: Hsu, C. and Robinson, P. (eds.): Springer Handbook of Petroleum Technology.

Picha, F.J. [2002]. Late orogenic strike-slip faulting and escape tectonics in frontal Dinarides Hellenides, Croatia, Yugoslavia, Albania, and Greece. *AAPG Bulletin*, **86**, 1659-1671.

Wygrala, B.P. [1989]. Integrated study of an oil field in the southern Po Basin, Northern Italy. PhD thesis, University of Cologne, Germany, 1989.