Source Rock Potential and Maturity Modelling in the Southern Adriatic Sea Area: Key Controls for Predicting Hydrocarbon Distribution*

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Abstract

One of the most significant offshore hydrocarbon provinces in Italy is located in the Southern Adriatic. Important discoveries in this area (Zone F) include the Rovesti discovery and Aquila field. Proven source rock in the area is the Late Triassic (Rhaetian, Norian) Burano Formation: a paralic carbonate source rock developed in a sabkha type environment. Due to the lack of deep Triassic penetrations in the area, organic rich facies have not been encountered in any well. However, geochemical analyses indicate all the oils in the Southern Adriatic Sea area and Pre-Apulian zone (NW Greece) correlate with the Burano Formation in Central Italy.

The development of a new hydrocarbon maturity model indicates this source rock is probably fully mature within the Italian sector of the Southern Adriatic in both platform and basin areas. Long distance hydrocarbon migration from the Albanian Periadriatic Depression, as previously invoked by several authors, appears inadequate to describe the hydrocarbon distribution in this area. Paleogeographical reconstructions indicate progressive deepening of the Late Triassic (Rhaetian, Norian) facies towards Albania, implying unfavourable conditions for the deposition of organic matter associated with this type of source rock.

Maturity modelling indicates significant differences between the timing of hydrocarbon generation within the basin and in the Apulian platform domain. Large volumes of hydrocarbons within the platform are likely to have been expelled prior to the deposition of seals (Late Tertiary), thus explaining the unsuccessful exploration activities in the offshore Apulian platform domain. Furthermore, Cretaceous marly intervals within the Apulian platform may have acted as a vertical barrier to fluid migration and are probably associated with shaly levels of limited source rock potential. Waxy oil traces interpreted to be a late charge have been encountered in one well drilled on the shelf edge, indicating a terrestrial input, which is also suggested by the oleanane biomarker (derived from angiosperms), constraining the age of this source rock to the Cretaceous or Tertiary.

Hydrocarbon generation and migration within the basin likely occurred from the Middle-Late Miocene to Post-Pliocene, subsequent to the formation of hydrocarbon traps in most cases. Migration is thought to have occurred mainly through faults with sealing intervals being the

Maiolica Fm. (Early Cretaceous) and Late Tertiary marly sequences. Gas potential is associated with calcarenitic levels within the Tertiary marly sequence as proven by biogenic gas discoveries in the area and geochemical analyses of Tertiary sequences.

The integration of source rock potential, basin modelling, and the development of a new geological model for platform to basin transition is playing a key role in the evaluation of the remaining prospectivity in the Southern Adriatic.

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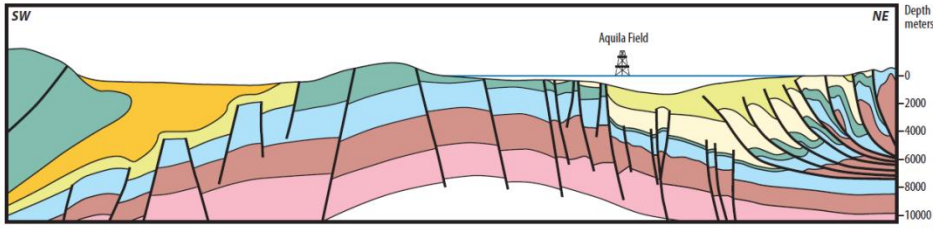
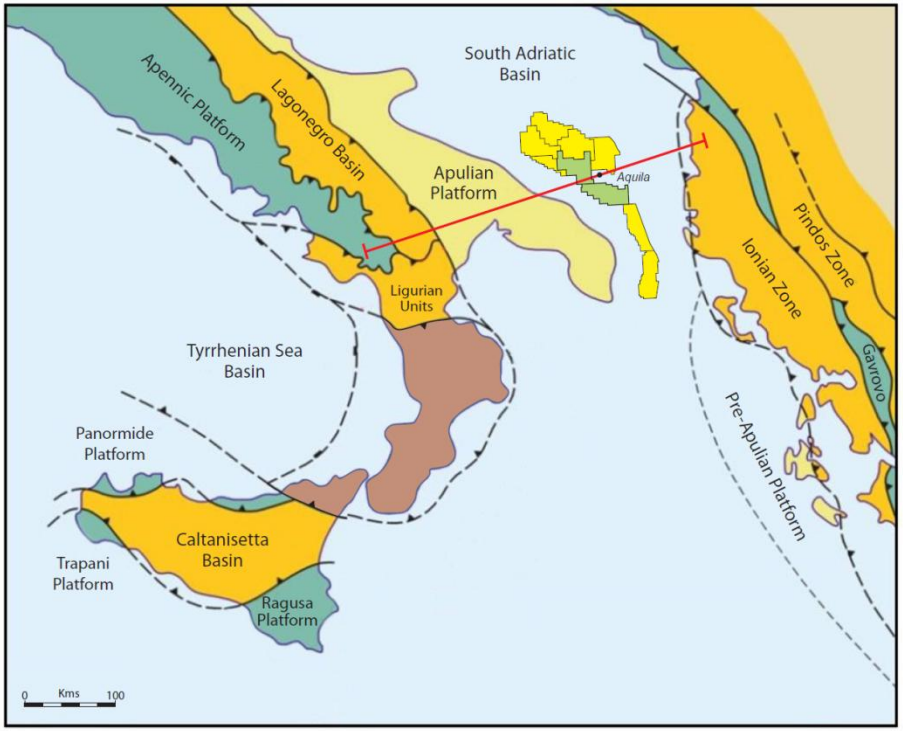
9 April 2013

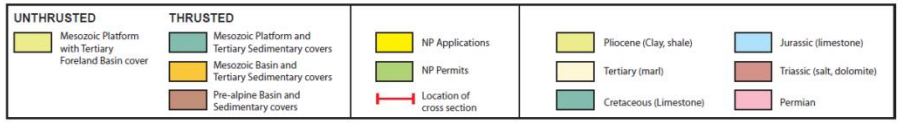
Southern Adriatic

- Regional geological setting
- Triassic source rock distribution
- Timing of hydrocarbon migration
- Basin modelling, Triassic and Cretaceous source rocks
- Current source rock and maturity models
- Oil-oil correlations
- Triassic organofacies distribution and implications on the model
- Liassic source rocks
- Conclusions

Southern Adriatic Sea Area – Location
Regional Geological Setting

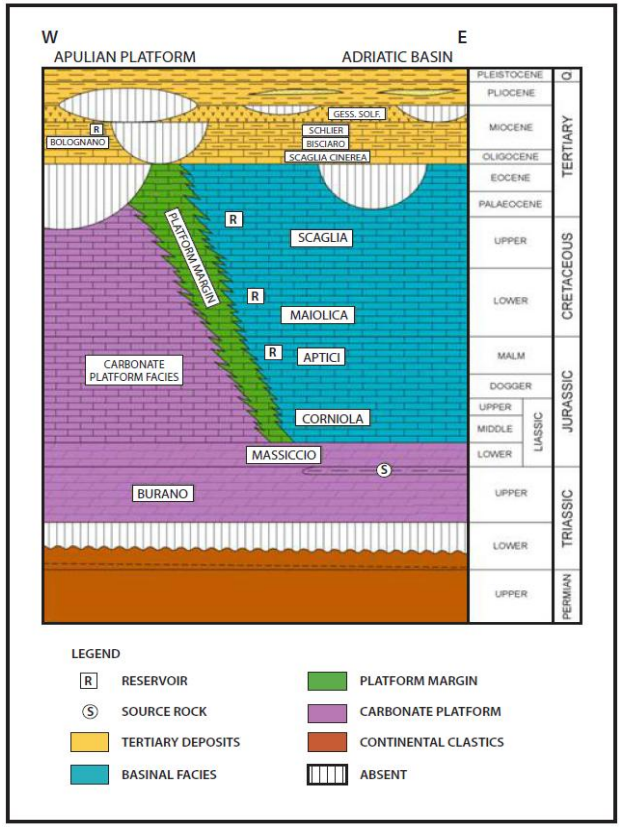






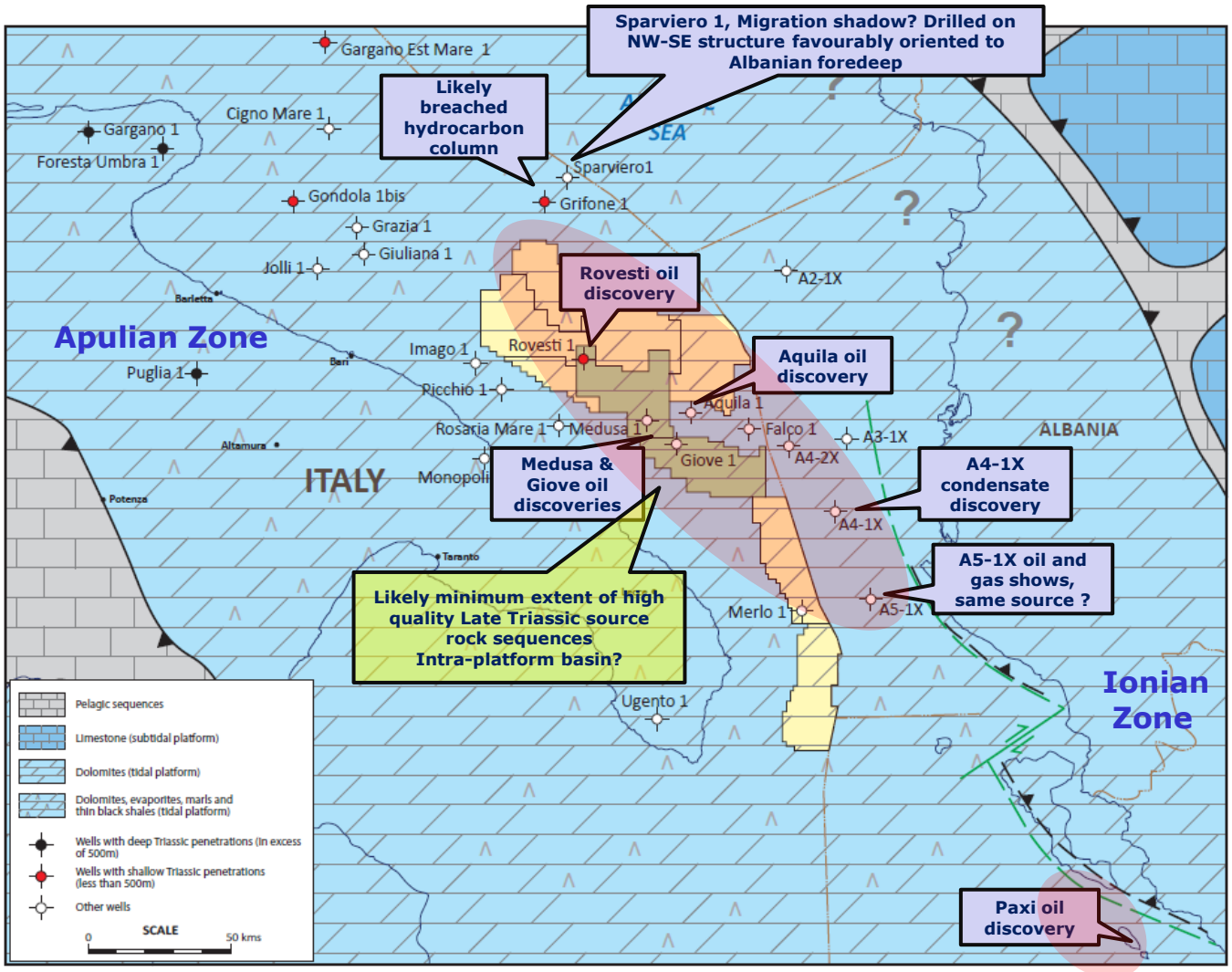
Palaegeographical domains of Southern Italy and cross section through the Southern Adriatic, modified after L.Mattavelli et al., 1991

- **Deformed foreland area in the Tertiary, carbonate sedimentation on passive margin from Late Triassic to Early Tertiary**
- **Overall setting, Mesozoic carbonates with Tertiary clastic cover**
- **Mesozoic margin starts to develop in the Early-Middle Jurassic marking division between platform and basinal facies**



Lithostratigraphical model of the Tertiary and Mesozoic formations in the southern Adriatic, modified after L.Mattavelli et al., 1991

Southern Adriatic – Source rock
Late Triassic (Norian-Rhaetian) Facies Map



- Vast peritidal shelf (Apulian and Pre Apulian Zone) grading into subtidal platform towards Albania
- Source rock deposition (Burano Fm.) occurs on the Apulian and Pre Apulian Zone (Paxi oil correlates with Aquila, Rovesti, Medusa, A4-1X oils)
- Triassic carbonate source rocks and evaporites in the Ionian Zone are Early-Middle Triassic
- Data on facies distribution is very limited
- Rifting in the Liassic, formation of localized intra-platform basin with organic rich sediments (Sparviero 1bis)

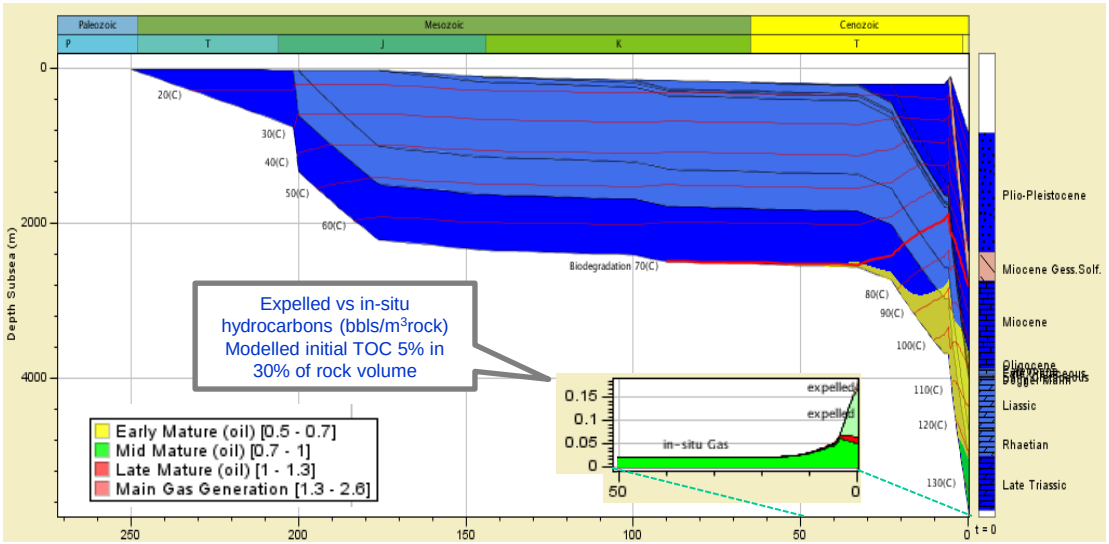
Southern Adriatic
Timing of Hydrocarbon Migration

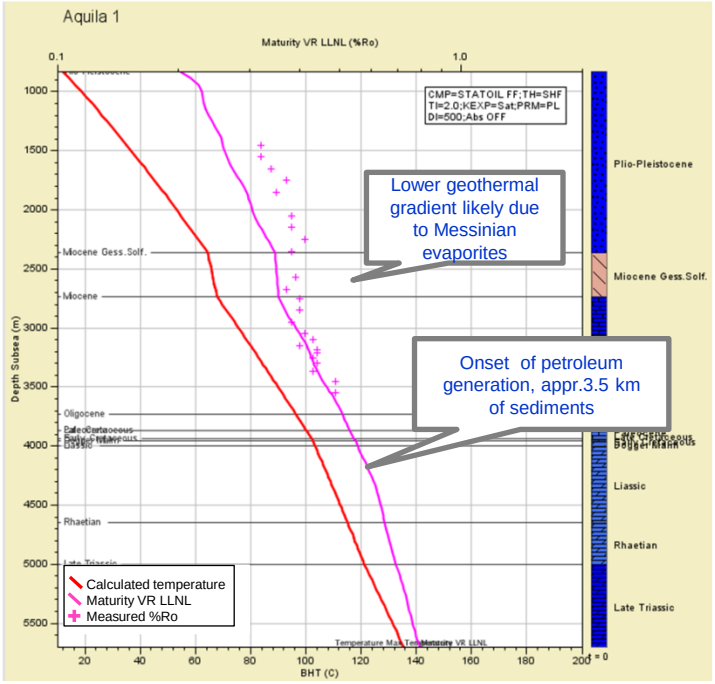
- **Maturity modelling suggests that generation occurred in the Late Tertiary - Most significant generation – Pliocene-Post Pliocene**

- **Major migration pulses likely occurred following two key events:**

  1. **Oligocene-Aquitanian orogenic event in the Dinarides and Hellenides - Middle Miocene migration of early mature oils in Northern Ionian Zone (Albania)**

  2. **Deposition of thick flysch sequences during Tortonian and Pliocene in the Southern Adriatic Basin. Post–Pliocene migration of over mature light oils and gases in the Northern Ionian Zone (Albania)**





Burial curve and modelled maturity for the Triassic Burano Fm. in the Aquila 1 well Modelling carried out with BasinMod 2012

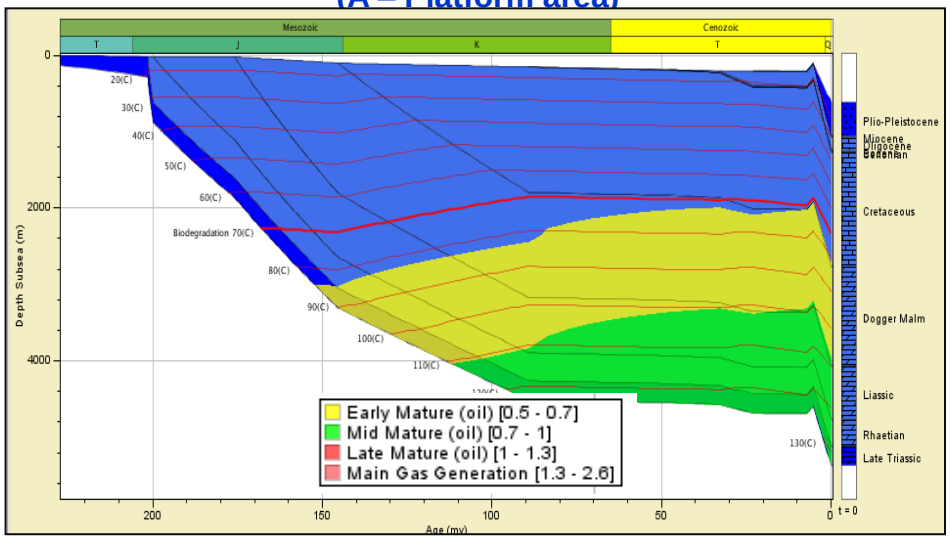
Heat flow 38 Mw/m^2
Temp. gradient approx. 2.0-2.6^{o}C/100m in the carbonate sequence
Measured %Ro is from the A4-2X well, this well has the same stratigraphy and WD of Aquila1

The calculated vitrinite reflectance and geothermal gradient is in good agreement with measured data, Aquila 1 well
Modelling carried out with BasinMod 2012

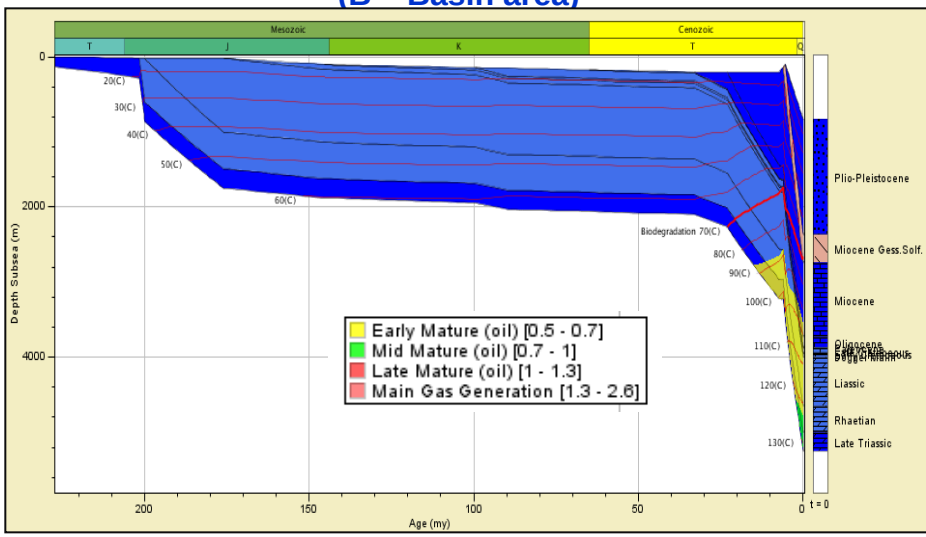
Southern Adriatic – Dry hole analyses
Platform wells

- **Maturity modelling indicates significant differences between timing of hydrocarbon generation within the basin and in the platform domain. Large quantities of hydrocarbons within the platform are likely to have been expelled prior to the deposition of seals (Late Tertiary)**

(A – Platform area)

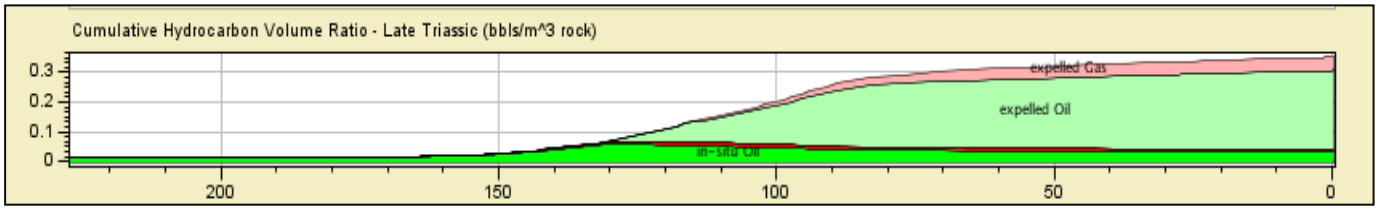


(B – Basin area)



(A) Maturity modelling of platform sequences (Giove 2) using BasinMod 2012; depths of sequences below the top of Cretaceous are estimated on the basis of well correlations and the interpretation of depth converted seismic data

(B) Maturity modelling of basin sequences (Aquila 1) using BasinMod 2012

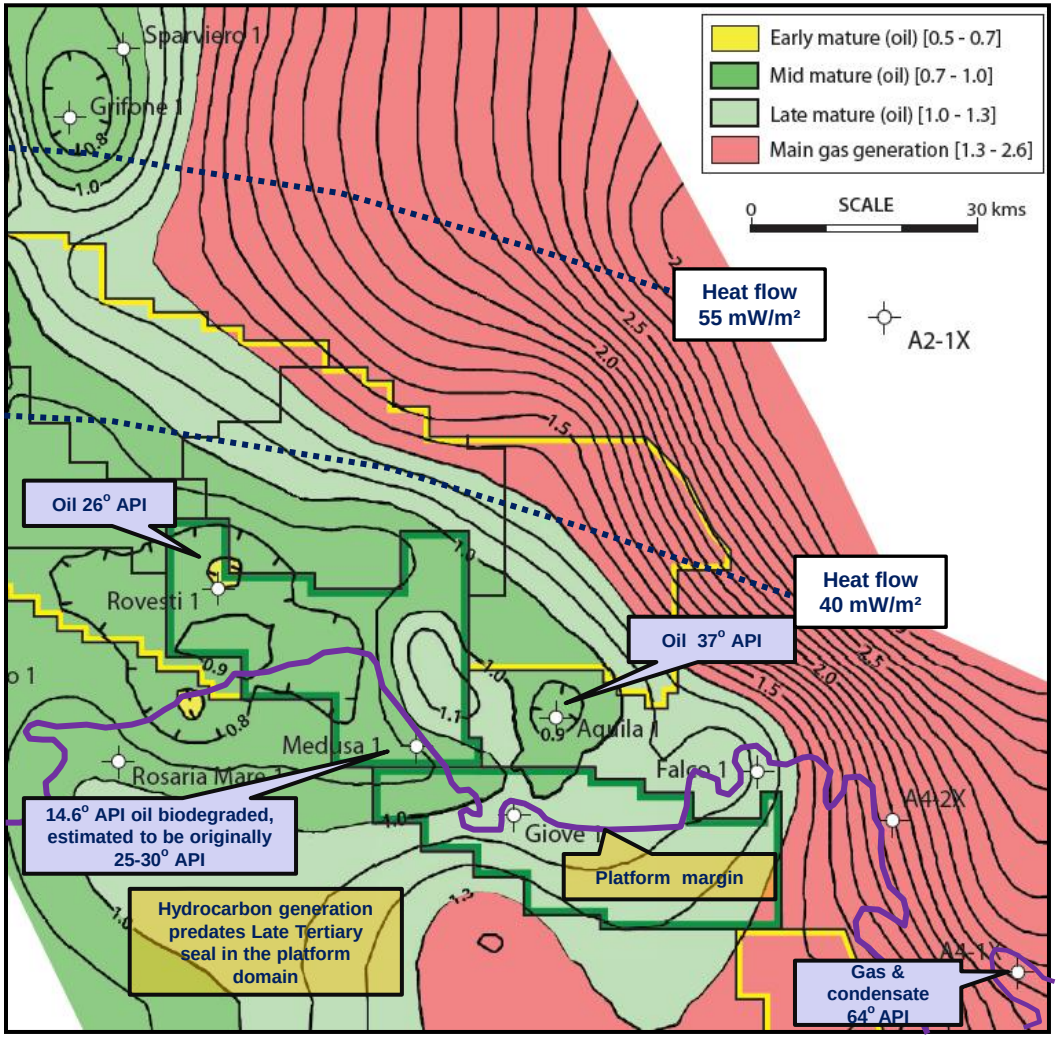


Generated versus expelled hydrocarbons through time for the platform domain, Giove 2 well
Modelling carried out with the BasinMod 2012 software

- **Marly intervals (encountered in the Cretaceous section in Rosaria Mare) could provide a barrier to fluid migration below drilled structures**

- **Lack of seal and organic lean Triassic source rock onshore**

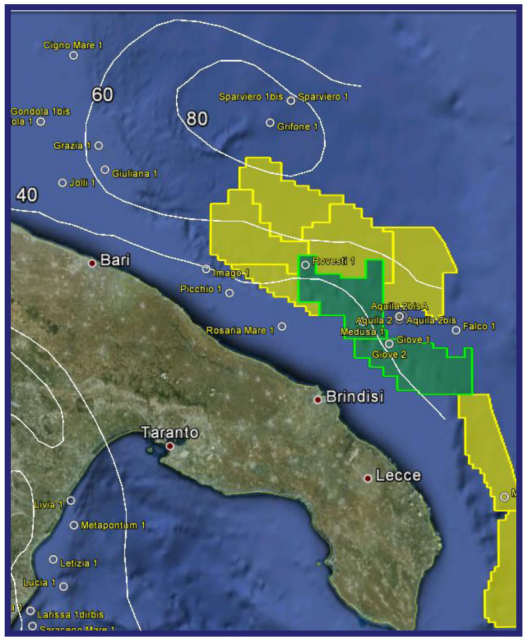
Basin Modelling in the Southern Adriatic Sea
Late Triassic Source Rock Maturity Map



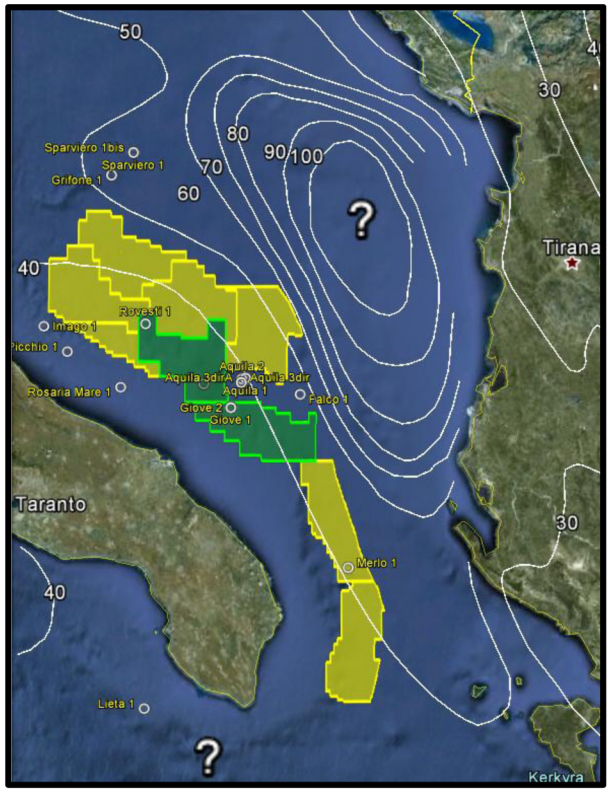
Calculated equivalent vitrinite VR LLNL (%Ro) within the Italian sector of the Southern Adriatic Sea area; maturity modelling carried out with the BasinMod 2012 software

- Modelled Triassic source rock interval is assumed 500m below the Top Triassic seismic pick
- Large uncertainty linked to the depth of the Top Triassic seismic pick due to limited well calibration and difficulty in identifying marker
- The mapped Top Triassic horizon follows a seismic marker which could be deeper than the true Top Triassic (in the order of few hundred metres)
- A good match has been achieved between the calculated maturity and the distribution and type of hydrocarbons in the area

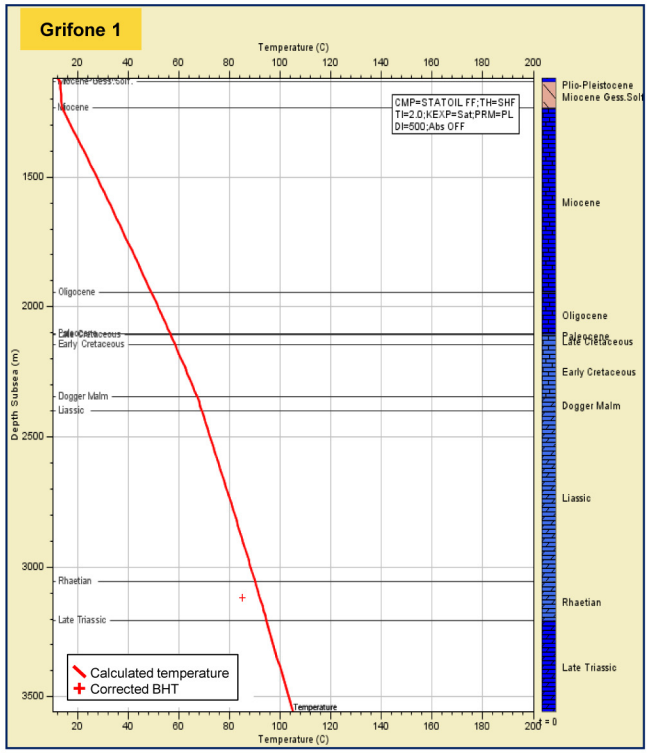
Heat Flow Distribution in the Southern Adriatic



Heat flow distribution in the Southern Adriatic Sea area, heat flow data after E.Carminati et al., 2012



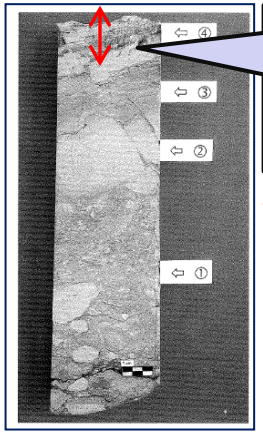
Heat flow distribution in the Southern Adriatic Sea area, heat flow data after V.Cermak et al., 1996



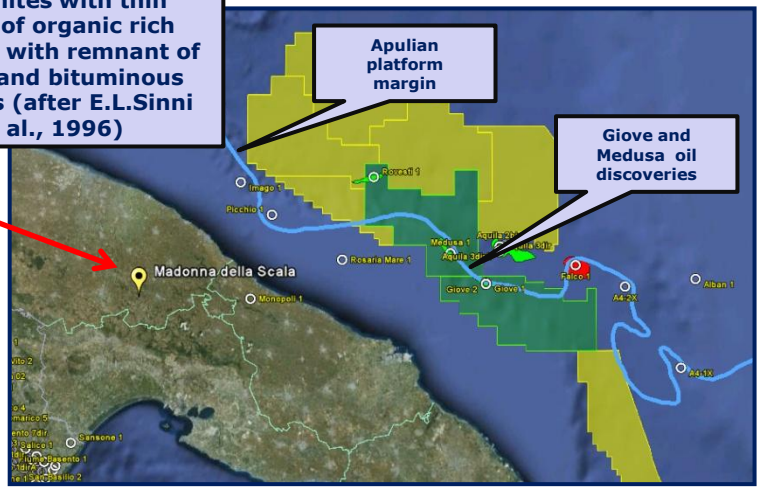
Calculated temperature versus BHTs. Temperatures in the shallow section are considered unreliable. Calculated BHTs through Horner plot is possible only in one example, however circulation time is not known.

- **Current heat flow distribution models in Southern Adriatic Sea area are poorly constrained and display significant differences depending on the method used. Limited data from wells north of NP applications (Sparviero 1bis, Grifone 1) suggest an increase in the heat flow towards the basin but not as significant as other models suggest.**

Cretaceous Source Rock Maturity within the Apulian Platform



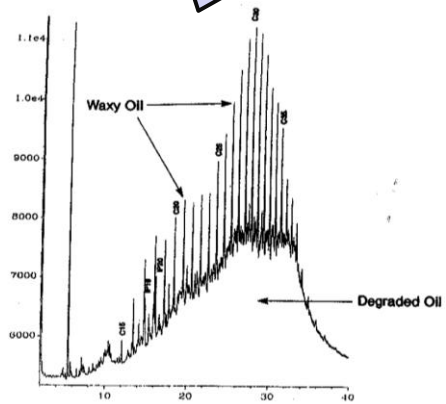
Dolomites with thin levels of organic rich material with remnant of plants and bituminous breccias (after E.L.Sinni et al., 1996)



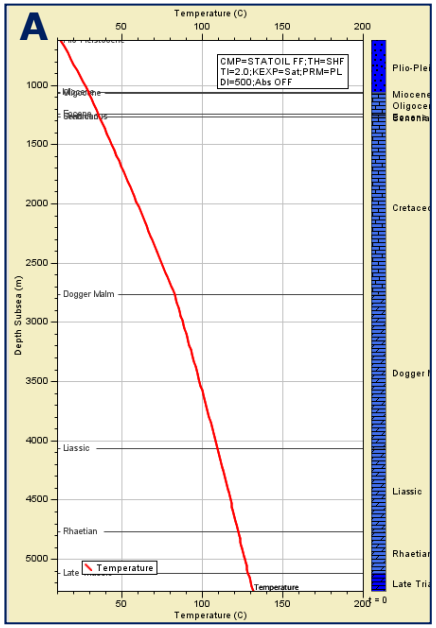
- Geochemical analyses on the Medusa oil indicate presence of traces of very early mature shaly oil from Cretaceous or Tertiary source (presence of oleanane biomarker). In Giove 2 early thermogenic gas likely released by the same source beginning to enter oil window (high iso-butane/n-butane ratio), temperature range in the order of 60-70 C

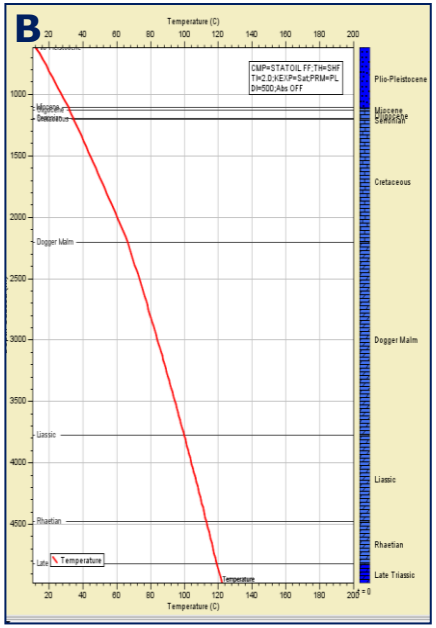
- This source rock could be linked to localised lacustrine sequences following the Turonian uplift of Apulia

Waxy Cretaceous oil overlying biodegraded Triassic oil from the Medusa 1 well



Example of saturates chromatogram for the Medusa oil, after Enterprise Oil Plc study, 1997

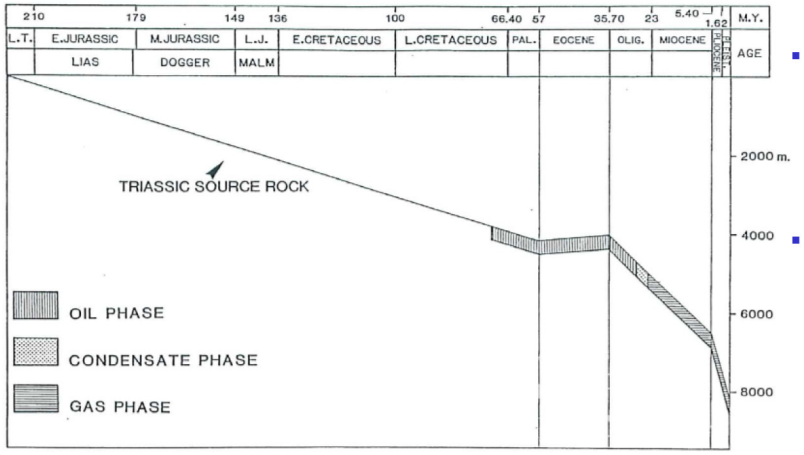




Turonian sequences could be very early mature in the platform or at the toe of the slope

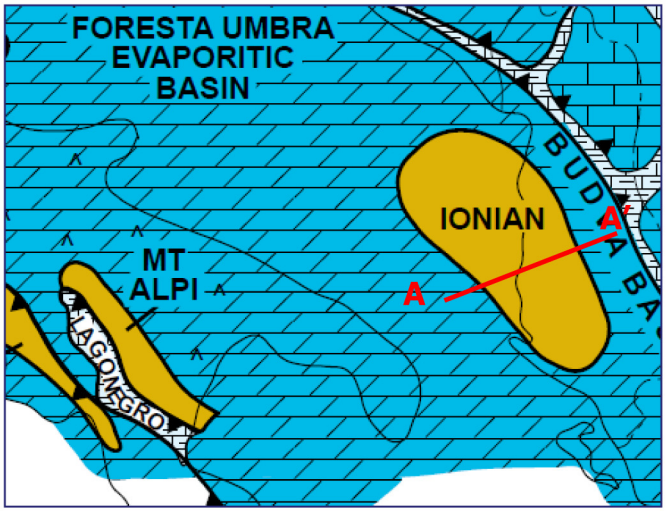
Calculated temperature profiles for the Giove 1 (A) and Medusa 1 (B) wells, modelling carried out with BasinMod 2012. The depth of the Turonian sequences is not known, depths of sequences below the top of Cretaceous are estimated on the basis of well correlations and the interpretation of depth converted seismic data.

Source Rock Maturity and Distribution
Current Models from the Literature

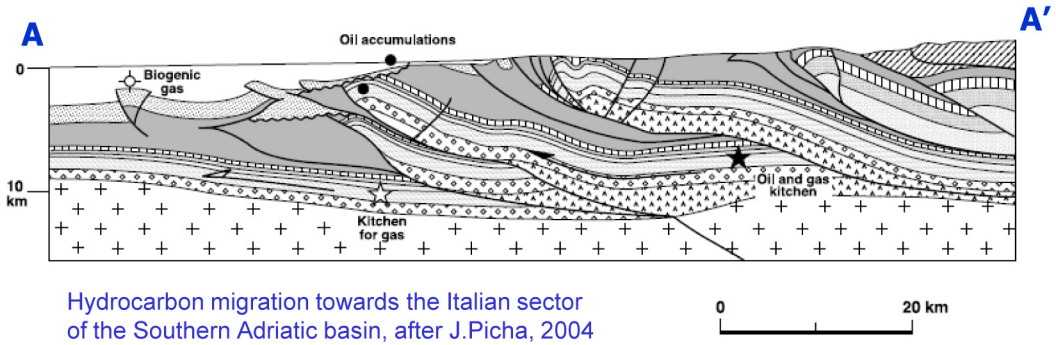


Burial history of a Triassic source rock in the Albanian foredeep, after Mattavelli et al., 1991

- **Extensive lateral migration has been invoked from a hydrocarbon kitchen located in the Albanian foredeep, hydrocarbon migration occurred from Paleocene to Oligocene according to Mattavelli et al., 1991**
- **Oil discoveries in the Italian sector prove however that hydrocarbon migration occurred in the Plio-Pleistocene, i.e. Giove 1 and Medusa 1 have a Plio-Pleistocene seal. These wells were drilled after most basin modelling studies were carried out in the Adriatic. Subsequent studies have however still indicated an anoxic basin located towards Albania, How to explain hydrocarbon migration in Italy during the Plio-Pleistocene and absence of late generated gas –condensates?**
- **Source rock maturity model and distribution needed to be revisited**

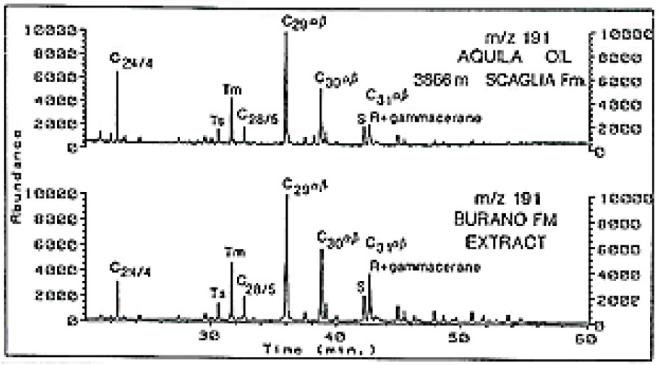


Late Triassic intraplatform basin in the Southern Adriatic Sea area, after E.Zappaterra, 1994



Hydrocarbon migration towards the Italian sector of the Southern Adriatic basin, after J.Picha, 2004

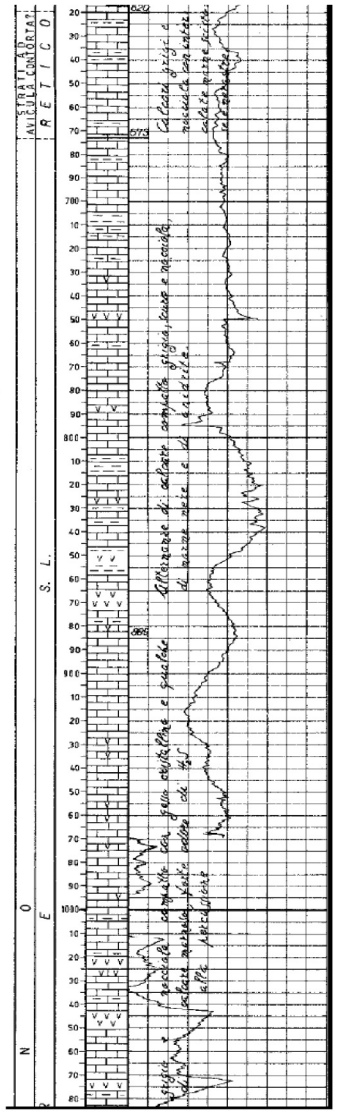
Southern Adriatic
Late Triassic Source Rocks



After Mattavelli, Novelli,1991

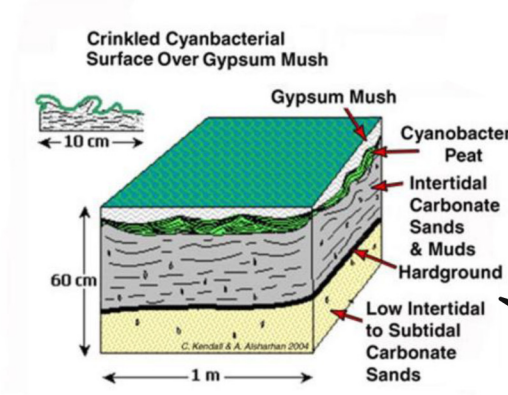
- Geochemical analyses indicate the Aquila and Rovesti oils correlate with the Burano Formation from Central Italy
- The Burano Fm, was deposited in an intertidal setting, similarly to a modern sabkha type of environment

Burano 01 well



Late Triassic samples from onshore Italy show HI of 500 to 600 but low TOC (0.1-0.6%)

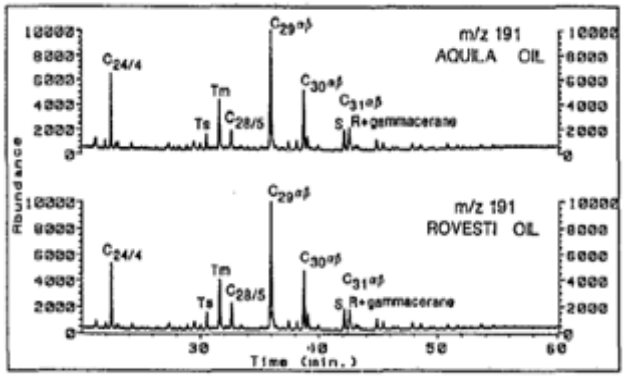
Typically preservation of organic matter is a problem in these settings, analogues (i.e. Noto Fm., offshore Sicily) indicate highest potential is associated with shaly intervals interpreted as trangressions and/or cyclic variations in weather patterns



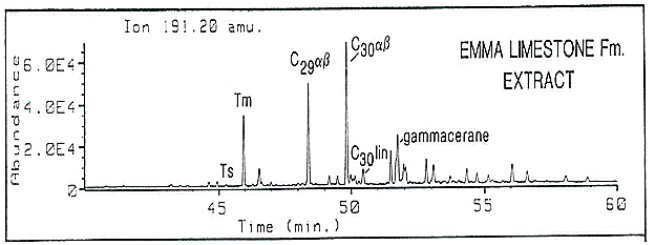
After C,G.St.C Kendal et al., 2004

Organic matter in modern sabkha environments is often deposited as a bacterial or algal peat overlain by gypsiferous sequences

Triassic Source Rock Distribution and Oil-Oil Correlations in the Southern Adriatic Basin



Terpane m/z 191 fingerprint for the Rovesti and Aquila oils, after Mattavelli et al., 1991



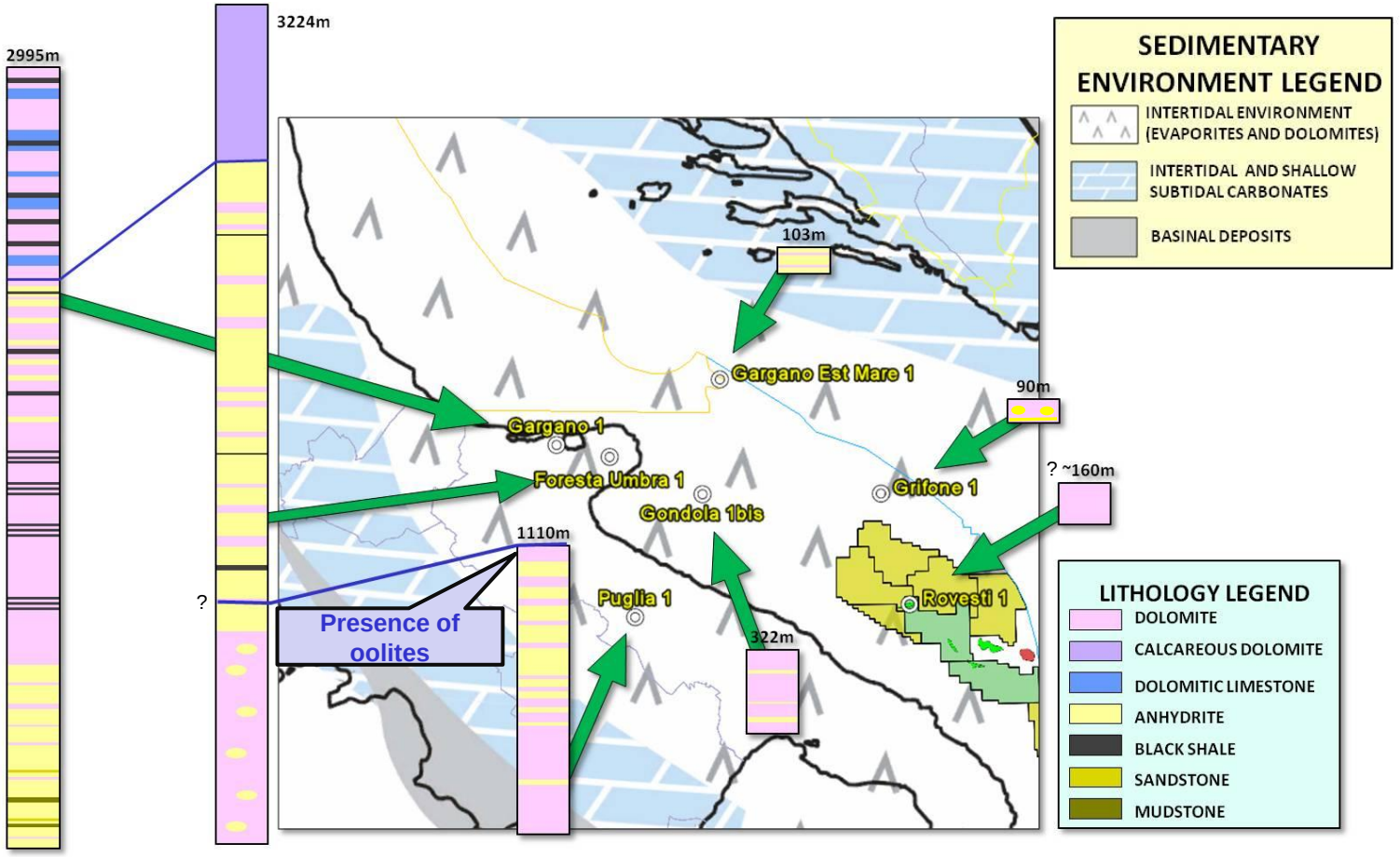
Terpane m/z 191 fingerprint for the Emma Limestone (intra-platform basin, Liassic, Central Adriatic) , after Mattavelli et al., 1991

- The Late Triassic source rock was deposited in a strongly reducing carbonatic environment as indicated by the high sulphur content, Ts/Tm<1, C29/C30 hopanes >1
- The higher diasterane/sterane ratio in Rovesti 1 could suggest a more shaly source, this however could also be the result of low Ph, high Eh depositional environment
- Terpane m/z 191 fingerprint reflects source rock depositional environment, however similarities can be displayed between carbonate source rocks deposited into "lagoonal, sabkha" environments and those deposited in deeper intra-platform basins

	Gravity (API)	S%	δ 13C Aromatic	Diasterane/ Reg.sterane ratio	Gamma cerane index	Pr/Ph	C29/C30 Hopanes	C27/C29 Ster.(218)	Terpanes Ts/Tm (191)
Aquila	36	1.8	-27.71	0.17	1.8	0.93	2.04	0.92	0.28
Rovesti	27	2.6	-27.64	0.35	3.3	<1	N/A	N/A	0.36

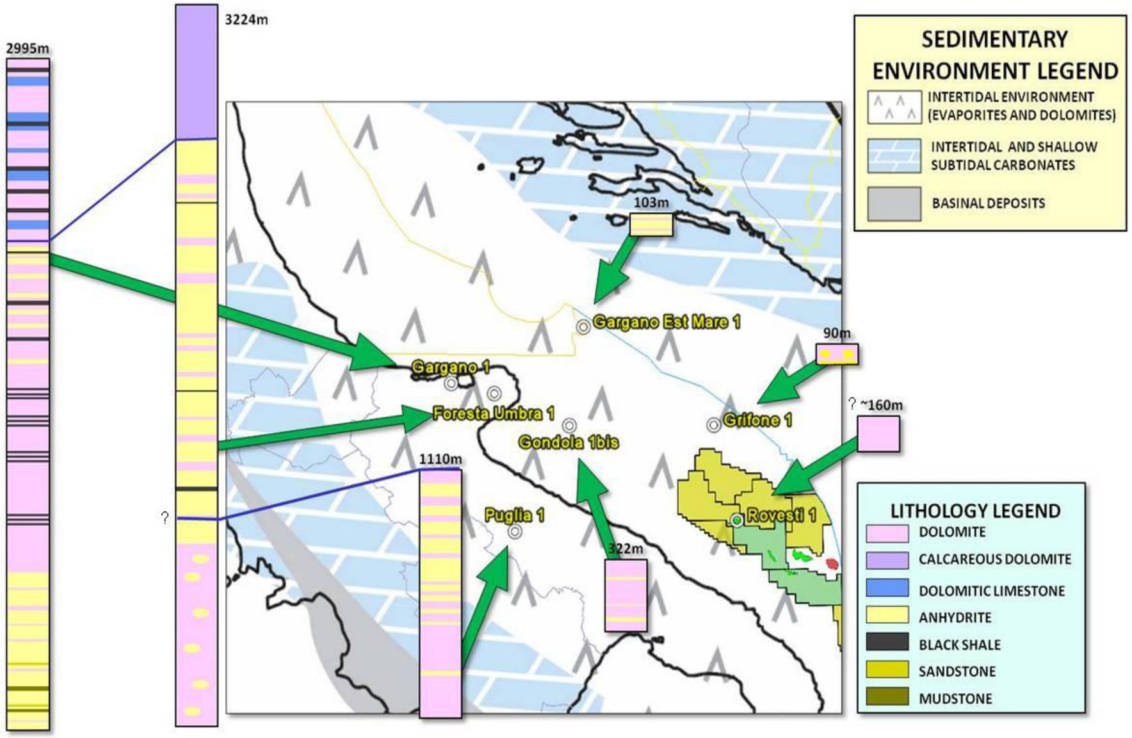
Geochemical data for the Rovesti and Aquila oils, after Mattavelli et al., 1991, Moldowan et al,, 1989

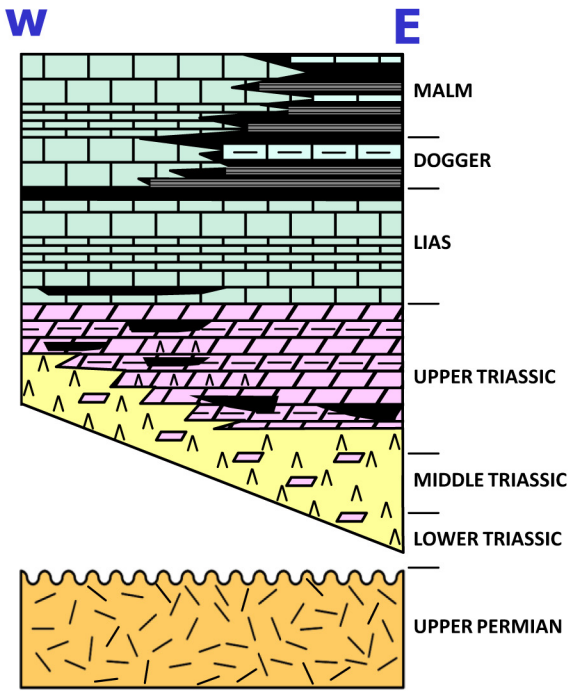
Southern Adriatic – Source rock
Late Triassic Penetrated Lithology & Thickness



➢ **Deep Triassic penetrations in the Southern Adriatic indicate a predominantly evaporitic member (supra-tidal conditions) followed by a thinner dolomitic member. The environment of deposition is fairly heterogeneous, high to moderate energy facies are common within the dolomitic member**

Southern Adriatic – Late Triassic Source Regional Setting

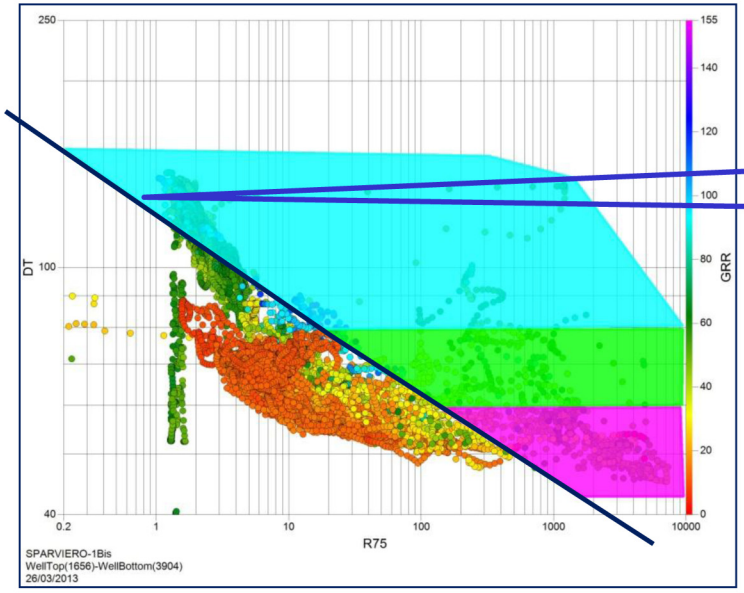




- Evaporitic facies in Albania are Lower to Middle Triassic in age and are thought to progressively migrate to the west following increasing subsidence and possibly tectonic activity

- The presence of salt in Albania, although it cannot be correlated with organic enrichment, suggest the presence of localised restricted basins within this vast epicontinental platform, possibly tectonically driven. The presence of salt in Italy is more questionable, however salt has been found in shallow drilling in southern Tuscany (Larderello) and in the Umbria region (Civitelle well), (G.Ciarapica et al., 1994) and is present in the Central Adriatic (Vlasta-1 well)

Liassic Source Rock in the Southern Adriatic Analysis of Well Log Data from Sparviero 1bis Well



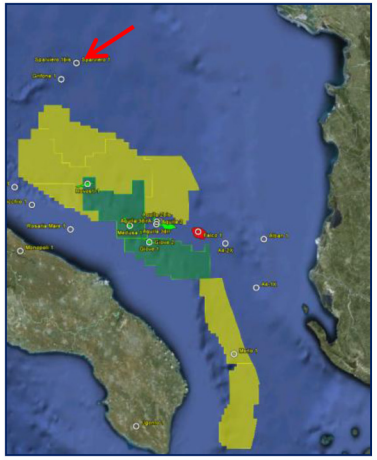
- Moderate source rock potential is associated with Liassic shaly intervals developed within intra-platform basins. In the absence of geochemical analysis, well data has been used to qualitatively identify organic rich intervals

Method description

- Based on source rocks data collected around the world, a general formula has been derived for simply separating source from non-source rocks using a sonic-resistivity combination (Meyer and Nederlof, 1984). A regression line separates source rocks from non source rocks for both shale and limestone (M.H. Nederlof et al.,1984).
- In addition the Gamma ray has been used to identify facies rich in sapropelic organic matter

Regression line:
$D = -6.906 + 3.186 \log_{10}\Delta t + 0.487 \log_{10} R75°$
where Δt=sonic log value, µs/ft,
R75° = log resistivity corrected to 24 °C

- High potential for good quality source rock
- Moderate potential for good quality source rock
- Low potential for good quality source rock



Location of the Sparviero-1 well in the Southern Adriatic basin

Conclusions

- A new maturity model for the Southern Adriatic basin is proposed, this model indicates hydrocarbon generation from a Late Triassic source rock within the Italian sector and not from the Albanian foredeep, as previously proposed. As a result less risk in the area is perceived to be associated with hydrocarbon charging and migration losses.
- Geochemical analyses indicate a Late Triassic carbonate source rock deposited under strongly reducing conditions which could have analogies with equivalent facies deposited in Albania. This source rock could have been deposited in a “sabkha “ or “lagoonal” type of environments, however deposition within an intra-platform basin appears more likely on the basis of the high source rock potential of these facies and the lack of any significant evidence for effective “lagoonal” type of facies within the Burano Formation.
- Early Liassic source rock linked to intra-platform basins could be locally prolific within the basin. A recent review of well log data suggests the presence of organic rich shales of moderate potential in the Sparviero 1 bis well.
- Early generation of gas and oil within the offshore Apulian platform can be correlated with lacustrine organic rich facies in the Murge area which were deposited during the Turonian unconformity event. This suggest a similar paleo-tectonic evolution for the offshore Apulian platform.