The Petroleum Prospectivity of the Apulian Carbonate Platform and Key Tectonic and Stratigraphic Controls*

Carlo Caldarelli[1], Alberto Riva[2], and Raffaele Di Cuia[2]

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[1]Cabot Energy Plc, (previously Northern Petroleum Plc), London, United Kingdom (c.caldarelli@cabot-energy.com)
[2]GE Plan Consulting, Ferrara, Italy

Abstract

The Apulian Platform is the most prolific Mesozoic carbonate platform domain within the Central Mediterranean as highlighted by the giant oil fields of the Val d'Agri Complex in Southern Italy. The margin of the Apulian Platform is buried westwards beneath the Apennine thrust sheets, whereas to the east the adjacent domain includes basinal sequences of the Ionian Basin and their lateral equivalent units offshore Italy. In the southern portions of the Adriatic foreland there are still conflicting and often erroneous interpretations in the literature on the location of the platform margin. The main petroleum plays in proximity of the Apulian Platform margin are oil bearing Cretaceous karstic carbonates as evidenced by the Rospo Mare heavy oil producing field (94 MM bbl EUR), and oil discoveries in Oligocene carbonate build-ups which are yet to be appraised (eg. Giove-2 and Medusa-1 wells offshore Italy, and A4-1X well offshore Albania). A major exploration development could be represented by prolific deeper objectives within Cretaceous karstic carbonates in the latter oil discoveries. In the Medusa-1 well significant oil shows were encountered in the Cretaceous carbonates, due to drilling difficulties the Cretaceous target could not be tested. The distribution of such oil shows suggests an OWC significantly deeper than the deepest closing contour at top Cretaceous structural level, likely due to the presence of intra-formational seals.

The margin of the Apulian Platform is characterised by a well-developed rugosity being strongly controlled by a complex fault network, this is well documented onshore (Gargano Promontory, Maiella Mountain) where the margin outcrops. Mesozoic extension and foreland subsidence ahead of the westward migrating Dinarides thrust belt during the Late Tertiary are the key controls for hydrocarbon generation. Significant hydrocarbon generation occurred in the Late Tertiary and short distance migration pathways likely resulted from mature Triassic source rocks in proximity of the Apulian Platform margin in several areas. This study integrates all available subsurface and outcrop data from southern Italy, southern Albania and Greece to better define the correct location of the Apulian Platform margin in the southernmost part of the Adriatic sea which is still largely underexplored. The results of this study and review of past works highlight the significant hydrocarbon potential of the Apulian Platform margin and the adjacent base of slope carbonate sequences.

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- Carlo Caldarelli, Cabot Energy Plc (previously Northern Petroleum Plc)
- Alberto Riva, GE Plan
- Raffaele Di Cuia, GE Plan

17th October 2017

Summary

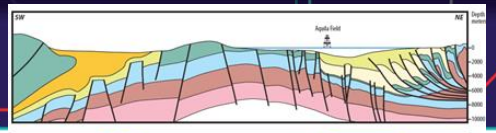
Summary

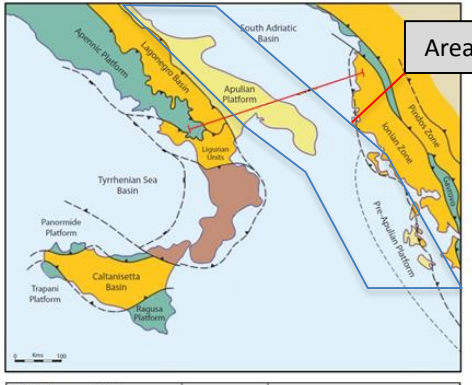
- Offshore Apulian carbonate platform (Adriatic foreland), geological setting & exploration history
- Prolific petroleum systems are located in proximity to the Apulian carbonate platform margin:

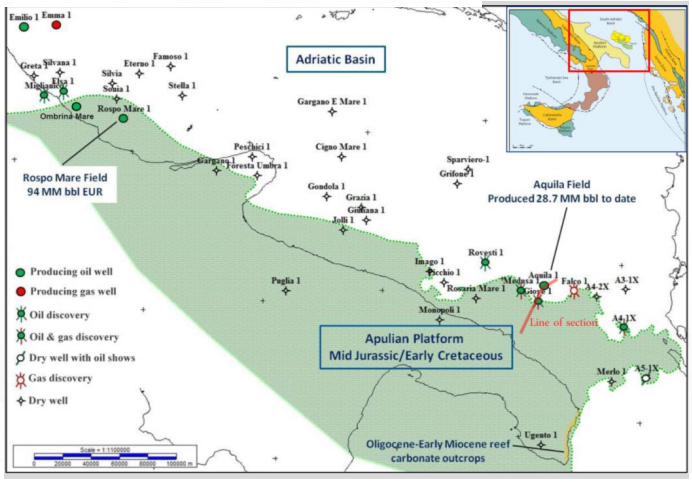
- The Cretaceous karstic play proven by the Rospo Mare Field, largely underexplored. The example of the Medusa-1 well with significant oil shows in the Cretaceous, yet to be appraised.

-Oligocene/Early Miocene carbonate build-ups, existing discoveries and further potential

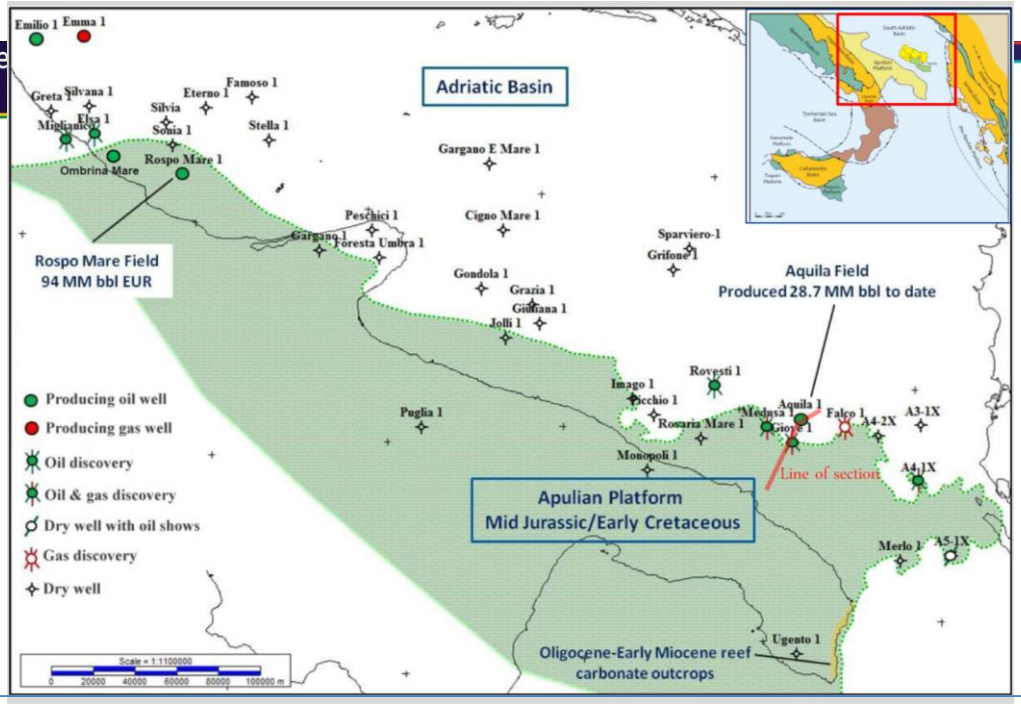
- Timing of hydrocarbon generation/migration and implications for petroleum prospectivity
- The south-east sector of the offshore Apulian carbonate Platform: erroneous interpretations in the literature and a reassessment of the petroleum potential
- Conclusions





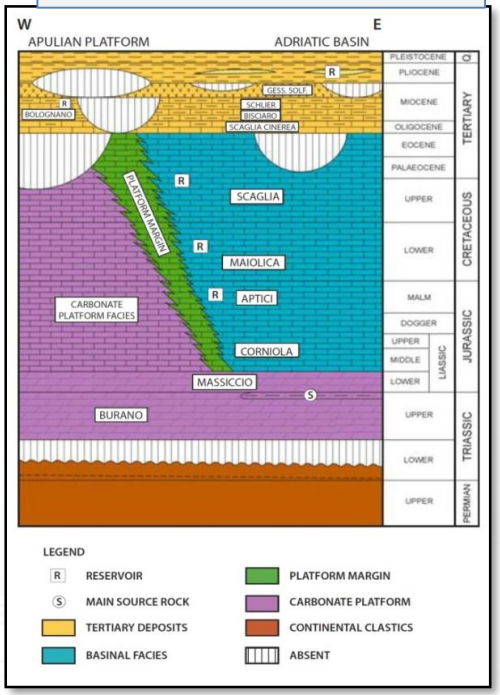


Offshore Apulian Platform and its Margin_ Adriatic Foreland



Stratigraphic overview_ Apulian Platform to Basin

- Deformed foreland area in the Tertiary, carbonate sedimentation on passive margin from Late Triassic to Early Tertiary
- Overall setting, Mesozoic platform with Tertiary basin cover



Well established petroleum system, numerous oil and gas discoveries and producing oil fields

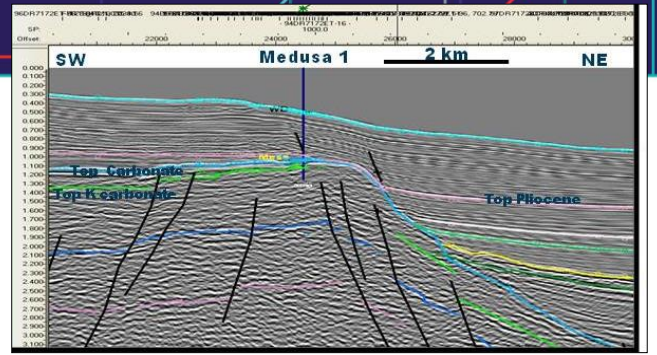
<u>Offshore Apulian Platform</u>

- Cretaceous karstic carbonates, eg. Rospo Mare 94 MMbbls EUR, heavy oil production 11/12 API gravity) <u>lack of exploration & appraisal to the south of this oil field</u>
- Platform margin build-ups (Oligocene, Early Miocene) and deeper Cretaceous targets , several discoveries to be appraised (eg. Giove, Medusa, A4-1X)

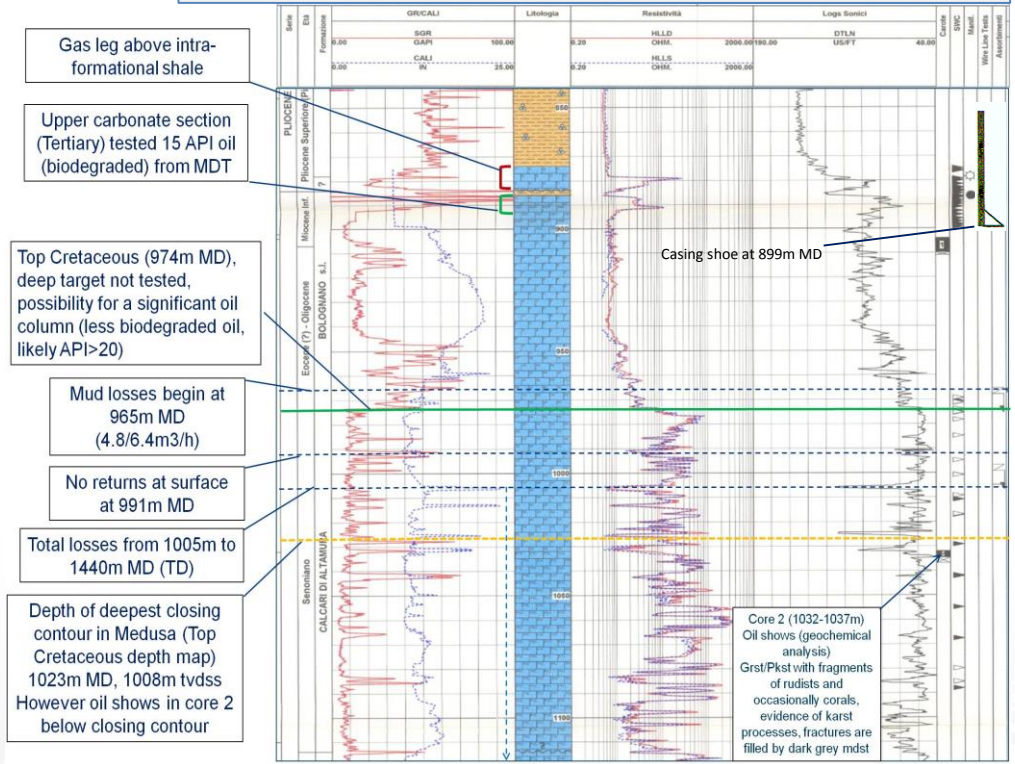
<u>Basin</u>

- Paleo-structures with likely additional stratigraphic trapping, eg. the Aquila Field produced 30.8 MMbbls to date

Medusa-1- Oil & Gas Discovery



Medusa-1 Composite Log, reservoir section (Tertiary & Cretaceous carbonates)



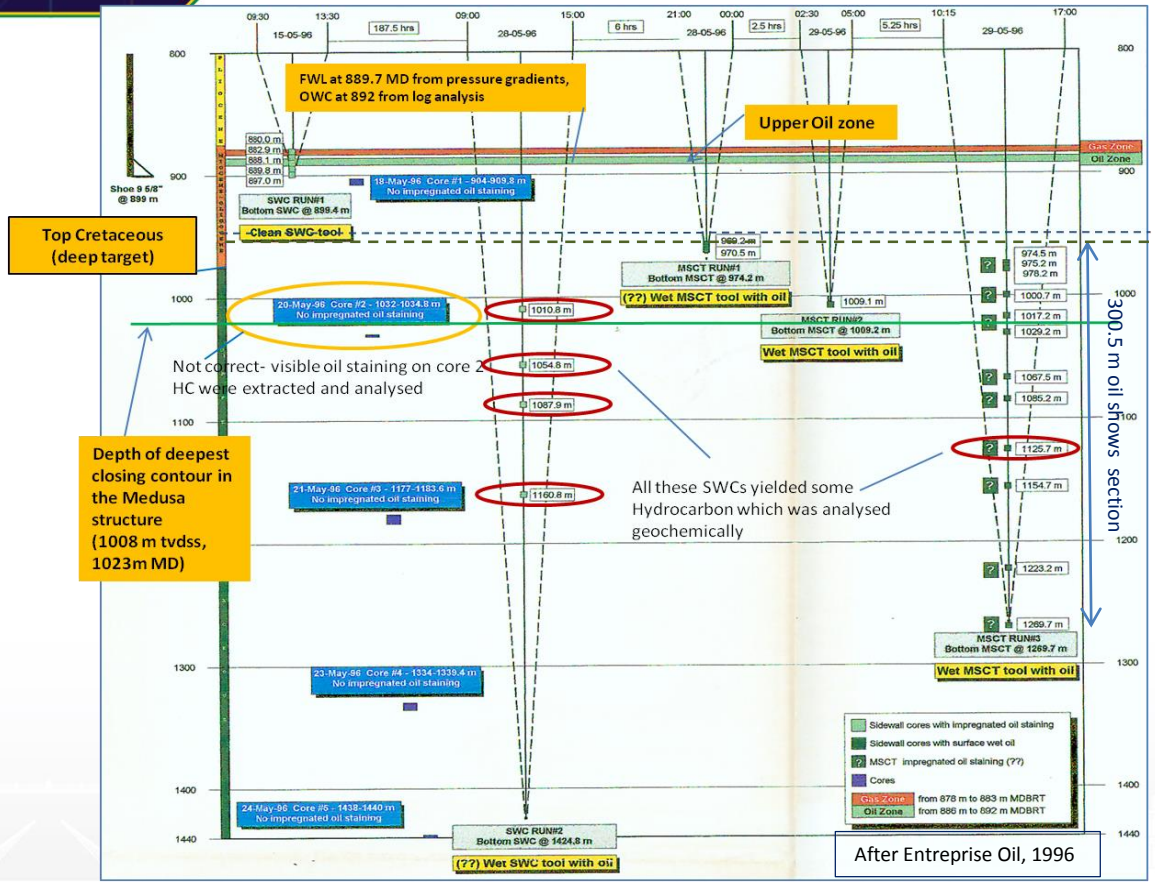
- Drilled in 1996, Enterprise Oil
- Water Depth 377m, TD 1440m MD in Cretaceous lsts
- 12m hydrocarbon column – intraformational shale in-between accumulation
  - 878-883m MD gas (likely mix of biogenic and thermogenic)
  - 886-892m MD oil (15 API, biodegraded, recovered by MDT at 879m MD)

Significant oil shows in the Cretaceous section (next slides), Cretaceous karstic carbonates could not be tested due to drilling difficulties, the evaluation of this section is problematic:

- Total losses from 1005m to TD
- Petrophysical evaluation is very challenging: resistivity is not reliable, incomplete log suite with no density and neutron logs
- Lack of clear indication of sealing unit at top Cretaceous level:

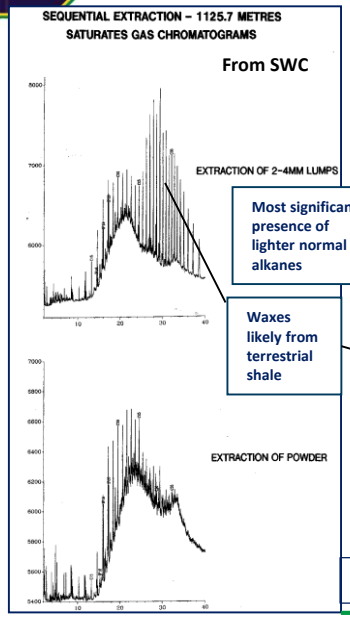
-Base Tertiary section (requires marly/clay rich section), lack of regional evidence for such unit

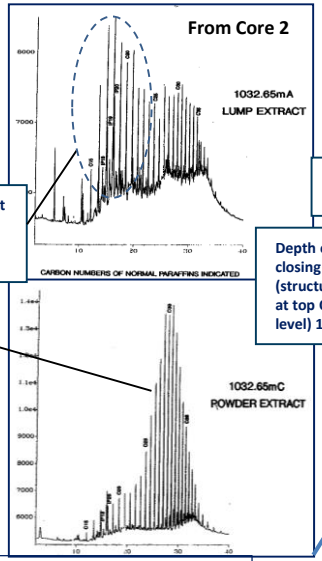
Medusa-1 well_ Summary of Hydrocarbon shows in Cretaceous section (1)



- Oil was found on the surface of the coring tool (MSCT), this tool was only run in the deep 8 ½ inch section when the upper oil bearing zone was behind casing.
- Upper oil zone in Oligo-Miocene carbonates is well defined from logs and pressure gradients (tested 15 API oil from MDT), few meters above casing shoe
- The oil recovered from the MSCT tool is less biodegraded than the oil recovered with the MDT tool in the Tertiary carbonates (additional phase of lighter normal alkanes).
- Week to moderate oil shows from SWC's in almost 300m of Cretaceous section

Medusa-1 well_ Summary of Hydrocarbon shows in Cretaceous section (2)



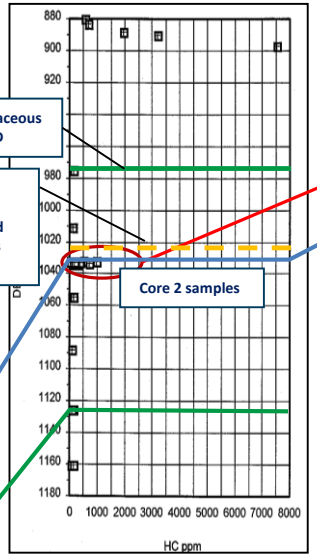


Most significant presence of lighter normal alkanes

Waxes likely from terrestrial shale

After Entreprise Oil, 1996

Total HC extracts vs depth (m)
SWC & core 2



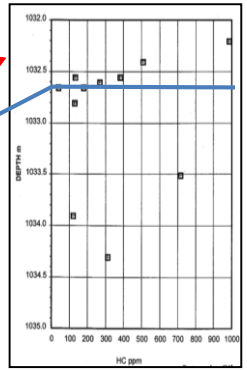
Top Cretaceous 974m MD

Depth of deepest closing contour (structure defined at top Cretaceous level) 1023m MD

Core 2 samples

Core 2_Most significant amount of hydrocarbon extracted (mud losses and sample preservation are critical factors)

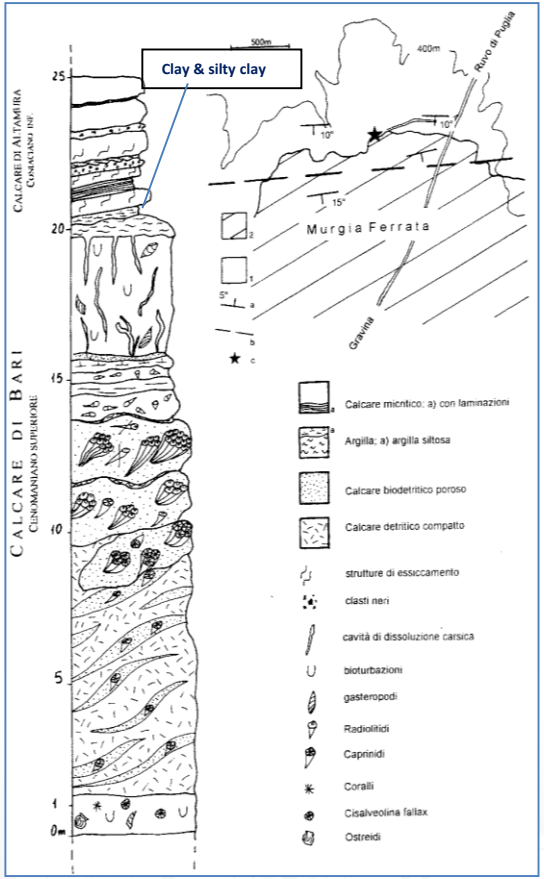
Total HC extracts vs depth (m) core 2



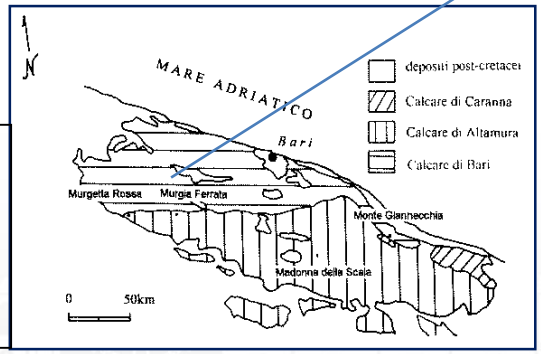
- Sequential extraction: solvent extraction from lumps followed by power extraction: overall it appears oil migrated in the less accessible pore space within the matrix even in oil shows well below the deepest closing contour in the structure
- Second oil charge not biodegraded (more evident in core 2) with normal alkanes stronger than isoprenoids above large unresolved zone (biodegraded oil)_ Both oils share same biomarker signature consistent with Triassic generated oil
- Contamination of waxes from highly immature oil from terrestrial shale, not consistent with Triassic oil (algal, marine kerogen), the likely low maturity and mobility of this oil suggest it was generated in close proximity or within the Cretaceous sequence

Medusa-1 well_ Intra-formational shales within the Cretaceous section

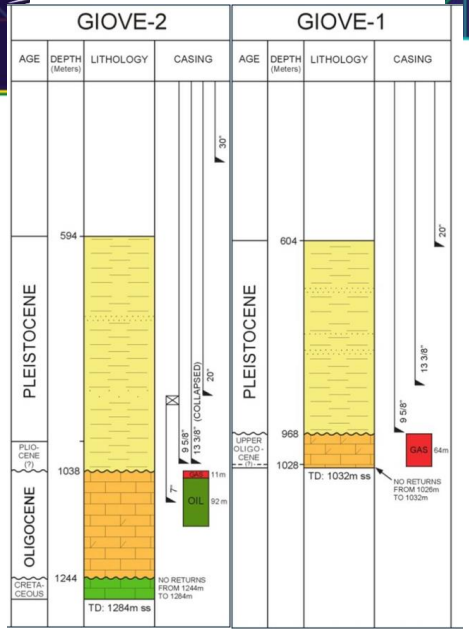
- Likely presence of intra-formational thin shale units (below log resolution):
- Oil shows from core 2 & SWCs are significantly deeper than deepest closure at Top Cretaceous level
- Shale fragments filling karst vugs recovered from core 2 (1032-1034.8m MD), described as dark grey laminated mudstone with good petroleum potential, likely consistent with the source of contamination from highly immature waxy oil observed in the GCs.
- Presence of oleanane biomarker in some oil samples, again indicating minor hydrocarbon generation from terrestrial shale (from angiosperms which are only present from the Cretaceous)



Outcrop examples of Cretaceous sequences showing shale levels within a karstic environment, After L.Sinna, A.Reina 1996



Giove oil discovery

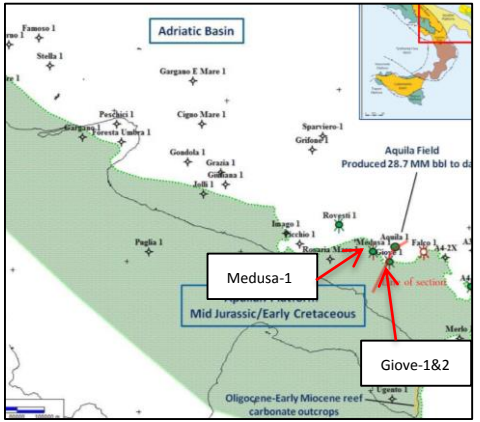


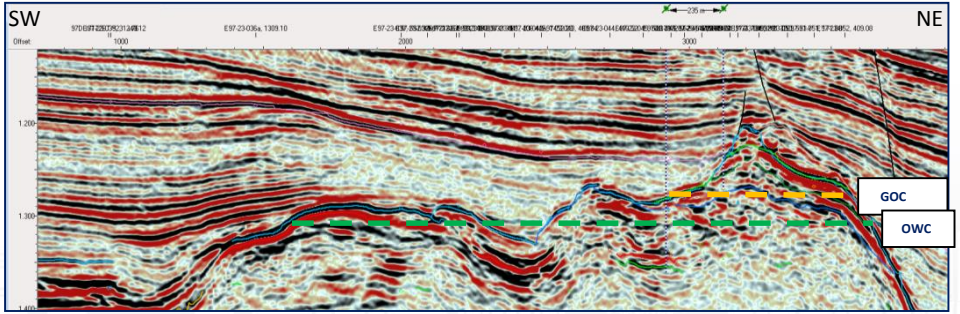
Giove 1 (Enterprise 1998)

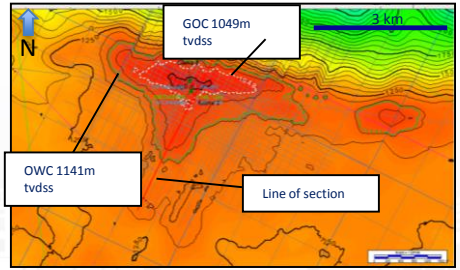
- Water depth 604m, TD @1032m tvdss in Upper Oligocene LST
- No returns at TD, gas kick, damaged BOP, had to TD early, reservoir section not logged
- 3 cores cut from 978.1 to 1009.6 m tvdss with good recovery
- Gas and oil shows over interval 968-1032m tvdss (68m)
- Gas 99% C1; 1% C2-C5
- Fluorescence and oil traces in cuttings

Giove 2 (Enterprise 1998)

- 237m south of Giove 1 and off structure
- Water depth 594m, TD @1284m tvdss in Cretaceous lsts
- Gas leg 1038-1049m tvdss; Oil leg 1049-1141m tvdss
- 1 core cut from 1097.8 to 1101.8m tvdss with poor recovery (25% = 1 m) with oil shows
- Gas and Oil sampled with MDT, Oil 16° API
- Total losses from 1244m tvdss
- Not tested. Considered 'uneconomic' (1998) $11/barrel







Giove oil discovery

Giove-1 (Full reservoir interval in gas leg)

- Reservoir description: Bioclastic pkst with abundant benthonic macroforaminifera (Lepidociclyna, Operculina, Amphistegina), large rhodolites (coralline algae nodules) are common.

- Reservoir properties: 3 cores cut from 978.1 to 1009.6 m tvdss with good recovery (reservoir interval 64m, 31.5m with core)
Av. porosity of 27% from cores, excellent interparticle and intra-bioclastic porosity, very limited fine grained matrix, evidence of leaching

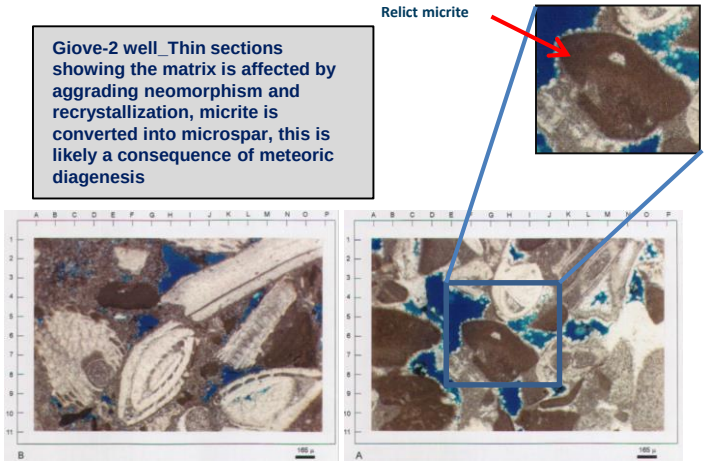
Giove-2 (Reservoir interval in oil leg)

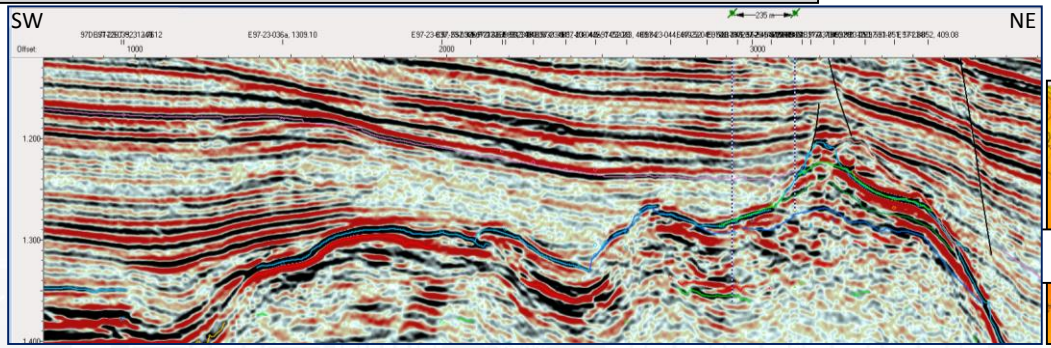
- Reservoir description: Bioclastic Pkst/Wkst with abundant benthonic macroforaminifera (Lepidociclyna, Operculina, Amphistegina), large rhodolites (coralline algae nodules) are common

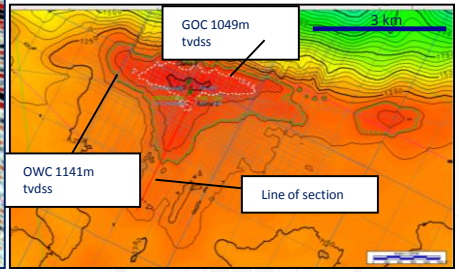
- Reservoir properties (oil zone): av. porosity of 13% from logs, evidence of leaching and re-crystallization, significant amount of matrix

Key question: only one well penetrated the oil bearing zone, are the petrophysical properties likely to vary significantly away from the well?

Giove-2 well_Thin sections showing the matrix is affected by aggrading neomorphism and recrystallization, micrite is converted into microspar, this is likely a consequence of meteoric diagenesis





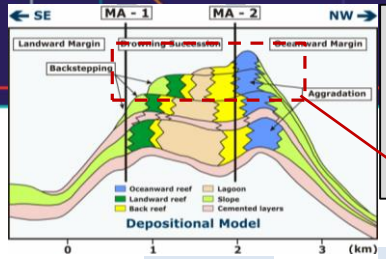


Giove oil discovery

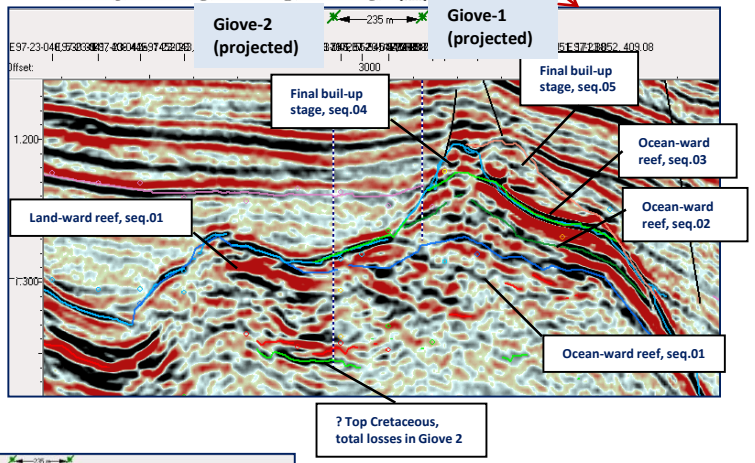
- Seismic mapping has highlighted the presence of several reefs built at different stages. The Giove-2 well was likely drilled in a relatively off-reef position between the main reed body and the land-ward reef

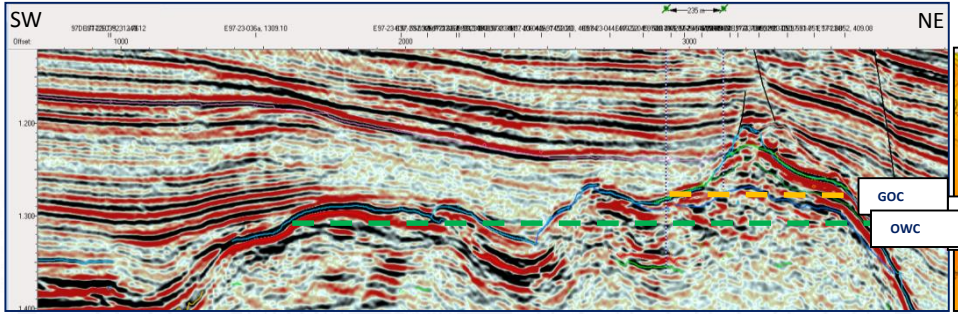
- The Malampaya Tertiary carbonate build-up example in the Philippines has been used as a reference model to constrain the facies distribution in the Giove discovery, as result the mean STOIIP has been upgraded to 235MMbbl.

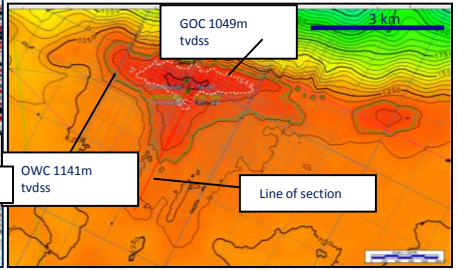
- As highlighted in papers on the Malampaya build-up (F.Fournier et al., 2005), the role of tectonics is key in determining the stratigraphic architecture of these systems



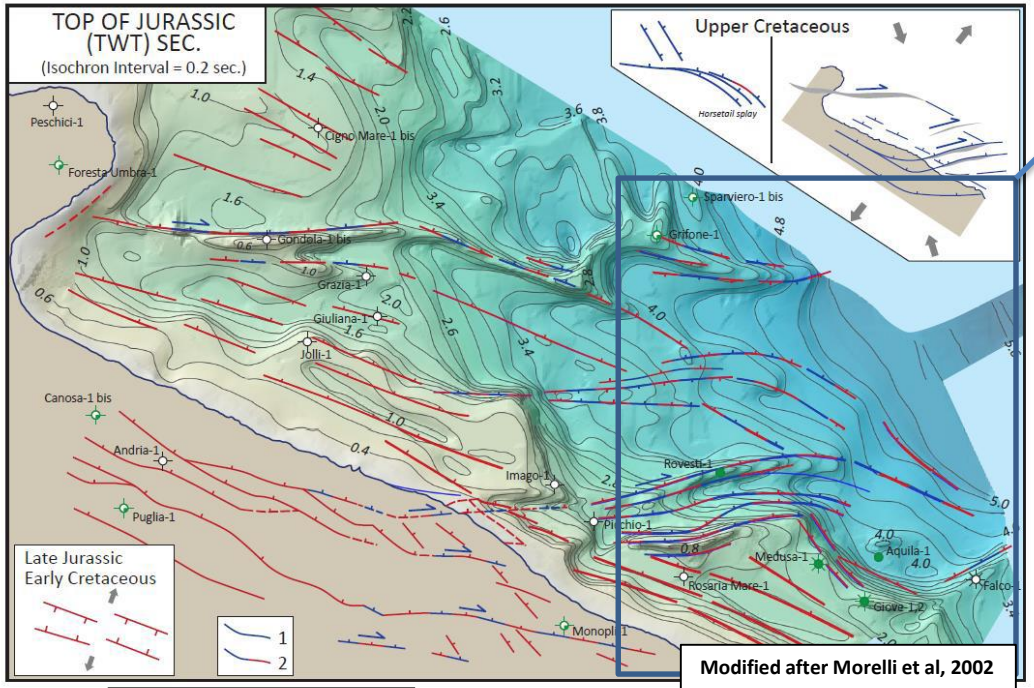
Reservoir analogue, Tertiary Malampaya and Camago buildups, Philippines, after J.Grotsch et al., 1999. Dashed line includes build-up stages recognised in the Giove discovery



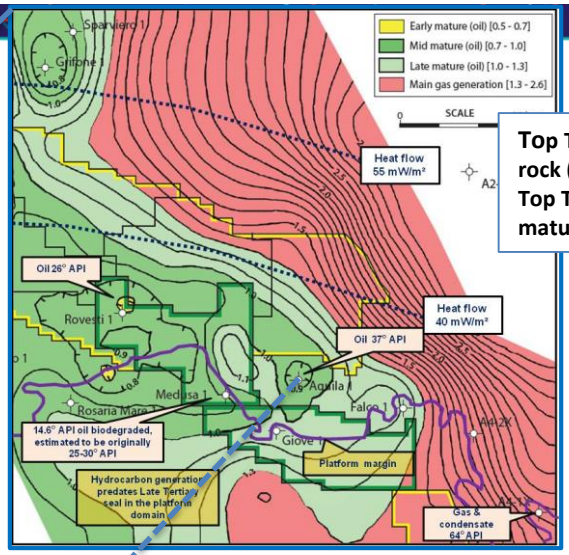




Hydrocarbon generation, migration & tectonic phases

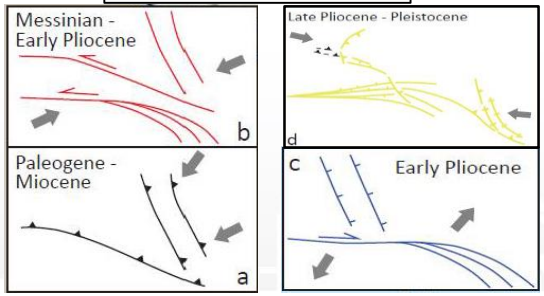


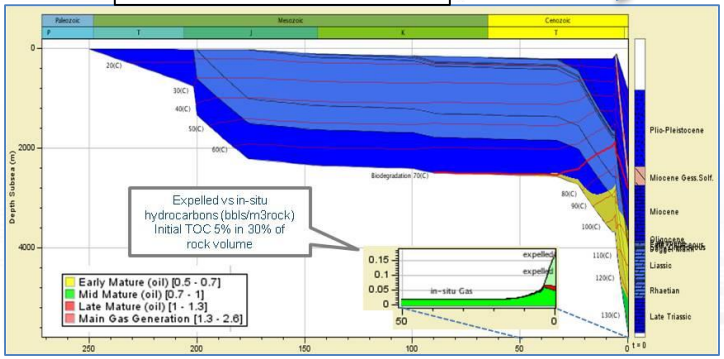
Modified after Morelli et al, 2002



Top Triassic source rock (500m below Top Triassic) maturity map

Tertiary tectonic phases



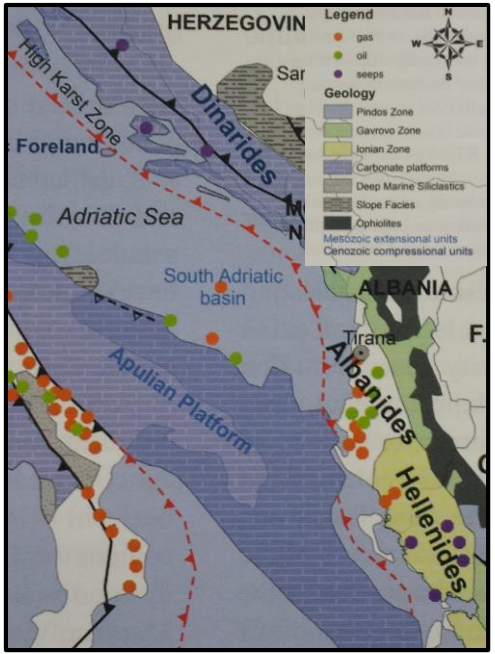


- **Good correlation between modelled maturity and the type of hydrocarbon occurrences**
- **Generally deepening of the basin towards east-south east in Dinarides foredeep**
- **Late phase of petroleum migration (Plio-Pleistocene) coinciding with Dinarides thrust belt migration and tectonic reactivation**

Burial curve and modelled maturity for the Triassic Burano Fm. in the Aquila 1 well
Modelling carried out with BasinMod2012

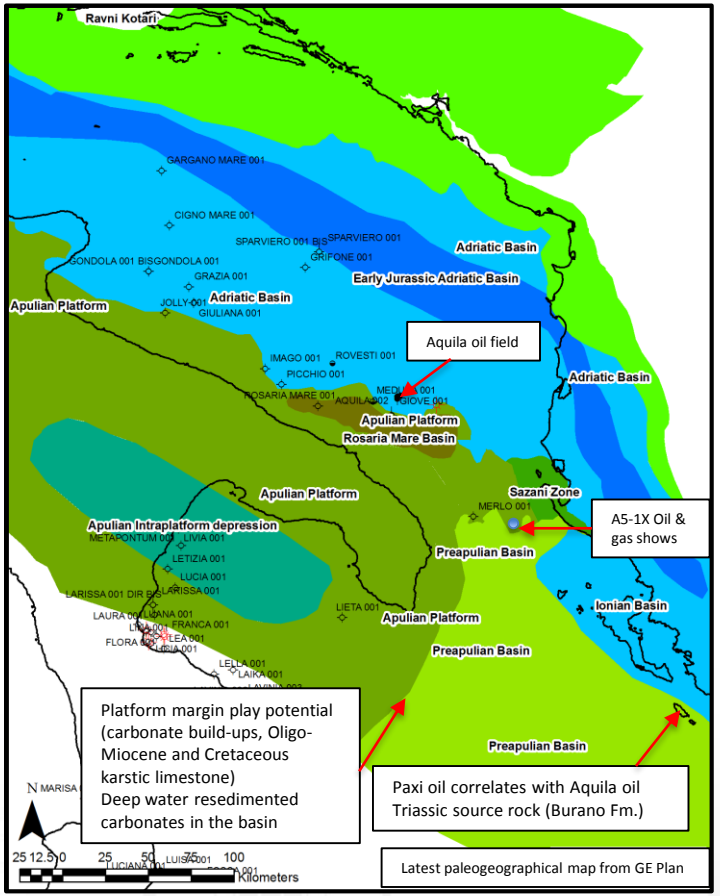
Adriatic Foreland_ Southern sector

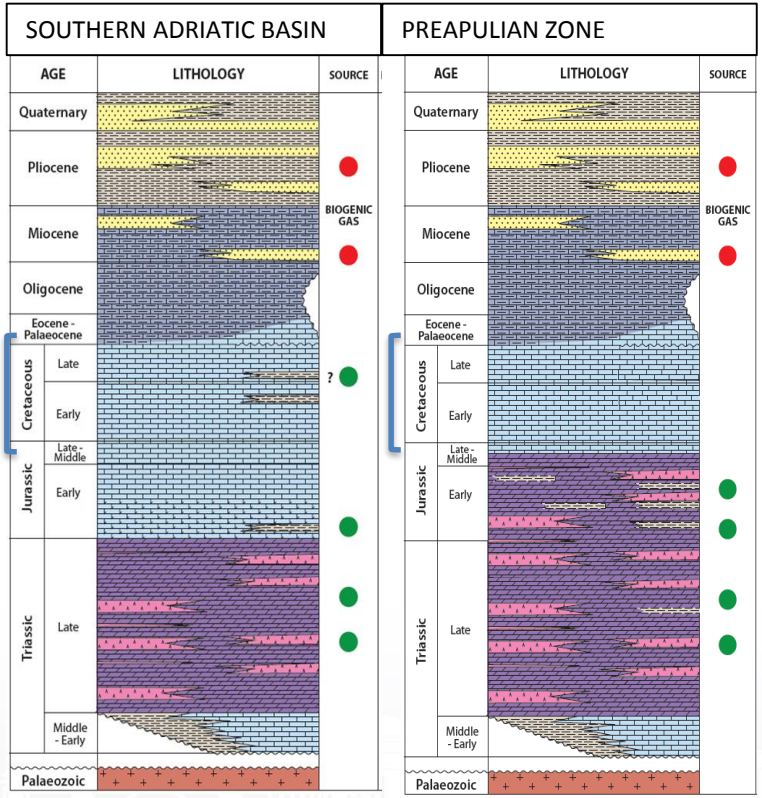
Erroneous interpretations in the literature on the location of the Apulian platform margin



Geological map of the Adriatic area showing a continuous Apulian Platform domain from Italy to NW Greece (no Pre-Apulian Basin), after A.Zelilidis et. al., JPG, July 2015

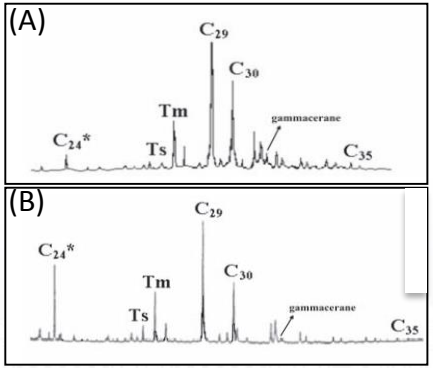
- Most recent studies ignore the presence of the Pre-Apulian Basin which crops out in the Paxi Island and north-west Greece
- All available subsurface and outcrop data from southern Italy, southern Albania & Greece have been integrated to define the correct location of the Apulian platform margin
- The Pre-Apulian Basin share similarities with the Southern Adriatic and Ionian basin with similar tectono-stratigraphic evolution and platform drowning since the Late Jurassic (Dogger-Malm)

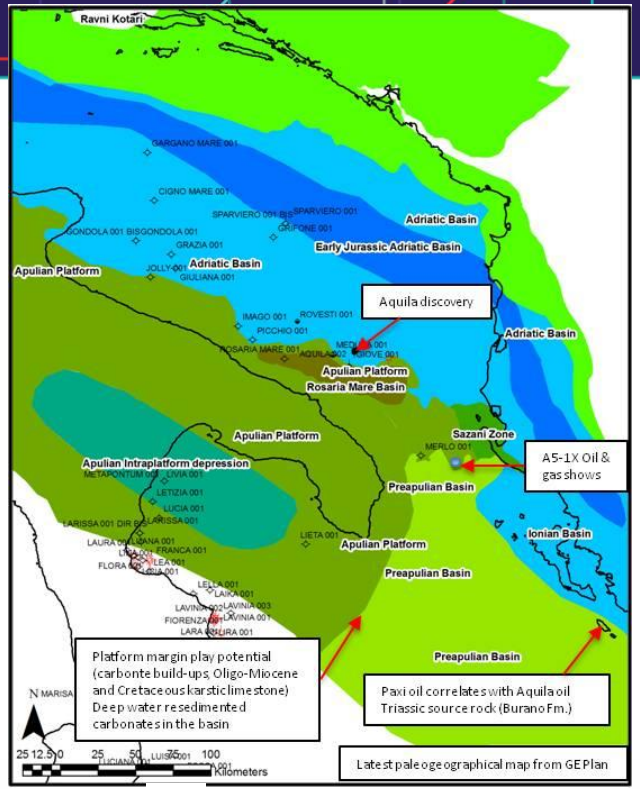




Modified after V.Karakitsios et al., 2007
Based on stratigraphy from Paxos (Pre-Apulian Zone)

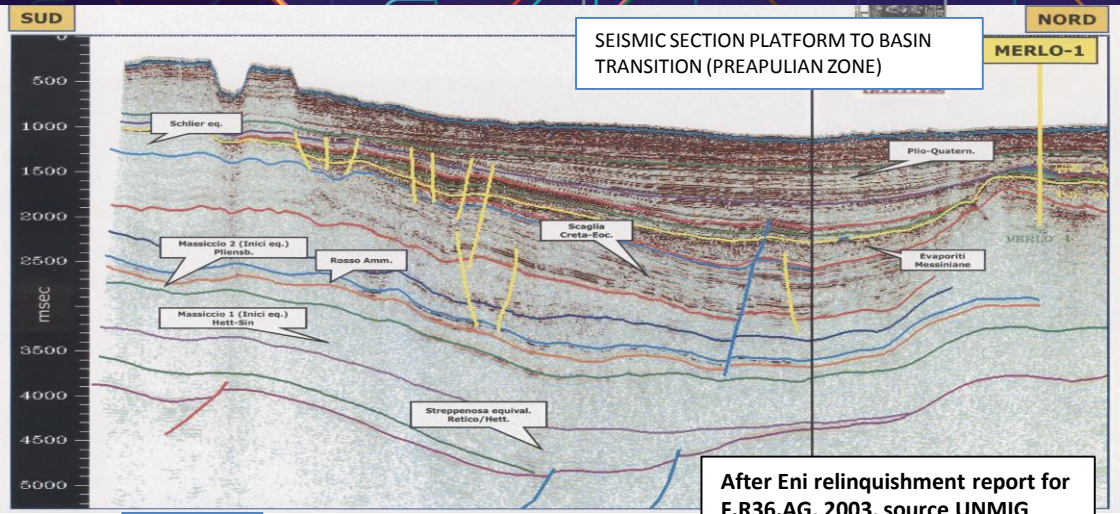
- **Hydrocarbons from the Southern Adriatic Basin and from the Pre-Apulian zone appear to share similar geochemical characteristics, good correlation between the Aquila oil and oil from the Paxi-Gaios-1X well**
- **In the Pre-Apulian zone the dolomitic/ evaporitic sequence with source rock potential also extends into the Lias**

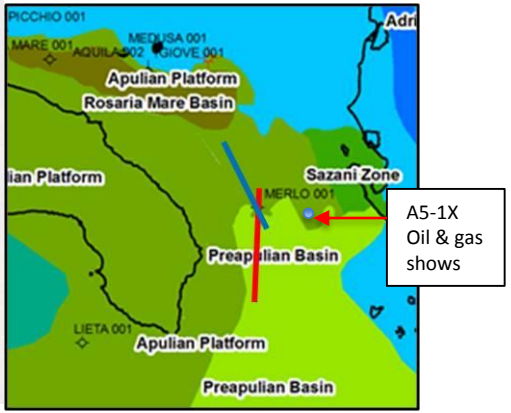




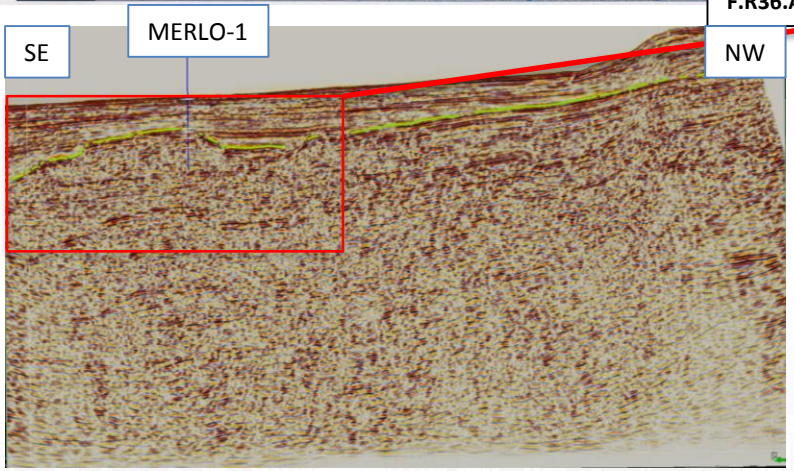
Comparison between the gas chromatogram m/z191 for the Paxi oil (A) and the oil from Aquila (B), after V.Karakitsios et al., 2007

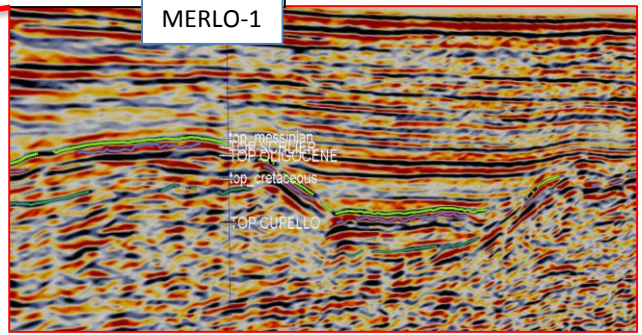
Adriatic Foreland_ Southern sector Seismic examples





After Eni relinquishment report for F.R36.AG, 2003, source UNMIG





- **Limited seismic dataset throughout this area**
- **Merlo-1 well penetrated a carbonate build-up feature (Oligocene-Early Miocene), dry well, often explained due to lack of hydrocarbon charging**

Conclusions

- Prolific petroleum systems are located in proximity to the Apulian carbonate platform margin. The Cretaceous karstic play proven by the Rospo Mare Field is largely underexplored. A key issue for hydrocarbon prospectivity is whether deeper independent closures within the Cretaceous karstic carbonates can exist below the Tertiary reefs. Significant oil shows have been encountered in the Medusa-1 well in the Cretaceous section, following drilling difficulties and mud losses it's likely that an hydrocarbon column has been missed in this well.
- Giove Field_ New facies model with higher porosity scenarios based upon the geometries observed on seismic data and reviewing analogue fields. This has been complemented by a review of well productivity and oil saturations (correcting for contamination from drilling fluids) which has highlighted an attractive appraisal opportunity. Similar build-up features occur along the Apulian Platform margin.
- Several recent studies ignore the presence of the Apulian carbonate platform margin adjacent to the Pre-Apulian Zone which could have significant hydrocarbon potential, the correct location of this margin has been better defined in this study. The limited seismic data available shows similarities in the tectono-stratigraphic evolution between the Southern Adriatic and the Pre-Apulian basins; oil to source correlations from the Pre-Apulian zone show similar Triassic source rocks as in the Southern Adriatic Basin, where the petroleum system is proven.