Hydrocarbon Systems in the Onshore and Offshore Sicilian Fold and Thrust Belt: New Constraints from Geochemical Data*

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Search and Discovery Article #30202 (2012)
Posted March 12, 2012

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

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Abstract

The onshore Sicilian thrust belt has been extensively studied, whereas little information is available for the offshore thrust belt. The paleo tectonic units which constitute the onshore thrust belt were deposited on a Mesozoic passive margin linked to the opening of the Tethys. These units bear some similarities, especially during the Cretaceous, with equivalent facies in North Africa. New geochemical data have been acquired in the onshore Sicilian thrust belt. The results obtained have been correlated with existing data from Northern Tunisia and offshore Sicily and integrated with a regional geological model. The occurrence of Late Triassic-Liassic intraplatform basins with proven hydrocarbon potential has been identified in western Sicily as well as in equivalent Mesozoic Trapanese facies in the inverted Tortonian-Messinian foredeep offshore Sicily. The Cenomanian-Turonian black shales outcropping in NE Sicily, regarded as a unit equivalent to the Bahloul Formation in North Africa, have the highest source rock potential of all the analyzed samples and can be regarded as a world class source rock. Our studies indicate these sequences were deposited in a near-shore environment consistent with slope facies of the Panormide platform. Geochemical studies have shown a possible correlation between the oils of the Nilde and Norma discoveries in the inverted offshore Tortonian-Messinian foredeep, the Bahloul Formation (Cenomanian-Turonian) in Tunisia, and the equivalent Bahloul facies in northeastern Sicily. These oils also correlate with the Fahdene Formation (Aptian, Albian) in Tunisia, however a contribution from the Bahloul Formation is considered more likely. Our studies concluded the most significant petroleum accumulations in the inverted offshore Tortonian-Messinian foredeep (e.g. Norma and Nilde discoveries) derive from hydrocarbons being generated in the offshore Sicilian thrust belt where different sequences, possibly Panormide type, are expected to occur and to have entered the oil window from Late Miocene to the present day. Tertiary source rocks, although prolific in Tunisia and Sicily, are not expected to contribute significantly to the hydrocarbon system of the offshore Sicilian thrust belt.

Introduction

Northern Petroleum and its partner Shell Italia E&P are jointly engaged in oil & gas exploration in a large area of relatively deep water offshore western Sicily. The area under study contains the offshore extension of the Atlas fold & thrust belt of North Africa which links to the north-east with

the onshore Sicilian thrust belt continuing to the Apennine mountain chain (Figure 1). Only one well, Ermione-1 (Agip/Deutche Shell, 1989, P&A, dry), has been drilled in the offshore thrust belt, while the foredeep and foreland have been explored in the 1970'-80's with one significant developed discovery, the Nilde oil field (Figure 2).

A geochemical fieldtrip was undertaken in Sicily, sampling the thrust belt with the aim of determining the hydrocarbon potential of all possible source rocks and trying to tie source rocks to oil & bitumen seeps. In order to determine the hydrocarbon potential of the offshore Sicilian thrust belt, the results of geochemical analyses (pyrolysis, GC and total extract data, biomarkers, isotopes, etc.) have been correlated with existing geochemical data from northern Tunisia and offshore Sicily. Geochemical data have been integrated with a regional geological model which also included an inferred stratigraphy and tectonic evolution for the offshore Sicilian thrust belt.

Paleotectonic Setting of Sicily and its Relation to the Hydrocarbon System

The Sicilian fold and thrust belt is characterized by the convergence and thrusting of different paleogeographical domains, most of which have clear affinities with African geology with the exception of the northeastern corner of Sicily (Peloritani Mt.), which includes European derived Hercynian basement and a related sedimentary cover (Figure 4 and Figure 5). Different tectonic processes from the Late Triassic to the Early Tertiary allowed the formation of a complex pattern of pelagic basins adjacent to shallow water carbonate platforms, separated by geometrically articulated margins. The main basinal units (Late Triassic-Early Tertiary) are represented by the Sicanian succession in central Sicily, the Imerese unit in the Termini Imerese and Palermo Mountains areas, and the Prepanormide unit in westernmost Sicily and in the Marettimo Island (G.Granath et al., 2004, R.Catalano et al., 2002). All these basinal units have formed allochthnous nappes which have been tectonically emplaced with a general southward vergence on thick carbonate units: the Panormide and Trapanese sequences. Source rocks of significant petroleum potential are not present in the basinal units. The importance of the latter units for the petroleum system is linked to the possible seal effectiveness of the pelagic lithofacies and the presence of intercalations of resedimented carbonates in the Early Lias and Late Cretaceous (i.e. Imerese units, L. Basilone, 2009) which could provide multiple reservoir intervals.

The Panormide and Trapanese units are marked by shallow water carbonate sedimentation in the Late Triassic to Lias. From the Middle-Late Jurassic to the Early Tertiary the Trapanese unit shows a tectono-stratigraphic evolution typical of a drowned platform, whereas shallow water carbonate sedimentation continued in the Panormide domain throughout the Cretaceous, representing an anomaly in the Tethyan realm (G.Zarcone et al., 2008). Equivalent Cretaceous shallow water carbonates are present in Tunisia (Zeggab Formation), however the Late Cretaceous interval (Campanian-Maastrichtian) is characterised by deep water pelagic deposits of the Abiod Formation.

Associated with the Panormide and Imerese units, there are nappes of Numidian Flysch (Oligocene, Early Miocene) formed in distal portions of the African margin and subsequently caught up in the accretionary prism in the early phases of deformation in Sicily (G. Granath et al., 2004).

Crustal shortening onshore Sicily was accompanied by significant structural rotation which, according to paleomagnetic data, is in the order of 60 to 134 degrees clockwise in the northern portions of the thrust belt (F.Speranza et al.,1999). The rotation vectors are related to the opening of the Tyrrhenian Sea and the retreat of the subducting Ionian plate. The current orientation of the onshore Tortonian-Messinian foredeep (trending approximately east-west) is likely the result of this peculiar tectonic evolution, whereas offshore Sicily (Nilde area) a coeval foredeep is oriented NE-SW to NNE-SSW, suggesting limited rotation occurred in the offshore (possibly in the order of 15-20 degrees clockwise).

The Late Triassic-Liassic Petroleum System

Tectonic Setting of Hydrocarbon Seeps

A system of NE-SW oriented inverted faults in the offshore Tortonian-Messinian foredeep and foreland (exemplified by the Nilde Field) likely initiated in the Late Triassic-Lias as extensional faults which were subsequently inverted during multiple compressive events occurring from the Paleocene to the Early Pleistocene. The analysis of bitumen seeps onshore Sicily has shown all the samples are genetically related and are thought to have formed from Late Triassic-Liassic intraplatform basins which are possibly oriented E-W at present day. These basins are not outcropping, however their occurrence has been inferred from the distribution of seeps. An example of such intraplatform basin is provided by the Marineo Basin drilled by Agip in 1992 (Marineo-1 well), which showed the presence of bitumen within Mesozoic sequences. Paleohighs linked to extensional tectonics during the Late Triassic-Lias are still visible in some areas in western Sicily (i.e. M. Kumeta, M. Busambra), displaying a structural orientation similar to the trend of the intraplatform basins. Structural restoration of the onshore sequences indicate these units were likely deposited in lateral continuity with the offshore inverted foredeep foreland domain being characterised by an approximate NW-SE direction of extension during the Late Triassic-Lias.

Geochemistry of Late Triassic-Liassic Source Rocks in Sicily

All the bitumen samples analysed in western Sicily (Figure 6) are heavily degraded oils very rich in asphaltenes. A carbonate source rock for these hydrocarbons has been determined due to the absence of diasteranes, the dominance of Tm (17α(H)-22,29,30-trisnorhopane) over Ts (18α(H)-22,29,30 trisnorneohopane), and the dominance of C29 hopane over C30 hopane. Other geochemical parameters, including sterane transformation ratios, indicate these bitumens were generated by a fully mature source rock.

All the potential source rocks analysed in Sicily in this work are non-carbonate source rocks. Previous studies pointed out that the only carbonate source rocks which are thought to occur in western Sicily are Late Triassic to Liassic in age. Significant petroleum potential could not be found in any of the Late Triassic and Liassic samples in Sicily and it was therefore assumed that localised buried anoxic basins were the source of the bitumen seeps. An example of such a basin is represented by the Marineo Basin drilled by Agip in 1992 (Marineo-1 well) which drilled through slope facies of the Inici Formation (Modica Formation equivalent, Lias) with a fair petroleum potential (50 kg HC/t). The sequence underlying the Inici Formation in this well, the Sciacca Formation (Late Triassic), may also be characterised by a fair petroleum potential as indicated by a TOC

content varying between 0.6-1%. The carbon isotope data for the aromatic and saturate fractions for the analysed bitumens point out a possible correlation between these hydrocarbons and the oils generated by Late Triassic source rocks in the Ragusa Basin (Figure 7).

A comparison between the available geochemical data for the Ragusa Basin oils and the bitumens in western Sicily indicate the latter hydrocarbons were generated in a more restricted marine environment characterised by carbonate sedimentation and absence of a clastic input. The gammacerane index for the analysed bitumens is on average higher than in the Ragusa Basin oils, suggesting a well-developed stratification of the water column and enhanced salinity. Diasteranes, which are indicative of presence of clays in the source rock, are absent in the analysed bitumens but present in the Gela oil (Mattavelli et al., 1990). The C29/C30 hopane ratio is also higher in all the bitumens collected in western Sicily (ranging from 0.59 to 1.24), whereas it is less than 0.4 in the Gela and Ragusa oils (Mattavelli et al., 1990). The Ragusa Basin oils and the bitumens in western Sicily are also characterised by a relative enrichment of %C29 regular sterane with respect to %C27 regular sterane, the ratio of the latter to the former being in the range 0.45 to 0.66 in western Sicily, and 0.66 in the Gela oil (Mattavelli et al., 1990). This is likely indicative of a significant algal content in the kerogen of these source rocks.

The Hydrocarbon Potential of Late Triassic-Liassic Source Rocks Offshore Western Sicily

The presence of seeps onshore western Sicily is limited to intraplatform basins within the Trapanese platform unit, no hydrocarbon seepage occurs within the inner thrust belt in the Panormide platform unit (Figure 6). An example of intraplatform basin offshore Sicily is provided by organic rich facies of Liassic age in the Nora Nord 1 well (re-examination of cores, JV internal report, R. Di Cuia, 2010). The oil from the Narciso-1 discovery has been tied to a carbonate source rock which is likely the same for the analysed bitumens and the Marineo Basin. Oil shows in Nada-1 were also likely generated from a carbonate source rock as suggested by the low API gravity, the high sulphur and the low paraffinic contents of this oil.
The hydrocarbon potential of Late Triassic-Liassic source rocks in the offshore thrust belt is unknown as no stratigraphic information is available in the area (only one well, Emione-1, has been drilled). The Marettimo Island (Figure 2, Figure 5) displays sequences which could be representative of part of the stratigraphy expected in the study area in the offshore thrust belt. There is no evidence of intraplatform basins of Liassic age in this island, however organic rich facies are represented by dolomitic sequences of the Sciacca Formation (Late Triassic) deposited in a lagoonal to sabka type environment, the potential of which is still unknown.

The Cretaceous Petroleum System

Tectonic Setting of Late Cretaceous Source Rocks Onshore Sicily

Cenomanian-Turonian organic rich facies were sampled in north-eastern Sicily in proximity of the villages of Floresta and Novara di Sicilia (Figure 3 and Figure 5). These sequences are considered as part of the Argille Scagliose Formation, described by Cavazza et al., 1997, as a melange unit characterised by a fine grained matrix bearing huge exotic blocks which include nummulitic calcarenites, quartz-arenitic turbidites of the Numidian Flysch,

Cenomanian-Turonian organic rich facies and roughly coeval fossiliferous marly limestone known as “Cenomaniano in Facies Africana” (Vincenzi et al., 1997, G. Scopelliti et al., 2008). The latter sequences have been correlated with equivalent lithofacies outcropping in Tunisia, the Zeggab Formation which formed within the shallowest portions of a carbonate ramp system, whereas the organic rich shales were deposited in deeper water on the distal ramp (G. Scopelliti et al. 2008).

The Argille Scagliose Formation has been considered by some authors to be the result of gravity flows dismantling a depositional carbonate ramp located southward and subsequently involved in a tectonically active front inside an accretionary wedge (G.Scopelliti et al., 2008). A southern provenance, probably not far from the region which is now Tunisia, was proposed for the Novara di Sicilia exotic blocks (G. Scopelliti et al., 2008). However the “exotic” organic rich friable shale blocks appear undeformed, implying that they could not have travelled a large distance in a gravity driven flow and that they were likely to be tectonically displaced during the collision of the African units with the European Kabylie basement. It is suggested that these sequences formed within slope facies of the Panormide Platform domain and were emplaced on the Argille Scagliose Formation by large back thrusts during the Langhian tectonic event.

Geochemistry and Implications for Petroleum Exploration in the Offshore Thrust Belt

The Cenomanian-Turonian black shales outcropping in northeastern Sicily, regarded as a unit equivalent to the Bahloul Formation in North Africa, have the highest source rock potential of all the analysed samples. This is indicated by the high TOC ranging from 3% in the most carbonate rich intervals to 29.8% in the shaly levels. Measured Hydrogen Index varies from 412 to 649 indicating type I/II organic matter, with excellent petroleum potential of up to 183.33 kg HC/ton. The geochemical data presented in this study are in good agreement with previous analyses carried on the same outcrops by the University of Palermo (G. Scopelliti, 2008). The thickness of the exposed Cenomanian-Turonian organic rich interval in Novara di Sicilia is in the order of 19 m, however correlations based on organic and carbonate carbon isotope suggest that only phase A of the Cenomanian-Turonian anoxic event is represented in this location (G. Scopelliti et al., 2008). The moderate diasterane content and the low tricyclic C22/C21 and C24/C23 ratios are indicative of a clastic input and a near-shore environment of deposition. Geochemical data indicate the Cenomanian-Turonian sequences in Sicily are characterised by higher source rock quality than equivalent facies in Tunisia. By comparison the Bahloul Formation in northern Tunisia exhibits up to 14% TOC with an average value of 2%, and petroleum potential ranging between 2 and 50 kg HC/ton (El Euchi et al., 2004).

Oil - source rock correlations based on stable carbon isotopes indicate a correlation between the oils of Nilde and Norma in the inverted Messinian-Tortonian foredeep, the Bahloul Formation in Tunisia and the equivalent Bahloul facies in northeastern Sicily. The latter oils are characterized by δC13 aromatic values close to Cenomanian-Turonian source rocks but saturate values are closer to an Early Cretaceous or Numidian Flysch age (Oligo-Miocene). This possibly reflects a greater terrestrial input (Figure 7). The Numidian Flysch is not present in the inverted Messinian-Tortonian foredeep. Although it likely occurs in the offshore thrust belt, as suggested by geophysical mapping it does not appear to be buried deep enough to have generated hydrocarbons. A contribution from the Fahdene Formation (Early Cretaceous) cannot be ruled out.

In Tunisia extracts from the Bahloul Formation are characterised by Pr/Ph ratios ranging from between 1.5 and 3, a moderate diasterane content, a C27 sterane approximately equal to C29 sterane, a high C28/C29 sterane ratio (0.82-0.99), (El Euchi et al., 1997). The oil in the Nilde discovery is also characterised by a moderate diasterane content, a Pr/Ph ratio close to 1 (L. Mattavelli et al., 1990), however it is by comparison highly enriched in C29 regular sterane with still a relatively high C27/C29 ratio (0.84) but a low C28/C29 sterane ratio (0.43). The Bahloul eq. samples from north-eastern Sicily have shown a similar C29 sterane content with a low C28/C29 sterane ratio ranging from 0.41 to 0.67. The Pr/Ph ratio in the latter source rock differs from the Nilde oil (2.18 to 2.69 onshore Sicily), 0.98 in Nilde (Mattavelli et al., 1990), this is likely due to the different maturity of the source rock (immature) with respect to the Nilde oil (peak mature).

All of the wells drilled in the inverted Messinian-Tortonian foredeep (exemplified by the Nilde discovery), indicate Cretaceous sequences could not have generated significant quantities of hydrocarbons locally due to the lack of sufficient burial and the absence of organic rich facies. This suggests generation of hydrocarbons must therefore have occurred within the adjacent thrust belt. Cenomanian-Turonian lithofacies in the Nilde area are not consistent with the deposition of carbonate ramp deposits like the Bahloul Formation and are characterised by pelagic marls with planktonic foraminifera (Trapanese eq. deposits). Geochemical data suggest the Nilde oil was generated by a source rock which was influenced by the proximity of a shoreline and with possibly a limited input of terrestrial deposits. This is evidenced by the presence of diasteranes, stable carbon isotope values which support the possibility of a limited terrestrial input, correlation with onshore source rocks characterised by a near-shore environment of deposition. This would suggest the presence of shallow water carbonates of the Panormide unit in the offshore thrust belt and a shallow water carbonate system leading to a deeper basin as observed in Sicily.

Tertiary Petroleum System

The Potential of the Numidian Flysch (Oligocene-Early Miocene)

Due to the absence of published analyses from the organic rich Numidian Flysch of Sicily, source to oil correlations were carried out using the available geochemical data from the Numidian Flysch in Tunisia. Oil-source rock correlations based on δ13C for the aromatic and saturate fractions indicate a good correlation between the Tunisian Numidian Flysch, the oil from the Gagliano field in eastern Sicily and the Madonna dell'olio seep located in proximity of the village Blufi, about 30 km west of the Gagliano Field. Geochemical analyses of the Madonna dell'olio seep indicate the oil has been generated by a carbonate source rock with an elevated clastic component.

Available geochemical data for the Gagliano Field (L. Mattavelli et al., 1990) also suggest generation from a carbonate source rock with a significant clastic component as demonstrated by the presence of gammacerane, a relatively high C29 to C30 hopane ratio and the presence of diasteranes. This oil is also characterised by a distinctive pattern of sterane distribution with a high C27/C29 ratio (1.25), (L. Mattavelli, 1990). By comparison the Madonna dell'olio seep displays a C27/C29 ratio close to one, higher than any other source rock and bitumen analysed in Sicily.

A possible Tertiary source rock for the Gagliano oil was also identified on the basis of small amounts of oleanane (oleanane index of 0.04, L. Mattavelli et al., 1990). However the reliability of this biomarker appears questionable as small traces of oleanane could have been picked up by oil migrating through Late Cretaceous and Tertiary rocks (L. Mattavelli, 1990). Oleanane was not found in any of the hydrocarbons seeps analysed in Sicily.

Other Potential Source Rocks in Sicily

Organic rich pebbles in the Argille Scagliose Formation (Early Tertiary, Sicilide Unit) were collected in central Sicily, close to the village Villarosa. These samples showed excellent hydrocarbon generating potential with TOC concentrations up to 46%, HI up to 515 and excellent petroleum potential of up to 238.7 kg HC/ton. However organic rich pebbles are dispersed into a clay matrix and are generally quite rare in the outcrops. Another issue of these sequences is the lack of sufficient burial to generate hydrocarbons which could only be attained in the most internal domains of the thrust belt.

Expected Stratigraphy and Basin Modeling Study in the Offshore Thrust Belt

A stratigraphic model for the offshore thrust belt has been built based on correlations between northern Tunisia and Sicily. Following possible analogies with the onshore Sicilian thrust belt, the model considers the occurrence of allochthnous pelagic units (Late Triassic-Early Tertiary) with interbedded resedimented carbonates overlying a repeated thick carbonate succession (Late Triassic-Early Tertiary) which has similar characteristics to the onshore Panormide platform. A review of the available data on the Prepanormide succession in Marettimo Island (Figure 5) indicates the presence of turbidites and resedimented carbonates (Early to Late Jurassic) which could have been sourced from an equivalent Panormide platform. Resedimented carbonate intervals which formed in a similar paleotectonic setting onshore Sicily have been correlated with sea level fall and shelf margin collapse (Panormide-Imerese correlation, L. Basilone, 2008). The Panormide platform is the only domain in this region which is characterised by an unconformity with subaerial exposure (presence of bauxites, L. Basilone, 2008) which locally extends from the Early to the Late Jurassic. The presence of shallow water carbonate sedimentation throughout the Cretaceous is another peculiarity of the Panormide platform. As previously pointed out, geochemical data indicate Late Cretaceous source rocks, which likely generated oil within the offshore thrust belt, are characterized by a near-shore environment of deposition.

Source rock maturity modeling has been undertaken in the inverted Messinian Tortonian foredeep using the 1D Petromod software. The results obtained have been extrapolated to the offshore thrust belt where different hypothetical tectono-stratigraphical models have been considered.
A basal heat flow of 60 mWm2 has been used in the modelling, this value has been derived from published maps and reservoir temperatures from corrected bottom hole temperatures. Calculated maturities have been compared to actual maturities derived from vitrinite data in the available wells (Figure 8), and a reasonable match has been achieved. A linear function of depth versus maturity has been determined for the top Triassic showing the top of the oil window occurring at approximately 2.5 Km (Figure 9). Fluid flow studies onshore Sicily have shown hydrocarbon migration occurred in the Middle-Late Miocene, coinciding with the maximum burial reached in the thrust belt, (B. Dewever et al., 2010). Assuming limited

exhumation occurred in the offshore, source rocks could be still generating oil at present day at depths of 2.5 km to 4.5 km, the Cenomanian-Turonian source rocks are expected to occur within this interval.

Conclusions

The analysis of new geochemical data indicates hydrocarbons from seeps in western Sicily within the Trapanese domain are most likely derived from Late Triassic-Liassic intraplatform basins. These basins extend offshore in the inverted Tortonian-Messinian foredeep and foreland, providing the source rock for some of the hydrocarbons discovered in the area. Geochemical data have shown a possible correlation between these hydrocarbons and the oils generated by Late Triassic source rocks in the Ragusa Basin in southeastern Sicily, where prolific oil fields have been discovered. However hydrocarbon seeps in western Sicily were generated from source rocks deposited in a more restricted marine environment characterized by carbonate sedimentation and absence of any clastic input. Although Triassic – Liassic source rocks are likely to contribute to the petroleum system of the offshore Sicilian thrust belt, the most prolific source rock of the area is considered to be the Cenomanian-Turonian black shale known as Bahloul Formation in North Africa. These sequences were sampled onshore Sicily and displayed the highest source rock potential of all the analyzed samples. Analysis of geochemical data concluded that these sequences developed in a near-shore environment, likely within slope facies of the Panormide platform. Our studies suggest hydrocarbons were generated from a Cretaceous source rock, possibly the Fahdene Formation (Aptian-Albian) or more likely the Bahloul Formation (Cenomanian-Turonian) within the offshore thrust belt from Late Miocene to the present day. These hydrocarbons migrated towards the inverted foredeep-foreland forming the oil accumulations of Nilde and Norma during the Plio-Pleistocene. Tertiary source rocks, although prolific in Tunisia and Sicily, are not expected to significantly contribute to the hydrocarbon system of the offshore Sicilian thrust belt.

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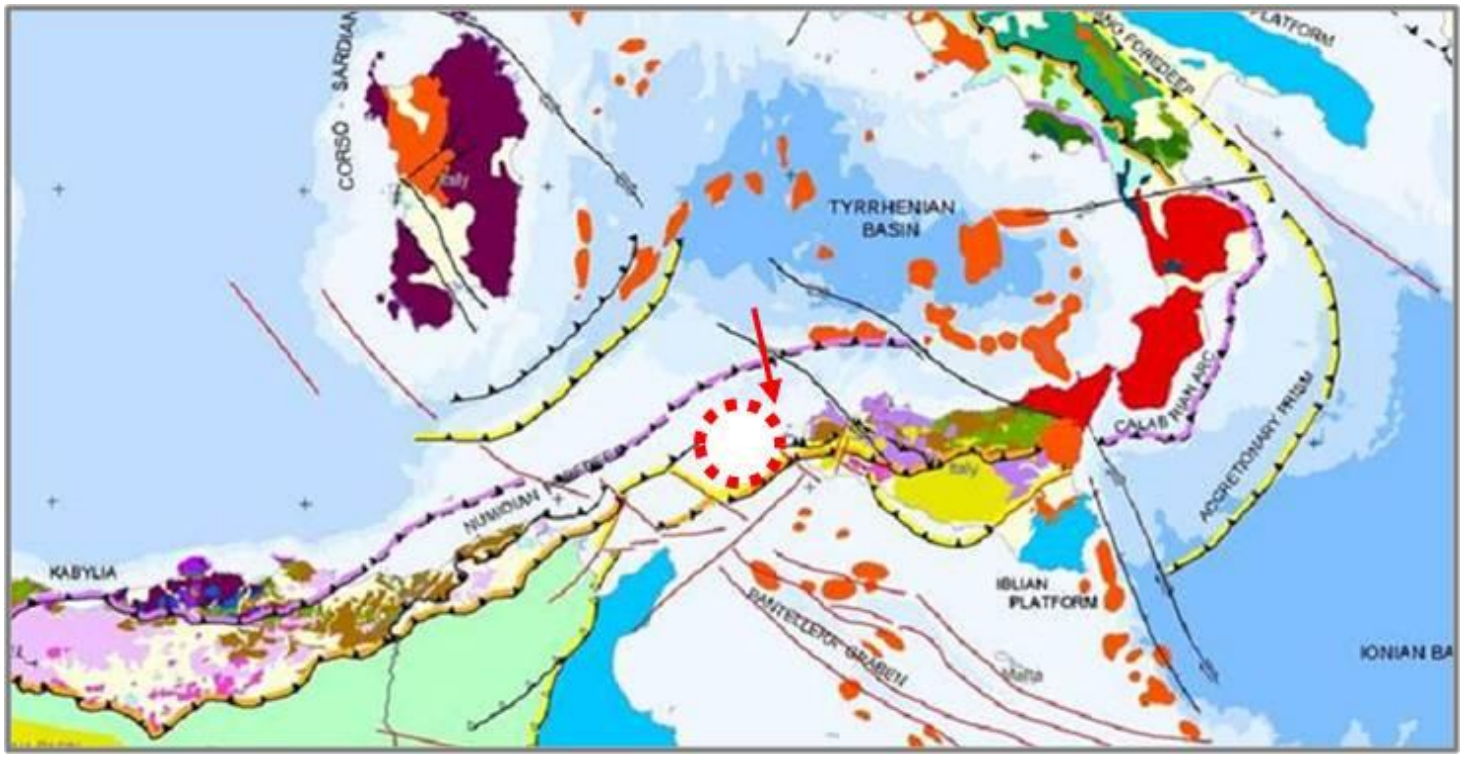

Figure 1. Location of study area. The offshore thrust belt links the Atlas thrust belt with the onshore Sicilian thrust belt. (After Shell International and Production B.W.)

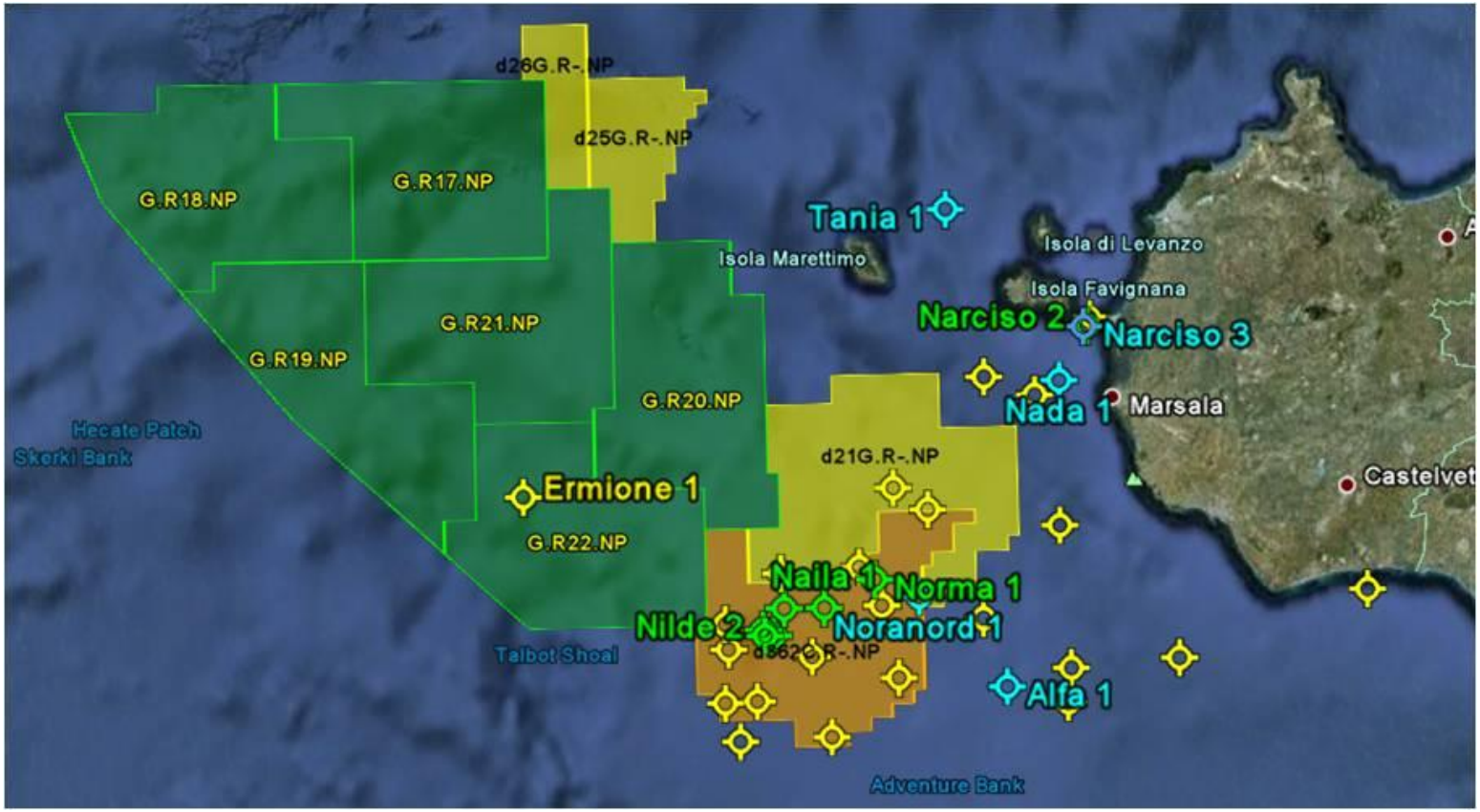

Figure 2. Offshore thrust belt well database and Northern Petroleum (NP) permit areas. Drilled wells: green indicates discoveries, in yellow are dry wells, blue indicates wells which had oil or bitumen shows. NP permit area: green polygons indicate NP awarded permits, yellow polygons are NP applications, orange polygons are NP contested applications. (Image from Google Earth).

Figure 3. Location of seeps and source rocks analysed onshore Sicily. (Image from Google Earth).

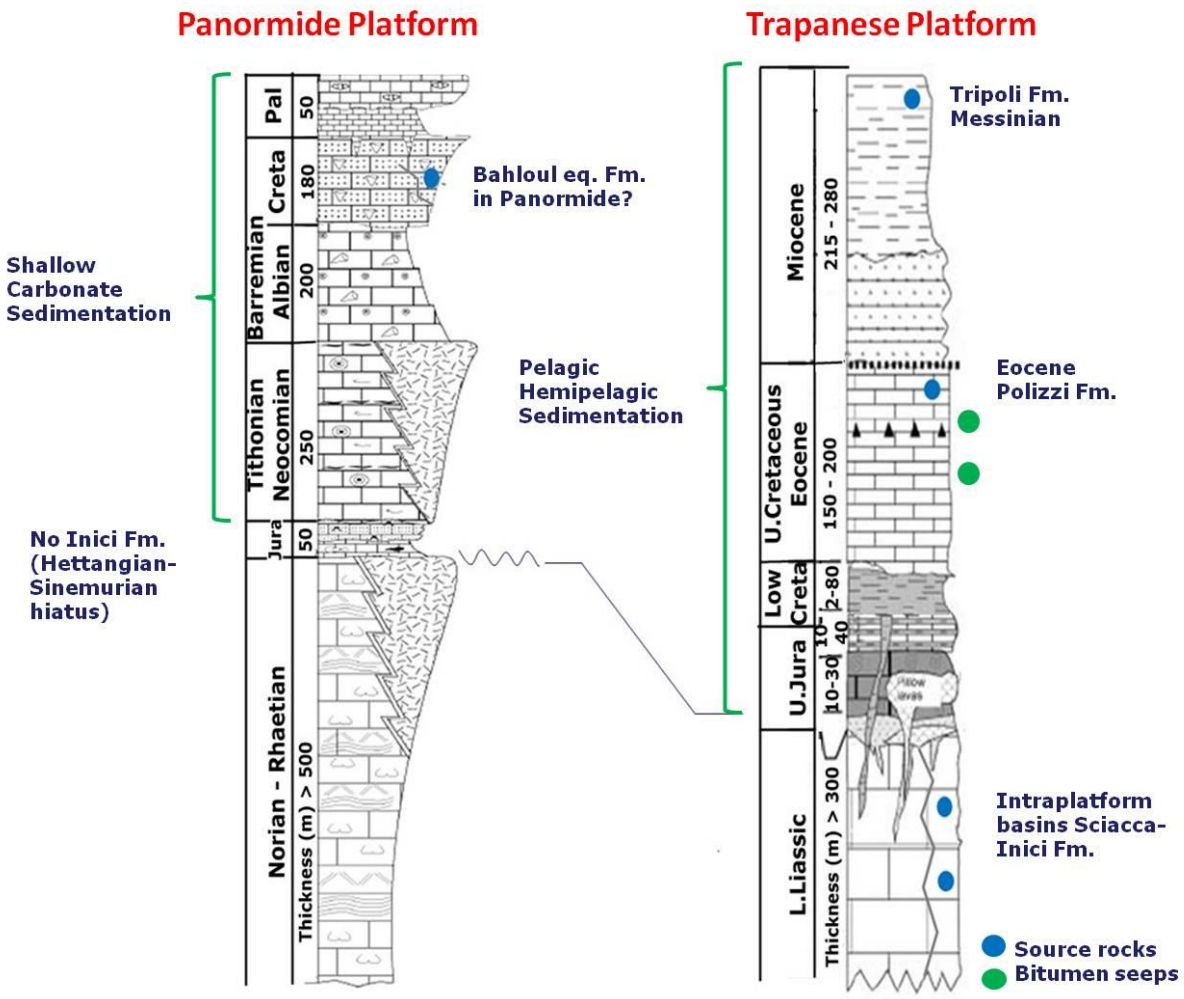

Figure 4. Simplified stratigraphic columns for the Panormide and Trapanese units in Western Sicily (modified after L. Basilone, 2009; G. Avellone et al., 2010).

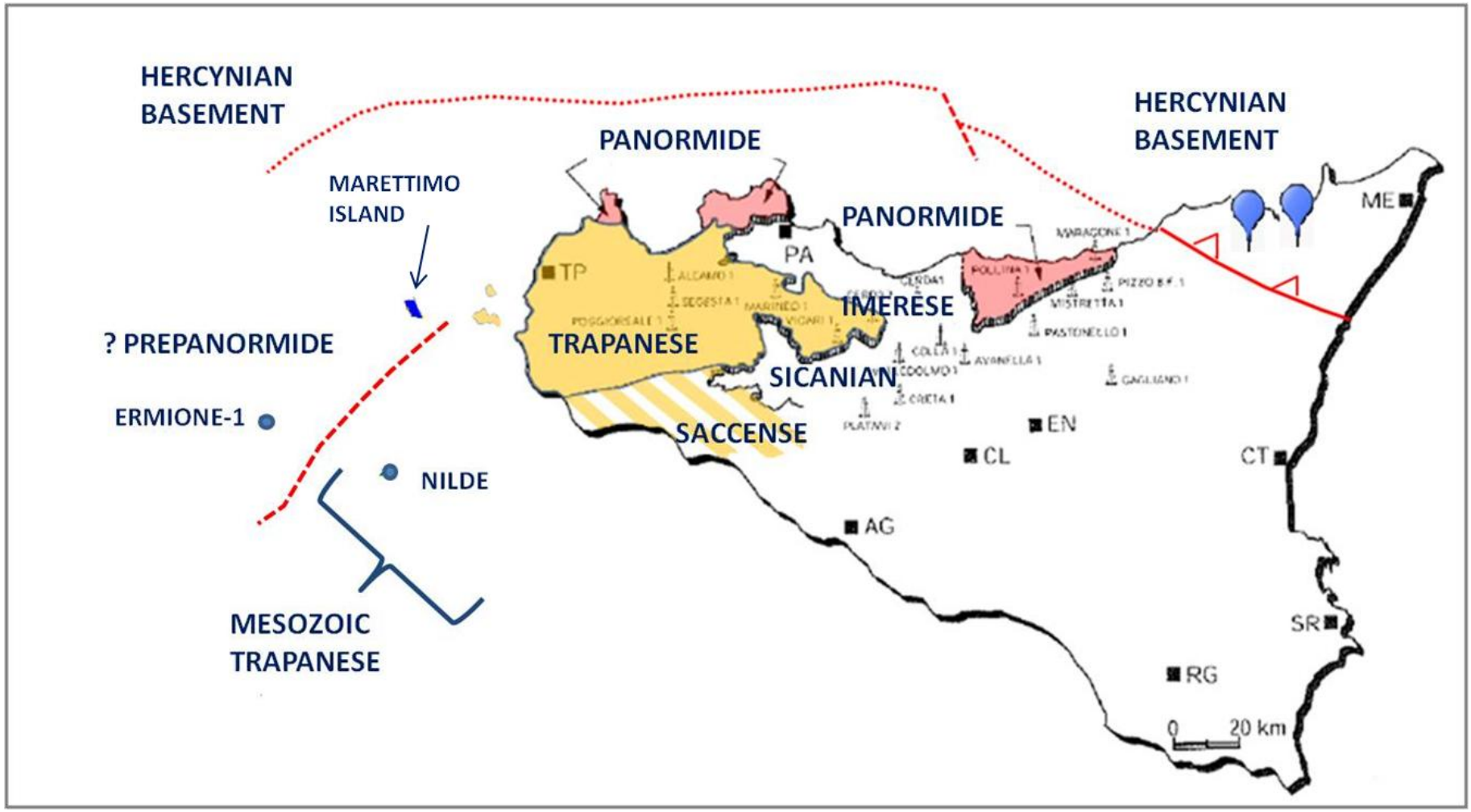

Figure 5. Tectonic map of Sicily representing the main paleogeographical units in the onshore/offshore thrust belt (modified after G. Miuccio et al., 2000). Thick platform units in the onshore thrust belt (reached by wells and outcrops) are in colour, allochthonous units are indicated but left blank. Blue place marks in north-eastern Sicily refer to Late Cretaceous organic rich samples from Novara di Sicilia and Floresta.

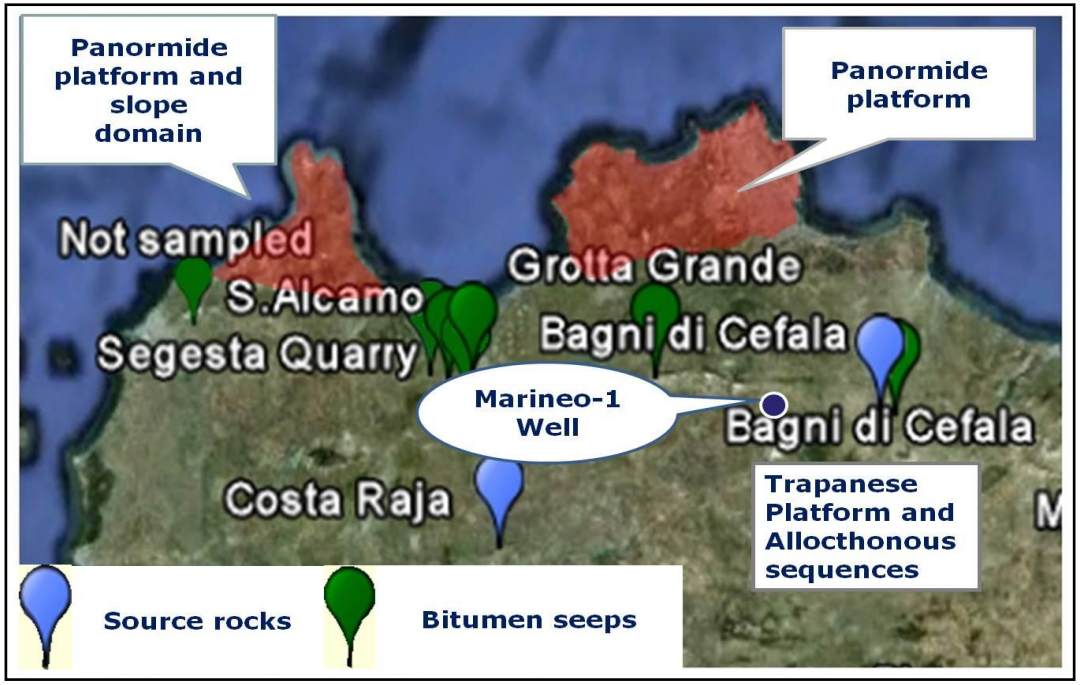

Figure 6. Location of analyzed bitumen and oil seeps onshore Western Sicily. Image from Google Earth.

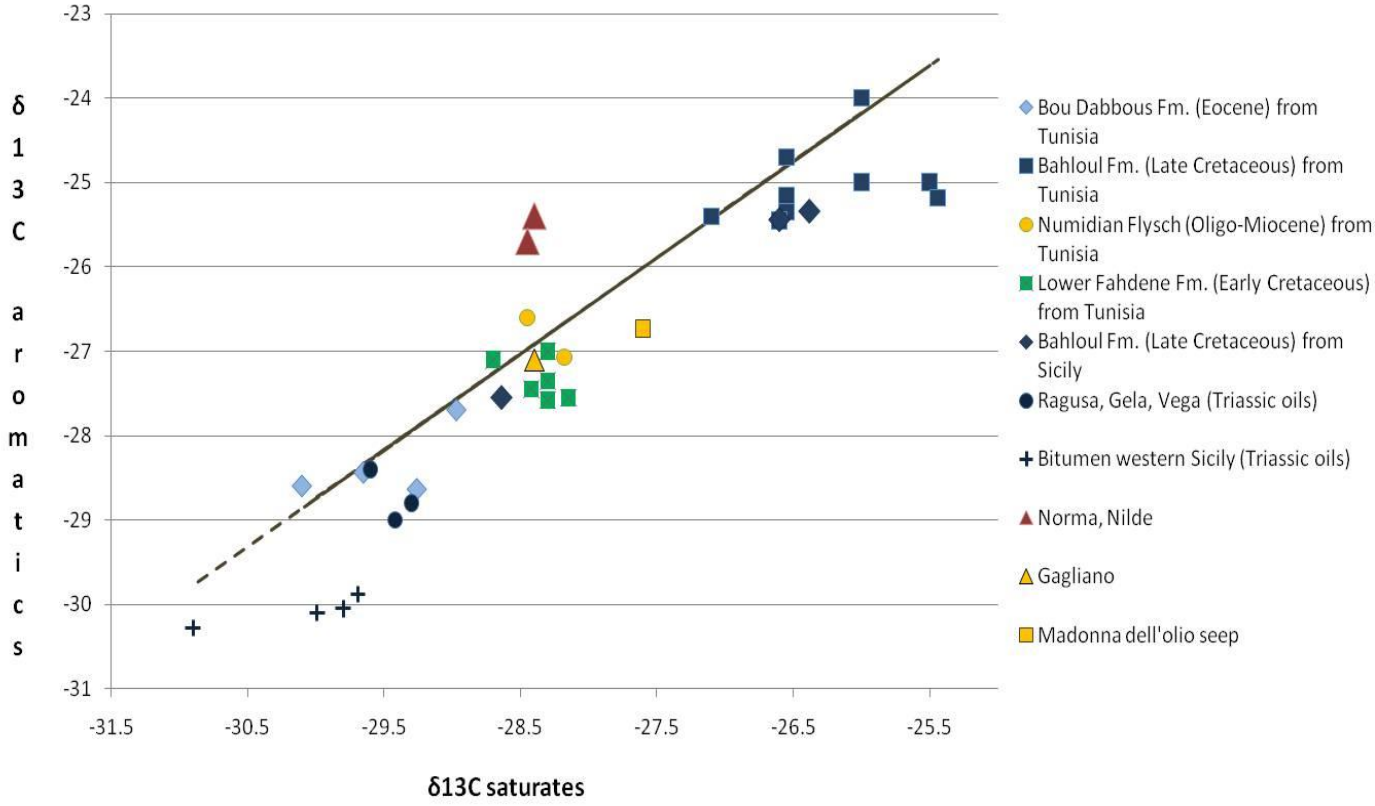

Figure 7. Sofer plot of δ 13C values for the saturate and aromatic hydrocarbon fractions of oils and source rocks from Sicily and Tunisia. Source rocks and oils from Tunisia are from the N. Kairouan area (M. Sadi et al., 2002) and from the Northern Tunisia Thrust Belt (H. El Euchi et al., 2004). Data from Sicily oils (Gagliano, Norma, Nilde, Ragusa, Gela, Vega oil fields) after L. Mattavelli et al., 1990. A straight line (calculated as δ 13Caro=1.14 δ 13sat+5.46) separates samples with terrestrial input (above) from marine (below).

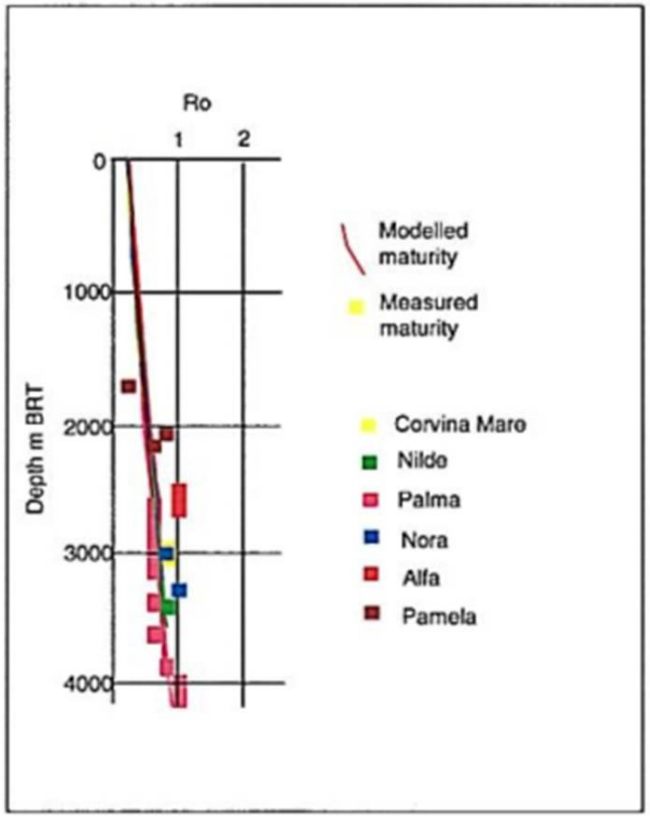

Figure 8. A good correlation has been achieved between the modelled maturity and the maturity measured from vitrinite reflectance data for wells offshore Sicily.

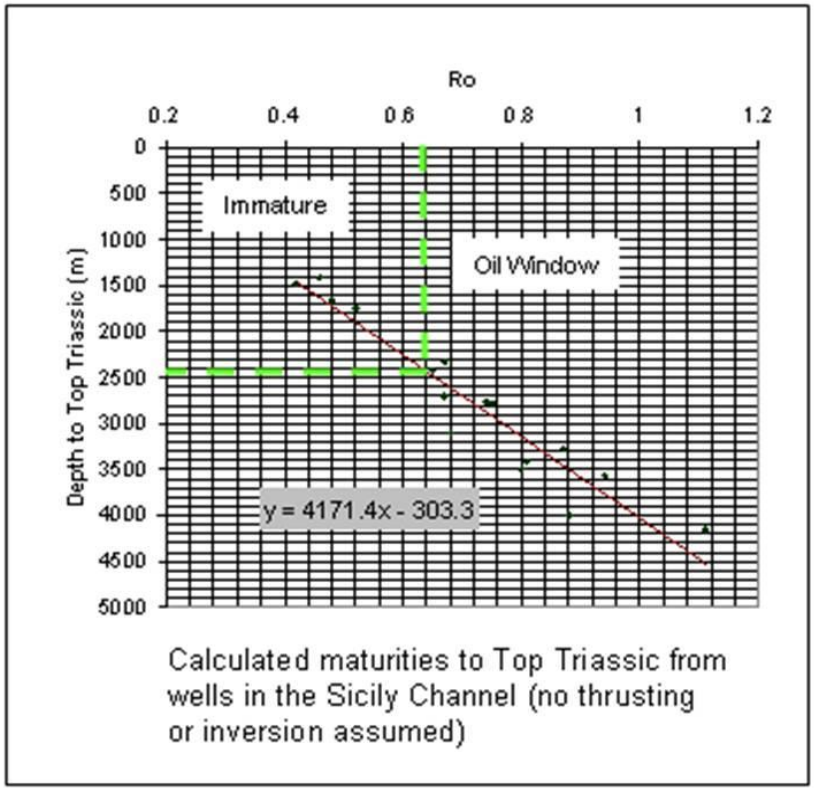

Figure 9. A linear function of maturity versus depth for the Late Triassic has been calculated.