SOUTHERN APENNINES GEOLOGIC FRAMEWORK AND RELATED PETROLEUM SYSTEMS

INQUADRAMENTO GEOLOGICO DELL'APPENNINO MERIDIONALE E RELATIVI SISTEMI PETROLIFERI

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ABSTRACT

The geology of the Southern Apennines, as it can be derived from the integration of surface (literature and published cartography) and subsurface (wells and seismic) data is briefly described. The related petroleum systems (PS) are analysed and tentatively classified in three main categories: a) oil-prone PS; b) biogenic gas PS; c) mixed thermogenic gas & condensate/light oils PS.

The main features of each of the three families are discussed. The presence of non hydrocarbon fluids associated with a and c PS is indicated.

RIASSUNTO

In questa nota viene sinteticamente descritto l'assetto geologico dell'Appennino meridionale, dedotto da dati di superficie (letteratura esistente e cartografia pubblicata) e di sottosuolo (pozzi e sismica). I sistemi petroliferi (PS) relativi a questo contesto geologico vengono analizzati e tentativamente classificati in tre principali categorie: a) sistemi a olio; b) sistemi a gas biogenico; c) sistemi misti a gas termogenico & condensati /oli leggeri.

Vengono quindi discusse le principali caratteristiche di queste tre famiglie.

Infine viene indicata la presenza di fluidi non idrocarburi associati ai sistemi di tipo a e c.

KEY-WORDS: *SOUTHERN APENNINES, PETROLEUM SYSTEMS, ITALY*.
PAROLE CHIAVE: *APPENNINO MERIDIONALE, SISTEMI PETROLIFERI, ITALIA*.

1. GENERAL GEOLOGICAL PREMISE

The Southern Apennines are a segment of the general Apenninic chain that forms the backbone of the Italian peninsula, which extends continuously from the Ligure-Piedmont basin to Sicily.

The Apennine chain has essentially springed from the Neogene flexuration/inversion of the North Africa continental margin.

Along the latter, throughout the Mesozoic and the Paleogene, the epicontinental sedimentation was predominantly calcareous. Important sedimentary environment variations, both sub-parallel and transversal to the margin, were present, mostly controlled by active extensional syn-sedimentary faults.

To be extremely simple, facies analysis allows to recognize two environmental domains (Fig. 1):

- carbonate platform domain;
- deep water basin domain.

In different geologic times, euxinic conditions areas developed within the carbonate platform domain.

The sedimentary record of the deeper domain is basically continuous, from the stratigraphic viewpoint. Its average thickness (about 1,500 m) indicates a low subsidence rate, while the carbonate platform domain contains a large Paleogene hiatus and reveals high subsidence conditions (5 to 6 km).

During the long accretion times, both extensional and compressional tectonic episodes affected the margin, followed by local erosional phases.

Starting from the Paleogene, the continental margin was progressively (landward) flexured and subsequently tectonically inverted.

The general trend of the flexed belts was sub-parallel to the margin, but the main facies changes in the epi-continental sequences (i.e. deep water vs. carbonate platform) locally controlled their extension and style.

At each flexural phase, an asymmetric space (foredeep) was created between the incipient chain and the un-flexured foreland.

This space could be accommodated by either "normal" flysch sedimentation or under-water gravity emplacement of allochthonous nappes décolled from the raising chain.

Roughly, the Apenninic chain is the result of the superposition of two orders of flexure/inversion phases. The first, Paleogene to Lower Messinian in age, is common to the entire Magrebide/South Alpine/Dinaric chain and its drive

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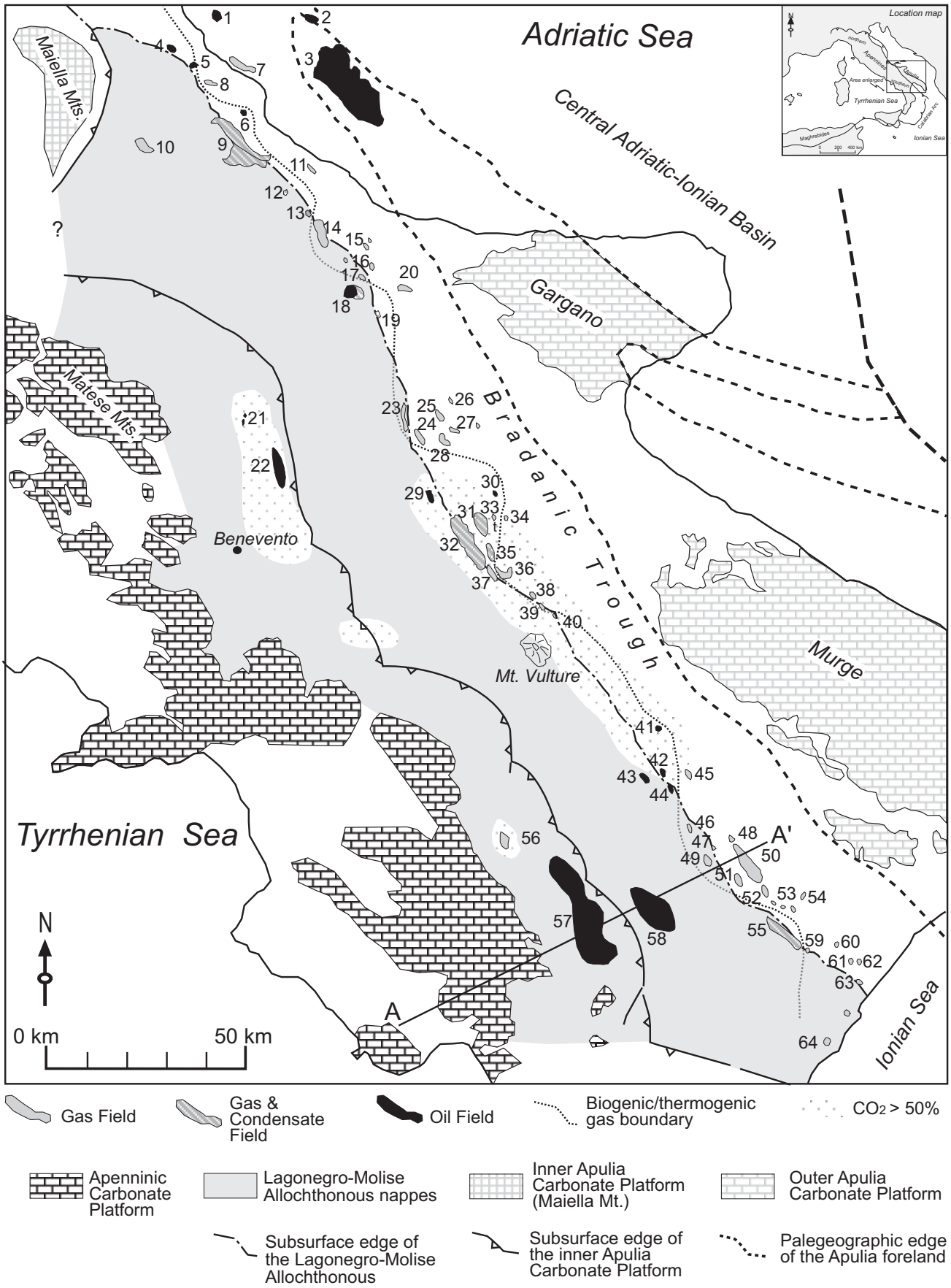

Fig. 1 - Geologic scheme of the Southern Apennines. Essential surface and subsurface data allow defining the geo-petroliferous framework of the area. Location of main oil and gas fields is present (see also Tab. 1).

Schema geologico semplificato dell'Appennino meridionale, nel quale vengono riportate le principali informazioni di superficie e di sottosuolo essenziali per un inquadramento geo-petrolifero dell'area, con la localizzazione dei principali campi a olio e gas (vedi anche Tab. 1).

n.	Field name	n.	Field name	n.	Field name
1.	Ombrina	23.	Roseto-Montestillo	45.	Calderasi
2.	Katia	24.	T. Vulgano	46.	Canaldente
3.	Rospo mare	25.	Mezzanelle	47.	Masseria d'Eufemia
4.	Lanciano	26.	Palmori	48.	Golfo
5.	S. Maria	27.	S. Caterina	49.	Accettura
6.	M. Odorisio	28.	Reggente	50.	Grottole-Ferrandina
7.	S. Stefano mare	29.	T. Taverna	51.	Demma-Locantore
8.	Villalfonsina	30.	Soriano	52.	Galgano
9.	S. Salvo-Cupello	31.	Ascoli Satriano	53.	Cretagna
10.	Bomba	32.	Candela-Palino	54.	Pomarico
11.	Colle Scalella	33.	Faragola	55.	Pisticci
12.	Montecilfone	34.	Carrera	56.	Vallauria
13.	Guglionesi	35.	T. Carapelle	57.	Monte Alpi-Cerro Falcone gr.
14.	Portocannone	36.	Serra del Riposo	58.	Tempa rossa
15.	T. Cigno	37.	Pietralunga	59.	Dimora
16.	T. Saccione	38.	Serra Spavento	60.	F. Basento
17.	T. Mannara	39.	Masseria Spavento	61.	Il Salice
18.	T. Tona	40.	Colabella	62.	Metaponto
19.	Melanico	41.	Genzano	63.	Cupoloni
20.	Chieuti	42.	Masseria Pepe	64.	Nova Siri Scalo
21.	Cercemaggiore-Jelsi- S.Croce	43.	Strombone		
22.	Castelpagano-Benevento	44.	Orsino		

Tab. 1 - Main Oil and gas fields located in Fig. 1. - Principali campi a gas e olio riportati in Fig. 1.

can be found in Africa-Europe continental convergence. The second, post-Lower Messinian in age, is specifically "Apenninic" and is associated with the relative Northward Africa motion and with the Thyrrenian sea opening.

2. THE SOUTHERN APENNINES GEOLOGIC EVOLUTION

The Southern segment of the Apenninic chain extends from the Aventino/Sangro line in the NW to the Taranto Gulf in the SE (Mostardini & Merlini, 1986; Casero *et al*., 1991).

From a genetic view-point the segment is clearly individuated from the fact that post-Lower Messinian flexural foredeeps are accommodated by the sub-marine gravitational emplacement of allochthonous nappes décolled from the pre-Messinian chain domain.

The integrated interpretation of regional surface (mostly published data) and subsurface (reflection seismic lines and oil wells) data have allowed reconstructing the geologic evolution of the area with acceptable confidence.

The rocks building up the Southern Apennines are derived from four paleogeographic domains:

- the internal Ligurian domain
- the Apenninic carbonate platform
- the Lagonegro/Molise basin
- the Apulia carbonate platform

A tentative palinspastic restoration of these domains essentially suggests how:

- the Apenninic carbonate platform and the Lagonegro/Molise domain were paleogeographically deeply indented: the Lagonegro basin was much larger to the South and strongly narrowed toward the North-West, first into the Molise basin and finally into the thin Genzana basin, indenting with the Abruzzi/Campania carbonate platform; the latter, instead widened considerably;

- similarly the Apulia carbonate platform domain has a rough triangular shape: several hundred km wide to the South-East, it progressively narrows to the North-West, where it drowns in the Umbro/Marchigiano pelagic domain;

- a set of evidence (wells stratigraphy, seismic features, structural considerations) suggest that a narrow, deeper water sea-way with Umbro/Marchigiano basin affinities exsisted inside the Apulia carbonate platform domain, at least during Upper Cretaceous and Paleogene times; in this sense we can therefore distinguish an "Inner Apulia carbonate platform" and an "Outer Apulia carbonate platform" unit.

The present-day geologic setting of the area is achieved trough a complex poly-phased history.

During Tortonian times the Apenninic carbonate platform unit was flexured and covered by flysch deposits. Internal domain, Liguride type, nappes thrust onto the flysch series.

Beginning from the Lower Messinian pre-evaporitic, coeval with the Apenninic carbonate platform inversion, the Lagonegro domain started to become the site of flysch deposition.

Thanks to its width, differential flysch facies were deposited, from SW to NE, ranging from wild flysch-like to distal, fine grained ones.

Later the domain initiated to be progressively inverted, starting from its inner part. Thanks to the presence of over-pressured shales levels in the basin's sedimentary record, the terrigenous cover décolled from its substratum and slipped onto the outer domain series.

At this time the Apenninic carbonate platform units thrust on the denudated inner part of the basin domain.

In upper Messinian times the stacked Apenninic/inner Lagonegro units thrust on top of the outer Lagonegro (=Molise) series.

In Lowermost Pliocene times the Apulia shelf sank and was covered by a thin series of pelagic Globigerina mud. Then the inner part of the domain was involved in the foredeep. The flexural space was accommodated by the underwater gravitational emplacement of the stacked Apenninic shelf/Lagonegro nappes.

In basal Middle Pliocene times the orogenic system moved onward. The Outer Apulia domain was in its turn flexured.

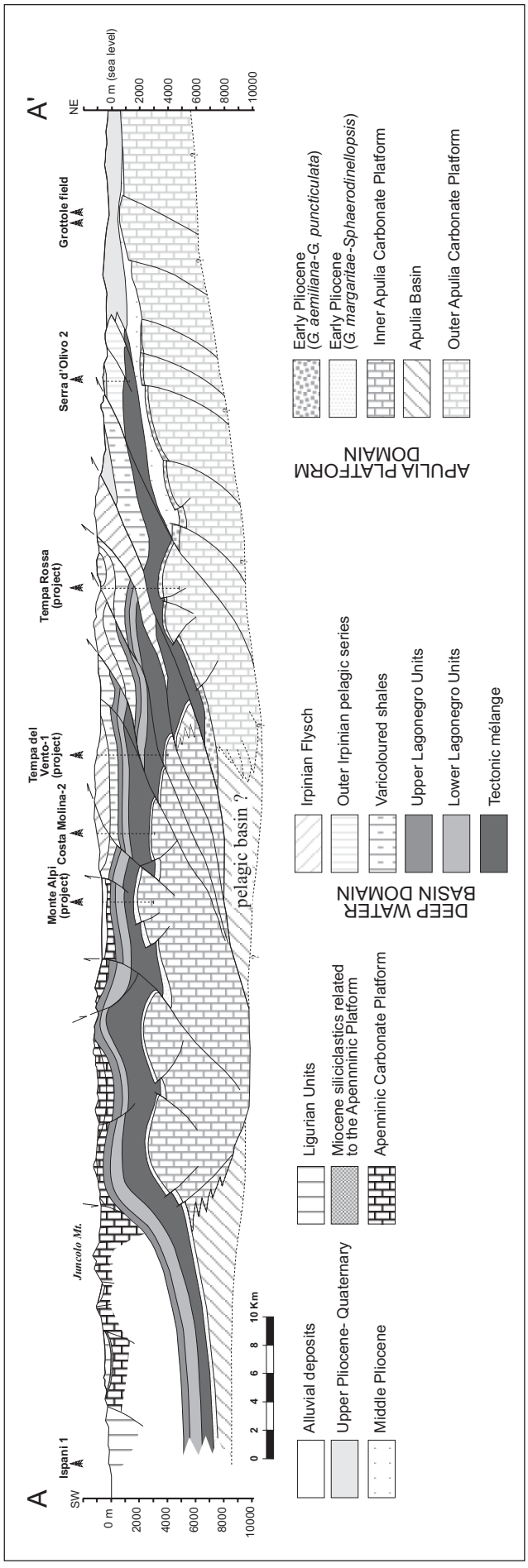

Fig. 2 - Schematic geological section across the Southern Apennines' main stratigraphic/structural domains. - Sezione geologica schematica attraverso i principali domini stratigrafico-strutturali dell'Appennino meridionale.

While the whole Inner Apulia carbonate platform and the overlying nappes commenced to be compressionally inverted, detached allochthonous series of the outernmost Lagonegro domain (Daunia flysch) slided on the thin Globigerina marls in the new foredeep.

The deformation pattern of the Inner Apulia shelf series is well imaged by the seismic data (Fig. 2).

The vertical relief at top of limestones is important (up to 4 km). Frontal and conjugated back-thrust ramps are rather high-angle, probably inverting old normal faults. The décollement level is located about 5 to 6 km deeper, probably in Triassic evaporitic/clastic levels at the base of the carbonate platform series.

The lateral shortening inside the unit is thus minor. On the other hand, the total North-East displacement of the plate could be significant. Thanks to the presence of a system of deep conjugated, almost N-S and almost W-E, wrench faults (or lateral ramps?) the outer margin of the inner Apulia carbonate platform appears to be arranged in a number of major arcs with different relative movement, with respect to the outer Apulia unit (see Fig. 1). This causes the almost complete closure of the intervenient deeper water seaway at the front of the arcs.

In intra Middle Pliocene times (*G.crassaformis* zone), the carbonate series of the inner part of the Outer Apulia carbonate platform belt, together with their allochthonous cover, are affected by compression. Starting from the innermost margin of the unit, the old Mesozoic normal ramps commence to be inverted.

The outer part of the Outer Apulia plate is further flexured. A new foredeep is individuated between the outermost inverted ramps and the flexured carbonate series: the so called "Bradanic Trough" (Figs. 1 and 3; SELLA *et al.*, 1990).

This physiographic element extends, highly cylindrically, all along the Southern Apennine foothills. Nevertheless, in the North it is probably older in age and narrower, as far as more external normal ramps appear to be inverted.

A fine wedge of turbiditic sandy argillaceous series accommodate the foredeep.

On the back of the thrust complex, coeval piggy-back basins of various extension settle discontinuously on structural lows.

In the upper part of Middle Pliocene, an out-of-sequence reactivation of the ramps within the trough occurred (see Fig. 3). The *G. crassaformis* flysch series are truncated and/or duplex folded under the ramp plane.

In the previous foredeep, with the intermediary deposition of a thin, gently unconformable, sandstone level (the so-called *"calcarenite"*), a new sand/shale sequence of shallow marine, high-subsidence environment is deposited in a basin that progressively widens on the foreland.

In the piggy-back basins the depocenter shifts westward and a thin coeval series deposited (see Fig. 3).

At the Upper Pliocene/Quaternary boundary, a new tectonic reactivation occurs at the edge of the chain. Coarse grained bottom-set-beds are followed by a thick, passive margin, prograding clay-sandy series.

Tectonic events coeval with those described at the outer

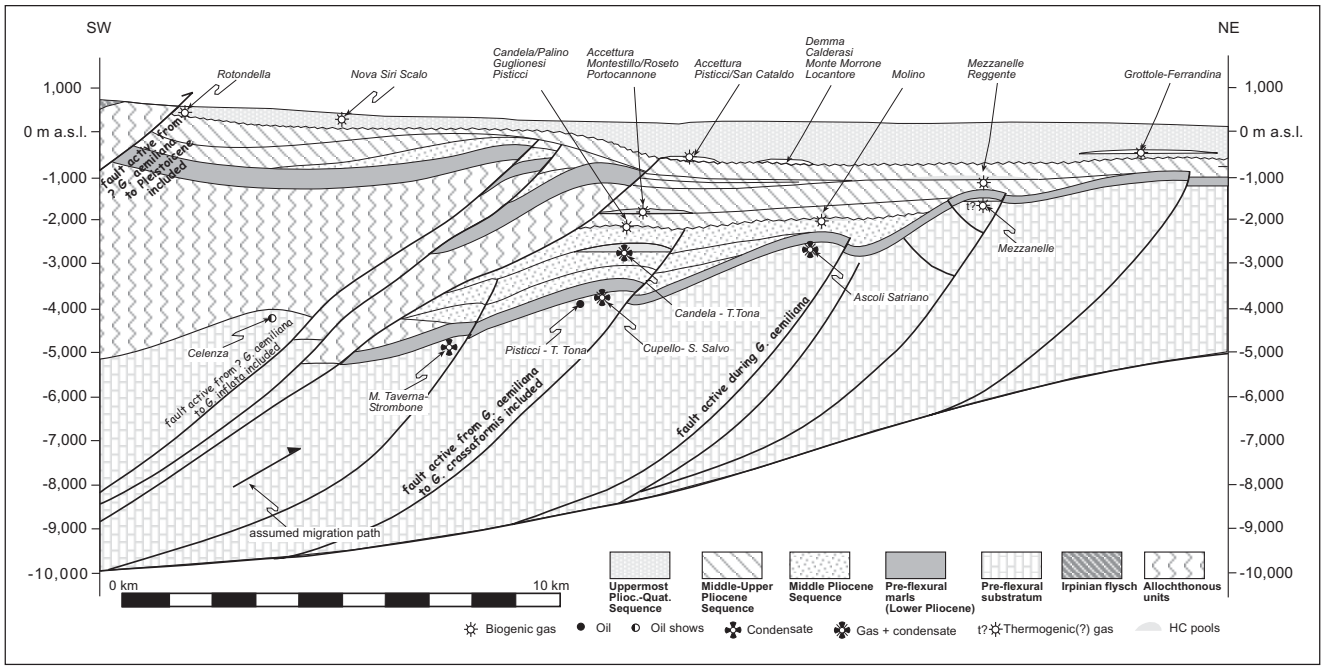

Fig. 3 - Schematic geological section across the North Bradanic Trough. Main oil and gas field located in Fig. 1 are projected at depth.

Sezione geologica schematica attraverso la porzione settentrionale della Fossa Bradanica. I principali campi a olio e a gas riportati in figura 1 sono qui proiettati in profondità.

margin of the orogenic belt must have occurred in the chain but are difficult to discriminate because of the erosion.

Important neo-tectonic extensional faults are, on the contrary, well detectable, especially to the West of the prism. These faults, that have mostly SW, but also NE vergence, probably flatten at the base of the carbonate platform sequence, re-utilizing the previous thrust décollement level.

3. THE SOUTHERN APENNINES PETROLEUM SYSTEMS

3.1 PREMISE

In this note a Petroleum System (from here-on **PS**) is intended as "the concurrence of a number of geologic parameters that must coexist, in space and time, with physical-chemical features sufficiently good to allow the genesis of a commercially significant hydrocarbons accumulation".

There is a general agreement in assuming that a **PS** is formed by the following parameters:

- source rock potential / maturity
- reservoir characters / thickness
- seal characters
- trap type / size

We believe that it should be important to consider, in addition to the above parameters,

- the ***geometrical relationships kitchen / trap*** at the time when the source rock is in the maturity window, that is the presence of a gradient (slope) between the kitchen and a formed trap at the generation time;

and

- the ***drainage area extension***, which is the area, connected to the trap by the slope, where the source rock is in the maturity window.

3.2 PETROLEUM SYSTEMS

The known **PS** in the Southern Apennines are described in relation to their regional geologic setting, from the inner structural/stratigraphic units toward the foreland (see also, Anelli *et al.*, 1996; Mattavelli & Novelli, 1988; Pieri, 2001; Pieri & Mattavelli, 1986; Sella *et al.*, 1990).

In the ***Apenninic Carbonate Platform*** unit no commercial hydrocarbons discoveries are known. Nevertheless the consistent oil shows encountered in some of the few wildcats drilled (i.e. Cicerale 1) within the limestones prove that an active **PS** exists.

The source rock related to the system is to be found either in intra-platform euxinic series or, possibly, in the lowermost, restricted circulation, flysch facies.

Of course the intense tectonics likely favoured the dismigration of the oil.

In any case, one can say that the exploration in this unit has been quite limited.

Some small size commercial accumulations of associated light oil (42-48° API) and CO_2 (i.e. Jelsi/S.ta Croce and Cercemaggiore fields) were found in the Benevento area (see Fig. 1) within the ***Lagonegro/Molise allochtonous*** unit.

The geochemical features of the oils suggest a doubtful Tertiary source (? Miocene flysch).

The reservoir is made of fractured deep-water facies limestones/dolomites of Triassic age. These series are implicated in thin-skin, East-vergent, duplex thrust-folds.

The **PS** is not very efficient, probably because of the small drainage area and trap size.

On the other hand, in the late '80s a tremendously efficient **PS** was discovered in the Southern part of the Southern Apennines within the ***Inner Apulia Carbonate Platform*** unit.

The Monte Alpi/Cerro Falcone group of fields (see Fig. 1)

has potential reserves of several hundreds billion BBLS. The oil is stored in fractured Lower Miocene/ Upper Cretaceous limestones and is density-segregated along the several hundreds m thick column (from about 42 to about 12° API).

We do not dispose of geochemical information concerning the oil-source correlation.

Based on regional geologic considerations, the source of the oil is probably to be found in euxinic intra-shelf limestones series related to the world-wide extended Turonian-Cenomanian and/or Aptian-Albian, climatic controlled, anoxic events.

The oil migration is probably lateral/updip from the large flanks of the structural area.

The trap is a large, high relief, double-vergent, thrust fold complex, derived from the Lower Pliocene age structural inversion of old extensional ramps (see Fig. 2).

Lower Pliocene pelagic marls provide the seal.

As a matter of fact, a similar **PS** was already known from the '70s more to the North in the much smaller Castelpagano and Benevento fields. Here, light oils (30 to 42° API) are associated with abundant (90%) CO_2. Due to the presence of oleanane, a source from Messinian shales was postulated in the past, but this hypothesis seams quite unlikely.

Further to the North, the Maiella Mountain is an unfortunately tectonically exhumed giant accumulation, ascribable, from any viewpoint to the same **PS**.

Multiple reservoirs contain large bitumen reserves that were known and exploited since ancient Roman times.

At the end of the '80s, along the inverted inner margin of the ***Outer Apulia Carbonate Platform*** unit, the major oil discovery of Tempa Rossa (see Fig. 1) revealed the presence of a new **PS**.

It is a high relief, double vergent, thrust-fold feature of basal Middle Pliocene age involving the carbonate series (which can be seen as a mega short-cut of the Outer Apulia domain); the field contains oil on a section of over 2,000 m (O/W contact still unknown).

The column height exceeds the estimated four-way dip closure, so one must assume that either the thrust ramps are sealing or the field area is larger (see Fig. 2).

A rather isopach series of Lower Pliocene pelagic Globigerina marls assure the seal.

Under this seal the wells encountered different stratigraphic terms, indicating how the Pliocene orogeny has rejuvenated pre-existing tectonic features.

The different reservoirs are made of thin Lower Miocene calcarenites, Middle Eocene Nummulitic limestones, fractured Upper Cretaceous limestones (main reservoir) and dolosparites.

Some of the wells penetrated the source rock, represented by argillaceous dolomicrites of Middle Cretaceous age.

The migration is very likely lateral-updip from SW, along the inner flank of the structure, with a possible contribution of the intervenient deeper water sea-way series (see Fig. 2).

Toward the North West this play has never been drilled, mostly because the trend is very deep.

Nevertheless the middle-sized field of Bomba, SE of the Maiella Mountain (see Fig. 1) can be definitely assigned to the same **PS**. As the field produces thermogenic gas associated with CO_2, N_2, and H_2S, a different maturity level of the system must be considered.

Along the up-dipping flank of the ***Outer Apulia Carbonate Platform*** unit (the pre-flexural substratum of the ***Bradanic Trough***) a number of small to middle sized fields can be tentatively ascribed to a same **PS**.

These fields produce associated condensate (or very light oil) and thermogenic gas from Lower-Middle Miocene calcarenites and fractured Cretaceous carbonate platform limestones.

The traps are asymmetric, East vergent, inverted thrust-folds set along different structural trends on the slope, from the most internal (i.e. M. Taverna, Strombone under the Allochthonous edge) across the intermediate ones (i.e. Cupello/San Salvo), to the most external (i.e. Ascoli Satriano, Mezzanelle) (see Figs. 1 and 3).

As usual, a good seal is provided by the Lower Pliocene pelagic marls.

The source of these hydrocarbons is uncertain. In order to explain the general high maturity of the system and the stratigraphic position of the reservoir, one can assume that hydrocarbons are probably generated from Mesozoic, reducing environment, marine organic matter and that the migration was lateral up-dip, along the slope, from a mature kitchen located SW.

Some heavy oil accumulation was found in similar geologic setting (i.e. Pisticci and Torrente Tona fields). These oils have been interpreted both as immature and biodegraded; the second hypothesis seems better explained by the geologic setting.

A particular case is represented by the Candela and Torrente Tona fields in which Middle Pliocene turbiditic sand pools produce gas and condensate associated with CO_2.

Geochemical analysis indicate that these HC are sourced from shaly terrestrial organic matter.

Due to the difficulty of seismic imaging under the front of the Allochthonous nappes, as soon as they thicken to the SW, the historic exploration of the deeper inner trends was relatively poor and some potential upside still exist for this play.

In term of volumes and economic interest by far the large majority of the HC found and produced in the ***Bradanic Trough*** is associated to biogenic gas accumulations.

Sandy reservoirs belonging to all three first order post-flexural sequences contribute, even if with different rates, to the impressive cumulate production of the area.

The turbiditic Middle Pliocene *G. crassaformis* sands produce in several tens of fields.

Most of them are located in the innermost part of the foredeep wedge and are related to the burden of the Allochthonous frontal ramp.

Multiple layers of sands are implicated in various trap types (see Fig. 3), such as: duplex folds under the ramp (i.e. Accettura, Montestillo/Roseto, Portocannone); westward updipping levels truncated by the ramp (i.e. Candela/Palino, Guglionesi, Pisticci); four-way dip thrust folds (i.e. Candela, Torrente Tona, Guglionesi).

In the outer part of the wedge, the traps are more gently inverted thrust folds (i.e. Molino) conformably implicating the Middle Pliocene sands and the carbonate substratum. The

latter often produces thermogenic gas and/or condensate.

The shallow marine sands of the overlying Middle-Upper Pliocene sequence also produce in differently set fields (see Fig. 3).

In the inner part of the basin, westward updipping beds are truncated under the re-activated allochthon front ramp (i.e. Montestillo, Lucera), while in the larger remaining area most of the traps are four-way closed, gently reactivated, inverted thrust-folds, or even drapings on the previous highs (i.e. Reggente, Mezzanelle).

In some cases mixed structural/stratigraphic traps can be postulated (sands shale out).

Amplitude anomalies on the seismic lines (bright spots) are very often associated to the gas accumulations.

Sandy levels of the Pleistocene sequence also contribute, even though to a lower extent, to the Bradanic Trough gas production.

In the outer part of the basin, bottom set beds are trapped in gentle drapings, at times of large size, of the underlying structural highs (i.e. Grottole /Ferrandina).

Overlying discontinuous sand levels produce in many fields located in different parts of the basin. Traps are either gentle drape folds or of mixed type (i.e., Demma, Calderasi, Monte Morrone, Locantore, etc.). In this case also amplitude anomalies point out the presence of gas.

Basal Pleistocene sandy levels are gas-bearing along the inner margin of the basin in a peculiar type of trap either on-lapping or being truncated by the outermost reactivation of the allochthonous front (i.e. Accettura, Pisticci/San Cataldo).

Finally, small gas accumulations were found in Pleistocene piggy-back basin sandy lenses (i.e., Rotondella, Nova Siri).

4. SUMMARY OF CONCLUSIONS

Resulting from its geologic complexity Southern Apennines petroleum systems are much various in characters.

One can tentatively group these **PS** in three main families:

- oil-prone ***PS***
- biogenic gas-prone ***PS***
- thermogenic gas & condensate/light oil-prone ***PS***.

With some minor exceptions the oil-prone **PS** family is related to the, Mesozoic platform limestones series of the ***Inner Apulia unit*** and of the inner margin of the ***Outer Apulia unit***.

In fact, both the postulated ***source rocks*** and the producing ***reservoir rocks*** were found in the Mesozoic (mostly Cretaceous) sedimentary record.

The lower Pliocene series concur in the **PS** providing the ***sealing cover***, while the following flexural phase allows the source rock to enter in the ***maturity window*** and thus generate. The Middle Pliocene structural inversion phase generated the ***traps*** and the geometric gradient (slope) to favour the ***migration***. This occurred most probably laterally-updip, from the mature kitchen North-Westward into the trap.

On the contrary, the biogenic gas family of **PS** is essentially related to the Middle Pliocene to Pleistocene age terrigenous sequences of the ***Bradanic Trough*** foredeep.

The gas is generated by terrestrial organic matter trapped mostly in argillaceous beds.

Intercalated beds of various facies and age provide the ***reservoirs***. Middle Pliocene turbiditic, Upper Pliocene shallow marine and Pleistocene prograding sands were recognized.

Traps are much varied and set on different trends in the foredeep.

Along the inner belt they are associated to the allochthonous front ramp in the form of truncated westward updipping beds, duplex thrust-folds or four-way dip closed thrust folds.

On more external trends they are mostly gentle thrust folds or draping folds. Mixed structural/stratigraphic traps are less common.

The ***migration*** is "in situ" from adjacent source beds.

The thermogenic gas/condensate-prone ***PS*** family is the most hybrid and of questionable interpretation.

The ***source rock*** is probably given by marine organic matter from reducing environment, intra platform successions.

Traps, despite located along different trends in the foredeep, are almost everywhere thrust folds generated by moderate invertion of pre-existing normal ramps.

Migration is lateral updip from a deeply buried mature kitchen situated to the SW, beneath the allochthonous frontal ramp.

As usual, the ***seal*** is granted by the pre-flexural Lower Pliocene marls.

Notice that in some cases thermogenic and biogenic gases are mixed in the same pool.

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