Geological model, advanced methods help unlock oil in Italy's Apennines

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Tempa Rossa oil field is 50 km south of Potenza in the Basilicata region on the eastern side of the southern Apennine mountains at more than 1,000 m elevation.

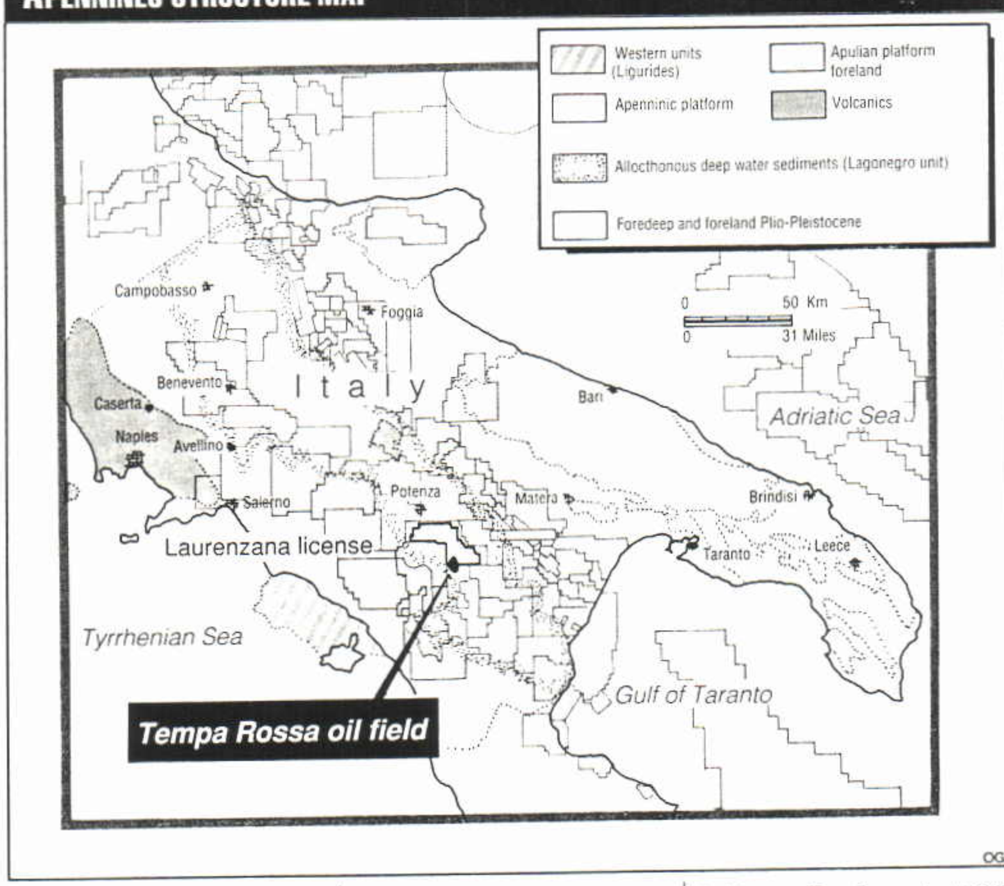
It represents one of the most interesting oil fields discovered in the Apulian platform target beneath a regional thickness of allochthonous strata of 4,000 m.

Modern hydrocarbon exploration in the southern Apennines started during the late 1960s and resulted in small but significant oil fields in the following decade: Castelpagano with 31.1° gravity oil; Benevento with 46° gravity oil, and Pieri e Mattavelli, 1986.

However, only a few companies were seriously involved in the exploration of the Campania-Lucania Apennines. This is due to poor quality seismic data, the depth of the expected reservoir, and major drilling difficulties related to the penetration of an overpressured allochthonous sequence before getting to the balanced or slightly overpressured target.

Fig. 1

APENNINES STRUCTURE MAP

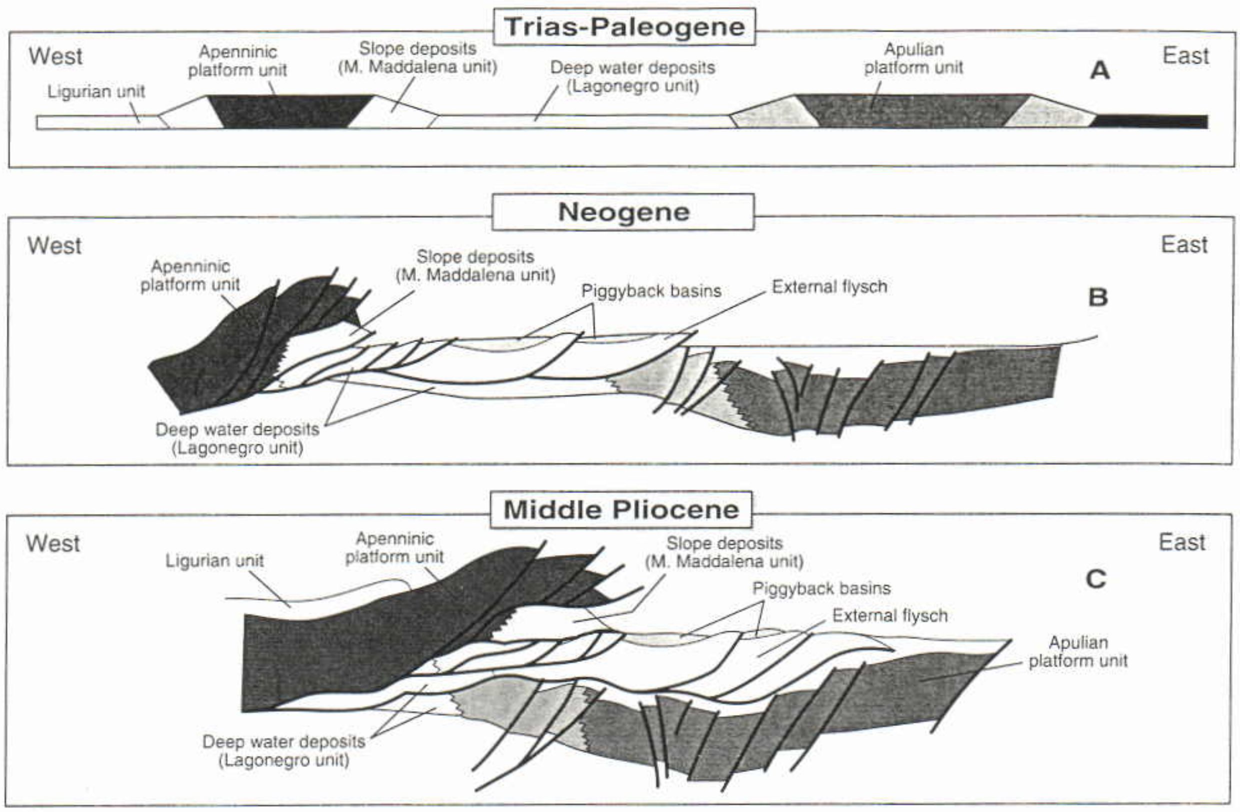


The small but encouraging AGIP Costa Molina oil field discovery (20.3° gravity oil) in 1982 only slightly increased the general interest for the region, which is inhibited by the relative high risk investments implied.

Relevant improvement of seismic acquisition and processing techniques raised the interest of the area in the early 1980s. A small group of companies, especially FINA Italiana, Total, and AGIP concentrated the efforts in testing and evaluating all the more advanced exploration techniques available so as to

Fig. 2

STRUCTURAL EVOLUTION



Not to scale

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reasonably assess the southern Apennines plays and targets.

Helicopter seismic acquisition became routine in the area because the rough topography and environmental problems did not allow access to land seismic crews.

The oil price drop caused a remarkable reduction of the number of exploration companies active in the area during the late 1980s just before the petroleum potential of the region was completely assessed.

In 1987 the Monte Alpi license joint venture, headed by Petrex, discovered Monte Alpi light oil field. In 1988 the Laurenzana license joint venture, led by FINA Italiana, started drilling the 1D Tempa Rossa, the discovery well of Tempa Rossa oil field. It encountered at least 1,000 m of oil column, and the oil-water contact depth is still unknown.

Exploration techniques

A careful geological analysis, integrated with a wide and updated knowledge of compressive belts case histories and structural, stratigraphic, and depositional models, is probably the major exploration technique for this area.

Southern Apennines seismic line interpretation, even if it is still the main tool, due to poor quality data is definitely insufficient for prospect evaluation if not driven by a predictive geologic model integrating all the available data.

Several papers dealing with southern Apennines structural and stratigraphic models have been published the last two decades.[1,2,3,4,5]

However, the complexity of structural and stratigraphic relationships and the lack of detailed structural analysis within well-defined stratigraphic constraints has resulted in reconstructions of tectono-sedimentary evolution of the region that remain largely conjectural.

Therefore, getting deeply involved in the local complex geology seemed to FINA Italiana the only way to perform a reasonable assessment of the hydrocarbon potential of the southern Apennines.

During the first exploration phase, all the published and public subsurface data were collected and new data were acquired. These data were referred to surface data both from articles and direct observations.

The integration of surface and subsurface available data, most of which have been gathered during the last few years, led the Laurenzana license operator to generate its own general structural and stratigraphic model. Major efforts focused on establishing a qualitative stress regime model for the Apulian platform carbonates.

This work led through a new approach to the poor quality seismic data interpretation that resulted in the Tempa Rossa oil discovery within a previously explored area. Furthermore, this approach strongly enhanced the petroleum potential of previously neglected areas in this region.

Essential background references to our work include the already cited papers plus others.[6,7,8]

Geological framework

The Southern Apennines fold-thrust belt resulted after the compressive deformation of the Tethys ocean southwestern margin during the Neogene convergence of the African and European plates.[9]

From west to east, three major elements can be recognized within the Campania-Lucania sector: the Apenninic carbonate platform, the Lagonegro deep marine basin, and the Apulian carbonate platform.

Foredeep Plio-Pleistocene deposits separate Apulian platform foreland carbonates from overlying thrusted strata. Overthrusted deep marine sediments (Ligurian units) bound westward Apenninic platform outcrops (Fig. 1).

Neogene emplacement of tectonic units marks the end of a story started in the early Mesozoic (Fig. 2). From the late Triassic up to the Paleogene the paleogeography and the tectonic regime were monotonous; the Apenninic platform and the Apulian platform kept growing separated by the deep and starved Lagonegro basin (Fig. 2A).

The first relevant collisional phase could be attributed to the end of Paleogene: Ligurian units overthrust Apenninic platform. The Apenninic platform is thrusted over its eastern margin and the western sector of the Lagonegro basin. The resulting foredeep is filled by the "external flysch" strata (Fig. 2B).

A further, probably more intense, compressive phase occurred at the end of the early Pliocene. The "external flysch," overlain by part of the Lagonegro basin, thrusted over the Pliocene foredeep, above the Apulian platform (Fig. 2C).

Apulian platform foreland carbonates

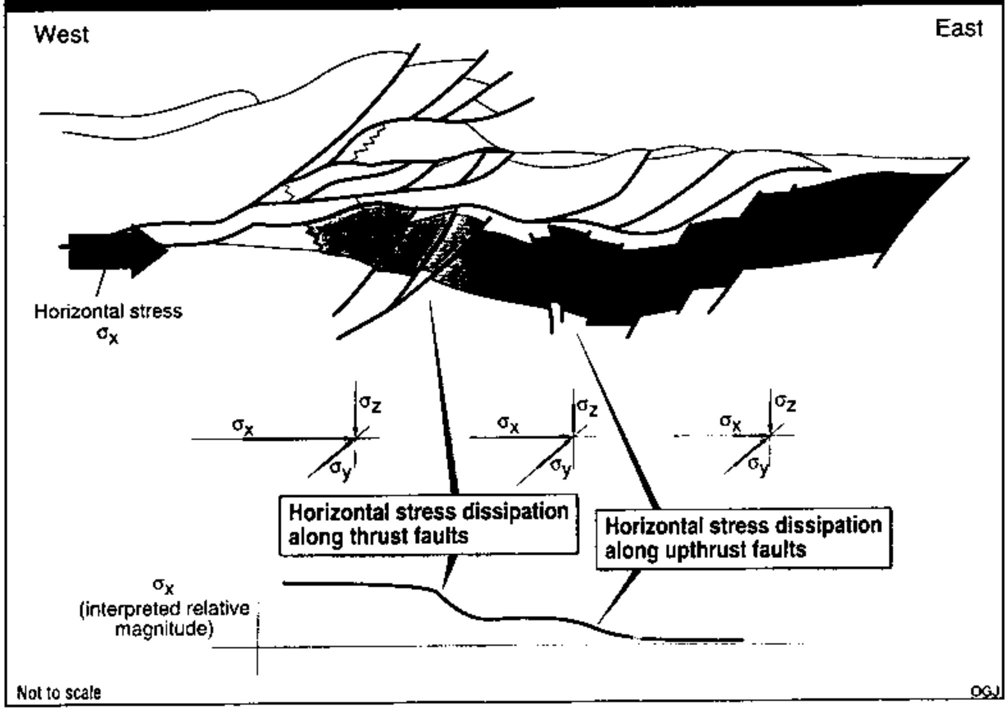
Inferred buried foreland structural style has to be related to the above mentioned tectonic phases. Compressive features along the Apulian platform western margin can be interpreted from the seismic lines, while within the eastern sector of the buried foreland and the Murge area outcrops extensional features occur.

Between these two zones a relatively deep belt is present. These subvertical reverse faults occur with major vertical displacement (several hundreds of meters), interpreted as "upthrust" or flower structure.

Based upon these observations, an eastward decreasing horizontal compressive sigma-1 stress axis[10] can be inferred within the Apulian platform (Fig. 3).

Fig. 3

APULIAN PLATFORM STRESS REGIMES



The western sector of Apulian platform, characterized by compressive features, could be interpreted as affected by a compressive regime with an horizontal northeast oriented σ_1 and vertical σ_1. Compressive stresses presumably dissipated along the western margin thrust faults.

Eastward of this compressive belt, a still horizontal, even though reduced with respect to the other stress axes, σ_1 can be inferred: σ_3 axis should therefore be horizontal and σ_2 vertical. A transpressive tectonic regime is therefore interpreted as responsible for the observed structural style.

Easternmost extensional regime with vertical σ_1 and horizontal σ_2 and σ_3 is probably a consequence of the peripheral bulge migration during the different tectonic phases.

Excellent reservoir properties of wrenching induced positive structures highlighted by Harding,[11] led us to concentrate our efforts toward this neglected main target.

The Tempa Rossa 1D discovery, confirmed by Tempa Rossa 2 and Tempa Rossa 1D-sidetrack, supported our model pointing out the potential of previously explored but underestimated areas.

Well histories

TR-1 directional was drilled as a deviated well—due to terrain problems in siting a vertical location—at 5,050 m measured depth, through the allochthonous sequence and encountered about 700 m of oil bearing limestone of Tertiary and Cretaceous age.

Technical problems that occurred after the third drillstem test didn't allow deepening or completion.

A second well, TR-2, was planned by the same group of companies on the neighboring license of Torrente Sauro in 1991 about 3 km south of the discovery well.

During 1992 the TR-2, which penetrated an oil column of more than 800 m, was put on a 135 day extended well test and produced at a controlled natural flow rate approximately 1,220 b/d of oil with no water and no reduction of flow rate or wellhead pressure.

Following these very encouraging results, TR-1 directional well was reentered and sidetracked to 5,401 m in the limestone and dolomite from Miocene and Cretaceous age and tested 16-22° gravity oil over three intervals at flow rates of 1,600, 2,560, and 3,470 b/d.

Tempa Rossa reservoir

The unusually thick oil column and the various lithology and porosity types characterize this nonconventional reservoir.

Modeling the Tempa Rossa reservoir is difficult due to fracture porosity not homogeneously distributed all through the section, microfracture and fissure, opened stylolite, vuggy interval solution enlargement, and moldic and matrix porosity (especially in dolomite strata).

In order to get the best reservoir knowledge, efforts had been focused toward a high quality acquisition and elaboration of well site data.

A special mud-logging unit was used, equipped with a small mud loss recording tool, a quantitative hydrocarbon occurrences indicator on the cuttings; the continuously recorded penetration rate was processed with the other geological information to detect fractures and fracture behavior during drilling.

About 100 m of oriented core were collected with a low invasion coring system, when possible, in order to evaluate this methodology in low porosity fractured reservoir.

Petrophysical measurements on cores concerned conventional and special core analyses on plugs and full size cores. The special core analysis was performed to obtain resistivity measurement, capillarity curves, and flooding tests; tomography was also performed on all the whole core blocks.

The logging program included the last generation of Schlumberger tools. Attention was devoted to fracture quantitative characterization using an azimuthal Laterolog as resistivity tool, a DSI (dipole shear imager) as sonic tool, and FMI (fullbore microimager) as micro-resistivity tool. The program was completed by radioactive logs. An MSCT mechanical coring tool and MDT (modular formation dynamic tester) were not technically possible to run even though planned.

Several processings of the data acquired were performed. For the FMI, a FLIP (fracture identification by normalized imaging) Fracview (aperture determination by calibrated imaging)[12] was run. A prototype called SPOT (secondary porosity typing) for vugs characterization is under evaluation (J.P. Delhomme, in press).

For the DSI, an STC—SONFRA (Stonely wave analysis) was done. This product had compared with FMI results for fractures identification and for width determination.[13]

A project study on CPI calculation is proceeding. Unfortunately the cementation factor 'm' experimental determination didn't supply appreciable results. In the future it has to be planned an 'n' calculation on core at reservoir condition.

The porosity calculation is another source of problems because of hole enlargement due to the fractures and probably to the larger vugs. Anyway the porosity response on logs has to be calibrated with core results even if in vuggy zones this procedure is not unequivocal. The unconventional reservoir complexity is strongly increased by the oil column thickness. Within a 1,000 m thick oil column, the various porosity types are expected to be distributed with an extreme vertical and horizontal heterogeneity.

The statistic modeling on the third dimension of the data, gathered in the few wells drilled, is therefore thought to be at this stage a risky task.

The history of fracturing assessment in situ, stress determination, diagenetic study will be performed to define a geological model that, supported by well test data, could reduce the risk of a statistical simulation.

Conclusions

Tempa Rossa oil discovery confirmed the remarkable petroleum potential of the southern Apennines.

There are still many structures to explore. They will probably be found only through improving and updating the geological model and testing the new geophysical processing techniques. Advanced techniques are also necessary to improve the acquisition and processing of the wellsite data so as to maximize the information gathered from the few and widely separated wells available.

FINA Italiana will continue its exploration activity, following and improving its regional integrated approach with the evaluation of new and old acreage, being presently involved in about 20 licenses and applications from the Gulf of Taranto offshore to the Benevento mountains.

Acknowledgments

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Salvatore D'Andrea has more than 10 years' experience as explorationist and later chief geologist in SIR Esplorazioni Mediterranee (now Petrex) before joining FINA Italiana in May 1982. He joined FINA as chief geologist and deputy exploration manager to set up the exploration department and create the exploration permits portfolio and helped establish the company as an exploration play concepts innovator.

He was appointed exploration manager and deputy E&P manager in January 1986. Petrofina SA assigned him in 1991 to Libya with FINA Exploration Libya BV, where he is exploration manager and deputy general manager.

Roberto Pasi was formerly involved in academic research for neotectonic national project. In May 1978 he joined AGIP SpA, where he worked as explorationist mainly devoted to prospect generation of Adriatic Sea gas and oil plays.

He joined FINA Italiana in 1984, where he dedicated his effort mainly to regional studies and particularly gave his contribution to develop FINA's structural model of the southern Apennines as senior geologist, then as chief geologist, and from July 1991 as exploration manager of FINA Italiana. He received geology degrees from the University of Pavia, Italy.

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He is chief geologist in charge of reservoir evaluation and modeling of the Tempa Rossa complex including seismic and well test data. He has a geology degree from the University of Parma, Italy.

Paolo Dattilo received a geology degree from the University of Parma. During 1985-88 he did undergraduate and graduate work under Prof. E. Mutti on facies analysis and sequence stratigraphy of Upper Cretaceous and Eocene strate of the southern Pyrenees.

In October 1988 he joined FINA, where hs work dealt with sedimentology, basin analysis, and hydrocarbon potential of the Pliocene Adriatic foredeep. This study resulted in a complete reevaluation of the area and the generation of a number of prospects.

He is presently senior geologist involved among other things in regional studies, new areas evaluation, and elaboration of a structural and stratigraphic model of Apulian carbonates.