Bollettino di Geofisica Teorica ed Applicata Vol. 52, n. 4, pp. 607-623; December 2011
DOI 10.4430/bgta0016

Seismic exploration of a possible gas-reservoir in the south Apulia foreland

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(Received: March 31, 2010; accepted: August 27, 2010)

ABSTRACT We have observed a strong seismic reflection, with high attenuation below the event, at a depth of 1700-1800 ms TWT (about 700 m below the sea bottom), above the Apulia carbonate platform, in the Salento Adriatic offshore, Otranto Channel. The Merlo-1 explorative well penetrated the Plio-Pleistocene and Upper Miocene sediments covering a structural high of the Cretaceous-Oligocene units of the platform margin. This position, in our opinion, compromised the possibility of crossing the reflector, terminating in onlap or in pinch-out around the structure drilled by the well. We performed a dedicated signal analysis in order to evaluate if this bright spot effectively represents a gas reservoir. We used seismic attribute analysis considering amplitude, phase and frequency related attributes, velocity analysis and AVO to improve the interpretation and to obtain semi-quantitative data. Interpretation of all the available seismic profiles was used to map the extension of the possible reservoir and its relation to the Apulia platform margins.

Key words: seismic profile, seismic attribute, Otranto Channel.

1. Introduction

In this work we analyzed a seismic profile located offshore south-eastern Italy, along the Otranto Channel (Fig. 1).

Since the beginning of the 1980's, when some explorative boreholes were drilled in this area (Mattavelli *et al*., 1991), the hydrocarbon possibilities of the south Adriatic basin have been discovered and analysed. In the south Adriatic basin two oil fields (Rovesti and Aquila) and one gas field (Falco) are located in the transitional area between the Apulia carbonate platform and the Ionian pelagic domain; the reservoir rocks are platform edge carbonates (calcareous turbidites and dolomite) deposited from Late Jurassic to Paleogene (Mattavelli *et al*., 1991). Interpreting the MS-29 profile, we noted a "bright spot" in the Pliocene sequence over and near the eastern margin of the Apulia carbonate platform. This reflector appears to be characterized by a prominent negative amplitude, anticlinalic shape and by a length of about 10 km. Because of the above specified reasons, we cannot directly infer a gas origin for this feature, also because there are no boreholes calibrating the horizon, or rather, the only well located in the area of the MS-29 line, is dry (Mattavelli *et al*., 1991).

Seismic evidence of a gas saturated level is often represented by a strong reflector reported in literature as a “bright spot”. The presence of gas or light-oil causes an increase in the compressibility of the rock and a drop of the P-wave velocity value; these variations cause a

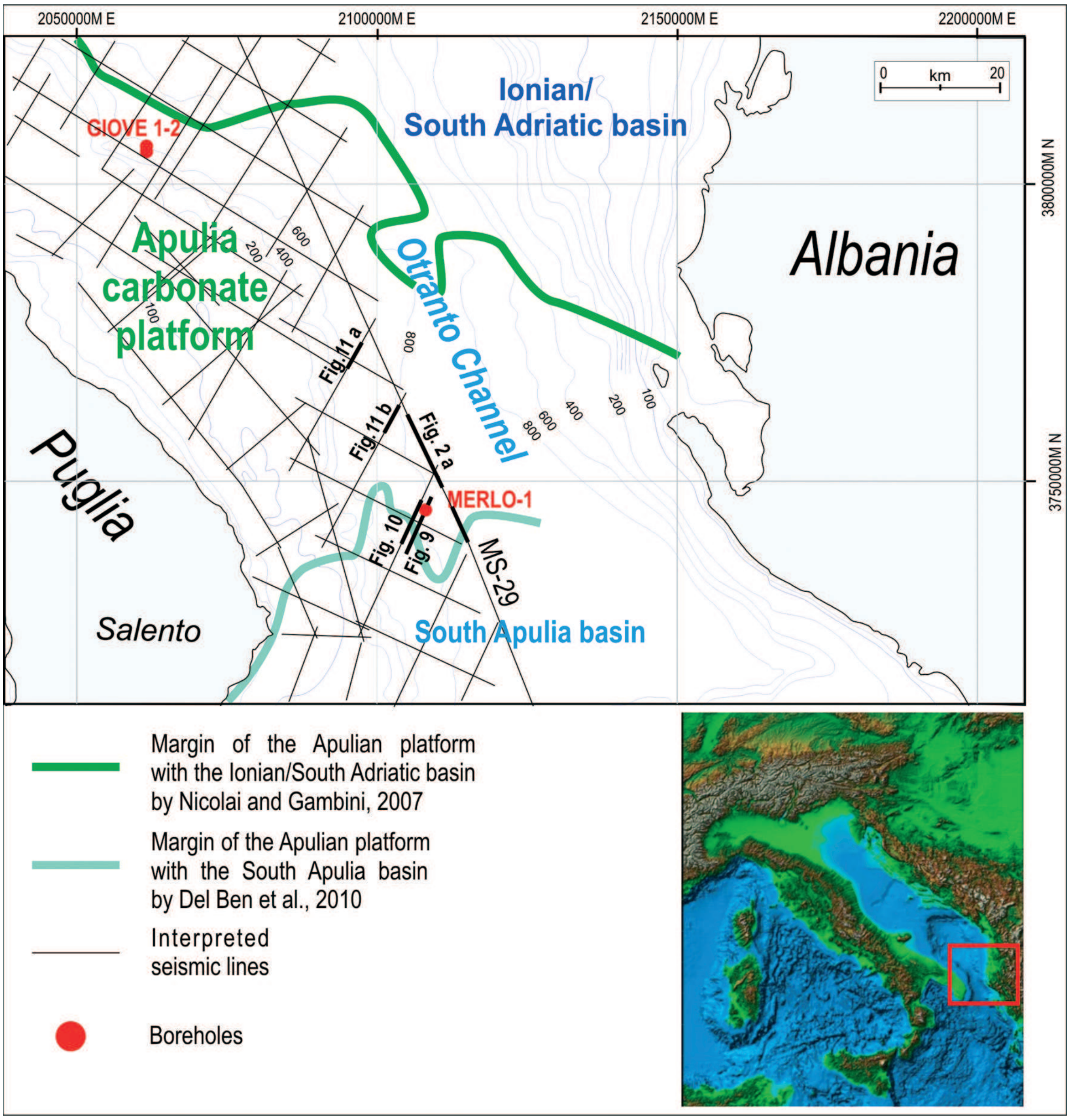

Fig. 1 - Location map of the studied area showing the position of the MS-29 and of other interpreted seismic lines.

strong reflector on the seismic section, often with negative polarity. During the pioneering hydrocarbon explorations, bright spots were recognized as Direct Hydrocarbons Indicators (DHI) but drillers soon learned that not only gas or oil are able to produce this kind of reflections: common "false bright spots" are volcanic ashes, highly cemented sands, coal beds, top of salt diapirs, low-porosity heterolithic sands and over-pressured sands and clays (Avseth *et al*., 2005). For these reasons, specific seismic data procedures were implemented like Amplitude Versus Offset analysis (AVO), Amplitude Versus Angle (AVA) and several seismic attributes.

The presence of gas usually produces an increase of reflection wave amplitude with offset;

using the AVO behaviour, it is possible to classify gas reservoirs into different sand-classes. Rutherford and Williams (1989) divided gas-reservoirs into three sand classes based on normal incidence reflection coefficient. Further development of these studies, showed that gas-sand amplitude may even decrease with offset; Castagna *et al*. (1998) added a fourth sand-class using a crossplot plane of the AVO attributes intercept and gradient.

A seismic attribute is a specific measurement of geometric, kinematic, dynamic or statistical features derived from seismic data (Chen and Sidney, 1997). A seismic attribute is a descriptive and quantifiable characteristic of seismic data that can be displayed at the same scale as the original data. It represents a subset of the total information contained in the original seismic data and a seismic attribute analysis is therefore a decomposition of seismic data into constituents (Barnes, 1999).

Seismic attribute analysis began with the search for bright spots in the early 1970's. Initially, it included instantaneous amplitude, phase and frequency; instantaneous amplitude was the most used attribute for petroleum exploration. In the 1980's and 1990's seismic attribute technology dramatically advanced in several directions, with multi-attribute and multi-dimensional analysis. These are computed and analysed for two main reasons: remove false and extraneous information and reveal features or patterns not visible in the original data.

From the origin, the meaning of the expression "seismic attribute" changed as the technologies improved. At first, the term referred only to instantaneous attributes derived from the Hilbert transform or complex trace analysis of seismic data. Later, surface-based seismic attributes received more attention especially when 3D seismic became popular. Only in recent years, several specific trace constituents that usually require special processing (or inversion) and are often complex to generate, have been widely viewed as "seismic attributes". Therefore, in the most general sense, the definition of seismic attributes encompasses all quantities derived from seismic data; thus, we consider interval velocity, inversion for acoustic impedance, pore pressure prediction, reflector terminations, as well as complex-trace components and amplitude variation with offset (AVO) to be attributes (Chopra and Marfurt, 2007).

Trace and section-based attributes are usually of instantaneous type or result from a processing step such as velocity or impedance computation. Event-based attributes are extracted from the data associated with a surface, providing information about how they vary at or between geological boundaries. Different methods can be used to calculate event-related attributes: instantaneous, single-trace windowed and multi-trace windowed extraction.

Volume-based attributes are calculated with single or multiple steps from a 3-D data volume without any previous surface definition.

The aim of this work is to 1) analyze the MS-29 seismic line using seismic attribute calculations which may point out fluid saturation changes within the Plio-Quaternary sequence; 2) interpret all the available seismic profiles to analyze the continuity of the high amplitude reflector, its terminations, the geometry of its inner sedimentary sequence; 3) estimate the extension of the bright spot within the considered area.

2. Geological setting

The regional geological contest is one of the fundamental features that might, or not, favour gas accumulation in permeable layers. The studied area is located in the south Apulia plate, characterized by the presence of the Apulia carbonate platform and the adjacent pelagic sequences of the Ionian/south Adriatic basin and of the south Apulia basin, as defined by Del Ben *et al*. (2010). The platform margin has a complex trend, outlined in its north-eastern sector by Bosellini *et al*. (1993), Argnani *et al*. (1996), Ballauri *et al*. (2002) and Nicolai and Gambini (2007) and, in its south-eastern sector by Del Ben *et al*. (2010).

The Apulia carbonate platform consists of Jurassic-Miocene, shallow-water carbonates disconformably covered by open-ramp carbonate deposits (Bolognano formation), followed by Messinian evaporites (Gessoso Solfifera formation). Nicolai and Gambini (2007) identify, in the Apulia platform, the intraplatform Rosaria Mare basin, developed mainly from the Late Cretaceous to the Eocene.

According to Mattavelli *et al*. (1991) the pelagic sequence of the Ionian/south Adriatic basin is characterized by limestones and marls from the Liassic to the Paleocene, by a clastic succession shed by orogen processes that have been growning since the Oligocene, by a regular alternation of sands and shales of the Bisciaro formation of the Lower Miocene and by marly silty and clay turbidites of the Schlier Formation of the Serravallian-Tortonian. This is overlain by the Upper Messinian evaporites (Gessoso Solfifera formation), that is seismically characterized by a strong reflector and is usually considered as a guide horizon. Finally, the Plio-Quaternary deposits are characterized by marl and clay sediments and include the well reflecting horizon studied here.

3. Seismic data

Hydrocarbon exploration of the peri-Italian seas has been carried out since the 1960's through seismic surveys and drillings (Mattavelli and Novelli, 1990). The first seismic data set (medium resolution – petroleum target) was acquired offshore the Italian coast (public data set of Zones D and F), and several boreholes have been drilled in different settings (Mattavelli and Novelli, 1990). The data set is presently available as scanned paper seismic records, that are not a format useful for re-processing or for other specific applications. These seismic profiles represent the basic information to extend a 3D interpretation between the Italian shore and the Italia-Albania offshore boundary.

In 1971, crustal MCS profiles were acquired in the Mediterranean Sea (MS profiles) by the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) of Trieste and processed in 1972. Only the MS-29 profile crosses the studied area: it represents the starting point and the basic data for our analysis. These data, in fact, are available in digital format, thus offering a possibility to better visualize interesting features for interpretation and to extract fundamental information on seismic attributes.

4. Reprocessing of the MS-29 seismic line and critical analysis of the “bright spot”

Seismic profile MS-29, acquired along the Otranto Channel shows a clear continuous reflector of high acoustic contrast within the Plio-Pleistocene sequence covering the Apulia carbonate platform. The gentle anticlinalic shape of the structure, the sharp tips of this reflector and the clear attenuation below the reflection, particularly evident for the top of the Messinian evaporite sequence, suggested to explore the possibility of the presence of a gas reservoir.

The length of the high amplitude reflector along the MS-29 profile is about 10 km, thus representing an eventual, very consistent reservoir in the area. Interpretation of other seismic profiles by Zones F and D, crossing or close to the MS-29, seems to picture a large extension of this "bright spot", especially towards the western sector of the Otranto Channel.

Anstey (1977) classified seven different criteria for the recognition of a gas accumulation (direct hydrocarbon detection). We used these criteria to obtain a critical and convincing examination of the possibility of a hydrocarbon-associated bright spot. Furthermore, we have implemented the observation of the seismic data with reprocessing and analysis of seismic attributes of the MS-29 profile (the only profile available in digital format).

In the following section, each of the seven criteria of Anstey (1977) are critically evaluated:

- The gas-liquid contact: it is the generally flat boundary between gas and water-saturated sediments. This is always best seen at compressed horizontal scale. In this case, we have not enough vertical resolution to resolve the top and the bottom of the reservoir, and the eventual inner gas-liquid contact. Furthermore, the whole interpreted seismic data set shows a clear deepening of the bright spot from WSW to ENE (from 740 to 1800 ms TWT, as we will discuss in the next paragraph). We infer that the reservoir thickness could be entirely gas saturated, so it could be eventually crossed by this contact only in its deepest (eastern) sector, also if a relative flat spot has not been recognized.
- Anomalous reflection coefficient: the high amplitude signal is well recognizable along several seismic profiles; we have analysed the pre-stack MS-29 data to exclude the effect of AGC or other processing steps that could modify the field data. The possibility that the bright spot could be originated by constructive interference between the top and the bottom of a thinning unit (the so called "tuning" effect, that is clearly a fortuitous local condition) has been discarded because of the large and continuous extension of the reflector. Common "false bright spots" (Avseth *et al.*, 2005) have been considered to exclude improper ascription to a gas reservoir. Alternative interpretation of volcanic intrusion or ash layer seemed initially to be a possible cause for such a high amplitude: a high-reflecting, tuffite horizon of Pliocene age (Patacca *et al.*, 2008), easily recognizable in the central Adriatic Sea, or other ash layers has been recognized in the Adria plate. This hypothesis has been rejected due to the deposition of the sediments above the carbonate platform anticlinalic structure and its prosecution, without high amplitude in the deeper area (Fig. 2). Other options as highly cemented sands, low porosity heterolothic sands, overpressured sands have been considered, but they do not seem to be convincing if we evaluate the stratigraphic position and the settlement of the reflector.

Seismic attributes analysis could be very helpful to characterize the anomalous amplitude of the reflector under examination.

The Reflection Strength (also reported as instantaneous amplitude, or envelope) can be used as an effective marker because it mainly represents the acoustic impedance contrast and so the reflectivity of a horizon. It is useful in identifying bright/dim/flat spots and lateral fluids, lithologic and stratigraphic variations within hydrocarbon reservoirs (Chen and Sydney, 1997). This algorithm has been applied first to the stacked profile (Fig. 3a); the strong amplitude reflector has been highlighted, but the amplitude absorption above the bright spot due to a strong, lithological or fluid, vertical contrast is more important.

This analysis has been applied also to the pre-stacked data; we formed Super Gathers of 4 CDPs in order to cover the entire offset range (320 m-2620 m). The table in Fig. 3 summarises the acquisition parameters of MS-29 profiles. The bright spot (Fig. 3b) preserves high amplitude value also for far offsets; this characteristic seems to remove the misgiving of a false bright spot because a common brine/water saturated seismo-stratigraphic layer should present, with the same analysis, a behaviour as in Fig. 3c, where the amplitude decreases with increasing offsets.

Furthermore, the presence of the bright spot along several seismic profiles, deriving from different data sets, assures us that the AVO anomaly is not a false one due to the acquisition or processing (Avseth *et al*., 2005).

- Anomalous low velocity: low velocities and inversion phenomena can be related to the gas saturating the sediments. A velocity analysis has been applied to Super Gathers obtained combining 4 close CDPs, in order to increase the folding and obtain more accurate analysis with negligible effects due to lateral velocity changes. Fig. 4 shows the coherency spectrum obtained on a CDP crossing the bright spot and the picked root mean square velocity function used to remove the NMO delay and to obtain the stacked section (Yilmaz, 2001). The related interval velocities computed using the Dix relation (Dix, 1955) reveal a velocity inversion in correspondence of the bright spot.

This asserts the fact that the strong negative amplitude of the bright spot could be related to the presence of a very low velocity lens within the post-Messinian sedimentary sequence.

In order to verify the fact that the velocity anomaly belongs to the whole of the reflector length and that it is not just a local situation, we made a detailed velocity analysis considering all the available CMP (Fig. 4).

A peculiarity of locally low interval velocity values is the pull-down effect. For the actual situation this check is hardly feasible, due to the anticlinalic shape of the reflectors below the bright spot and the low vertical seismic resolution due to the low frequency source used.

- Phase change: conditions for polarity inversion may or may not occur in typical gas reservoirs and in our study this is observed only occasionally. Anyway, in the interpreted seismic data set the recognition of an inversion polarity is often ambiguous due to the presence of some faults, probably related to differential compaction above the platform margins, that could originate a small vertical throw of sedimentary horizons especially above the margin neighbourhood. These characteristics could be seen better on some public seismic profiles (an example is reported in Fig. 9).

We applied the Cosine of Instantaneous Phase, which helps in defining the lateral extension of the bright spot (Fig. 5). We can see that toward NW there is a gentle closure (pinch out), while to the SE there is an abrupt closure, with some diffractions.

- "Shadows": along the MS-29 and other public seismic profiles, we recognized an overall attenuation just below the high reflecting top of the Messinian evaporites. Oil and gas reservoirs usually cause a drop-off of high frequency components, generating a low frequency zone (shadow) below the hydrocarbon saturated horizons. For this reason, frequency-related attributes can detect spectral variations due to hydrocarbons. Usually, seismic data show a decrease of high frequency content for late acquisition times, occasionally masked by high frequency noises. Therefore, if we are able to evaluate the

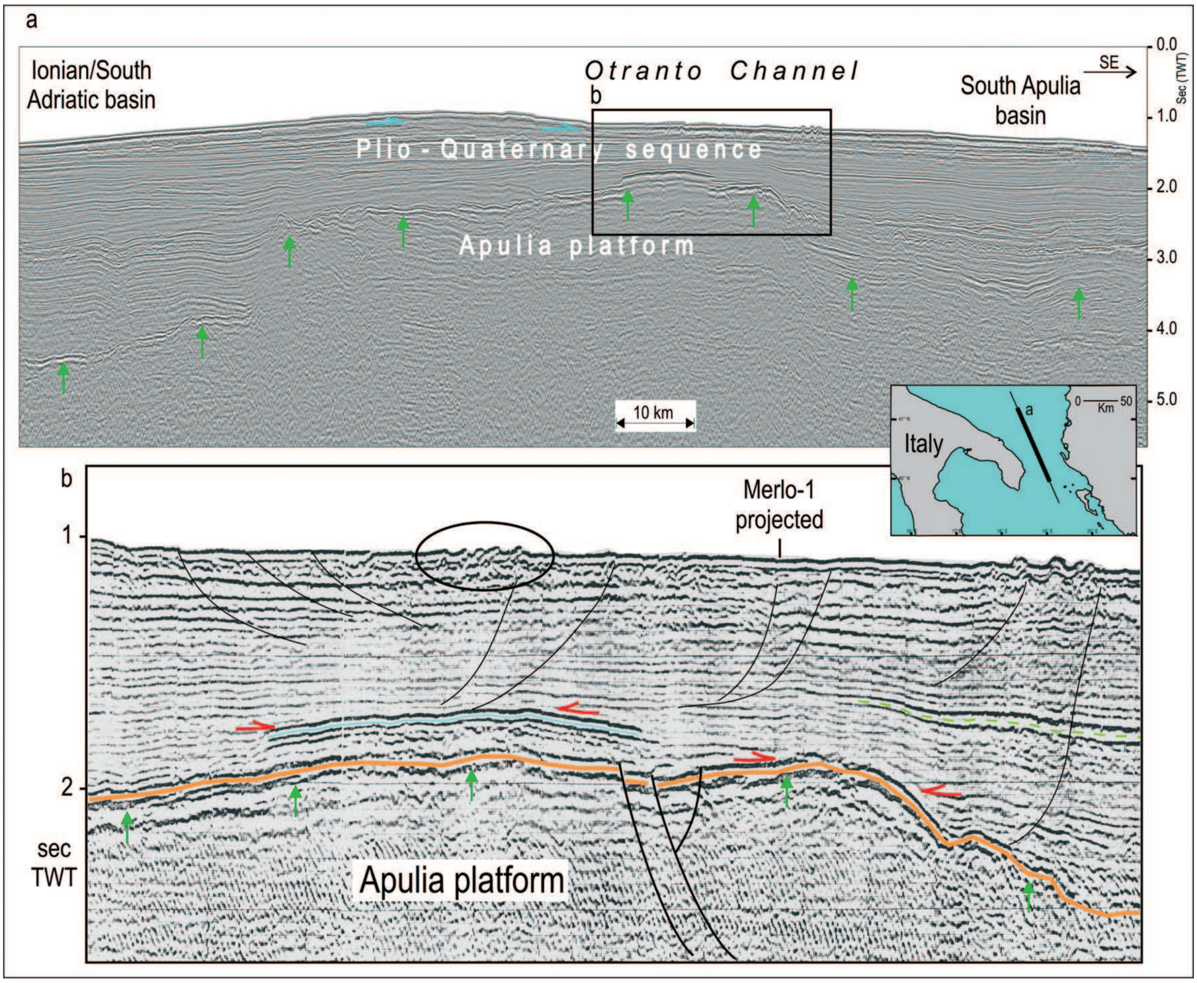

Fig. 2 - Part of the MS-29 seismic profile across the Otranto Channel. The green arrows highlight the top of the carbonate platform. In a) the margin with south Adriatic basin and with south Apulia basin [as defined in Del Ben *et al*. (2010)] are evident respectively to the north and south. Erosion of the recent shallow sequence (toplap pointed out by blue arrows) originated the Otranto Channel on the Apulia platform. The detail of the profile in b) clearly shows the seismic signal associated to the studied "bright spot" (blue line). The red arrows point out the Pliocene horizons onlapping the bright spot or, in the Merlo-1 structure, the top of the Messinian sequence (orange colour). A further possible bright spot has been interpreted (green dashed line) on the right. The small structures of the sea bottom in the circle area was investigated in detail by swath bathymetry and a sub-bottom profiler (see Fig. 8).

frequency variations as a function of recording time and position, we can extract information about the changes of properties of the investigated materials.

Many attributes can be calculated using the Short Time Fourier Transform (also reported as Short Windowed Fourier Transform or Gabor Transform) or via wavelet analysis. Usually wavelet analysis can achieve better time and frequency resolution, but other more sophisticated techniques can be adopted.

The most common spectral related attributes, usually calculated within sliding time windows encompass the following:

a) Instantaneous Frequency is calculated using the Hilbert transform; it is the first derivative of the Instantaneous Phase respect the time. This attribute has been well known in seismic

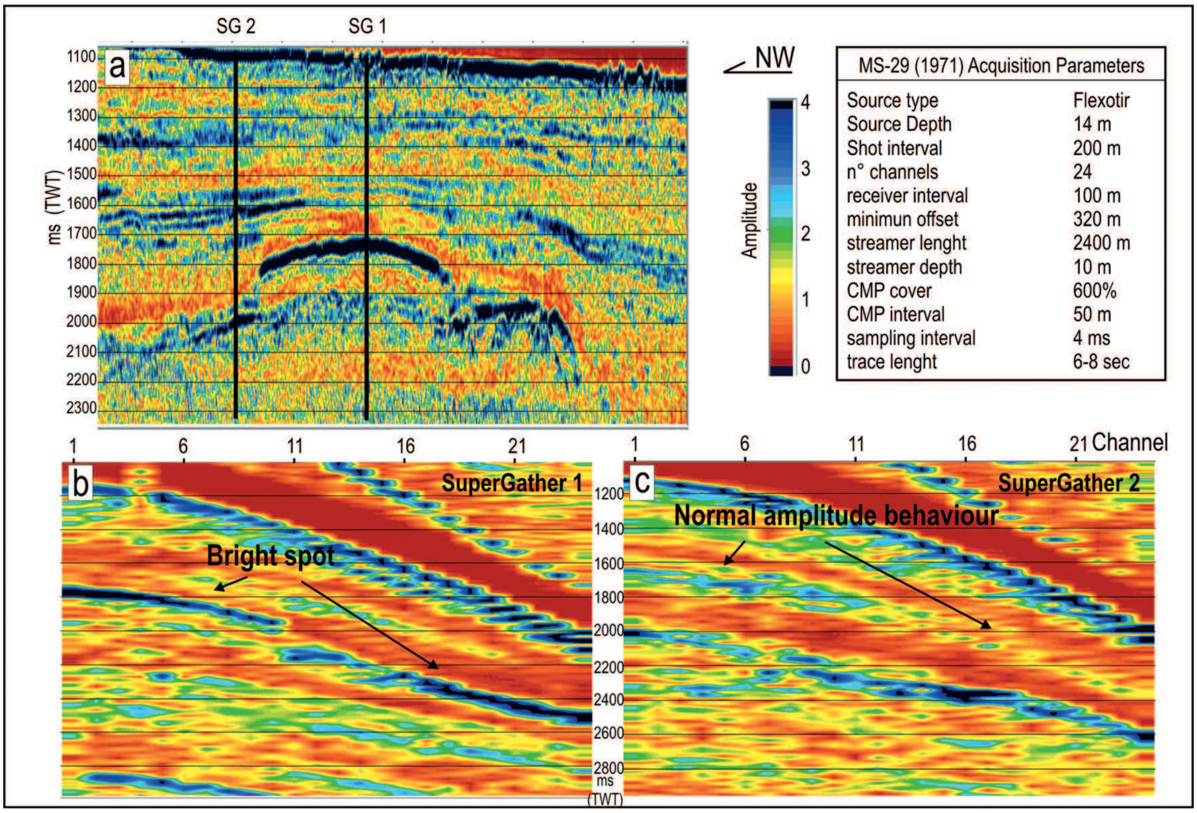

Fig. 3 - a) Reflection strength attribute calculated on stacked MS-29 profile; b) the same attribute applied to a Super Gather centred on the bright spot (SG1 position in a) and c) out from the bright spot reflector (SG2 position). On the bright spot, the amplitude values are relatively high also for far offsets, while, the "normal" behaviour is an amplitude attenuation with offset. The table in the inset summarizes the acquisition parameters of the MS-29 seismic profile.

analysis since the late 1970's and is one of the first adopted for bright spot localization.

b) The Dominant Frequency is the frequency with the highest amplitude within the considered time window.

Fig. 6 shows the Instantaneous Frequency (a) and the Dominant Frequency (b) calculated on profile MS-29. Both attributes show a low frequency zone that extends about 200 ms below the bright spot, with frequency values not exceeding 20 Hz. The attenuated area perhaps reaches a greater depth, but it is crossed by the coherent noise of the sea bottom multiple reflection. According to Anstey (1977) we should infer the presence of a considerable total thickness of the reservoir.

- Diffractions: as argued by Anstey (1977) significant diffractions are not present in the case of a lenticular decreasing thickness of sand, but they are expected in association with thick gas reservoirs and when the trapping mechanism is a fault or the lateral limits are abrupt. Generally all the interpreted profiles appear to be free from relevant diffractions; only locally some diffractions have been recognized, as along the MS-29 profile (Fig. 5). This could be related to the termination of the gas saturated sedimentary sequence by thinning and by its closure in pinch-out between adjacent sealing sequences.

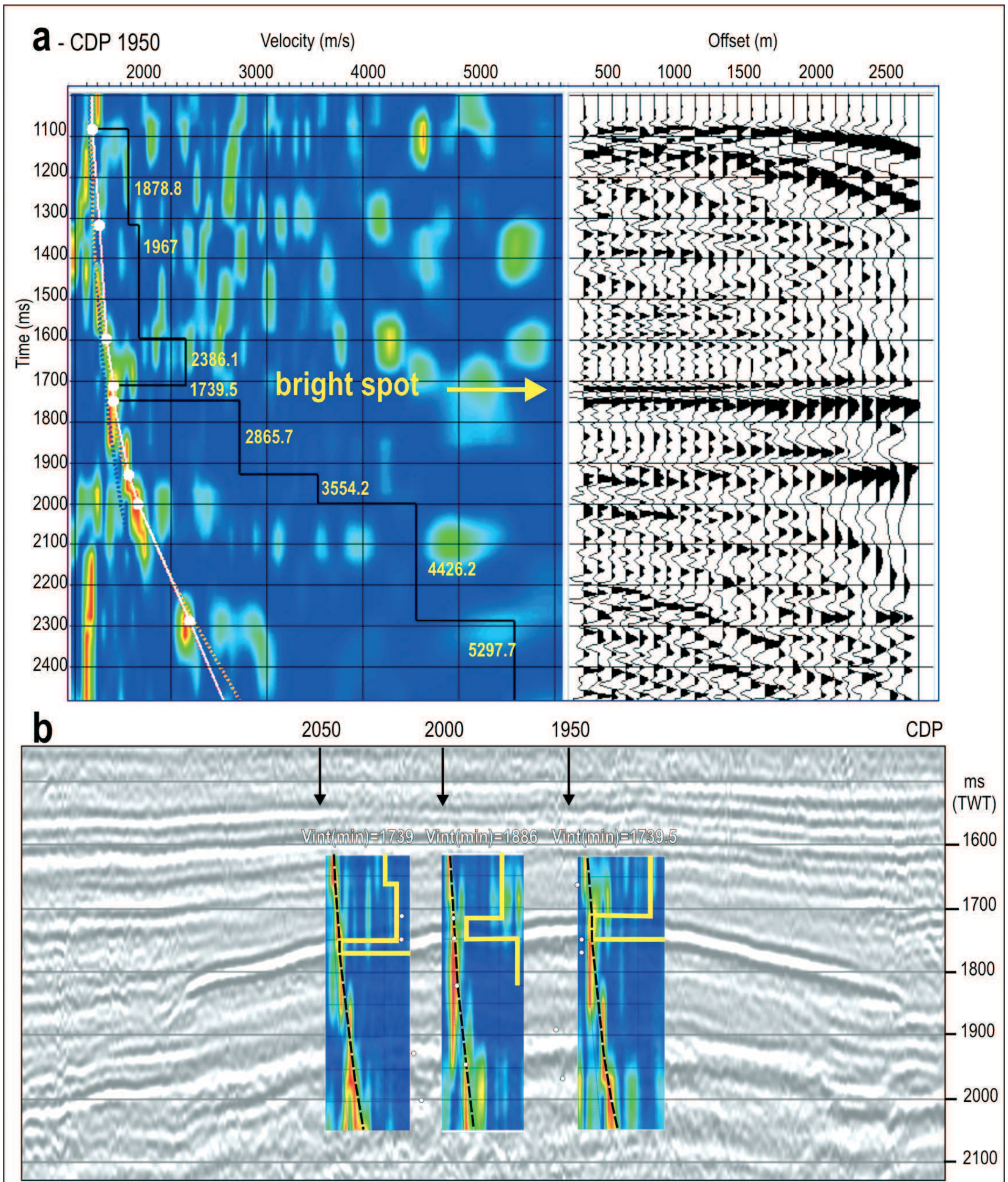

Fig. 4 - a) Velocity analysis of a Super Gather on the bright spot; the black line represents the interval velocity function, while the white one the RMS velocity. b) Three examples of Super Gather coherence spectra calculated for different positions on the bright spot, superimposed on the MS-29 stack section. The velocity inversion can be followed along the entire reflector length with similar values.

- <u>Inter-relation of these criteria:</u> not all the above criteria have been matched in our analysis, but some of them seem to be mutually compatible and possibly related to the presence of a gas reservoir.

Some years after the commercial use of bright-spot technology as a DHI, Ostrander (1984) showed that the presence of gas in sand capped by a shale would cause an amplitude variation with offset in pre-stack seismic data due to the reduced Poisson's ratio. This originated the

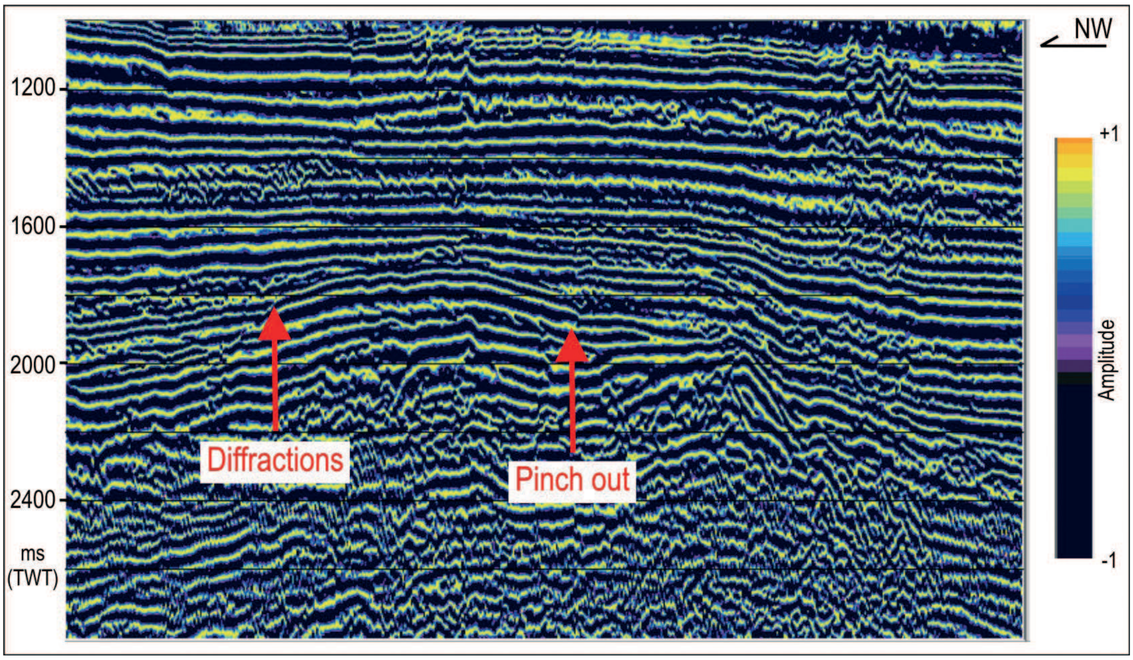

Fig. 5 - Cosine of Instantaneous Phase.

Amplitude Versus Offset (AVO) technology, that is today a very common application for hydrocarbon exploration.

AVO interpretation can be improved crossplotting two AVO attributes called "Intercept" and "Gradient". In absence of hydrocarbon saturated levels, within a fixed temporal window, these crossplotted parameters form a defined “background trend” (Smith and Gidlow, 1987). The deviations from this trend could be a hydrocarbon indicator and as function of the different quadrants where the anomaly is located, 4 classes of gas sand can be recognized (Castagna *et al*., 1998).

We applied AVO on the MS-29 profile and we computed the crossplot inside several different polygons, including and not including the possible bright spot. Fig. 7a shows (in blue) a polygon centred on a portion of the bright spot. The crossplot (Fig. 7b) shows (in blue) the background trend of the strata within the polygon; we enclosed the anomalous points that fall outside the trend, and correspond to green points in the AVO intercept profile. These points are located on the bottom of the bright spot (even evidenced with orange pocking) and inside the anticlinalic structure. The position of these points falls mostly inside class 3, characterized by strong negative normal incidence-reflection coefficient, which becomes more negative with increasing offset (Castagna *et al*., 1998).

The low folding (600% on CMP) of the MS-29 seismic profile does not allow the further implementation of the AVO analysis, which could give a more quantitative and detailed study about the presence of a gas saturated level. Anyway, the graphs obtained are compatible with a gas saturation within the considered sedimentary sequence.

Moreover, some small sea bottom features (extension 100-200 m, height 10-20 m), above the

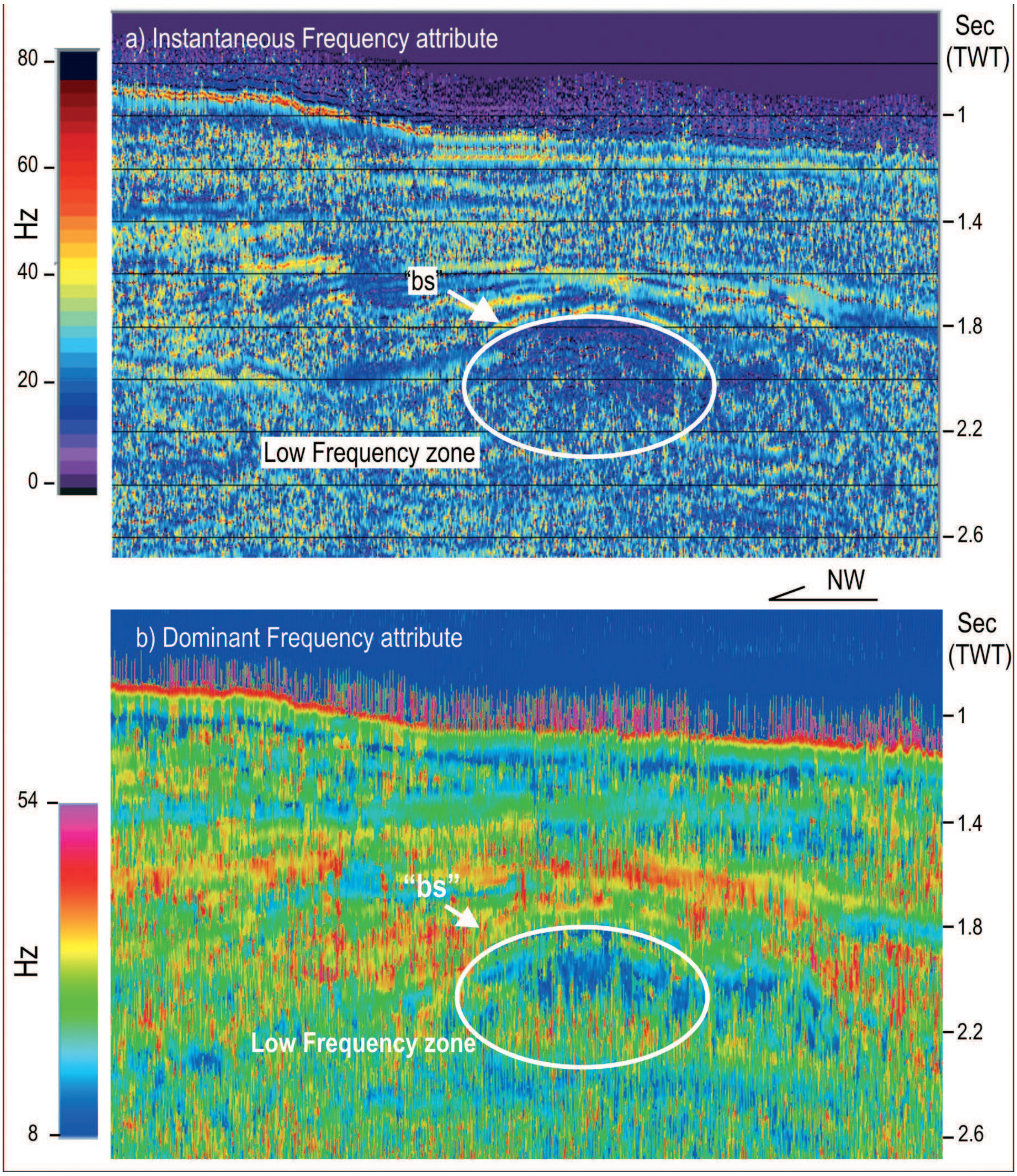

Fig. 6 - Instantaneous Frequency; b) Dominant Frequency calculated on the MS-29 stack section. Both attributes show a low frequency zone just under the bright spot (bs).

interpreted reflector, seem to be compatible with the presence of a gas reservoir in the Plio-Pleistocene sedimentary sequence. These features (Fig. 8), evidenced along the seismic profiles and investigated with sub-bottom profilers by MV OGS-Explora (Geletti, 2008), are probably referable to coral mounds, by analogy with similar features dredged in the central Adriatic by

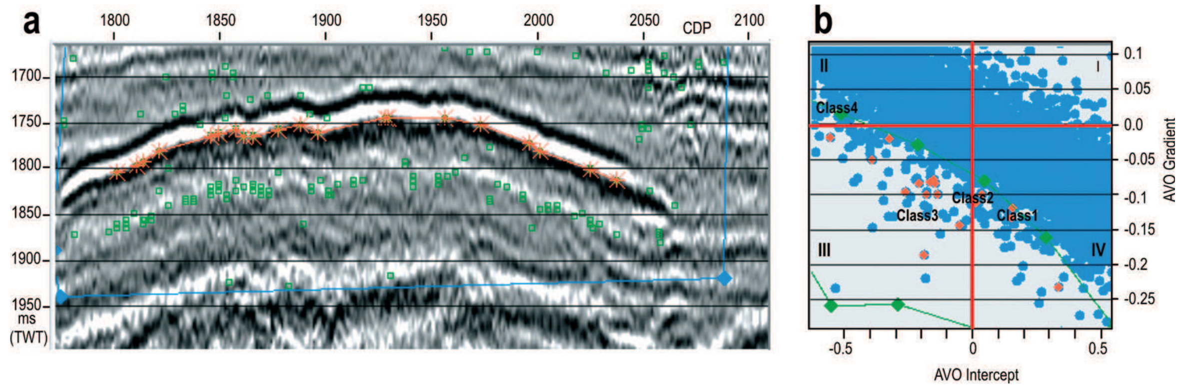

Fig. 7 - a) AVO Intercept attribute and crossplot analysis. b) The picked values related to the bottom of the bright spot reflector fall mostly in gas sand class 3 (Castagna *et al*., 1998).

Taviani (2008) and in the Ionian-Apulia offshore by Fusi *et al*. (2006). Some studies have hypothesized a role of light hydrocarbon seeps that would fuel a microbial ecosystem based on the microbial consumption and oxidation of methane (Hovland *et al*., 1998).

5. Areal extension of the supposed gas reservoir

The good probability of a possible gas reservoir along the MS-29 profile, prompted us to cross and interpret all the available seismic profiles of the area. These are mainly constituted by the public seismic sections of Zones D (down to a sea bottom depth of 200 m) and F (beyond the 200 m to the boundary of the Italian offshore). The Merlo-1 well (Fig. 9) has been used to calibrate

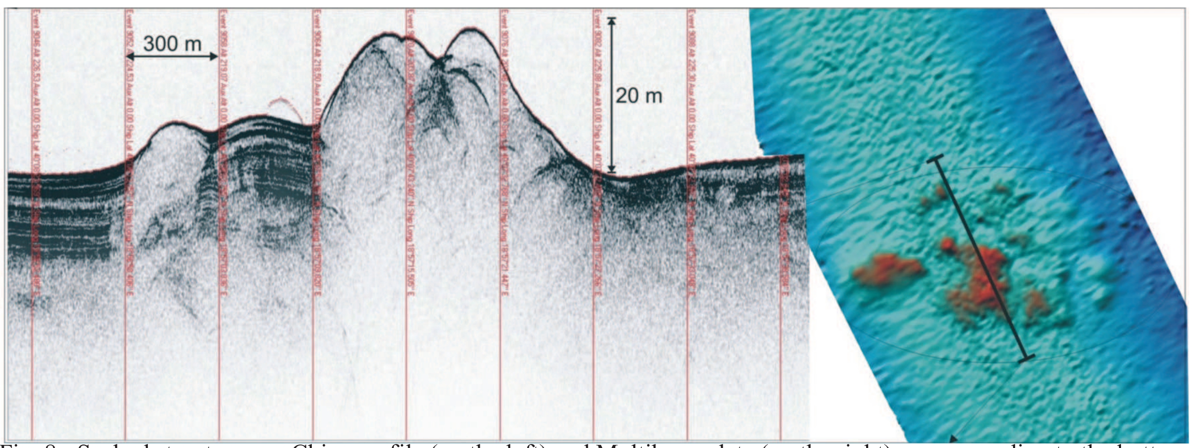

Fig. 8 - Seabed structures on Chirp profile (on the left) and Multibeam data (on the right), corresponding to the bottom features previously highlighted on the MS-29 profile. Their picture has been interpreted as coral carbonate mound, often related to light hydrocarbon in near surface sediments. A dredging carried out by MV OGS-Explora in February 2011, confirmed that these structures represent “Lophelia pertusa coral mounds” (R. Romeo, pers. com.) Location in Fig.1.

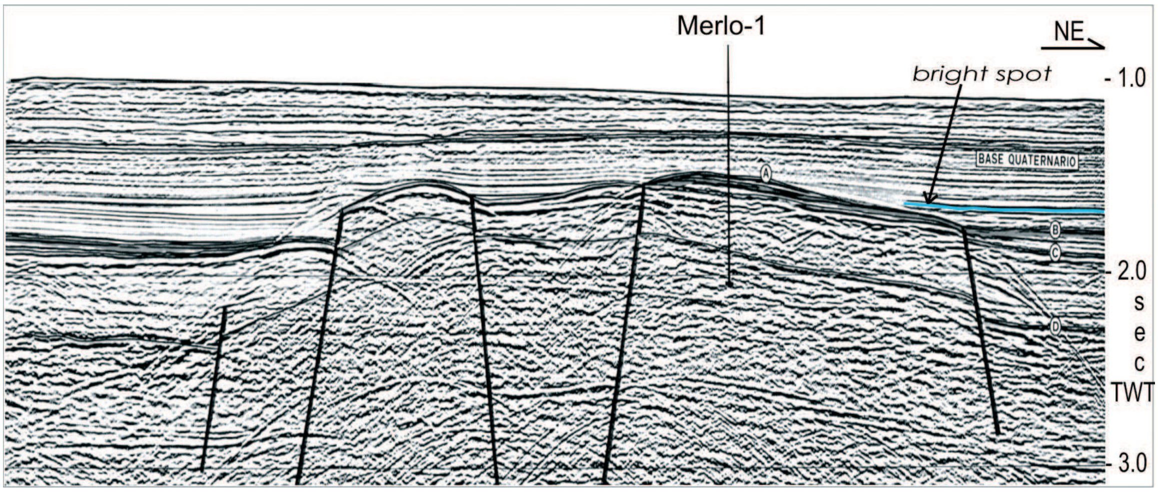

Fig. 9 - Part of the seismic profile F-81-105 crossing the structural high drilled by the Merlo-1 well. On the right, the well-reflecting horizon (blue colour) terminates on the flank of the structure: resolution of the seismic data does not allow us to recognize onlap or pinch-out geometry.

the Cenozoic sedimentary sequence covering the margin units of the Apulia carbonate platform.

The MS-29 (Fig. 2) shows that the carbonate platform is delimited by two margins: the northern margin represents the transition from the platform to the Ionian/south Adriatic basin, subsided since the Liassic. The southern margin represents the transition to a younger basin, the south Apulia basin, described by Del Ben *et al*. (2010), developed in the SE-Salento offshore probably since the Early Cretaceous. The complex trend of this margin depicts a sort of promontory drilled by the Merlo-1 well (Fig. 1). The well-reflecting horizon (bright spot) does not seem to be crossed by the well, due to its closure on the northern flank of the structural high. A low tectonic activity during the Lower Pliocene and a differential compaction between the sediments covering the platform and the basin, would have continued the structural deformation on the platform domain, favouring migration and trapping of gas in folded anticlinalic Pliocene layers.

In Fig. 9, we can see the southern extremity of the bright spot suggesting a closure of the gradually thinner reservoir sequence, probably lying between two impermeable sequences of the Santerno Formation of Pliocene times.

The comparison between MS-29 (Fig. 2) and F-81-105 (Fig. 9) profiles, shows how the Merlo-1 well does not cross the bright spot: the Pliocene reflectors onlap the top of the Miocene sequence on the calibrated structural high, and they describe a very gentle anticline, mainly due to differential compaction. The same situation can be recognized in Fig. 2, in the southern sector, where the Merlo-1 well has been projected. The bright spot, present in the north-western sector, is located above an anticlinalic structure: this structural high involves the top of the Miocene sequence and also the lower Pliocene horizons lying below the bright spot. The anticlinalic shape should be related to the last active phase of the normal faults. Therefore, our interpretation is that the Merlo structure is a sort of promontory of the Apulia platform (see Fig. 1) covered by a mainly onlapping Pliocene sequence. This seismic sequence is sub-horizontal, without any

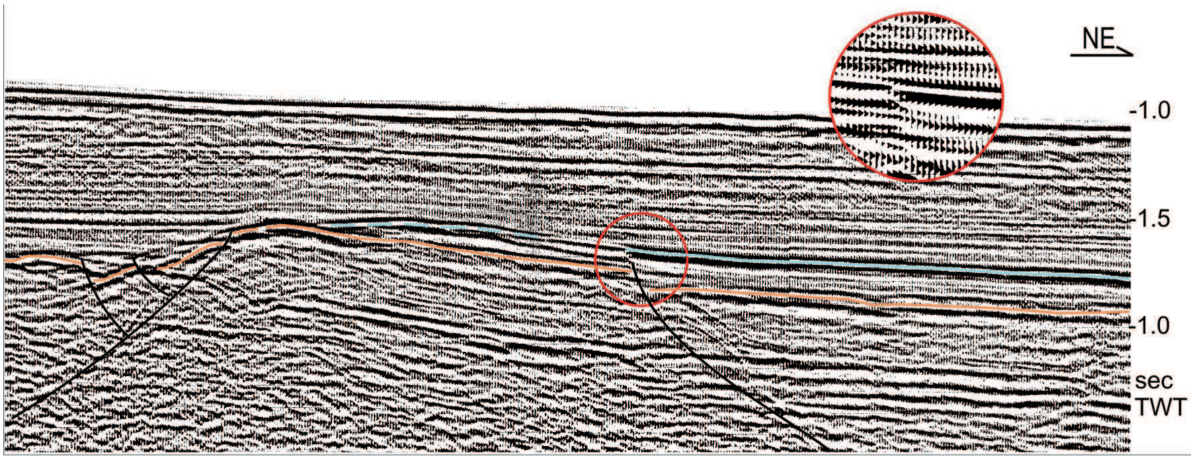

Fig. 10 - Part of the F-75-49 seismic profile. In blue the bright spot; in orange the top of the faulted Messinian unit.

anticlinalic shape favourable to gas accumulation, as occurs immediately to the NW, where the bright spot suggests a reliable indication of gas reservoir.

The same high amplitude reflector, evident along the MS-29 profile, shows a clear southern boundary (Fig. 2): this phase change could also be recognized on the F-49 seismic profile (Fig. 10), also if the presence of post-Messinian normal faults, that eventually interest the analyzed reflector, do not assure this interpretation.

In Fig. 11 terminations of the bright spot are evidenced towards the right side on both seismic sections, where the reservoir ends, on the SW-sector of the Italian offshore: the bright spot lies on the top of a (Lower?) Pliocene sequence weakly fractured by post-Messinian normal faults. In Fig. 11b, these faults seem to determine migration of gas in an upper layer (green colour), that

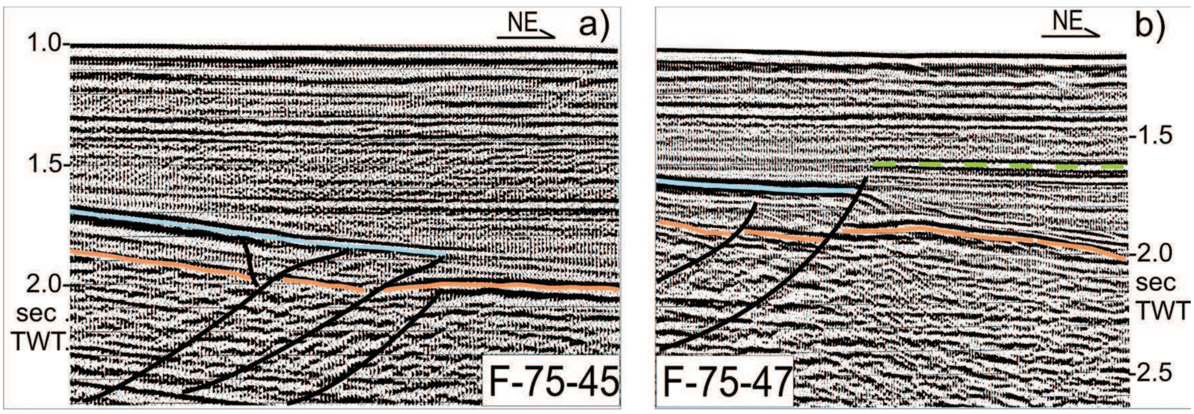

Fig. 11 - Eastern limit of the bright spot (blue colour) along the F-75-45 (a) and the F-75-47 (b) seismic profiles. The Messinian top (orange colour) appears less reflecting below the bright spot, due to the typical energy absorption, on both sections. In b) a shallower well reflecting horizon (green colour) suggests an upward gas migration, favoured by normal faults.

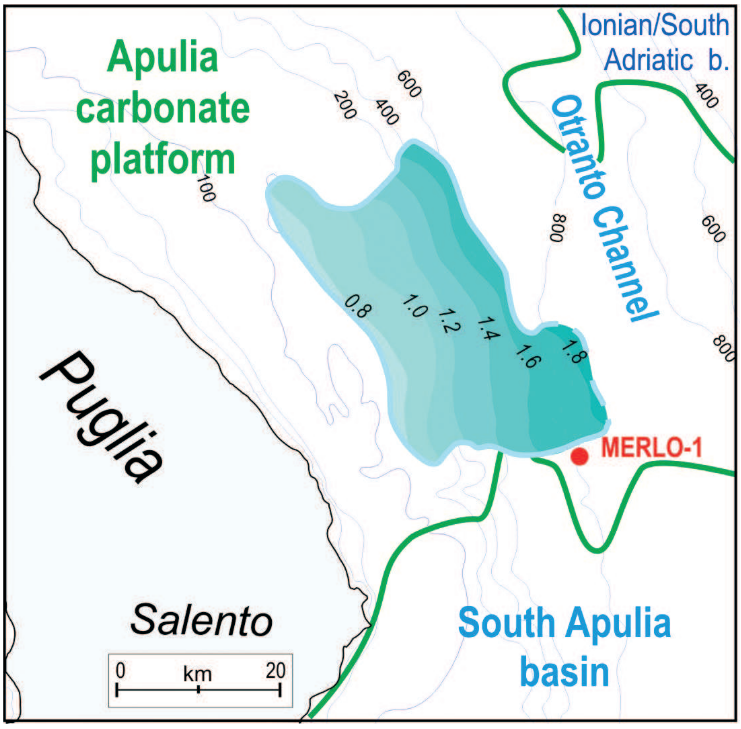

Fig. 12 - Contour map of the studied bright spot. Values are in seconds TWT: 0.8 s (where the water depth is 150 m) correspond to about 750 m from sea level; 1.8 s (where the water depth is 800 m) correspond to about 1500 m. Relation with the Merlo-1 well (dry) and with the relative structure (a sort of "promontory" of the Apulia platform, not covered by high reflecting horizons) is highlighted.

shows, in turn, a high reflectivity: this new shallower bright spot, extending in a NE-direction and not investigated in detail in this paper, is therefore largely southward extending, as also evident along the MS-29 profile (Fig. 2), where it has been interpreted on the right sector, at a depth of about 1.8 s TWT.

Interpretation of all the available seismic profiles allowed us to hypothesize a total extension of the interpreted bright spot (Fig. 12), included between the above depicted boundaries, reaching at least 600 km^2. The time-structural map of this high amplitude reflector shows a contour from 0.7 s TWT in the NW sector (corresponding to about 400 metres below the sea level), deepening towards SE and reaching 1.8 s TWT (about 700 metres below the sea bottom depth of 800 metres). It extends above the Apulia platform that is gradually east-deepening towards the front of the Albanides. This inclination, added to a weak tectonic activity during the Lower Pliocene and to the differential compaction between the platform and the pelagic domains, could have favoured the gas accumulation.

6. Conclusion

The detailed analysis of the MS-29 seismic line and of all other available data allowed us to critically evaluate the hypothesis of the presence of an important gas reservoir in the Pliocene sequence covering the Apulia carbonate platform in the Otranto Channel. The possible alternative causes of amplitude anomalies (volcanic intrusion or ash layer, highly cemented sands, overpressured sands or shales, coal bed) have been considered in order to exclude a false bright spot.

Seismic attribute analysis is one of the most reliable techniques allowing us to consider bright spots as real "Direct Hydrocarbon Indicators". We had at our disposal only one digital, old, low folding (600%) seismic profile (MS-29) which does not provide detailed geometrical parameters of the possible reservoir, as thickness, flatspot, presence of brine-reservoir, so we processed it in very high detail to severely consider our reservoir hypothesis.

The most trustworthy detection is represented by the AVO analysis, that confirms the typical increase of amplitude with offset for incident angles up to 30°. Besides, we know that ambiguities regarding the AVO technique could be caused by different effects due to tuning, lithology, incorrect acquisition, processing, etc., so we have considered them singularly and we believe that these alternative interpretations can be excluded.

In this study, several integrated analyses have been performed to evaluate the possible presence of a gas reservoir and the extension of such a structure. Its interpretation allowed us to reconstruct the contour map of the interpreted bright spot, testifying an area of more than 600 km^2.

The good reliability of evidence of a conspicuous gas saturated sequence anyhow needs to be validated by new, high-folding seismic reflection profiles to obtain a better subsurface imaging and to analyze the AVO, AVA and attribute variations possibly induced by hydrocarbons. In accordance with our future development of these topics, we also intend to use the Merlo-1 well log information to model the seismic parameters on the base of the rock-fluid properties and to improve the imaging of this possible reservoir.

Furthermore, acquisition of new data and the rock physics modeling could also investigate other high reflecting horizons recognized in the Plio-Quaternary sequence of this area.

Aknowledgement. The authors are very grateful to Patrizia Rocchini of ENI and to Erik Ødegaard of STATOIL for their helpful comments. The authors gratefully aknowledge Haliburton through the Landmark academic grant. This work was presented at the 28° GNGTS (Gruppo Nazionale di Geofisica della Terra Solida) Conference, Trieste, 16-19 November 2009.

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