Introduction. The Northern Adriatic sea is characterized by a widespread occurrence of gas in the subsurface, testified by the presence of gas-related seabed and sub-seabed features, and by gas seeps, mostly composed by CH4 (Donda et al., 2015). However, the origin of the gas and its migration paths through the sedimentary column are still not well constrained. Several gas fields have been discovered and exploited off the Venice Lagoon during the 60’s, while no hydrocarbon-related activities are currently underway in the study area. In 2009 and 2014 OGS carried out two seismic surveys in the Gulf of Venice collecting more than 1200 km of multichannel 2D seismic lines, CHIRP sub-bottom profiles and swath morpho-bathymetric data (Fig.1).

These data were acquired with the main aim of constraining the relationship between gas emissions and the regional geological setting of the study area and to characterize the gas-charged fluids occurring within the sedimentary succession. The objective of this work is the quantification of gas content along two perpendicular profiles within the Plio-Quaternary sedimentary succession, through the petrophysical characterization of the sediments using well-log seismic attribute correlation. The proper characterization of the gas occurrence in the study area has direct implications for different points of view: 1. The innovative and multidisciplinary approach used could be applied in other areas characterized by gas-charged fluids in similar geological settings; 2. The comprehensive evaluation of the gas occurrence and its migration throughout the sedimentary succession will help in constraining the role of tectonic features.
identified. Moreover, due to the shallow water conditions of the area, the potential transfer of
gas from sediment to the water column and then into the atmosphere is supposed to be rapid.
Therefore, the importance of understanding the mechanisms of natural gas seepage has direct
climatological implications, since CH$_4$ is the 2nd most significant long lived greenhouse gas.

**Data analysis.** The seismic data analyzed in this work were collected in the Northern Adriatic
Sea within the framework of two projects, i.e., STENAP “Stratigraphic and Tectonic Evolution
of the Northern Adriatic Sea” and GANDI “GAs emissions in the Northern ADriatic Sea”. Two
perpendicular seismic lines, STENAP 08 and GANDI 09, were chosen for the analysis (Fig.1).
All the well log data used in this work come from the ViDEPI database, designed to make all the
documents concerning Italian oil exploration easily accessible. Amongst the 18 composite logs
available in the study area, 5 wells, crossing the selected seismic lines or located nearby, have
been analysed. However, not every well includes all the fundamental logs, so that relationships
between logs had to be evaluated, in order to extrapolate the quantities needed for the analysis.

**Log Processing.** Log data were digitized, edited and resampled to be consistent with the
seismic frequency content. Experimental relationships between each pairs of signals were
investigated via cross-correlation, fit and χ$^2$ tests. The basic idea was to seek for a common
trend in the log properties of each well and of the different wells, which could be representative
of rock formations. This has then been used to find the best empirical relationship between the
available and missing logs. Density profiles were reconstructed for each borehole of interest
with an iterative procedure of comparison between synthetic and real signals. The procedure
was guided by a geological interpretation of the lithostratigraphic column of the boreholes,
and based on the geological information taken from the technical drilling reports. Density profiles
were then used, together with sonic logs, to calculate acoustic impedance at well-location and
to perform acoustic inversion.

**Seismic Data Processing.** A first processing flow has been applied to the two chosen seismic
profiles (STENAP 08 and GANDI 09) to better image the subsurface. Data were strongly
affected by multiples, especially water-bottom reverberations, so that the whole procedure was
focused on removing them. Apart from filtering out low frequency noise, pre-stack processing
consisted in deconvolution in τ-p domain; correction for spherical divergence; a trimmed mean
dip filter (TMDDF); migration and predictive deconvolution. TMDDF removes high amplitude
random noise and locally weak coherent events without eliminating useful information by too
severe lateral filtering. Data were then migrated in time, in common-offset, with a double-square
root operator and of aperture. Velocity fields were built using the sonic log for the shallower
part and through a semblance analysis for the deeper part. In post-stack, a F-X deconvolution
and a time-variant filter were applied. This processing flow resulted in seismic sections where
the geometry of the seismic event has been well displayed, crucial for geological interpretation.

A second processing flow used specific algorithms to improve the S/N ratio and to remove
multiples without affecting the relative amplitude information. This implies that specific
processes, such as deconvolution or migration, which are commonly used and are very effective
to enhance data quality, were not applied because influencing the original amplitude of the
signal. Instead, the focus of the ‘true amplitude’ flow is the surface-related multiple elimination
(SRME), an adaptive amplitude-preserving algorithm which does not assume any model of
the subsurface nor source signature. The resulted processed lines are the ones used in the
correlation, inversion and gas content quantification.

**Post-stack stratigraphic inversion.** Stratigraphic acoustic inversion combines seismic
and log data to produce P-impedance (IP) sections. IP are crucial in constraining every kind of
reservoir model and they are used in this work as input data in the porosity estimation with
EMT (Effective Medium Theory). The coupling between data acquired at different scales of
resolution is very powerful because it gives back a calibrated information on a broad-band
frequency. The inversion performed here is based on a geological ’a priori’ model, which reduces
the space of solutions. The whole procedure can be summarized in three steps: well-seismic
calibration, creation of a geological model and inversion. Well-seismic calibration consists in finding the optimal wavelet and well-position for every seismic section. A preliminary zero-phase wavelet is extracted from the seismic. Then, logs are used to apply a delay, a dephasing and a normalization coefficient to this wavelet. Optimal wavelet is the one which maximises the correlation between the synthetic trace at well-location and the observed ones. The geological model is built using some key horizons picked in the seismic to define the main geological units. A depositional mode is assigned to each unit. This model constrains the inversion and provides a basic, low-frequency, structure for the parameters to be inverted.

**Porosity estimation through EMT.** The Effective Medium Theory (EMT) relies on a Representative Elementary Volume (REV), i.e. the smallest volume over which a property is considered as a representative value for the whole material. The EMT model used in this work is an homogenization approach based on Eshelby’s inclusion theory (Adelinet and Le Ravalec, 2015). A homogenized Eshelby’s model considers a medium composed by a matrix and a given amount of inclusions. Evaluating the elastic properties of this medium is evaluating the macroscopic elasticity at the REV scale. Using sonic, density and impedance logs (sonic is measured, density is estimated and impedance is calculated) five facies were modeled. These facies represent the main lithostratigraphic units recognizable in the wells, they have been interpreted integrating all the information reported in reports and analyzing all the available logs (not only sonic log but also resistivity, SP, γ-ray logs). Every modelled facies consisted of a solid matrix and a porous part. A mineralogic composition was supposed for the solid matrix and the correspondent elastic moduli (Bulk modulus and shear modulus) were calculated. For every facies in every well, ellipsoidal pores with a constant aspect ratio were considered and a mixed-fluid, totally saturating the pores, was assigned. Local information about gas content comes from well reports. From these facies distribution, IP logs were inverted into porosity. Two different inversions were performed, the first one assuming a fully water saturated medium and the second one considering a mixed-fluid. The accuracy of the minimization process was checked evaluating the minimum value reached by an objective function.

**Correlation with multi-attributes analysis.** This technique allows prediction of petrophysical parameters along seismic lines, starting from well log information and using a wide family of seismic-derived attributes as a guide. The algorithm combines attributes with the target log through a generalised multiple linear regression (Coren et al., 2001). At each time sample, the target property is modelled as a linear combination of several attributes and the related eigenvalue equation is solved by least-square minimisation of the total prediction error (RMS between the actual value and the predicted value). This process is repeated iteratively for all wells to optimise the order of polynomial and the number of attributes to consider. The result of the training is then applied to the seismic section. When the validation is completed, prediction between wells along the seismic profile can be performed. In this work, multi-attribute analysis was performed to predict 2D panels of P-velocity, resistivity and porosity, using the available sonic and resistivity logs at wells, and the calculated porosity pseudo-log estimated through EMT. Resistivity was estimated in two way: excluding or including frequency-related attributes, i.e. the ones considered more sensible to gas presence.

**Gas content quantification.** Gas content was quantified with Archie’s second law, using resistivity and porosity obtained by multi-attributes analysis. The resistivity section estimated without the frequency-related attributes would represent the background resistivity, i.e. water-saturated sediments. The resistivity section estimated including the frequency-related attributes would represent the total resistivity, i.e. partially water saturated, gas bearing, sediments. Gas saturation can be derived from these two resistivities, assigning a reasonable value to the saturation exponent $n$.

The application of different approaches to predict the petrophysical properties along seismic profiles yields some important results in the studied case.

The IP sections represent the lateral and in-depth heterogeneities of the lithological
formations showing a good continuity only at the main lithological boundaries (i.e. carbonates/marls, marls/sand and clays), which correspond also to the main unconformities. Porosity sections do not show any relevant characteristics in term of anomaly, being not representative for the identification of gas. Results obtained by applying the multi-attribute analysis to predict P-velocity and resistivity panels demonstrated that only resistivity anomalies can be considered as an indicator of gas within sediments. Fig. 2 shows gas concentration on the seismic line STENAP 08. The first 2500 CDPs appear to be characterized by a sub-horizontal gas distribution from the surface down to 1.2 s, while the rest of the line shows local increases in gas concentration along vertical paths. The most evident vertical path matches with a velocity pull-down, located in proximity of an abandoned gas field. Some of the bright spots recognizable in the seismic profile are not associated to high gas concentration. This is because porosity estimation fails in a few isolated points, leading to exclude these points from the quantification. Gas can reach considerable values of concentration and it is very difficult to give an estimate of related errors (especially in the shallowest part, where seismic is very noisy). However, relative variations show a specific distribution that can be justified through the geology of the area. The occurrence and distribution of gas within the sedimentary succession, in fact, reflects the stratigraphic setting, being characterized by the presence of thick sandy and clayey turbidite layers, permeable for gas-charged fluid accumulation. Gas appears to be hosted at various levels within the Plio-Quaternary succession and to migrate upward through high-permeability paths and, in places, through sub-vertical faults. Only part of it would reach the surface and partially contribute to gas seepages (Donda et al., under review). Further studies will be assessed in better understanding the gas dynamics in the subsurface, especially in relation with the present tectonic activity and past fluid industrial extraction.

References