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First results of the SEISBIT® 3D RVSP project

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Abstract - In the frame of the SEISBIT® 3D RVSP project, a 3D drill-bit Reverse VSP was acquired in Sicily. The aim of the project is to obtain detailed information in the well area by using the working drill-bit source, and to demonstrate the reliability of the 3D seismic-while-drilling method in an onshore environment. A saw-toothed seismic layout was used to monitor, while-drilling, a vertical well run. Walkaway VSP and multi-offset CDP mapping were processed in the field to predict geological interfaces ahead of the bit and to obtain a reservoir 3D image.

1. Introduction

The signal generated by the drill-bit during drilling is used as a downhole seismic source (Rector and Marion, 1991). This signal can be utilized for check shot analysis, to calibrate well logs, and for predicting ahead of the bit (Miranda et al., 1996). The drill-bit noise is recorded by multichannel lines deployed on the surface and by reference sensors (pilots) at the rig.

By crosscorrelating the pilot signal and geophone data, it is possible to reinforce the coherent signal. The other main steps of the processing sequence are the pilot deconvolution and the correction of the absolute seismic time by applying the drill-string travel time. The continuous drill-bit monitoring by multi-channel seismic lines produces reverse Vertical Seismic Profiles (VSPs) useful to multicoverage processing. Seismic-while-drilling (SWD) has several advantages over conventional VSP: geophysical information is available while drilling is in progress, no rig-time is lost, and interference with drilling operations is limited to the installation of pilot sensors on the rig.

Onshore SWD acquisitions utilize 2D seismic lines deployed in correspondence with the principal geological structures to be investigated. However, if the target is located in complex geological features (e.g., overthrust, salt diapir, etc.) or for a better reservoir geometry characterisation, a 3D approach is necessary.

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While 3D VSP surveys are frequently acquired offshore, this technique cannot be performed easily onshore. The difficulty to locate a lot of shot points on the surface and the limited number of receivers in the well are the principal limitations of the traditional 3D onshore VSP. On the contrary, the while-drilling 3D Reverse VSP (RVSP) may have a less dense distribution of the receiver points on the surface, and has more source locations (i.e., bit levels) in the well. Fig. 1 shows an acquisition layout comparison between conventional and reverse 3D VSP.

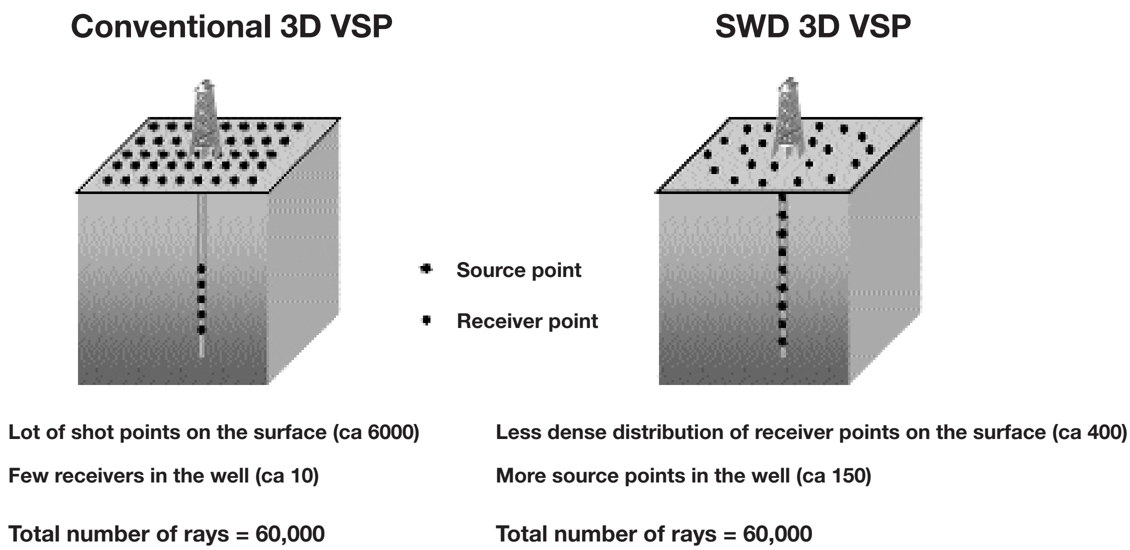

Fig. 1 - 3D VSP acquisition layout comparison.

The aim of the European Community project entitled "SEISBIT® 3D RVSP: while drilling seismic imaging and areal velocity investigation by using the drill bit signal" is to demonstrate the applicability of 3D drill-bit seismic-while-drilling technique onshore. This application is based on the innovative 3D while-drilling acquisition system (Comelli et al., 2000) developed by OGS, ENI-Agip and ProSol Technology starting from the 2D drill-bit seismic technology realised during previous projects partially supported by the European Community. The goal of the project is to map, while drilling, the velocity information in the area surrounding the well, to obtain seismic imaging, and, in general, to increase the availability of geophysical information useful for exploration. In the frame of this project an acquisition was performed during the drilling of a vertical well located in Sicily. Several drill-bit depth levels were recorded by more than 400 surface channels. This acquisition geometry allowed us to obtain a dataset suitable for 3D mapping of the reservoir and overburden.

2. Geological setting and acquisition planning

Careful design of the appropriate layout geometry is important for acquiring good quality data, particularly in 3D acquisition, where a large number of channels, and, therefore, a high cost for the survey are involved. A theoretical analysis of the acquisition layout for a 3D SWD was performed by Bertelli et al. (1998). A circular layout is the most appropriate geometry for imaging the formations surrounding a vertical well. However, since for such a constant offset layout the shot-gather records have different arrivals with equal moveout, multichannel wave separation techniques – such as median filter and f-k – are not effective in the azimuth-time domain. To separate signal and noise in this domain, a saw-toothed disposition of receivers in the circular lines was designed (Fig. 2).

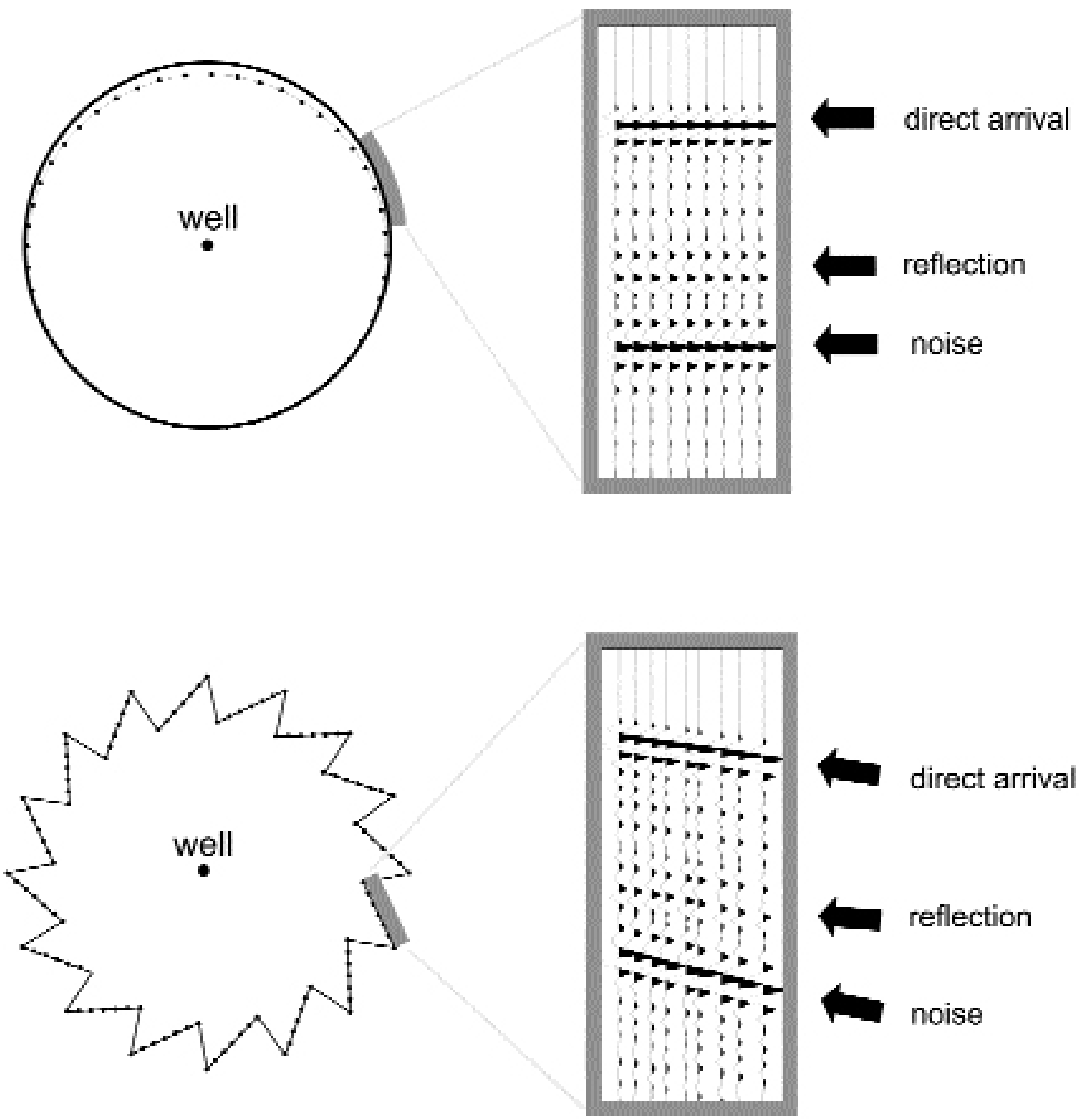

Fig. 2 - Comparison between circular and saw-toothed geometry. In a common-shot-gather recorded by circular layout (i.e., constant offset), different arrivals show equal moveouts. This characteristic limits the applicability of signal – to – noise separation techniques in the azimuth domain as well as the interpretation of the arrivals. Data acquired by saw-toothed layout show arrivals with different apparent velocities and multitrace such filtering as f-k and median filters are applicable.

An onshore 3D drill-bit reverse VSP was acquired for the purposes of the project in the summer of 2000. The vertical well is sited in south-eastern Sicily on the Ibleo-Maltese plateau and runs across a complete stratigraphic sequence reaching the Upper Triassic. Fig. 3 shows the estimated lithostratigraphic column in the well area. Triassic-Early Jurassic tectonic phase faulted Mesozoic carbonatic platform and in the following period a subsidence phase determined the deposit of Streppenosa clay and the other basinal formation facies.

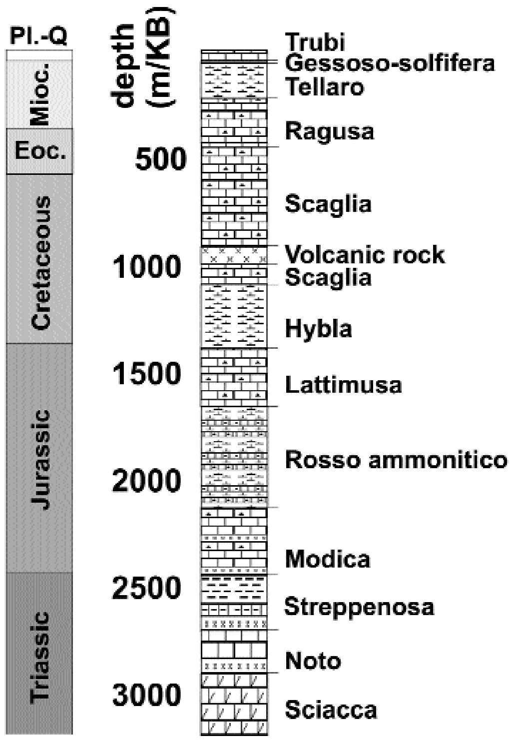

Fig. 3 - Estimated geological sequence of the well area.

In the acquisition planning, a 3D geological model was built starting from reflection seismic data and log information from two wells, drilled near the well site. Before the seismic layout deployment, an elastic 3D seismic wave modelling (Carcione, 1999) was utilized to simulate 20 common-shot-gathers to generate a 3D RVSP dataset suitable for processing tests and for evaluating signal and noise interference at different drill-bit depths (Petronio et al., 2001). The availability of this information before drilling, together with evaluation of the site conditions, allowed us to optimise the acquisition geometry.

3. Acquisition

Acquisition was carried out by laying out four radial (two diametrical) seismic lines, in correspondence to the surface reflection seismic lines acquired before drilling the well.

These directions are respectively parallel and orthogonal in respect of the principal tecto-

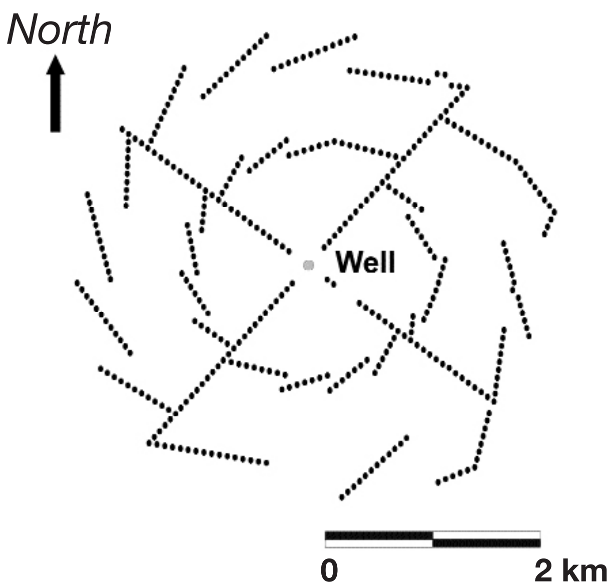

Fig. 4 - Seismic layout adopted for the experiment. Irregular disposition of the receivers in the SE sector are due to the presence of a tilled area and greenhouses.

nic alignment of the carbonate platform. Two circles were connected to the radial lines. Fig. 4 shows the map of the seismic layout adopted. On the base of the synthetic data analysis, we used the irregular (saw-toothed shaped with a variation of radial offset of about 200 m in the external and about 100 m in the internal saw-toothed line) circular disposition of receivers to discriminate the signal and noise arrivals in the azimuth domain. The internal saw-toothed seismic line has a radius of approximately 1100 m, while the external one about 2200 m. The trace interval of the circular lines (75 m) was calculated to preserve frequencies less than 80 Hz from being aliased, by considering a diffraction point located at a minimum depth, 1500 m and 400 m away from the well. Linear receiver patterns with variable lengths at different offsets were used.

Table 1 - Recording parameters utilized in the 3D SWD test.

Acquisition parameters	**Description**
Seismic layout	36 km of seismic cables 426 channels: - 398 vertical component (string of 24 10 Hz-geophones with different linear pattern [75 - 38- 30 m] deployed along the radial direction - 16 horizontal component (radial and transverse direction) - 12 pilot sensors
Trace interval	75 m
Levels acquired	166 drill-bit depths
Interval depth-level	10-20 m
Sampling rate	2 ms
Record length	45 s
Acquisition time	2 months
Amount of data	159 Gbyte of raw data 10 Gbyte of pre-processed data

The SWD monitoring started at a depth of 428 m and was completed at a depth of 3060 m, after two months of acquisition. With respect to conventional 2D SEISBIT® acquisitions, this survey required many more efforts for the maintenance of more than 400 channels spread along several seismic lines with an area coverage of about 15 km^2.

The configuration with two circles was used from a 428 m to a 2700 m drilling depth. Below this depth, the configuration of the seismic lines was partially modified due to the impossibility of approaching the areas involved in seasonal harvesting work. A modified and reduced configuration was studied to maintain the continuity of the radial lines and a consistent coverage of the 3D acquisition in the different quadrants of the investigated area.

The well was mainly drilled by using roller cone bits and a downhole motor and, after 2700 m, only rotary drilling. A short interval (from 2101 m to 2395 m) was drilled by using a polycrystalline diamond compact (PDC) bit. During the survey, 166 drill-bit depth levels were acquired. The total SWD raw data set, all re-processable in the field with on-line access, consists of about 159 Gbytes. The pre-processed RVSP data (cross-correlation and stack) correspond to about 10 Gbytes. The acquisition parameters are displayed in Table 1. During the acquisition an instrumented down-hole tool was also experimented to record a pilot signal near the bit.

4. Data processing and SWD results

The quality control was performed while drilling by seismic analysts in the field. In general, a good signal – to – noise ratio was obtained also due to the favourable geological condition of the area characterised by moderate tectonics and hard rock (marls and limestones). The direct arrival of shallow and deep data, according to the radiation pattern of the drill-bit source, were detectable in the radial and in the saw-toothed seismic lines. Figs. 5 and 6 show examples of

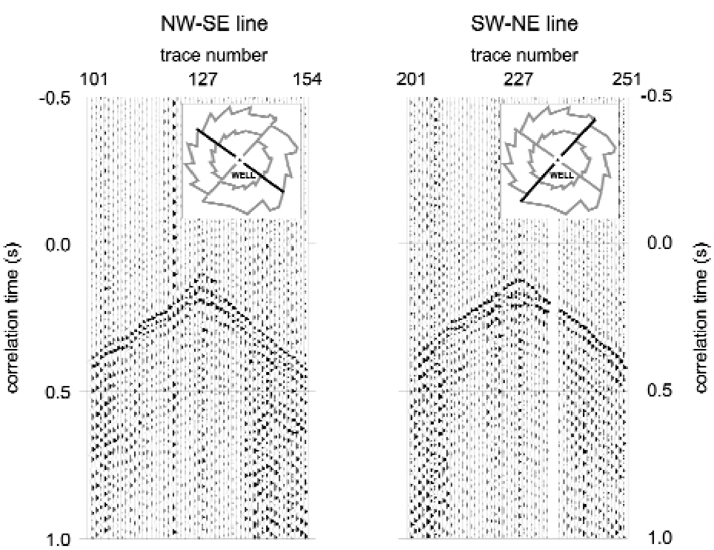

Fig. 5 - Common-shot-gather (2081 m/Kb) acquired by NW-SE and SW-NE lines. Drill-bit signal is clearly detectable along the lines. At near-offset, the drill-bit arrival is anticipated by head wave.

the data acquired by the seismic layout at a 2080 m drill-bit depth with reference to the kelly bushing (Kb) corresponding to drill floor. Near-offset VSPs have been used to locate the bit on seismic sections, to build up the velocity curve while drilling (Fig. 7) and to calibrate the intermediate run of the sonic log.

In correspondence with stronger seismic impedance contrast, reflection can be detected directly on the raw data. Fig. 8 shows a reflection coming from the interface between the basinal facies of the Scaglia and Hybla formation. During the survey, selected RVSPs were processed to predict the formations ahead of the bit.

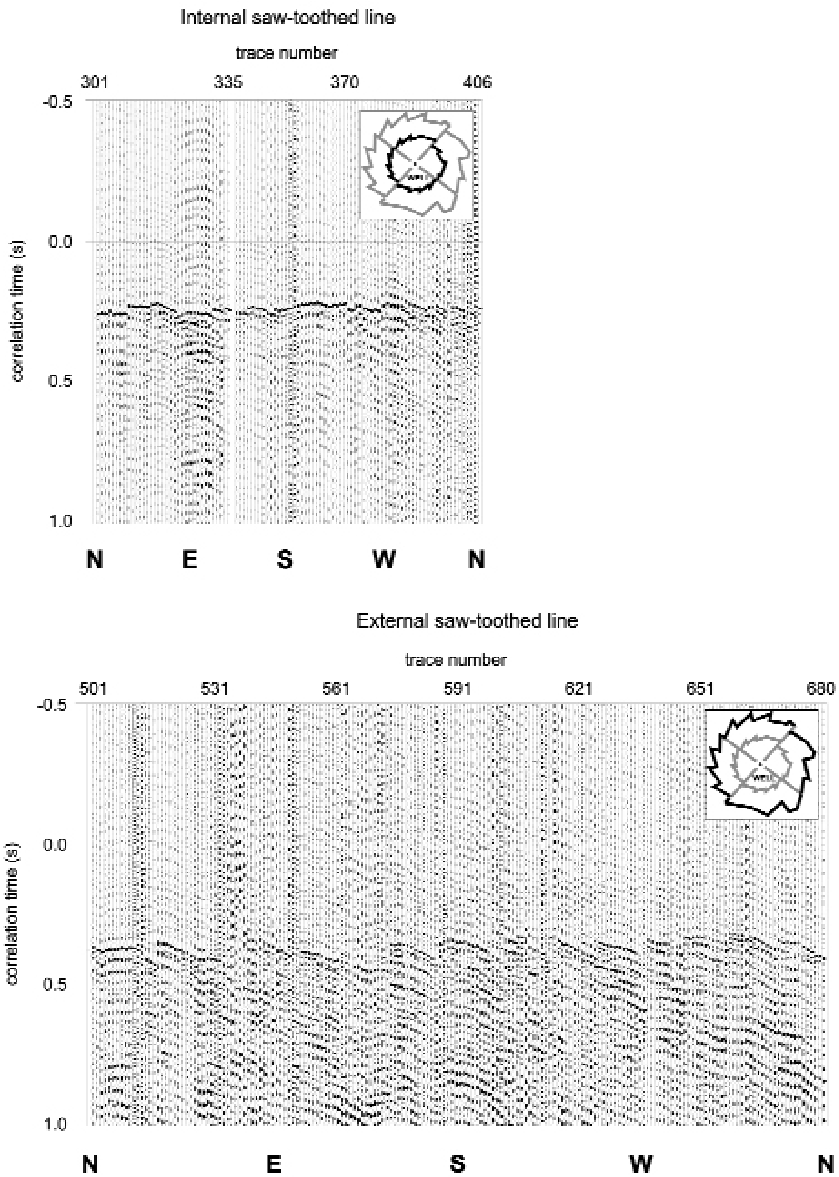

Fig. 6 - Common-shot-gather (2081 m/Kb) acquired by internal and external saw-toothed lines. Drill-bit direct arrival is recognizable at about 0.250 s correlation time in the internal and at about 0.400 s in the external saw-toothed line, respectively.

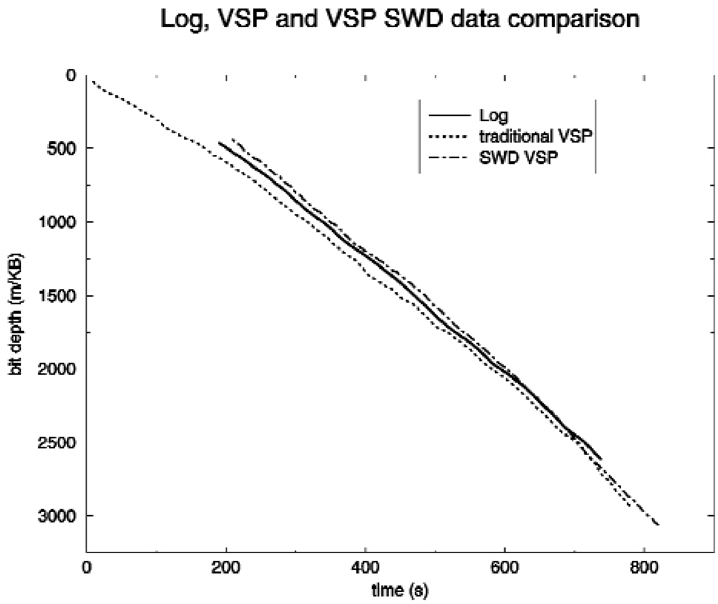

Fig. 7 - Comparison of time-depth curve obtained by acoustic log, traditional near-offset (74 m) VSP and near-offset (225 m) SWD RVSP. The VSP times are verticalised.

The identification of direct arrivals to perform the picking is a basic step for VSP processing. When coherent noises, like stationary noise and head waves, mask or interfere with the signal, the direct arrival detection can be difficult. The availability of an accurate 3D model has provided good quality synthetic data used to guide the analysts in the wavefield

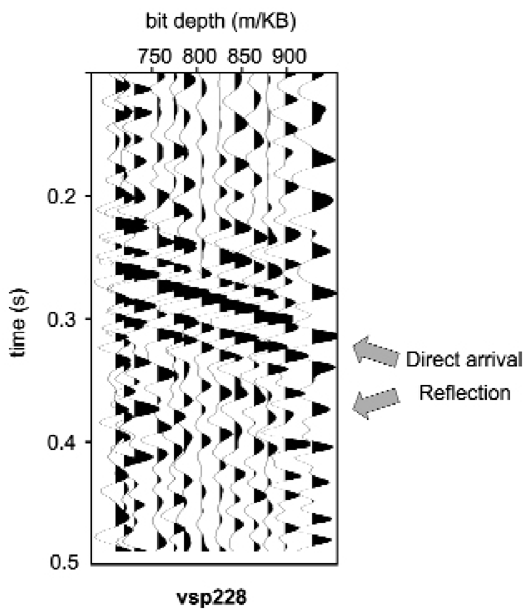

Fig. 8 - Near-offset SWD VSP (225 m) shows a strong reflection coming from the interface between the Scaglia and Hybla formations. Data are filtered with a band-pass 24-70 Hz. In this case the prediction was performed, directly on the raw data, about 130 m above the geological interface.

interpretation and picking (Fig. 9).

In the first step of the SWD elaboration, we process near-offset RVSPs, using traces of the 4 radial seismic lines for quality control and prediction of shallow reflections. Table 2 reports the sequence used for the RVSP processing. Fig. 10 shows an example of the data processed for the upgoing-wavefield extraction.

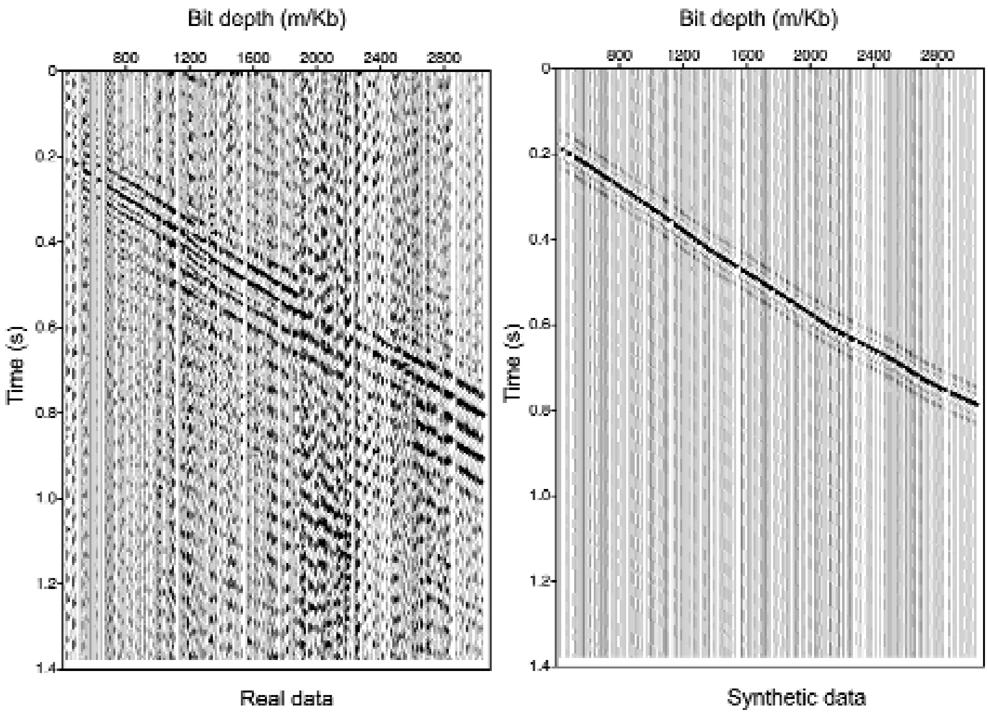

Fig. 9 - Common-receiver-gather (125 m offset): real and synthetic data comparison. In presence of coherent noises, synthetic data are a useful tool for the in-field first-arrival picking and interpretative processing.

During the SWD survey it was possible to identify reflections from interfaces hundreds of meters ahead of the bit. Both tops of the Upper Cretaceous volcanic deposit (970 m/Kb) and of the Hybla formation (1136 m/Kb) were predicted.

The next step in the SWD data elaboration was to obtain pseudo-seismic sections along the radial lines by VSP CDP transformation (Dillon and Thomson, 1984). These data were used

Table 2 - In-field RVSP processing sequence.

Trace editing
BPF 13/16/70/90 Hz
First arrival picking
NO Time Amplitude Recovery
Normalisation on first arrival
Median filtering 9 levels and BPF 13/16/70/90
Wave-shaping decon. only (no predictive decon.)
Static corrections (field static)

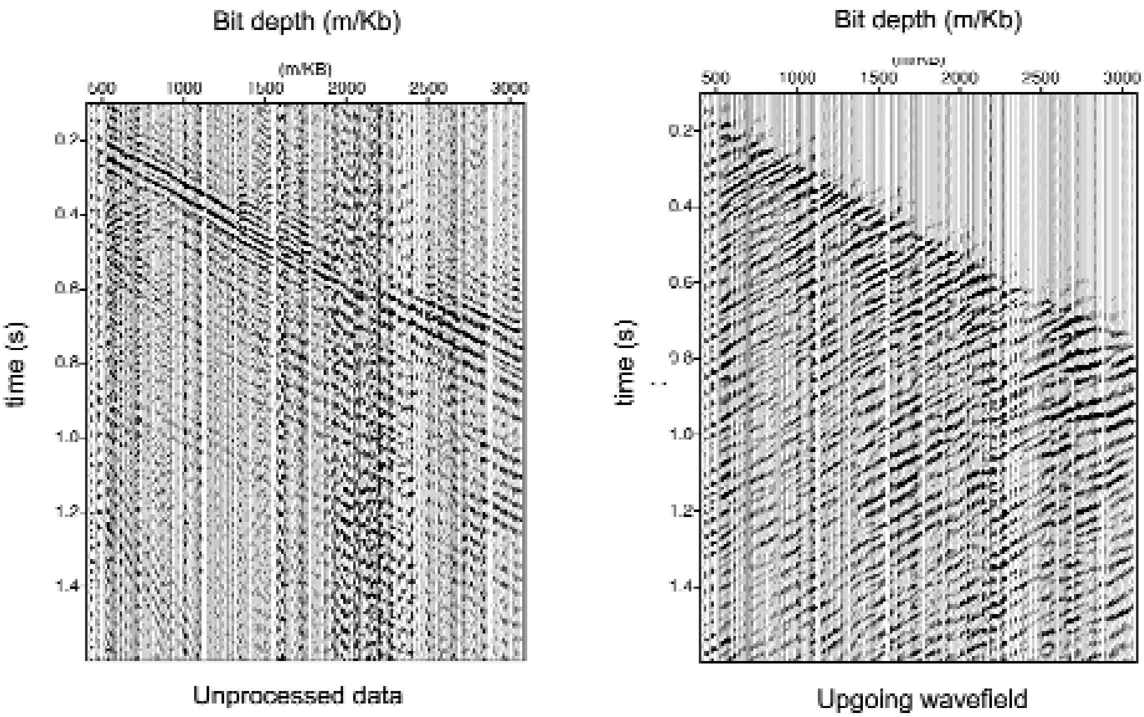

Fig. 10 - Common-receiver-gather (375 m offset) before and after the processing to extract the upgoing wavefield. A bandpass filter 19-60 Hz is applied.

to predict deep reflections and its lateral extension, and to improve, while-drilling, the seismic image in correspondence to the surface seismic lines. In Fig. 11, the 2D VSP CDP transform along the NE-SW direction is tied with the surface seismic data.

5. Conclusions

The survey performed in the frame of the SEISBIT® 3D RVSP project was a first demonstration of 3D SWD technology in onshore domain. This test required the development of an innovative while-drilling acquisition system to manage the large number of channels utilized for a 3D survey. Before the seismic layout deployment, an elastic 3D seismic wave modelling was utilised to optimise the acquisition geometry. A seismic layout, with more than 400 channels deployed along 4 radial and 2 saw-toothed circular lines, was adopted for monitoring the drilling of a vertical well located in Sicily.

SWD data have been utilized to locate the bit on seismic sections, to build up the velocity curve and to calibrate the intermediate run of the sonic log. RVSP and RVSP CDP transform were processed in the field to predict geological interfaces ahead of the drill-bit. In-field data analysis allowed us to obtain while-drilling velocity and seismic images along different directions around the well area. These preliminary results will be used to update the velocity model for subsequent 3D imaging processing.

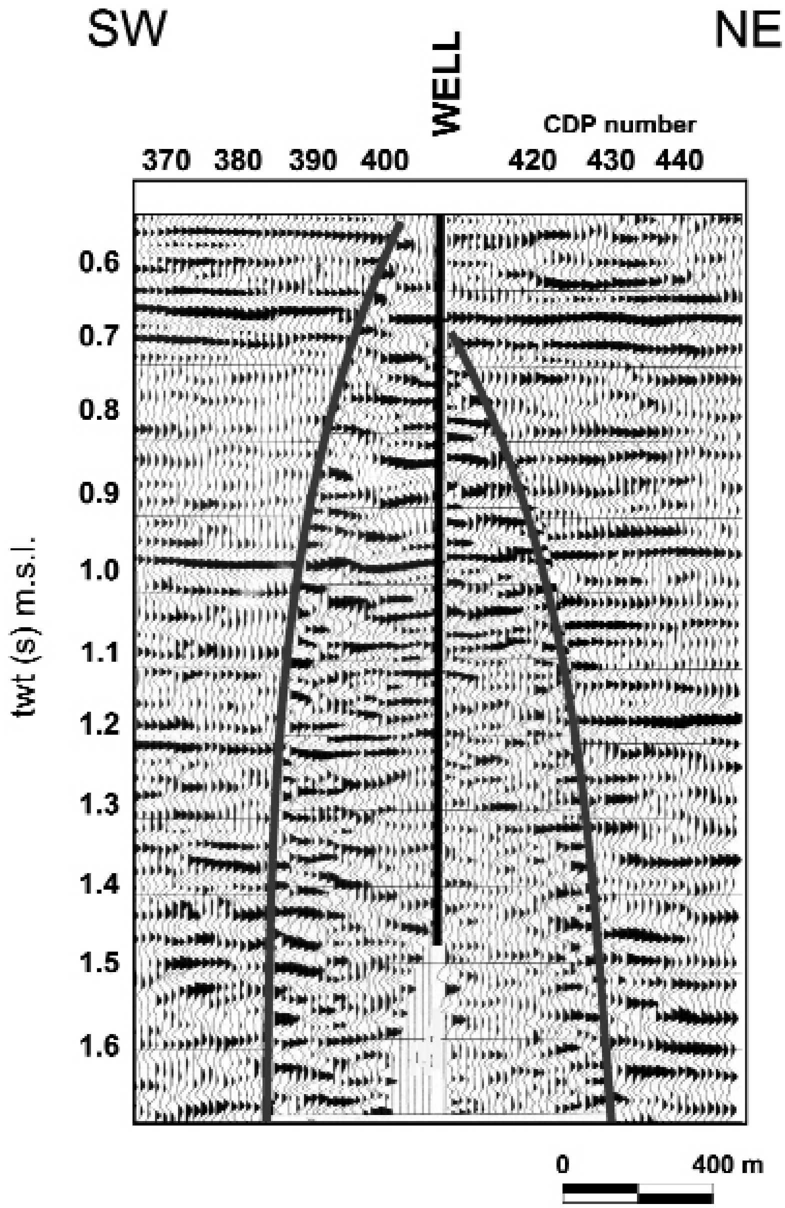

Fig. 11 - Multi-offset VSP CDP mapping computed along the SW-NE alignment superimposed on the surface reflection seismic section.

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