On-shore 2D C-wave seismic images in Poland

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Summary

Converted-wave on-shore seismic surveys have become an affordable reality within last few years. Introduction of new generation, digital seismic receiver was the turning point. The seismometer, being reliable and having high quality characteristics, encouraged investment in that technology. Presentation covers a way of development and today state of the C-wave technology offered by Geofizyka Torum (GT), Poland - a seismic service company.

Academic-level investigations combined with early works on multicomponent seismics (commenced by GT in 2000), and converted-wave technology in particular, founded a base. First, located in Poland, experiment with digital sensor designed over the Bronsko-Koscian reefs burried under Permian sediments turned out to be a breakthrough. Fortunately, the 3-component VSP, and full-wave sonic logs were recorded in a well located on the surface line. Well data enabled identification of recorded reflections, and efficiently guided processing. Success of the Bronsko-Koscian C-wave experiment determined the continuation of development and collecting experience on C-wave method.

Next step in development of the on-shore converted-wave seismics in Poland was execution of two production-scale surveys: Nova Deba and Rajsko, located in the South of the country, at the Carpathian Foreland. Targets are in Miocene, Cretacious and Jurassic sediments, where the gas and oil has already been exploited, but the surface-seismic images did not tie properly to well data. Geologic tasks have been two-fold: use of converted waves to improve mapping of gas saturation, and try to get higher vertical resolution of the P-wave images, which are characterized by lack of strong, contrasts in P-wave acoustic impedance. Both surveys, acquired with vertical vibrator as a source were specifically designed in order to get both: high-resolution P-wave images, and good quality C-wave data. Lessons from previous surveys showed usefulness of the three-component LVL soundings providing calibration of the S-wave statics. Such calibration, applied jointly with scaled, low-frequency component of the P-wave statics constitutes the basic method of receiver statics estimation for converted waves.

Each seismic experiment provided an opportunity to upgrade acquisition parameters, equipment, and dedicated software necessary for converted-wave processing and interpretation. Continuously growing number of C-wave surveys performed in Poland proves that technique brings useful information complementing P-wave images. Attatched figure gives an example of S-wave polarization planes, which can be mapped from C-wave seismic data. Several steps leading to that result are explained herein.

Current state of C-wave data processing and interpretation flows are presented and discussed. Digital receiver, dedicated recording instrument, software for elastic wave modeling and C-wave acquisition planning, processing software specific to C-waves, and entirely new interpretation package have been tested and adopted to meet the challenge. Several different software packages make the solution complete. To get those elements working together, needed application of several proprietary solutions, like interactive static corrections or interactive, multi-line mistie analysis and correction in processing or few extra options added to interpretation package.

Purely P-wave benefit from digital vector receiver turned out to be a bonus to C-wave seismic prospection. Digital geophone means good quality of recorded signal, and digital, noise-proof transmission from receiver to the recording instrument. Subsequent processing profits of that quality signal. Three-component measurement means a tilt measurement and correction. Single receiver per station means possibility to get higher frequencies as there is no intragroup static. A bit misleading feature is higher noise level of raw data. Fortunately, introduction of this technique coincides with development of processing techniques allowing for efficient supression of various types of noise. The appropriate measure of data quality is presently at final stage of processing, not in the field. In-field QC examines merely whether the searched signal is caught at all. After sophisticated processing, digital accelerometer allows get high quality, high-resolution seismic images. Extensiveness of the digital receiver application to the P-wave surveys can even outnumber its use in MC seismic projects. Comparisons of digital vs analog receiver were carried out and examples are shown.

Introduction

Continuous development of the P-wave seismic exploration suggests that results are still not fully satisfactory to the geophysical industry. For some purposes, instead of small-step improvements, a need of new technology seems to be important. Converted-wave on-shore seismic surveys became an affordable reality within last few years. Introduction of new generation, digital seismic receiver VectorSeis™ was the turning point. The seismometer, being reliable and having high quality characteristics, encouraged investment in that technology. Presentation covers briefly a way of development and present state of the C-wave technology offered by a seismic service company. GT contributes to development of that new technology. Continuously growing number of C-wave surveys performed in Poland proves that technique brings useful information complementing P-wave images.

Turning point – first digital experiment

Early after the digital accelerometer had been launched for land seismics, preliminary study of a single, digitaly recorded, converted-wave 2D line, was executed in western Poland. It was located in the province of largest discoveries of hydrocarbons in Poland, over the Bronsko-Koscian reefs burried under Permian sediments. Simultaneously, 3- component VSP, and full-wave sonic logs were recorded in a well located on the surface line.

Success of that experiment, achieved in spite of serious problems with receiver statics and processing/interpretation software at early stage of development, resulted in subsequent orders from the client. That was the turning point to implementation of the new technology in Poland.

A way of development

Extensive investments at various stages of the data flow have been a key point on the way to success. GT has already had some experience with multicomponent seismics (Nidzica 9C seismic data recorded in 2000 with analog 3C geophones). Moreover, GT has a long record of participation in academic investigation, including multicomponent seismic data analysis. That general background combined with GT expertise in land seismics have been essential to understanding and efficient application of multicomponent seismic technique.

Digital receiver, dedicated recording instrument, software for elastic wave modeling and C-wave acquisition planning, processing software specific to C-waves, and entirely new interpretation package have been tested and adopted to meet the challenge. Several different software packages make the solution complete. To get those elements working together, needed application of several proprietary solutions, like interactive static corrections or interactive, multi-line mistie analysis and correction in processing or few extra options added to interpretation package.

What more: digital receiver, designed for MC seismics, turned out to be an attractive alternative to the classical, analog geophone and to the way of its application. Extensiveness of the digital receiver application to the P-wave surveys can even outnumber its use in MC seismic projects. Comparisons of digital vs analog receiver were carried out and examples are shown. At first glance, application of highly sensitive, and single per station, digital receiver yields seismograms more noisy than traditionaly records. Actually, we witness a shift of noise suppression from acquisition to processing. Several techniques are available. Especially adaptive subtraction of multi-model noise is very efficient.

Production-scale technology: multicomponent and much more

Based on extensive small-scale experiments in various geologic settings, production-scale surveys have been commenced in Poland. Converted-wave, multi-line 2D surveys are examples: Nova Deba in 2003 and Rajsko in 2004. Both surveys were shot on the South of Poland in Carpathians Foreland.

Targets are in Miocene, Cretacious and Jurassic sediments, where the gas and oil has already been exploited, but the surface-seismic image did not tie properly to well data. Geologic tasks have been two-fold: use of converted waves to improve mapping of gas saturation, and try to get higher vertical resolution of the P-wave image, important in that area characterized by lack of strong, isolated contrasts in P-wave acoustic impedance. Some examples of solutions adopted to carry out the tasks are presented.

Rajsko project. Geologic setting

Major geological objectives in the area are located in the Cretacious and Jurassic sediments. The Carboniferous, Devonian and Silurian deposits, lying beneath, are the source of hydrocarbons found in Cenomanian sandstones and Upper Oxfordian dolomites, whereas thick Miocene sediments provide regional seal for lower layers. The traps are of structural and stratigraphic type, associated to facial changes

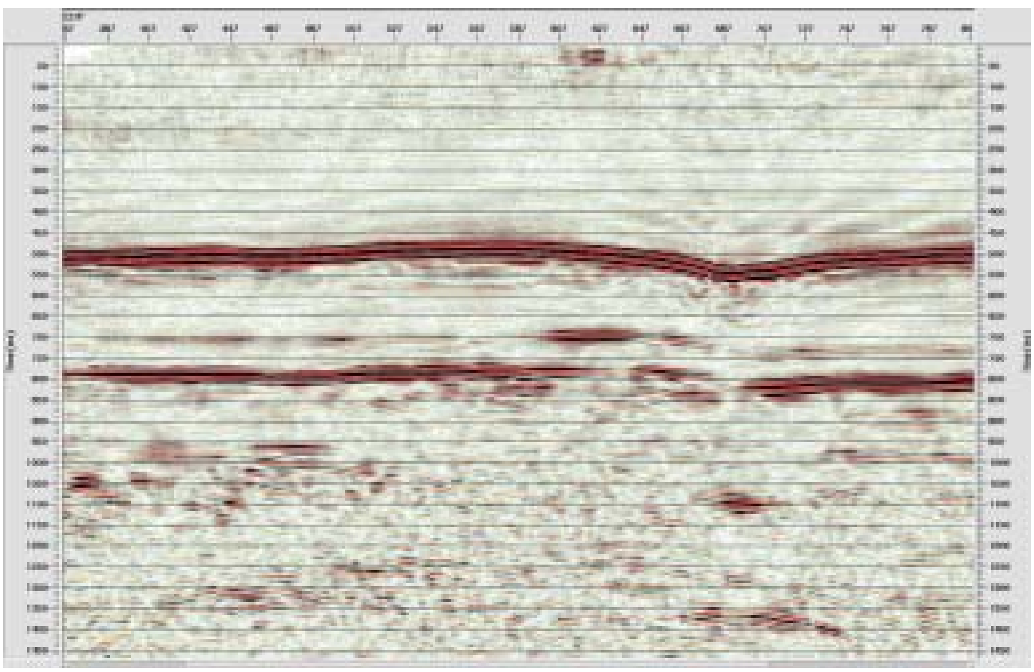

Fig.1. Line 5. Vertical component.

and unconformities. Hydrocarbon potential of the area is known from 1962 when oil field Grobla was discovered. It is confirmed further by three gas field discoveries; the latest gas discovery, Rajsko is associated with structural prospect recognized by 2D and 3D seismic.

Data processing

Typical of C-waves, processing workflow was applied to the Rajsko data. Pictures show details. Individual tools were combined from four different sources: three commercial packages (ProMAX, FOCUS, GeoDepth) plus GT proprietary programs. General stages of the processing were:

- signal pre-processing,
- estimation and correction for anisotropy – see Fig.6,
- noise suppression (including ground roll),
- signal processing,
- ACP binning,
- estimation of static corrections (esp. S-wave statics),
- velocity analysis (P-wave, and Vp/Vs),
- C-wave DMO or C-wave PreSTM,
- C-wave stacking (including CCP binning),
- migration (if DMO was selected). Post-stack processing.

Processing of the Rajsko C-wave data revealed good quality of all the three components (Fig.1, Fig.2, and Fig.3). Anisotropy is clearly present in the area. Suitable parameters were estimated. Fig.2 and Fig.3 display S1 and S2 component, respectively. Features like time delay between S2 and S1

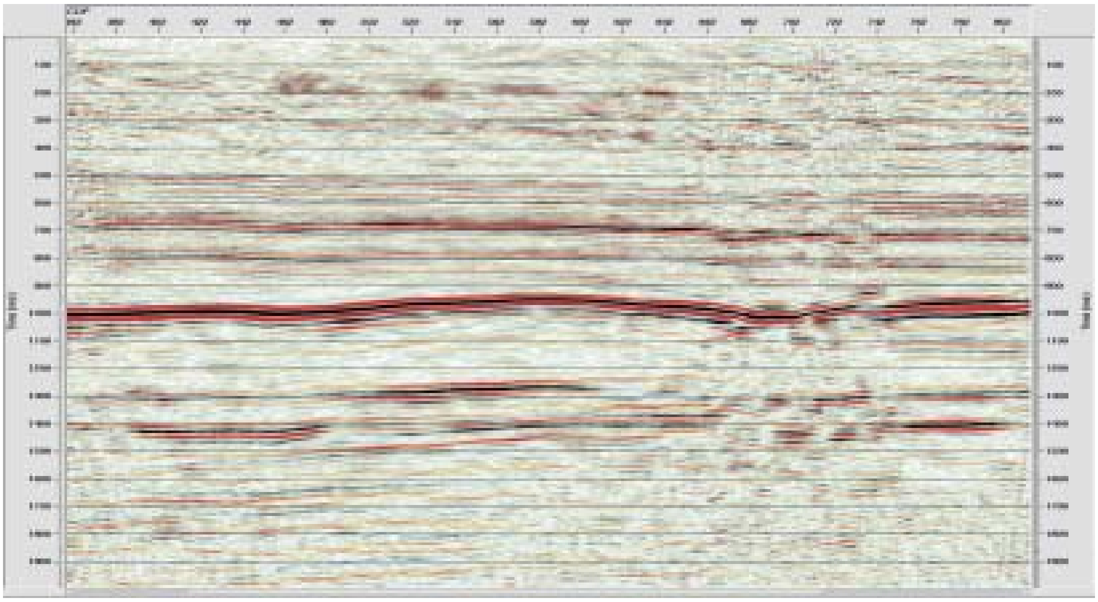

Fig.2. Line 5. S1 (fast) component.

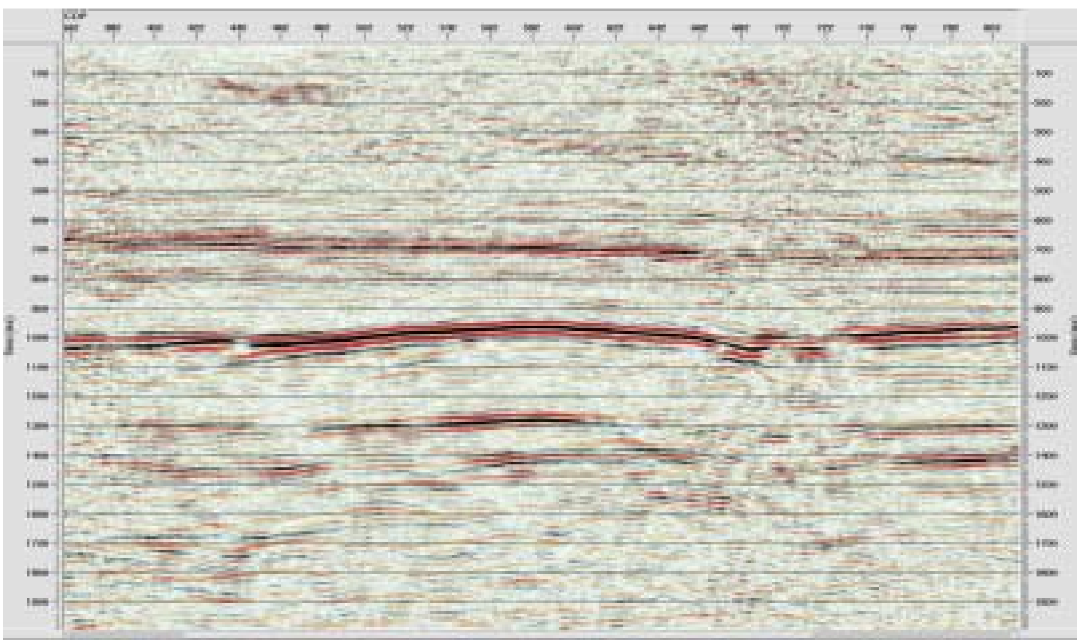

Fig.3. Line 5. S2 (slow) component.

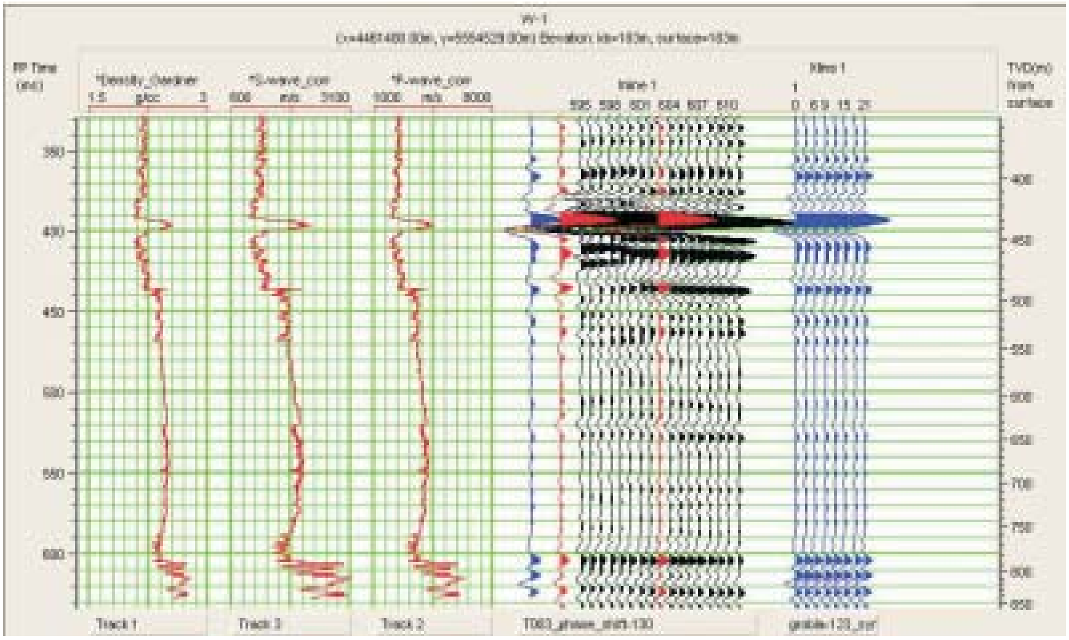

Fig.4 Composite plot. Synthetic seismogram provids tie well data to seismic

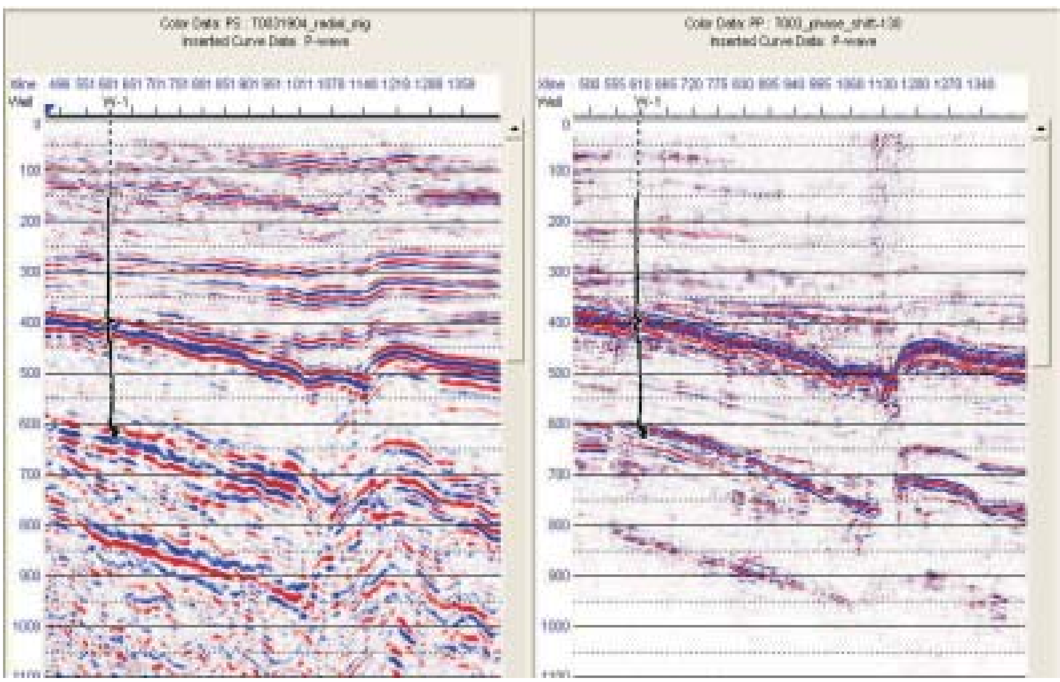

Fig.5 Comparison of PP image (right) to PS image (left) scaled to PP domain.

images can be seen and measured. It can be seen also, that C-wave reflections in the upper interval of horizontal components are of superior quality to those seen on vertical-component data. Converted waves thus bring more detailed picture of the upper part.

Interpretation workflow

At the early stages of 2D3C studies standard interpretation software (SeisWorks 2D) was used, but it does not lend well to multicomponent interpretation. New, dedicated interpretation software system ProMC is employed for interpretation of C-wave data from the Rajsko project.

Interpretation workflow consists of several steps:
- seismic and well data loading
- wavelet analysis
- synthetic seismogram generation – Fig.4
- tie seismic to well
- horizon picking and event registration
- Vp/Vs mapping
- conversion of PS data into PP time scale – Fig.5
- attribute calculation and anisotropy analysis
- fluid identification

Multicomponent data can establish relationship between seismic image and fluid content and delineate

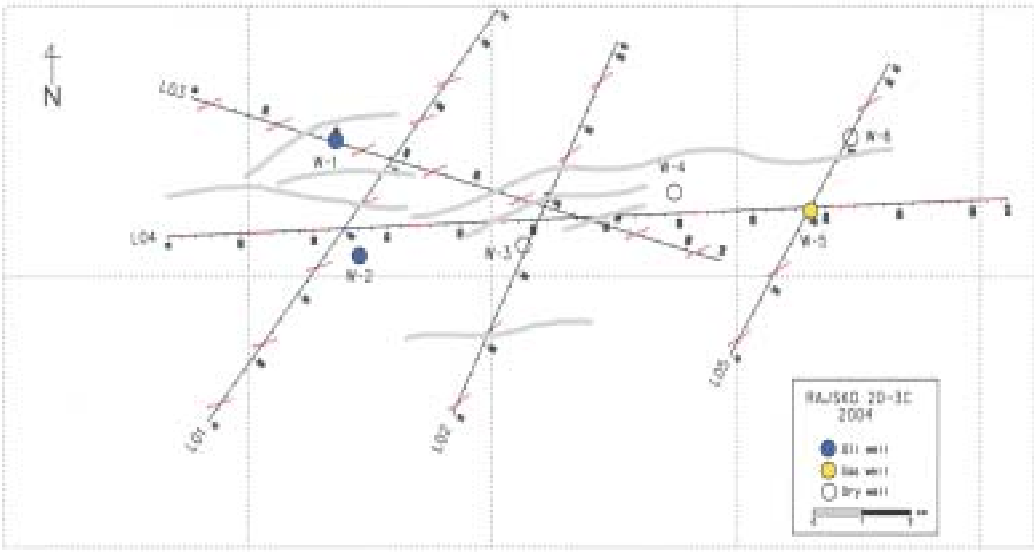

Fig.6. Shear wave polarization orientation estimated from pre-stack data. Red arrows indicate direction while their length is proportional to the time delay. Interpreted major faults are also plotted. Note three wells turned out to be dry. That was the main reason for application of the new technology.

extension of discovered hydrocarbon accumulations. Fig.6. Shear wave polarization orientation estimated from pre-stack data. Red arrows indicate direction while their length is proportional to the time delay. Interpreted major faults are also plotted. Note three wells turned out to be dry. That was the main reason for application of the new technology.

Conclusions

- Digital technology turned out to be success in areas with problems not solved with analog approach.
- Classic P-waves gained higher signal to noise level.
- Good quality of recorded data (Nowa Deba, Rajsko), and processing results, ensure that MC technology, delivering new petrophysical parameters, can reduce drilling risk.
- Extensive investments in hardware, software, experiments dedicated to C-wave seismics as well as cooperation with academic organizations made GT one of the leading providers of that new technology.

Acknowledgements

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References

R. Stewart, 2005, Course in multicomponent onshore seismic, Torun, Poland.

M.P. Harrison, 1992, Processing of P-SV Surface-Seismic Data: Anisotropy Analysis, Dip Moveout, and Migration, PhD Dissertation, University of Calgary, Canada.

A. Shabrawi, A. Smart, B. Anderson, G. Rached, A. El-Emam, 2005, How single-sensor seismic improved image of Kuwait’s Minagish Field, First Break, Feb. 2005.

R. Garotta, P-Y. Granger, A. Gresillaud, 2004, About compressional, converted mode, and shear statics, The Leading Edge, June 2004.

X. Wei, X-Y. Li, O Yang, S. Songqun, 2003, Case study of using converted PS-waves to image gas reservoirs in the Ordos Basin, China, 73rd International Annual SEG Meeting, Dallas, Texas.

P. Cary, 2001, Multicomponent seismic exploration in Canada – one person’s perspective, CSEG National Convention, Calgary.

Highlights of the SEG/EAGE Summer Research Workshop, 2000, Recent advances in shear wave technology for reservoir characterization: A new beginning?