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*Professional paper*

# Bright Spot, AVO Inversion and Synthetic on Grubišno Polje Locality

PROCEEDINGS

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**Key words:** Bright spot, AVO inversion and analysis, Restricted gradient stack, Synthetic.

## Abstract

Bright spot analysis is generally used in exploration for hydrocarbons, especially in the search for gas. However, many seismic amplitude anomalies have not been caused by gas accumulations, but they are related to lithological changes. AVO methods (amplitude vs. offset methods) can be used to distinguish between the presence of gas and lithological changes.

The Grubišno polje field has been defined and mapped by these methods, and a well, drilled afterward confirmed the results. After acquiring the well-logging data a Synthetic was computed. The correlation of the Synthetic with the reprocessed seismic sections and the AVO data enabled the more precise vertical and horizontal definition of the gas accumulation. This method and results contribute to the more rational exploration and development of a gas field.

**Ključne riječi:** bright spot, AVO pretvorba i analiza, ograničeni gradient stack, sintetski seizmogram.

## Sažetak

Analiza "Bright Spot" opće je prihvaćena u istraživanju ugljikovodika, naročito plina. Međutim, mnoge seizmičke amplitudne anomalije nisu uzrokovane plinskim akumulacijama, nego su odraz litoloških promjena. Za njihovo razlikovanje služe AVO metode (ponašanje amplituda glede udaljenosti izvor-prijemnik).

Lokalitet Grubišno Polje je utvrđen i okonturen ovim metodama, locirana je bušotina, koja je potvrdila njihove rezultate. Nakon izmjerenih karotažnih podataka izrađen je sintetski seizmogram. Korelacije sintetskog seizmograma i seizmičkih profila (moguće reobrade i korekcije seizmičkih podataka i mjerenih brzina) i "AVO" metode pretvorbi, omogućile su točnije okonturivanje ležišta u vertikalnom i horizontalnom smislu. Sve to doprinosi racionalnijem istraživanju i razradi lokaliteta.

## 1. INTRODUCTION

Bright spot analyses have been accepted in exploration for hydrocarbons, especially in gas bearing areas for twenty years. A Bright spot is related to gas accumulations in the beds, which significantly affect the seismic amplitudes (reflection coefficients) and cause amplitude anomalies on seismic sections.

However, seismic amplitude anomalies can also be generated by lithological changes. To distinguish between the presence of gas and lithological changes AVO inversions (amplitude vs. offset inversion, i.e. amplitude related to the source-receiver distance), have been used during the last ten years.

The AVO inversion and the Bright spot methods have been used together to analyse the Grubišno Polje field. The location and structural contours of this field can be seen on Fig. 1. It is important to mention that the analysis of AVO inversion does not imply the gas quantity in a bed. After analyzing the drilling results, and creation of a Synthetic, the complexity of this gas accumulation and the advantage of joint methods became clearer.

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## 2. INTERPRETATION

The Grubišno Polje field, which is a part of the Bjelovar Depresssion, is situated in central Croatia, approximately 120 km east of Zagreb. In the region surrounding this field the wells Gr-1 (1940), Gr-2 and Gr-3 (1965) were drilled on the basis of contemporary knowledge by gravity surveys performed before 1940 and between 1962-1965. The survey density was 1 point/km$^2$. The data from the seismic survey performed by single fold and analogue equipment were also used. All three wells were barren.

Between 1975 and 1981 a detailed gravity survey was performed over a broader area with the density of 10 points/km$^2$ which resulted in easier recognition of the gravimetric maximum. In 1990 more intense regional seismic exploration of the Bjelovar Depression was performed, while the Grubišno Polje field has been intensively explored by seismic methods since 1992.

Based on the newly recorded regional line V. Zdenci-2V-92 and the re-processed older lines which implied the existence of the Bright spot, the interpretation of Grubišno Polje locality was performed. In 1994 a new well Gr-1z was drilled. At -654 m depth the well encountered the gas accumulation, with the gas/water contact at -740 m. During 1994 and 1995 additional

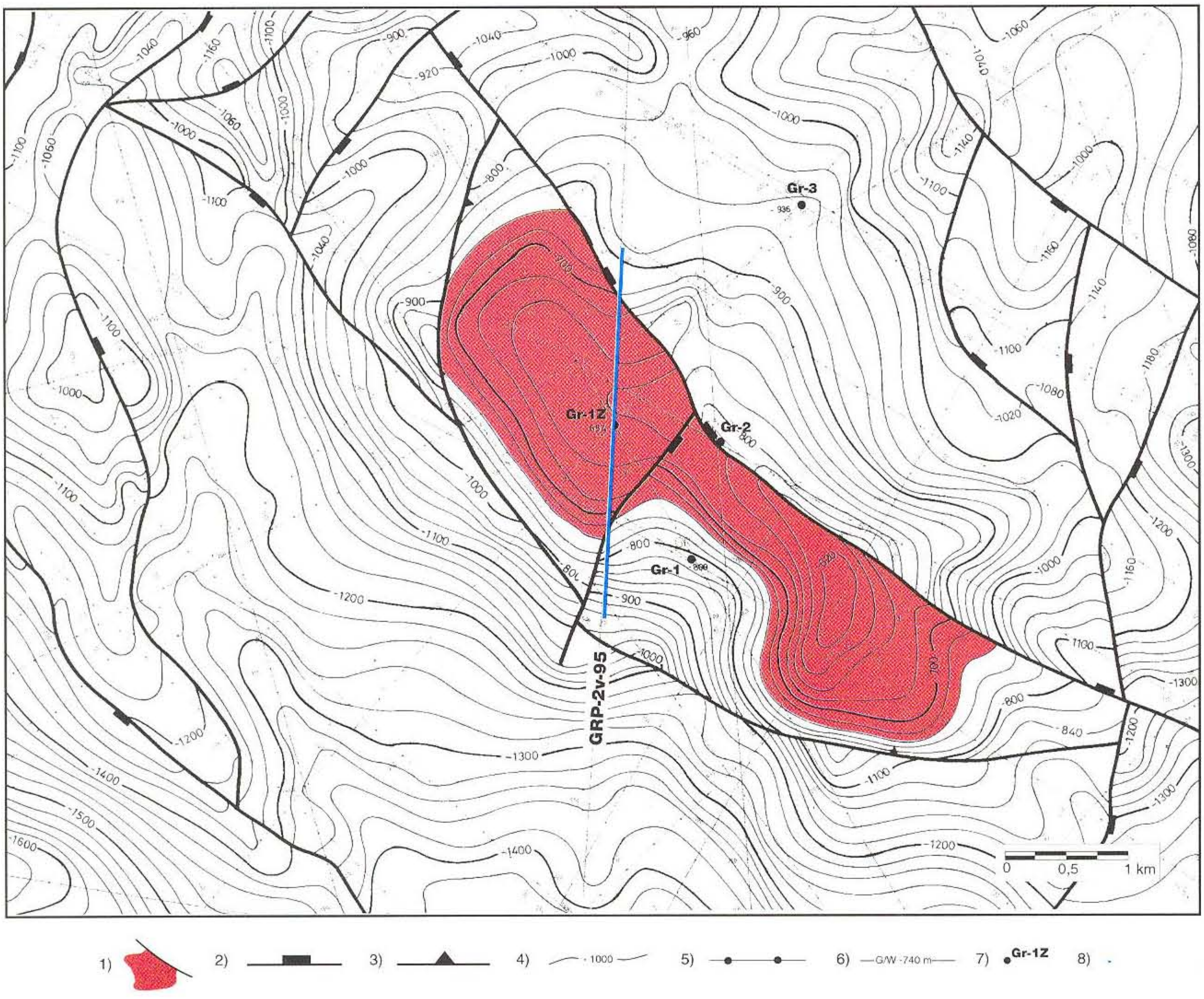


Fig. 1 Structural map of the EK- marker Rs7 with the contoured main reservoir. Legend: 1) gas reservoir; 2) normal fault; 3) reverse fault; 4) isodepth lines; 5) seismic lines; 6) estimated gas/water contact; 7) exploration well; 8) analysed part of seismic section.

seismic lines were shot, processed and interpreted. The result of this interpretation enabled more precise gas accumulation contouring (Fig. 1).

During the interpretation the following seismic displays were used: RAP-stack (Reflection amplitude preservation-stack), Phase and Frequency attributions, AVO inversion data (AVO angle trace analysis), Gradient stack, and Restricted gradient stack. As all the interpretations cannot be presented in this paper, only the RAP-stack section, AVO angle trace analysis (Fig. 2a), Restricted gradient stack (Fig. 2b), and correlation of well and seismic data (Fig. 3) have been included.

Figure 2a represents the RAP-stack section of the seismic profile GRP-2V-95. In the central part along the well Gr-1Z, three Bright spots are visible in the interval between 600-674 msec. The shallowest Bright spot was caused by a gas pool, and a 100% relative gas concentration was registered during the well drilling (OP - overpressure) in the lower part of the equivalent of Bregi sandstones of EK-marker Rφ - silty sandstone (Fig. 3). The deeper Bright spot was caused by entering the Kloštar Ivanić formation (EK-marker Δ), which is lithologically represented by clast fragments and fossil karst. The deepest Bright spot is related to the low velocity zone within the Kloštar Ivanić formation (sonic log in the Fig. 3), probably to the marker Rv. These Bright spots are accompanied by the presence of gas and the whole interval is overpressured[1].

The main gas accumulation is situated in the Mosti member of the Moslovačka gora formation (EK marker Rs7), and in the basal Tertiary (BT). The Mosti member is represented by biocalcirudites - biocalcarenites, while the basal Tertiary is represented by metamorphics. The top of the main reservoir is not represented on a RAP-stack section with a Bright spot, because of the considerably higher velocity of the carbonate matrix. Due to the gas accumulation the reflection coefficients are weakened (Dim spot). The positive amplitude is barely visible on the section. Entering the main gas accumulation, the overpressure is lost.

[1] Vukadinović, M. (1995): Završno geološko izvješće za istražnu bušotinu Grubišno Polje-1 zapad.- Unpublished report, Ina-Naftaplin Library.

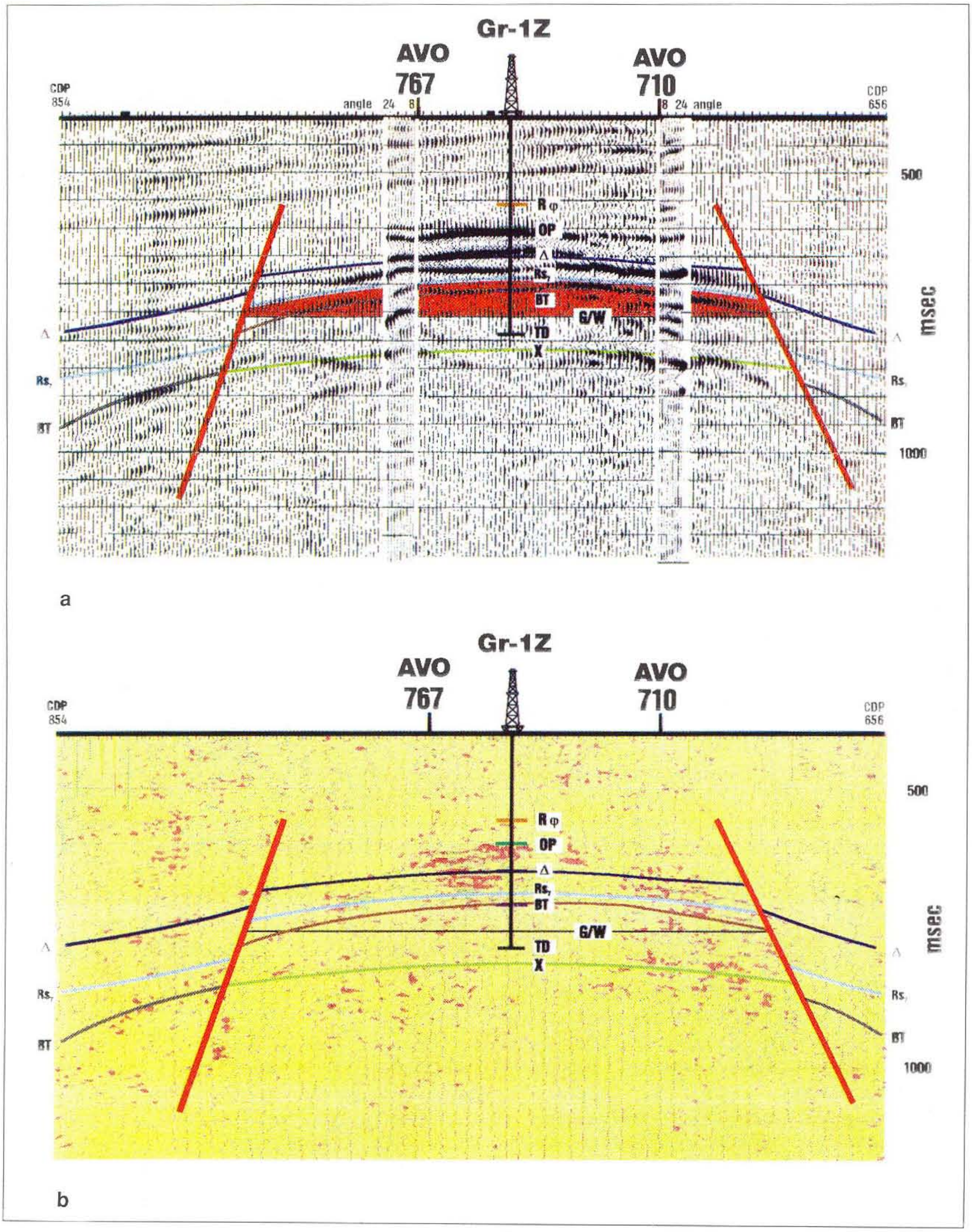


Fig. 2 a) Interpretation of RAP stack section with two AVO analyses (CMP 767 and 710) included; b) interpretation of Restricted Gradient stack. Red anomalies indicate the potential presence of gas.

The basal Tertiary is characterized by a slightly higher amplitude. The gas/water contact is related to a mild Flat spot. The bottom of the Gr-1Z well is at 790 msec within the Tertiary basement.

Below the bottom of the well, at approximately 820 msec laterally to the well there is a Bright spot, which represents a probable lithological change, maybe even an erosional unconformity, which has not yet been reached by any of the wells. This Bright spot is weakened in its central part because of the absorption of seismic energy (Shadow zone below Bright spot ).

On the RAP-stack section the interpretation of EK-

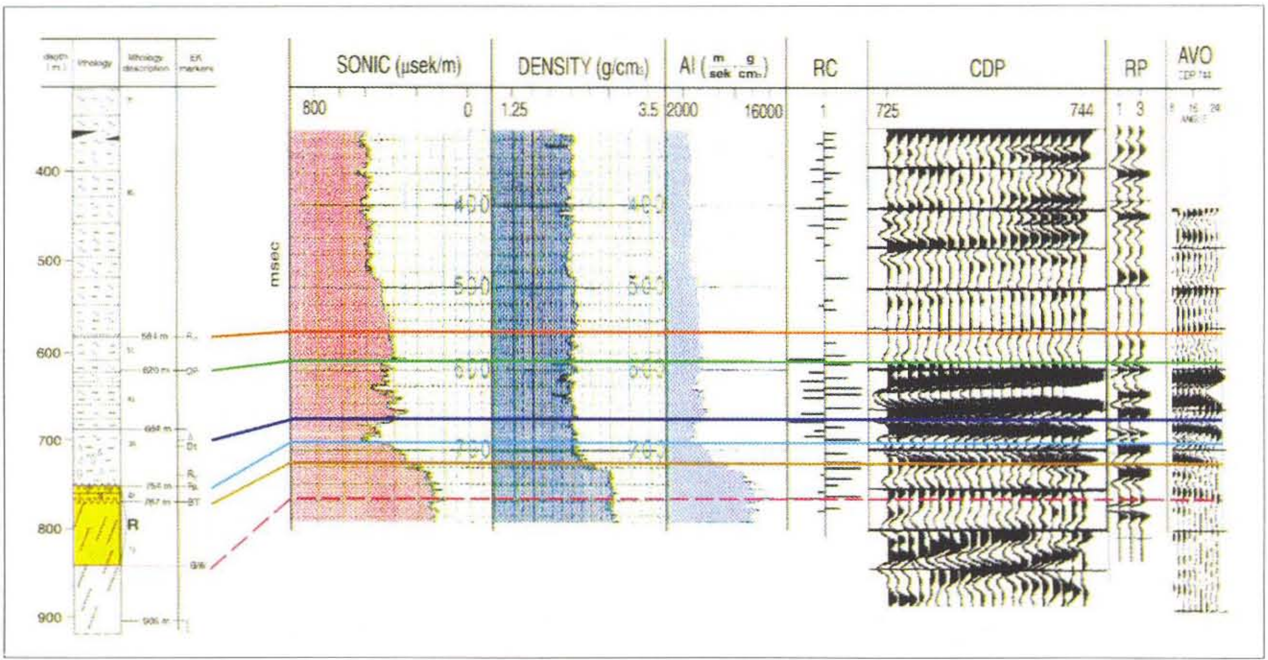


Fig. 3 Comparison of well, seismic data and schematic lithological column. Legend: 1) metamorphites (granit mica schist); 2) biocalcirudite to biocalcarenite; 3) sandy argillaceous marl to calcareous clay, clastics and fossil karst fragments; 4) marl and silty sandstone; 5) silty to argillaceous marl; 6) argillaceous marl with sandstone interbeds; 7) marly clay with sand interbeds; R) main reservoir.

markers: Δ, Rs7, BT and a probable lithological change "X" are shown. There are also two AVO angle trace analyses, on CDP (Common Depth Point) 767 and 710 with angles of 8 to 24 degrees, to illustrate the possible gas saturations in the sediment complex.

Figure 2b (Restricted Gradient stack) is discussed below and indicates that the results of AVO analyses of pre-stack seismic data show good correlation with the RAP-stack section (Fig. 2a) confirming the presence of gas.

## 3. AVO INVERSION

It has been proven that the P-wave reflection coefficients on the boundary of two elastic media change with the angles of incidence, or with the offsets because of the various relative values of Poisson's ratio across the reflecting interface.

These facts were already noticed on the seismic data prior to stacking (KOEFOED, 1955), and were later confirmed theoretically and by laboratory measurements. The results of the laboratory measurements showed that the highly porous, gas saturated sandstones, give a very low Poisson's ratio. In the natural underground conditions in sandy sediments, if gas is present, it is proved that the P-wave reflection coefficient increases with the angle of incidence (OSTRANDER, 1984; DOMENICO, 1976; RUTHERFORD & WILLIAMS, 1989).

During the AVO inversion procedure special attention should be paid to the quality of the seismic data, both field recording and during seismic processing, because they significantly affect the recorded reflection amplitudes as a distance function from the source. During the survey attention should be paid to whether the analysed horizons are at suitable depths, considering the distance between the source and the receiver; if there is enough coverage (at least three-fold on target horizons); how the field data are affected by noise; and whether the seismic energy can be lost during shooting, because of some natural conditions, e.g. weathering zone.

Generally the following factors affect AVO inversions: angles of reflection incidence, reflector curving with significant impact at small depths (it is not recommended to perform the inversion up to approximately 400 m), transmission coefficients, multiples and inelastic smoothings.

During the seismic processing it is important to restore the energy lost with time and distance, because of the spherical spreading of wavefronts. The other factors that affect the relative amplitude relations are: the diminishing of amplitudes because of geophone arrays and sources, especially at shallow depths, where the angles of incidence can be increased, while part of energy can be lost because of refraction. This is why it is not recommended to analyse the longer offsets. The same happens for greater depths at short offsets. Generally speaking, very shallow and deep reflections are not reliable for AVO inversions.

The next factors affecting amplitude relations are the tuning effects. Closely situated reflections cannot be expressed on seismics, but they merge into one, which could be analyzed through the NMO equation and by higher seismic resolution (OSTRANDER, 1984; West-

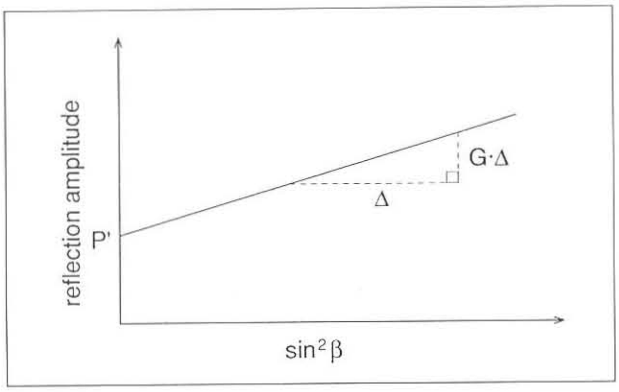


Fig. 4 Linear fit of AVO curve of reflection amplitude vs. $\sin^2\beta$.

ern Geophysical[2]). These effects in thinner shallow sands (approximately 12-15 m) can result in diminishing amplitudes at greater distances from the source.

Various noises can also significantly affect the amplitudes, and in the case of long offsets they can provoke diminishing of amplitude. This is why analysis of the S/N ratio (Signal-to-noise ratio) is recommended. To improve the S/N ratio in accordance with the Fresnel-zone width, the partial averaging of several offsets or several angles was undertaken.

It is recommended to use data recorded under the constant conditions for AVO inversions, while during the seismic processing one should keep to the chosen processing schedule. The most important phases of the processing are: treatment of the spherical spreading of wavefronts, phase correction due to various recording conditions, detailed velocity analyses, deconvolution; it is not recommended to perform statistical deconvolution which may introduce amplitude and phase variations. Here, surface consistent deconvolution of the spiking type was performed, because the operations are separately created: a) operator in the source domain to erase the differences from source to source, b) operator in the receiver domain that corrects the contacts during the recording receiver/earth (coupling), c) operator in the common offsets domain, to reject reverberations.

All the figures were produced without amplitude equalisation, so that relative energy on all the recorded receivers could remain in real terms. Figure 2a shows the RAP-stack display and amplitude vs. offsets for two common depth points (CDP 767 and 710) on the sorted seismic traces. It should be mentioned that the AVO effects according to the angle of incidence are more obviously expressed, than those according to the offset.

Beside AVO inversions of seismic data before stacking, attributive stacks were made: Gradient stack and Restricted Gradient stack. Gradient stack G is based on the principle that the reflection amplitude $R(\beta)$ of P-waves reflected from the interface between two elastic media, varies linearly with the $\sin^2\beta$ (Fig. 4) according to the equation:

$$R(\beta) = P + G \cdot \sin^2\beta$$

where P is intercept, $\beta$ reflection angle, and G gradient (slope).

The linear fit of AVO curve of reflection amplitude vs. $\sin^2\beta$ run correctly for reflection angle $\beta$ less than 25°, and data must be corrected for statics and NMO by carefully obtained velocities.

The values are calculated on each seismic trace before stacking data and for each sampling period. The section of Gradient stack G contains the information on the increase in amplitude changes depending on $\sin^2\beta$ (offsets).

Different companies have various programs for analysing the amplitude vs. offset. The elementary algorithms are the same, the differences occur in the various kinds of representation and inversion into attributes. The Restricted gradient stack GR (Fig. 2b) is recommended. This is the Gradient of absolute amplitudes depending on $\sin^2\beta$:

$$GR = \mathrm{sgn}(P) \cdot G$$

When P and G have the same sign GR is positive, when they are opposite signs GR is negative.

Comparing Restricted Gradient stack GR (Fig. 2b) with RAP-stack (Fig. 2a) showing Bright spot indicators on the GR section, there are positive anomalies (shown in red) when the absolute amplitudes increase with offsets.

In a typical sand-marl sequence, the large positive anomalies indicate the potential presence of gas. They are related to the increase of absolute amplitudes in relation to the increased angles, while the negative amplitudes deny the presence of gas.

On Fig. 2b, red positive amplitudes are situated above the main gas accumulation, approximately between 600 and 675 msec, supporting the above mentioned interpretation of this complex area.

## 4. SYNTHETIC

Logging data and velocity measurements provided data for a Synthetic to be created after the well was completed and logging and velocity data became available. The procedure for the creation of the Synthetic enables control of the basic interpretation assumptions and correlation of the drilling results, well-log data and seismic profiles.

The curve correction of the sonic log was performed first, the so-called Calibration of the recorded sonic log with the recorded velocity (velocity survey or VSP - Vertical seismic profiling). The control points that are chosen have geological importance and they are located at lithological changes or stratigraphic boundaries.

Differences in velocities can appear for a variety of reasons, such are the case of two different sources of

[2] Western Geophysical (1994): Manuals for Users, Help.- Unpubl. Disc Documentation.

velocity survey. The sonic log integrated travel time, measured on the basis of refraction may not truly reflect the seismic travel time. Sonic log integrated velocities can differ from the seismic waves velocities, because the frequency of the seismic line is lower and its wavelength is longer. Velocities depend on the places where the geophones were sited in a well. Sometimes fractures in formations during the drilling process have a greater effect on seismic velocities than on the sonic log.

After the calibration has been performed, the Synthetic can be created from the sonic log and the density log transforming them into two-way-time. Simultaneously the seismic profiles with wells marked on them are loaded. Due to the better corelation all other available logs were loaded, while the lithological column according to the lithological profile was compiled (Fig. 3). AVO analysis of seismic data CDP 744, from the nearby well Gr-1Z was added to the end of Fig. 3.

This allows comparison and identification of the horizons on seismic profiles, logging curves and on Synthetic.

Wavelets for convolving the reflection coefficients can be for example Ricker wavelets, but the correlation wavelet can also be extracted by comparing the seismic profiles and reflection coefficients. During this procedure one can indicate the need for corrections of the seismic profiles, sonic log or velocity survey.

During the study of all these compiled data, the problems of phase corrections can be explained, and also the time shifts in seismic data, and lithological impacts, which can be different on the Synthetic and the surface seismic. The problems during the seismic processing can be defined and any requirement for the reprocessing of seismic profiles can be indicated.

On the example of the well Gr-1Z there was no need for the correction of seismic profiles, because they were especially reprocessed for the needs of AVO. The Synthetic was formed with the Ricker wavelet, which represents the real picture of the Synthetic seismogram. Small discrepancies are explained in the interpretation, according to the well data and the complexity of this gas accumulation.

If the Synthetic is shifted along the profile to the well, the stratigraphic continuity can be followed during the process of extracting the correlation wavelet, as a better or weaker correlation.

## 5. CONCLUSION

Bright spots enabled the definition of gas accumulations along with the usual interpretation methods. The difference between gas accumulations and lithological changes can be identified by the AVO analysis inversion of seismic data, and this also contributed to the more rational contouring of the gas accumulation and to the well location.

In the complex subsurface geology AVO methods can be unreliable, while the results of these analyses must be interpreted very carefully, so the impact of local changes in geology can be separated from the anomalies of the amplitudes related to the source-receiver distance.

It is important to mention that these methods must be confirmed by other methods, and the results must be reviewed in terms of the problems of the exploration area. Due to explanation of this complex gas accumulation, we include all the well data, that in the seismic section along with Bright spots contains also Dim spots. This can also point to any need for reprocessing and correction of seismic data, and more accurate contouring of the reservoir in the vertical and horizontal sense. If the various data are well correlated, they represent and confirm the interpretation and indicate other favourable drilling locations. In all, this is a contribution toward more rational exploration and has a positive impact on business decisions.

The processings was performed with the programs of Western Geophysical and Western Atlas Companies on IBM RISC-6000.

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