Multi-component merged interpretation and joint PP-PS inversion workflow for lithology identification in the Northern Caspian clastic reservoir

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Introduction

Multicomponent seismic surveys are often carried out in shallow sea environments that prevent us from using towed streamers, and require seismic receivers to be placed on the sea floor. Air guns are used as sources, and four-component receivers (three acceleration meters and a hydrophone) are becoming more and more common for such acquisition programs. The resulting multicomponent data account for both the reflected pressure-waves and converted polarized waves. The arrival times and amplitudes of pressure and converted waves may be used together to improve the identification of reservoir rock physical/elastic properties based on seismic data.

The Northern Caspian Sea is an area of current exploration in shallow sea environments, with water depth up to 5 m and clastic Lower Cretaceous and Middle Jurassic reservoirs at 1,500 to 2,000 m.

This paper describes a workflow for processing, interpreting and inverting 2D4C seismic data to delineate clastic reservoirs based on their lithology. The results of joint PP-PS inversion are compared against the results of AVA inversion that are limited to pressure waves at different incidence angles insteadof using direct shear wave measurement results.

Field program

The acquisition program used a layout with overlapping source coverage that shortens the survey time for sea-floor receivers and is better suited for P-waves. However, the non-overlapping receivers' arrays impose limitation on obtaining converted waves from deeper intervals. The data was acquired using five non-overlapping sea-floor receiver arrays, each 4,500 m long, with 25 m intervals between receivers. The source lines were 4,500 m long, with 2,250 m overlap and 25 m intervals between sources. The maximum source-receiver offset was 6,750 m. An example of acquisition data is shown in Figure 1.

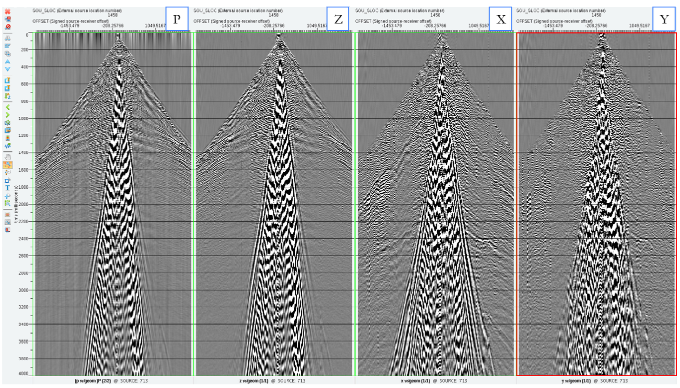

Figure 1*Four-component field gather*

Processing and interpretation

The main processing sequence procedures included:

- P- andZ-component stacking;
- XandYorientation;

- gain adjustment, noise removal, deconvolution;
- staticsandmoveoutcorrections;
- identification ofPPandPS-wave reflections, calculation ofγ = Vp/Vs;
- CCP-binningforPS-waves;
- PSTM;
- PSDM.

The final PSDM images converted to time are shown in figure 2. PP section is in PP time and PS sections are in PS times. It can be seen that PSv data (figure 2, middle) contains the most of converted energy and it was used together with PP data (figure 2, left) for further interpretation and inversion. The results were interpreted in two stages. The first stage consisted inVp/Vsevaluation for individual intervals that served as an input forCCP-binning of PS-wave data (TessmerandBehle, 1988).

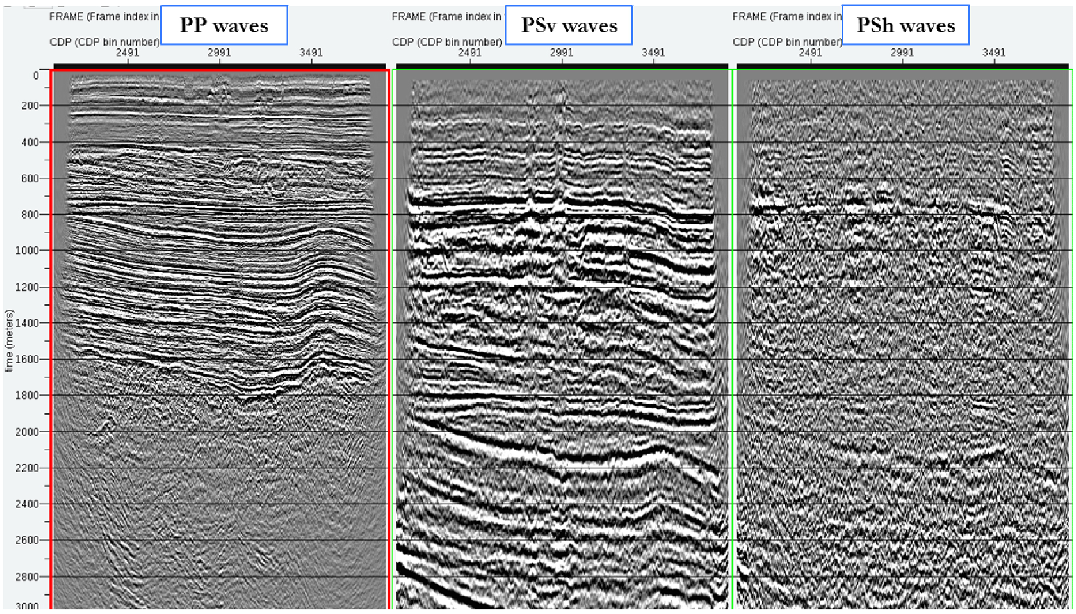

Figure 2*Final timesectionsofdifferent wave types*

Registrationof the reflected PP- andPS-waves and its subsequent interpretation is a critical step that defines the low-frequency model for deterministic inversion.
The main interpretation procedure consisted of merged correlation for anyregistered T_{pp2} and T_{ps2} timehorizons, which appear justbelow T_{pp1} and T_{ps1} time horizonson final pressure and converted wave images respectively. This lets us control the quality of correlation forPPand PStime horizons by settingtime ranges $T_{pp2}^{\min}, T_{pp2}^{\max}, T_{ps2}^{\min}$ and $T_{ps2}^{\max}$ (equations (1))in each of the time intervals ΔT_{pp1-2} and ΔT_{ps1-2}, for which variations inγ(equation (2))valuesreflect differences in physical properties of the rock.

$$T_{pp2}^{\min} = \frac{2\gamma^{\min}}{(1+\gamma^{\min})}\Delta T_{ps1-2} + T_{pp1}, \qquad T_{pp2}^{\max} = \frac{2\gamma^{\max}}{(1+\gamma^{\max})}\Delta T_{ps1-2} + T_{pp1},$$

$$T_{ps2}^{\min} = \frac{(1+\gamma^{\max})}{2\gamma^{\max}}\Delta T_{pp1-2} + T_{ps1}, \qquad T_{ps2}^{\max} = \frac{(1+\gamma^{\min})}{2\gamma^{\min}}\Delta T_{pp1-2} + T_{ps1}. \tag{1}$$

Thus, the intervals are identified based onPPandPSmerged interpretationusingevents correlation principle which satisfies γ minimum and maximum criteria (equation (2)).

$$\gamma^{min} = 0.2, \gamma^{max} = 0.65, \text{where } \gamma = Vs/Vp. \qquad (2)$$

The results of the merged interpretation are shown on figure 3 in PP times.

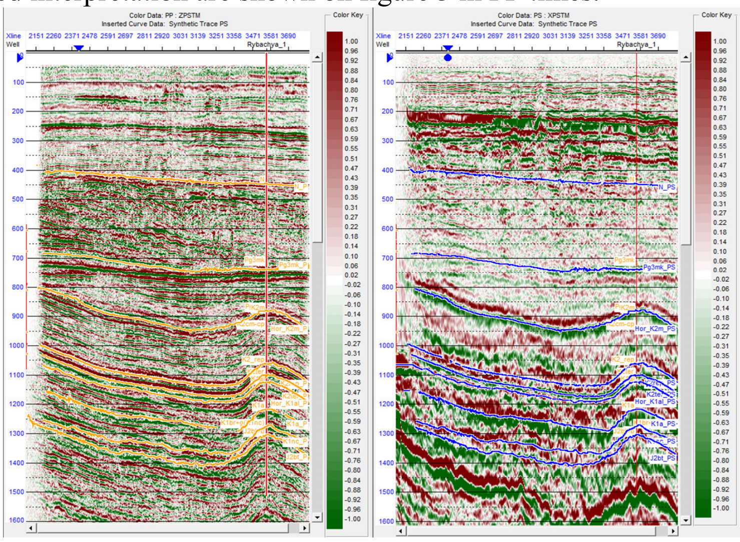

Figure 3*PP-section (left) andPS-section (right) in PP times, along with interpretation results*

Inversion

An analysis of cross-plots of log data in the target interval has indicated a possibility of identification of such rock properties as clay, quartz and calcite contentbased on rock elasticity and bulkporosity. Unlike the acoustic impedance data, a cross-plot of Vp/Vs data and bulk porosity supports a high level of confidence in differentiation between clay, calcite and quartz content.

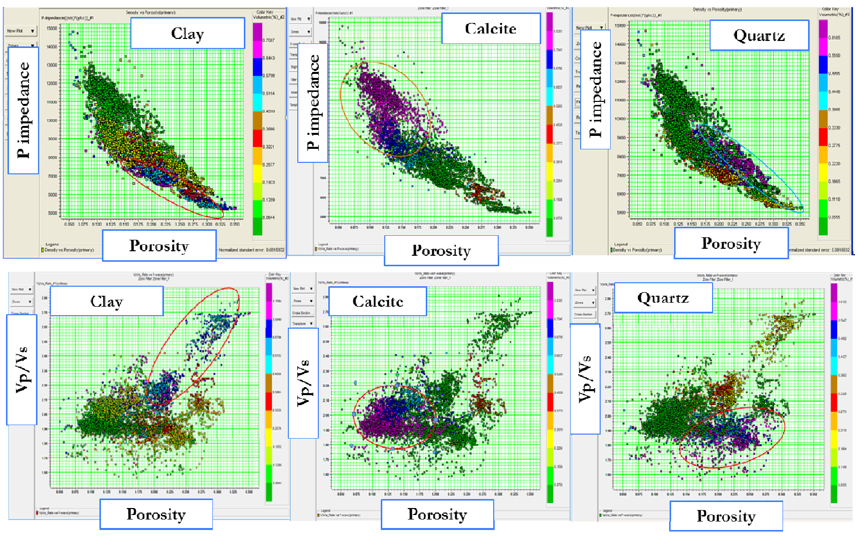

Figure 4*Cross-plots: acoustic impedance (top)andVp/Vs(bottom)*

The high degree of confidence in rock lithology identification based on Vp/Vsratios that has been confirmed by well log data provides grounds for applying inversion for rock elasticity evaluation. Thesimultaneouspre-stackinversion relies on P-wave data only that is thePP angle-gathers data are convertedto acoustic impedance, shear impedance and density. The jointPP-PSinversion is an extension of thesimultaneouspre-stackmethodfor converted waves (Hampson, 2005).The results are shown in figure 5. TheVp/Vssections (figure 5, right) afterjointPP-PSinversionare characterized by a much better lateral resolution that enhances our confidence in determination of rock lithology fartheraway from the wellbased onVp/Vs values.

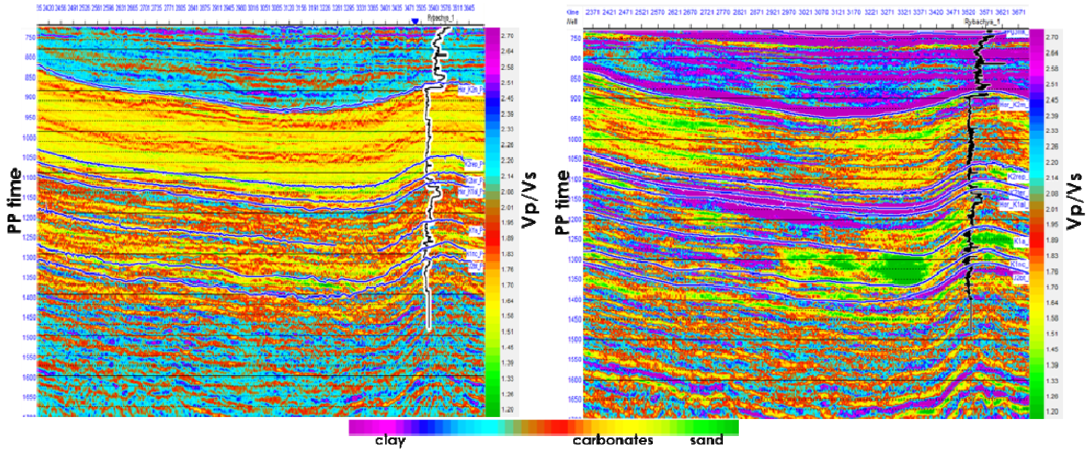

Figure 5*Inversion results: simultaneouspre-stack(left) andjointPP-PS (right)*

A comparison betweenVp/Vsinversion data and well log data shows that the jointPP-PSinversion data are much closer to the well log (see figure 6) and is characterized by a correlation factor of 0.8 (vs. 0.6 forsimultaneouspre-stackinversion).

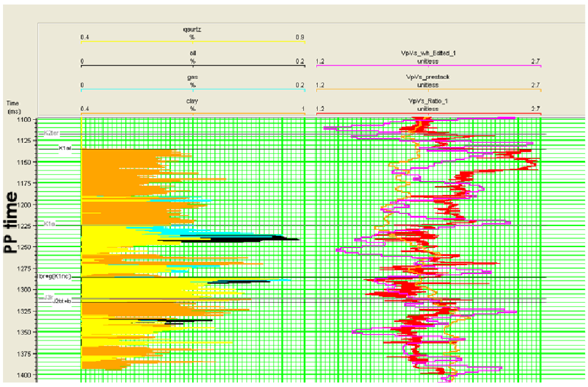

Figure 6*Bulk content of sand, clay, oil and gas (left) vs. inversion results (right). Vp/Vscurves: simultaneouspre-stack (yellow), jointPP-PS (purple) and well log data (red)*

Conclusions

This multi-component acquisition technique and the related processing, interpretation and inversion workfloware a robust methodology for identifying terrigenous rock lithology in the Lower Cretaceous and Middle Jurassic intervals in the Northern Caspian area. Interpretation ofPP-andPS-wave sections in combination with a cross-check ofγvalueson interval-by-interval basis provided a better low-frequencymodel to enhance thejointPP-PSinversion.

Acknowledgements

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References

Hampson, D., Russell, B., and Bankhead, B. [2005] Simultaneous inversion of pre-stack seismic data.*SEG Annual meeting, Houston, 2005.*

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