Seismic Elastic Inversion of a Cretaceous Oil Field in Campos Basin, Brazil

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Abstract

In an Upper Cretaceous oil field it was difficult to distinguish the turbiditic oil saturated sandstones reservoir from low impedance shales and water saturated sandstones. The logs indicated that it would be possible to discriminate them using elastic impedances. The estimation of the compressional and shear impedances was obtained through the simultaneous seismic inversion of two angle stacks applying the constrained sparse spike approach. The results, when compared to the log information, were very good. The volumetric interpretation of the inverted data, specially using *Ip-Is* cube, allowed the mapping of the different facies, and the estimation of the fluid in the reservoir. Therefore, reservoir could be better characterized, resulting in a better geological model.

Introduction

A new seismic 3D survey acquisition in Campos Basin, had as one of its aims to guide the development planning of a Cretaceous field. One of the main difficulties of the interpretation in this field was to distinguish the porous sandstones from the low velocity shales. The analysis of the logs indicated that it would be possible to separate these two litologies in the seismic data. Based on analysis volumes of P and S wave impedances were generated from the simultaneous inversion of two angle stacks. The elastic parameters derived from this information allowed a better quality characterization of the reservoir. The inverted data were interpreted and the final results indicated to be very promising, allowing an improvement in the geological model.

Geologic Model

The Upper Cretaceous reservoirs present two different sedimentary systems tectonically controlled by faults and folds of NE-SW direction related to halokinesis: one is the syndepositional Turonian/Coniacian System and the other ranges from Santonian to Maastrichtian. Conglomerate, sand deformed by gravitational action and igneous activity comprise the rocks between these systems and indicate that the maximum tectonic and halokinesis activity occurred during this period. Confined sands and channel turbidite deposits define an external geometry which is supported by data from formation tests and production rate. The Upper Cretaceous is divided into three stratigraphic sequences: Turonian/Conician, Lower Santonian and Upper Santonian.

The most important reservoir belongs to the Turonian/Coniacian sequence. This reservoir shows up to 60m of total thickness with NW-SE channelized amalgamated sand bodies. The presence of massive sandstones is interpreted as high density turbidite flow deposits and the intercalated sand/shale deposits as mud-rich turbidites.. Canyons of NE-SW directions eroded the Turonian reservoir and served as a by-pass way for the younger sediments. The Lower Santonian Sequence was deposited over a regional erosive surface. By it turn, the Upper Santonian Sequence was composed by confined sand-rich channels. At this time, tectonism was not anymore the mechanism for depocenter creation. The reservoirs seem to be partially connected, despite significant structural and stratigraphic barriers. The Tertiary reservoirs are composed by Lower Oligocene sandstones which were deposited in a NW-SE oriented narrow channel and placed in the shoulder of a canyon.

Seismic Data

The inverted seismic data were obtained from the 3D survey which parameters were defined to allow a better reservoir imaging. The main processing steps included (a) deterministic deconvolution for suppressing the effects of source signature and source and receiver ghosts, (b) spike deconvolution, (c) pre-stack time migration in the longitudinal direction (with geometric spreading correction), (d) stacking near and far offsets volumes, separated by incidence angle (0-20 and 20-40 degrees), (e) multiple Kirchhoff attenuation in near offsets volume, (f) transverse WX algorithm migration, (g) residual multiple attenuation with linear radon transform, (h) predictive deconvolution, (i) random noise attenuation and (j) frequency filtering. The stack velocities came from DMO corrected gathers interpretation, with a distance of 500m between the points. The processing flow intend to preserve the data frequency content and to improve signal to noise ratio, maintaining the amplitude confidence.

Seismic Inversion

The inversion method to obtain the compressional (*Ip*) and shear (*Is*) impedances was based on the simultaneous inversion of partial angle stacks of P-wave seismic data following a “Constrained Sparse Spike” approach (Pendrel et al., 2000). In this method, the angle dependent reflectivity series is assumed sparse, i.e., the seismic traces can be modeled with fewer reflection coefficients than the number of samples. The reflectivity is modeled using the Knott-Zoeppritz equations or the Aki-Richards approximations. The algorithm is based on the minimization of a combination of Lp norms subject to constraints which are important for both guarantee the uniqueness of the solution and to add the low frequencies components that are not present in the seismic data. Those constraints were defined relative to the geological model generated from the P-sonic, S-sonic and density at the well logs, interpolated for the whole volume according to the seismic interpretation of the full-stack seismic amplitudes. Some additional constraints are added based on the P and S-wave relation, to stabilize the S-wave impedance result, and P-wave and density relation because the data angle range used were not enough to give any trustable density information.

A key point in the methodology is the estimation of the seismic wavelets. In this case, a different wavelet for each angle stack was derived matching the seismic amplitudes with the synthetic traces modeled by the Aki&Richards equations. This procedure is specially interesting because it automatically takes care of possible offset-dependent bandwidth, scaling or tuning effects. Some of the alignments problems across the stacks can be also attenuated using different wavelets for each stack. The fact that no a priori information is introduced beyond that of the low frequency model and the constraints, allow the use of the high-cut filtered well information as a quality control check of the inversion result.

Interpretation Results

Seismic inverted data were loaded and interpreted in a workstation using a volumetric interpretation software. Reservoirs interfaces had been interpreted previously using the full-stack seismic amplitude cube and the acoustic impedance generated a model based seismic inversion of this data. The validation of the results comparing high-cut filtered log information and the coherence between different data and geological model indicates the obtained results are consistent, increasing interpretation confidence. Fig. 1 shows *Ip* and *Is* data.

Some operations between *Ip* and *Is* volumes were produced. The volume generated with *Ip-Is* was the one with best results for reservoir characterization. *Ip/Is* ratio do not presented any good result, being visualized in 3D as scattered cloudy points in all volume for any transparency value.

Reservoir top reflector is strongly negative (reversed SEG standard), or is a low impedance layer in acoustic inversion data. Some shales or more intercalated portions of the reservoir show acoustic response similar to the good reservoir portions. However, this facies can be easily identified and mapped using *Ip-Is* cube. The Turonian reservoir occurrence limits, that wedges toward northwest, were more evident in these data. The Santonian reservoir appeared discontinuous, as in the actual model. Limits and communications between Turonian and Santonian sandstones were enhanced. Sections between wells of worse quality reservoirs and the central region of the field, with better quality, show a coherent behavior with this model (Fig. 3).

After initial interpretation, in the 3D volume, using transparence techniques, a good correlation between the smallest values of *Ip–Is* and the oil presence in the reservoir was verified. It is noted that all oil saturated sandstones, from different depths and ages, presented similar values in *Ip–Is* cube, that are different from the values of water bearing sandstones and non-reservoir rocks. Then, well drilled outer from the opacity generated bodies, that corresponds to oil reservoir zones, would probably be dry (Fig. 2).

Conclusions

Reservoirs with complex stratigraphic relationships, including various oil/water contacts, could be better characterized using P and S-wave data derived from the simultaneous inversion of multi-angle partial stacks. It's possible to build better reservoir quality and predominant facies models using this elastic inversion data. One aspect that has been beyond the expectations is the relation between *Ip* and *Is*, used successfully to distinguish oil and water bearing reservoirs. At last, it has been verified that field exploitation could be improved with elastic data interpretation and incorporation of these data in the geological model.

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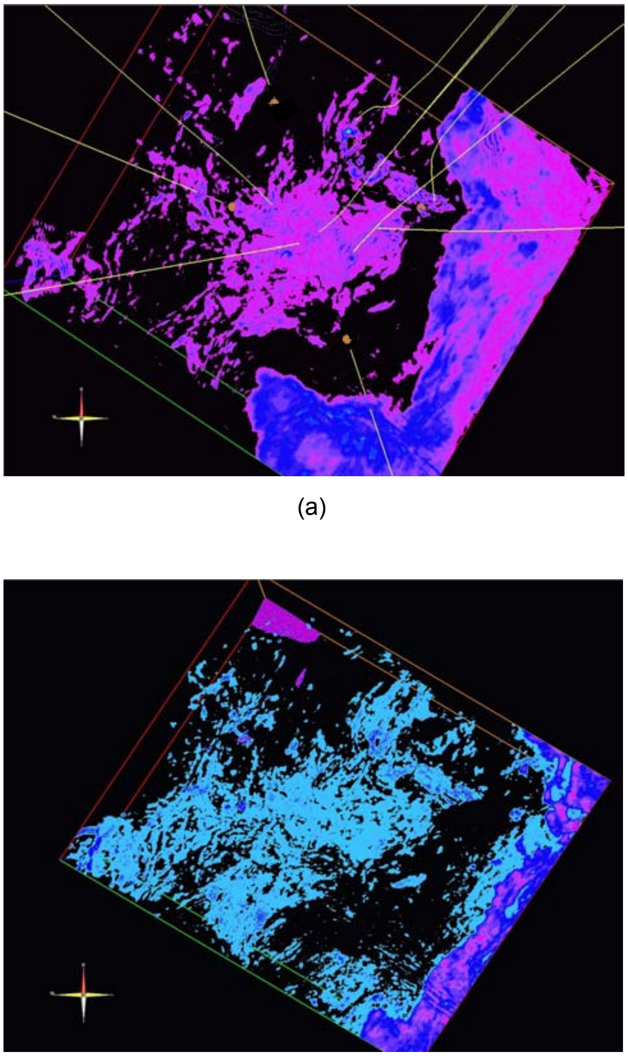
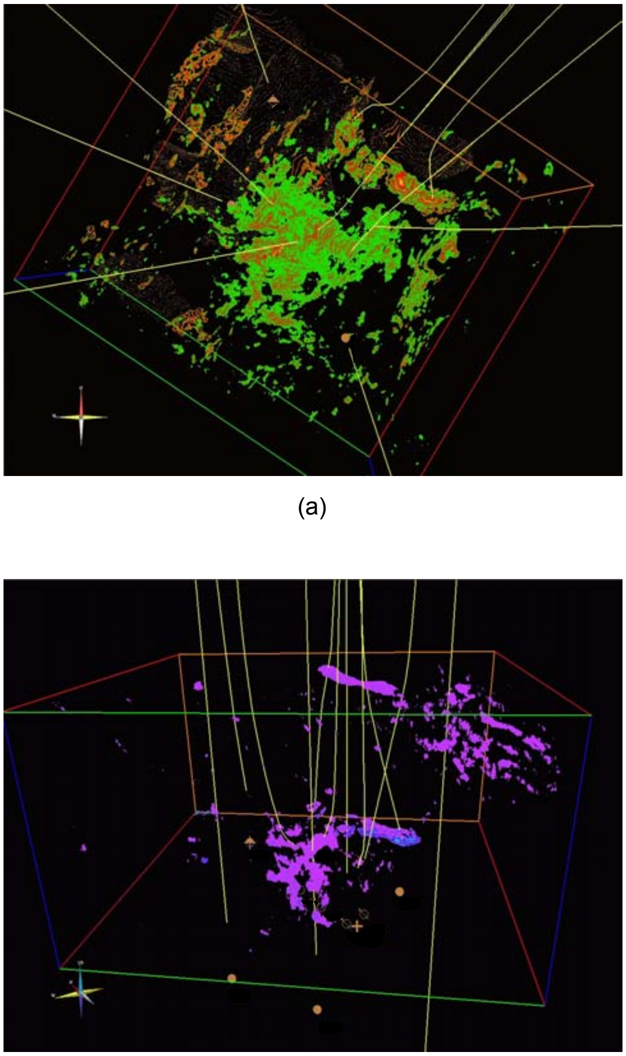


(a)

(b)

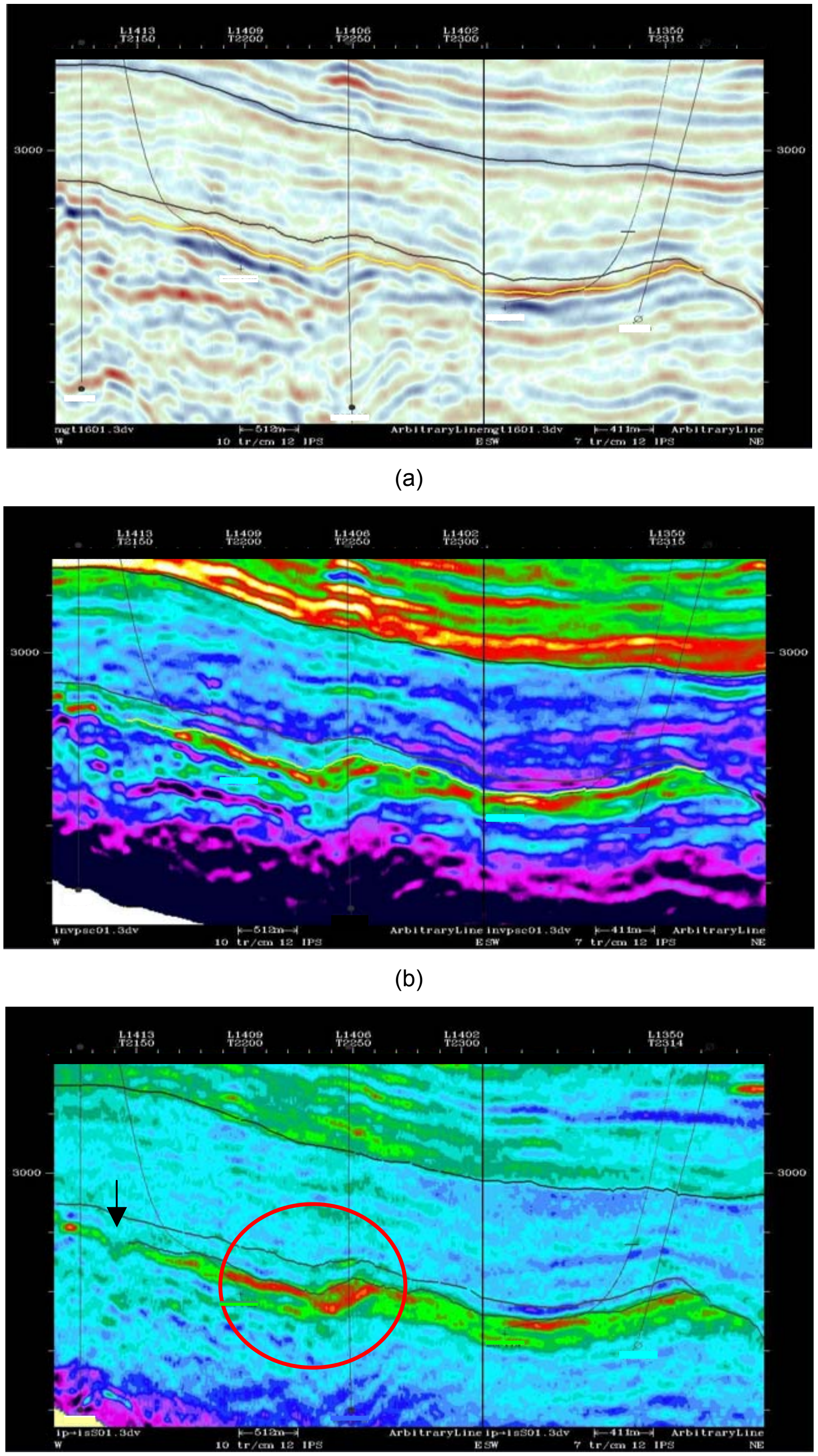
Fig. 1 **–** Impedance volume using transparency (reservoirs impedance opaque), upper view, showing Cretaceous reservoirs . (a) *Ip* and (b) *Is*.



(a)

(b)

Fig. 2 –*Ip*-*Is* volume using transparence (reservoirs impedance opaque) - (a) upper view and (b) southwest view.Using this criterious, all the oil reservoirs, from Cretaceous and from Tertiary, can be identified.



(a)

(b)

(c)

Fig. 3 –Acoustic impedance (a), *Ip* (b) and *Ip-Is* (c) seismic sections. Despite the likeness showed by all attributes, *Ip-Is* volume is the one that better fits well and production data, showing the separation between different reservoirs (arrow), and indicating the better reservoir portion (red circle).