# Interpreting multicomponent seismic data: Clastic and carbonate case histories

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## SUMMARY

Analysing both the compressional (PP) and converted (PS) wavefields from a multicomponent seismic survey can provide more information about subsurface structures, lithologies and their fluid saturants. This paper discusses the techniques of jointly interpreting P-wave data in association with converted-wave seismic data. The methods include log analysis, generation of synthetic seismograms, VSP correlation, along with registering, picking, and calculating ratios of the PP and PS sections. Two cases of oilfields in clastic (sand-shale) environments are discussed - the Cambay Basin, India and the Williston Basin (Ross Lake), Saskatchewan. In addition, two carbonate cases are considered from the Cantarell oilfield in Mexico and the Lousana field, Alberta. Vp/Vs values from traveltime thickness (isochron) ratios are especially useful for characterizing lithologies.


## INTRODUCTION

Many of the current exploration or development targets in the resource industry require quite detailed information about the subsurface. Can we remotely determine actual rock type, sand versus shale or dolomite versus limestone, for example? Can we refine our structural image? Can we detect the presence of fluids? P-wave imaging has been enormously useful in these pursuits, but additional information in the form of S-wave properties can improve the understanding of the subsurface. This paper discusses four cases in which multicomponent seismic data was used to assist in the search for hydrocarbons: two of the examples deal with clastic reservoirs and two with carbonates.

### Methods

In a project which has multicomponent seismic data, we first interpret the P-wave data to the fullest extent possible. This involves our classic techniques of geological review of the area, log analysis (assuming we have well information) and editing, synthetic seismogram generation, and correlation of the synthetic seismograms with the surface seismic sections or volumes. Having VSP data for in situ seismic values and correlation is a welcome bonus. We pick horizons of interest to create time structure maps, determine time-thicknesses between horizons, look for amplitude features, and perhaps undertake inversions. We're seeking geological understanding, anomalies, and reservoirs. With multicomponent data, we next take our logs and construct PS synthetic seismograms. If we don't have an S-wave log then we can estimate one using empirical Vp-to-Vs relationships, VSP velocities, a geological model, or a gross PP-to-PS section mapping function. Now, we'll correlate the PS synthetic seismogram to the PS section (usually in native PS time). In this way, we have a consistent geological model as represented by the well logs. We might shrink the PS sections in time by some factor (say 1.5 to 4) to see if we can find a compelling approximate correlation with the PP section. The Vs model and correlations may now be refined to better register the PS sections with the PP sections. A result of this refined correlation will be a macroscopic Vp/Vs function varying in depth for each surface location. We could output the PS sections in PP time for further horizon correlations and Vp/Vs extraction. In both PP and PS time, we can assess the PS data for all of the features that we sought in the PP data: time structures, amplitudes, anomalies, etc. In some cases, the PS data may actually be more resolved or indicative of the target that we seek. This workflow is shown in Figure 1.

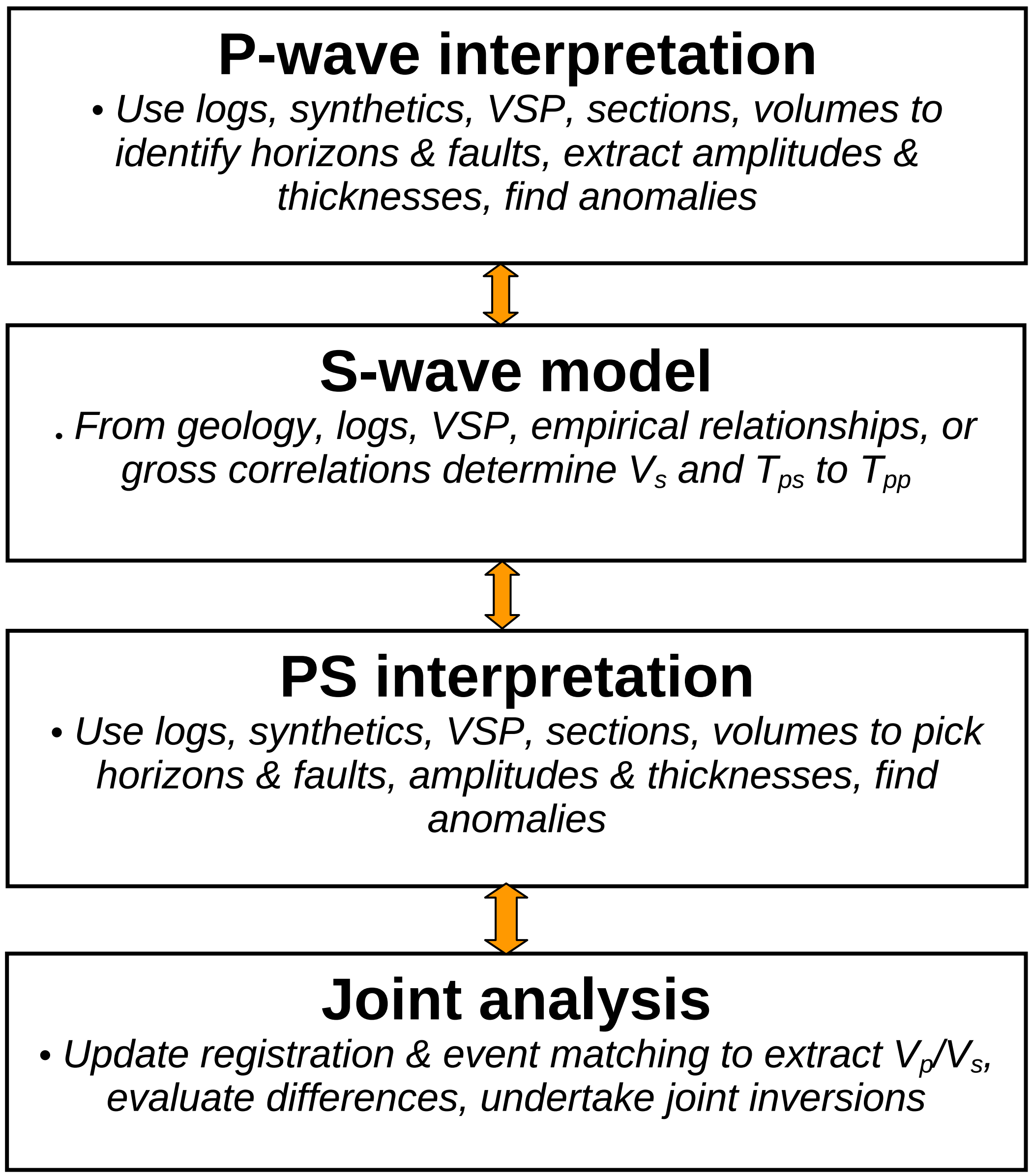


FIG. 1. Multicomponent seismic workflow including PP-and PS-wave interpretation plus joint analysis.

## CASE HISTORIES - CLASTICS

Let's now apply the multicomponent seismic workflow to several case histories. The first example is from Husky Energy Inc.'s Ross Lake heavy oilfield in Saskatchewan, Canada (Stewart et al., 2007). The target is a lower Cretaceous incised-valley channel sand at about 1150m depth. The high porosity (over 30%) and high permeability (3 Darcy) sand can be over 30m thick with a sizeable heavy oil zone. The well logs (from the 11-25 well), synthetic seismograms for both PP and PS, and the proximal seismic sections are shown in Figure 2. We note the significant increase in Vs as we enter the sandstone reservoir (between the IHACM and Rush Lake horizons). The Vp change is less pronounced and thus, there is an accompanying drop in the Vp/Vs value. We use these observations to attempt to delineate the sand-rich areas in the clastic environment.

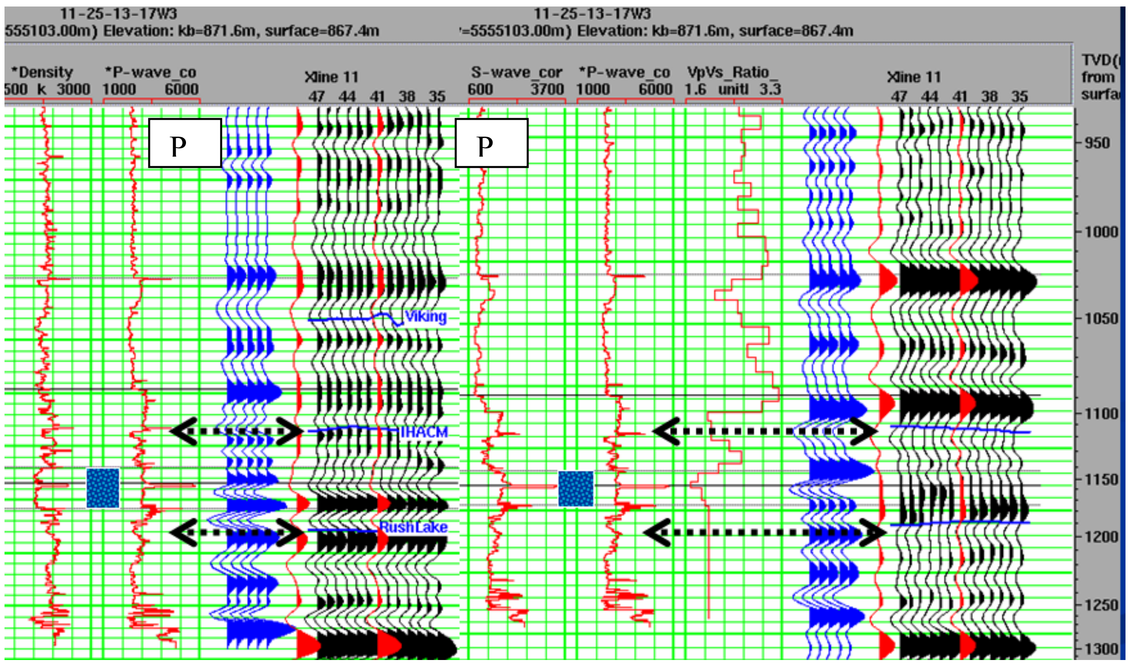


FIG. 2. Compendium of well logs (11-25 well), synthetic seismograms, and proximal surface seismic sections for PP and PS waves (Xu and Stewart, 2006).

A 3C-3D seismic survey, using a dynamite source and VectorSeis recording system, was conducted by Husky and VeritasDGC in the summer of 2002. Both PP and PS data sets were processed through migration. The arrows in Figure 2 indicate time horizons, which bound the reservoir, that are picked on both the PP and PS data. The interval between them (the time thickness or isochron) for the PP data is shown in Figure 3. The thick areas (in yellow and green) are interpreted to be the less compactible channel sands.

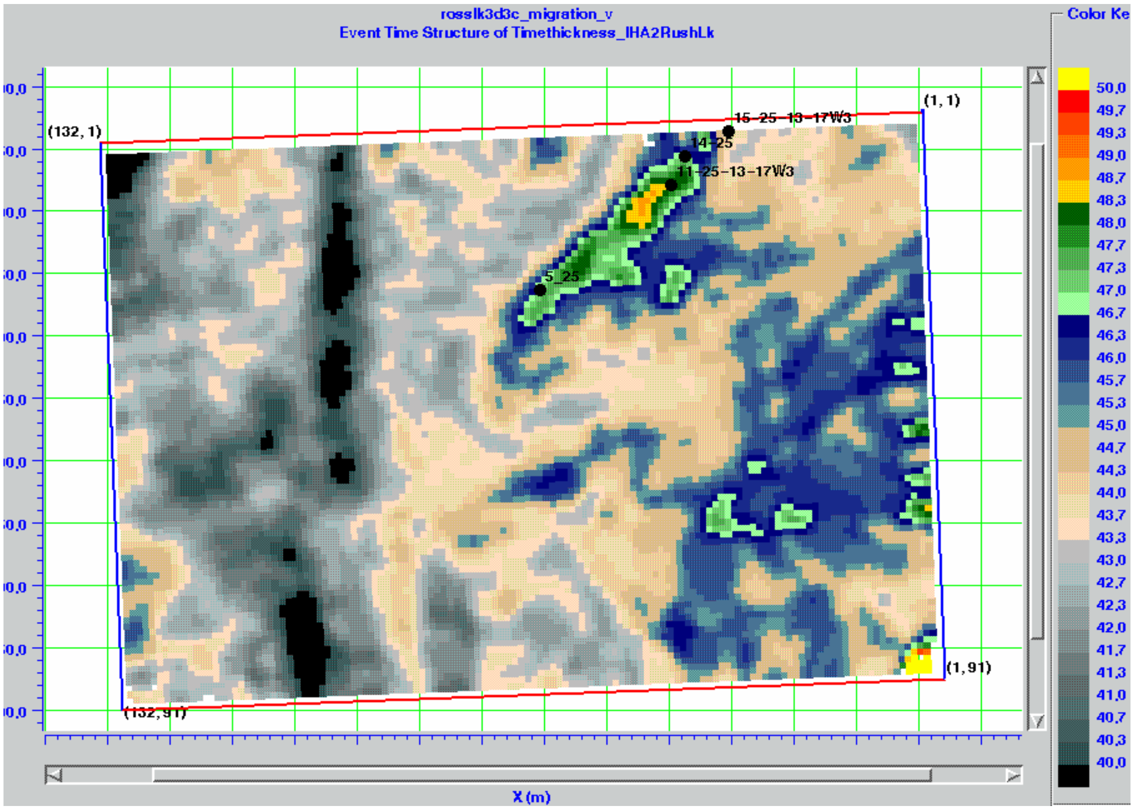


FIG. 3. P-wave time thickness (sometimes called an "isochron") surrounding the reservoir region. The thicker area is intepreted as a less compactible sand channel in the midst of shale-rich rock.

When we take the ratio of the PP and PS time thicknesses around the reservoir, we can calculate the interval Vp/Vs (Figure 4). Relatively low Vp/Vs values are considered to be an indicator of sand development. Both the P-wave time thickness and the Vp/Vs map indicate a good sand body stretching from the SW to NE at the top of the map – which has been confirmed by a horizontal well. We also undertook PP and PS amplitude inversions (for impedance) to further identify the reservoir. The ratio of the so-determined P and S impedances gives us another indication of the Vp/Vs value. The inversion results outlined a similar area for enhanced sand as did the time-thickness analysis.

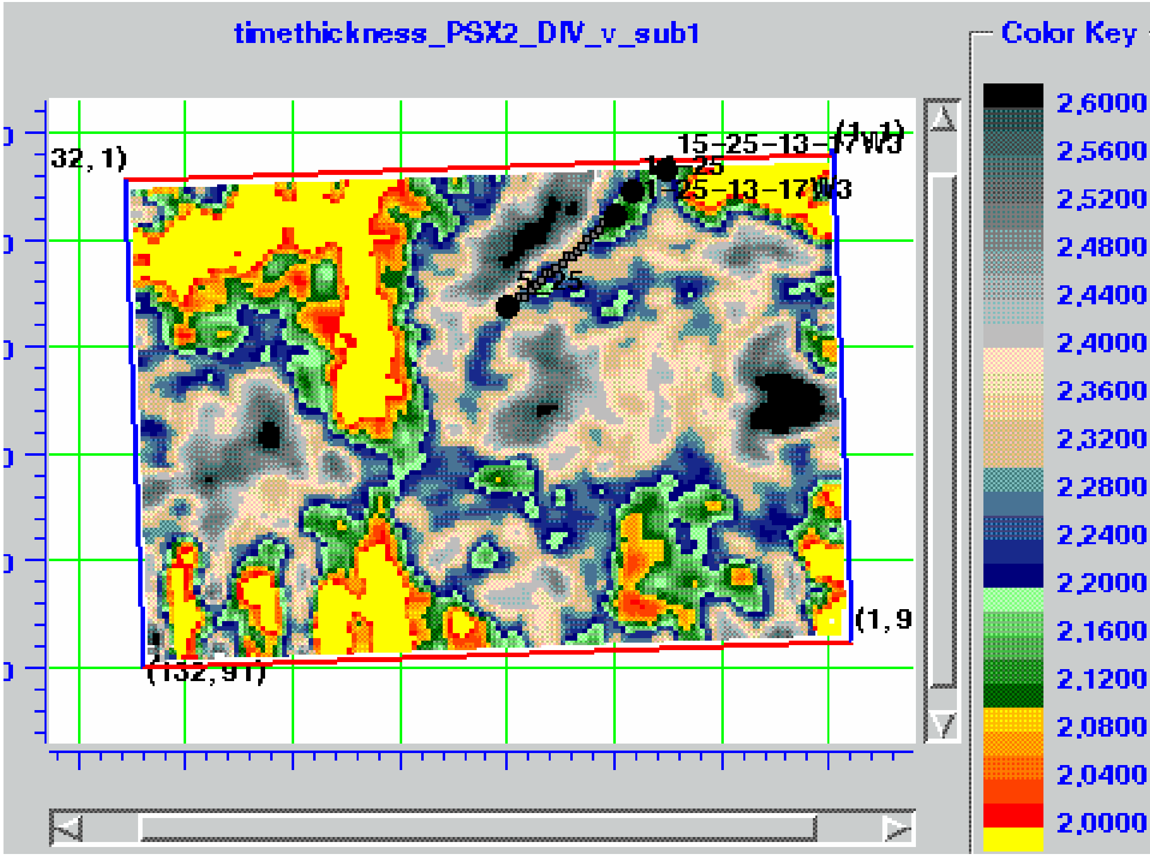


FIG. 4. The Vp/Vs value determined from a ratio of the PP and PS time-thicknesses (isochrons) surrounding the reservoir. The green area in the northeast corner has a lower value and is interpreted as a sand-rich region.

We'll now move across the Pacific Ocean to another clastic envoironment – that of the Cambay Basin, Gujurat in northwest India. The Cambay Basin is an intracratonic rift graben formed during India's northward tectonic drift after the Cretaceous breakup of Gondwanaland. The basaltic Deccan Traps form the floor of the basin and are overlain by Tertiary and Quaternary sandstones, siltstones, claystones, coals, and shales (some of which are major oil producers). The first multicomponent seismic survey (to my knowledge) to be conducted in India was undertaken by ONGC and Geofizyka Toruń in the Basin (Zabik and Podolak, 2006; Lukaszewski et al., 2006). A number of orthogonal 2D-3C dynamite lines were shot and processed. The targets are thin lenticular, oil-saturated sand bodies encased in sequences of coals, shales, and silts. We once again take the well logs and generate synthetic seismograms. There were several VSPs and they were also used in the interpretation. We correlate the P-wave data as shown in Figure 5.

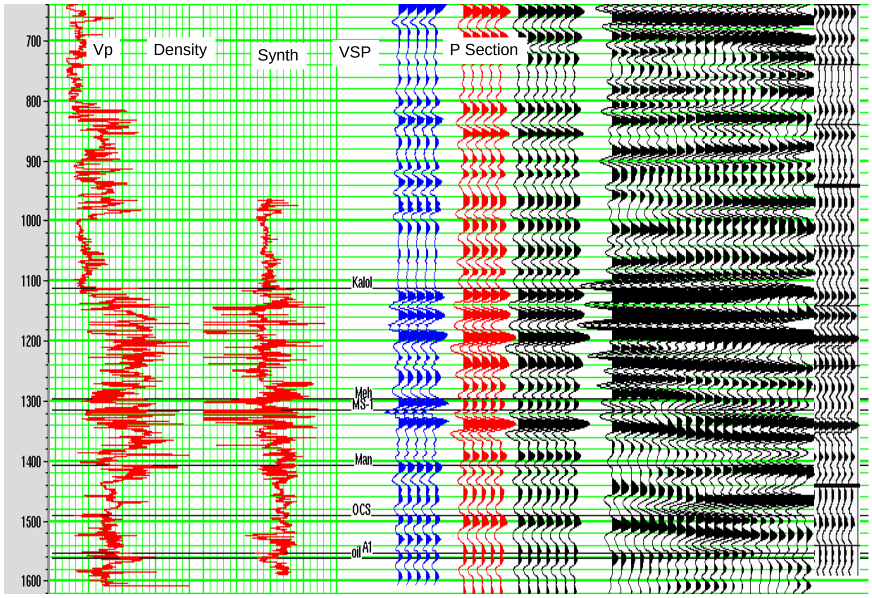


FIG. 5. Logs, PP synthetic seismograms, VSP, and PP surface seismic from the Cambay Basin, India.

Similarly, with a dipole sonic log, we generate PS synthetic seismograms and correlate with the PS surface data (Figure 6). Using the correlations at specific wells, we tie all of the 2D lines into a consistent set of horizons.

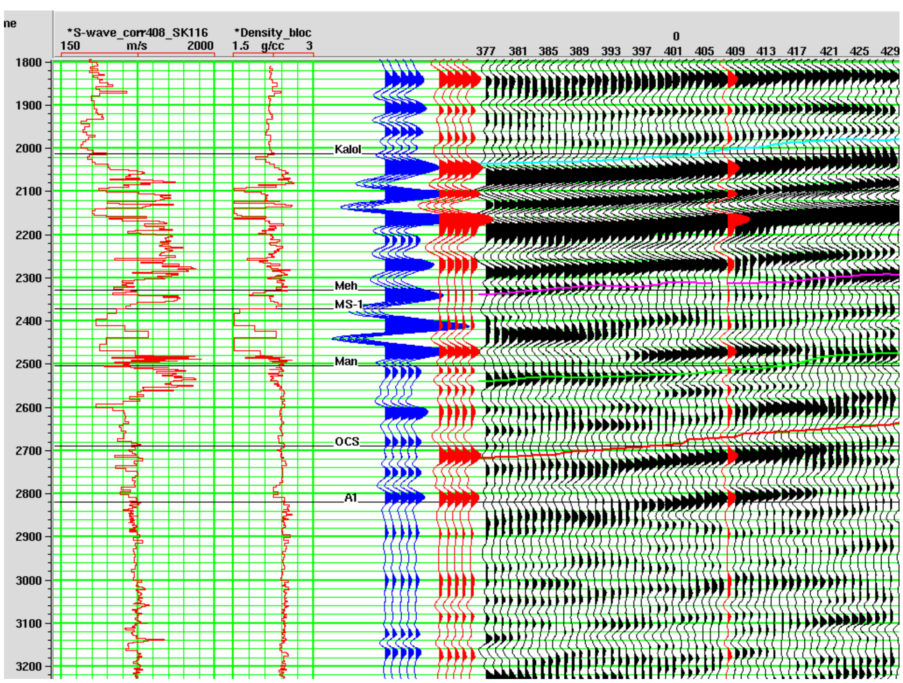


FIG. 6. Logs, PS synthetic seismogram, and PS seismic section from the Cambay Basin, India.

Then, from the picked horizons in the zones of interest, we generate time thicknesses. From the ratio of the PP and PS thicknesses, we can generate a Vp/Vs map (Figure 7). We interpret this map as an indicator of sand enrichment. It can be used with other geologic, petrophysical, and seismic results to assist in further hydrocarbon development of the area.

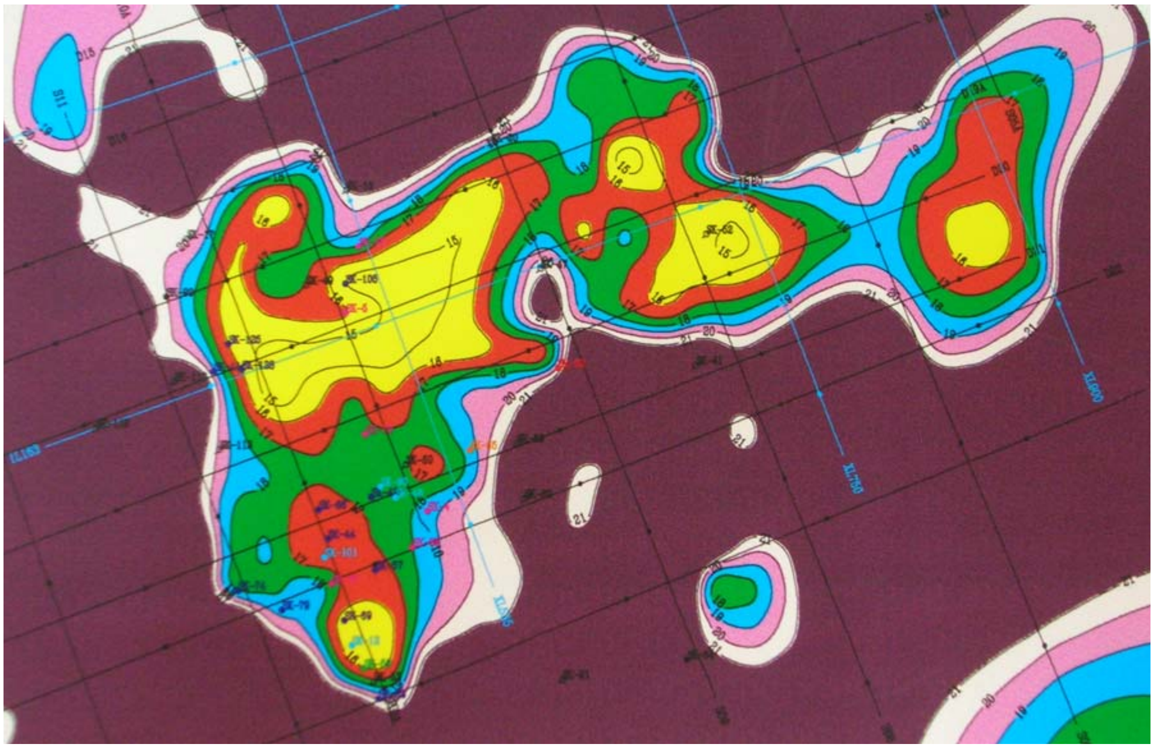

FIG. 7. Vp/Vs map as inferred from a number of 2D multicomponent seismic lines. The yellow and red areas show regions of low Vp/Vs which are interpreted to be sand-rich.

## CASE HISTORIES – CARBONATES

The first of the carbonate case histories concerns a dolomitic reservoir (in the Late Devonian Nisku formation) of the Lousana oilfield, Alberta. The reservoir is separated from the main carbonate platform, to the east, by an anhydrite basin (Miller, 1996). The problem here is to delineate the porous reservoir dolomite from the tight basinal anhydrite. Measurements on dolomite indicate that it has a somewhat lower Vp/Vs value than anhydrite and limestone (e.g., Rafavich et al., 1984). Again, we use PP (Figure 8) and PS synthetic seismograms to correlate the sections.

In the Lousana case, we had no S-wave velocity information (outside of the values determined from surface seismic processing). So, we used a number of Vs values until we could match the character of the synthetic seismograms to the PS seismic data (Figure 9). Then, time-thickness (isochron) ratios were again used to find the Vp/Vs value in the reservoir interval (Figure 10).

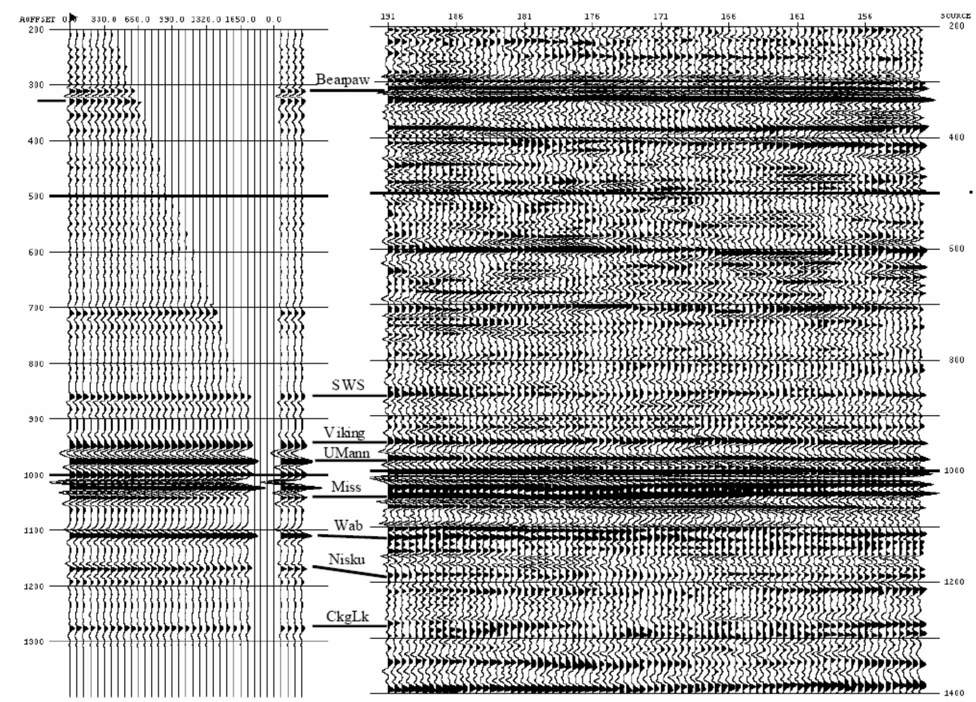


FIG. 8. P-wave synthetic seismogram and correlation with a surface seismic section from Lousana, Alberta.

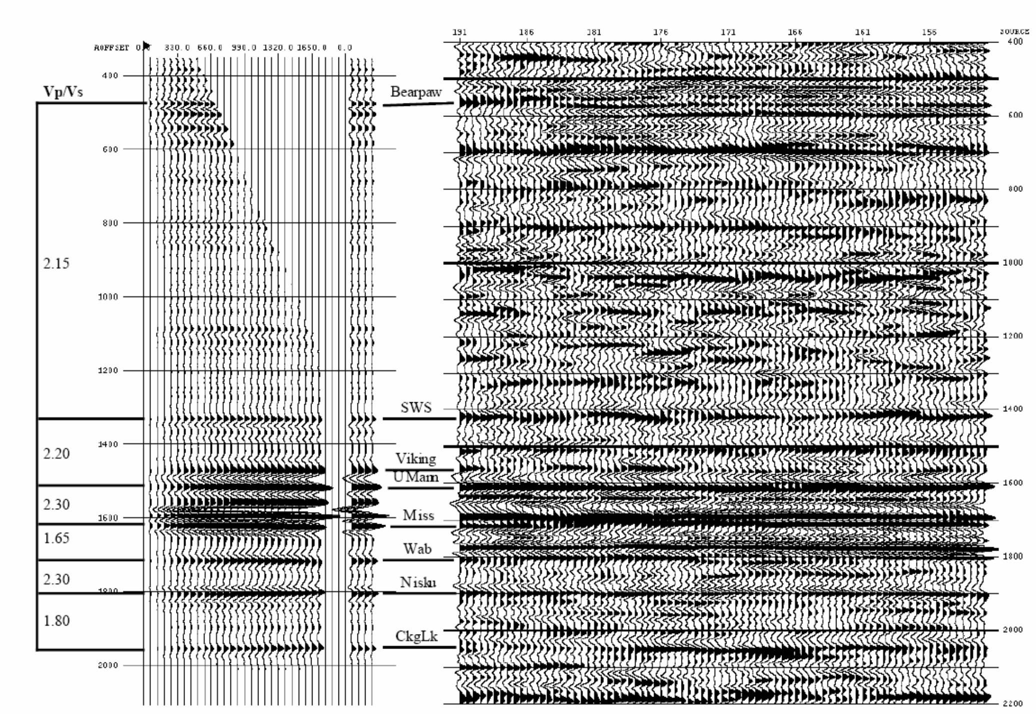


FIG. 9. Converted-wave (PS) synthetic seismogram and correlation with a PS surface seismic section from Lousana, Alberta. Vp/Vs values, which were used to generate the synthetic seismogram, are annotated on the left of the Figure.

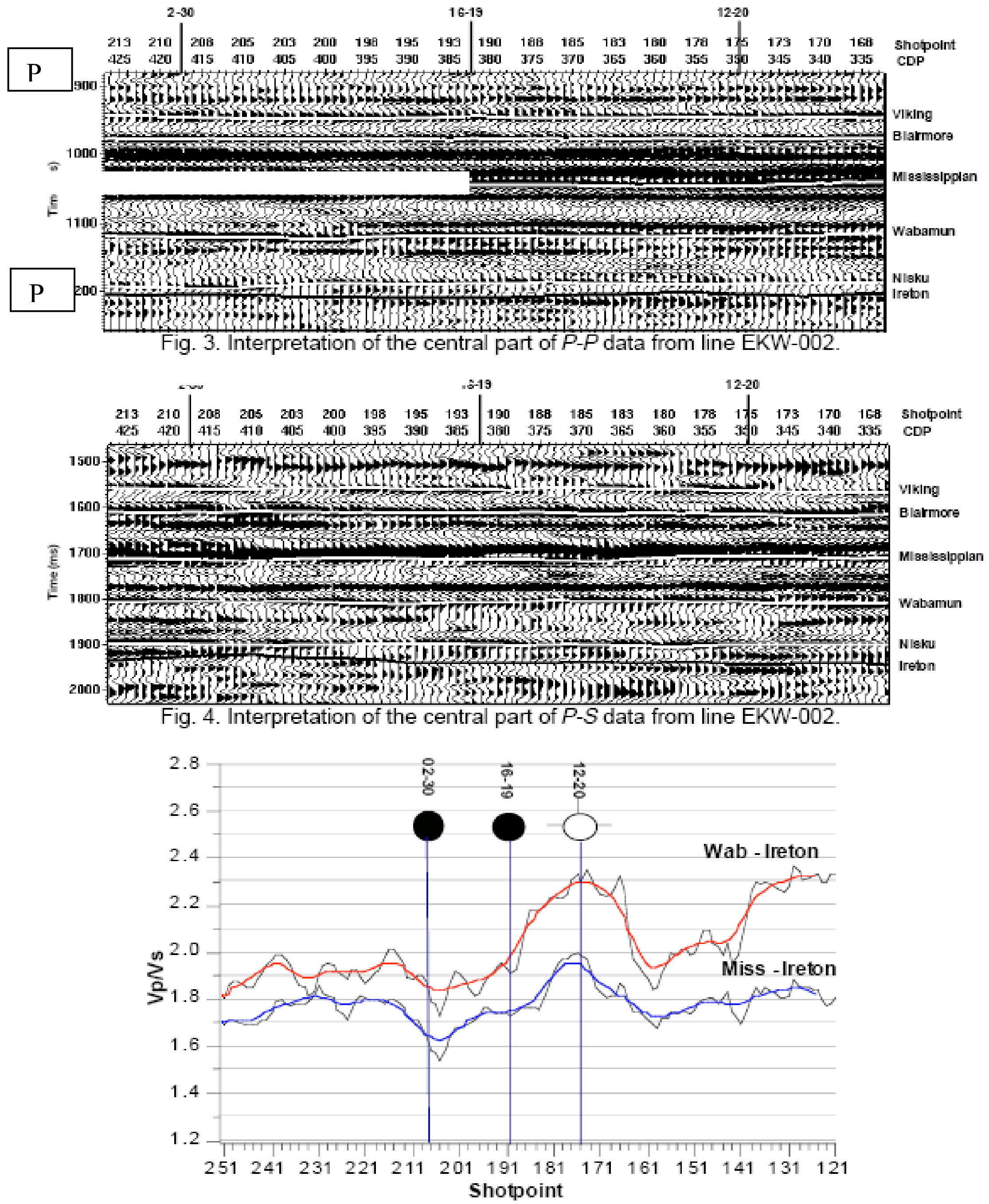


FIG. 10. PP and PS sesismic sections above with interpreted horizons (Miller et al., 1995). The lower Vp/Vs values are interpreted to represent dolomitic regions.

The high Vp/Vs values correspond to anhydrite regions, while the lower Vp/Vs values are associated with dolomite build-up.

The final case history is from one of largest offshore oil reservoirs in the world - Cantarell, Mexico. The Cantarell oilfield is located in the Gulf of Mexico some 80km northwest of the Ciudad del Carmen, Campeche. The region has a complicated tectonic history including major compressional and extensional episodes as well as the enormous

Chicxulub meteorite impact event. The reservoirs are mainly composed of carbonate rocks (Upper Cretaceous breccias and Kimmeridgian shallow dolomitized ramp facies). A large 3D ocean bottom seismometer (4C) survey was undertaken to assist in refining the interpretation of the existing Akal reservoir as well as to search for new targets (Vasquez et al., 2005). Chernikoff et al. (2007) discuss the interpretation of the resultant PP and PS data volumes. The interpretation process once again included assessment of the well logs, construction of Vs values, generation of PP and PS synthetic seismograms, correlation of VSP information, and finally tying these results to the seismic volumes. In Figure 11, we interpret the smeared PP section above the anticlinal structure (the Akal reservoir) as resulting from a "gas cloud" or gas-saturated sedimentary column. The PS image, while lower frequency, gives a continuous top to the reservoir. Figure 12 shows the PP and PS time structures, picked from the PP and PS data volumes, for two of the important horizons – the top of the allochthonous Cretaceous and Kimmeridgian. We can then find the PP and PS time thicknesses and take their ratio.

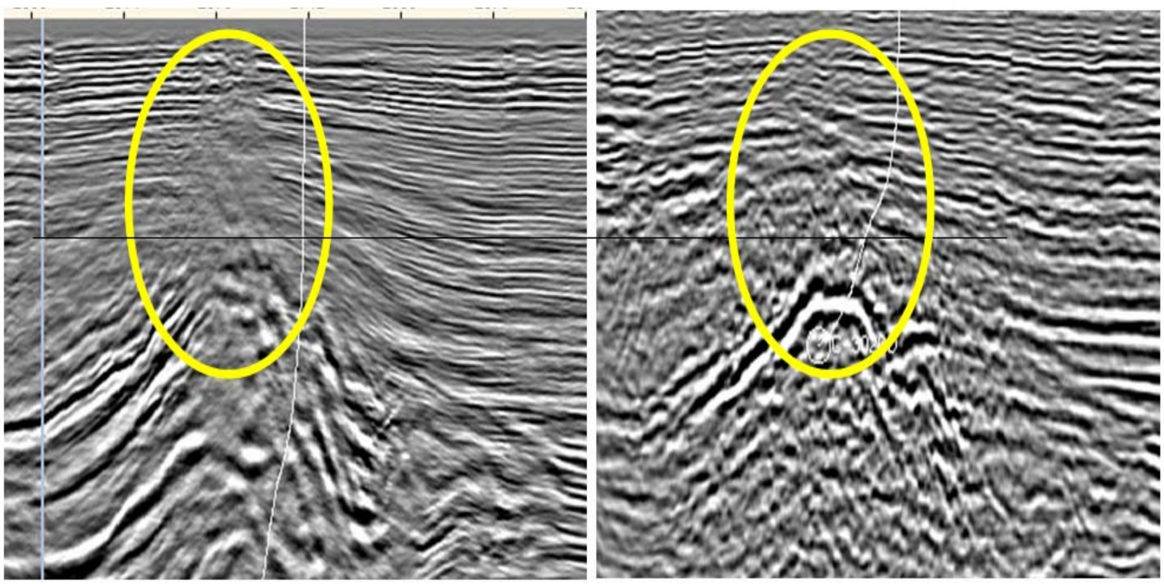

FIG. 11. PP and PS sections over the Akal anticlinal structure (Chernikoff et al., 2007). Note the washed-out area (circled) on the P-wave section over the poorly defined anticlinal peak. The top of the Cretaceous is more definitive on the PS section. This is the classic signature of a "gas chimney".

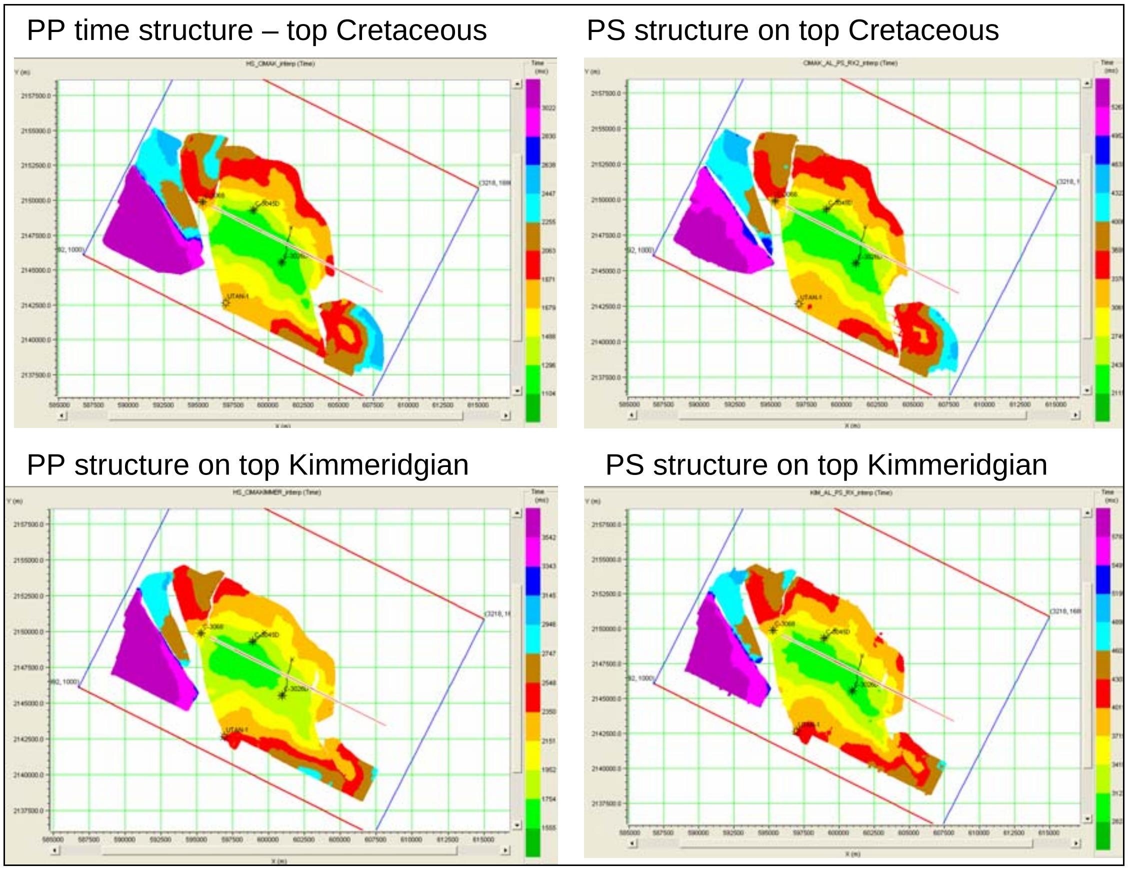


FIG. 12. Time structures for PP seismic volumes and PS volumes on the top of the Cretaceous as well as Kimmeridgian in the Cantarell oilfield, Mexico.

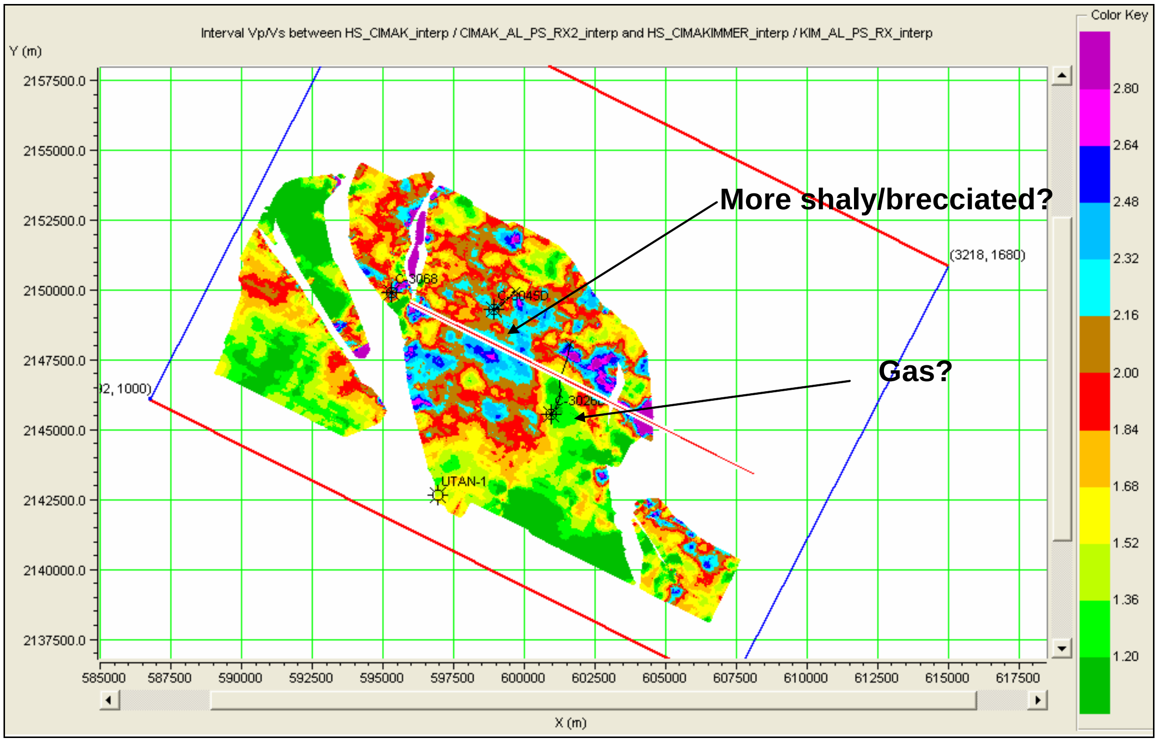


FIG. 13. Interval Vp/Vs map between the Cretaceous and Kimmeridgian horizons in the Cantarell oilfield, Mexico.

The resultant map (Figure 13) is interpreted to show the effects of greater shaliness as well as possible gas saturation.

## CONCLUSIONS

Multicomponent seismic data (both P-wave and converted wave) can assist in delineating clastic and carbonate reservoirs. The PP and PS images can be interpreted jointly in structural and stratigraphic terms. Vp/Vs values, as computed from time-thickness ratios, have proved useful in estimating rock type as well as delineating reservoirs. Multicomponent seismic data, in the four cases discussed here, assisted in understanding and delineating potential as well as known reservoir areas.

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