Unearthing New Layers - Crosswell Seismic Redefines Seismic Imaging in Bunyu Field, Indonesia

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SUMMARY

Surface seismic is fundamental information for reservoir mapping and in-fill drilling decisions. A good seismic is critical to successful development of a field. However, at times, the surface seismic is of degraded quality due to various reasons which makes the mapping and interpretation of the reservoir layers difficult and uncertain. Near-surface conditions such as topography, weathering layer adversely affect the surface seismic data acquisition & processing. In Bunyu field in Indonesia, problem is further compounded by the presence of near-surface coal seams which renders seismic to be of poor quality. In order to optimize the field development and boost recovery, enhanced seismic is seen as a fundamental requirement to make informed in-fill drilling decisions.

Crosswell seismic provides high resolution imaging of the subsurface at the reservoir scale. The technology is used for delineating complex structure. It is not affected by the surface conditions as the transmitter and receivers are deployed downhole in separate wells, providing velocity tomogram and reflection imaging between the wells.

Bunyu Field in East Kalimantan is on production since 1950 with declining production over the years. It is primarily a discontinuous sand-shale sequence with shallow coal layers. The existing 3D seismic is of poor quality which makes reservoir interpretation very uncertain. It is difficult to map these channel sands due to poor seismic. Crosswell seismic was thus acquired to complement the 3D seismic information for informed in-fill drilling decisions and field optimization.

Crosswell seismic has provided a dramatic improvement in seismic imaging even at large interwell distances and will be helpful in delineating reservoir and ultimately aid in better in-fill drilling

Key words: Crosswell Seismic, Surface Seismic, in-fill drilling, mature field, field optimization, recovery

INTRODUCTION

Traditionally, measurements in oil & gas industry have inverse relation between formation vertical resolution and spatial coverage. The logs provide hi-resolution information but close to the wellbore while surface based measurements such as seismic & gravity provide field wide spatial coverage at coarser vertical resolution resulting in measurement gap at reservoir scale. Crosswell seismic bridges this measurement gap and provides enhanced imaging of the interwell space at reservoir scale (Figure 1).

Crosswell seismic acquires two basic pieces of information; first, the direct arrivals between source and receivers are used to create a 2-D profile of seismic velocity (velocity tomogram), and second, reflection information from horizons above and below the source and receiver positions to create a structural image between the wells. The combined velocity and reflection imaging provides detailed information about the structure of a given reservoir as well as rock properties. Additionally, mode converted (S) processing will provide additional insight into the reservoir definition.

The case study discussed here is from Bunyu field in East Kalimantan in Indonesia. It is a very difficult seismic area with high surface attenuation due to varying surface topography, unconsolidated weathering layer and presence of near surface coal seams. The formation is dominantly discontinuous sand-shale formations with intercalations of coal seams. Seismic interpretation becomes increasingly difficult as the surface seismic is not of high quality. Structurally, the acquisition area encompasses several major faults that create sub horst-graben features as shown in Figure 2. The map is primarily derived from well log information, since surface seismic data is of poor quality. Crosswell seismic was acquired over eleven (11) profiles, overlain on the structure map (Figure 2). The results of the profiles to be presented in this paper are highlighted in Figure 2 (right).

The interwell spacing of these profiles ranged from 686 m to 1758 m, very challenging distances for the attenuative geological conditions. The profiles were chosen so as to maximize the coverage over the Bunyu field to help in refining the seismic interpretation and potentially to reduce the uncertainty in infill drilling decisions and field optimization. The seismic sections generated clearly show remarkable improvement over the existing seismic despite high seismic attenuation observed in this area.

METHODOLOGY

Crosswell seismic is an emerging technology that provides high resolution imaging of the subsurface at the reservoir scale and is used for delineating complex structure. The technique employs tomographic surveying, whereby a transmitter and receiver are deployed downhole in separate wells. As a result of the inherent source-receiver geometry, interwell velocity profiling and structure can be obtained from direct wave and reflection processing respectively. The inverted velocity tomogram is in reflection imaging processing.

Data Acquisition

The downhole source & receiver technology has evolved over the last decade. Piezoelectric source technology (monopole, 100-2000 Hz) has been supplemented by a more powerful, magnetically clamped source Z- Trac^{TM}, exciting both the compression (P) & shear (S) energy providing resource to advance processing possibilities such as AVA etc. Operating at a frequency range of 30–800Hz, this source produces about 20 dB more amplitude than the traditional piezoelectric source. The source distributes energy produced over an area in the wellbore that is large enough not to cause damage to the casing or cement. The single component hydrophone strings have given way to 3-C geophones resulting in shear imaging capability in addition to conventional compressional imaging. The source and receiver well equipment are synchronized through a fiber optic interface unit. The data in Bunyu field was acquired using Z-Trac^{TM} and 60-level 3-component geophone array (OYO) as the well distances were quite large for these highly attenuative formations. The large receiver array was chosen to reduce the acquisition time to cover large depth interval (200-2000m) as well as to capture the shear energy.

In a typical acquisition both source and receivers are placed at the base of the reservoir or zone of interest. The source is raised and swept until the entire zone is imaged at that receiver station. The result is the recording of a complete fan, which represents the data from all shot positions for a single position of the receiver array. Once done, the receivers are raised to the next station, the source is lowered to the base of the reservoir, and the sweeping process is repeated.

The acquisition parameters such as sweep frequency, sweep length, number of sweeps were determined through pre-job feasibility assessment and modeling conducted to assess the feasibility of technique for given field parameters (well separation distance, interval velocities, and expected attenuation for these formations). However, some of these parameters had to be optimized in the field based on the maximum recorded seismic bandwidth. Based on field data, two set of parameters were chosen for acquiring the data. For interwell distances less than 1000 m, a total of 32 sweeps, each with a bandwidth of 30-200 Hz, were acquired at a depth increment of 7.5 m. In order to improve the SNR for larger well separations in this attenuative environment, the number of sweeps was increased to 128 with a frequency bandwidth of 30-120 Hz. Accordingly, the depth sampling was increased to 15 m as per Nyquist relationship.

Data Processing

The processing flow for crosswell seismic is made up of two major steps (Figure 3); tomographic inversion and reflection imaging.

Since the source tools has 2-axes of excitation of compressional and shear energy which is recorded on a tri-axial receiver, data needs to be rotated into the plane between the wells. The typical raw data after rotation is displayed in Figure 4. A common receiver gather is a set of traces from all source positions for a unique receiver depth location. The compressional and shear arrivals can be clearly identified. Data after the initial pre-processing (time picking, rotations, bandpass filter and wavefield separation) were migrated using the inverted velocity tomogram as the velocity model. A gently dipping structural model based on the formation tops in the wells was used for tomographic inversion.

The tomographic inversion process may use direct arrival travel times, reflected travel times or a combination of both to produce a seismic velocity field. In this case study only direct arrival travel-time information were used for tomographic inversion and resulted in two tomograms or velocity fields (P&S). The seismic velocity field from the tomographic inversion also serves as the high-precision velocity model for reflection imaging. The final reflection image product is generated in depth.

During the reflection imaging step, data is processed in time and depth domains. The time-depth transformation is made through ray tracing of the optimal velocity field previously generated. Wavefield separation is performed in the time domain and refers to removing arrivals other than the reflection events in the data set. Crosswell seismic processing methods are a hybrid of multi-fold techniques used in surface seismic processing and wavefield separation and imaging methods from VSP data processing. The general workflow in depth domain includes: VSP-CDP mapping followed by a pre-stack, post-map migration and finally an angle selection for incidence angles to be used in final stacking. A significant advantage in crosswell seismic data is the high fold available for stacking the reflection data. Stacking attenuates many of the unwanted arrivals in the crosswell wavefield.

In this project, independently processed upcoming and downgoing P-wave reflection sections were merged to produce a final reflection seismic section. The use of both upcoming and downgoing reflection data allows image coverage of the full reservoir section and the zone above the reservoir. Additionally, S-Wave processing was performed for some profiles.

RESULTS

The results of profile P11 (well I-F) are presented in this paper. This profile is of significant importance as it passes a recently drilled producer (Well J, Fig 2) and Pertamina wants to further exploit this part of the field. Figure 5 shows a gd correlation between inverted crosswell tomogram for this profile and sonic velocities in well J. It is important to note that well J has not been used in any sort of processing.

Figure 6 compares the crosswell reflection seismic for profile P11 (well I-F) with the extracted seismic line along the profile. A synthetic (blue trace) computed from sonic log in existing well J is also superimposed on crosswell & seismic profile in this display. The synthetic trace shows very good correlation with the crosswell reflection image. It can thus be said that the crosswell provides better geological detail of the sub-surface. On the other hand, it is difficult to trace the reflections on the surface seismic.

Seismic attribute analysis can further enhance the value of crosswell seismic. Relative acoustic impedance (RAI) links the reflection series to porosity & fluid content and is helpful in identifying apparent acoustic contrast, unconformity surfaces and discontinuities. Relative acoustic impedance was computed from the crosswell reflection section in order to enhance the interpretation & delineation of potential reservoir sand. The reservoir sand delineation is enhanced by combining the interpretation on crosswell reflection seismic and its AI section as displayed in Figure 7. A potential hydrocarbon bearing zone (Figure 7) was identified in the petrophysical analysis in well J but was not tested. It was difficult to track this potential reservoir in the surface seismic. The crosswell seismic very nicely delineates this potential sand body as can be seen from the reflection as well attribute display. The work is still in progress but the match of the crosswell seismic attribute with the gamma ray log is very promising.

All crosswell seismic profiles have provided much more structural & geological details and show some stratigraphic features not seen on existing seismic. A random line connecting different crosswell profiles (P6, P7, and P8 Figure 2) has been displayed in Figure 8. Figure 9 shows the re-processed surface seismic along the same profiles. It can be inferred from Figure 8 & 9 that the crosswell seismic reveals much more detailed reflectivity than the corresponding seismic and has a potential to reveal the unseen before and will be helpful in refining the seismic interpretation in this field. The work is still in progress.

CONCLUSIONS

The crosswell profiles exhibit significant improvement in the seismic imaging in Bunyu field. The images reveal new stratigraphic plays that were not visible before in the existing seismic and achieve the overall project objective. The crosswell migrated sections and the related attributes such as RAI will provide useful data for in-fill drilling location identification and field optimization.

WORK IN PROGRESS

The data is still being integrated along with the surface seismic and the logs to enhance the process of in-fill location selection. The reprocessing of surface seismic is also being undertaken to maximize the value of integration. The crosswell tomogram may also be used to update the 3D seismic velocity model which could be used in re-processing of 3-D seismic data. New in-fill locations will be identified once the data integration and interpretation is completed.

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Figures

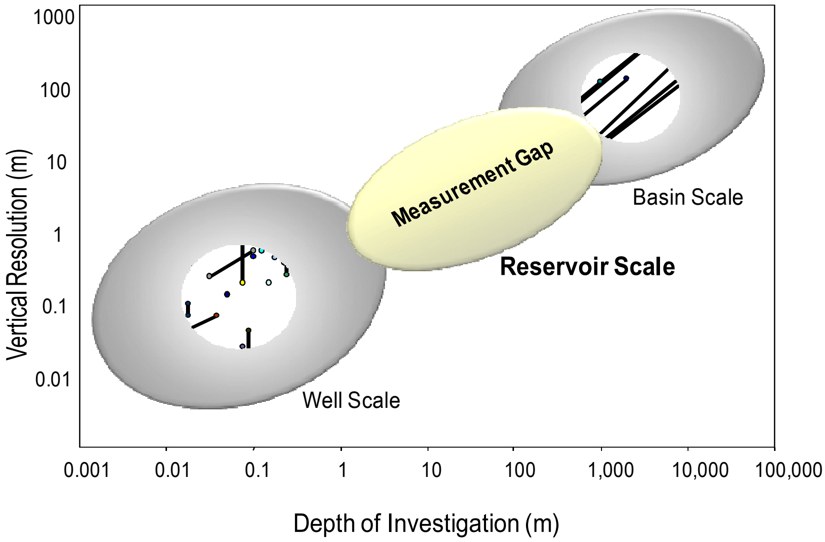

Figure 1 : Crosswell measurements bridge the gap (yellow zone) between the well and basin scale.

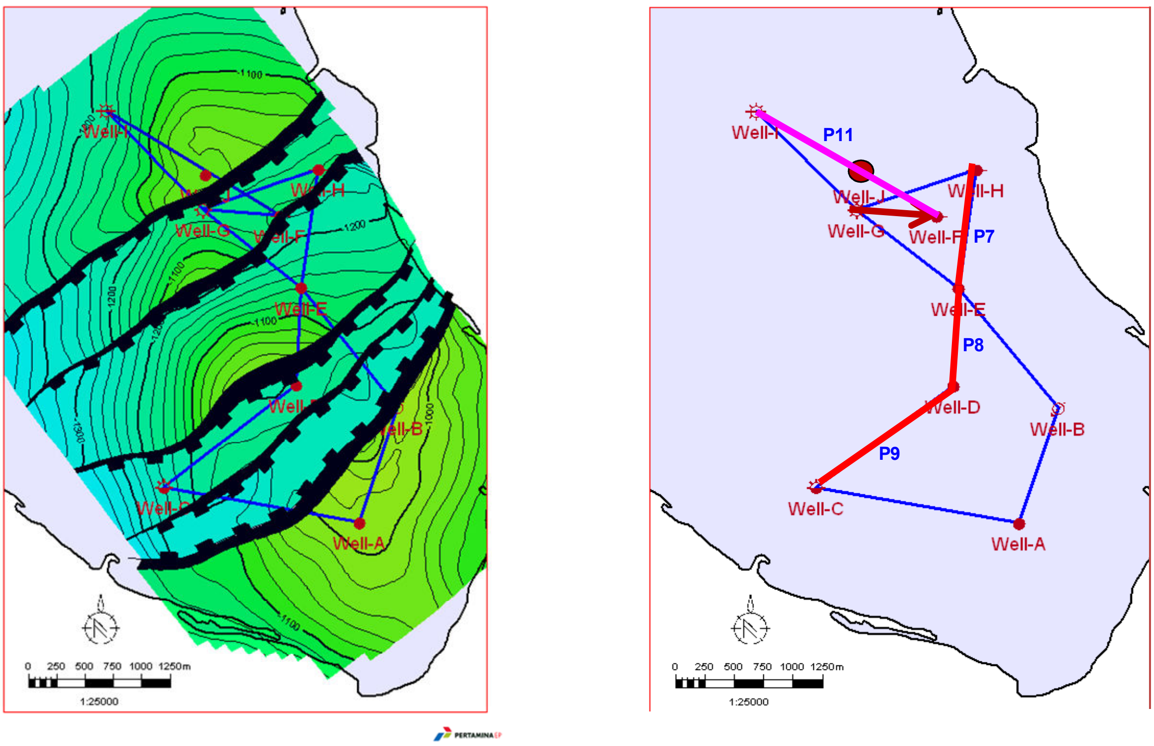

Figure 2 : Map of the Crosswell Seismic Profiles overlain on the structure map. On right are shown highlighted profiles (pink & red) whose result are discussed in this paper.

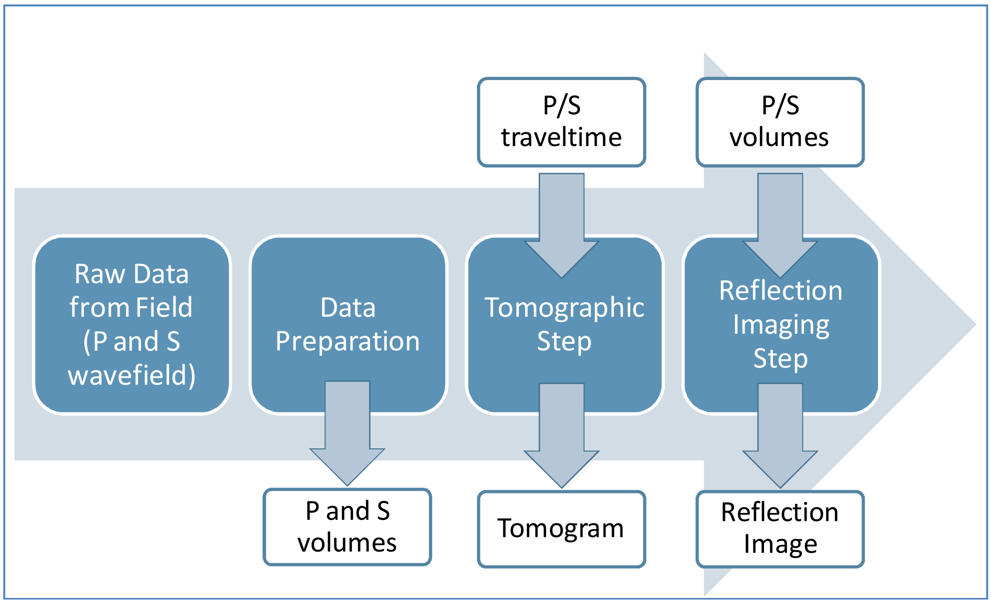

Figure 3: Crosswell seismic processing workflow applied in Bunyu Field. P-wave processing was executed for 11 eleven profiles and S-wave processing for selected profiles in the area.

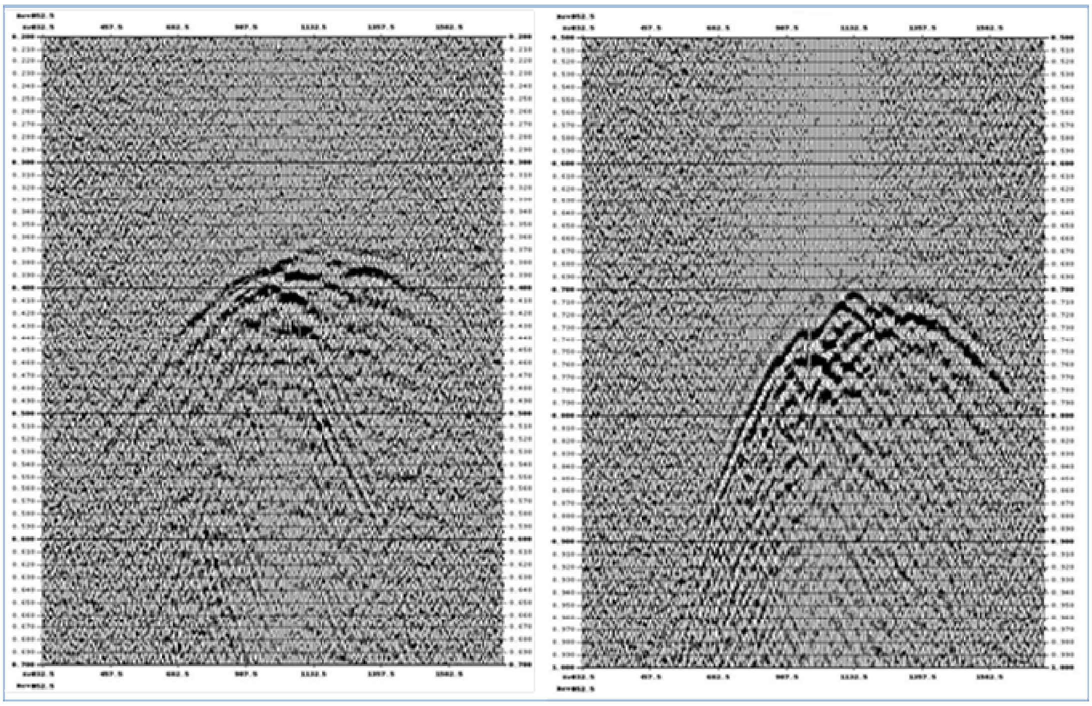

Figure 4 : Raw Data (Common Receiver Gather) showing compressional arrivals (left) and Shear arrivals (right). The horizontal axis represents increasing source depth and travel time on represented on vertical axis. Note the time axis is different for the compressional & shear displays.

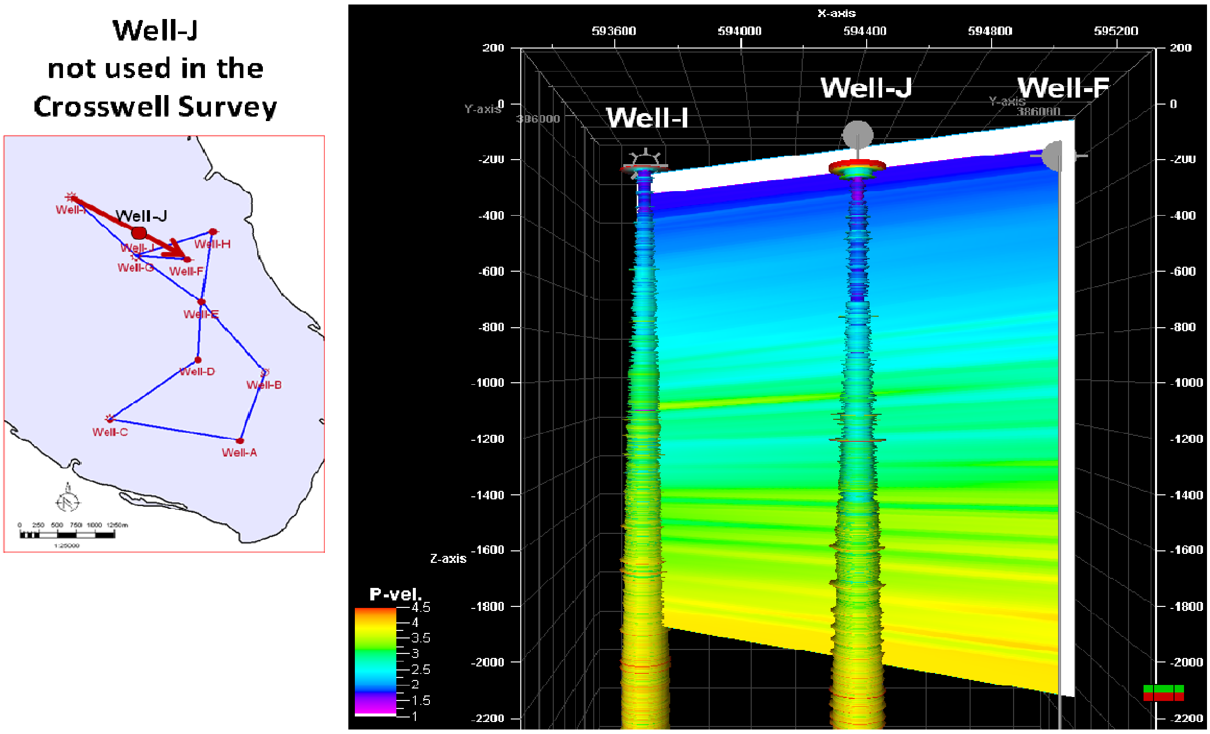

Figure 5: Compressional tomogram (Km/s) for crosswell profile I-F. Vp from a blind well-J in the vicinity of this profile is overlain in the center, Well J is not included in the inversion process. Vertical axis is Depth in meters.

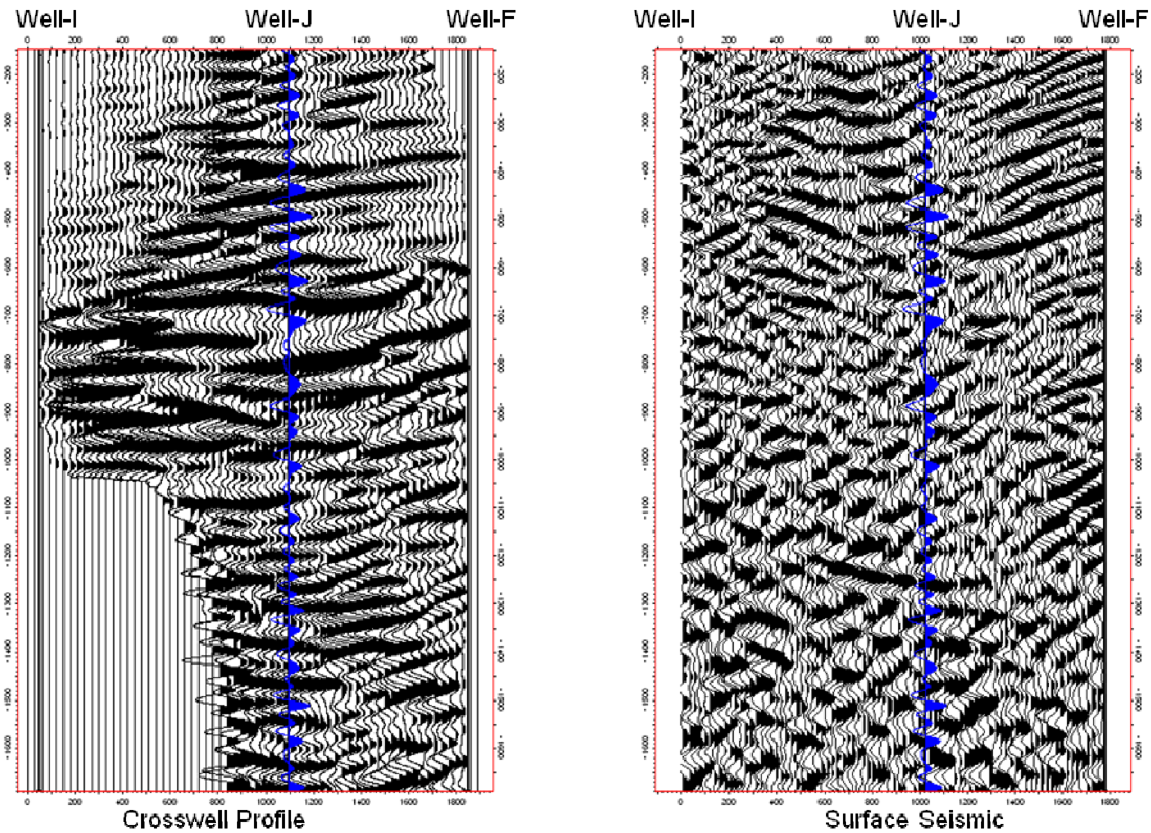

Figure 6: Crosswell Seismic Profile (left) and the surface seismic profile (right) for profile P11(Well I-F). The blue trace represents the synthetic computed from sonic log in well J in the vicinity of profile.

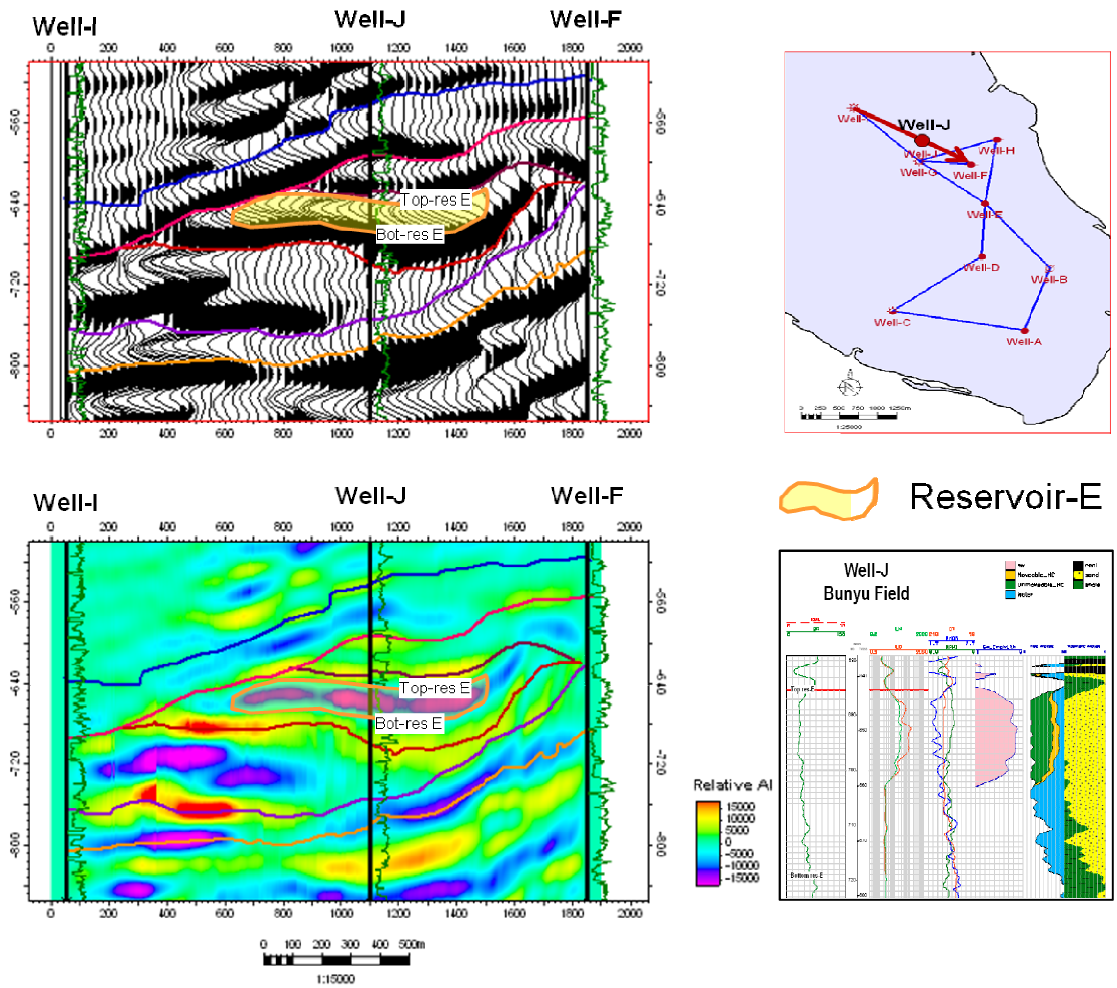

Figure 7: Preliminary structural and advanced interpretation of crosswell reflection profile between wells I and F. Sequence boundaries and GR log correlation with the reflection seismic (top) show potential sand pinchouts in the region of Well J (highlighted lens section). The bottom image shows the same interpretation overlain with relative acoustic impedance attribute - useful for identifying intra reservoir detail. Bottom right shows the petrophysical evaluation with hydrocarbon potential. Vertical axis is Depth in meters.

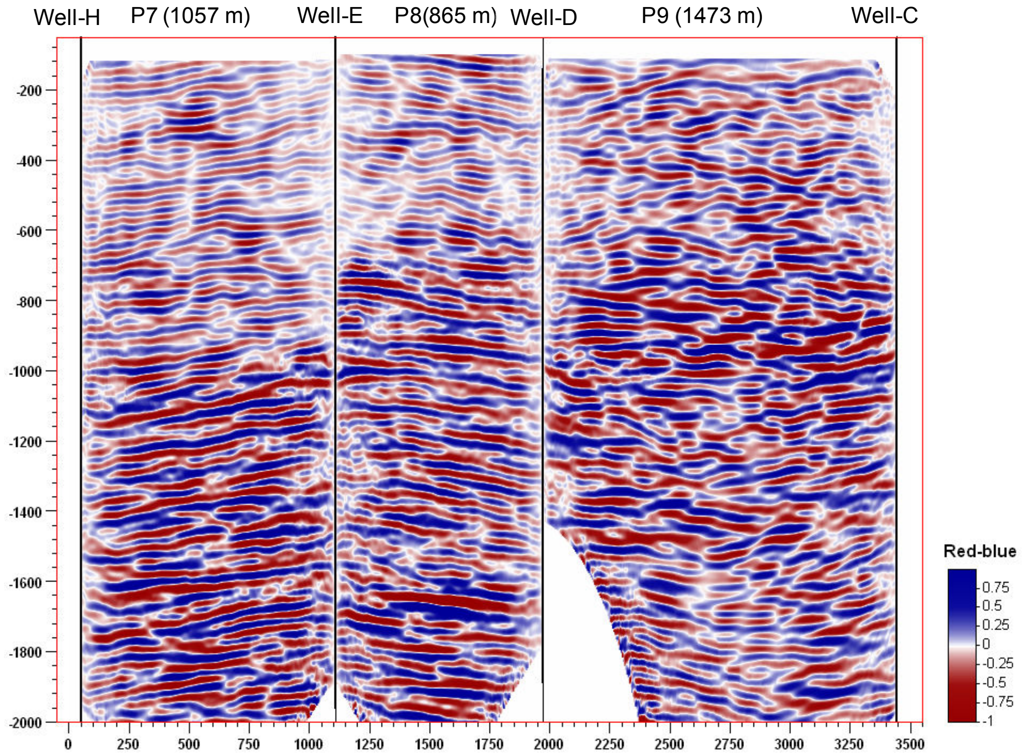

Figure 8: Crosswell reflection image panel comprising three profiles P7,P8 & P9. Vertical axis is Depth in meters. The annotated distance is the distance between wells.

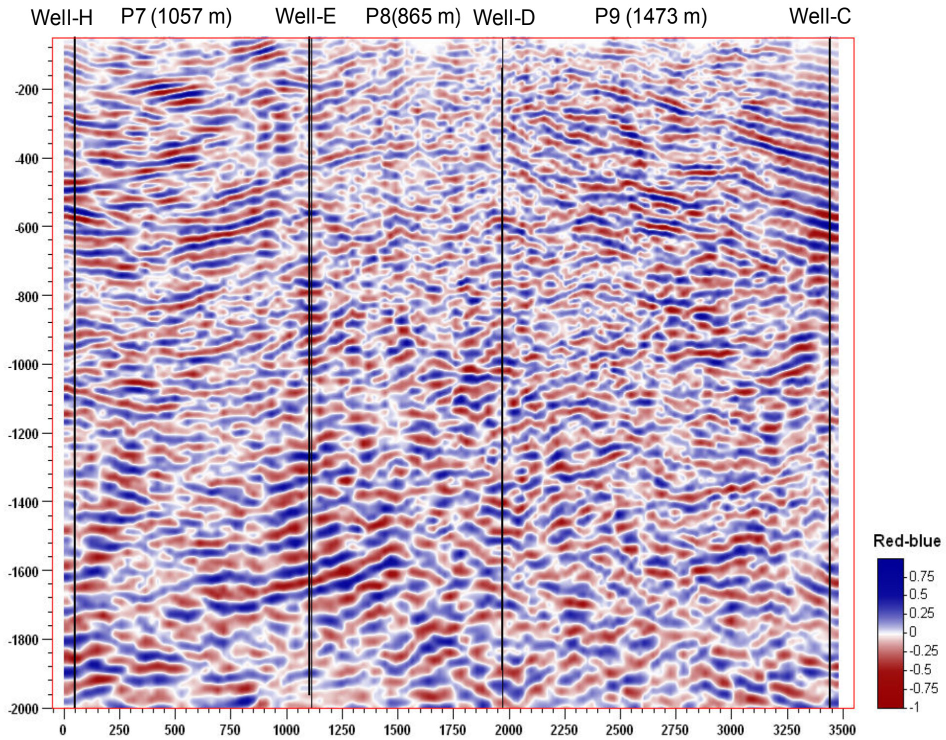

Figure 9: Surface seismic extracted line through same wells as Fig 7. The seismic signal quality is degraded with depth not allowing further interpretation of the reservoir or finer scale structural features. Vertical axis is Depth in meters. The annotated distance is the distance between wells.