Interpretation of PP and PS seismic data from the White Rose oilfield, offshore Newfoundland

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ABSTRACT

During the summer of 2002, an ocean-bottom seismometer test line was conducted over Husky Energy Inc.'s L-08 well in the White Rose oilfield, offshore Newfoundland. The Avalon reservoir at the White Rose field is difficult to image using conventional marine seismic. Therefore, a 21-seismometer/hydrophone ocean-bottom test was recorded from an airgun source. The correlation between the PP and PS synthetics from well L-08 and the OBS data (vertical and radial components) gave confidence to the interpretation of the resultant PP and PS seismic sections. After matching both radial and vertical component seismic sections, the events on both sections are clear. The *Vp*/Vs values obtained from the seismic are related to the values from the well L-08. There are some *Vp*/Vs anomalies going laterally on the seismic sections. In general, the values decrease with depth.

INTRODUCTION

The White Rose offshore oilfield (Figure 1) is located in the Jeanne d'Arc Basin 350km east of St. John's, Newfoundland. The field was discovered in 1984. Structurally, the White Rose oilfield is situated in a complex, faulted region located on the hanging wall of the Voyager Fault and situated above the deep-seated Amethyst salt ridge and White Rose diapir (Enachescu et al. 1999).

The White Rose Field is the third largest field in the Jeanne d'Arc basin. The field has three major Avalon formation pools (Figure 2), the South Avalon Pool, the North Avalon Pool and the West Avalon Pool. The three different pools have been penetrated by the following wells: West Avalon Pool, well J-49; North Avalon Pool, wells N-22 and N-30; and South Avalon pool with wells E-09, L-08, A-17 and H-20 (Husky Energy, 2001).

At the southern end of the oilfield, on a separate geological structure, delineation wells F-04 and F-04Z have been drilled in the White Rose area. The results obtained from well F-04 implied that the reservoir characteristics are comparable to the characteristics in the South Avalon Pool; well F-04Z will help to delineate the structure (Husky Energy, 2003). Up to now, four more wells have been drilled in the area, an oil producer that underwent testing, and three water injectors (Husky Energy, 2004).

White Rose imaging challenges

After numerous seismic surveys it was found that the White Rose field presents a number of imaging problems. These imaging challenges, according to Hoffe et al. (1999) are:

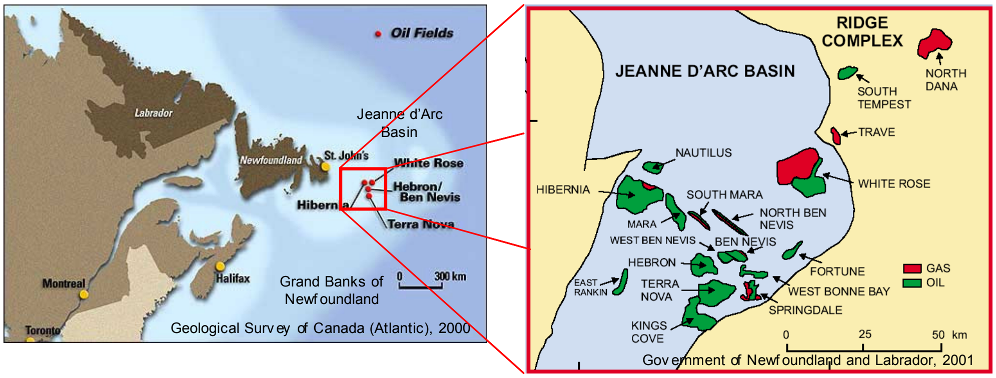

FIG. 1. Location of the White Rose oilfield offshore Newfoundland. (Modified after GSCA, 2000, and GSNL, 2000.)

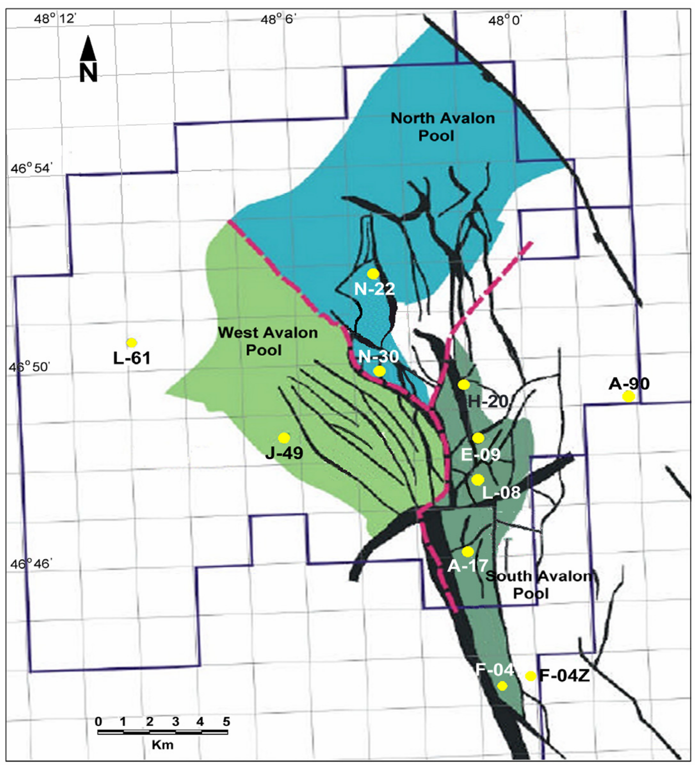

FIG. 2. Location of White Rose oilfield wells and pool. (Modified after Husky Energy, 2001.)

Hard water bottom

The occurrence of high ocean-bottom reflection coefficients creates serious water-column reverberations. The quality of the final seismic image created from data acquired with towed streamers over these hard ocean-bottom areas is diminished, due to the water-column reverberations. The water depth is about 125m, causing numerous short period reverberations

Strong P-wave impedance contrast at the Tertiary-Cretaceous Unconformity

The reflection coefficient at the K-T interface is large, and significant energy is reflected from it causing interbed multiples. These Base-of-Tertiary multiples interfere with the primary reflections from the Avalon reservoir level, degrading the final seismic image of the reservoir.

Poor P-wave impedance contrast at the reservoir top

Sandstone of the Avalon formation is overlain by shales of the Nautilus formation; the P-wave impedance contrast between these two formations is small, as a result of the top of Avalon reflector is quite weak, making it difficult to image.

Distortion of the reservoir image by gas

Faults from extensional movements affect the reservoir level breaking the Base-of-Tertiary unconformity and forming gas clouds by up-dip leakage of gas along the fault structures. These gas clouds have a damaging effect on the final stacked PP image from the White Rose field.

We attempt to overcome some of these problems by using 4-C OBS data. With the generation of shear waves, the quality of the image of the reservoir will increase, improving the conventional P-P data acquired in the area, identifying the events in the area of interest, and minimizing the different problems that obscure these events.

LITHOLOGY OF THE WHITE ROSE FIELD

For this study, we concentrate our analysis on the following units (Figure 3):

Eastern Shoals Formation (*Hauterivian to Barremian*)

Massive calcareous sandstone/oolitic limestone sequence and a thick sequence of interbedded sandstone and siltstone.

Avalon Formation (*Barremian to late Aptian*)

A complex and variable siliciclastic sequence, the Avalon sandstones, which consist of stacked aggradational shoreface sandstone units, culminate in an upward-fining shaly siltstone. According to McAlpine (1990), this Formation is subdivided into 3 subunits, displaying a coarsening upward pattern:

Basal subunit: a "red mudstone" sequence, characterized by varicolored shales containing a few thin interbeds of sandstone.

Middle subunit: thicker sandstone beds, and interbedded grey shales.

Upper subunit: slightly coarsening upward, sandstone-dominated unit, with siltstone at the top.

The contact with the Eastern Shoals Formation is sharp. The Avalon Formation grades laterally into the Nautilus Shale (McAlpine, 1990). The Avalon sandstones hold the reserves in the White Rose and North Ben Nevis oilfields. The most important sandstone accumulations take place in the southeastern part of the field, with a thickness of up to 350 m of sandstone (wells E-09, L-08 and A-17).

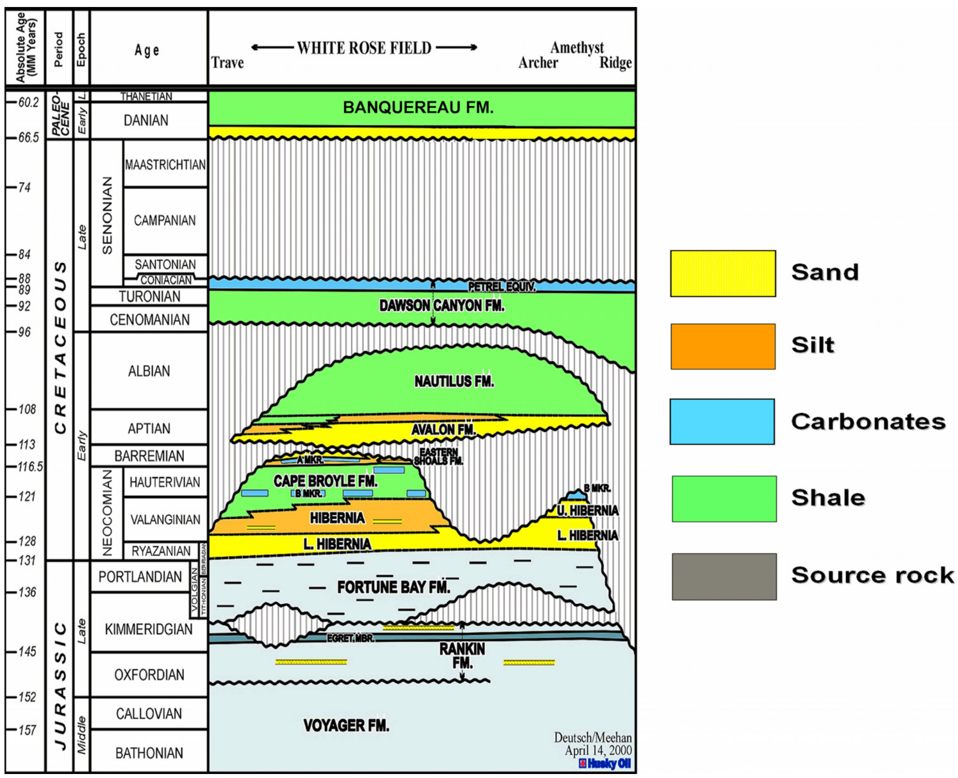

FIG. 3: Stratigraphy of the White Rose field. (Modified from Emery, 2001)

Nautilus Formation (*Late Barremian to Late Cenomanian-Turonian*)

The formation is a monotonous unit dominated by grey calcareous shale or mudstone. This unit is subdivided in three subunits:

Basal subunit: intercalated beds of silty sandstone that grade upward into siltstone.
Middle subunit: siltstone beds with sandstone stringers.
Upper subunit: very calcareous and argillaceous siltstone and argillaceous, silty, microcrystalline to chalky, limestone beds.

The lower contact, usually taken to be the Albian unconformity where the Ben Nevis Formation is present, is abrupt and unconformable to conformable. The upper contact is also abrupt but possibly conformable. The formation is almost everywhere in the Jeanne d'Arc Basin where middle Cretaceous strata were deposited and preserved (http://agcwww.bio.ns.ca/, 2000)

South Mara unit (Danian-Thanetian)

Unit of delta front sands and prodelta turbidites (McAlpine, 1990).

WELL LOG ANALYSIS

The well log analysis was performed to understand the petrophysical behaviour around well L-08. This analysis helps to understand the relation between the well-log data, the synthetic seismograms data, and the seismic data.

To understand the behaviour of the petrophysics around well L-08, and thus to understand the relation that should exist between the well-log data, the synthetic seismograms, and the seismic data, we did a well-log analysis. In this way we could be more confident during the interpretation stage of this work.

The well-log analysis was conducted on most of the wells (A-90, E-08, H-20, J-49, L-08 and N-22) that have been drilled at the White Rose area; this helped to understand the petrophysical behaviour of the area. The well-log analysis examines the different relationships among many of the wells; it also provides a closer and more detailed look at the relationships between wells H-20, and L-08, where we were able to work with both *Vp* and *Vs* log data.

In this paper, the petrophysical analysis of wells L-08, E-09, and H-20 is important to understand the petrophysical signatures that are present on the Nautilus, Avalon and Eastern Shoals Formations, thus being able to give a more accurate interpretation of the OBS data.

Vp and Vs versus depth

As expected, there is a general increase of *Vp* and *Vs* with depth in the area (Figure 4 and 5). Some portions of the curves do show velocity decreases that could be due to a local change in lithology, due to the presence of sequences of interbeded sandstones, shales and limestones.

Vp and *Vs* versus GR

The main units of the wells were analyzed, showing common behaviour according to the lithology where it is shown on the *GR* values. As we go from shales and limestones into sandstones, the velocities increase as expected. Figure 6, shows the general tendency of Nautilus and Avalon on the wells.

In Figure 7, the wells have similar velocities (between 3000-6000 m/s), and there is a slight variation on the *GR* range; but the values still accord to the type of lithology. A general tendency is notable; if we look closer at Nautilus, the tendency is to decrease *GR* with increase of *Vp*, and the Avalon has a fixed range of *GR* value (~10-60), this range is kept constant as the P velocity increases. The Nautilus shale shows a constant tendency on the properties (*GR, Vp*). The variability of the *GR* (on H-20: ~28-129, E-09:~10-90, and on L-08:~31-71), *Vp*, and *Vs* values in the Avalon sandstone could be indicative of porosity and shale content. This knowledge might have an impact on how the interface between the Nautilus and the Avalon is identified on the seismic data. The similar behaviour of the units on the three wells could be indicative of the same conditions of diagenesis (compaction, cementation) for each unit, even knowing that the area of deposition was extensive.

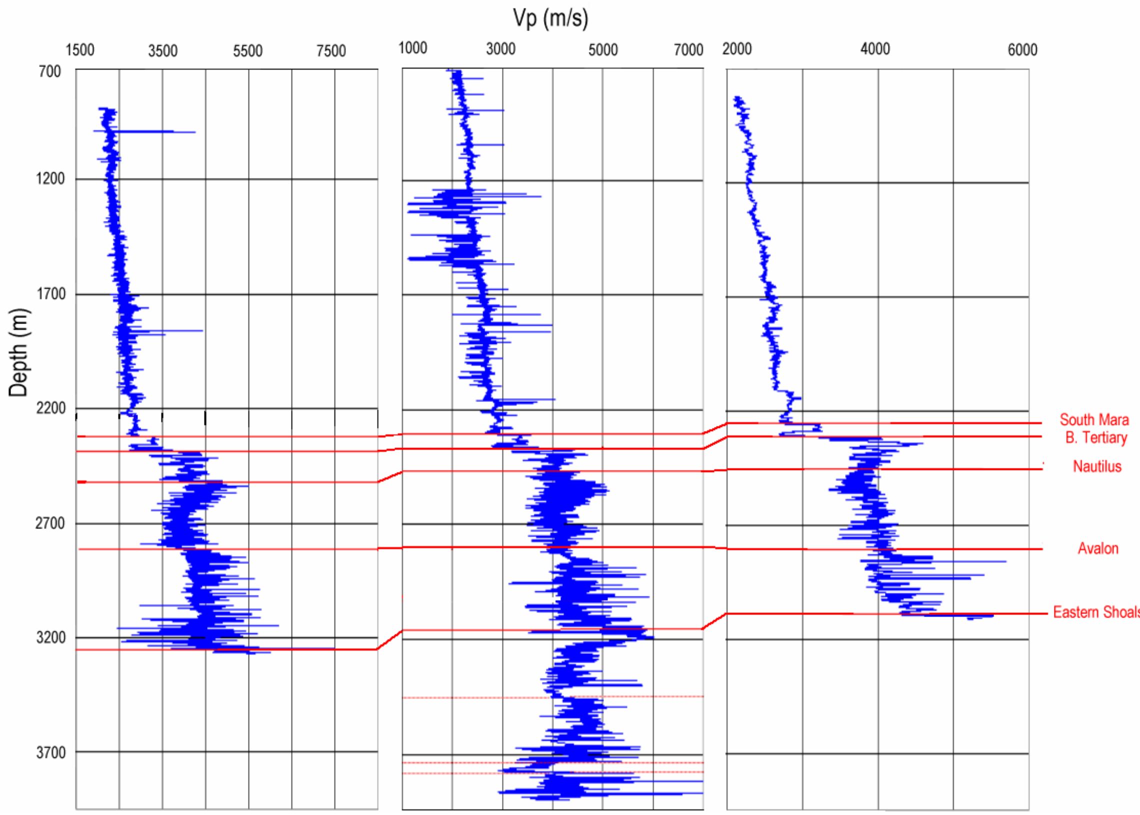

FIG. 4. Depth versus *Vp* log curves; from left to right, wells H-20, E-09, and L-08.

Vp/Vs versus GR,

Table 1 shows general trends for each unit on wells H-20 and L-08. In Figure 8, more instances of a relationshipbetween the two wells are observed. For all the wells, the general trend has a decrease in *Vp*/*Vs* as we go deeper in the wells. The *GR* for the wells show that the range of different lithologies correspond to the *Vp*/*Vs* values; high *Vp*/*Vs* values (3.5-4.0) are related to the *Tertiary* unit (shallow rocks), which agree with high *GR* values (60-130, Banquereau shales); as the depth increases, the GR decreases (going from shales to limestones to sandstones), also *Vp*/*Vs* decreases (Figure 8). The decrease in value of *Vp*/*Vs* (from 4.0 at the top of the well to 1.5 on the bottom of the well) is likely due to a number of effects including compaction, aging and lithology.

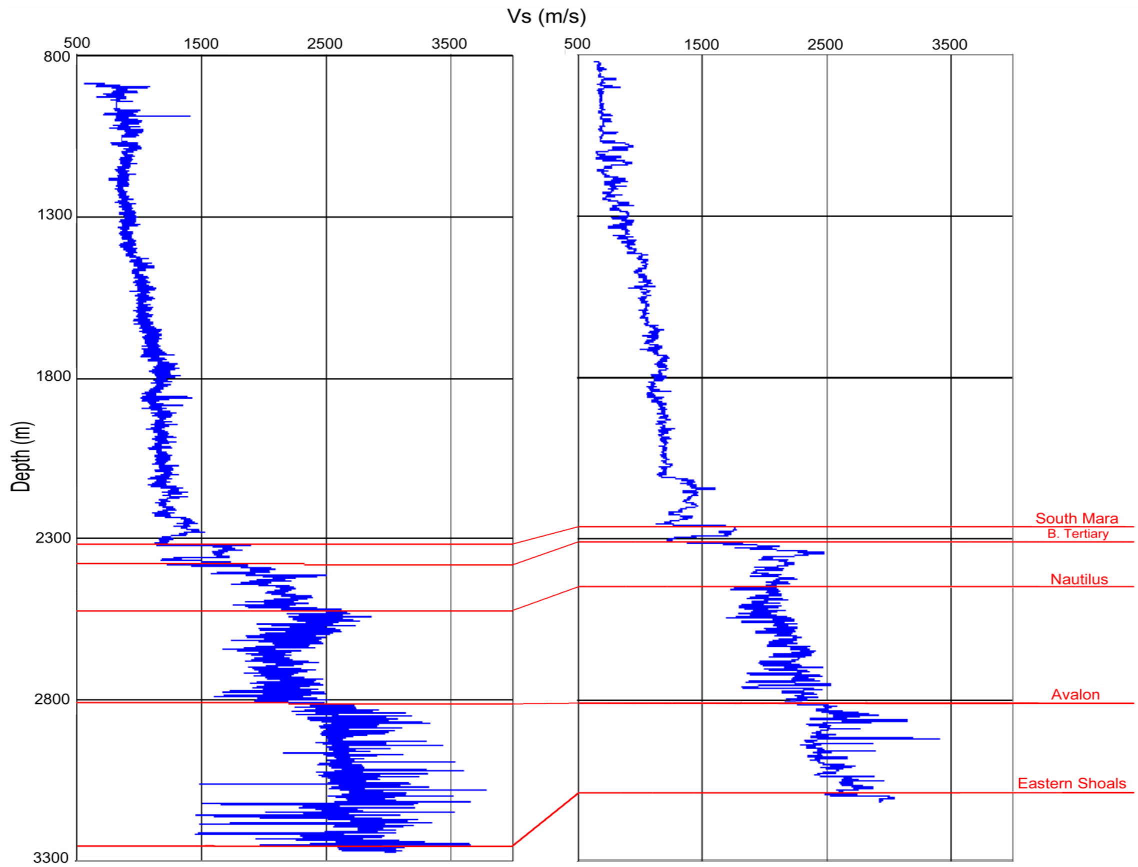

FIG. 5. Depth versus *Vs* log curves; from left to right, wells H-20 and L-08.

In general (Figures 8 and 9, Table 1), *Vp*/*Vs* decreases with depth, and the *GR* values depend on the lithology. If we compare the *GR* and *Vp*/*Vs* values in wells (H-20, E-09, and L-08), it is observed that the *GR* values for L-08 well have a range between ~31-118; for well L-08 the range is between ~28-129; their *Vp*/*Vs* ratios are also very close to each other (H-20: ~1.46-2.06, and L-08: ~1.52-1.98); these different ranges are embedded between each other (Avalon silstone embedded into the Nautilus silstones), and therefore this could make it difficult to make a distinction between the two lithologies based exclusively on *Vp*/*Vs* and *GR*.

Table 1: Range of GR versus *Vp*/Vs for each unit.

Unit	H-20		L-08	
	GR (API)	*Vp*/*Vs*	GR (API)	*Vp*/*Vs*
Nautilus	58-117	1.59-2.06	78-117	1.67-1.98
Avalon	28-129	1.46-2.00	31-71	1.52-1.91
Eastern Shoals	30-117	1.76-1.84	32-46	1.70-1.81

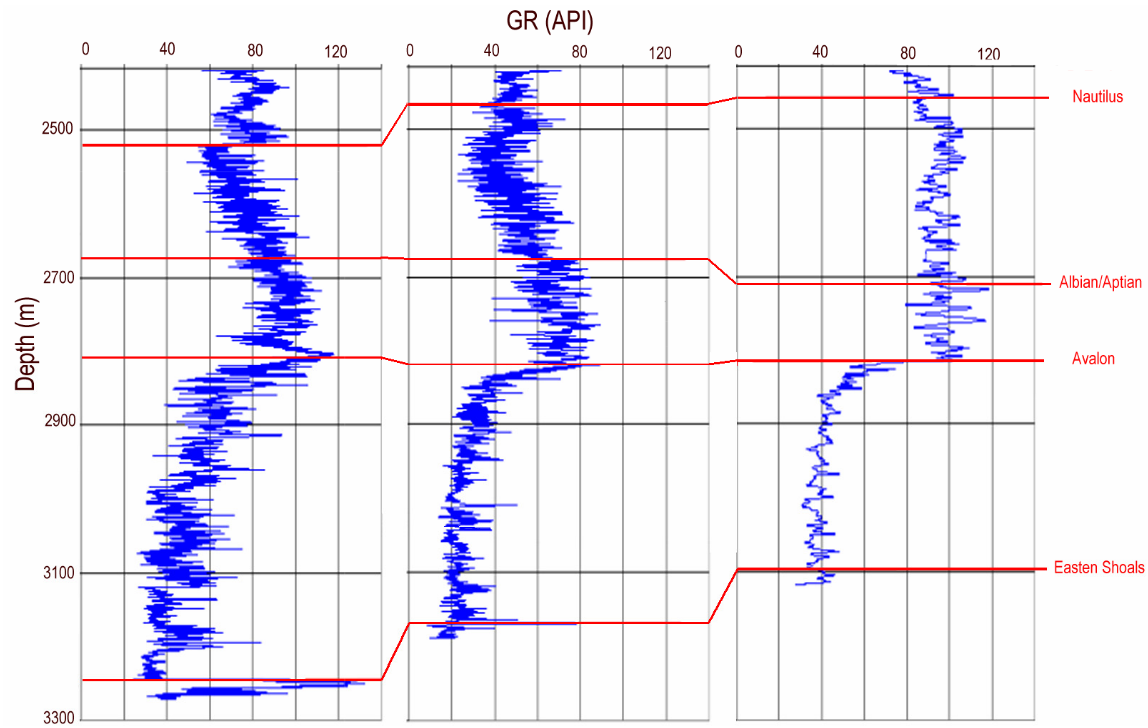

FIG. 6. Depth versus GR log curves; from left to right, wells H-20, E-09, and L-08; zooming at the Nautilus and Avalon units.

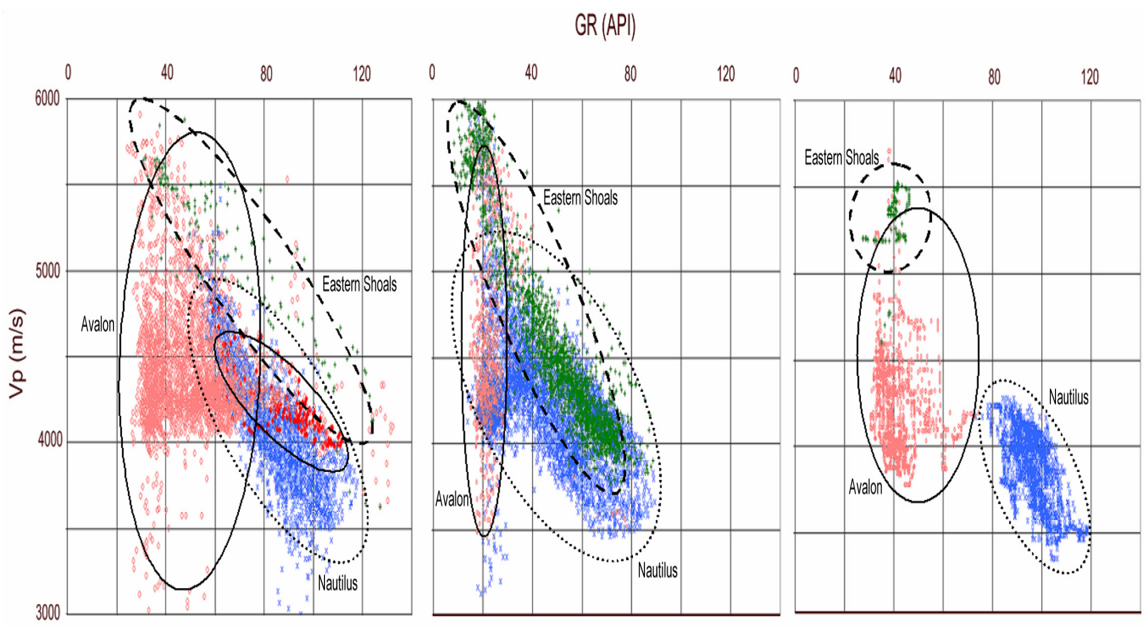

FIG. 7. *Vp* versus GR crossplots; from left to right, wells H-20, E-09, and L-08.

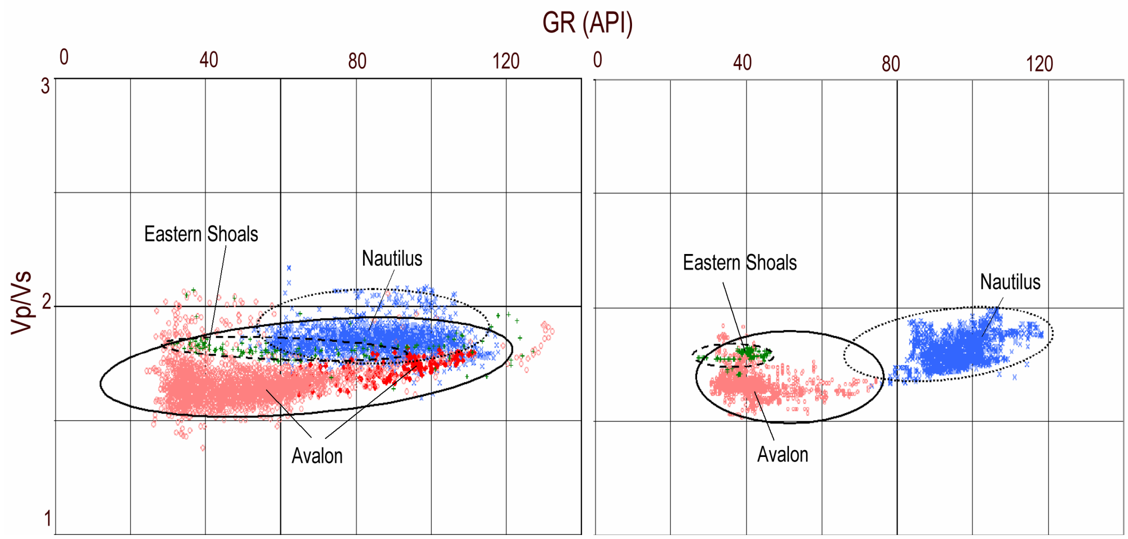

FIG. 8. *Vp*/Vs versus GR crossplots; from left to right, wells H-20 and L-08.

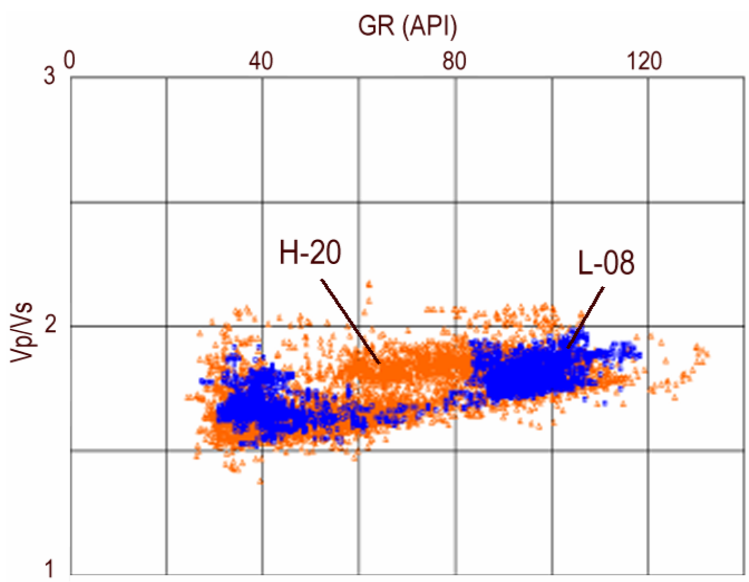

FIG. 9. *Vp*/Vs versus GR crossplots; wells H-20 and L-08.

4-C OCEAN-BOTTOM SEISMOMETER (OBS) SURVEY

Four-component ocean-bottom cable (OBC) acquisition has not been attempted yet on the East Coast of Canada to our knowledge, largely because of its novelty and mobilization expense. However, Dalhousie University has been conducting ocean-bottom seismometer (OBS) surveys for deep crustal seismological research. Several shot gathers from a deep deployment in the summer 2000 cruise of the Dalhousie OBS, showed energy on both the vertical and radial geophones; based on these encouraging results, a four-component ocean-bottom seismometer (OBS) survey was acquired over White Rose oilfield using the Dalhousie OBS.

Acquisition and Geometry of the OBS survey

During May of 2002, Dalhousie University and the Geological Survey of Canada (GSC) acquired a MARIPROBE crustal refraction line (2002-11 Line 1, Figure 10) using four-component ocean-bottom seismometers (OBS) (Figure 11). On the same survey, in a joint effort of the CREWES Project at the University of Calgary and Husky Energy Inc., second line with much smaller receiver spacing was shot over White Rose 2002-11 (Line 2, Figure 10)

The 2-D seismic line centred on Husky Energy's L-08 well was acquired. Twenty-one OBS instruments were used to acquire the survey; the instruments were deployed over the ocean floor (drifted to the bottom through approximately 125 m of water) approximately 50m apart in order to form a 1 km east-west line of receivers. A total of 12 east-west source lines (8km long each line) were acquired in a spiral pattern (Figure 12) starting above the OBS positions, with a 1966 cu. in., 1650- 1800 psi, 5 airgun array. The source interval was 50m and the source line interval varied from 50m to 200m (Hall and Stewart, 2003). Data was successfully downloaded from twenty of the twenty-one OBS (one OBS failed to record any signal at all).

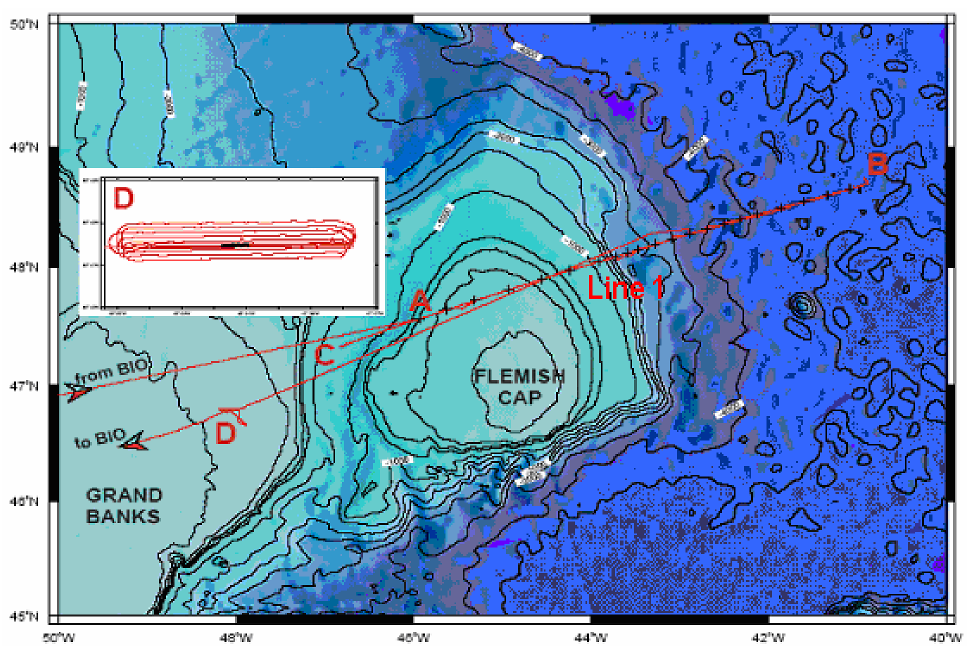

FIG. 10: Scientific expedition FLAME 2002 with Hudson 2002-011 Line 1 and Hudson 2002-011 Line 2 (point D on the map). (Modified from Jackson, 2002.)

The positions of the drop points were known from GPS, and the final location point (Figure 12) of the OBS's were calculated with a technique that reduced the difference among the actual and predicted first-break times (assuming a constant water velocity of 1500m/s through the water column). The instruments moved south from the drop points, drifting anywhere from 10 to 20m to their final locations on the sea floor (Cary and Stewart, 2003).

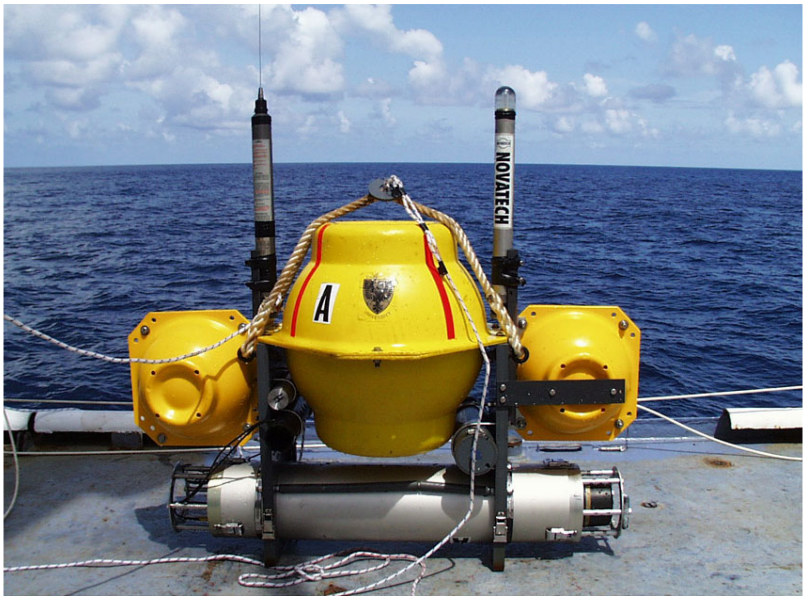

FIG. 11: Dalhousie ocean-bottom seismometer (OBS). (Modified from www.dal.ca, 2002)

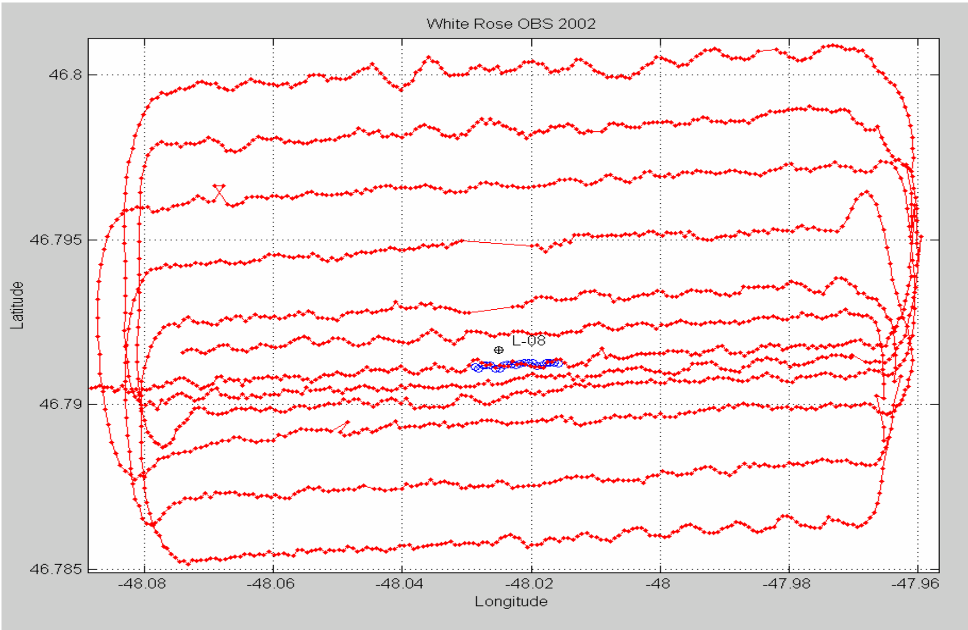

FIG. 12: Location of source lines (red) and approximate position of 21 OBS receivers (blue). (Hall and Stewart, 2002)

Processing of the OBS data

The processing of the data was done at Dalhousie University, Sensor Geophysical and CREWES. According to Cary and Stewart (2003), during the processing stage of the data, the polarity of the data for all components was kept equal to the recorded polarity. It was assumed that the three elements of the geophone shaped a right-handed coordinate system.

There were numerous problems with the data, but some promising final sections were achieved for both PP waves (vertical channel) and PS waves (radial channel). Processes applied to the data included data clipping repair, F-K and tau-p filtering, PP and PS stacking, and post-stack migration. The final images show substantial promise for multi-component marine data in the White Rose area (Cary and Stewart, 2003).

Interpretation

To start this interpretation we used SYNTH (Larsen et al., 1997) (now syngram) to estimate the synthetic seismograms (for wells H-20 and L-08). It was necessary to select the wavelet to work with the well log information from several wavelets, and also to work with different top velocity values for P and S velocities, and to work with a maximum offset value of 3000m (according to Hall et al., 2001).

Before starting with the OBS data interpretation, the results obtained from a previous study on well H-20 will help to solve difficulties that we can encounter with the interpretation of the OBS data. There were several synthetic seismograms estimated before picking the best synthetic seismogram that could be matched with the field data. The best values to work with well H-20 were a Ricker wavelet of 45 Hz. The events to study are South Mara, Base-of-Tertiary, Nautilus, Avalon, and Eastern Shoals Formations.

The matching of the PP synthetic seismogram with the H-20 PP VSP-CDP transform-P section (Figure 13) shows a better correlation between both sections. In these graphics it is possible to correlate the following:

- South Mara (SMAR): the event is easy to follow in the synthetic seismogram section, but its amplitude starts to decrease from 1200m from the source. In the VSP section it is a strong event.

- Base Tertiary Unconformity (BTUN): a strong event on both sections. The amplitude decreases with the offset in the synthetic seismogram.

- Nautilus (NTLS): the top is easy to recognize; the amplitude on both sections is strong, decreasing slightly with offset in the synthetic seismogram. The formation in the VSP section shows several events that can be related to the three subunits of the Nautilus shale; in the synthetic seismogram it is not too clear, due probably to the low amplitude of the events.

- Avalon Formation (AVAL): the top of this formation is a siltstone that is in contact with the basal unit of the Nautilus, a silty sandstone that grades upward into siltstone; so, the low amplitude that is in this area is probably due to the fact that the reflection coefficient between this two units is almost imperceptible. It is possible that there is a low reflection coefficient product to the presence of the Nautilus silty sandstone. In the synthetic seismogram the AVALS is not clear, but in the VSP section it is clearer.

- Eastern Shoals (ESHL): easy to follow on both sections.

The matching of the PS synthetic seismogram with the S-waves from H-20 VSP-CDP transform section (Figure 14) shows the following information:

- South Mara (SMAR),: it is shown on both sections; on the synthetic seismogram the amplitude increases with the offset.

- Base Tertiary Unconformity (BTUN): a strong event on both sections. The amplitude increases with the offset in the synthetic seismogram.

- Nautilus (NTLS): the top is easy to recognize, the amplitude on both sections is strong and increases with the offset in the synthetic seismogram. The subunits of the Nautilus shale are clear.

- Avalon Formation (AVAL): as in the PP matching, the reflection coefficient between the Nautilus silty sandstone and the Avalon siltstone is too low, but in these matching (PS synthetic seismogram and S-VSP) sections it is clearer. The predicted density value shows a little improvement of the event. In the base of the Avalon Formation it is possible to see subdivisions, probably related to the basal subunit that has shales interbedded with sandstones.

- Eastern Shoals (ESHL) is easy to follow on the synthetic seismogram, but in the VSP section it is not very clear.

In Figure 15, the comparison between the PP synthetics seismogram from well H-20 and the PP seismic section, the correlation is reasonable. However the interface between the Nautilus shale and the top of the Avalon sandstone (which is a siltstone) is difficult to observe.

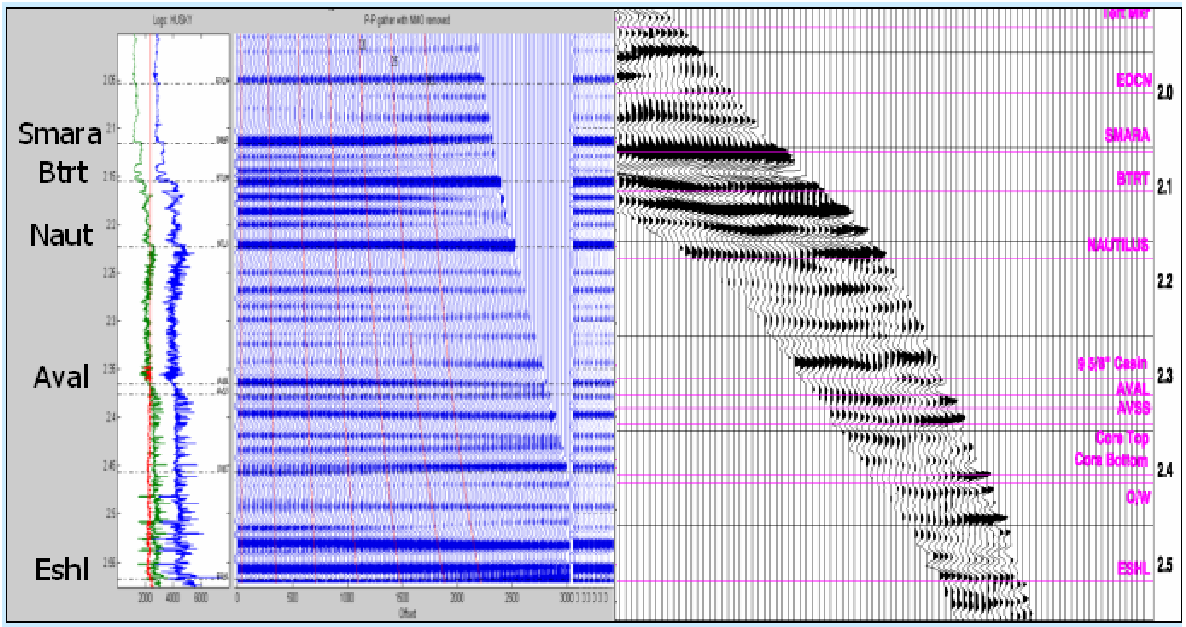

FIG. 13. Result from matching the PP synthetic (Ricker 45Hz) and the H-20 offset VSP section.

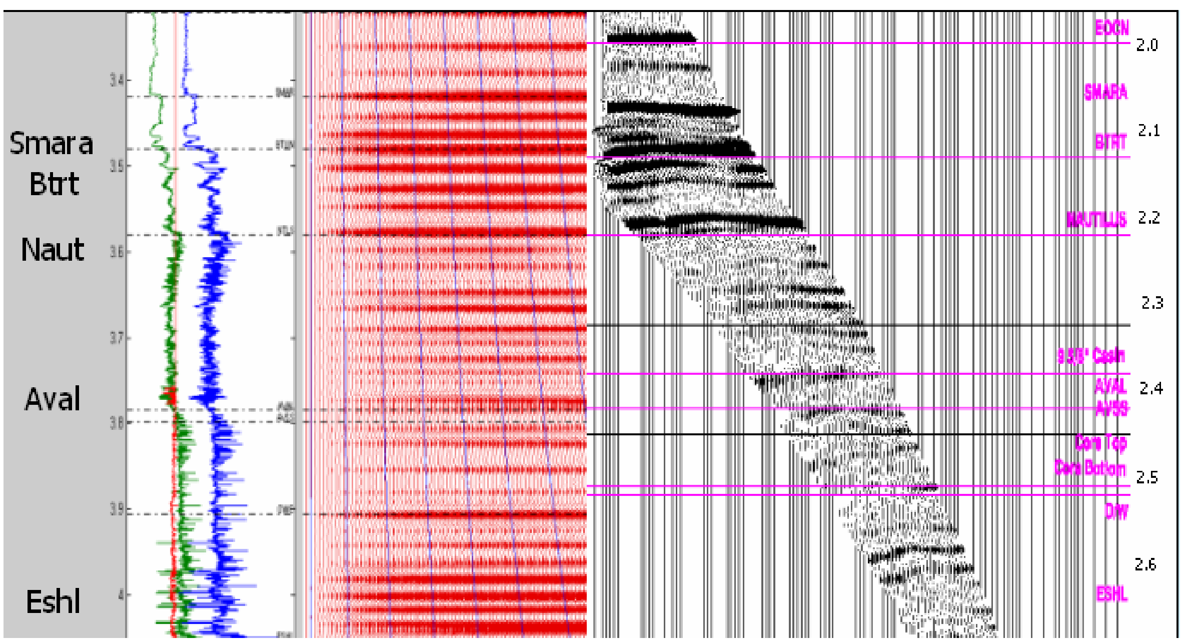

FIG. 14. Result from matching the PS synthetic (Ricker 45Hz) and the H-20 Offset VSP section.

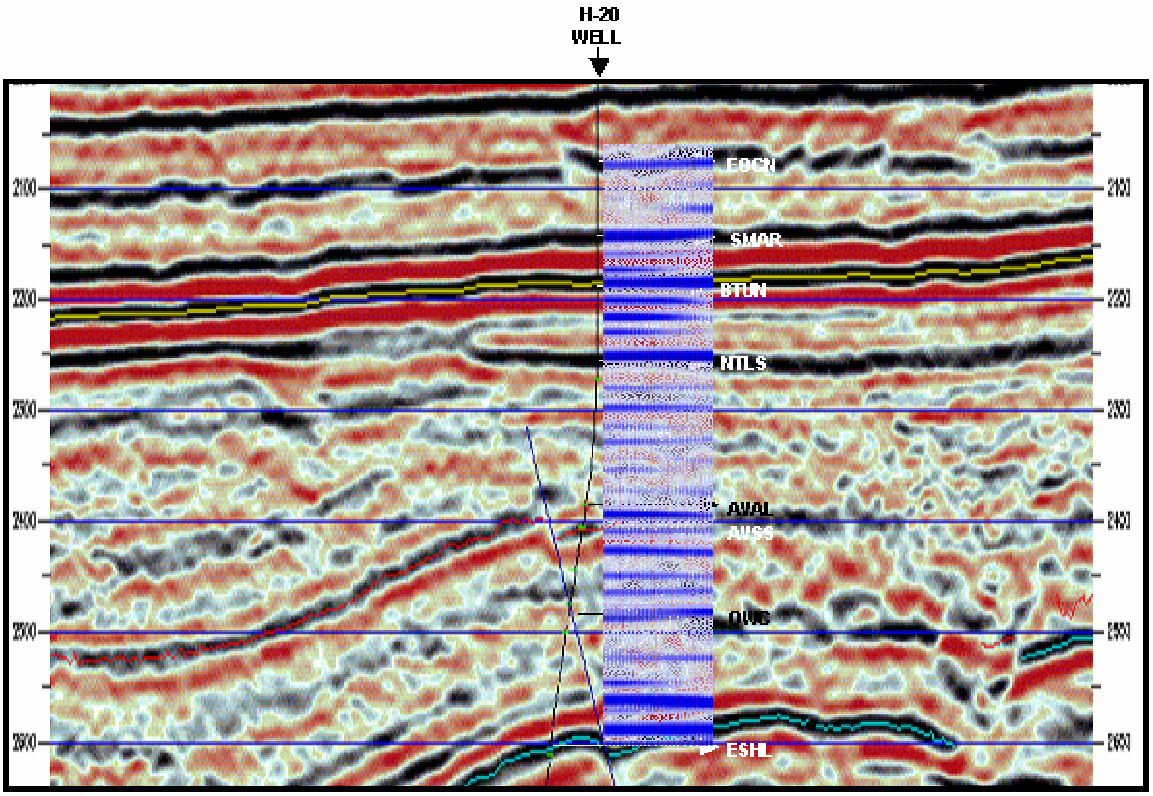

FIG. 15. Result from matching the PP synthetic (Ricker 45Hz) and streamer seismic section, showing well H-20 (modified after Emery, 2001).

The synthetic seismograms estimated from the well L-08 data used a bandpassed wavelet 4/8-25/30. During the interpretation stage of the project we used Hampson-Russell PROMC software, software designed to help in the analysis and interpretation of multi-component seismic data. After loading the OBS data (vertical, radial, and hydrophone component data), the well L-08 was tied, to be able to have more confidence with the definition of the horizons on the OBS data.

Also, the use of synthetics seismograms using the L-08 well log data helped to have a more accurate correlation (Figure 16). The results from correlating the PP and PS synthetic seismograms were encouraging:

- South Mara (SMAR): shows on both sections; on the PS synthetic the amplitude is stronger than on the PP synthetic.
- Base Tertiary Unconformity (BTUN): a strong event on both sections, but is less strong on the PS synthetic. The amplitude stays constant with offset.
- Nautilus (NTLS): on both synthetics it is difficult to recognize the top of the unit, the subunits of the Nautilus can be seen.

- Avalon Formation (AVAL): the reflection coefficient between the Nautilus silty sandstone and the Avalon siltstone is better on the PS synthetic.

- Eastern Shoals (ESHL): easy to follow on the PP synthetic, the event on the PS synthetic has a low impedance contrast.

The interpretation of the seismic data began with the correlation of the base of the Tertiary unconformity (using well log, synthetics, and seismic data) and from that point we started to correlate the other events, in this case South Mara, Nautilus, Avalon and Eastern shoals. It was also noticeable that in the presence of another unconformity, Albian-Aptian, which was correlated with a strong event above the Avalon and below the Nautilus Formation. It was difficult to follow the Eastern Shoals and Avalon events in some parts of the interpretation. It was necessary to use the Albian/Aptian unconformity as a guide to be able to define these events.

On Figure 16, we can also observe the correlation between the synthetic seismograms from well H-20, and how these synthetics match reasonably well with the synthetics from well L-08. Note that the correlation between the Nautilus and the Avalon on these synthetics (from wells H-20 and L-08) is not exact. This could be due to the distance between the wells (distance ~4km), compaction processes, and the different structures that are present in the area.

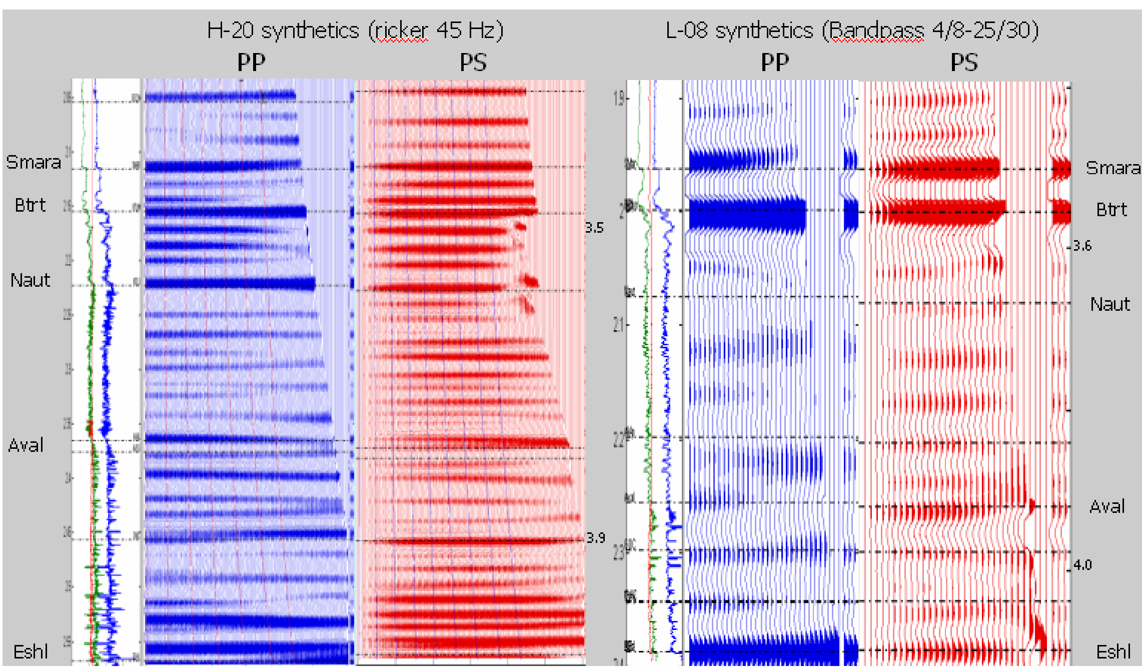

FIG. 16. Result from matching the PP and PS synthetics, from wells H-20 and L-08.

PP (P $_{wave}$ vertical component) interpretation

The data found in this component is clear (Figure 17). There are some seismic events that can be followed along the survey without difficulty (South Mara, Base-of-Tertiary, and Nautilus). After tying up the L-08 well log (P wave curve) to the OBS vertical seismic data, the horizons were defined as follows:

- South Mara and Base-of-Tertiary unconformity are the two events that have a strong seismic signature along the survey, both events are strong and display a flat horizon

- Nautilus: this event can be interpreted as a "flat horizon". Analyzing the data from north to south we can observe that the top is affected by some compressional faults on the west side of the survey, the presence of these thrust faults is more evident on the west side of the survey than on the east side. On the east side the faults are not affecting the event as much as on the west side

- Albian/Aptian unconformity: this appears as a strong seismic signature above the Avalon, it is easy to follow along the survey.

- Avalon: this event is related in most of the seismic to the Albian/Aptian event, in some parts the event disappears into the unconformity event, in some other parts it is easy to follow.

- Eastern Shoals: this event can be followed, but in some parts we can see some type of break up which could indicate the presence of faulting events.

After comparing the seismic vertical component data and the PP synthetic (Figure 17), a good correlation between the South Mara, Base-of-Tertiary and Nautilus was found. The results for the Albian/Aptian, Avalon, and Eastern Shoals were not as good, but the results are encouraging.

PS (S $_{wave}$ radial component) interpretation

This component (Figure 18) shows complex seismic results, most of the horizons are difficult to follow, but in general the final outcome is good. Below the Nautilus (~4100 ms PS time) the horizons cannot be defined easily, there is irregularity and faulting on the horizons that make it difficult to follow the events (Albian/Aptian unconformity, Avalon and Eastern Shoals Formations). After tying the L-08 well log (S-wave curve) to the OBS horizontal seismic data, the horizons were defined as follows:

- South Mara and Base-of-Tertiary Unconformity: once is identified as the base of the tertiary event; the South Mara is the strong event above the unconformity. In the northeast and southeast, the unconformity seems to be faulted. These events are not as flat as was observable on the vertical component. The Base of the Tertiary event is not as strong as it is on the vertical component; this is good, because this will allow better observation of the reflections from the Avalonthan just with the PP data.

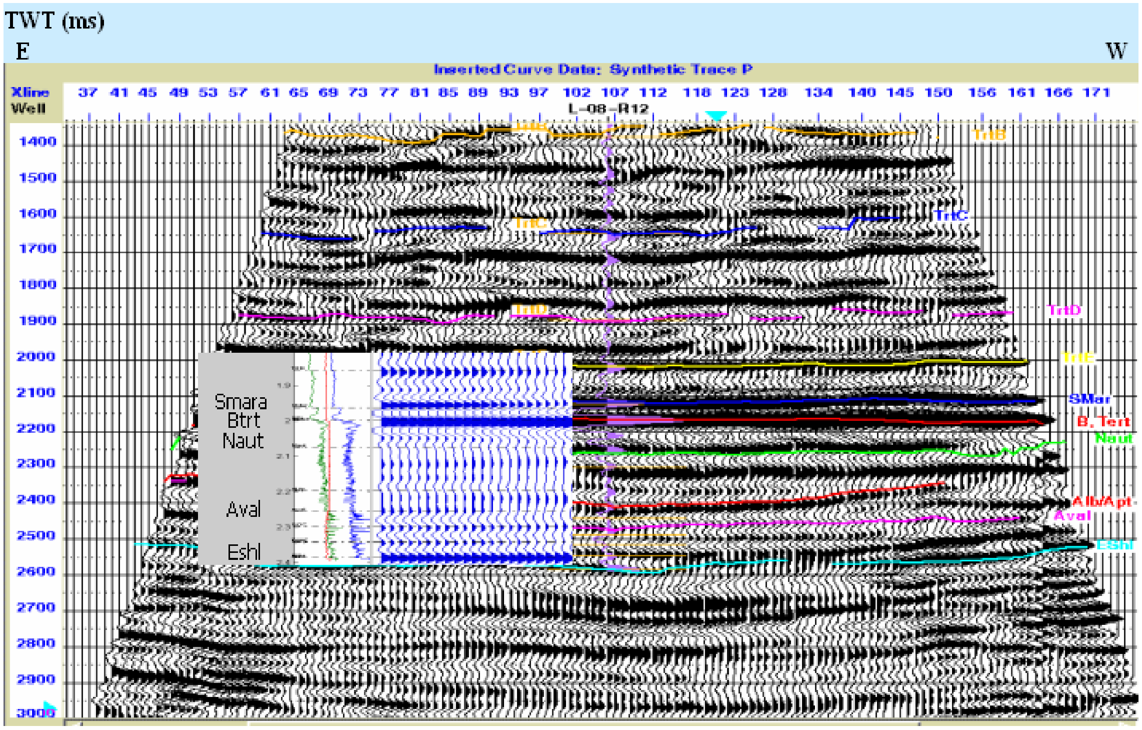

FIG. 17: PP synthetic and vertical component section. The horizons defined (TrtB, TrtC, TrtD, TrtE, South Mara, Base of the Tertiary, Nautilus, Albian/Aptian Unconformity, Avalon and Eastern Shoals) after tying the well L-08 with the seismic; showing Inline 19.

- Nautilus: identifiable because of the presence of the Base-of-Tertiary unconformity, it is difficult to follow, yet despite that has a strong seismic signature. This event is faulted and irregular in much of the area.

- Albian/Aptian unconformity: does not appear as a strong event as it does on the PP section. Is difficult to follow, and this does not help to define the Avalon horizon. It seems to be affected by noise, which makes it difficult to define the unconformity.

- Avalon: on the PP section it was difficult to define, on the PS section it is even harder observe a small continuity on the event. Among all the events discussed so far this one is the most irregular. This could be due to he presence of noise.

- Eastern Shoals: comparing the results from the Albian/Aptian unconformity and the Avalon top, this event shows a small continuity of the horizon. Still, it is not a strong peak, but gives some kind of continuity of the event.

The results from the comparison between the seismic radial component data and the PS synthetic (Figure 18), show that the matching is better than with the PP results. All the different matches of the events are improved with the PS data; still, we have to remember that the continuity on the radial section sometimes makes it difficult to be able to follow the events (Albian/Aptian unconformity, Avalon, and Eastern Shoals Formations) along the seismic section.

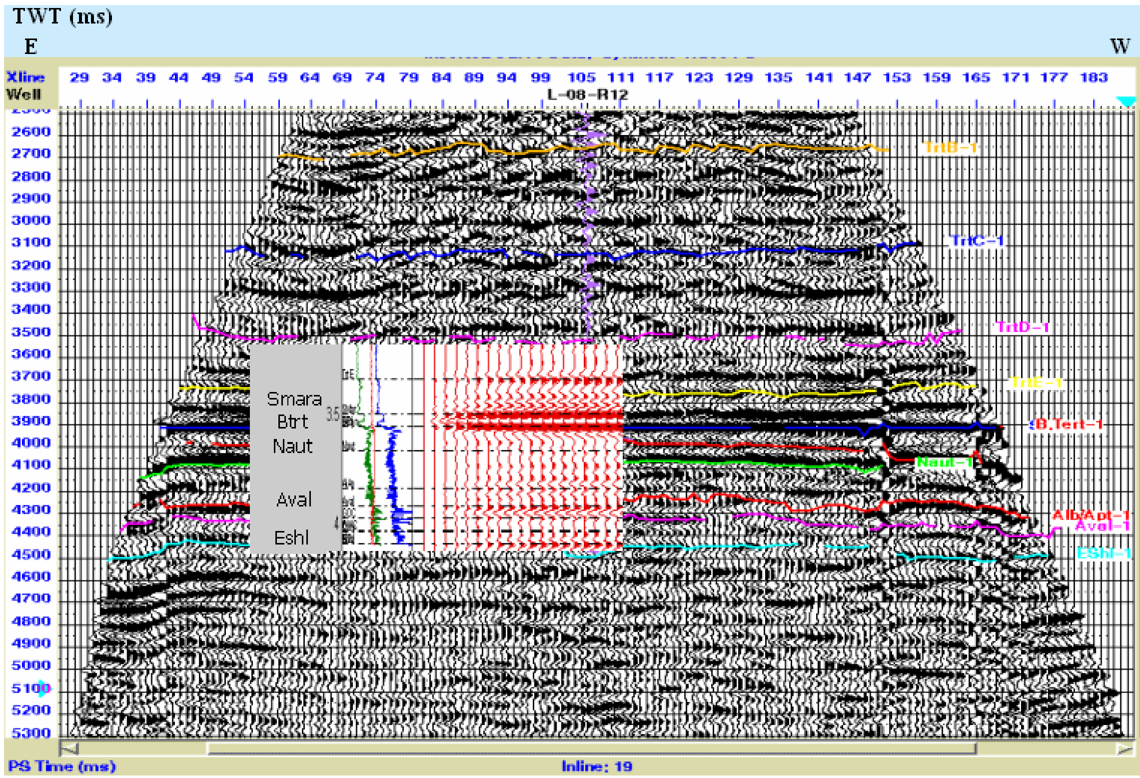

FIG. 18: PS synthetic and radial component section. The horizons defined (TrtB, TrtC, TrtD, TrtE, South Mara, Base-of-Tertiary, Nautilus, Albian/Aptian Unconformity, Avalon and Eastern Shoals) after tying the well L-08 with the seismic; showing Inline 19.

Correlation

Correlating the vertical component and the radial component seismic sections (Figure 19), it is observable that all the different events involved in the interpretation (TrtB, TrtC, TrtD, TrtE, South Mara, Base-of-Tertiary, Nautilus, Albian/Aptian Unconformity, Avalon and Eastern Shoals) have a good match; still some work remains to be done with the Nautilus, Avalon, and Eastern Shoals events as there are some problems in correlating these units, but despite this, the results show a great advance in the imaging of the reservoir.

Vp/Vs analysis

We performed an analysis of the *Vp*/*Vs* values for the OBS data, and compared the resultant values (shown in Table 2) with the *Vp*/*Vs* results obtained from the well L-08. The results indicate that the two data sets are similar. In general, the *Vp*/*Vs* ratios decrease with depth. Additionally, we can detect *Vp*/*Vs* anomalies trending laterally across the seismic data. This lateral variation could be due to changes in lithology, compaction, or aging, as we have discussed above.

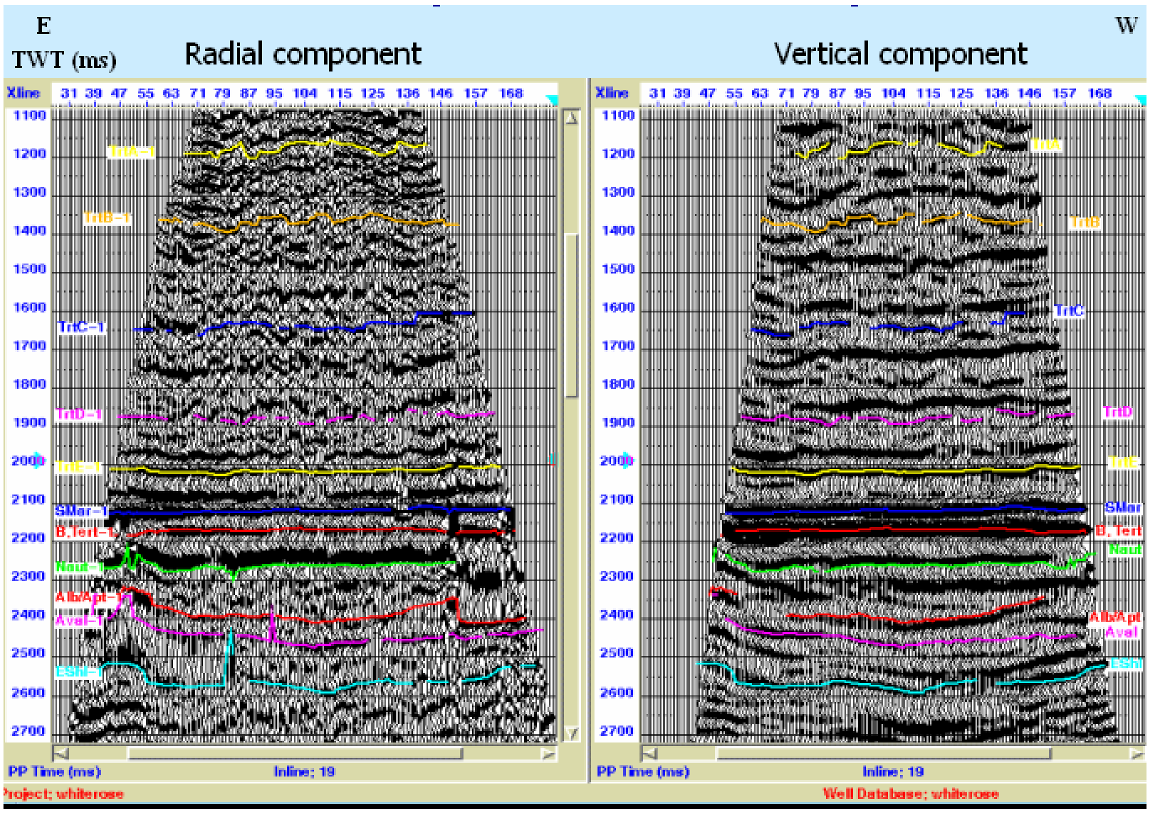

FIG. 19. Radial component (left) and vertical component (right) seismic sections on PP time. Showing the different horizons defined (TrtB, TrtC, TrtD, TrtE, South Mara, Base-of-Tertiary, Nautilus, Albian/Aptian Unconformity, Avalon and Eastern Shoals) after tying the well L-08 with the seismic. Showing Inline 19 for both sections.

Table 2. *Vp*/Vs values for each unit, for the seismic and the well L-08.

Unit	Seismic	L-08	Difference
	Vp/Vs	*Vp/Vs*	
South Mara	2.68	1.96	0.72
B.Tertiary unc.	1.70	1.82	0.12
Nautilus	1.38	1.88	0.50
Albian/Aptian unc.	1.15	1.88	0.73
Avalon	1.46	1.65	0.19
Eastern Shoals	1.69	1.72	0.03

CONCLUSIONS

Detailed correlation information from the wells L-08 and H-20 enabled the interpretation of the low impedance contrast between the Avalon Fm and the overlying

Nautilus shale Fm on the synthetics. A reasonable data to model match was found for: PP synthetics & PP vertical component seismic section, and PS synthetics and PS radial component seismic sections.

On well H-20, after comparing the PS to the PP synthetic, and the PS offset VSP to the PP offset VSP, the PS seismic images showed a better (higher amplitude over the surrounding signals) ability in illuminating the Avalon Fm top.

Results from the use of converted-wave data show that the various seismic reflections of the White Rose field may be resolvable.

Converted-wave reflections from the high P-wave impedance contrast of the T-K unconformity indicated that the interface might not be a strong shear reflector.

The interpretation of the weak impedance change at the Avalon Fm / Nautilus Fm boundary can be improved through the use of converted waves.

The most consistent results came from the radial component section. The radial components show strong converted-wave reflections that will help to image the reservoir.

The *Vp*/Vs values from the seismic and the well L-08 data are related, the presence of lateral *Vp*/Vs anomalies is evident on the seismic, but overall the values decrease with depth.

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