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A new frontier being revealed; Using Spectral Decomposition in an old universe of multiples and noise.

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ABSTRACT

Space

EXTENDED ABSTRACT

Introduction

Progress has been made in recent years to improve seismic quality in the Southern Oman Salt Basin, however despite this effort, the "classic" challenge of interbed multiples remains. The latest re-processing techniques are now providing a much higher "image" content, but the seismic still appears complex. To address the residual uncertainty of the seismic multiple challenge, interpreters are given choices of "seismic products" that follow different de-multiple algorithms. The interpreter needs to carefully consider the input within the algorithm in order to use a seismic product that better reflects the geology in the subsurface, specifically the "size of the structure". These decisions will bear direct impact in the mapping of faults -in some cases some faults are totally removed or could be "artifacts"- and the choice of the continuity and hence geometry of the structure being mapped. Once the preferred demultiple selection has been made, Spectral De-composition, as a post-processing technique, can be applied because, in theory, the interpreter is then able to extract the "real" frequencies from the actual data rather than frequencies from multiples which bear no relationship with the "real" geology.

De-multiple Algorithm rationale

The general strategy with interbed de-multiple is to flatten the seismic on the generating events and remove parallel reflectors on the assumption that these are multiples. This approach is undertaken as a strategy both with projects processed by PDO's internal Processing team and PDO's inhouse Processing contractor, CGG. The normal practice with this demultiple technique is to generate different versions based on the wavelength of the structural filtering. The demultiple result is sensitive to the window for this operation. In the case of projects processed with CGG, the horizon based demultiple method applied is the EVPFI module. This technique utilizes transformation of the data into the Tau-Px-Py (i.e. a 3D Tau P transform, whereby Tau is time and P is slowness or dip).

Within this domain, dips which are parallel to the multiple generator topography can be filtered and the filtered data then transformed back to the time distance domain. Probably the most important element within this process, as it is associated to the "assumed" geology, is the "spatial size" of the volume (wavelength) which defines the spatial size of the 3D window to extract the linear events from the seismic which will be mapped in the tau-Px-Py domain.

The extracted linear events need to cover the entire window size which should be decided based on the real wavelength of the geological structure. What defines the window for the linear event extraction is the "range" equivalent to ¼ of the wavelength (Figure 1).

This range needs to be large enough to have a stable and precise estimation of the slopes, but small enough to correctly map all the seismic events in the Tau-Px-Py domain. Using the wrong range will create linear artifacts, hence understanding the structure, based on well data, structural or regional models, becomes critical.

Internally, PDO has also developed horizon based demultiple tools which incorporate the ability to model and remove dipping multiple. This technique utilizes a combination of FK (Frequency and Wavenumber) filtering and a linear radon transform based filtering routine to remove multiple.

This technique has been designed to honor the case where the subsurface multiple generating event is dipping rather than a benign dip overburden topography.

In this situation the multiple train has the behavior of a reverberation train of the multiples from a marine setting with a dipping seabed multiple generator, the travel time of the multiples increase with each reflection of the multiple leg from the sea surface thereby increasing the apparent dip of the multiple in relation to the previous multiple.

In this case a demultiple technique based on filtering a single dip range will leave the steeper dip multiples in the data. This factor is incorporated into the PDO internal technique to scan over predicted multiple dip from the topology of the generating surface and removing each 'bounce' of the associated multiple.

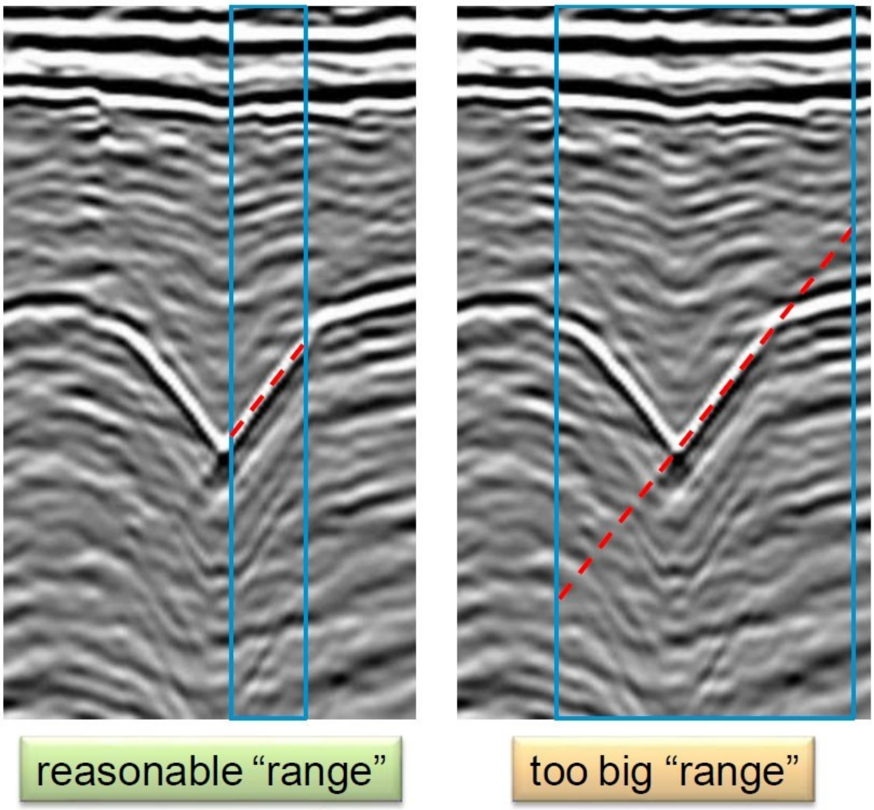

Figure 1. The definition of the range needs to be based on the understanding of the actual geometry of the structure. A "reasonable" range will provide a product that removes the right multiples and other artifacts will not be created. If the range is too big the algorithm artifacts will be created, and the de-multiple process will not be appropriate.

Geological Considerations

The first challenge is to understand which is the "geological wavelength" or the structural geometry of the area of interest: is the area defined by large or small structures? It is also important to get an idea of how steep the flanks of the structures are and the "wavelength" of the fold. This will imply that the resulting seismic product will not become the "best" solution in all cases, but careful considerations need to be given, depending on the size of the structures being analyzed.

Figure 2 is a long regional line where the two types of seismic products are compared. It is immediately evident that, depending on the size of the structure, the interpreter will have to use different EVPFI products.

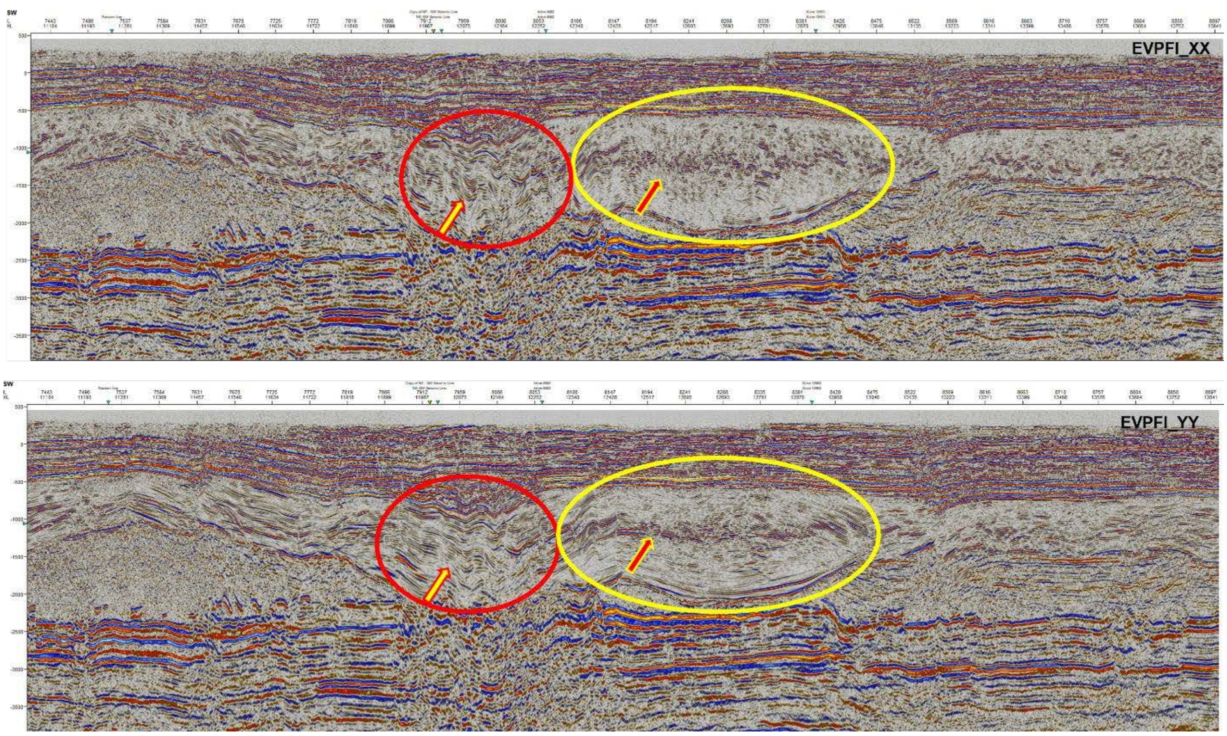

Figure 2. Two different EVPFI products. The one leveled as EVPFI YY appears less faulted and with . more reflector continuity, while the EVPFI XX above shows more faulting and higher fault density

An additional challenge is the impact of the type of process on the fault interpretation. What tcthe interpreters have observed is that careful analysis needs to be given because either produ directly impacts the density/presence of faults. In some instances, the processed seismic shows a less faulted structure with more reflector continuity than what the other process will .show

In Figure 2 the red and yellow ellipses point to structures where there is very good well control from where the interpreter can infer the size and geometry of the target hydrocarbon accumulation.

The red ellipse points to a region where the structure is highly faulted and the flanks are small but steep. The yellow ellipse points to a large field with hundreds of wells. The structure has a large wavelength and, although it is also faulted, the well control shows that a much better reflector continuity should be expected. Additionally, the flanks of the structure, based on well control, are gentler than what was observed in the area of the red ellipse.

These considerations are important elements of both the input for the processing, as per Figure 1, and the approach and choice of product that the interpreter needs to consider.

Spectral De-composition

Spectral de-composition is a post-processing technique that uses the blending of different frequency ranges from the seismic spectrum of a specific volume and combines them using a RGB blending tool to then highlight potentially identifiable geological features such as channels. The frequencies need to be identified in the area/window of interest. The approach could use a "Wide Band Spectral Decomposition" (WBSD) which extracts a wide frequency band or a "Narrow Band" approach which extracts the amplitudes in a smaller frequency band (Figure 3).

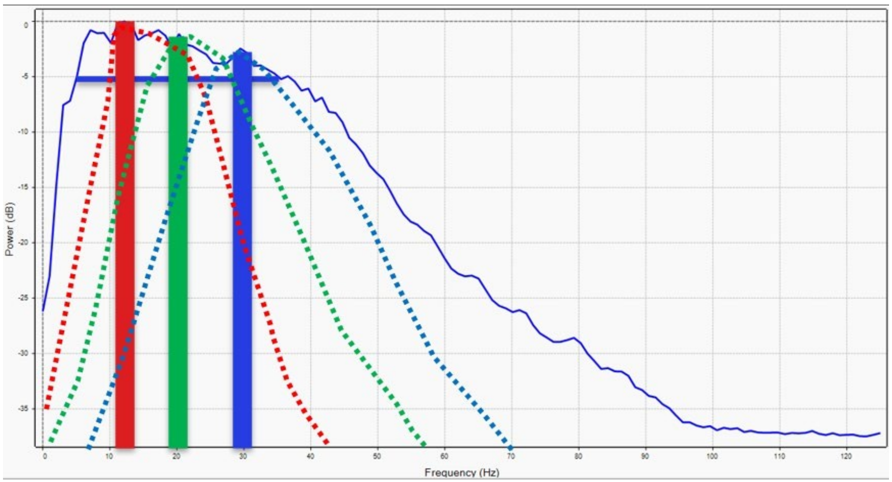

Figure 3. Theoretical representation of the spectrum and way to assess the frequency ranges in a narrow band (solid bars), while a wide band extraction would encompass the dashed lines.

The interpreter then focuses on the individual peaks in the spectrum and selects three values that capture those ranges. This step becomes crucial particularly in Oman where the level of the Haushi reservoir in southern Oman is known to be filled with multiples. If the available seismic is filled with multiples, as had been the case until this new seismic processing has been made available, the selection of frequencies is prone to errors, making this approach unreliable.

Figure 4 shows a seismic volume where the EVPFI process has been applied. Three different frequencies were selected based on the Spectrum obtained from the seismic where the de-multiple process has been applied using the correct “range” for the structure of interest.

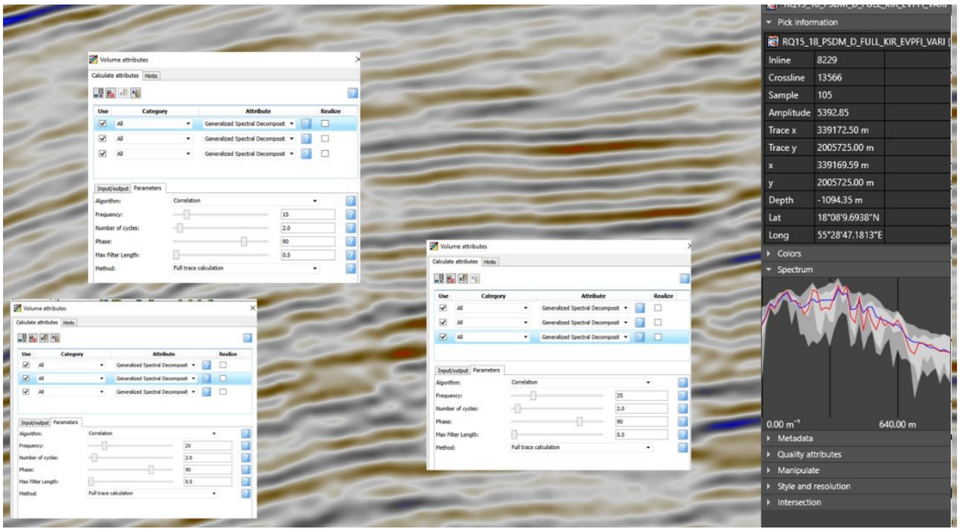

Figure 4. Analysis of the Spectrum and selection of frequencies for one of the Areas of Interest that will be discussed in this study: Field B (Schlumberger’s Petrel was used in the study).

Study Cases and impact of Spectral decomposition in Field Development

The Permian Haushi group is separated from the shallow Cretaceous Natih formation (Wasia Group) by a major unconformity. Multiples of these carbonate rocks make the interpretation, and the application of any attributes or quantitative seismic interpretation, unreliable in the deeper Haushi units. The Gharif is a channelized formation with different levels of vertical and lateral channel stacking. Planning the wells has been very challenging because of lack of understanding of the channel orientation/geometry. New re-interpretations have been made using these recent EVPFI volumes in several fields producing from the Huashi group (Gharif and Al Khlata production). These new volumes are giving a new insight into the fault geometry and lateral/vertical extent, provided, as stated before, that the proper volume is used, based on the wavelength of the structure being mapped.

This paper will use examples from two fields located in the southern Salt Basin of Oman. Field A has a larger structure than that observed in Field B. Field A also shows a far better seismic quality and reflector continuity in a 3 way fault bounded structure, while field B is a much smaller 4 way closure but highly faulted structure with poorer reflector continuity.

Several closely spaced wells (~0.4-1 km apart) in Field A showed major sand variability and also there were cases with different fluid contacts and pressures. The interpreters tried to "find" faults that could, perhaps, explain some degree of sand isolation but, in a highly channelized unit like the Gharif, this is certainly not the most likely cause for sand variability and fluid isolation.

Post processing "Semblance", which highlights faults and channels, was used providing the first insights that these new volumes have removed enough multiples allowing for the true seismic reflectivity to show "geological" features (Figure 5).

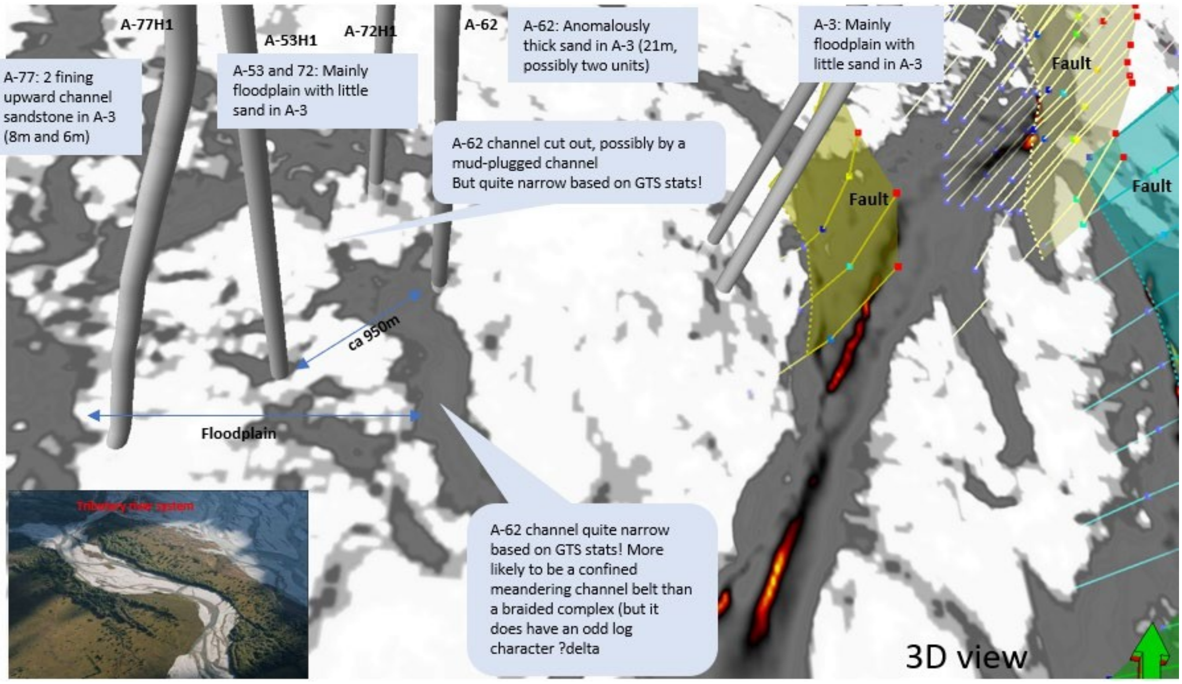

Figure 5. 3D view displaying a problematic area with wells which were difficult to correlate with differences, both in sand presence and pressure (in some cases). Low confidence Faults were initially mapped, but once a volume was created using the "Semblance" post processing attribute, some depositional geometries became apparent. Each well's depositional model is indicated to help place the wells within a modern-day analog model (lower left insert), in a meandering poorly connected channelized system. Alternative interpretations are possible (i.e. well A-62)

These geological features were not identified by most of the interpreters as they lacked experience in sedimentology and understanding of meandering and anastomosed channel systems. When present day analogs were used (insert in Figure 5), the interpreters started picking up the geological features and realized that the main differences in the wells were driven by the depositional architecture of a poorly connected meandering channel system.

Encouraged by the results observed by using the "Semblance volume" the team decided to use Spectral Decomposition with the "hope" that, this being a more robust methodology to identify channels, the outcome of the analysis would provide a clearer picture of the depositional architecture and would help in the modeling and planning of future wells. Ideally, the seismic should be flattened to then be able to follow a particular reflector, but a lot of distortion takes place when doing this. In the case of Field A, there is very minor structural dip allowing for long sections of reflectors to be captured in a "flat" slice.

Once the frequencies were carefully picked up in the loops of interest, and after the RGB blending was done with some degree of color manipulation the results were truly encouraging (Figure 6).

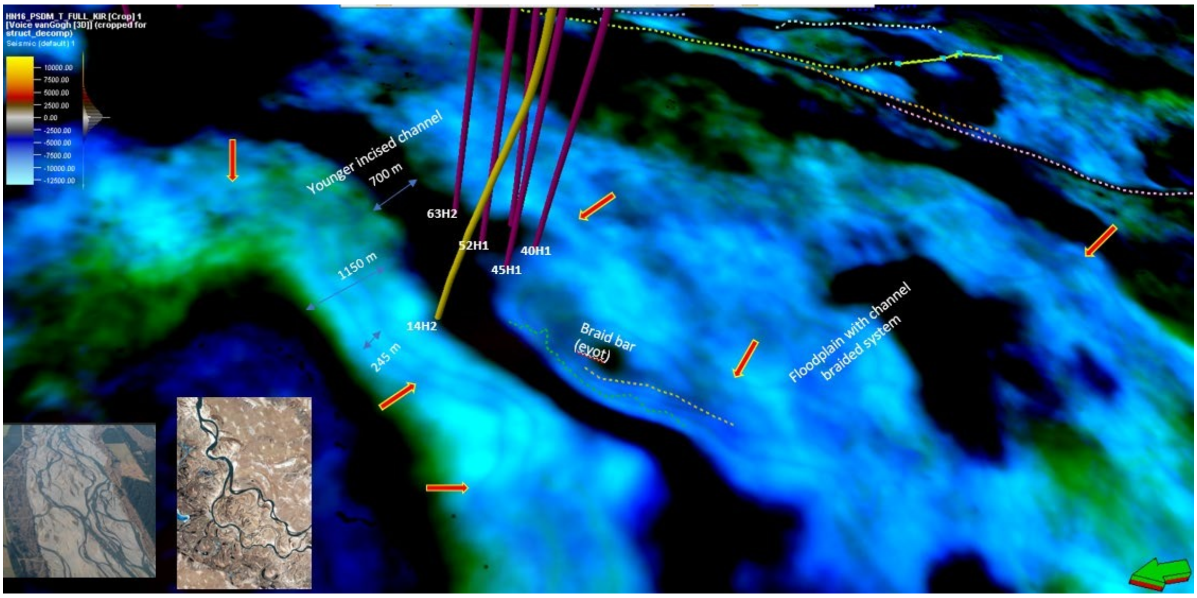

Figure 6. 3D view of the RGB blended output on a flat slice from the Spectral Decomposition process. The channel belts (blue-green tones) were clearly discernable, with the individual channels running inside the channel complex also being easy to identify (arrows).

The channel belts (blue-green tones) were clearly discernable with the individual channels running inside the channel complex being also easy to identify (arrows). The wells were shown in different slices and, once the structural dip was carefully considered, it was possible to explain the observed differences in sand presence, pressure and fluid levels.

Analogs were always used, and the depositional architecture changed from initially considering a braided system to a meandering system when a larger area was interrogated.

Different frequencies blended in Arbitrary seismic slices (taken from the 3D volume), placed as perpendicular to the channel direction as possible, were used to calibrate the "channels" in the Seismic sections. As previously indicated, considering the structural dip is important as the channel geometry will be reliable mainly where the reflectors are "flat" matching the "flat slice" geometry, but once the calibration was done, it was possible to "extract" the channels and map them from the 3D volume (Figure 7).

All throughout the study the "scale" or dimensions of the interpreted depositional features were compared to modern analogs (see dimensions in Figures 6 and 7).

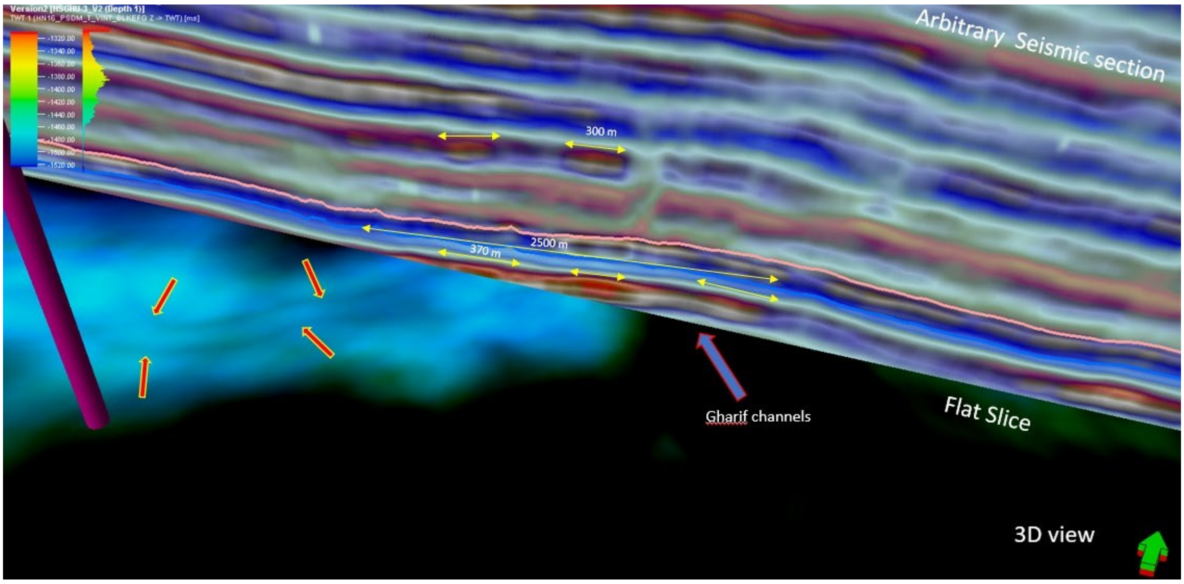

Figure 7. 3D view showing a Flat Slice and an Arbitrary Seismic section with blended frequencies using the RGB blending. The arrows point to clearly distinguishable channels within the channel complex. Because the seismic is not flattened, many iterations were carried out focusing in areas where the reflectors were flat. The arbitrary slices were then used to calibrate the amplitudes that represent channels. Careful consideration to analog dimensions is crucial to properly distinguish these features.

A similar approach was used in Field B. The seismic quality is not as good and there is a more considerable seismic structural dip. Nevertheless, taking into consideration the aforementioned approach, the results were also very encouraging. The interpreter learned to focus carefully in areas with no structural dip, which could be easily distinguished from the "impression" of dipping reflectors in the Flat slice, where there was no information regarding channel cuts (arrows in Figure 8).

The same geological formation and well related issues prevailed. Relatively closely spaced wells showed drastic pressure and sand reservoir thickness changes. Faults were initially used to "isolate" the wells, but well planning became challenging as some surprises of lack of reservoir presence required sidetracks. Spectral Decomposition has been effectively used to plan and drill two wells that fit the prognosis, and where the results were easily explained using this approach.

Flattening of the seismic does not always work nor facilitates the interpretation. Depending on the quality of the interpreted reflector used for flattening, the seismic can get seriously distorted and any frequency pick does not appear to provide similar results as when using the original reflectivity volume. It should nevertheless be considered on a case-by-case basis.

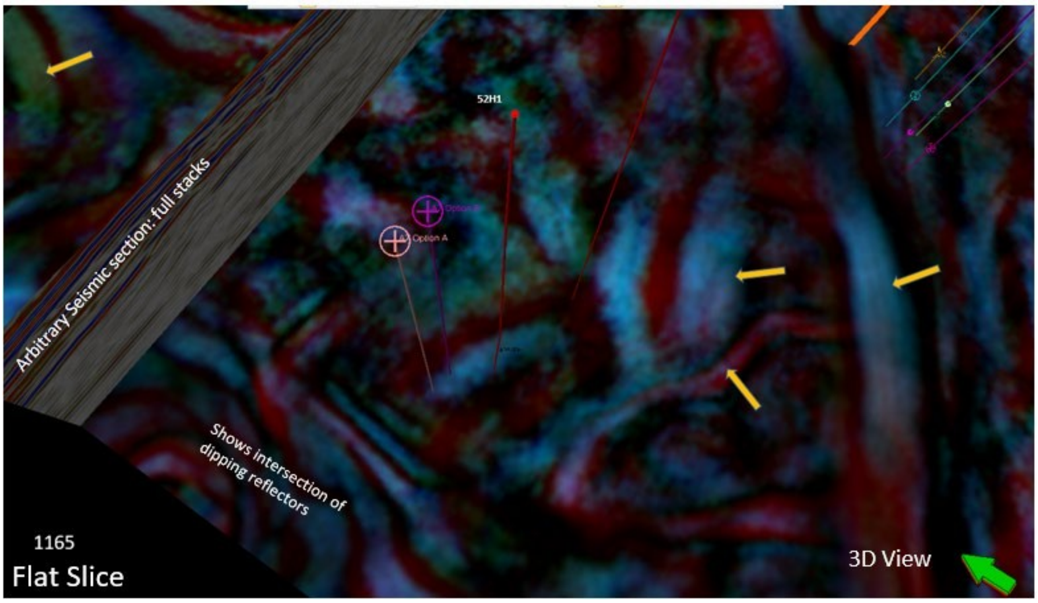

Figure 8. 3D view showing a Flat slice with the RGB blended Spectral Decomposition approach. The channel complexes, and in some cases the individual channel sets (arrows) can be identified. Because of the higher structural dip, careful attention was given to areas where the structural dip was close to zero, while areas with larger dip could be easily identified. The depth of the slices was annotated to then interpret the well placement and results. The two red wells, did not find sand at the expected level, while the purple (Option A) and cream (Option B) wells found thick sand sections.

Conclusions

- It is the Seismic Interpreter who has to decide which is the right volume for the project. Newer/latest seismic processing does not necessarily mean "better".
- Always communicate with your processing geophysicist to better understand what went into the latest acquisition-reprocessing.
- Spectral Decomposition is a Post-processing techniques that relies HEAVILY on the quality of your seismic and where multiples will make the analysis most likely incorrect. It relies on frequency contrast.
- This approach does not always work but, because of its simplicity and the latest work on removing multiples, it is worth inspecting the outcomes.
- The seismic does not need to be flattened to get good results. Use the available seismic for the initial inspection. Look for areas where your seismic is relatively flatter and observe the results.
- It is worth flatting the seismic volume for final assessment, if your seismic pick used for flattening is appropriate.
- You cannot interpret what you have not seen before. The interpretation of Spectral Decomposition requires good understanding of depositional architecture for different facies.
- Once the channels have been identified you can map them and they can be included in the static model adding great value to the understanding of fluid flow, sand distribution, pressure variations and overall field heterogeneities.

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