An application of Trace Inverted Seismic and Well Image Logs to the Development of a Single Sand Target in the Cañadon Seco formation of the San Jorge Basin, Argentina.

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Abstract

Vintage Oil Argentina comenzó la exploración del área de Cañadon León con el pozo CLa-4002 perforado en 1998 con datos sísmicos de 2D existentes. Habiendo obtenido buenos resultados productivos, se registró sísmica 3D en el área en el año 2000.

Los primeros pozos perforados por Vintage fueron ubicados usando los datos adquiridos en la sísmica 3d y basados sobre todo usando una interpretación estructural y estudios sísmicos de amplitud convencionales. Siendo los nuevos pozos conceptualmente distintos, los resultados fueron desalentadores. Vintage se enfrentó al problema de tener un buen pozo productor de una sola arena en posición estructural baja, un pozo en la misma posición estructural que perdió la arena productiva principal y un pozo más alto en la estructura desprovista de buenas arenas.

Después de un período de reflexión, Vintage inició un proyecto de Análisis de Atributos e Inversión de Trazas con el objeto de mapear el buen nivel productivo visto en el primer pozo, y en base al nuevo conjunto de datos, continuar con el desarrollo en el área. Se investigó entonces la característica sísmica de la arena objetivos con la ayuda de un estudio de atributos sísmicos multivariados en combinación con procedimientos determinados como la computación en 3D de la impedancia acústica y volúmenes de porosidad alrededor de la arena principal).

En pozos posteriores Vintage registró perfiles simultáneos de Imágenes Acústicas y Resistivas para determinar la dirección de sedimentación de la arena reservorio. La metodología utilizada consistió en la sustracción del buzamiento estructural definido en los niveles pelíticos, al buzamiento de la estructura interna de la arena. La dirección de depositación de la arena definida a partir del perfil de imágenes fue correlacionada con las anomalías de inversión de trazas sísmicas para ubicar nuevos pozos.

History

Vintage Oil Argentina took over the operation of the Cañadon Leon Area in November 1995, and unlike the previous acquisitions, this area was deemed exploratory in that there were no wells in production at the time. At the time of writing Vintage is close to drilling the 50th well in this area, hence confirming the validity of our initial interest in the hydrocarbon potential of the area. The majority of these wells were located following conventional structural mapping, but we would like to present an exploration and development story, that is to a certain degree

Figure 1: Location of the Study Area within the Cañadon Leon Area, southern flank of the San Jorge Basin, Santa Cruz Province.
unconventional, and adds to the mystique of the San Jorge Basin.

Location

In Figure 1 we show a map of the Vintage areas in the southern flank of the San Jorge Basin, located in the north of Santa Cruz Province. The enlarged area shows the precise location of the area under study, south of the town of Caleta Olivia and lying to the west of the National Route No. 3.

Exploration

By 1997, Vintage had a well established policy of drilling development wells and step-out wells using 3d seismic data tied into existing well control as the basic data set. As such Cañadon Leon, with no wells in production, was at that time in danger of being ignored, but thanks to guidance from Vintage Senior management, we embarked upon an evaluation of the existing 2d data and generated two exploration prospects.

The first well was drilled on a conventional fault structure, encountered hydrocarbons, and subsequent work based in 3d seismic has confirmed the structure which is under current development. The second prospect to be identified was classified as an east-west trending terrace lying to the north of a horst structure that had been previously drilled by an unsuccessful exploration well. In Figure 2 we show the results of the 2d seismic mapping, in this case a map that represents the top of CS1 member and the area of the conceptual terrace is shaded. The well location, subsequently named CLa-4002, was located on the track of an existing 2d seismic line. The target CS1 sands were interpreted to have been faulted out in the EBLx-1 well, located to the south of the prospect, and

Figure 2: The original prospect map generated using 2 seismic data, with the area considered prospective shaded.

Figure 3: This cross-section shows the position of the CLa-4002
the dry hole O-38 was deemed to be in a separate fault block. To the south-east and in a high position lay the CL-1691 a shut in well with no oil accumulation. Figure 3 shows the position of the CLa-4002 well located structurally in a relatively low position to the existing wells drilled in the area, but with encouraging hydrocarbon bearing sands in the CS1, Caleta Olivia and Mina del Carmen. The inset is a detail showing the sand in the CS1 which probed to be the main contributor to the production of the CLa-4002 well.

First Phase of 3d Based Activity

A 3d seismic survey was recorded in the area in late 2000 and drilling started in June of 2001. As well seismic was available from the EBLx-1 well and a sonic log had been recorded in the CLa-4002 well, Vintage were quite confident about the seismic well tie, and in Figure 4 we show the seismic horizon amplitude map of the reflector that was deemed to be representative of our main target sand. The development well CL-4003 was effectively located using this map as the main source of information. As the new 3d seismic showed that the CLa-4002 well has been drilled in a very low structural position, the CLa-4005 step-out well was located high in the structure, some 2500 metres distant from the original well and gaining some 40 metres (see the inset to Figure 4). The results of these two wells can be seen in the cross section shown in Figure 5. We can see that whilst our main target sand (r130) was present in the development well CL-4003, the petrophysical characteristics were markedly poorer than in CLa-4002 but still tested oil although subsequently not
producing well. The CLa-4005 step-out well was successfully drilled updip from the discovery well, but this time the CS1 sequence was completely different from the previous two wells and only a very poor sand was found and tested in the same stratigraphic section, hence resulting in a poor producer.

**Second Phase of 3d Based Activity**

Whilst the results of the first two wells drilled with 3d seismic data were hugely disappointing, and left Vintage in a similar situation to after the drilling of the discovery well, i.e. a producing oil sand in an intermediate structural position, the information gained was sufficient to re-evaluate the seismic amplitude correlation and mapping. In Figure 6 we can see the new seismic horizon map of the re-interpreted data which correlates with the results seen in CL-4003 and CLa-4005. The inset to Figure 6 shows some trace inversion work undertaken in-house to support this interpretation. Based on both these data sets the wells CL-4011, CL-4015 and CL-4017 were drilled. The inset well cross section shows the results of these wells and we can see how the target sand first found in CLa-4002 had been successfully found in each of these new wells. The seismic anomalies mapped both using conventional reflector amplitudes and trace inverted data were now quite restricted in area with little room left for further development using this same philosophy, hence Vintage initiated an Attribute Analysis and Trace Inversion Project.

![Figure 6: Location of CL-4011, CL-4015 and CL-4017](image)

**The Study of the Acoustic Response of the r130 Sand**

PAIS Geophysical Software Ltd of the UK undertook this study on behalf of Vintage. The sand unit ranged from 3 to 7 metres and was at a depth of 1000 metres. The seismic signature of the target sands was investigated with the aid of a multivariate seismic attribute study. The work also combined more deterministic procedures, such as the computation of 3D acoustic impedance and porosity volumes around the target sands. True amplitude 3D seismic data, well log data from six wells including the tables for the formation tops and sequence boundaries and the interpretation data for six horizons were provided for the study.
Good quality wavelets were computed using the well data. In the study area, few strong seismic reflections around 300 to 400 msec. often dominate the wavelet computation procedures. Nevertheless, at some well locations, (such as CL-4015), it was possible to use fairly large temporal computation gates containing the reservoir zone. All the computed wavelets were found to be very close to zero phase. Hence, prior to acoustic inversion procedure, the phase correction of the original seismic data was not necessary. An example of the computed wavelets is presented with Figure 7.

For this study, 3D acoustic impedance data was computed in two stages. First, the Low Frequency Compensated Recursive Inversion procedure, (R.O. Lindseth, 1979), was used to compute the acoustic impedance data for a time range of 0 - 2000 msec. The results from recursive inversion were then cycled back as input to Optimized Sparse Spike Inversion Procedure (Oldenburg et al, 1983), for further refinement. Sparse Spike inversion was computed for the time range of 450 to 1300 msec. At each well location, the computed pseudo acoustic impedance is compared with the well acoustic impedance data, and an example of the results is again presented with Figure 7.

Principal component analysis was performed to discover structure in the multi-dimensional attribute data. Usually, once a set of effective seismic attributes are selected, the principal component analysis is used to examine if these can be represented by their reduced principal components without any major loss in the data's information content. In other words, the procedure effectively combines attributes by removing the redundant information. Principal component amplitudes are dimensionless and there are as many principal components as attributes used in the computation. In general, the first principal component contains the most coherent information that exists in the supplied attribute set. For this project, the principal components were computed using the combination of attributes; Average Reflection Strength, Average Impedance, Weighted Average Frequency and 71 Hz. Spectral Decomposition Amplitudes. The First Principal Component which normally collates the most coherent information from the above attributes is displayed in Figure 7.
The classification procedure groups the multivariate into several clusters such that, in terms of selected attributes, each cluster is as homogeneous as possible. The procedure does not make use of spatial relationship between the data points. The number of clusters created by a classification process is statistically determined. Once this process is completed a colour is assigned to each cluster for display purposes. A Classification Map was generated by combining attributes; Average Reflection Strength, Average Impedance, Instantaneous Likeness and 71 Hz. Spectral Decomposition Amplitudes. This map is shown as the final inset of Figure 7. The current producing regions and several possible productive areas are shown in green colour.

Third Phase of Development Activity

Using the seismic attribute study presented by PAIS Geophysical, Vintage was now sufficiently confident to locate the CL-4021 well and Figure 8 shows the well location in relation to the final seismic attribute map. In addition to the conventional logging suite, Vintage requested that Baker-Atlas record simultaneous Acoustic and Resistivity imaging logs, with the objective of identifying and analyzing the paleocurrent depositional direction of the r130 sand.

The methodology used to obtain paleocurrent directions from image logs, consists in undertaking a statistical analysis of the recorded dip information, determining the structural dip of the shale sections in each well and by subtracting that structural dip, the direction of the paleocurrent of the target sand interval can be determined. In figure 8, the resultant calculation for the CL-4021 well shows an easterly direction which corresponds with the orientation of the seismic anomaly. Based on the coincidence of these two data sets, the CL-4032 well was located and again in figure 8 the result of the “STAR” is shown, and in this case we see a north-easterly orientation which again corresponds with the seismic attribute anomaly. In Figure 9 we show the well cross sections showing the presence of the r130 sand. As can be seen from the log response and STAR interpretation in the CLa-4002, CL-4011 and CL-4015 the r130 sand was interpreted as a typical channel with its facies associated with a coarsing upwards sequence, but once we reach CL-4032 well, more evident is the lack of a channelized facies with some characteristics of abandoned deposits. Due to our
interpretation of this kind of depositional environment the sand was unfortunately deemed too thin to encourage further development.

Finally this same technique was applied to a separate anomaly show from the seismic attribute analysis, and as can be seen in Figure 10, whilst the target sand was encountered, it was too thin to be productive.
Review

In Figure 11 we show the original map made from the 2d seismic data with all the new drilled wells located. We can see that with the exception of the original CLa-4002 discovery well, all the subsequent producers lie outside of the originally mapped prospect. In addition we can see that the CL-4003 and CLa-4033 wells fall well within the originally mapped anomaly, and it was only the prudent practice at the time to drill only on the path of an existing seismic line, that the discovery well was located at the successful CLa-4002 site. We show two insets to this figure; below left is the structural map generated from the 3d seismic data, and above left is a sketch map of the estimated ultimate oil recovery of each well drilled in this area. We can observe that the best well by far is that drilled in the lowest structural position and ponder over the potential consequences of not having drilled the original well on the 2d data.

Conclusions

We are very encouraged at the correlation between the paleocurrent direction of our study sand as seen from the “STAR” Image log and the seismic attribute analysis. As such we deem it appropriate that in development of areas in which the main production is anticipated from a single sand unit, that this combination of tools is considered at an early stage of the development process.

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