Seismic Velocity Quality Control: from picking to regional gathering

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Abstract

Most of technicians who participated in Seismic Reflection Processing or Interpretation have one story about seismic velocity. In Seismic Processing sequence there are few capital chances to strongly decrease the quality of a seismic section. Among then we may point out errors in acquisition geometry and errors in seismic velocity interpretation. Seismic velocity is a very important attribute derived from seismic data that have immediate implications in seismic section quality and subsequently in petroleum E&P projects. Poor quality seismic section with a bad depth conversion holds enough conditions to reach an E&P project failure. Bad seismic velocities might result from interpretation by inexperienced geophysicists, or obtained from bad seismic data quality. Seismic Velocity Interpretation is a difficult job that requires experienced technicians. As a general rule, in petroleum major companies as much as in the petroleum service companies, this job is delegated to inexperienced technicians. Sometimes the technician involved in velocity interpretation has knowledge about seismic but has not enough knowledge about the local or regional Geology. One perception about seismic velocity is that every interpreter has a fingerprint: in a word, seismic velocity interpretation is an art form.

Introduction

Seismic velocity interpretation is a very important step in processing flow. Why this step is often done by junior technicians? The answer to this question may be easily extracted from the following sentence: it is common to generate thousands of velocity analysis in a 3D seismic processing sequence. The interpretation of these data is a repetitive task that takes a long time period. So, this task is not considered to be done by senior geophysicists, who normally are involved in jobs that require a lot of experience. Is the seismic velocity interpretation an easy job? The answer is no, because it requires good knowledge about seismic reflection method and good knowledge about the local or regional Geology. How to avoid bad results and enhance the final quality of a seismic velocity interpretation? This is the scope of this paper. All figures in this paper, except figure 3, are generated by computer applications developed by the author.

The online velocity database and the velocity picking

One important item that helps seismic velocity interpretation is to build an online velocity database. This database may be composed by old seismic 2D or 3D velocity functions, VSP data, CheckShot data and Time-Depth curves obtained from well transit time integration (Souza, 2001). The idea is to use the database to provide the interpreter with all possible velocity information at the time the velocity analysis is being picked. Figures 1 and 2 are graphic images obtained with an interactive computer application. The **figure 1** presents a basemap including well locations. The blue circle in this basemap limits the geographic area to capture velocity information to support interpretation decision in an actual velocity analysis picking. The area extension is user defined, one time he selects the circle ray value. One usual ray value in a mature petroleum basin is 2 km.

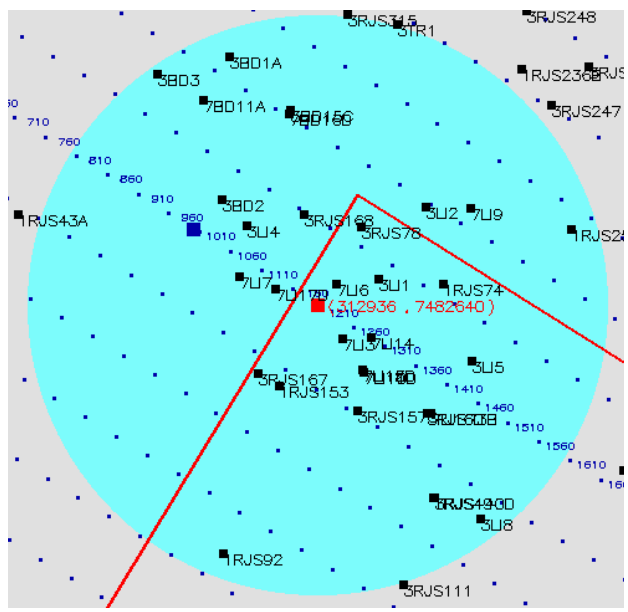

Figure 1 – Basemap showing a velocity analysis location (red box with UTM coordinates), previous velocity analysis position (dark blue box), well locations (black boxes) and a blue circle that limit the area to collect velocity information from the database. Red line is cultural data (ring fence limit).

Basemap of figure 1 may be used also to show graphically Geology information (as an example, the main structural features) and to show sea bottom depth contours. These informations are helpful, because introduces the interpreter in the Geologic Site and alert about possible presence of seismic multiple interference in the seismic velocity data. Seismic multiples predominate in hard bottom geologic sites and are strongly related to sea water layer thickness.

The figure 2 is a graphic presentation of velocity information. The green (superposed) and black curves are time-velocity functions retrieved from the velocity database. In this example, for illustration purpose, the data was collected from an area with 10 km circle ray. The light blue curve in the middle is the average among all green curves. The colored boxes (brown, purple, gray) are checkshot information from wells.
As long as the interpreter has the geological and geographical information, knows about the possible presence of multiples and may confront the interpretation being done with previous interpretations and well velocity data, he has all the chances of doing a good job. The use of this methodology is quite useful in onboard (offshore) seismic velocity interpretation, where the interpreter has no help from experienced technicians.

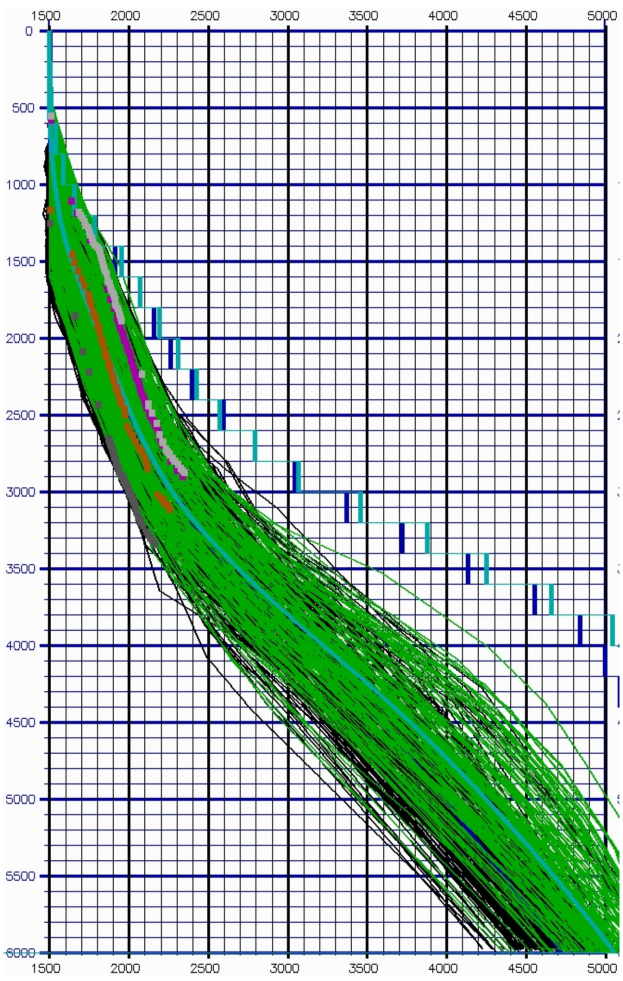

Figure 2 – Graphic presentation of seismic velocity functions and well checkshot data. Values in the top and botton are velocities (m/s) and values in the left side are time (ms). Green and black curves are velocity functions from 3D seismic data and colored boxes (brown, purple and gray) are well checkshot data.

The **figure 3** shows an isovelocity section. The velocity interpretation was initially done without any access to a velocity database. This interpretation was revised afterwards using the information retrieved from the velocity database. Clearly in this section we may separate two images: the left side with smoothed data and the right side with high frequency displacements. The left side shows the data revised, the right side is an original interpretation. Since the seismic data was recorded in a Marginal Passive Basin, we may assume that the left side is the one that best represents the Geology. The image in the right side is unexpected and doesn't agree with the local Geology.

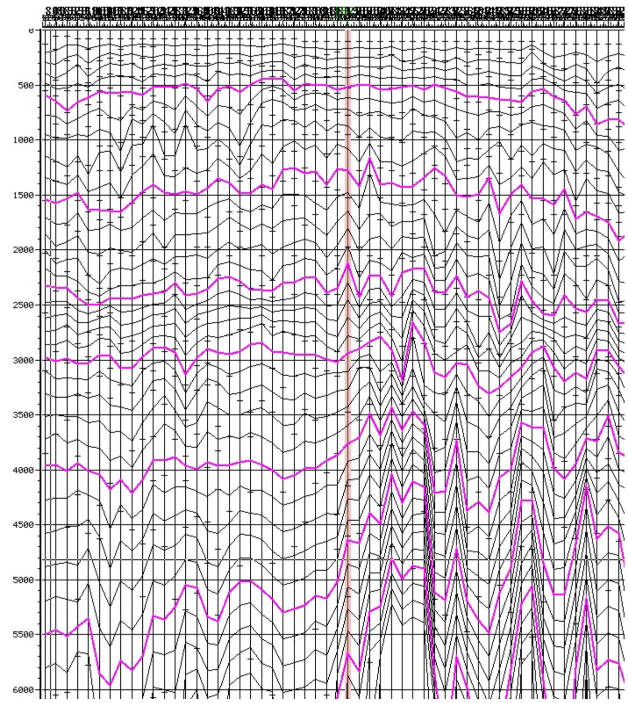

Figure 3 – Isovelocity section. The left side section was revised with the methodology here explained.

The 3D context

Nowadays, most of seismic data is obtained in 3D surveys. Although the acquisition is 3D, the seismic velocity analysis and interpretation sometimes is done with a 2D methodology. Basically, the interpreter moves forward along 2D lines and has no chance to check the velocity information in a 3D context. It is frequent the occurrence of conflicting values among 2 velocity functions placed nearby in 2 parallel seismic lines. This is explained by the fact that there is a delay of hours between the 2 interpretations: the interpreter doesn't remember what technical decisions he took when picking the first analysis. The methodology illustrated by figures 1 to 3 might reduce the presence of those discrepancies because the data retrieved from the database is in the 3D context. Another methodology that may minimize the discrepancies is the edition of previous interpretation by identifying the problem with the use of isovelocity or isotime maps. The **Figure 4** illustrates the problem: there are 2 velocity functions showing conflicting values at the SE portion of map (red circles). It is utterly important to identify any velocity problems right at the beginning when functions are been picked up – one has always the chance to reanalyze the data and correct eventual mistakes. This is a 2D example and the same procedure could be applied to any 3D data.

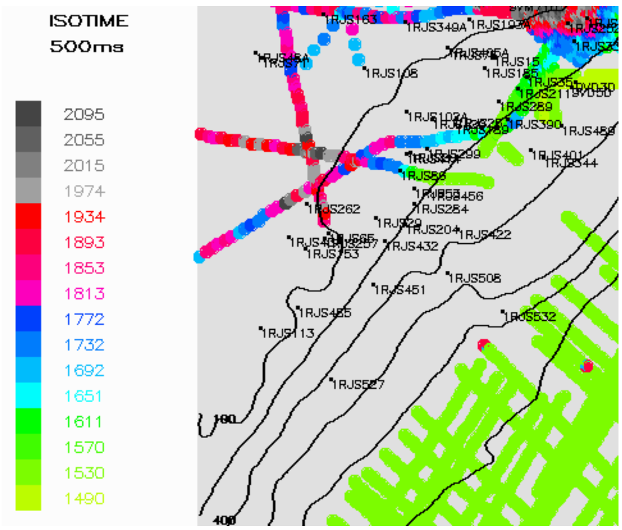

Figure 4 – Map showing velocity values at the isotime 500 ms. Attempt to two red circles in the SE portion: those are the discrepant values that need to be edited.

Controlled Statistical edition

The automatic statistical edition of time-velocity functions by computer applications may return non-expected bad results. Basically the bad results are associated with geological aspects such as water depth, faults, and structuring. The computer application parameters are good enough under certain geological conditions but may fail if these conditions change. So, the computer applications must provide the user the chances to do spatial and temporal control based on application parameters. The f**igure 5** presents time/velocity curves from a computer application. Red curves are candidate to be edited (excluded) based on orthogonal deviation value. The black curve in the middle is an average of all velocity functions. The orthogonal deviation is computed between the black (average) curve and the actual velocity function obeying the time window marked by the red horizontal lines in figure 5. Orthogonal deviation is obtained in the following mathematical expression:

$$\mathbf{OD} = \sum_{i=1}^{n} (\mathbf{PVi} - \mathbf{AVi}) \ / \ \mathbf{n} \ ,$$

OD is the orthogonal deviation, **PV** is the picked seismic velocity, **AV** is the average velocity off all velocity functions analyzed simultaneously and **i** is the time sample index within time window. In this example, the time window has been selected considering the interesting zone limited between 1 and 3 seconds. So, figure 5 illustrates the edition with time control. The f**igure 6** exhibits a basemap with the seismic velocity field at time 2000 ms. The black curves are water layer thickness. The rectangular boxes in the left illustrate the spatial area used to collect velocity functions. These functions are analyzed simultaneously, as showed in figure 5. In this case the spatial control was done, minimizing unexpected results due to geological changes.

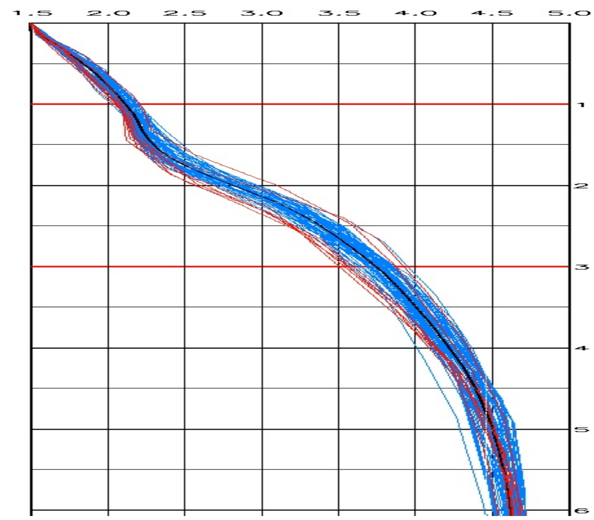

Figure 5 – Time/velocity functions. The red curves are candidates to be edited (excluded) based on orthogonal deviation.

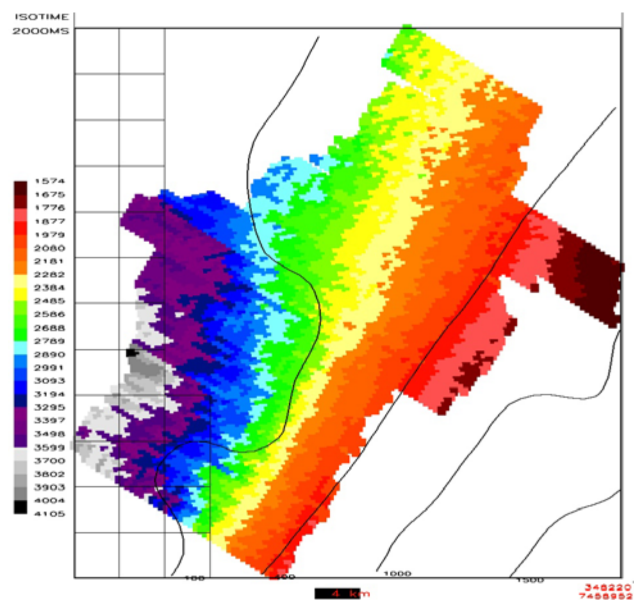

Figure 6 – Basemap showing the velocity field at time 2000 ms and water layer thickness curves (black). Rectangular boxes are used to do spatial control of velocity functions that goes to simultaneous edition (figure 5).

In the computer application the user may control the minimum deviation value that allows edition, the maximum number of velocity functions excluded simultaneously and the size of rectangular box. Another parameter permits the definition of a geographic area to avoid the edition action externally.

Regional concatenation of seismic velocity fields

It is common use to do regional studies based on seismic converted depth sections. This may involve the use of 2D data and 3D data cubes. Regional studies are necessary to understand the petroleum system. It is well known that the big changes between seismic sections and depth converted seismic sections occur in the deeper part. This is mainly associated with the abnormal increase of seismic velocities with depth. Also the seismic quality decreases with depth increasing, with immediate implication in the velocity picking quality. Associated with this quality decreasing with depth, the interpreter avoids picking deep seismic events due to doubts in primary reflection reconnaissance. The consequence is the absence of velocity control in the deeper sedimentary section and corresponding errors in depth converted seismic sections. One action to reduce the amount of these errors is to extrapolate the velocity function maintaining the velocity gradient of last picks. How to manage 2D and 3D velocity functions of many distinct surveys? One idea is simply concatenate the seismic velocity files. Is this new file operational? No, it is not. Distinct surveys have different quality, and corresponding velocity cubes, as a general rule, were interpreted by different technicians. An immediate conclusion of these assertive is that a converted seismic section using such concatenated velocities will show plenty of displacement events due to the presence of discrepant velocities positioned side by side. The f**igure 7** is a seismic velocity map. The input file to this map is a concatenation of 2D and 3D velocity data files previously edited. Clearly it may confirm the presence of discrepant velocities placed side by side in this figure. To minimize the problem one solution is to concatenate and to gather data to new collection cells, to stack the velocity functions in the gather and to perform spatial and temporal smoothing. The amount of smoothing must be user defined to give him the chance to evaluate the final results.

The next figures (8 to 11) will present the solution discussed above. **Figure 8** is a velocity location basemap that shows information about thirty one 2D/3D surveys, in a 100 x 100 km square area. As it may be observed, some 2D/3D are overlapping. The f**igure 9** is a basemap showing the new velocity positions of data of figure 8, now collected, gathered, stacked and smoothed. In this case we used a 500 x 500 m cell size. The f**igure 10** is an isotime (3000ms) seismic velocity map of concatenated, gathered and stacked data. It may be observed fast lateral velocity changes, since data smoothing was not performed. The f**igure 11** is similar to figure 10, now with smoothing step applied. By comparing figures 10 and 11 we conclude that the additional smoothing step brought new characteristics more close to what we may expect from the regional Geology. So, the smoothing step is quite important. In the example on figure 11 it was used a 5 point mix (2 km) space operator and 120 ms time operator. The sample rate in time is 20 ms. The user must be very careful when using long operators because high frequency seismic structures may receive severe attenuations.

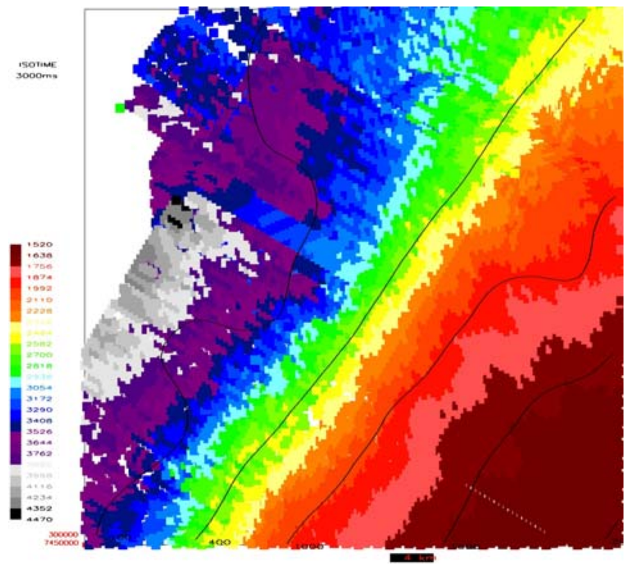

Figure 7 – Seismic velocity map. The input data is a concatenation of some 2D/3D velocity data files. It may be observed high discrepant velocity values positioned side by side. This discrepancy is associated with distinct velocity surveys interpreted by different technicians.

Figure 8 – Basemap showing velocity locations of 31 2D/3D surveys, each 2D/3D represented by a different color. Black curves represent sea water bottom.

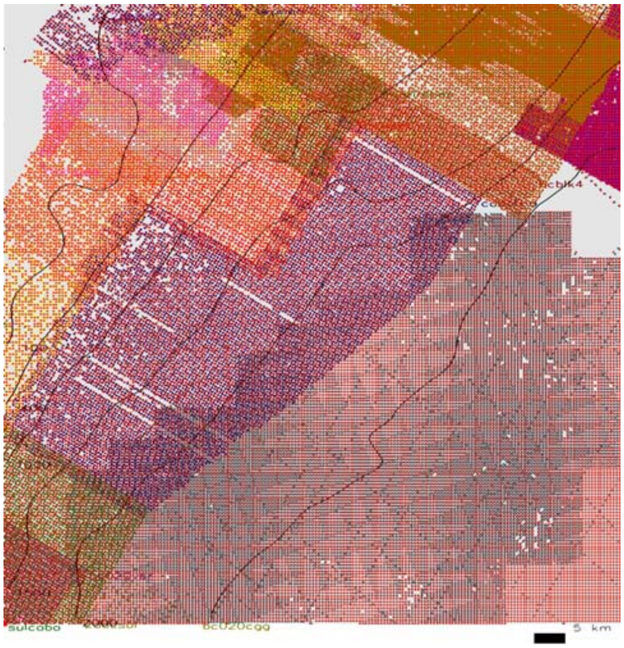

Figure 9 – Map showing the new velocity locations (red dots) after collection, gathering, stacking and smoothing. In this case it was used a 500 x 500 m cell size. The original velocity locations (see figure 8) are underneath.

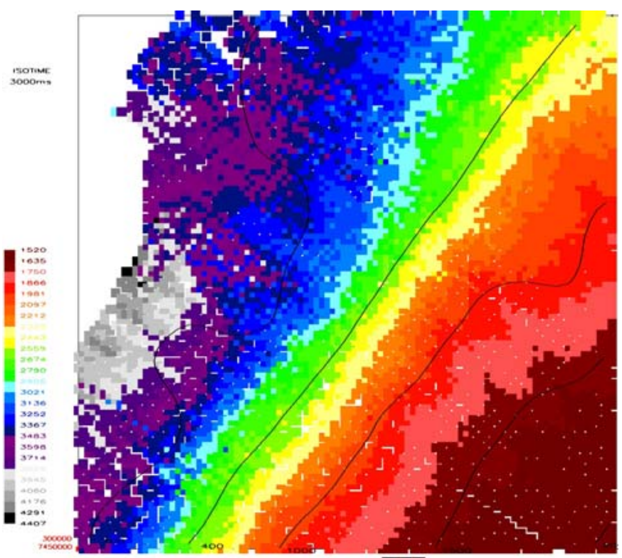

Figure 10 – Isotime (3000 ms) seismic velocity map of data concatenated, gathered and stacked. The presence of high frequency value changes may be observed. Sea bottom depth (black curves) has a narrow correlation with the velocity values. This map is the NW portion of map in figure 9 (1/4 area).

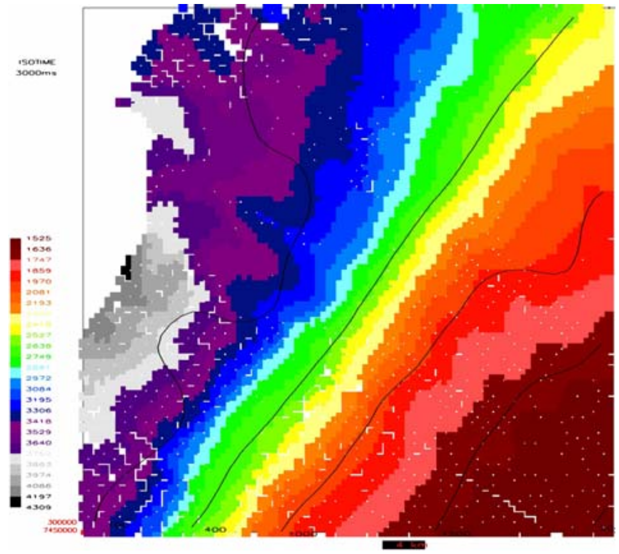

Figure 11 – Similar to figure 10, now with a smoothing additional step. It was used 2 km space operator (5 cell mix) and 120 ms time operator (7 mix points, 20 ms sampled)

Conclusions

In this paper we presented the importance of seismic velocity quality control. We discussed the need for an online velocity database to help seismic velocity interpretation. Computer applications may access this database and bring velocity information in real time. The use of this information reduces doubts and consequently enhances the interpretation picking quality. In the sequence, we discussed the necessity of seismic velocity filtering and one methodology to do it. The methodology is to do velocity edition with space and time control by means of a computer application based on orthogonal deviation computation. Finally we presented a methodology to build regional seismic velocity fields based on 2d and 3D data cubes. This methodology is robust and combines concatenation, gathering, stacking and smoothing of seismic velocity functions. Regional seismic velocity fields are necessary to do petroleum system regional studies.

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