IMPROVING TIME MIGRATION VELOCITY FIELDS USING GEOSTATISTICS

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Abstract

The control of the spatial consistency of the velocity fields that are input to the time migration process is crucial as it directly impacts the resulting migrated amplitude data. Small local velocity inconsistencies in the vicinity of a new planned well location may result in unexpected misfit between well records and seismic interpretation.

The migration velocity fields are often derived from the existing stacking velocity ones. A smoothing factor is applied to the raw stacking velocity data to ensure the suitable continuity of the migration velocity field that is required for the migration process. It is then advisable to look for a reliable control of the spatial quality of the velocity field input for the migration process.

Geostatistics provides a quick and operational way of assessing the spatial quality of the migration velocity fields, and then to improve their derivation by using the relevant spatial filter:

- The computation of a Spatial Quality Index®1 (SQI) attached to each stacking velocity pick helps to locate areas with spatial consistency problems before deriving the migration velocity field.
- The use of a geostatistical filter with parameters specified using the stacking data set (kriging weights) allows to optimize the spatial continuity of the derived migration velocity field.

Introduction

When aiming at a geophysical processing dedicated to structural interpretation and furthermore to reservoir characterization, the control and the quantification of the quality of the geophysical processing is a key issue. Today, such a quality control heavily relies whether on criteria internal to the processing itself that lack objectivity or on qualitative ones such as the visual appreciation of the quality of a seismic section.

When looking for other ways of assessing the quality of a seismic data set, it is recommended to consider the statistical approach, and more precisely the geostatistical approach which is conceived for seismic analysis in space and time domains. Geostatistics proves to be both useful and operational for contributing to the improvement of the migration velocity fields. A dedicated methodology has been developed and tested which is described below and illustrated on a case study.

Method

The spatial quality control of time migration velocity fields relies on the results and the interpretation of a 3D geostatistical analysis of the raw stacking velocity data that were used to derive the initial migration data. It combines the use of the Spatial Quality Index to the filtering of the stacking velocity data on the 3D velocity migration support (3D or 2D average velocity or interval velocity fields) :

- Step 1: The 3D experimental variogram of the stacking velocity data is modeled in order to reflect the underlying geophysical interpretation of the spatial ranges as anomalies or to consistent parts of the velocity field. The variogram model is the basis for the following steps.
- Step 2: Quality check of the raw stacking velocity data: The computation of the Spatial Quality Index (SQI®) is conducted as described in reference [1]. The display of the high SQI values allows to localize possible anomalous velocity picks and to highlight risky areas where spatial inconsistencies may occur during migration.
- Step 3: Specification of the spatial filter to be applied to the stacking velocity data to obtain a consistent migration velocity field. This spatial filter consists in the kriging weights applied to the data surrounding the target location to be filtered. The kriging parameters and neighborhood are defined after the results of the variography in step 1. The kriging algorithm is a factorial kriging one where only the spatial ranges interpreted as consistent or "geology" related are estimated.

Case study

Stacking and migration velocity data originated during the processing of a 1994 seismic survey covering 700km^2 inside the North Sea Basin. After drilling a new well in 2001, it now appears that final migrated time data show a non-linear shift of 40 ms below about 1100 ms (TWT) when compared to VSP recorded time. In addition to that, the migrated data suffer from both lateral and temporal low resolution and contain multiples, reverberation artefacts and poor signal to noise ratio. It was therefore considered that the inaccuracy of the velocity field used in the original processing of the data was a possible major factor contributing to the poor quality of the seismic data. The question was raised of evaluating the quality of the migration velocity data set in order to possibly explain the time difference observed at the well and improve the migration velocity before reprocessing the data.

Quality assessment of the stacking velocity data using SQI® (Spatial Quality Index).

Figure 1 displays the base map and basic statistics for 45151 raw stacking velocity hand picks.
As it is described in reference [1], the Spatial Quality Index is computed after the 3D variography of the raw velocity data and the interpretation of the 3D variograms in terms of "possible artefacts" and consistent or "geological" spatial structures.
Figure 2 illustrates the interpretation of the variogram : The Inline direction is more continuous than the Cross line and other ones. This indicates a processing Inline effect which is an artefact. The spatial ranges identified in the inline direction are interpreted as spatially consistent and linked to geology.
The Spatial Quality Index **SQI®** is computed as the ratio estimated "artefact" / estimated "geology" after splitting the velocity data using factorial kriging into their estimated "artefact" (mainly in line effect) and "consistent" components.
In order to be able to locate velocity anomalies that could explain the 40ms shift observed between seismic and well data to below 1.1 s, a 3% cut –off is applied to SQI® values attached to velocity picks. SQI® values above the 3% cutoff indicate possible anomalous picks.
Figure 3 displays the location of velocity picks with SQI above 3% inside a 1s to 1.5s time window. 4092 picks show SQI® higher than 3%, which represents 9.06% of the whole dataset. These data highlight possible anomalies, whether linked to short scale geology variations (faults) or to geophysical processing.
The high spatial quality index values are mainly located just below the sea bottom, around 1000mstwt (area of interest) and in the deeper part of the field.
A number of them are located along inlines, which confirms that they are possibly linked to geophysical artefact (picking strategy and lack of homogenization after the picking). A number of them are located in the vicinity of the well location.
At the end of the quality assessment, a number of anomalies are detected inside 1s –1.5s the time window of interest. The further processing of these spatial anomalies is thought to impact the migration velocity field and it is advisable to check them in order to explain the time shift observed at the new well location.

Quality assessment of the migration velocity field using factorial kriging

The velocity field actually used for the time migration is available along two main horizons H1 and H2 inside the 1s – 1.5s time window. Horizon H1 is just above 1.1 s at the well location and horizon H2 is located around 1.4 s. A spatial quality assessment of these two horizons should allow to investigate the time shift observed at the well. The actual migration velocity field is compared to the spatially consistent part of the stacking velocity field, as it results from the above interpretation of the 3D variogram of the stacking velocity data. The factorial kriging technique used to estimate this "geological" part of the stacking velocity field acts as a spatial filter that removes high spatial frequencies according to the variogram parameters. It enables to estimate the consistent part of the velocity field along the H1 and H2 horizons, and then to compare it to the migration velocity field.
Figure 4 (horizon H1) and **Figure 5** (horizon H2) display the results of this comparison by mapping the ratio between the two velocity fields migration / stack. Local areas with higher and lower ratios than the average clearly appear on these maps. They indicate places where the filtering of the raw stacking velocity data is significantly different from the smoothing used for computing the migration velocity field. The display of the high SQI® values in the vicinity of the horizons shows the link to these local ratio anomalies. It confirms that the way the spatial high frequencies are filtered out from the raw velocity data clearly impact the resulting migration velocity field.
The histograms of the values of these ratios for horizons H1 and H2 summarize these comments. They are displayed next to the ratio maps in **Figure 4 and 5**. Most of the ratio values belong to the average classes between 0.91 and 0.94, which correspond to the correction coefficient applied to migration velocities to be "geology" consistent. These average classes account for more than 70% of the ratio values. The local high and low ratio values are represented by the classes at both edges of the histogram. These are where the meaningful differences between the two velocity maps are located. Highlighting the ratio value at the well location on the histograms for both horizons will help to analyze the time shift with the VSP.

Validation using the well VSP velocity data

The well location is indicated in **Figure 4 and 5.** High ratios areas that are correlated to high SQI values are located in the vicinity of the well for both horizons. This indicates a possible non-consistency between the two velocity data nearby the well:

- At horizon 1, above 1100ms time, the well ratio is 0.935 (red arrow on the histogram of **Figure 4**) and it belongs to the average classes of the histogram of the ratios (between 0.91 and 0.94 , average 0.923, black arrow on the histogram).
- At horizon 2, below 1100 ms time, the well ratio is 0.947 (red arrow on the histogram of **Figure 5**) and it no more belongs to the average classes of the histogram (average 0.921, black arrow on the histogram). It belongs to the 10% highest ratio values of the horizons, meaning that there is a local non-consistency between the two velocity maps.
- At the well location, the difference between the two data sets at horizon 2 amounts to 2.6 % of the stacking filtered velocity that is 65 m/s.). Assuming that the stacking filtered velocity field is more reliable that the migration one, this difference at the well location is interpreted as an overestimation of the migration velocity. (0.947 ratio higher than the average 0.921).
- On the well marker chart, at horizon 2, the migrated twt seismic time is 40ms higher than the twt log time, which is consistent with an overestimation of the migration velocity. The corresponding average velocity difference at is 52 m/s.

The 65m/s average velocity difference with the stacking velocity should be applied the average 0.91 correction coefficient to be compared to the 52 m/s difference with the average VSP velocity. This leads to 59 m/s compared to 52 m/s. Provided that such a simple computation is valid, this indicates that the stacking filtered velocity field is more reliable that the migration velocity one, and that the 40ms time shift observed at the well location below 1.1 s could be explained as a local overestimation of the migration velocity field itself linked to a local inconsistency of the raw stacking velocity field.

Conclusions

This case study illustrates the operational use of geostatistics to assess the spatial quality of a stacking velocity field and of its derived migration velocity field. It is a post mortem case history. Should the spatial control of the migration velocity field had been operated at the time of the processing, a more reliable velocity field would have been input to the migration process and a better match would have been observed to the well data. This kind of spatial quality check is very quick to run and it does not delay the geophysical processing. On the contrary, it contributes to speed and to validate the supervision step, thus bringing additional value to the seismic information. Such spatial quality controls are now applied with great operational success to a full range of seismic processing parameters such as velocities or statics, and to seismic attributes such as impedance or 4D amplitudes.

References

C. Magneron, A. Leron L.Sandjivy, 2003, “Spatial Quality control of seismic stacking velocities using geostatistics”, EAGE 2003 Stavanger

L.Sandjivy, S.Légeron, J.-L. Piazza, 1997, “Use of geostatistics to improve seismic velocities : case studies”, 67th meeting of SEG

C.Magneron, D.Lemeur, 2000, “Quality check of automatic velocity picking”, 62nd meeting of EAGE

Acknowledgments

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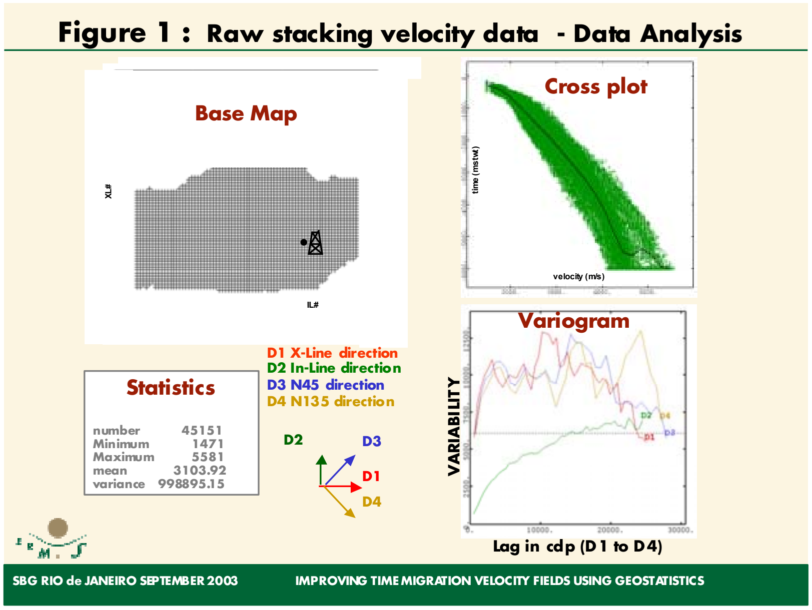
Figure 1 : Raw stacking velocity data - Data Analysis
Base Map
XL#
IL#
Cross plot
time (mstwt)
velocity (m/s)
Variogram
VARIABILITY
Lag in cdp (D1 to D4)
D1 X-Line direction
D2 In-Line direction
D3 N45 direction
D4 N135 direction
Statistics
number 45151
Minimum 1471
Maximum 5581
mean 3103.92
variance 998895.15
D2
D3
D1
D4
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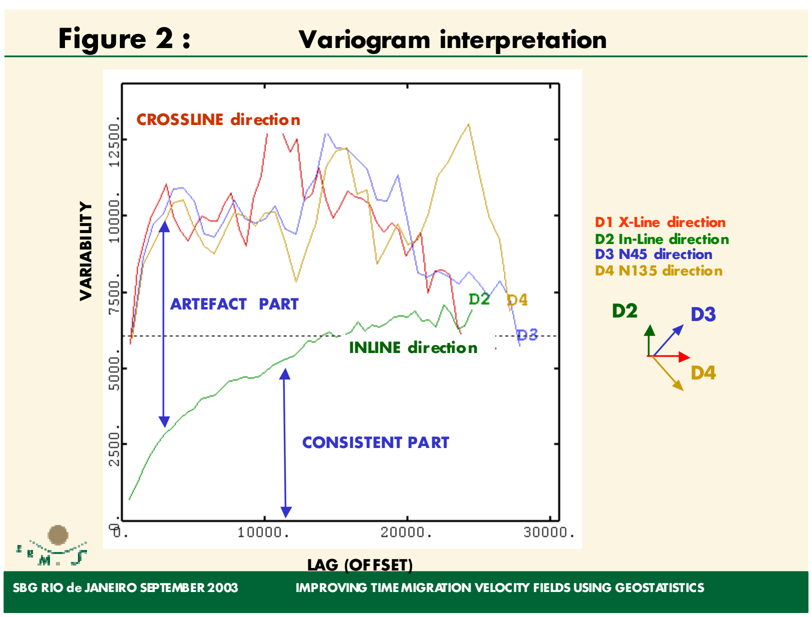
Figure 2 : Variogram interpretation
CROSSLINE direction
ARTEFACT PART
INLINE direction
CONSISTENT PART
VARIABILITY
LAG (OFFSET)
0.
2500.
5000.
7500.
10000.
12500.
10000.
20000.
30000.
D2
D4
D3
D1 X-Line direction
D2 In-Line direction
D3 N45 direction
D4 N135 direction
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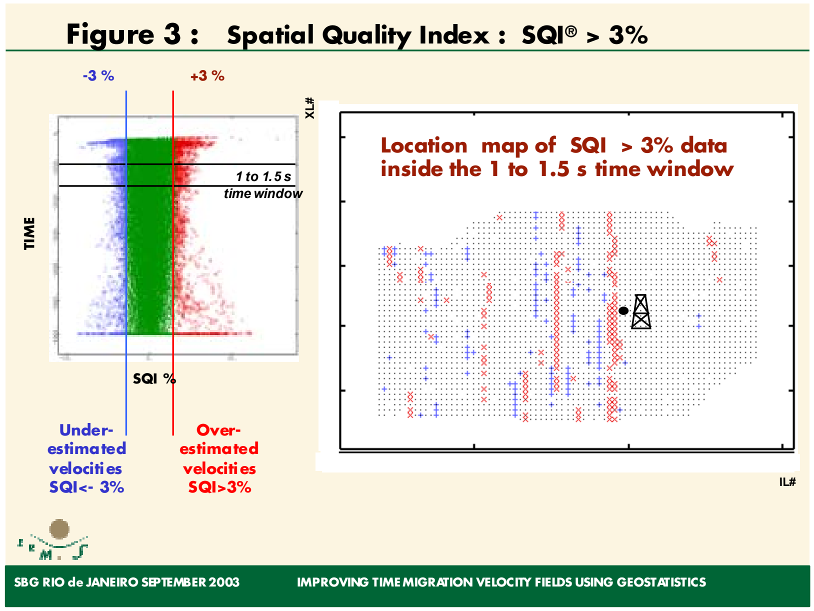
Figure 3 : Spatial Quality Index : SQI® > 3%
-3 %
+3 %
TIME
1 to 1.5 s time window
SQI %
XL#
Location map of SQI > 3% data inside the 1 to 1.5 s time window
IL#
Under-estimated velocities SQI<- 3%
Over-estimated velocities SQI>3%
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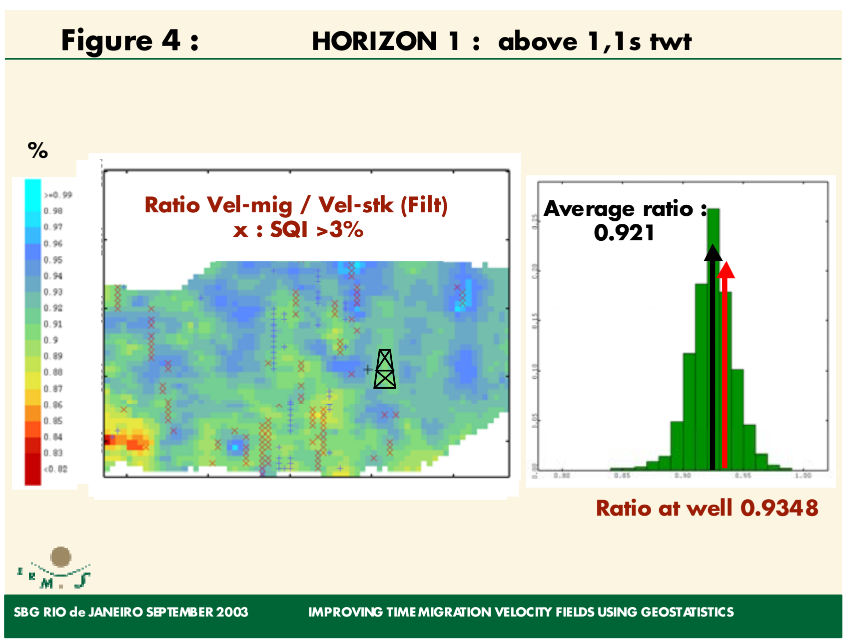
Figure 4 : HORIZON 1 : above 1,1s twt
%
Ratio Vel-mig / Vel-stk (Filt)
x : SQI >3%
Average ratio : 0.921
Ratio at well 0.9348
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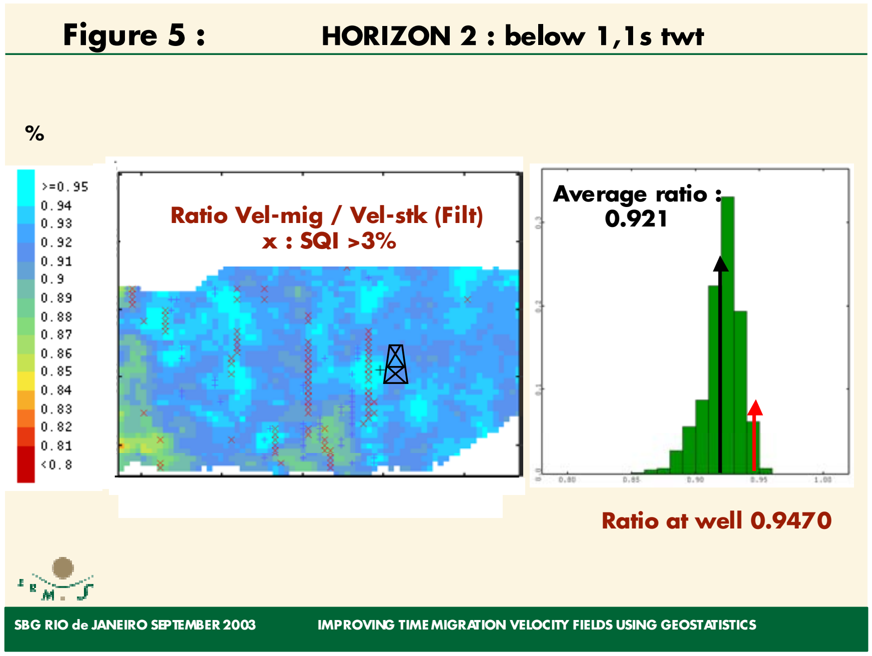
Figure 5 :
HORIZON 2 : below 1,1s twt
%
>=0.95
0.94
0.93
0.92
0.91
0.9
0.89
0.88
0.87
0.86
0.85
0.84
0.83
0.82
0.81
<0.8
Ratio Vel-mig / Vel-stk (Filt)
x : SQI >3%
Average ratio :
0.921
Ratio at well 0.9470
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