2D SEISMIC LINES REPROCESSING TEST USING COMMON REFLECTION SURFACE TECHNIQUE

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ABSTRACT

This work presents the results of the reprocessing test on two onshore 2D seismic lines acquired in 1999 in Southern Apennine. Even if a great number of seismic lines are available in this area, the data are old and processed with obsolete technique. Legacy seismic data are often suboptimal in terms of bandwidth, fold and offset distribution; further issues come from the limitations of legacy processing. Modern workflow for the processing and imaging of legacy data has therefore a big potential, in both offshore and onshore exploration. To improve the seismic image quality, the Common Reflection Surface (CRS) technique was applied. The test was performed in order to define and optimize a reprocessing workflow and to improve the signal-to-noise ratio.

INTRODUCTION

One of the structural elements recognized in Southern Apennine is the autochthonous Apulian carbonate platform, deformed in the sub-thrust location below alloctonous complex. The Apulian fractured carbonates represent the producing reservoir of the main oil complex in the area. Different deep prospect lying on the same trend have also the Apulian carbonates as objectives.

In the area of interest a multitude of seismic data is available from past acquisition campaigns, but due to geological and tectonic complexity, and probably by un-adapted acquisition parameters too, the quality is very poor.

A new seismic survey could be useful in order to test different acquisition parameters. Due to the presence of Natural Park, sites of European community importance (SIC) and zones of special protection (ZPS) on the south area of interest, and following uncertainties on the possibility to succeed in the regional mandatory authorization process for a new acquisition campaign, it appears today quite unlikely to acquire new seismic data to cover the southern part of one of the identified prospect and to properly define its southern closure.

The reprocessing of existing data seems to be the only way to improve the image quality and to better define the prospect geometries. For this reason, it was necessary to define and apply an integrated iterative workflow, using the CRS technique as data preconditioning.

OBJECTIVES AND METHODOLOGY

Over the past years different operators acquired seismic data in the area of interest, but not all the seismic data can be reprocessed at the present time and, in case, they may not be reprocessable with the same potential. The expected quality is very variable, seismic data were acquired from 1975 and 1999 by different contractors with different acquisition geometries and sometimes, when it is not very difficult, it is quite impossible to recover all the important field documents linked to the acquisition and especially the geometry.

The existing processed sections have been generated using, in general, rather basic approach and technologies; moreover the detail of the processing sequence and workflow are not known for all existing processing products.

The objective of this test is the assessment of the potential improvement of the seismic images achievable by means of reprocessing. The enhancement evaluation is referred to the overall visibility of the targets and structures, to the imaging of reservoir and especially of its

top, to the improvement of signal-to-noise ratio and to the achievement of an estimation of the impact of velocity. Even if unlikely, the data analysis could also support the survey design for any future seismic data acquisition.

The work methodology consists in a preliminary data analysis needed to design a processing workflow and to identify the challenges of this reprocessing study. The processing parameters are defined in the second step, when the reprocessing of two lines has been performed. At the end, we analyze the results in order to have an estimation of the improvement and understand if the same workflow and parameters could be possibly applied to a large set of legacy data.

DATA ANALYSIS

The reprocessing test focuses on a couple of seismic lines chosen considering multiple criteria. Their location with respect to the prospects geometry, for example, is the main one: the test lines need to be the most representative in terms of geological and geophysical characteristic (Figure 1). Moreover, the different raw data qualities could help to evaluate the potential of the CRS technique applied to data acquired in different periods and with very different acquisition geometries.

Following a preliminary data analysis on the chosen 2D test lines, some key geophysical challenges were identified and considered for the design of the reprocessing sequence. The most evident was the presence of a complex near surface, with important topographic and velocity variations. This leads to the identification of very strong and rapid changes of scattered surface waves, especially due to near-surface scattering of primary energy. The processing solution has to take into account this noise attenuation and the perturbation correction as its essential ingredients, becoming the crucial points of the processing strategy.

The complex geological structure leads to hypothesize a resulting complex velocity model, with possible 3D effects and out-of-plane events on 2D geometry.

The preliminary data analysis showed excellent first breaks, suggesting the good potential of the refraction tomography for statics and velocity modelling.



Fig 1: Example of legacy section chosen as test line

The large lateral variations of the near surface velocity appears from the variations of the refracted wave arrivals, as visible comparing the gathers with common kinematics reference (red dashed line) at point A and B in figure 2. Evidence of a considerable subsurface complexity is suggested by the presence of clearly asymmetrical reflections. Looking at point

C, for example, the large impact of near-surface perturbations is clearly visible, with time distortions correlation between refraction and reflection.



Fig 2: Example of shot gathers

PROCESSING WORKFLOW

A detailed processing sequence has been designed, adapted and optimized during the test. A considerable effort was devoted to solving the noise and perturbation issues before moving to subsurface imaging. The key steps of the processing sequence are schematically represented in figure 3.



Fig 3: Schematic processing workflow (A. processing; B. CRS preconditioning; C. imaging; D. signal enhancement)

The processing sequence includes the following steps:

A. PROCESSING

Following the geometry data digitalization, analysis and quality control (QC), the data were integrated with the Digital Elevation Model (DEM), leading to a geometrical reconstruction of the test lines. Iterative first break picking was performed via tomography inversion up to a satisfactory accuracy over maximum possible offset range. Then, consistent depth floating datum and velocity based intermediate datum were defined, followed by the computation of refraction based primary and residual statics. After the traces edit and despike, the geometrical spreading correction was applied. The data conditioning includes perturbation correction and noise attenuation; to ensure maximum signal protection, mild and safe noise

attenuation methods were used. This step contains the initial Pre-Stack Time Migration (PSTM) velocity analysis, leading to an amplitude preserved bending-ray Kirchhoff PSTM.

B. CRS PRECONDITIONING

This is essentially an attenuation tool. The CRS analysis starts from the gathers and initial velocity preparation. Following the CRS parameters (wavefield dip and curvature) estimation, the CRS stacks were generated in order to design and validate these parameters, used at the end to generate the CRS enhanced gathers.

C. IMAGING

The imaging stage includes a time refined PSTM velocity analysis using the CRS gathers with the generation of a CRS-PSTM section. An iterative velocity model building was applied, taking into account the geological information and the horizons interpretation constraint, obtaining the final PSTM product with optimized velocities.

In depth domain, the model building uses essentially an iterative manual strategy with layerbased velocity update and final Kirchhoff Pre-Stack Depth Migration (PSDM).

D. SIGNAL ENHANCEMENT

Post migration mute picking on image gathers, noise attenuation and residual move out correction at this step have the aim to attenuate the migration noise.

The post-migration, pre-stack signal enhancement sequence was applied to improve the signal-to-noise ratio using a combination of coherency filter applied with a structure preserving constraint. The analysis of offset contribution was performed in order to obtain the best possible image.

PROCESSING DETAILS

The geometry is built using the observer logs and the survey data available in different formats. The test lines have accurate geometry information coming from the acquisition campaign, but incomplete elevation data at the edges of the lines, since the available elevation survey covered only the CDP coordinates.

The elevation being crucial for the static corrections, and required at source and receiver locations, additional data were used to validate and extend it to the edges of the line. Source and receiver elevations were interpolated using the digital elevation model. An example of elevation reconstruction is provided in the following figure 4. The elevation is graphed with the solid red line over a shot gather at the end of the line: on the left the surveyed elevation, on the right the interpolated elevation. After QC of the elevation statics, the interpolated elevation is used only at the edges of the lines, where the surveyed values were not available (see yellow box in the following figure 4).



Fig 4: Example of elevation reconstruction from DEM. At the beginning and end of the lines no elevation data were available. The source and receiver elevation has been reconstructed from the available DEM

The geometry is then QCed displaying different trace attributes as a function of shot and receiver. The correlation analysis of the attributes in the stacking chart allows the identification of geometry errors and their correction: dead traces, noisy traces and polarity inversions are particularly useful for this task. The following figure 5 shows an example of geometry correction guided by a noisy trace.



Fig 5: Example of geometry correction based on the shot-to-shot correlation of trace attributes

The first break picking was performed iterating A) an automatic, shot based first break picking module and B) ray tracing traveltime simulation that generates an accurate time-offsets-position prediction to guide the picking. A simple energy ratio in moving window threshold works well with the considered data.

The first break picking is relatively straightforward with the considered lines, shot with explosive sources.

The first breaks were QCed displaying the picked traveltimes and the reciprocal error, averaged at shot locations. The reciprocal error is in general below 10 ms, indicating a high quality first break picking and the target misfit for the refraction tomography. As an example, the first break validation is illustrated in figure 6.



Fig 6: Picked first break travel times (top), line elevation (mid) and reciprocal error (bottom)

A nonlinear, grid based refraction tomography was then performed. The whole offset range was used for the refraction tomography, and the investigation depth is about 300 to 400 meters. Large lateral variations were identified, as in figure 7. They are likely correlated to lithological variations in the near-surface.



Fig 7: Velocity section of the near-surface, in depth. The large lateral variations, with the high velocity zone at the centre, have evidence in the traveltimes and are very likely true velocity anomalies related to lithological boundaries

Primary statics were computed defining a smoothed topography as floating datum (in depth) and an intermediate datum corresponding to an iso-velocity surface (in depth). The shallow portion of the near-surface was therefore replaced by a constant velocity layer: sources and receivers were moved to a surface consistent smoothed topography, which preserved the asymmetric moveout for migration at the topography. The first-break residuals were decomposed with a surface consistent constraint to identify source and receiver high frequency perturbations: these refraction residual statics are rather large, with a range of almost 40ms. In the following figure 8, receiver statics are in blue and shot statics in red.



Fig 8: Refraction residual statics for shots and receivers

The primary statics and residual refraction statics were checked and validated with a cascaded application and a QC on shot gathers and on stack. They are particularly effective in correcting for the large and rapid perturbations of the seismic data in the area. In the example provided below in figure 9 and 10, the effectiveness of the statics is confirmed by the smoothness and continuity of the first breaks, and by the large improvements of the few clear reflections.

A close-up of the area in the red box is shown in the following figure 10. The effectiveness of the refraction residual statics is important to reduce the amount of the perturbations and allow the reflection residual work properly. The sample gather of the figure has good primary reflections on which reflection residual statics would be effective: but this is not general, and on large sections of the lines the low signal-to-noise ratio of the reflections could be an issue for standard reflection-based residual statics.



Fig 9: Example of a shot gather before and after statics, primary and refraction residuals summed. The first breaks are smooth and continuous, with a shape depending on the velocity and the smooth topography. The red box represents the area of the close-up of next figure 10



Fig 10:Close-up on the same shot gather of figure 10, before and after statics: notice the improvement of the continuity of reflections, besides the smoothness of the first breaks

Another example is provided in the following figure 12. The large difference of first break traveltimes between the positive and negative offsets could indicate large dips of the refractors.



Fig 11:Example of shot gather before and after the statics

After the computation of the statics, the first mild noise attenuation sequence was applied, followed by the signal processing stages, including surface consistent deconvolution and amplitude compensation. Residual reflection statics were computed using a stack power criterion, in Common Mid Point (CMP) supergathers. The multichannel dip filters were then tested and applied, after full static application, to maximize the signal protection.

The velocity picking was based then on velocity scans. The semblance was evaluated on migrated gathers, time slices and horizons. The initial PSTM velocity is shown in the following figure 12.

The velocity displayed in figure 12 (bottom) is the Pre-Stack Time migration RMS velocity: it shows a large lateral variation and suggests the possibility of a velocity inversion. The interval velocity obtained via refraction tomography is displayed as reference in figure 12 (top).



Fig 12:The preliminary PSTM velocity (RMS velocity, in time) is displayed in the bottom panel; the refraction tomography interval velocity of the near surface, in depth, is displayed in the top panel.

The preliminary PSTM section was generated with a Kirchhoff bending ray migration of the gathers. A 4km aperture and 75 degrees dip limit were used for this preliminary migration, whose objective is the QC of the preprocessing applied. A close-up of the first two seconds of the preliminary PSTM is provided in the following figure 13.



Fig 13: Example of preliminary PSTM stack section

The CRS process is then run. As a first step, the data analysis extracted the optimal wavefield velocity, dip and curvature for the computation of the CRS. The parameters were then used to generate a CRS stack, used to set and validate the aperture in the offset domain and in the CMP domain. The parameters were evaluated analyzing an unmigrated CRS stack. The process generated a series of stacks, corresponding to decreasing semblance.

The highest semblance partial stack is displayed in figure 14, together with the standard CMP stack. The denoise effect is very aggressive when selecting the partial stack corresponding to a high level of semblance. Both CMP and CRS stacks are at the floating datum, and therefore the section does not show clearly the topography.



Fig 14: Comparison of the CMP stack and of the highest semblance CRS stack

The CRS approach is then used to improve the signal-to-noise ratio of the gathers, with a local partial stack along the CRS surfaces for every input trace. The CRS gathers can then be migrated, to produce a first CRS-PSTM (figure 15), and used as input into the velocity picking workflow, for a second iteration of velocity picking.



Fig 15:Comparison of the raw PSTM (left) and the raw CRS-PSTM (right). The same velocity is used to migrate the original gathers and the CRS enhanced gathers

After updating the velocity, a series of percentage velocity scans was produced, to identify possible further velocity improvements via picking of horizons and features on the migrated sections.

The final velocity is then used to run the final CRS-PSTM. An example of final raw CRS-PSTM is displayed in figure 16.



Fig 16: Final raw CRS-PSTM, before signal-enhancement. The section is obtained stacking the raw migrated CRS gathers

The CRS-PSTM can contain migration artefacts, also related to the difficulties of handling the out-of-plane events, and residual noise.

To attenuate the migration noise, residual incoherent noise, balance the spectrum, compensate for time variant spectral content and signal to noise ratio, a final signal enhancement step was applied.

The process first identifies the usable offset ranges as a function of time with a space variant mute, applies a preconditioning to compute a residual-move-out, which is then applied. A coherency enhancement based on rank-reduction and steered dip-filtering is then applied on offset planes. A final prestack time variant filter and post-stack spectral enhancement are used.

The level of aggressiveness of the post-migration signal-enhancement sequence can be tuned and multiple sections can be generated.

The final CRS-PSTM of the two test lines is depicted in figure 17.



Fig 17: Example of the two CRS-PSTM after mild signal enhancement

Despite the possible large 3D effects, the tie between the two crossing test lines is reasonable. It has been monitored during the processing, and the final tie can be observed on a composite line in the following figure 18.



Fig 18: Example of composite line. Strike-line on the right side of the figure.

The depth imaging workflow essentially consists of the PSDM velocity model building. Despite the CRS preconditioning the quality of the gathers is not sufficient to adopt a reflection tomography strategy. The model building is therefore performed cascading layer based manual updates. The near surface model, in depth and with interval velocity, is extended and merged with the Dix-equation converted PSTM velocity model. The model is smoothed and used for a first PSDM. The gathers are analyzed, and first scan is performed below the base of the reliable zone. The scans are analyzed converting the image and the gathers back to time, and evaluating the RMO and the optimal, laterally varying velocity for consecutive layers that are built in the model.

The model building is however particularly challenging due to the high noise level, and the possible 3D effects.

With the final model, a Kirchhoff PSDM was run; the raw PSDM data were processed with a signal enhancement workflow similar to the one used for the time imaging results. The PSDM sections are shown in the following figure 19.



Fig 19: The two PSDM sections

RESULTS

The good results obtained in terms of imaging leads to a positive evaluation of the performed test: a considerable improvement of the seismic sections quality is visible and the processing workflow could be applied to the overall legacy seismic lines lying in the studied area.

In order to monitor the processing and adapt approaches and parameters to different data quality and types and even if the tested processing sequence seems to be appropriated for the entire considered dataset, it is important to analyze the data and define different categories based on acquisition geometry, quality of survey data, line location and direction with respect to the subsurface geology. Following the data classification, it is essential to select one test line per relevant category of data, to better understand if the sequence is applicable and to validate case by case the processing parameters.

CONCLUSIONS

A CRS reprocessing test has been proposed and applied to legacy data. Its results are the improved seismic images and a validated workflow sequence that could be applied to the entire available 2D dataset.

The application of the CRS technique to old seismic data provide an important opportunity to improve the reservoir imaging and better constrain the structural interpretation at the exploration target, especially in areas where new seismic acquisition campaigns appear unlikely.

The good results obtained during the test lead to the on-going reprocessing of the whole dataset, in order to use the new seismic interpretation of the reprocessed lines together with new gravimetric data to constrain the inversion of magnetotelluric data and to better define the future exploration well location.

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