Multi-Focusing imaging and regularization of an irregular 3D dataset in an urban environment

Nicole Elhaj[1], Steven Rutherford[1], Dan Gish[1], Marianne Rauch-Davies[2*], Danil Pelman[2] and Kostya Deev[2] present a technique that provides coherent stacking of seismic data and enhanced pre-stack gathers.

Increasing the fold for a coherent summation of the traces reduces random noise and increases the signal-to-noise ratio. The Multi-Focusing (MF) technology is based on multi-parameter and the correction formula is accurate, even for heterogeneous subsurface and strongly curved reflectors.

A multi-parameter approximation for the actual travel-time surfaces, three parameters in 2D and eight parameters in the 3D case, are being utilized. These parameters are connected to emergence angles for the normal waves and radii of curvature for fundamental wavefronts, namely normal incident point and normal waves. When stacking reflection events with a larger number of seismic traces that can span many CMP gathers, the signal-to-noise ratio is enhanced and by simultaneously scanning for the parameters, negative effects are avoided and artifacts minimized.

Methodology

The Multi-Focusing method belongs to the class of methods that consider the propagation of the seismic wavefront and is based on wave kinematics (Berkovich et al., 2008). It has been designed to approximate the response at the source and receiver points by two mutually related spherical waves.

The method is valid for arbitrary observation geometry and is thus perfectly suited for processing 3D data with an irregular acquisition design. In such a case, MF data regularization and interpolation pay major dividends in subsequent time and depth imaging. The result of this imaging is a 3D dataset in time that includes optimally stacked time-migrated seismic events that can be output with defined regular binning parameters.

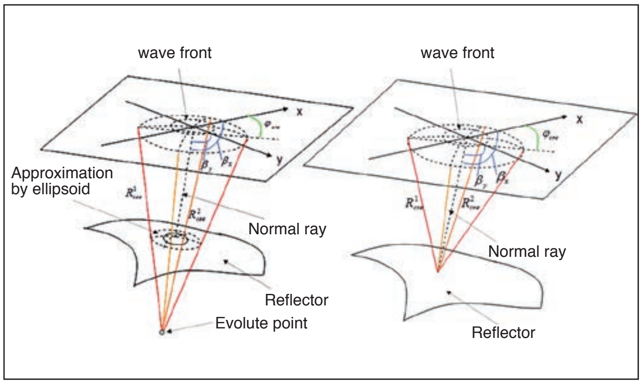

***Figure 1** 3D Multi-Focusing wavefield parameters.*

Implementation of this method is technically challenging because it requires the optimization of three parameters instead of a single parameter (stacking velocity) in the standard NMO velocity analysis for the 2D case. The three parameters Rcre and Rcee and the emergence angle β are estimated by scanning and analyzing the semblance response. In the full 3D case eight parameters need to be computed and estimated, see Figure 1.

The wavefield parameters that are estimated by the MF method can be used for prestack data regularization and enhancement. The idea is to apply the modified travel-time formula to compute enhanced prestack data, in which each trace is a result of the summation of data along the MF stacking surface over original prestack traces having similar offsets. The number and distribution of traces in the produced gathers can be different from those of the input gathers, and the resulting traces are regular with increased signal-to-noise ratio due to partial coherent summation. The method is robust in the presence of non-coherent, random noise.

The algorithm for data enhancement can be described as follows: According to the estimated parameters, the partial stack calculates a stacking surface around a specified CMP-offset location and performs the summation of data along that surface. The result of this summation is assigned to the same CMP, offset, and time coordinates. Repeating this procedure for all desired points generates a new gather that is called the MF-enhanced gather.

These gathers exhibit signal-to-noise ratio improvements, with preservation of all kinematic and dynamic features of the original data, according to the constraints picked by the processor and interpreter. Velocity analysis performed on the enhanced gather is cleaner, with a better definition of the primary reflection events compared to the velocity analysis using the original data.

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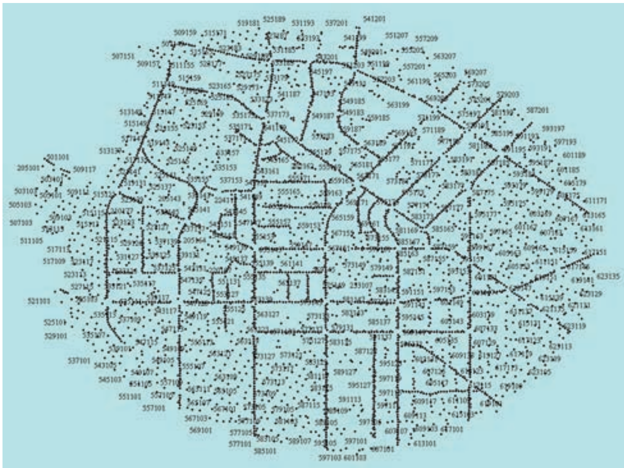

***Figure 2** Seismic acquisition design.*

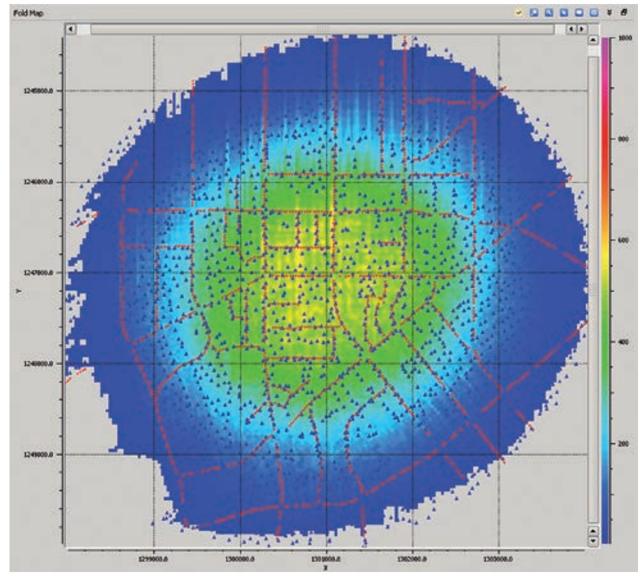

***Figure 3** CDP fold map after conventional processing and binning.*

Application

The 3D data were acquired in a densely populated city, which was extremely challenging and difficult. Acquisition was coordinated by LA Seismic LLC, who specializes in seismic acquisition in urban and sensitive environments. Figure 2 displays a base map outlining the circular acquisition design, which by its nature clearly demonstrates the problems. Gaps are present in sensitive areas where schools, retirement homes, hospitals, parks, personal residences, and industrial complexes prevent access to seismic operations.

The data were originally processed with a conventional processing sequence. Figure 3 shows the fold map after the conventional binning of the 3D dataset. High fold coverage could only be achieved over a relatively small area in the centre section of the survey and decreases rapidly towards the edges of the survey.

The input for the Multi-Focusing imaging is CDP sorted data before migration and without NMO application. The wavefield parameterization is tested and determined on pre-stack data at selected in-lines and cross-lines from this dataset.

One of the estimated wave-field parameters, the radius of the wave that's generated at an arbitrary image point, is directly related to the RMS velocity. As such, a unique velocity function is available at each trace and each sample interval. Furthermore, picking of a specific velocity value from a semblance display is replaced by choosing a velocity corridor. A mathematical solution establishes the velocity that produces the most coherent signal between a given slowest and fastest velocity value. The emergence angle is an additional attribute which describes the dip of the reflectors. This dip information is utilized to dip-correct the velocities before migration, producing a more accurate migration result (see Figure 4).

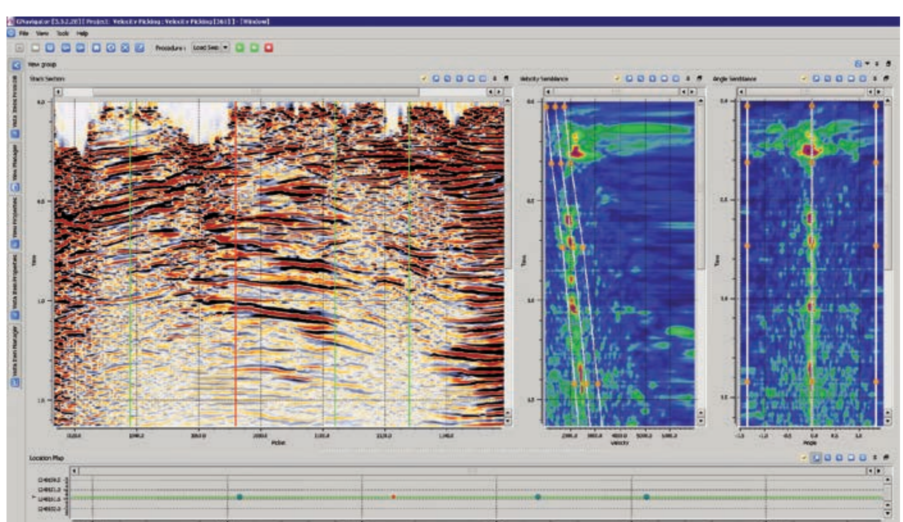

***Figure 4** Left part displays MF stack, middle part velocity semblance with MF velocity corridor and right part emergence angle of the wavefield.*

After optimum MF parameters were established and arbitrary traces were estimated, the data can be subsequently binned in any desirable grid. For this study, two datasets with different bin sizes were generated. The original data were output with a bin size of 110 ft x110 ft, which already showed an improvement to the conventionally processed data. A finer grid of 55 ft x 55 ft was also created and both datasets are utilized for the geological interpretation. Figure 5 displays the final Multi-Focusing gridding and fold distribution which is much higher than resulted from the conventional approach.

Seismic processing results

The goals of Multi-Focusing are to calculate parameters for use in subsequent processing such as data regularization and enhancement, velocity model creation, and time/depth imaging. It is required to carefully tune the MF parameters at each output location. This method can entail stacking of many more traces than in traditional CMP stacking, but avoids introducing lateral or vertical smearing of reflectors.

The 3D seismic data were processed with both conventional processing, and the Multi-Focusing technology. The MF sequence created enhanced gathers that were subsequently pre-stack time migrated. Figures 6a and 6b show a comparison of the same CDP gather after conventional processing and binning, and MF imaging and binning respectively. Events that were very weak or masked by random noise after the conventional processing are visible on the MF result. Figures 7a and 7b display a comparison of a time slice (same time) producted by conventional processing and produced by the MF processing. The MF result contains less random noise and is preferred for the geological and reservoir mapping.

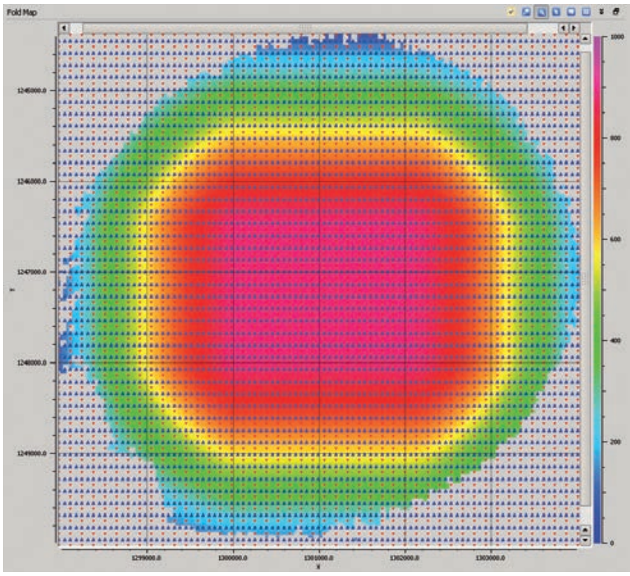

Figure 5 *Base map displaying Multi-Focusing fold map and regularized binning.*

Conclusions

The generalized approach of the MF method of moveout correction allows processing of data acquired with irregular acquisition design and is very useful in cases where the subsurface is highly complicated. The core of the Multi-Focusing

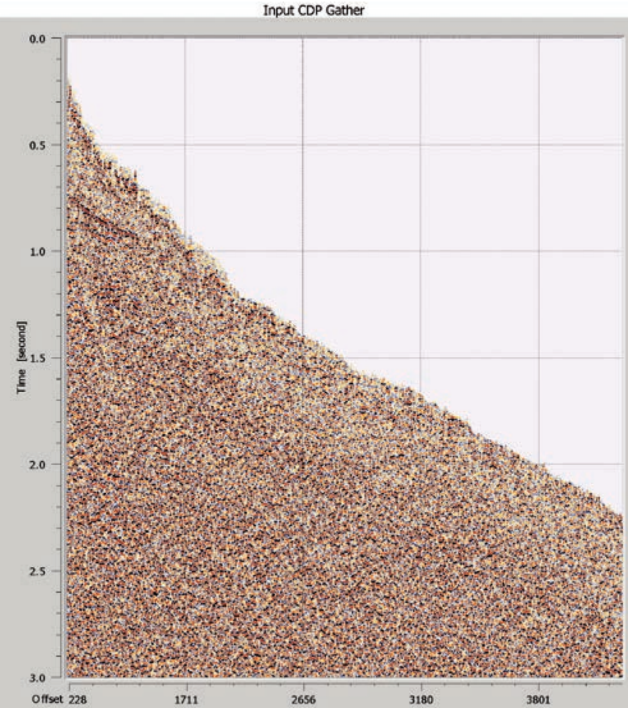

Figure 6a *CDP gather after conventional processing and binning.*

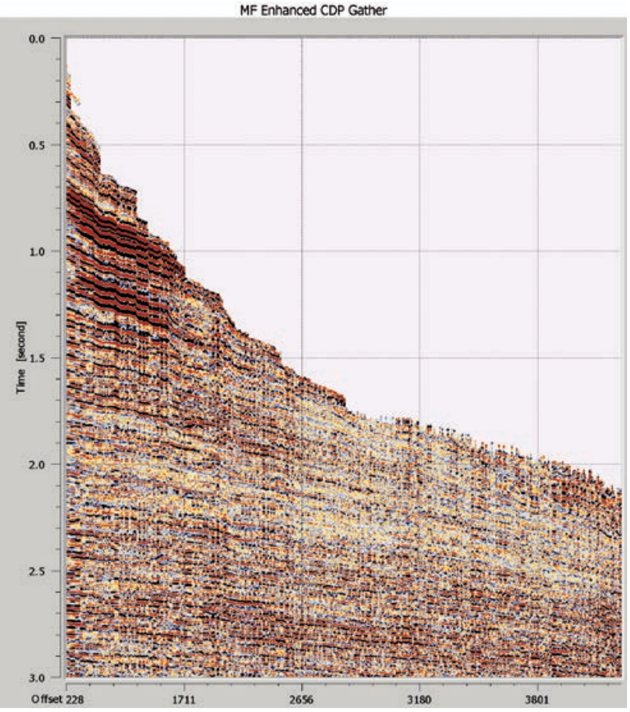

Figure 6b *CDP gather after MF processing and binning.*

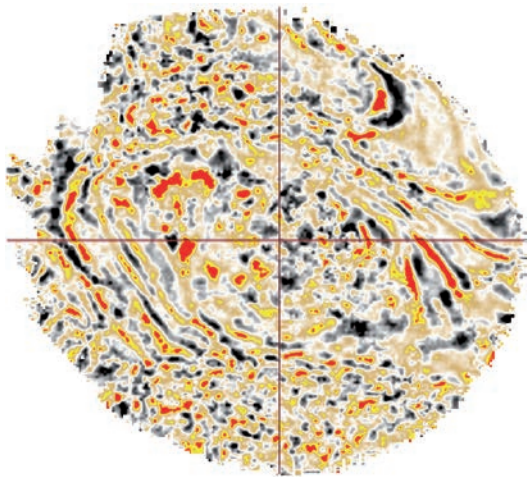

Figure 7a *PSTM time slice after conventional processing and binning.*

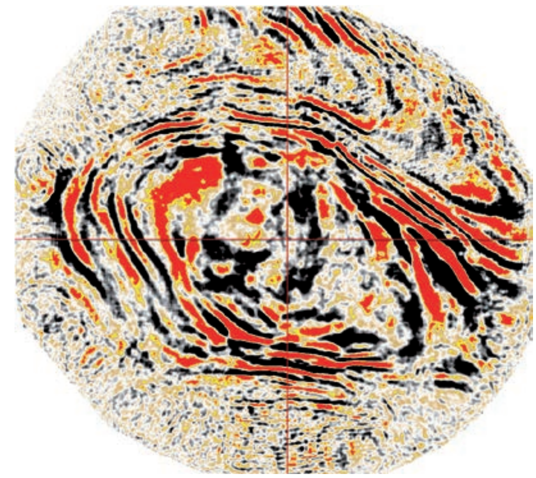

Figure 7b *PSTM time slice after MF processing and MF binning.*

stacking, based on paraxial approximation and dynamic ray tracing, is its Fresnel-zone basis for defining the large number of traces used in the stacking procedure. The resulting traces have a more densely sampled source-receiver distribution about each output location which allows the output dataset to be easily regularized.

The MF method not only provides coherent stacking of seismic data with arbitrary source-receiver distribution, creating high-quality time images, but also yields enhanced and regularized prestack gathers. In areas where acquiring a regular 3D dataset is impossible due to difficult terrain or high population density, conventional gathering and stacking often results in shallow gaps in coverage. Stacking these regularized, enhanced gathers can often 'heal' these gaps in coverage.

A 3D dataset that was acquired with a highly irregular design over a densely populated area was processed with a conventional processing sequence and also with the multi-dimensional MF methodology. The MF data regularization was crucial to the dataset for subsequent pre-stack time and depth imaging. The original acquisition design had a 110 ft x 110 ft binning. Further testing showed that with kinematic data regularization, binning at 55 ft x 55 ft reduced aliasing effects, produced the best results for horizon mapping, and subsequently was used for the final PSTM output.

References

Berkovitch, A., Belfer, I. and Landa, E. [2008] Multifocusing as a method of improving subsurface imaging. *The Leading Edge*, **27** (2), 250–256.

Landa E., Keydar, S. and Moser, T.J. [2010] MultiFocusing revisited - inhomogeneous media and curved interfaces. *Geophysical Prospecting*, **58**, 925–938.