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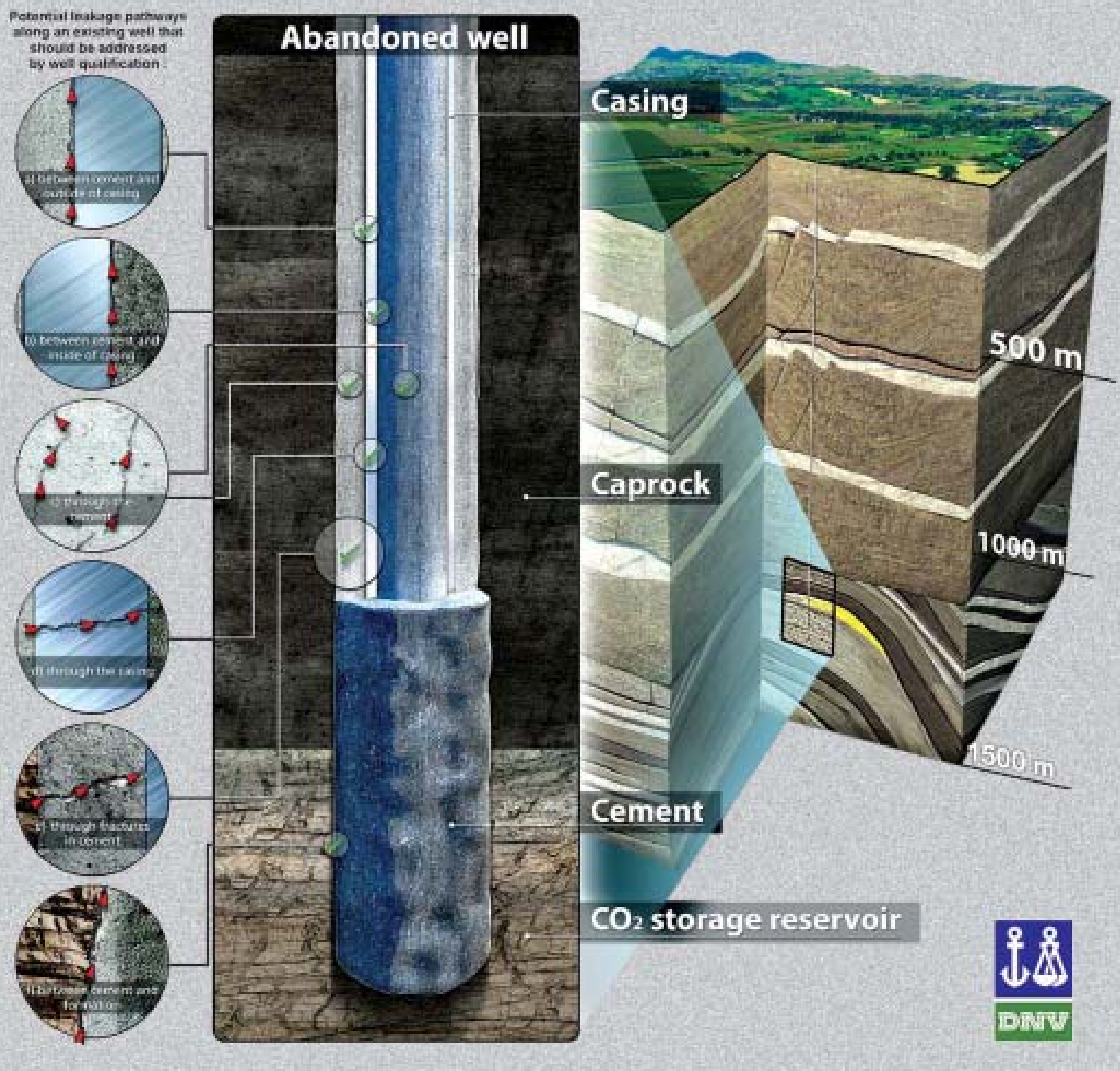

Improved seismic imaging by using multifocusing technology

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Multifocusing, as a non-CMP based imaging method, opens a new perspective for optimal approximation of the zero-offset sections. It is based on a new time moveout correction which can be obtained considering wavefront propagation in the depth domain. The new movout correction is valid for arbitrary subsurface model and for arbitrary observation geometry. Stacked sections obtained by the MultiFocusing method are superior to those obtained by the conventional DMO/NMO processing: they are characterised by higher signal-to-noise ratio and better approximate the actual zero-offset sections. Parameters (wavefield attributes) estimated by the MultiFocusing method have clear geophysical interpretation and can be used for several important applications such as velocity model building, migration, structural and stratigraphic interpretation. This paper presents basis of the MF method and illustrates its efficiency on real data examples.

Even with the advent of prestack depth imaging, time domain imaging techniques remain important for many reasons. A high-quality time image can provide a basis for interpretation in the processing sequence, and often a useful one, even in the case of poor data quality or strong structural complexity. Time imaging usually constitutes a key first step that facilitates the estimation of a velocity model for depth imaging even for complex areas that require depth migration for correct subsurface imaging. For these reasons, improving the quality of time imaging is a focus of intensive research. A recent advance is MultiFocusing (MF), a method with the potential to greatly improve the quality of time imaging.

In MF proposed by Berkovitch et al. (1994) and described in details in Berkovitch et al. (2008), Landa (2007) and Landa et al. (2010), each zero-offset trace is constructed by stacking traces that need not belong to the same CMP gather but, rather, whose sources and receivers are within the limits of a certain aperture in the vicinity of the central (imaging) point. The size of such an aperture is determined by the size of the first Fresnel zone. The number of traces falling in this zone can significantly exceed the number of traces belonging to one CMP gather. This allows a considerable increase in the signal-to-noise ratio for the target reflection. Since the traces being stacked no longer belong to the same CMP gather, this procedure requires a more general moveout correction than the one used in conventional CMP stacking. For a given source-receiver pair, the MultiFocusing moveout equation is based on the spherical approximation of the reflection event's wavefront near the observation surface. The moveout correction expressed by the zero-offset MultiFocusing formula is, in the 2D case, a three-parameter surface which accurately approximates the actual traveltime in the vicinity of the imaging point. The three parameters are: the emergence angle of the normal ray β and the radii of curvature Rcre and Rcee of the two fundamental wavefronts, namely, normal incident point and normal waves respectively.

This paper presents basis of the MF method and illustrates its efficiency on real data examples.

Multifocusing method

Let us consider the ray diagram in Figure 1. The central ray starts at the point X_0 (which is referred to as the central point) with the angle β to the vertical, hits the reflector Σ at CRE and returns back to X_0. A paraxial ray from the source S intersects the central ray at the point P and arrives back to the surface at the point G. These two rays define a fictitious focusing wave which initially has the wave front Σ_S, focuses at P, is reflected at the reflector Σ and emerges again at X_0 with the wave front Σ_G. We can write the moveout correction in the form:

$$\Delta\tau = \frac{\sqrt{(R^+)^2 + 2R^+\,\Delta X^+ \sin\beta + (\Delta X^+)^2} - R^+}{V_0} + \frac{\sqrt{(R^-)^2 + 2R^-\,\Delta X^- \sin\beta + (\Delta X^-)^2} - R^-}{V_0}$$ ....1)

where

$$R^{+} = \frac{1 \pm \sigma}{\dfrac{1}{R_{CEE}} \pm \dfrac{\sigma}{R_{CRE}}}$$ ....2)

and σ is the so-called focusing parameter given by

$$\sigma = \frac{\Delta X^{+} - \Delta X^{-}}{\Delta X^{+} + \Delta X^{-} + 2\,\dfrac{\Delta X^{+}\Delta X^{-}}{R_{CRE}}\sin\beta}$$ ....3)

In the above equations, ΔX^+ and ΔX^- are the source and receiver offsets for a given ray with respect to the central ray, R^+ and R^- are the radii of curvature of the fictitious wave fronts Σ_S and Σ_G in the vertical plane, respectively, and V_0 is the near surface velocity which is assumed constant along the horizontal observation line. Finally, R_{cee} and R_{cre} denote the radii of curvature of the two fundamental wave fronts corresponding to the normal (CEE) wave and normal-incidence-point (CRE) wave, respectively (Hubral, 1983). The CRE wave front is formed by a point source placed at the point where the zero-offset ray emitted from the central point hits the reflector (Figure 3). The wavefront of the CEE-wave front is formed by normal rays emitted by different points on the reflector (like in an "exploding reflector'' scenario, Figure 2).

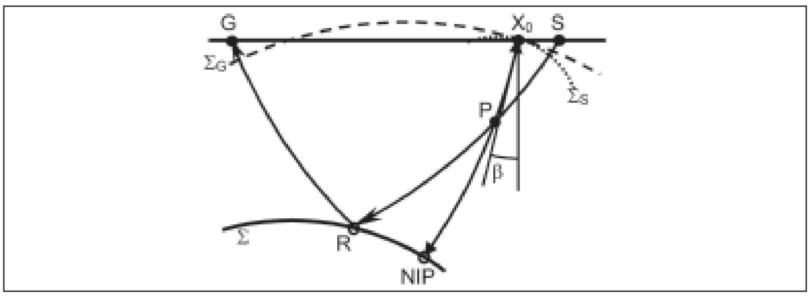

Fig.1 Ray scheme for MF method

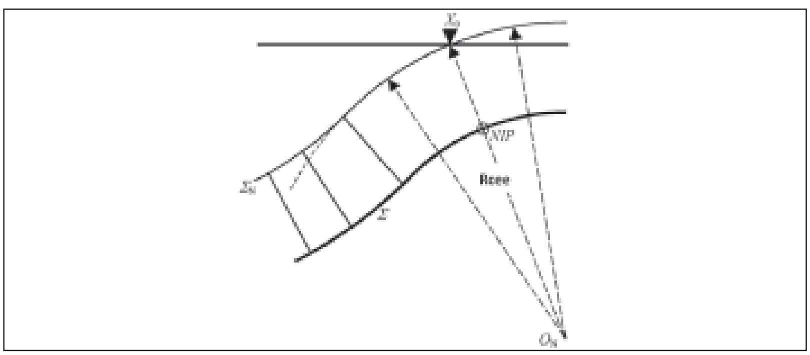

Fig.2 Wavefront Σ_N of the normal wave produced by a curved reflector Σ under a homogeneous overburden

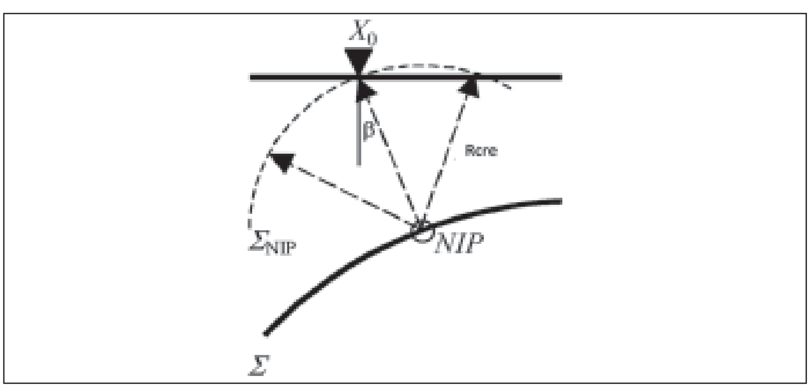

Fig.3 Wavefront Σ_{NIP} of the normal-incidence-point wave produced by a curved reflector Σ under a homogeneous overburden

The double-square-root equation (1) can be understood using the concept of an auxiliary medium which can be defined as a homogeneous medium with the velocity equal to the near-surface velocity V_0. In the auxiliary medium both the central and paraxial rays will be represented by combinations of straight line segments. Consider again the ray diagram in Figure 1. The first term in the right-hand side of (1) corresponds to the time along the ray segment SP which can be obtained from the triangle SPX_0. The second term corresponds to the time along the ray PRG, and can be obtained from a similar consideration involving the imaginary source. Quantities R^+ involved in equation (1) are radii of curvature of the fictitious wave fronts Σ_S and Σ_G. It is clear from Figure 1 that, for a given central ray, the radii R^+ depend upon the position of the point P where the paraxial ray intersects the central ray and thus upon the position of the source and receiver that define the paraxial ray. Equations (2) and (3) give the radii of curvature of the fictitious wavefronts R^+ via the fundamental radii of curvature R_{cre} and R_{cee}, which are defined by the central ray only and are the same for all the source-receiver pairs in the vicinity of the central ray. The dependence of the radii R^+ on the position of the source and receiver (or on the position of the point P on the central ray) is contained in the focusing parameter σ (equation 4).

Implementation of the MF

MF provides an appealing basis for an imaging procedure. Its practical implement in 2D requires, for each t_0 on each zero-offset trace, determination of three imaging parameters: β, R_{cre} and R_{cee} instead of a single parameter (stacking velocity) in the conventional NMO stack. Stacking velocity is usually determined by means of an interactive velocity analysis, consisting in displaying a panel of correlation measure (e.g., semblance) as a function of t_0 and velocity, and manual picking of the appropriate correlation maxima as a function of t_0. For the MultiFocusing parameters a similar procedure is out of the question for two reasons. First, the cost of calculating the correlation measure for all possible combinations of three parameters over a large super-gather is prohibitively high. Secondly, even if such computation were possible, an interactive procedure would have to involve displaying and picking maxima of the correlation measure as a function of four variables (t_0 and three imaging parameters), which does not look practical. Thus, the determination of the imaging parameters must involve some kind of automation, based on optimization methods. Implementation of the MultiFocusing method is based on the coherence analysis of the signal on the observed seismic traces. The data are moveout corrected along different travel time curves to find the surface closest to the travel time surface of the signal. The unknown parameters β, R_{cre} and R_{cee} are estimated by finding a set of parameters which maximizes the semblance function. Semblance is calculated over the super-gather in a specified time window along the trial travel time curve. Maximization of the semblance is achieved by a nonlinear global optimization method.

The correlation procedure described above is repeated for each central point and for each time sample forming a MultiFocusing time section. Each sample on this section represents the optimal stacked value corresponding to the optimal values of β, R_{cre} and R_{cee}. Estimated sets of parameters can also be displayed in space and time forming so-called angle-gram $\beta(x,t_0)$ and radius-grams $R_{cre}(x,\ t_0)$, and $R_{cee}(x,\ t_0)$. These three additional sections provide new physically sound wavefield attributes which may aid the interpretation and inversion.

Advantages of the MF method

As mentioned above, the MF moveout corrections can be applied to any trace if its source and receiver are in a certain vicinity of the central point (central point is defined as a point on the observation line, for which we want to obtain the zero-offset trace). Thus, these moveout corrections can be used to align reflection events in large super-gathers without loss of the spatial resolution. In the MF, a super-gather is a set of traces whose sources and receivers are in such a vicinity of the central point, in which wavefront arcs can be approximated by circular arcs.

Potential benefits of stacking such large super-gathers as compared to the CMP stack are as follows:

- Stacking a large number of traces spanning over many CMP gathers can increase the stacking power as compared to the conventional CMP stack. In the conventional CMP processing, the stacking power is defined by the number of traces in a CMP gather, and, ultimately, by the acquisition fold. In MultiFocusing, the stacking power depends upon the number of traces in the super-gather. This is a user-defined parameter unrelated to the acquisition fold and is limited only by the initial assumptions (circular shape of wavefront arcs within the aperture) and the computational cost. Typically, the number of traces in the super-gather exceeds the acquisition fold at least by an order of magnitude. This can be particularly beneficial for data with low fold and/or low signal-to-noise ratio.
- For a flat reflector under a homogeneous overburden, the NIP radius depends upon the distance between the central point and the reflector and is independent of the reflector dip. For an inhomogeneous overburden R_{cre} represents the distance between the central point and the reflector in the auxiliary medium, again, irrespective of the dip. Therefore, the events with similar t_0 beneath the same overburden have similar R_{cre} values irrespective of their dip. Thus, the MultiFocusing imaging based on the radii of curvature preserves dipping events. Hence, the multifocusing method incorporates the key property of the DMO transform.
- Simultaneous determination of the curvatures and emergence angle makes it possible to recover dip-independent RMS velocities V_{RMS} through a simple algebraic transformation,

$$V_{RMS}^2 = \frac{2R_{cre}V_0}{t_0}$$

where t_0 is the zero-offset arrival time at the central point. These velocities may be used for migration. In this respect the MF method is similar to the DMO

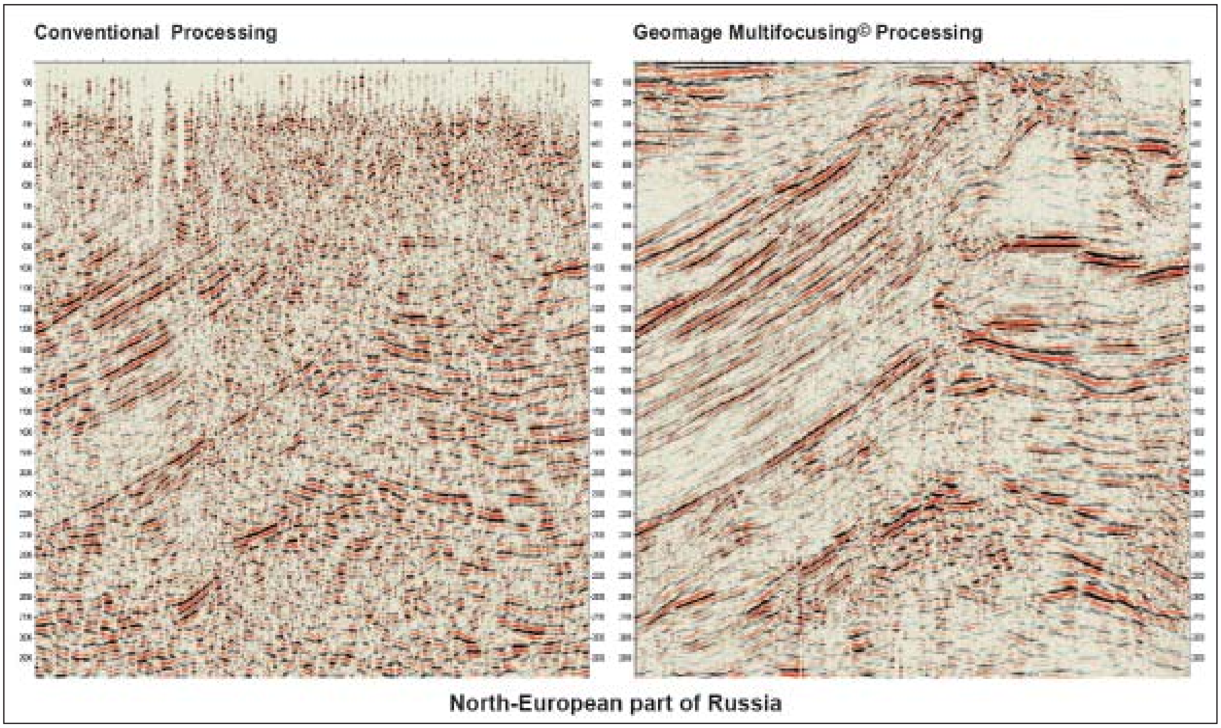

Fig.4 Conventional (left) and MF (right) migrated time sections

MF (right hand side in the figures) results are always proved superior to the conventional processing (left hand side in the figures) in both signal/noise ratio and reflectors continuity. The improvement is due to better traveltime approximation and higher summation fold

velocity analysis.

- The MF moveout correction for a given sample of the image trace at t_0 depends on the incidence angle and on curvatures measured on seismograms, and does not involve

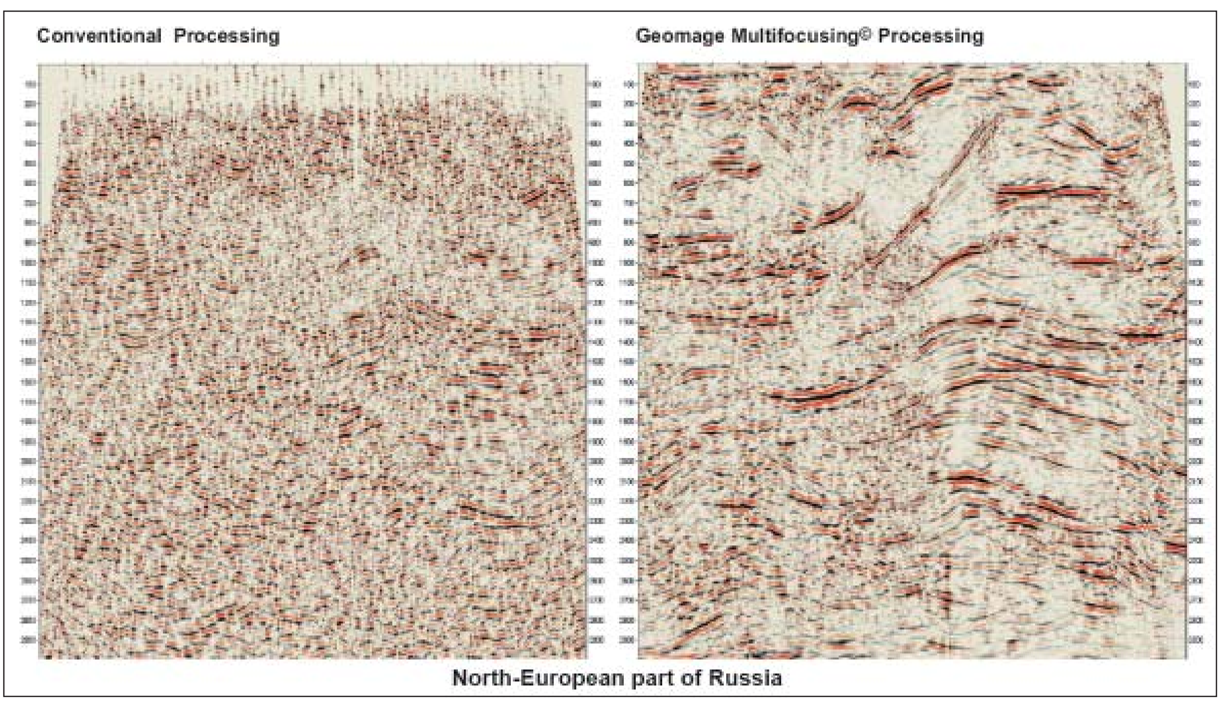

Fig.5 Conventional (left) and MF (right) migrated time sections

the value of t_0 itself. Thus, all the samples of a given reflection event on a given central trace would have the same parameters within the duration of the wavelet, and hence the moveout correction will be constant along the wavelet. Thus, the MultiFocusing moveout correction does not cause the phenomenon known as "NMO stretch".

- The estimation of the MF moveout parameters (analogy of velocity analysis in CMP processing) may be performed in a quasi- automatic manner.

Real data examples

Figures 4-5 illustrate application MF method to different real data sets. As clearly can be seen from these examples, MF (right hand side in the figures) results are always proved superior to the conventional processing (left hand side in the figures) in both signal/noise ratio and reflectors continuity. The improvement is due to better traveltime approximation and higher summation fold.

Conclusions

Multifocusing, as a non-CMP based imaging method, opens a new perspective for optimal approximation of the zero-offset sections. It is based on a new time moveout correction which can be obtained considering wavefront propagation in the depth domain. The new movout correction is valid for arbitrary subsurface model and for arbitrary observation geometry. Stacked sections obtained by the MultiFocusing method are superior to those obtained by the conventional DMO/NMO processing: they are characterised by higher signal-to-noise ratio and better approximate the actual zero-offset sections. Parameters (wavefield attributes) estimated by the MultiFocusing method have clear geophysical interpretation and can be used for several important applications such as velocity model building, migration, structural and stratigraphic interpretation.

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Evgeny Landa, is a M.Sc. in Geophysics from Novosibirsk University, USSR and a Ph.D. in Geophysics from Tel-Aviv University, Israel. He has held Post doctoral position in Institut de Physique du Globe, Paris, France during 1987-88. Presently Dr. Landa is Director of Applied Geophysical Research Group (OPERA), Pau, France. He is also Member of the Advisory Board of Geomage company. His research interest involves seismic data processing and imaging (time and depth), velocity model building, non-conventional seismic methods and super-resolution.

OPERA is a private applied geophysical research group founded and sponsored by TOTAL. The main goal of OPERA is to develop new methods and technologies for seismic data processing and imaging in complex geological environment (including sub-salt and over-trust structures). In this context OPERA build a strong professional network with best universities in the USA, Europe and Russia. Special efforts were made to establish a strong professional links with Moscow, Novosibirsk and St. Petersburg Universities and Russian Academy of Science. During the last three years OPERA carried out several projects together with Russian scientists on modeling of seismic waves in complex models which include small scale heterogeneities (including fractures).

With a wide experience of working for the industry in Russia, France, Israel and USA Dr. Landa has also been associated with the acaedimia as a faculty with Department of Earth Sciences, Tel Aviv University and in Moscow, St. Petersburg, Novosibirsk, Krasnodar, Kiev. He has also been invited speaker at Geophysical Society of UK (London), Amoco (Tulsa, USA), Elf Aquitaine (Pau, France), Geophysical Institute (South Korea), Education days (EAGE, London), Moscow University, St. Petersburg University.

Author of more than 50 papers in: Geophysics, Geophysical Prospecting, Applied Geophysics, The Leading Edge, Soviet Geology and Geophysics Dr. Landa has also authored the book "Beyond Conventional Seismic Imaging". He has even been the Editor of "Geophysical Prospecting" and "Journal of Exploration geophysics".

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