

Improved imaging of 3D marine seismic data from offshore Costa Rica by CRS processing

G. Gierse¹, J. Pruessmann¹, E. Laggiard¹, C. Boennemann², and H. Meyer² show how the Common Reflection Surface (CRS) imaging technique developed by German research and commercial organizations can be successfully applied to a 3D dataset, in this case from a seismic survey off Costa Rica.

The macro model independent Common Reflection Surface (CRS) imaging technique has proved to produce superior images in various 2D seismic case studies. A 3D marine dataset application demonstrates similar capabilities of the CRS technique for 3D data. The signal-to-noise ratio is strongly increased and dipping features are better resolved. The marine dataset is selected from the active continental margin offshore Costa Rica. The CRS processing aims at enhancing the image of the slope sediments and deeper crustal structures.

The resolution of complex subsurface structures in 2D and 3D still represents a major challenge to seismic exploration. Up to now, continuous efforts have been made throughout the oil and gas industry to improve the imaging of complex structures with the main focus on prestack depth imaging. The seismic wavefront that travels through the complex subsurface is likely to deviate from a spherical shape having passed all sorts of inhomogeneities. Prestack depth migration has the advantage of not assuming a spherical wavefront like conventional techniques, since it calculates the actual deformations of the wavefront from a more or less coarse model of the subsurface.

The derivation of the model, however, is a crucial step where prestack depth migration might fail. A very low signal-to-noise ratio in the seismic data often prevents the definition of a reliable basic model and the identification of the main horizons in the prestack data. Likewise, model building can fail in areas of complex tectonics, such as overthrust areas. Thus the strength of the model-based imaging cannot be exploited. For such cases, recent advances in time domain imaging with the CRS technique can be an alternative.

CRS processing strongly increases the signal-to-noise ratio, and produces a significant improvement of imaging results, as indicated in Figure 1. Poststack depth migration allows the transfer of the improved resolution from time domain to depth. In general, time processing has seen fewer efforts to improve the imaging techniques compared with

depth processing. In many exploration projects, the conventional NMO / DMO processing flow for producing the zero-offset stack still dominates seismic processing in the time domain. This standard technique has prevailed nearly unchanged throughout the seismic industry during the last two decades.

NMO / DMO processing uses a type of a macro model given by the stacking velocity field, which is derived from Common Midpoint (CMP) gathers. The velocity field describes the CMP reflection time curves, which are assumed to be hyperbolic. This assumption corresponds to undisturbed wavefronts from reflection points in a subsurface with plane horizontal layering. In case of dipping layers, the one dimensional subsurface model in the NMO approach leads to reflection point smearing, and requires a partial migration via the Dip Moveout (DMO) correction.

Time domain imaging approaches, that were considered alternatives to the established NMO / DMO technique with its simplified subsurface model, have frequently been proposed. At the end of the 80s, de Bazelaire (1986, 1988) and Gelchinsky (1988, 1989) proposed new strategies for a zero-offset imaging. In contrast to the NMO/DMO technique, as well as prestack depth migration, these strategies do not require a macro model, but estimate the imaging parameters directly from the prestack data.

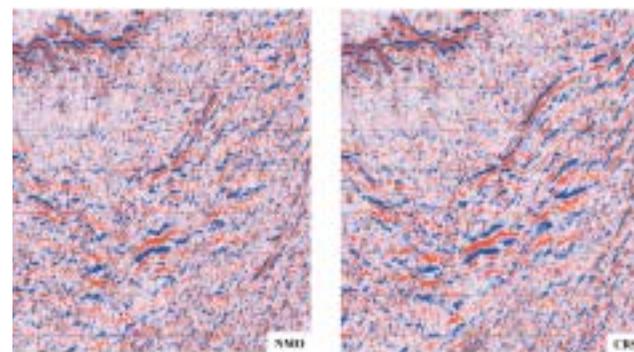


Figure 1 Time migrated sections from inline 295

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Marine Seismic

In recent years, both the development and application of macro model independent imaging methods have gained increasing attention (e.g. Hubral, 1999). Significant progress in this field was achieved by the WIT consortium which has combined several universities on the initiative of Peter Hubral from the University of Karlsruhe, Germany, and is open to industry partners worldwide. The CRS method (Mann et al., 1999; Jaeger et al., 2001), which has been developed at the University of Karlsruhe, has provided superior resolution in various geological environments and in numerous commercial projects (e.g. Trappe et al., 2001).

The technical details of the CRS method are well discussed in the aforementioned literature, allowing this paper to restrict the presentation of the theory and implementation of the method to a short overview. The discussion focuses on the advantages of CRS imaging within a case study, which was performed on 3D marine seismic data acquired by BGR from the active continental margin offshore Costa Rica.

Continental margins belong to areas which are seeing strongly increasing exploration and exploitation activities. Besides oil and natural gas, gas hydrates and mineral resources are becoming targets of intensive investigation.

Increased information from CRS

The CRS technique belongs to the macro model independent methods for time domain imaging, which on principle do not require a velocity field or any other imaging parameter model. In a data-driven approach, the CRS imaging parameters are locally estimated from the prestack data for each point of the image. Additionally, it is possible to use external stacking velocities from conventional processing as guide functions for the automatical parameter search. Unlike the horizontal-layering assumption of conventional NMO stacking, the CRS technique implies a subsurface with reflectors of arbitrary dip and curvature (Figure 2).

In accordance with this complex model assumption, the reflections from a subsurface element are not constrained to the seismic traces of a constant CMP position, but are dis-

tributed across several CMPs. As a consequence, CRS techniques involve stacking along reflection time surfaces that extend over several CMP locations. The subsurface fold can thus be increased by a magnitude compared with the NMO stack, where stacking follows the reflection time functions at exactly one CMP location. The CRS imaging parameters allow estimation of the CMP width of the Fresnel zone, i.e. the horizontal region which constructively adds to the reflection signal at the location being considered. Stacking within the Fresnel zone avoids a decrease of horizontal resolution by too large stacking apertures.

CRS reflection time functions are defined by a hyperbolic approximation, corresponding to undisturbed spherical wavefronts. This contrasts with prestack depth migration, where reflection events may be summed along arbitrary time curves, depending on the complexity of the depth model. However, CRS stacking involves sufficient subsurface coverage, even if the hyperbolic assumption is valid only for a small offset range around the zero-offset reflection. The fold achieved by the stacking across several CMP locations produces a signal-to-noise ratio that is competitive with prestack depth migration results in many case studies.

The local reflector-oriented strategy of the CRS method implies the following advantages:

- High signal-to-noise ratio as a consequence of high CRS fold
- Enhancement of faults at a general increase of reflector continuity
- Excellent imaging of dipping and curved reflectors due to explicit incorporation in CRS assumptions
- Good depth imaging in combination with poststack depth migration
- Automatic derivation or improvement of a velocity model
- CRS velocities and travel time curves for an improved AVO analysis
- Additional information from CRS parameters (e.g. the spherical divergence, Fresnel zone)

For the 2D case, the superior imaging by the CRS method has been proven in a large number of case studies (e.g. Trappe et al., 2001). In this case, the reflecting Common-Reflection-Surfaces are characterized by three properties, i.e. by their location, dip, and curvature. The corresponding reflection times are similarly described by three CRS stacking parameters, comprising the angle of incidence θ at the surface, and two wavefront curvatures R_{NIP} , R_N . The parameters are related to a hypothetical point source, or an exploding reflector source, respectively, on the Common-Reflection-Surface to be imaged (Figure 2).

The CRS processing mainly consists of the search for the stacking parameters, and of the actual stacking. A general simultaneous search for the three CRS parameters in the

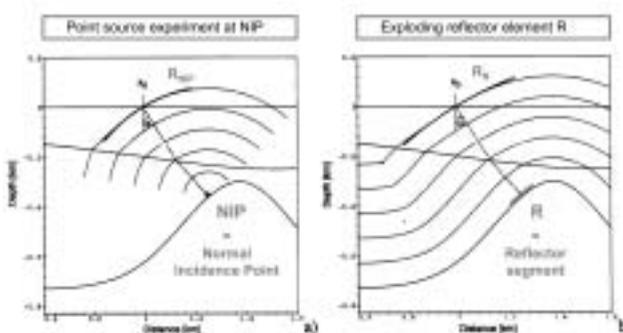


Figure 2 Geometrical description of the CRS attributes (Mann et al, 1999)

whole prestack dataset, however, is much too time-consuming. Hence, three semblance-based searches are performed in subvolumes of the entire seismic data, in order to estimate the three CRS stacking parameters (α, R_{NIP}, R_N) at any point of the stack. Subsequently, the estimate may be refined by a simultaneous search in the full prestack data allowing the three CRS stacking parameters to vary only in the vicinity of the estimate.

The described 2D CRS approach has been adapted and optimized for production processing. It is suited for the processing of 2D lines, and, additionally, for 3D marine data, which were acquired more or less in a 2D fashion. The 3D marine survey from Costa Rica, which is discussed in the following section, was acquired as a multitude of parallel 2D lines. Line-by-line CRS processing efficiently limits the numerical effort, making use of the stable and numerically optimized 2D CRS technique. This procedure corresponds to the line-by-line DMO processing of marine seismic data (e.g. Bancroft, 1998).

Full 3D CRS imaging is far more time-consuming, requiring eight imaging parameters at each point of the stack. This strongly boosts the numerical effort, and directs the present research towards optimum search strategies and algorithms for 3D CRS. The results of full 3D CRS imaging (e.g. Bergler et al., 2002) are similarly promising, as the CRS processing of 3D marine presented here.

CRS application to 3D seismic data from the active continental margin of Costa Rica

The active continental margin of Central America shows high complexity. Different types of oceanic crust are subducted and both areas with accreted sediments are observed as well as completely erosive margin areas. Wide parts of the margin are characterized by a wedge-shaped structure with high seismic velocities, which probably serves as a hinge for the downgoing plate.

The active continental margin offshore Costa Rica has been the focus of scientific research for many years (Hinz et al., 1996, Barckhausen et al., 1998). The investigations concentrate on structure and tectonics, with emphasis on natural risks such as earthquakes and submarine slides. Gas finds at the active continental margin of Nicaragua indicate that further investigations with respect to hydrocarbon reservoirs are promising as well. The complex structure of this target area motivated BGR (German Federal Institute for Geosciences and Natural Resources) to extend its previous grid of 2D reflection seismic lines (Figure 3) by a 3D seismic survey in 1992. The survey area has an extension of 15 x 30 km² and covers part of the subduction structures. The survey has a nominal fold of 30. The spatial resolution in dip direction is controlled by a CMP spacing of 12.5 m, whereas an inline separation of 100 m was chosen in strike direction. Offsets range from 190 m to 3165 m.

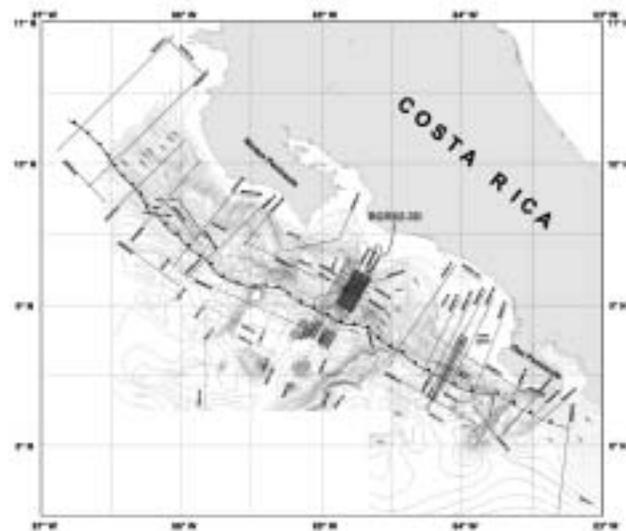


Figure 3 Location of 3-D survey BGR92-3D, with 2-D lines by BGR

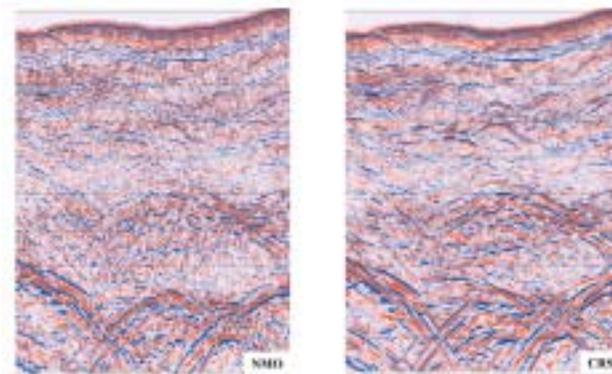


Figure 4 Stack sections from inline 380

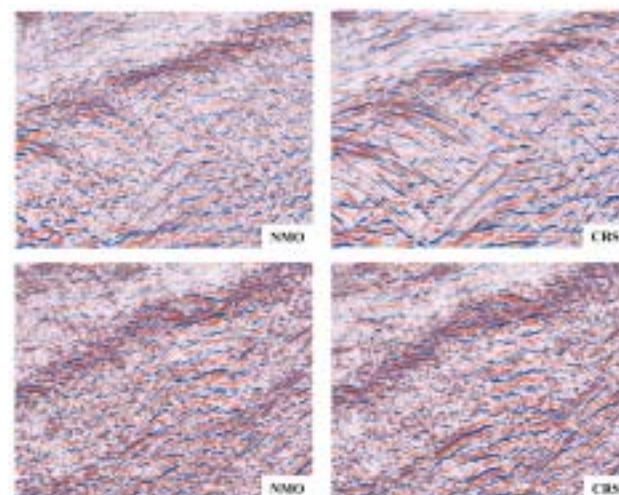


Figure 5 Stacks (top) and time migrations (bottom) from inline 300

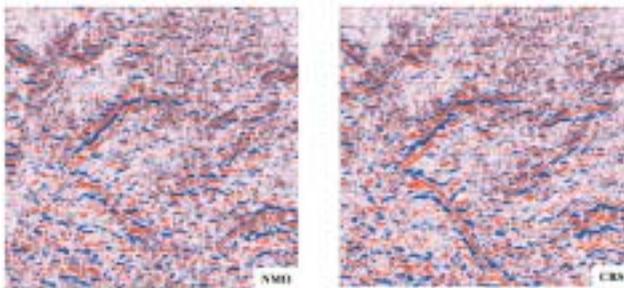


Figure 6 top Time migrated sections from crossline 1080

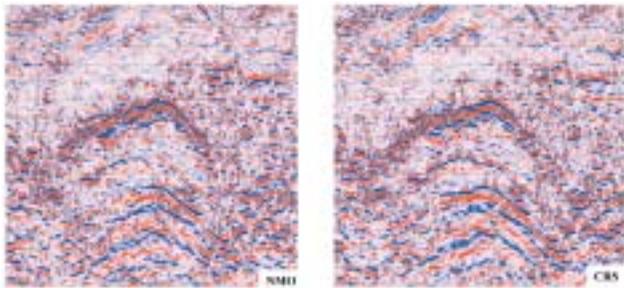


Figure 6 middle Time migrated sections from crossline 1180

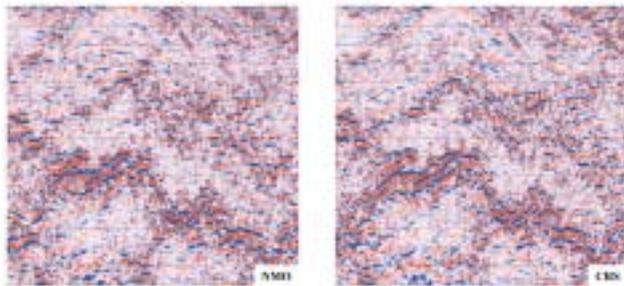


Figure 6 bottom Time migrated sections from crossline 1330

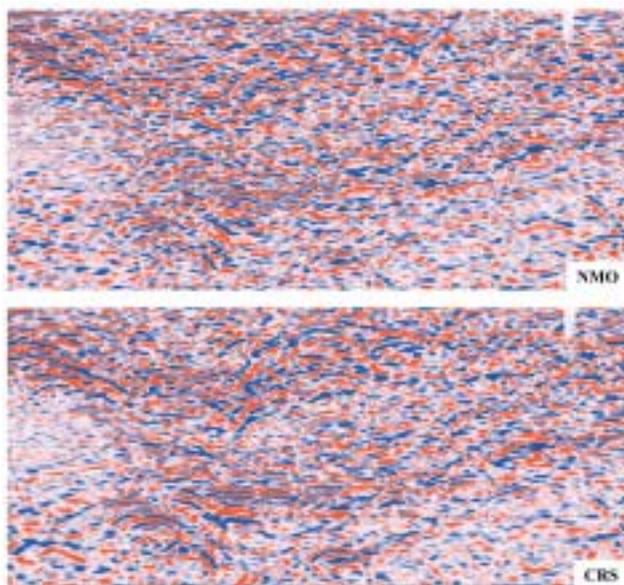


Figure 7 Time slices at 5660 ms from time migrations

The subduction of the oceanic plate is the key process that controls the tectonic setting in the survey area offshore Costa Rica. A detailed understanding of the subduction process and associated earthquake mechanisms requires a good resolution of the central subduction zone, and the downgoing plate below. Hence, this imaging project was performed in order to evaluate the increase of structural information by CRS processing, in comparison to a conventional NMO processing.

Stacked inline sections

Comparisons of NMO versus CRS stacks are given in Figure 4 for a section near the sea-bottom from inline 380, and in Figure 5 (top) for a deeper section from inline 300. The strong increase of the signal-to-noise ratio by CRS imaging is obvious. Moreover, the high frequency reflections near the sea-bottom are more continuous in the CRS stack. In the deeper section, incoherent high frequency noise is removed, and diffractions are more conspicuous in the CRS result.

Migrated inline sections

3D poststack time migration was performed both on the NMO stack, and on the CRS stack. Migration results for a deep section are shown in Figure 1. For another deeper section, migration results (Figure 5 bottom) are compared with the stacks (Figure 5 top). In the CRS sections, dipping reflectors are imaged with greater continuity, and better signal-to-noise ratio. In Figure 1 the migrated CRS stack includes a prominent steep-dip feature which is only partly visible in the conventional result.

Migrated crossline sections

The crosslines of the time migrated stacks show similar characteristics as the inlines. CRS processing leads to a strong structural improvement in crossline direction, despite performing the searches for dip and curvature on individual inlines only. The line-by-line approach for CRS processing of 3D marine data thus proved to work well. In the crosslines of Figure 6, the most obvious improvements from CRS are visible at dipping events. Some of these events are not resolved in the NMO result, for example, the high amplitude event in the deeper part of Figure 6 (top). A general increase of signal-to-noise ratio by CRS, however, can be observed at flat or low dip structures as well, for example at the anticlinal structure of Figure 6 (middle). Both the NMO, and the CRS results similarly show the main reflection in the centre of the displays, belonging to the top of the anticline. The migrated anticline reflection below, however, has a low signal-to-noise ratio in the NMO section, but is clearly defined in the CRS result. Again, the steep right flank of the main anticline is not imaged in the migrated NMO result, whereas it appears in the CRS section.

Migrated time slices sections

Time slices were extracted from the migrated datasets at the time 5660 ms (Figure 7). The migrated NMO stack generally produced slices with a high noise levels, which in many cases hardly permit the outlining of any structures. The migrated CRS stack, on the contrary, shows a clearer picture, with much higher signal-to-noise ratio. The better continuity of reflections can determine trends that are highly ambiguous in the NMO results.

Conclusions

The CRS processing of a marine 3D seismic dataset from the continental margin offshore Costa Rica led to a generally enhanced signal-to-noise ratio in comparison to the NMO results. An increased resolution and better continuity are observed both in the 3D CRS stack, and in the associated 3D poststack time migration.

Reflections with large dip were especially enhanced. The migrated CRS stack showed strongly dipping structures, which were not obtained by migrating the NMO stack. The enhancement of dip is frequently observed in CRS imaging which explicitly assumes dipping and curved reflector elements in the subsurface, and performs a direct search for dip.

The CRS processing provided improvements both in the inline and crossline direction, despite performing the searches for dip and curvature on individual inlines only. This supports the line-by-line approach for CRS processing of 3D marine datasets which proves to improve the 3D resolution of the subsurface structures. The improvements will enable a reinterpretation of the Costa Rica dataset aimed at a deeper knowledge of the subduction process at the active continental margin.

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