The Finite-Offset CRS stack: an alternative stacking tool for subsalt imaging

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Summary

Imaging in complex subsurface structures as, e.g., the imaging beneath a complicated salt body, is a challenging task. The application of standard processing schemes is often not sufficient to deliver consistent high quality images in such situations. Therefore, standard imaging schemes have to be improved or new approaches have to be developed to produce reliable images.

The Finite-Offset Common-Reflection-Surface stack has been developed in the last two years as an extension to the established Common-Reflection-Surface stack. It can provide any finite-offset section from multi-coverage data in a data-driven way. In this paper, we show that this new imaging tool can be an alternative in case of complicated subsurface structures. This is demonstrated by means of a complex synthetic data example which has especially been designed to investigate the difficulties that occur in subsalt imaging.

Introduction

Most data-driven imaging techniques introduced in the past years mainly aim at simulating zero-offset (ZO) sections from multi-coverage seismic reflection data (de Bazelaire, 1988; Hubral, 1999). These methods are data-driven in the way that they (a) use multi-parameter moveout formulas, where the moveout parameters are derived based on coherency analysis, and (b) do not make use of a velocity model. In a recording-time/midpoint/half-offset volume the multi-parameter moveout formulas describe surfaces rather than trajectories as, e.g. in the common-midpoint (CMP) stack. The Common-Reflection-Surface (CRS) stack belongs to this class of imaging methods (Jäger et al., 2001). The CRS moveout formula—often also referred to as CRS stacking operator—depends on three parameters when 2-D pre-stack data are to be stacked into a ZO section.

Data-driven ZO simulation techniques have proven to be successful in many difficult situations. This means they often yield better results in presence of complex subsurface structures and noisy data compared to conventional imaging methods like, for example, NMO/DMO processing (see, e.g., Trappe et al., 2001). However, in case of subsalt imaging a standard application of data-driven ZO simulation techniques does not guarantee good imaging results of subsalt structures. Glogovsky et al. (2001) give an explanation for this. They state that the ZO section suffers from bad subsalt illumination by normal rays and, therefore, does not contain the necessary information for a good subsalt image.

Thus, Glogovsky et al. (2001) propose a more complicated approach to obtain a good subsalt image. They applied the Multifocusing time imaging (Gelchinsky et al., 1999)—a data-driven ZO simulation closely related to the CRS stack—in combination with pre-stack wavefield datuming to a synthetic dataset acquired above a complex salt shape with rugose salt top in a relatively simple sedimentary environment. The datuming simplifies the complex, non-hyperbolic moveouts in the original CMP gathers resulting from the irregular shape of the salt body and make them applicable to a ZO simulation method like Multifocusing.

In this paper, we propose another approach to overcome the problem of lack of subsalt reflection energy in the ZO section and complex moveouts by the so-called Finite-Offset (FO) CRS stack. The FO CRS stack can provide any FO stack section such as common-offset (CO), common-midpoint (CMP) and common-shot (CS) sections from multi-coverage pre-stack data following the CRS philosophy (Hubral, 1999). In the recording-time/midpoint/half-offset volume, the FO CRS stacking operator approximates a reflection event in the vicinity of any selected point with arbitrary offset. Therefore, the FO CRS method does not rely on the illumination of a subsurface target by normal rays but expects only in the vicinity of the selected point an approximate hyperbolic moveout.

The application of the FO CRS stack to the Sigsbee2 synthetic dataset is shown. The Sigsbee2 dataset has been designed by the SMAART joint venture to exhibit the illumination problems due to a complex salt shape with rugged salt top (see Pfaffenholz, 2001). A CO section simulated with the FO CRS stack is compared with the ZO section obtained from the standard CRS stack. To clearly distinguish between the FO CRS stack and the CRS stack used for ZO simulations, we refer to the latter as ZO CRS stack.

Theoretical background

In the current FO CRS implementation a five-parameter second-order hyperbolic moveout formula serves as stacking operator (Bergler et al., 2001). The moveout formula has been derived in Zhang et al. (2001) by means of paraxial ray theory. Bergler (2001) showed that it can alternatively be derived by means of geometrical optics. This is achieved by relating kinematic characteristics of wavefronts (the propagation direction and curvature of the respective wavefront) at the measurement surface to traveltime curves. In this way, the FO CRS stacking operator can solely be described by five kinematic wavefield attributes plus the near-surface wave propagation velocity at shot and receiver. This emphasizes the model-independence of the FO CRS stack.

The practical procedure of the FO CRS stack is as follows: in the recording-time/midpoint/half-offset volume the FO CRS stacking operator defines a surface. By variation of the parameters the surface is fit to the prestack reflection event in the vicinity of a selected FO sample. An accompanying coherency analysis determines the parameters that yield the best-fit operator. To simulate the amplitude at the FO sample, the amplitudes along the operator are summed up and assigned to the respective FO sample. The result of this procedure is that the FO sample carries the following information: a stack value (summed amplitude), the stacking parameter values, and a coherency value. Of course, the locations of actual reflection events in the FO section are unknown. Therefore, the procedure described above is applied to a 2-D grid of FO samples. This yields a 2-D simulated (stacked) FO section, a coherency section, and the five stacking parameter sections.

The exact procedure of the parameter search is described in Bergler et al. (2001) where a solution of a fast and accurate parameter determination is given. The wavefield attributes are of use for a variety of seismic applications. Possible applications of the attributes including the computation of the geometrical spreading factor and wavefield separation are explained in Zhang et al. (2001) and Bergler et al. (2002).

Application to the Sigsbee2 synthetic dataset

The Sigsbee2 synthetic dataset has been especially designed to understand imaging failure due to a subsurface that consists of a salt body with very complex geometrical characteristics. The Sigsbee2 dataset is a 2-D acoustic FD dataset where free surface multiples have been omitted. The underlying velocity model is shown in Fig. 1. For a detailed description of the dataset we refer to Pfaffenholz (2001).

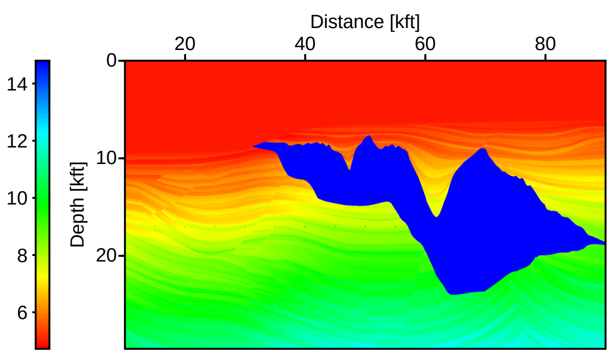

Fig. 1: Underlying velocity model of the Sigsbee2 dataset. The colors indicate the velocity in kft/s.

Fig. 2 shows a CMP gather of the Sigsbee2 dataset with a CMP location at 32487.5 ft on the surface. This CMP gather reveals the complexity of the dataset: there are many intersecting events as well as events that emerges only at large offsets. These large-offset reflections which also include subsalt reflections could generally not be imaged with a ZO simulation without the additional effort indicated in the introduction.

The FO CRS stacking operator can be fit to the reflection events at any selected position along any event. The CO section produced with the FO CRS stack shown in the upper part of Fig. 3 has, for instance, an offset of 18000 ft. This offset location is marked in the CMP gather shown in Fig. 2 by the bold line. We observe in this CMP gather that there are many events between

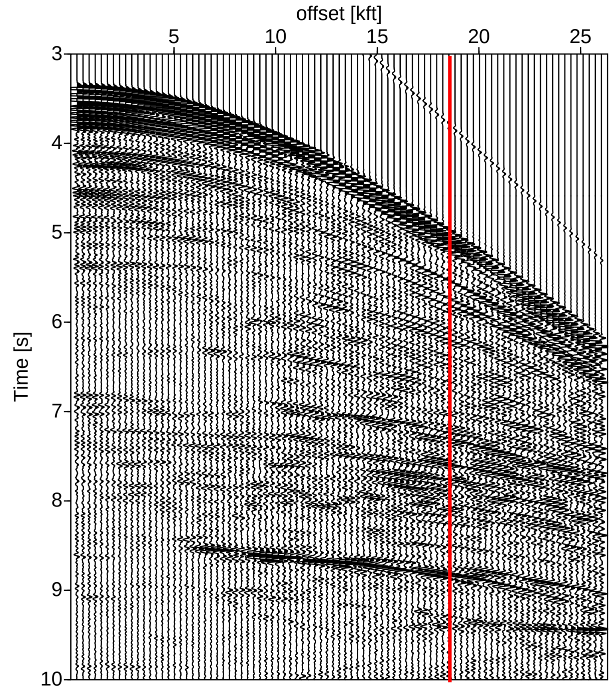

Fig. 2: CMP gather of the Sigsbee2 dataset with a CMP location at 32487.5 ft on the surface.

a recording time from 6 to 9 seconds at an offset of 18000 ft whereas there are only a few reflections near zero offset in the corresponding time window. So there should be events imaged at a CMP location of 32487.5 ft in the FO CRS-stacked CO section within this time window. In the upper part of Fig. 3, where the CMP location of 32487.5 ft is indicated by the dashed line, we see that this is indeed the case. In contrast to the stacked CO section, there are almost no events imaged at the same CMP location within the time window between 5 and 9 seconds in the ZO section simulated with ZO CRS stack. The ZO CRS-stacked section is shown in the lower part of Fig. 3 where again the CMP location of 32487.5 ft is indicated by the dashed line.

If there are subsurface reflections in the pre-stack data they are expected to be recorded within the above investigated time window. Thus, we can conclude that with the FO CRS stack we have the possibility to image subsalt structures even in presence of complicated salt shapes. Whether subsalt events have in fact been imaged can only be proven by a subsequent post-stack CO depth migration. Problems that may occur can be explained by means of Fig. 2. In the vicinity of offsets of around 20000 ft and a recording time between 7 and 8 seconds there are many intersecting events. In its current implementation, the FO CRS stack images in such situations the most prominent event, i.e. the event which provides the highest coherency value. This is, however, not necessarily an event of the target region to be illuminated but can be a multiple which superposes the searched event. Therefore, it is essential to devise a sophisticated search strategy to succeed the parameter search. In this regard, all information available to constrain the parameter search can be of help. The extracted wavefield attributes indicated above may serve this purpose.

Conclusions

We introduced a new data-driven imaging method—the FO CRS stack—which follows the philosophy of the meanwhile well-established ZO CRS stack. We demonstrated on a synthetic dataset that the FO CRS stack can be an alternative prestack stacking tool in complex situations such as subsalt imaging. The FO CRS stack is able to produce interpretable FO sections where ZO simulation methods suffer from bad illumination of target reflectors by small-offset reflections.

Finally, it should be mentioned that the CRS methods are much more than only stacking tools. The ZO CRS stack provides three and the FO CRS stack five kinematic wavefield attributes useful for many seismic applications. The attributes obtained from the FO CRS stack in a data-driven way are still subject of further investigations.

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The Finite-Offset CRS stack

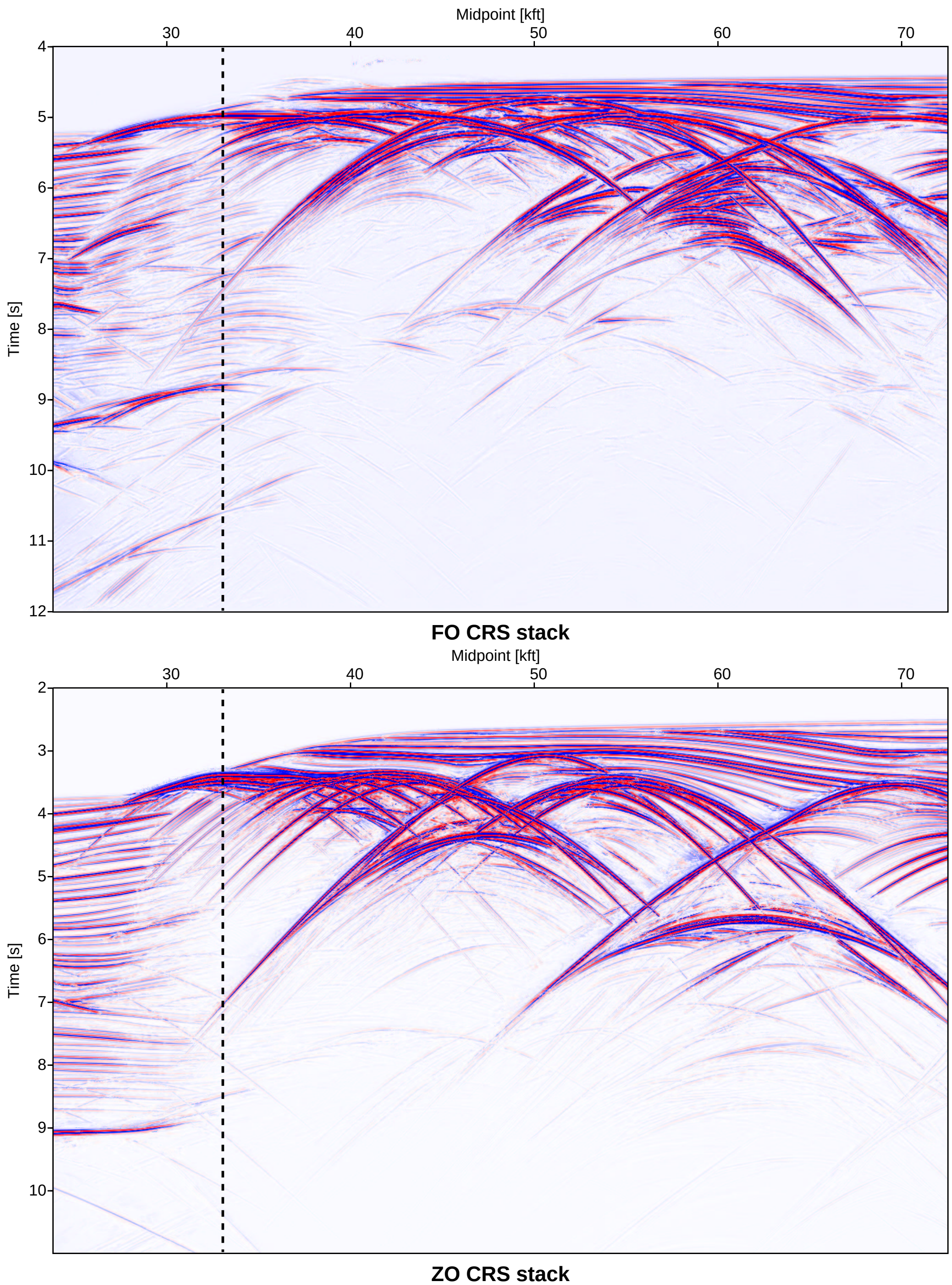

Fig. 3: Upper part: stacked CO section (offset at 18000 ft) obtained by the FO CRS stack. Lower part: stacked ZO section obtained by the ZO CRS stack.