# DIFFRACTION SEPARATION WITH MIGRATION APERTURES

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## ABSTRACT

*Diffraction separation becomes more and more important in seismic processing. Diffractions contain a lot of information about small-scale structures and improve resolution of the images. It is necessary to perform an adequate separation between reflected and diffracted energy becuase illuminatiopn and resolution is larger for diffractions and separation promises better images. We present a diffraction separation approach based on migration apertures where they serve as filters. The apertures for migration should coincide with the first Fresnel zone to optimally stack reflected energy. Diffractions require large apertures for good migration results. We make use of this principle and weight a large migrated coherence section with an appropriated migrated image. The final demigration produces diffraction only pre stack data. First tests with synthetic data show the potential of our approach but also the limitations we are facing.*

## INTRODUCTION

Seismic waves can be separated in reflections and diffractions. They are known for a long time whereas their mathematical behaviour, especially for diffractions, is complicated. Hoeber et al. (2017) gives a review about the description of diffractions. Diffractions are in the focus of seismic processing these days. Some geological features, e.g. pinch-outs, fractures, karst structures and in general small-scale structures, are better illuminated by diffractions. Therefore, they are essential for high-resolution imaging (Klem-Musatov et al., 1994). Using diffractions allows us an imaging beyond the Rayleigh limit of half a wavelength (Khaidukov et al., 2004). Furthermore, a velocity analysis with focussed diffractions can be made instead of common image gather flatness (Sava et al., 2005). Another application is shown in Bauer et al. (2017). They use diffractions as input for a wavefront tomography.

The challenge is to separate diffractions from reflections in an adequate process regarding computing efficiency and final separation results. Merzlikin et al. (2017) list three different possibilties to separate diffractions. First possibility is to use diffraction traveltime curves and obtain an optimal stacking of diffracted energy, e.g. Dell and Gajewski (2011). The second possibility includes the decomposition of the recorded wavefield in diffracted and reflected energy, e.g. Turhan Taner (2006). The third possibilty is a modification of the Kirchhoff migration kernel. Specular energy from the first Fresnel zone is eliminated and only the contributions of the diffracted energy remains, e.g. Kozlov et al. (2004).

We introduce a fourth possibility to separate the recorded wavefield. Migration apertures acts like a filter whereas small apertures within the range of the first Fresnel zone (Schleicher et al., 1997) enhances reflections, large apertures should illuminate diffractions more. Based on this principle we develope a diffraction separation method and apply it to diffrent synthetic data sets to test our assumption.

## THEORY

This section presents the fundamental theory we need for an examination of the diffraction separation. It contains time imaging operators based on multiparameter stacking methods. Furthermore, the diffraction separation is explained.

### Time imaging operators

The used time imaging operators are based on the implicit common-reflection-surface (CRS) operator. The time migration is designed as a diffraction summation operator, accordingly the implicit CRS prestack time migration (PreSTM) operator in apex coordinates reads:

$$t = \sqrt{\frac{t_{apex}^2}{4} + \frac{(\Delta x_a - h)^2}{V^2}} + \sqrt{\frac{t_{apex}^2}{4} + \frac{(\Delta x_a + h)^2}{V^2}}, \tag{1}$$

where $\Delta x_a = x_m - x_{apex}$ is the midpoint displacement, $h$ is the half-offset, $V$ denotes the time migration velocity and $t_{apex}$ is the apex travel time (Bobsin, 2014). The double-square-root (DSR) operator is similar to a Kirchhoff time migration operator (Yilmaz, 2001).

Schwarz et al. (2014) relate the implicit CRS parameters to the kinematic wave field attributes or CRS parameters, of which the incidence angle $\alpha$ and the radius of curvature of the so-called normal incidence point (NIP) wave, $R_{NIP}$ (Hubral, 1983) are pertinent to this work. They find for the velocity:

$$V = \frac{v_{NMO}}{\sqrt{1 + \frac{v_{NMO}^2}{v_0^2} \sin^2 \alpha}} \quad \text{with} \quad v_{NMO} = \sqrt{\frac{2 v_0 R_{NIP}}{t_{apex} \cos^2 \alpha}}. \tag{2}$$

Equation 2 includes the normal move out (NMO) velocity , $v_{NMO}$. Furthermore, by considering the incidence angle, we obtain a dip correction. That means, we receive root-mean-square (RMS) like velocities. These can be used directly for time migration. In our case the velocity (Equation 2) depends on four parameters: $\alpha$, $R_{NIP}$, a prescribed near-surface velocity $v_0$, and the considered time $t_{apex}$. The kinematic wave field attributes are available after the multiparameter stack.

To obtain the demigration expression, we solve Equation 1 for $t_{apex}$:

$$t_{apex} = \sqrt{t^2 - \frac{4(\Delta x_a^2 + h^2)}{V^2} + \frac{16 \Delta x_a^2 h^2}{t^2 V^4}}. \tag{3}$$

This is a single-square-root (SSR) expression in contrast to the double-square-root migration operator. The demigration as well as the migration equation are also valid for the poststack case, where the half offset $h$ vanishes and the equations are simplified.

### Diffraction separation

The principle of the diffraction separation is very simple. We perform a migration with suitable apertures. The next step requires a migration with apertures as large as possible to enhance diffractions. In general, apertures for reflections should have the size of the first Fresnel zone (Schleicher et al., 1997). The Fresnel zone for diffractions is non-existent in theory but in practice infinite. With large apertures diffractions are emphasized and have higher values in the coherence section because more energy is summed. From this large aperture migration we need the coherence section. For this section we define a certain threshold to destinguish between diffractions (above and multiplied with one) and reflections (below and multiplied with zero). The resulting image serves as mask for the migrated image with suitable apertures. As result the migrated image should only contain focussed diffractions. In the last step this masked image is demigrated and we obtain diffraction only pre stack data.

In the next section, we apply the proposed method to different synthetic data sets.

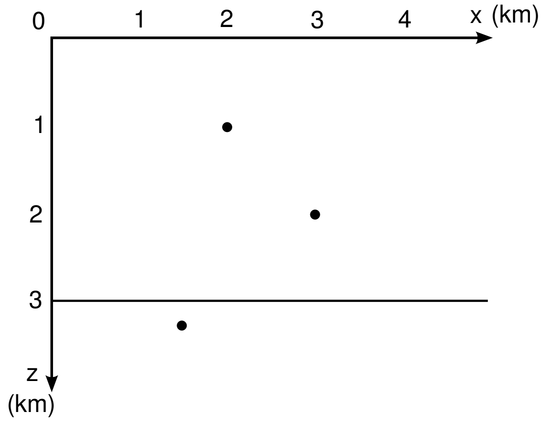



**Figure 1:** Simple model with three diffractors and one reflector embedded in a homogeneous constant velocity medium.

## APPLICATION

In this section we investigate the feasibility of our approach. Therefore, we choose two synthetic data sets and show the results of the different steps mentioned in the previous section.

### Simple synthetic data

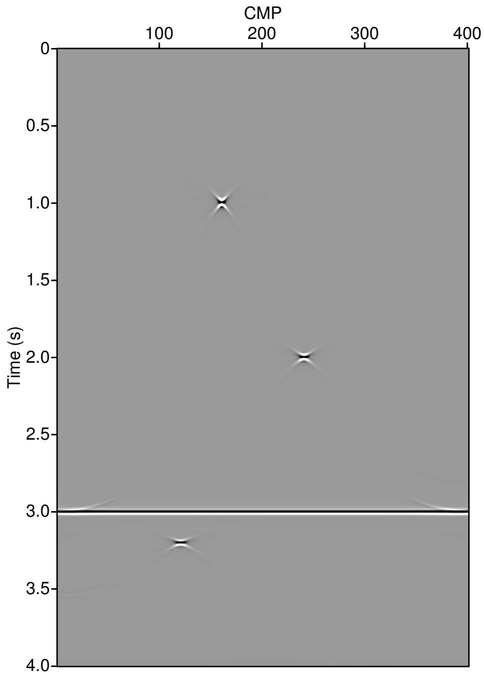
For the first application we consider a homogeneous model with a background velocity of 2000 m/s which contains a reflector and three diffractors (see Figure 1).

We aim for perfect synthetic conditions to test our separation approach under controlled conditions. Therefore, we choose the migration velocity to be the medium velocity. We start the migration with suitable apertures of $x_m$=500 m and $h$=500 m at the top and increase with depth up to $x_m$=1000 m and $h$=2000 m. The next step is the migration with large apertures, favouring diffractions (constant $x_m$=2000 m and $h$=2000 m). The migrated coherence section is the only section we need from this step. Afterwards we choose a threshold for this section to the point where mostly diffractions are visible. For this data, we find a coherence value estimated by semblance of 0.3 sufficient. All data above this value is kept and the rest is removed. The next step is the masking of the migrated section with the weighted coherence section. As final step, we apply the demigration to obtain pre stack data. Figure 2 shows the different steps, mentioned above. The migrated coherence (see Figure 2(b)) shows larger values for the diffractions as for the reflection.

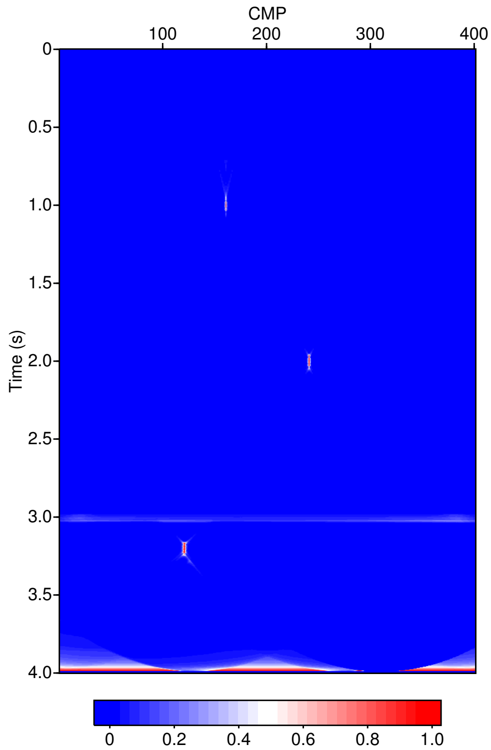
A final comparison of the pre-stack data shows that we are able to remove the reflection and only the three difrfractions remain. The diffraction tails of the separated data (see Figure 3(a)) are shorter in comparison with the original pre-stack data (see Figure 3(b)). This is due to aperture limitations of the demigration.

### Complex synthetic data

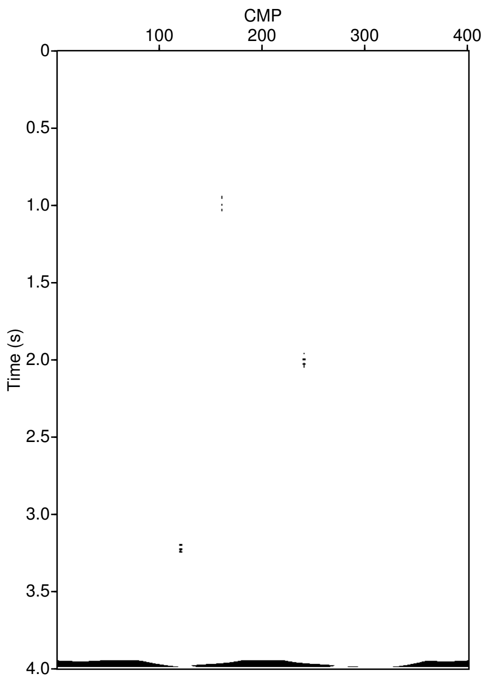
The second synthetic data set is the Sigsbee2a model which reflects a possible structure in the Gulf of Mexico. The complex setting includes a rugged salt body, fractures and additionally placed point diffractors. We choose a velocity model for migration and demigration which is calculated from the true intervall velocities and represents root-mean-square velocities. The first migration is performed with an aperture of $x_m$=2000-4000 m and $h$=1000-5000 m from top to bottom. The result is shown in Figure 4(a). Quality is satisfying until the salt body is reached. The performance of time migration is limited by the strong velocity contrast. For the second step, we choose apertures ranging from $x_m$=7900 m (constant) and $h$=5000-75000 m (top to bottom). The migrated coherence section is shown in Figure 4(b). In comparison with the first




(a) Migration with suitable aperture.

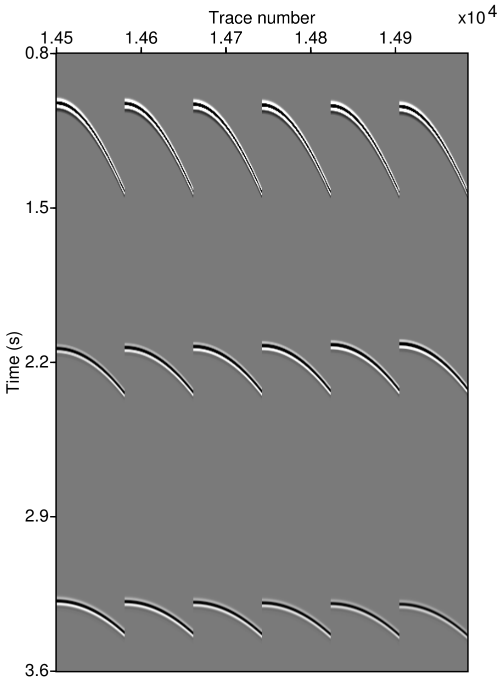



(b) Migrated coherence with large aperture.

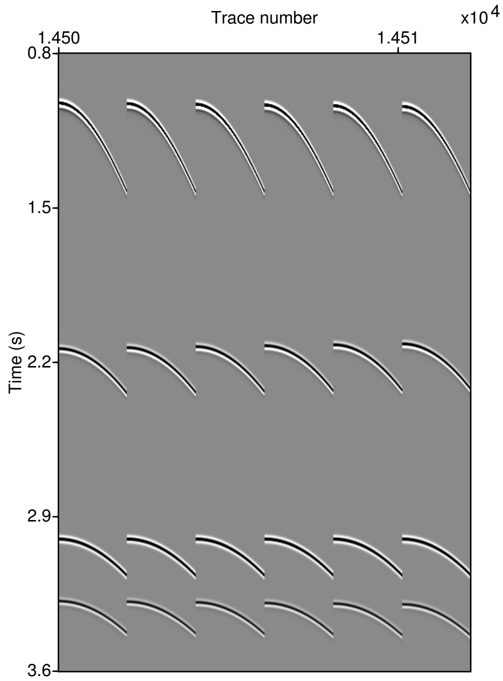



(c) Masked migration.

**Figure 2:** Different processing steps of diffraction separation.




(a) Demigrated pre-stack data.




(b) Original pre-stack data.

**Figure 3:** Comparison of diffraction only and original pre stack data. The reflector at three seconds at (b) is not visible in the separated data (a).

model the amplitudes are more realistic for the Sigsbee model. We see that reflections with stronger impediance contrasts also lead to larger coherence values. Nevertheless, the diffraction rows on the left sight and the rugged top of salt have also large coherence values compared to the reflections. The masked migrated image (see Figure 4(c)) shows some reflection artefacts, e.g. on the left side where sedimentary layering and faults can be found.
Figure 5 is a comparison of five CMP's between the separated and pre-stack data. The close-up shows the left side of the Sigsbee model and two diffractions are included. In general, the events are continiously imaged and stretched (see Figure 5(a)). Regarding the single events, the demigration changes the shape of the wavelet. Wavelets are not similar for all events and seems to appear influenced by the demigration. The process of migration and demigration is purely kinematic and recovering amplitudes and phases is not a part of this process. This should be an issue related to the forward and backward modelling. Furthermore, more events are visible in the original data (see Figure 5(b)). That means, we are able to remove events whether these are reflections as assumed or not has to be investigated. Therefore, we stack the diffraction only data again and overlay it with the stack of the full pre stack volume.

Figure 6 shows the overlayed stacks. We can see that the top of salt diffractions are recovered with shorter tails. However, not all diffractions concerning the salt body could be separated. Their amplitudes are to weak to appear as bright spots in the migrated coherence section. The sedimentary part on the left shows a removing of the reflections except for the reflection at nine seconds with a stronger impediance contrast and therefore larger migrated coherence values. Furthermore, we are not able to see the diffractions from the two lines. The other diffractions there are possible artefacts of the separation process.

## CONCLUSIONS AND OUTLOOK

We present an approach for diffraction separation with migration apertures. The migration aperture serves as filter for diffractions and reflections. Suitable apertures within the first Fresnel zone enhance reflections. In practice, the first Fresnel zone for diffractions is unlimited. Therefore, we choose aperture as large as possible to increase the energy of the diffractions. The migrated coherence section with large apertures serves as mask for the first migrated section. Afterwards a demigration is performed to obatin diffraction only pre stack data. The first synthetic data set mirrors perfect synthetic conditions to test the feasibility of our approach. It is possible to fully remove the reflection and keep the diffractions. The second test with the more complex synthetic Sigsbee data set shows a different result. We are able to separate prominent diffractions, e.g. from the top of salt area where impediance contrasts are high. Unfortunately, background diffractions embedded in the sedimentary layering are hardly separated. Additionally, some reflection artefacts are visible. Furthermore, the wavelet changes for the complex synthetic data in contrast to the simple synthetic data set. The changes are most likely induced by the purely kinematic demigration routine. In conclusion, we can say that in theory the approach performs well and leads to diffraction only pre stack data. More complex settings are quite challenging because other effects, e.g. low amplitudes, high impediance contrasts, have a strong influence. To account for some of these disadvantages, it would be possible to use a different migration/demigration operator which has a better performance than our presented implicit CRS based operator.

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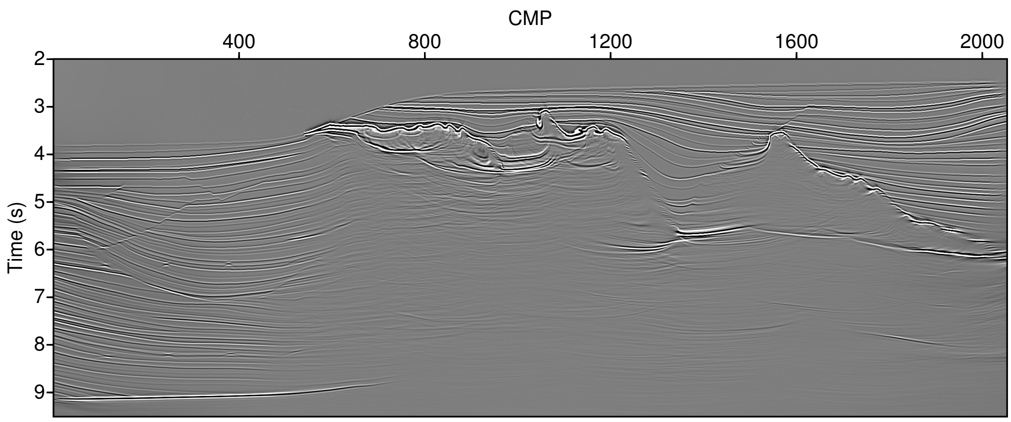
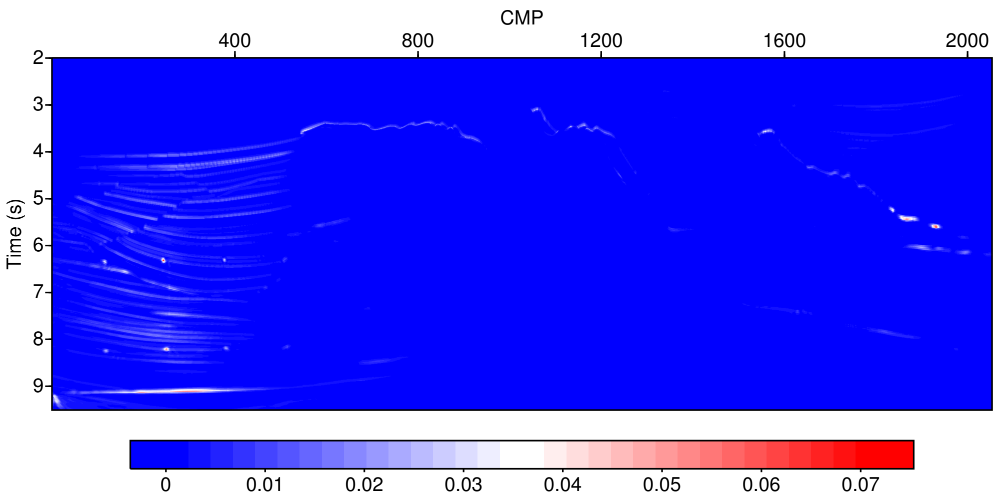
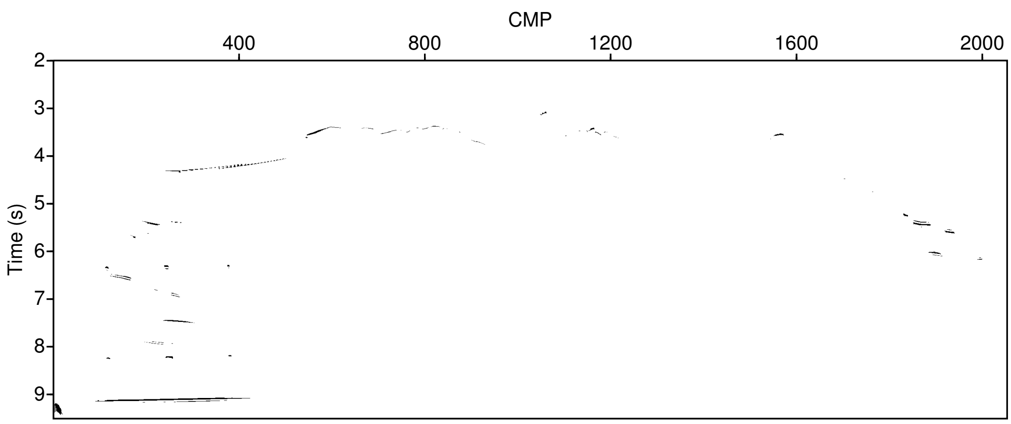



**(a)** Migration with suitable aperture.

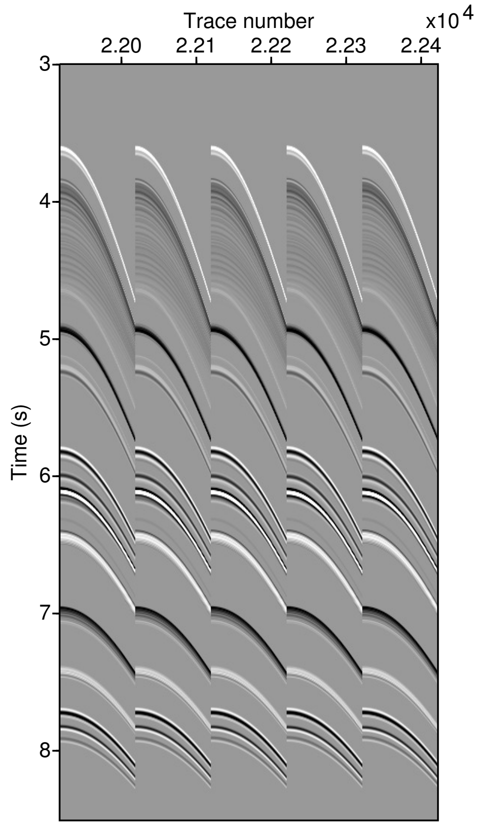



**(b)** Migrated coherence with large aperture.

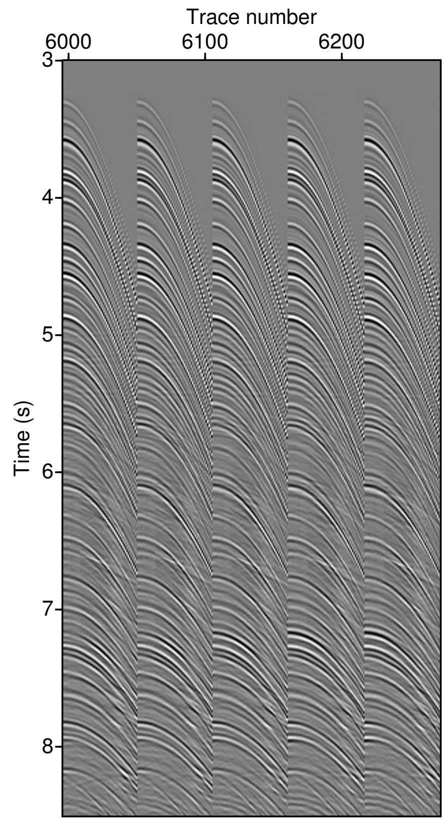



**(c)** Masked migration.

**Figure 4:** Different processing steps of diffraction separation.




**(a)** Demigrated pre-stack data.




**(b)** Original pre-stack data.

**Figure 5:** Comparison of diffraction only and original pre stack data.

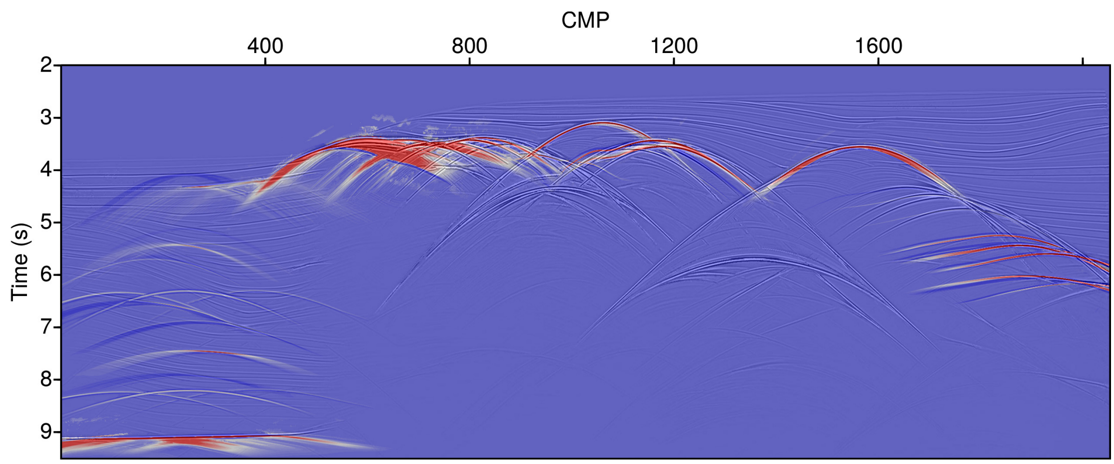



**Figure 6:** Overlay of diffraction-only and full stack.

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