Wave Equation Datuming (A Tutorial)

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Abstract

Referencing the data to a flat datum can resolve the static problems that can result from a rugged topography. There are two methods of datuming: the conventional way of datuming by applying vertical static shifts, and there is a more advance method that uses the wave equation. Both of these methods do not require a prior knowledge of the near surface velocity since the datum is at the highest elevation. However, using the wave equation datuming is more accurate than the vertical static shift datuming, especially for areas where the velocity contrast between the near surface and the substratum is not large. For the small velocity contrast between the near surface and the substratum, rays are not propagating near the vertical. Thus, applying wave equation datuming to the data is more accurate because it honors Snell's law. Further, it represents an image as if the shots and receivers are located on the flat datum. As a result, the static problems caused by a rugged topography can be resolved using this method. Further, processing and prestack migration algorithms can be applied to data that are referenced to a datum using the wave equation because it propagates the wavefield instead of just applying time shifts to the traces. Unlike the static shift method, the wave equation method does not effect the wave-based processing algorithms. Actually, it will be easier to process data that do not suffer from topographic statics. Further, if migration were to be applied on data datumed using the wave equation, it should give better results since reflections exhibit a more hyperbolic shape. This paper was meant to review some of the advantages of using a wave equation technique to resolve the static problems that are caused becaused of a rug topography.

Introduction

Rugged topography and complex near surface layer are some of the important challenges that we face in seismic data processing. Processing algorithms such as velocity analysis, NMO, and stacking are based on the assumption that data are recorded from a flat surface (Bevc, 1997). In conventional data processing, these processes are applied from a floating datum. The floating datum is just a smoothed version of the actual elevations. The difference between the actual elevations and floating is applied to the data. These high frequency statics are applied to the data to resolve some of the static problems. However, in the presence of a rugged topography, these high frequency statics may not be able to resolve all of them and sometimes it is hard to see the geometry of structures because of that. Thus, referencing the data to a flat datum can be very effective in resolving static problems due to a rugged surface. The conventional approach of datuming is to reference the data to the highest elevation by applying vertical static shifts assuming that the waves are propagating near the vertical. This implies that the contrast between the overburden and substratum is large enough to make the raypaths near the vertical. However, when this assumption is violated, using the vertical static shifts method to datum the data to the highest elevation can be inaccurate. Bevc (1997) introduced a method called "Flooding the Topography" in which he uses the highest elevation as the new datum using a wave equation method. In this paper, I will show a comparison between the two methods used to datum the data to the highest elevation.

Theory

For horizontal layers, the emergent angles of the raypaths at the interface separating the near surface from the substratum are governed by Snell's Law (Equation 1). In regions where the near surface velocity is much slower than the substratum, vertical static shifts can be used because the raypath emergent angles are small (Equations 2)

$$p = \frac{\sin\theta_1}{\alpha_1} = \frac{\sin\theta_2}{\alpha_2} \qquad (1)$$

Where

$\mathbf{p}$ = **ray parameter.**

θ_1 = **angle at which the ray enters the near surface.**

θ_2 = **angle at which the ray leaves the substratum.**

α_1 = **P - wave velocity in the near surface.**

α_2 = **P - wave velocity in the substratum.**

$$\textbf{For } \alpha_2 >> \alpha_1, \theta_1 \approx \mathbf{0} \tag{2}$$

Consequently, for large contrast between the near surface and substratum, raypaths are propagating near the vertical (Figure1). However, when this contrast between them is not large enough, the raypaths are not propagating near the vertical (Figure 1). As a result, applying vertical static shifts to the data can be inaccurate. In that case, it is more accurate to use the wave equation to propagate the wavefield to the highest elevation. This process does not require a prior knowledge of the replacement velocity. The section obtained after wave equation datuming exhibits better continuity and more accurately represents the structural image than the image obtained after static shift.

Synthetic Data Example

To illustrate this concept, I have created synthetic shot gathers using a finite difference program. Two datasets with two different velocity models were generated. The receiver spacing is 50 meters. The highest receiver elevation is 100 meters and the lowest elevation is –100. The receivers are planted on a rugged topography. This geometry will be used to create the two datasets, each with a different near surface velocity model. Throughout the synthetic data examples, you will notice that just by referencing the data to the highest elevation, a lot of the topography related statics were resolved. However, the accuracy of this method is sensitive to the velocity contrast between the near surface and the substratum. To further illustrate this point, I will investigate the following two cases:

Case 1: Large contrast between near surface and substratum velocities:

Figure 2.a shows the velocity model that was used to generate the data where the near surface velocity is much slower than the substratum. The receivers are planted on a top of a rugged topography as indicated by the arrow in Figure 2.a. Figures 2.b, show the raw data generated for that model. Figures 3.a and 3.b show the data after applying vertical static shifts and applying wave equation datuming to bring the data to the highest elevation, which is a 100 meter for this model. The vertical static shifts and wave datuming have resolved most of the static problems caused by this topography. This example illustrates that in the presence of a large velocity contrast between the near surface and substratum, vertical static shifts can economically be used to bring the data to the highest elevation. This large velocity contrast makes the raypath bending near the vertical.

Case II: Small contrast between near surface and substratum velocities:

Figure 4.a shows the velocity model that was used to generate the data where the velocities contrast between the near surface and the substratum is small. The geometry is same as in Case I, where the receivers are planted on top of a rugged topography. The synthetic shot gather for this model is shown in Figure 4.b. Applying vertical static shifts to the data could not resolve most of the static problems (Figure 5.a). The reason for that is the small contrast between the velocities of the near surface and substratum, which makes the raypath bending at the interface separating the near surface from the substratum away from the vertical. The vertical static shifts can only be used when there is a large contrast between velocities of the near surface and the substratum. However, for this model, this contrast is not large to make the raypaths near the vertical. However, after applying wave equation datuming, most of the topographic static problems were resolved (Figure 12). The reason for that is because this method uses the wave equation to correctly propagate wavefied to the datum to accommodate raypath bending.

Conclusion

Datuming the data to the highest elevation can resolve the static problems caused by a rugged topography f the correct method was used. In conventional seismic data processing, vertical static shifts are used for datuming. This method is based on the assumption that the near surface velocity is much smaller that the substratum velocity, which is true in some areas. In such cases, using the vertical static shifts can in fact resolve most of the static problems that are caused by the topography. However, when this contrast is not large enough, the raypath bending at the interface separating the overburden from the substratum is not close the vertical. Thus, applying this method of datuming can result in placing the data at the wrong positions. As a result, applying the processing algorithms such as migration and velocity analysis on the data that are datumed using the conventional way can be very inaccurate and the results can be very misleading. Wave-equation datuming is more accurate way for datuming. It takes care of the raypath bending when the contrast between the overburden and the substratum is small. Finally, the velocity contrast between the near surface and the substratum is a relative term. Thus, using wave equation based methods for datuming will always be superior to those methods that do not honor Snell's law.

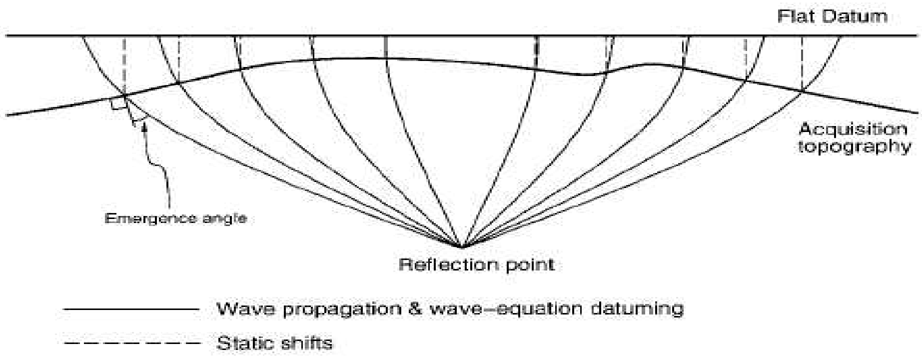
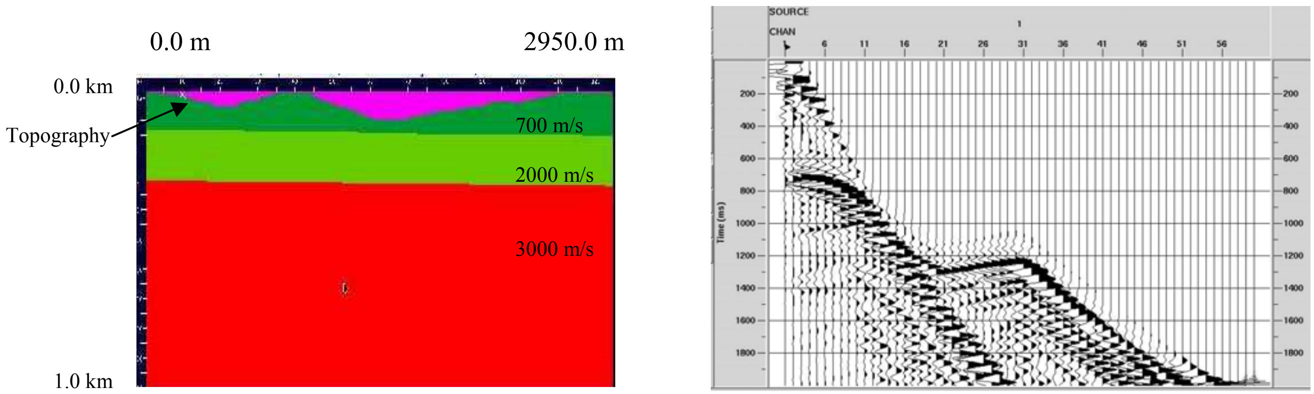
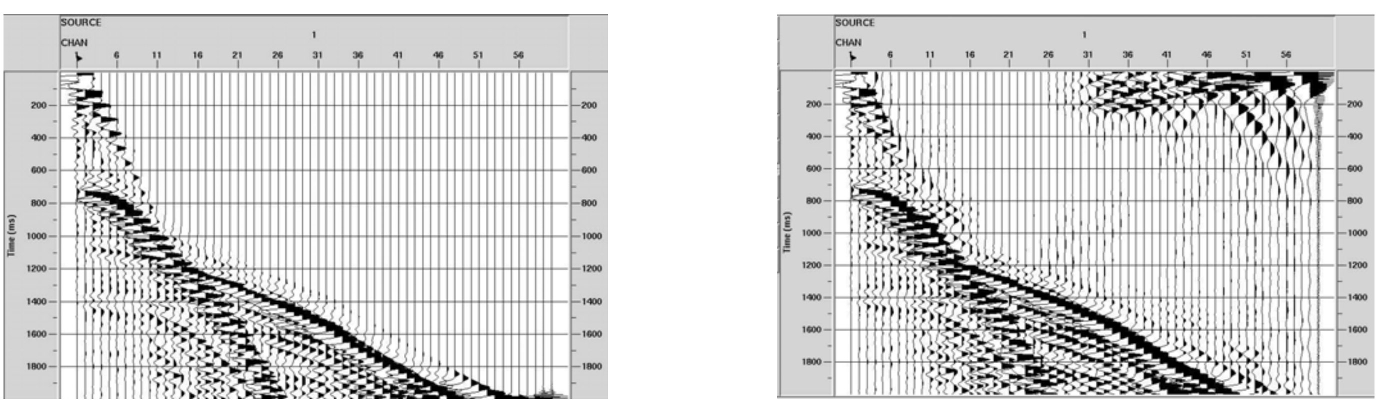


Figure 1. A comparison between wave equation datuming and vertical static shifts (taken from Bevc (1997)).



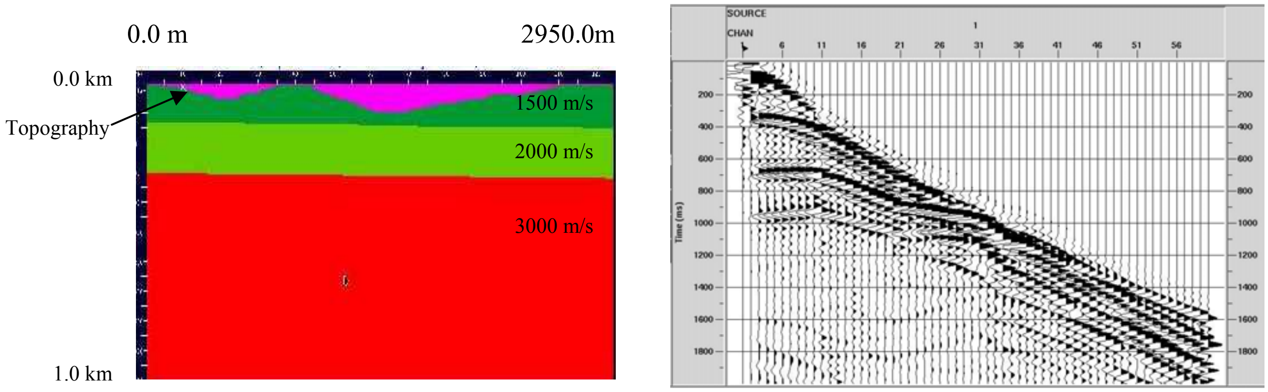
(a) (b)

Figure 2. (a) Velocity model used for case I. (b) The synthetic shot gather.



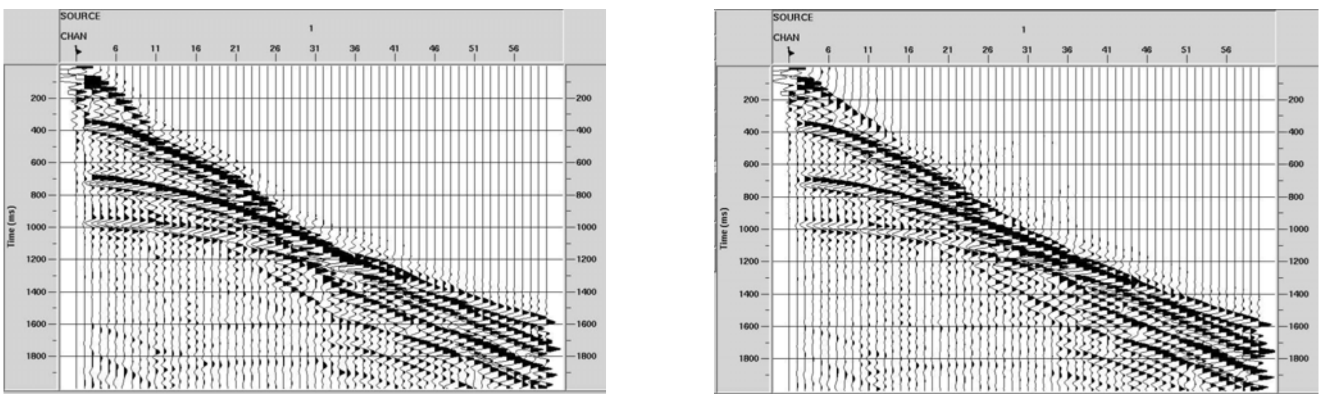
(b) (b)

Figure 3. (a) After applying vertical static shifts to move the data to a flat datum. (b) After wave equaiton datuming. Both have resolved most of the topography related statics. These results are for Case I.



(a) (b)

Figure 4. (a) Velocity model used for case II. (b) The synthetic shot gather for this model.



(a) (b)

Figure 5. (a) After applying vertical static shifts to move the data to a flat datum. (b) After wave equaiton datuming. Note that wave equation datuming result is superior to the vertical staic shifts where raypaths are not near the vertical (Case II).

References

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