Spatially Fixed Patterns For Resolving Large Magnitude Short Wavelength Statics and More.

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Abstract

In Saudi Arabia, the complex three-dimensional near-surface overburden can introduce large magnitude short-wavelength time delays greater than half a period and wavelengths greater than half an effective spread length. Since automatic residual statics algorithms fail to resolve these statics, additional geologic information is needed during the interpretation phase to constrain the near-surface model. These errors are overcome by combining this interpretation phase with a new partial-offset stack domain within a stand-alone PC-based interpretation system. This interpretation system uses multiple forward and reverse partial-offset stack displays in the common-receiver point (CRP), common-source point (CSP), and common-midpoint (CMP) domains to delineate and estimate surface-consistent source and receiver statics. However, it is only possible to decouple the source and receiver statics when the offset distance is greater than the anomaly width (i.e., under shoot).

This limitation is overcome by using a new 2D or 3D spatially fixed stacking pattern to organize CRP and CSP offset-dependent stacks for spatially fixed sources and receivers, respectively. These patterns are designed to "illuminate" the near-surface anomaly from different directions, discriminate between structural and surface-consistent velocity variations, and decouple shot and receiver statics. Each offset trace within a range of receivers or sources from a fixed set of binned sources or receivers will have the same constant surface-consistent static. This constant static term can be easily estimated and removed from the time picks when two patterns are overlapped. Hence, the surface-consistent source and receiver static components are decoupled. This is the only known efficient method for resolving short-wavelength surface consistent large magnitude and medium- to long-wavelength statics in three-dimensions.

Introduction

From the first days of seismic exploration, wells have been drilled on structural highs in the time domain – though for a good reason, some turned out to be false depth structures. In general, inadequate spatial sampling of the near-surface wavefield and direct uphole measurements were sited as causes for such failures. Each time a dry well was drilled, the near-surface issue was re-examined with geoscientists lobbying for additional deep uphole control. As a result, over the past fifty years, thousands of regularly spaced (approximately half-a-kilometer) shallow upholes have been drilled (approximately 100-foot maximum penetration depth) along seismic profiles during the acquisition phase throughout the kingdom of Saudi Arabia. And to a lesser degree, more expensive, deeper structural and velocity wells were drilled.

The purpose of uphole measurements is only to estimate the long wavelength statics (i.e., velocity) for improving the deep time structures as an approximation of a depth section. It is not to estimate short wavelength statics (i.e., velocity). Unfortunately, without a surface imprint, many of the short wavelength near-surface localized velocity/depth anomalies (i.e., leaching, buried channels and karsts) go undetected during the preplan scouting phase. Inevitably, some of the regularly spaced upholes will penetrate these zones and it is only during the interpretation phase, can we detect these zones and edit misplaced upholes (i.e., outliers) from the long-wavelength statics solution.

Four problems we face today are: (1) automatic residual-statics algorithms fail to resolve time delays greater than half a period, (2) the near-surface velocity-depth variations may extend several hundred meters below the surface in Saudi Arabia beyond the maximum penetration depth of existing upholes, (3) direct arrivals from most of the overburden are not normally observed due to velocity inversions (4) regions with discontinuous refractors (complex first-breaks), near-surface velocity inversions, and lack of overburden velocity control, limit the success of refraction statics methods (Cox, 1999). Ideally, isopach and final time maps should be free of inadequate datum corrections or velocity irregularities above a shallow “hanging reflector”.

Based upon extensive land seismic processing experience in such complex overburden cases, it is recognized that these limitations can only be overcome with an interactive integrated interpretation system. The workflow first requires the delineation of near-surface heterogeneities, followed by the discrimination of structural and surface-consistent anomalies, and the use of a priori geologic information to interpret the structural time expression. Multi-panel displays of partial-offset common-refection point (CRP), common-shot point (CSP), or common-midpoint (CMP) stacks and spatially fixed pattern (SFP) offset-dependent stacks are used to estimate decoupled surface-consistent source and receiver statics. Near and far partial-offset CMP stacks are used for verification.

In this paper, two sections describe how we delineate surface anomalies and discriminate structural and velocity anomalies within the interpretation system. This is followed by the concept of SFPs, offset-dependent stacks and how to decouple surface-consistent source and receiver statics. The final section demonstrates how SFPs are used to resolve large magnitude and medium- to long-wavelength statics for a 2D seismic data example. An actual 3D seismic data example will be shown demonstrating the merits of 3D SFPs.

Near-Surface Heterogeneity Delineation and Discrimination

First breaks and unfiltered partial-offset stacked time sections offer insight into the spatial extent of near-surface heterogeneities. For example, Figure 1 shows two long-wavelength time anomalies on a 2D common-offset section (4000m). This concept is used to delineate the spatial extent of these anomalies by analyzing the forward and reverse CRP and CSP near, middle, and far partial-offset stack displays. Figure 2 shows how the spatial position of the left edge (i.e. time discontinuity) remains stationary for different partial-offset CRP stacks (Fig. 2A - forward spread). The same is true for the right edge when comparing different partial-offset stacks for the reverse spread (Fig. 2B).

It is worth noting the schematics illustrate single fold constant amplitudes. But in the real-data case, you would expect the stacked traces to attenuate the signal along the edge of anomalies (right edge on forward profile, left edge on reverse profile).

To discriminate between surface-consistent velocity and structural anomalies, CRP or CSP near, middle, and far partial-offset stacks are displayed by CMP. This is referred to as CMP-Matching.

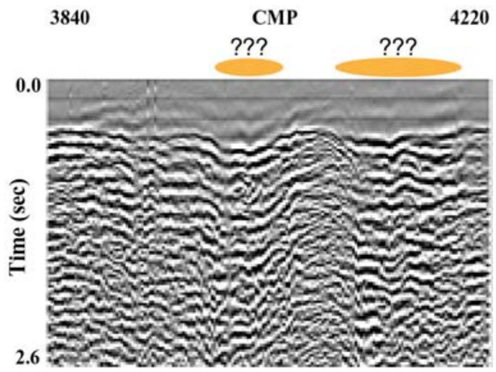


Figure 1. Common-offset (4000m) time section used to delineate near-surface heterogeneities.

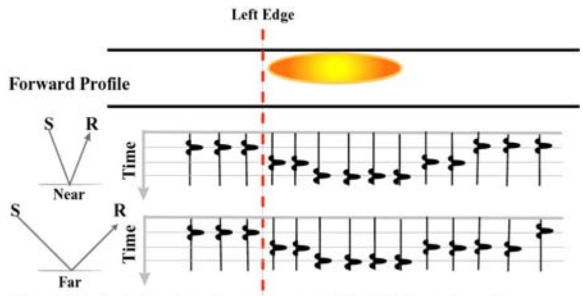


Figure 2A- Left edge detection with near and far CRP forward profile.

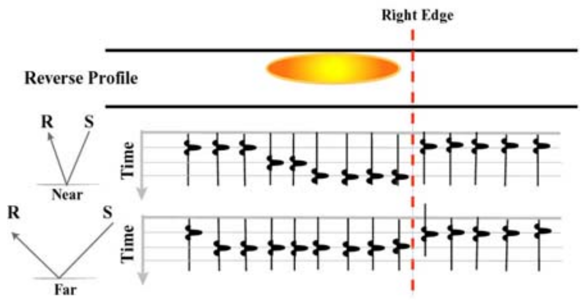


Figure 2B- Right edge detection with near and far CRP forward profile.

By using CMP-Matching display for different partial-offset stacks, the structural anomalies can be distinguished from surface-consistent velocity anomalies. Figure 3 shows how the different partial-offset stack time patterns are the same, while the surface-consistent velocity anomaly reflection time pattern will spread with further offsets. These surface-consistent ranges are recorded for further design of spatially fixed source and receiver patterns and analysis of CRP and CSP offset dependent stacks, respectively.

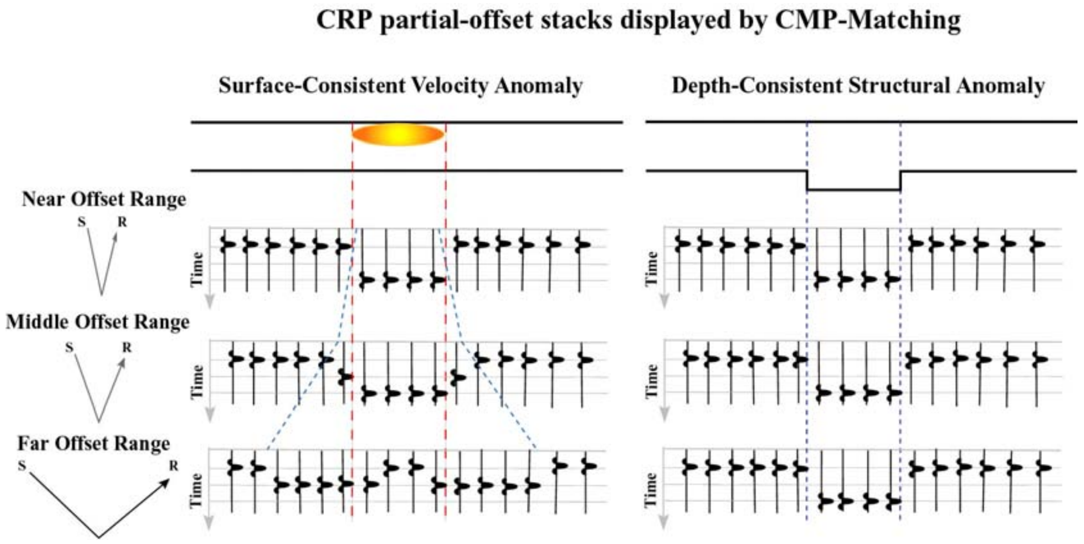


Figure 3 - CRP or CSP near, middle, and far partial-stacks displayed by CMP (referred to as CMP-Matching).

Concept of Spatially Fixed Patterns

A spatially fixed source or receiver pattern is a group of fixed binned sources or receivers (the number depends on S/N) and a corresponding offset-dependent set of receivers or sources, respectively. Figure 4 shows how two SFPs are combined to form a set and each set produces an offset-dependent stack. This new partial stack domain has two advantages over other domains. First, the reflection time delays are in the correct spatial position as compared to the double time anomaly formed when the spatially varying source-receiver pair under shoots the anomaly (Fig. 3). Second, the only difference between the two partial-stack displays is a constant source time delay (i.e. average source static) for Pattern 2–Set 2, because the appropriate fixed source pattern is located within the anomaly. This source static term is removed by block shifting this set of traces until Set 2 matches Set 1. Now with the source static term removed, the time delays are picked within the anomaly zone and subtracted from the structure term (for example, two points are picked to the left and right of the anomaly in CRP–CMP-Match domain and interpolate). Finally, the result is surface-consistent receiver statics. The same workflow is applied for estimating source statics with two sets of spatially fixed receiver patterns.

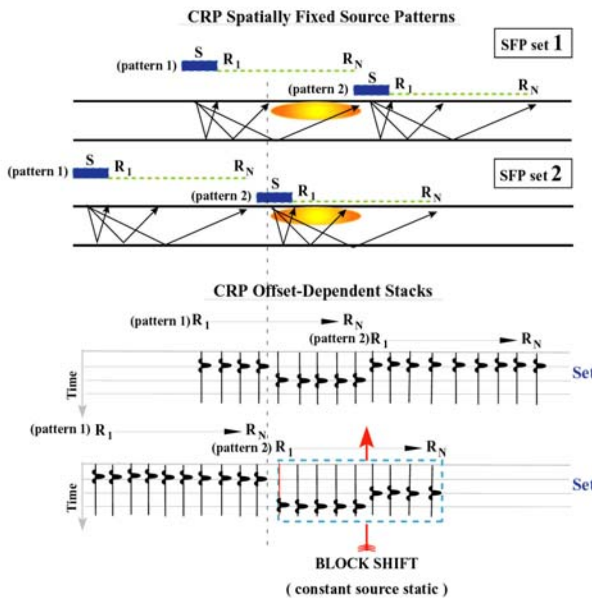
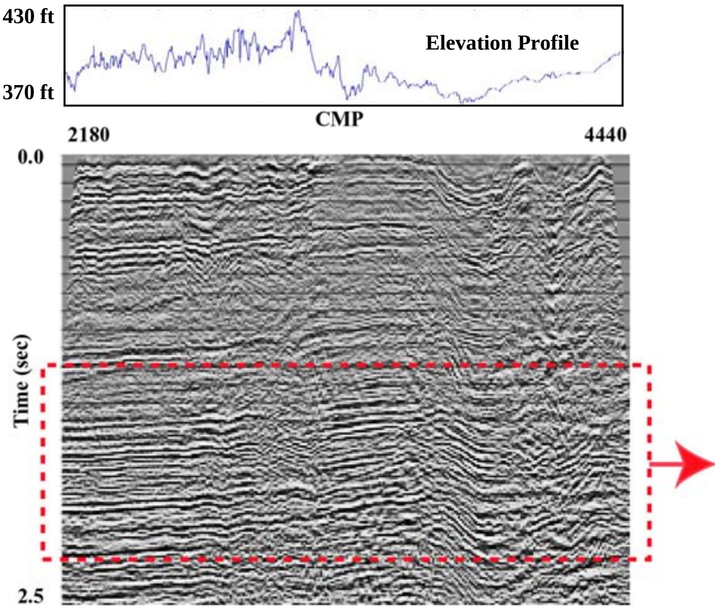


Figure 4 – CRP spatially fixed source pattern stacks are formed with two different patterns per set. Comparing these stacks, we can estimate the block shift needed to align the time delays in set 2 with set 1. This shift removes the constant shot static term from those traces. In the real data case, more than one shot is used to improve S/N. Subsequently, each pattern will have a unique average static value.



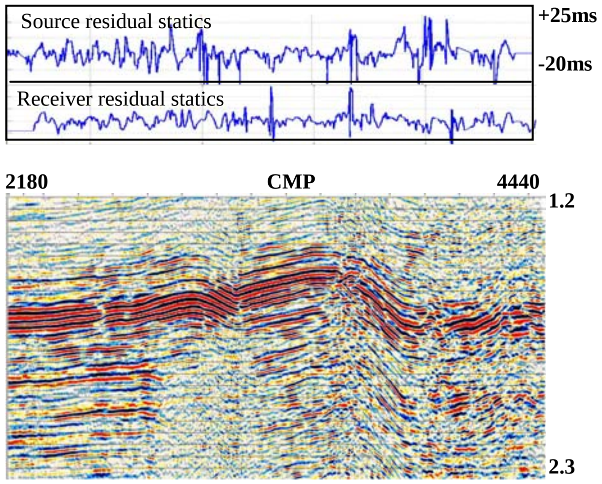


Figure 7A. Residual statics applied.

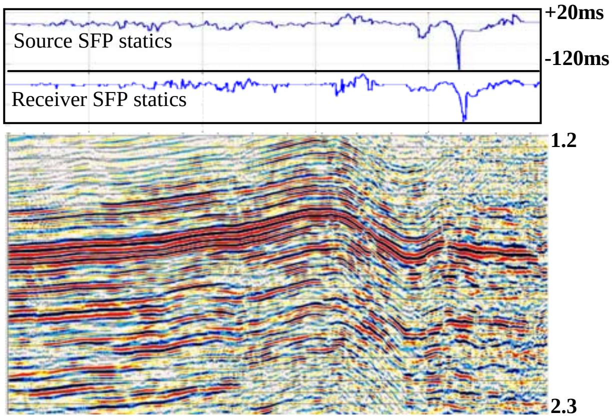


Figure 7B. Surface-consistent SFP statics applied.

2D Seismic Data Example

To test the SFP approach, a 2D seismic line was selected, which exhibits sharp discontinuities, and short to-long-wavelength time anomalies. Fig. 6 shows the time section with only elevation statics applied, and Fig. 7A a zoomed portion of the target zone (dashed rectangle - Figure 6) processed after several passes of residual statics. (-20ms to 25ms).

Using the interactive statics workflow described in the previous sections, new improved SFP surface-consistent source and receiver statics were estimated and applied. Fig. 7B, shows the dramatic improvement in reflector continuity over residual statics. Finally, comparing near and far partial-offset CMP stack displays verify the surface-consistent assumption before (Fig. 8A & 8B) and after SFP statics (Fig. 9A & 9B).

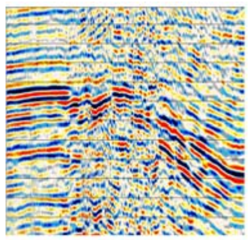


Figure 8A. Near-offset partial stack **WITHOUT** SFP statics

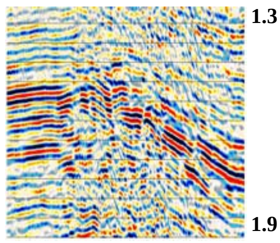


Figure 8B. Far-offset partial stack **WITHOUT** SFP statics

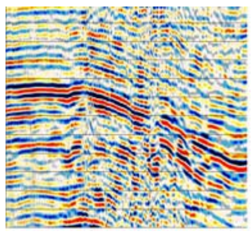


Figure 9A. Near-offset partial stack **WITH** SFP statics.

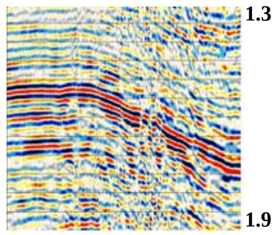


Figure 9B. Far-offset partial stack **WITH** SFP statics.

Conclusions

The interactive statics analysis workflow outlined in this paper, along with the new spatially fixed source or receiver patterns, offers an opportunity to resolve large-magnitude short wavelength and medium-to long-wavelength statics, where other conventional methods fail. The success of this method will always depend on the signal-to-noise ratio. In poor data areas, signal enhancement routines are required prior to forming these partial-offset stack domains. Simply put – no static corrections without reflections.

Acknowledgements

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References

Cox, Mike., Statics Corrections for Seismic Reflection Surveys, 1999, Soc. Expl. Geophys.