Spatially Fixed Patterns Illuminate Unresolved Static Anomalies.

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Summary

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 surface consistent short-wavelength 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, which subsequently 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 to estimate the long wavelength statics in order that the shape of deep structures on a time section approximates a depth section. It is not to estimate short wavelength statics. Unfortunately, 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, due to the lack of any surface expression. Inevitably, some of the regularly spaced upholes will penetrate these zones and it is only during the interpretation phase, that this misleading data (i.e., outliers) can be removed from the long-wavelength statics solution.
Four ongoing challenges 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 cannot be used to characterize most of the overburden, 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).
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 process of correcting unresolved statics involves four phases. First, the delineation of near-surface heterogeneities. Second, the discrimination of surface-consistent velocity and structural anomalies. Third, estimating decoupled surface-consistent source and receiver statics. Fourth, verification. All phases use multi-panel displays of partial-offset common-refection point (CRP), common-shot point (CSP), or common-midpoint (CMP) stacks and a new spatially fixed pattern (SFP) domain to form offset-dependent stacks.
In this paper, the following section describes how to 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 (up to –120ms) short-wavelength and medium magnitude (up to –45ms) medium- to long-wavelength statics for two 2D seismic

data examples. 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 initial insight into the spatial extent of near-surface heterogeneities. To delineate the spatial extent of these anomalies, forward and reverse CRP and CSP near, middle, and far partial-offset stack displays are analyzed for stationary time patterns. Figure 1 shows how the spatial position of the left edge (i.e. time discontinuity) remains stationary for different partial-offset CRP stacks (forward spread). The same is true for the right edge when comparing different partial-offset stacks for the reverse spread.

It is worth noting that the schematics used in figures 1, 2, and 4 illustrate single fold constant amplitudes. But in the real-data case, when more than one common-source or common-receiver trace is summed (improve signal-to-noise), you would expect the signal to attenuate along the edge of anomalies due to phase differences. For example, in figure 1, the signal will attenuate along the right edge anomaly on the forward profile and the left edge on the 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. Structural anomalies can be distinguished from surface-consistent velocity anomalies by comparing reflection time patterns on CSP/CMP-Matching or CRP/CMP-Matching partial-offset stacks. In the structural case, the time patterns remain the same, while for the surface-consistent velocity anomaly, the time pattern spreads with farther offsets (Fig. 2). These delineated surface-consistent zones are then used to design SFPs to estimate decoupled surface-consistent source and receiver statics.

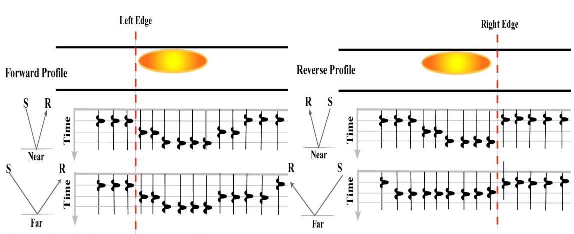


Fig 1. Left edge detection (left) and right edge detection (right) using near and far CRP partial stack displays for forward (left) and reverse (right) spreads, respectively.

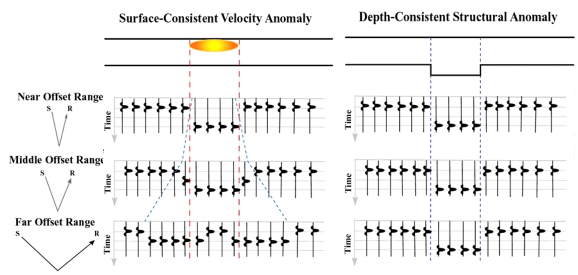


Fig. 2. CRP or CSP near, middle, and far partial-stacks displayed by CMP (referred to as CMP-matching) are used to discriminate between structural and surface-consistent velocity anomalies.

Concept of Spatially Fixed Patterns and Illumination.

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. One or more combined patterns form a set and a minimum of two sets are needed to decouple surface-consistent source and receiver statics within the delineated anomaly zone. Figure 4 shows a schematic example of two sets with two spatially fixed binned source patterns per set above a surface-consistent velocity anomaly. In the first set, the fixed binned sources are positioned outside the anomaly, while the second set is shifted laterally with one of the fixed binned sources positioned within the anomaly. It is this combination of sets, which gives the opportunity to decouple the surface-consistent source and receiver static components. These partial-stacks have three advantages. First, SFPs offset-dependent stacks displayed by CMP and receiver can verify surface-consistent anomalies (Figure 3). Second, the reflection time delays caused by the anomaly 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 (Figure 2). Three, the only difference between the two SFP partial-stack displays is a constant source time delay (i.e. average source static for fixed binned sources) for Pattern 2/Set 2, because the appropriate fixed source pattern is located within the anomaly. By removing the source static term (block shifting this set of traces until Set 2 matches Set 1) we have effectively decoupled the source from the receiver. Using this corrected time pattern, surface-consistent receiver statics are estimated by subtracting the interpreted structural term (for example, two points picked to the left and right of the anomaly in the CRP/CMP-Matching domain are interpolated) from the time delays picked within the anomaly zone. The same workflow is applied for estimating source statics with two sets of spatially fixed receiver patterns (Kozyrev, 1995).

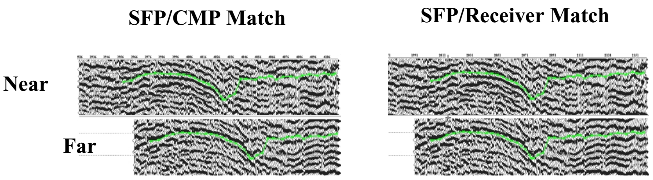


Fig. 3. Two SFP partial-stack panels (near and far offsets) displayed by CMP (CMP-matching) (left) and Receiver Number (right). The non-stationary time pattern on the left and the stationary time pattern on the right indicate this is a surface-consistent time anomaly.

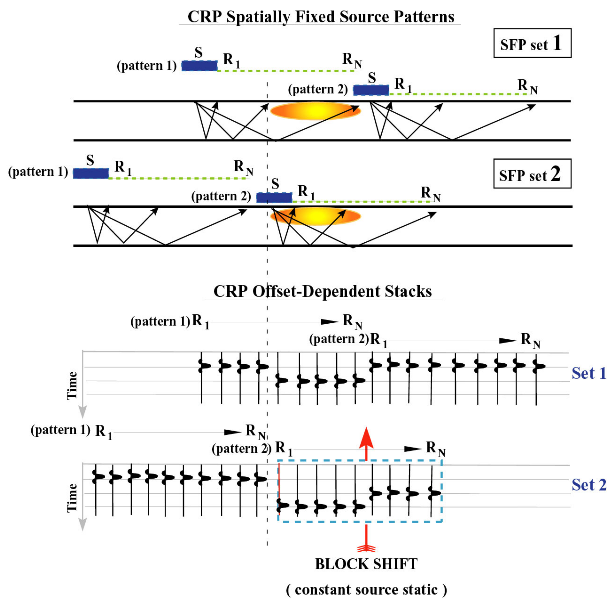


Fig. 4. – CRP spatially fixed source pattern stacks are formed with two different patterns per set. Comparing these stacks, we can estimate the block shift needed to align the time delays in set 2 with set 1. This shift removes the constant shot static term from those traces. In the real data case, more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

2D Seismic Data Examples

We show two examples where conventional processing failed to remove large magnitude and short to medium wavelength statics. In the first example, Figure 5 shows the time section after two passes of residual statics and Figure 6 shows the time section after estimating the new surface-consistent medium wavelength statics. A zoomed in portion of the time section is shown in Figure 7 for comparison. In the second example, a –120ms short-wavelength static was estimated along with medium wavelength statics. Figure 8 shows the time section with only elevation statics applied, and Figure 9A a zoomed portion of the target zone (dashed rectangle in Figure 8) processed after two 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 (-120ms to +20ms) and applied. Figure 9B, shows the dramatic improvement in reflector continuity over residual statics. Finally, the surface-consistent assumption is verified by comparing the near and far partial-offset CMP stack displays before and after SFP statics as shown in Figures 10 and 11, respectively.

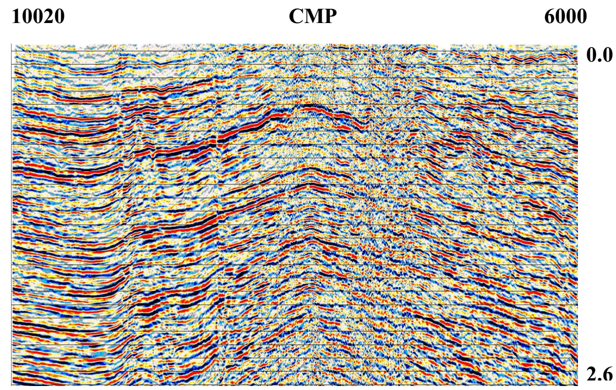


Fig. 5. Two passes of residual statics applied.

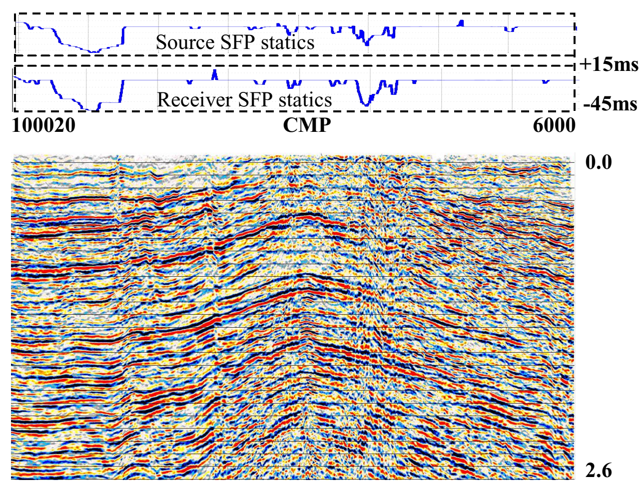


Fig. 6. Surface-consistent SFP statics applied

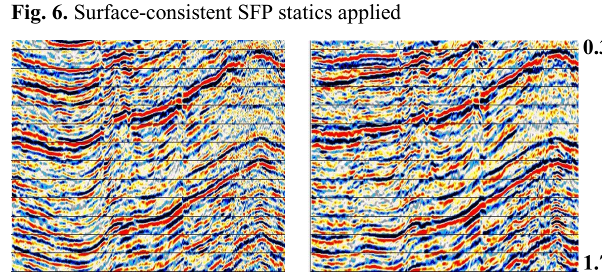


Fig. 7. Compare before (left) and after (right) medium wavelength SFP statics.

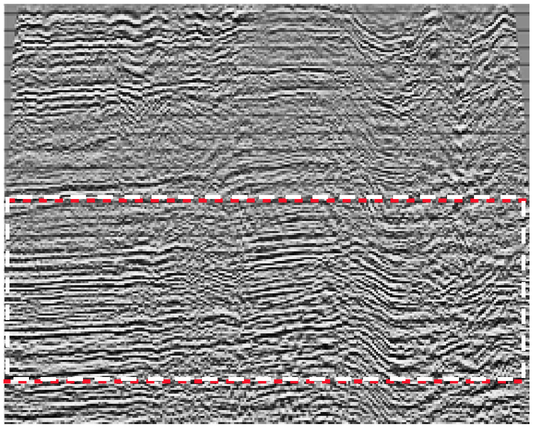


Fig 8. Elevation statics only. The zoomed portion (dashed rectangle) is shown below to compare the differences between residual and SFP statics.

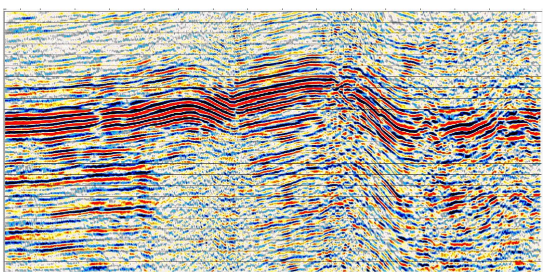
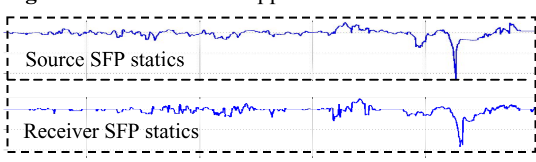


Fig. 9A. Residual statics applied.



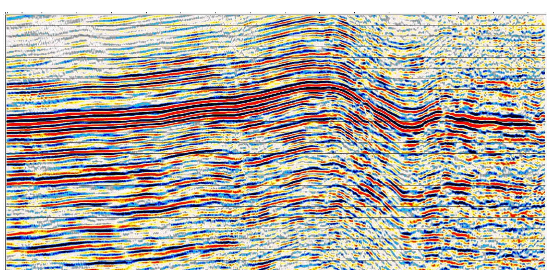


Fig. 9B. Surface-consistent SFP statics applied.

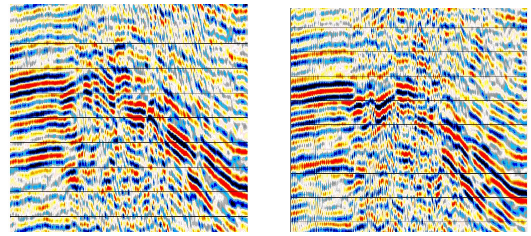


Fig. 10. Near-offset (left) and far-offset (right) partial-stack displays **WITHOUT** (left) SFP statics.

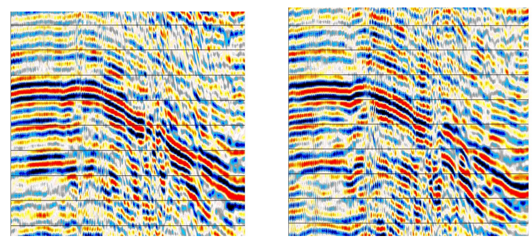


Fig. 11. Near-offset (left) and far-offset (right) partial-stack displays **WITH** SFP statics.

Conclusions

The interactive statics analysis 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 residual statics algorithms fail. This paper demonstrated how it is possible to estimate statics as large as 120ms by analyzing seismic data in different partial-stack domains and more importantly, gain confidence in the surface-consistent analysis by verifying near- and far-offset partial stack displays with SFP statics. The success of this method will always depend on the signal-to-noise ratio. In poor seismic data areas, signal enhancement routines will be required prior to forming these partial-offset stack domains. Simply put – no SFP static corrections without reflection signals.

Acknowledgements

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