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Multi-Fold Evaluation Criteria for 3D Seismic Acquisition Geometries

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Summary

Three-dimensional (3D) seismic surveys image subsurface reflectivity by deploying seismic sources and receivers across the surface above a target area. The acquisition layout defines two horizontal coordinates for sources (*Sx, Sy*) and two for receivers (*Rx, Ry*), forming a four-dimensional (4D) spatial sampling space (Naghizadeh and Crook, 2025). Elevation effects are typically handled through re-datuming and are therefore not treated as independent dimensions. This 4D dataset can be organized using various spatial sorting schemes, most commonly the midpoint–offset vector domain (*Mx, My, Ox, Oy*), where *Mx* and *My* denote midpoint coordinates and Ox and Oy represent offset components. Traditionally, the *Mx–My* fold map has been used as a primary indicator of data quality and signal-to-noise ratio. However, because 3D seismic acquisition spans four independent spatial dimensions, fold distributions can be constructed for all six possible dimension pairs; F1: *Mx–My*, F2: *Mx–Ox*, F3: *Mx–Oy*, F4: *My–Ox*, F5: *My–Oy*, and F6: *Ox–Oy*. Analyzing all six fold maps provide a comprehensive assessment of the spatial sampling and coverage of a given seismic acquisition geometry. We examine fold maps for various geometry types and illustrate sampling effects with real data decimation examples.

Methodology

Figure 1 presents three seismic acquisition geometries obtained by decimating a full-grid layout with 20 m source, receiver, and line spacing. Figure 1a shows a geometry with randomly distributed sources and receivers, where 67% of the full-grid stations are removed. Figure 1b applies the same 67% decimation to produce an orthogonal geometry with a 3:1 station-to-line ratio for both sources and receivers. Figure 1c illustrates an EcoSeis™ linear geometry (hereafter referred to as linear geometry), which shares the same line spacing as the orthogonal layout and maintains a 3:1 station-to-line ratio. In this configuration, sources and receivers are interleaved along the same line, enabling a 50% reduction in total seismic line length (Naghizadeh et al., 2023). All three geometries in Figures 1a–1c contain identical numbers of sources and receivers, leading to comparable trace densities across the surveys.

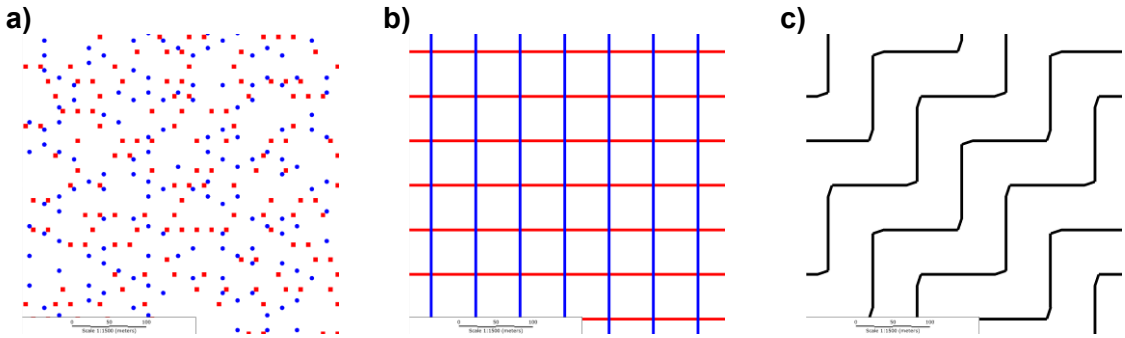


Figure 1: a-c) Random, orthogonal, and linear seismic acquisition geometries with similar trace densities, respectively.

Figures 2a-2f depict *Mx-My*, *Mx-Ox*, *Mx-Oy*, *My-Ox*, *My-Oy*, and *Ox-Oy* fold maps for random acquisition geometry shown in Figure 1a, respectively. All six fold maps of the random geometry show full coverage with no gap with different fold value variabilities.

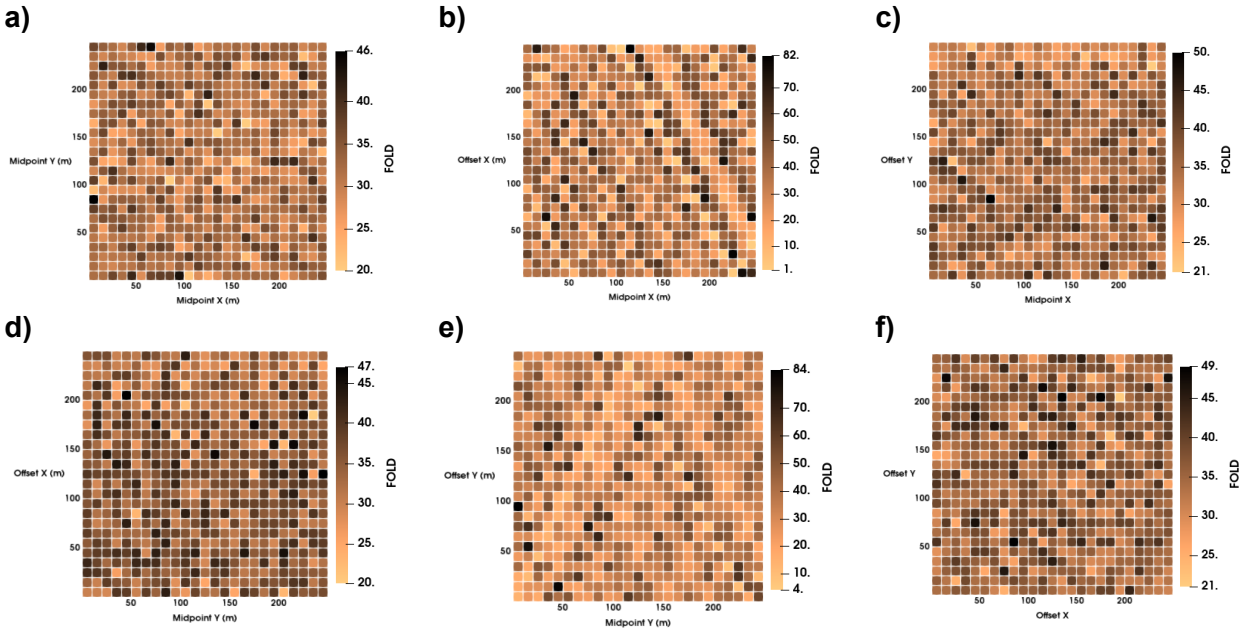


Figure 2: a) *Mx-My*, b) *Mx-Ox*, c) *Mx-Oy*, d) *My-Ox*, e) *My-Oy*, and f) *Ox-Oy* fold maps for the random acquisition geometry shown in Figure 1a.

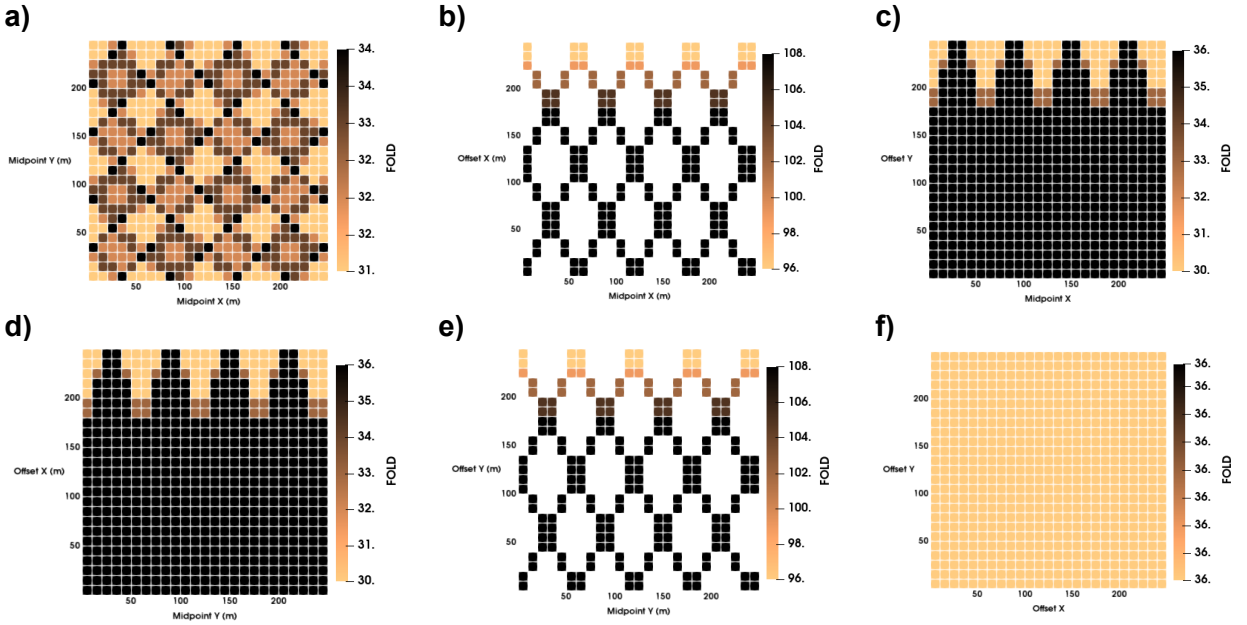


Figure 3: a) *Mx-My*, b) *Mx-Ox*, c) *Mx-Oy*, d) *My-Ox*, e) *My-Oy*, and f) *Ox-Oy* fold maps for the orthogonal acquisition geometry shown in Figure 1b.

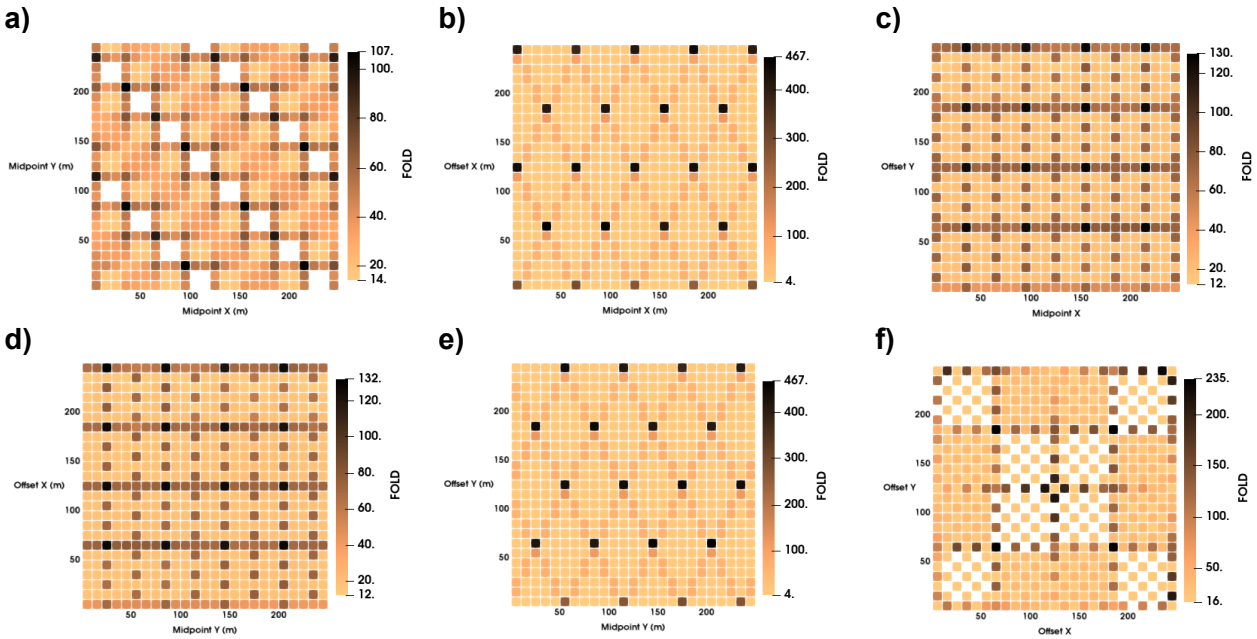


Figure 4: a) *Mx-My*, b) *Mx-Ox*, c) *Mx-Oy*, d) *My-Ox*, e) *My-Oy*, and f) *Ox-Oy* fold maps for the linear acquisition geometry shown in Figure 1c.

Figures 3a-3f and 4a-4f show *Mx-My, Mx-Ox, Mx-Oy, My-Ox, My-Oy*, and *Ox-Oy* fold maps for the orthogonal and linear acquisition geometries shown in Figure 1b and 1c, respectively. For orthogonal geometry, 4 fold maps (*Mx-My, Mx-Oy, My-Ox*, and *Ox-Oy*) have uniform and full coverage, however, the other 2 fold maps (*Mx-Ox* and *My-Oy*) contain large gaps with 67% empty bins (Figures 3a-3f). Such extensive gaps can significantly hamper the effectiveness of data reconstruction algorithms in achieving high-fidelity interpolation within unsampled regions pf the orthogonal geometry. Similarly, the linear geometry also has 4 fold maps (*Mx-Ox, Mx-Oy, My-Ox*, and *My-Oy*) with full coverage but with high fold variability. Meanwhile, the linear geometry has 11% empty bins in the *Mx–My* and 15% empty bins in the *Ox–Oy* fold maps. These small, semi-randomly distributed gaps can be effectively recovered using seismic data reconstruction methods (Naghizadeh and Sacchi, 2010).

Real Data Examples

Figure 4a displays a time slice of the estimated acoustic impedance derived from real data acquired using a full-grid geometry with 20 m station and line spacing (Goodway et al., 2025). The corresponding estimated Vp/Vs and density time slices for the full-grid geometry are shown in Figures 4d and 4g, respectively. Figures 4b and 4c present the estimated acoustic impedance time slices for the orthogonal (Figure 1b) and linear (Figure 1c) geometries. Likewise, Figures 4e and 4f show the estimated Vp/Vs for the orthogonal and linear geometries, while Figures 4h and 4i display the estimated density for these same layouts. Compared to the full-grid results, the Vp/Vs and density time slices obtained from the linear geometry contain fewer artifacts and exhibit a reduced acquisition footprint relative to those from the orthogonal geometry. The increased footprint and artifacts observed in the AVO-derived attributes from the orthogonal geometry are attributed to the large gaps in its *Mx–Ox* and *My–Oy* fold maps, which adversely affect the performance of seismic reconstruction techniques.

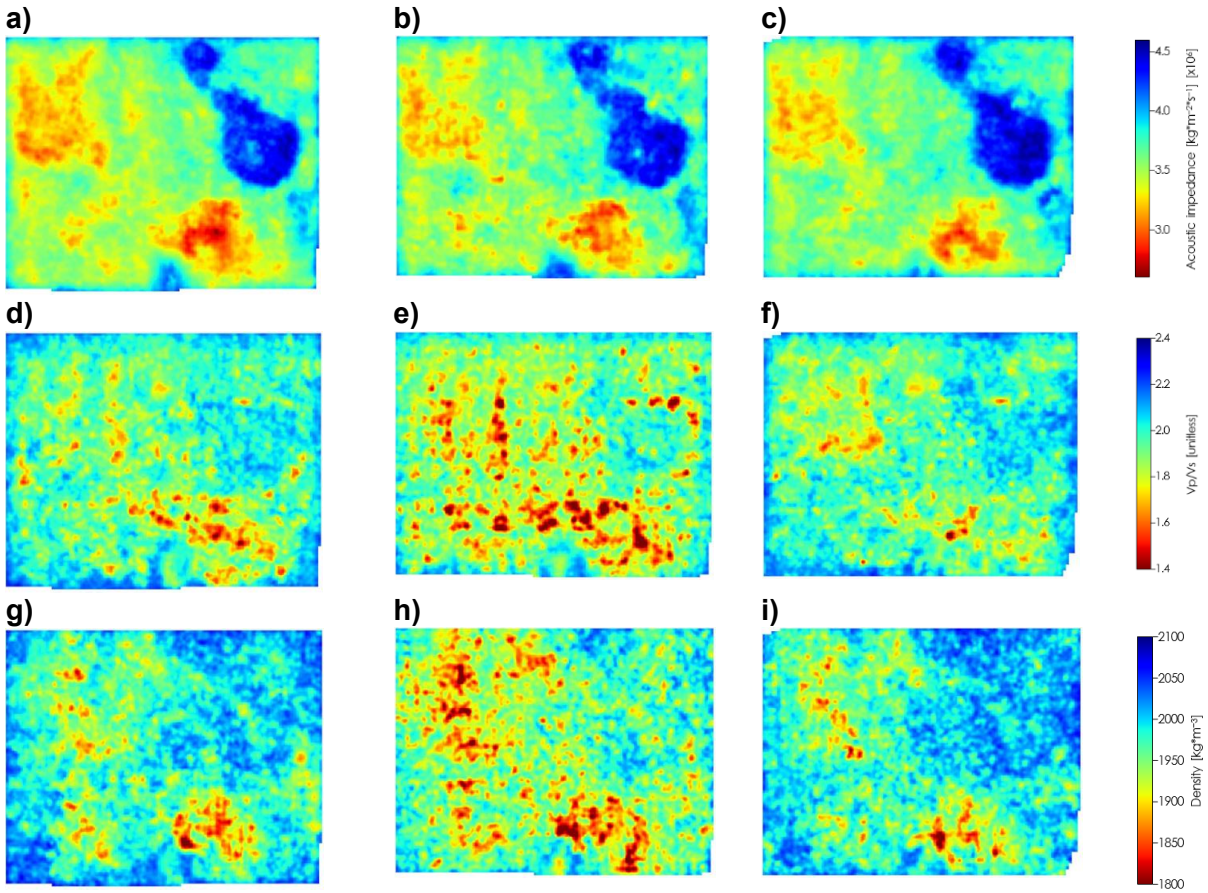


Figure 3: *Estimated a-c) Acoustic impedance, d-f) Vp/Vs, and g-i) Density time slices for the real data set from a full grid (a, d, g), orthogonal (b, e, h), and linear (c, f, i) geometries, respectively.*

Conclusions

Evaluating all six fold maps of a 3D seismic survey provides a complete assessment of acquisition sampling. Orthogonal geometries exhibit large contiguous gaps in specific offset-vector fold maps, limiting amplitude-preserving trace reconstruction, whereas linear geometries produce smaller, localized gaps that can be effectively recovered using sparse Fourier reconstruction methods. Because modern seismic processing and inversion rely on AVO-consistent workflows, acquisition designs must support accurate offset-domain reconstruction. Within operational constraints, linear geometry offers a practical alternative to random designs while maintaining an optimal collective fold distribution, as confirmed by improved inversion reliability in real data.

Acknowledgements

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References

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