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A New Method for Sustainable Seismic Acquisition

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Abstract Summary

Accurately imaging the subsurface with seismic, whether for traditional energy projects or in emerging cleantech areas such as geothermal, critical mineral exploration, carbon capture and storage, or nuclear waste management, requires the acquisition of a seismic survey. Generally, this involves deploying seismic sources and sensors in various patterns optimized to avoid surface exclusions and enable operational efficiency. However, for more sustainable seismic acquisition, these surveys can also be optimized to reduce environmental impact and lower greenhouse gas emissions. This can be accomplished by incorporating ecological data into the seismic planning and utilizing new innovations such as alternative sampling methods or equipment miniaturization. When combined with advances in seismic processing algorithms, the same subsurface data quality can be achieved as that of a conventional survey, but with a significantly reduced environmental footprint (Crook, 2024; Crook et al., 2025). Through extensive collaboration between multiple disciplines (ecology, biology, geoscience, and engineering), the EcoSeis™ project has developed sustainable seismic solutions which can reduce both the surface land footprint and emissions associated with seismic acquisition by as much as 50%, all while maintaining data quality and enabling safe and efficient field operations. This case study will highlight lessons learned throughout the development, from intial design through field optimization, processing, interpretation, and inversion.

Introduction

The development of innovative seismic acquisition geometries has become critical to addressing the dual challenge of optimizing imaging resolution while minimizing environmental footprints (Crook et al., 2025). If there were no environmental or cost constraints, the ideal sampling would be a fully sampled grid geometry where line intervals are equal to station intervals for both sources and receivers. Historically, a properly Nyquist-sampled grid geometry was not possible due to the large channel counts required. /with the advent of high-density Vibroseis techniques and modern nodal receivers, grid geometries are now possible and have been shown to have significant benefits due to fully sampling the wavefield in all dimensions (Sx, Sy, Rx, and Ry) (Ourabah et al., 2015). However, in areas with limited access and various environmental constraints such as sensitive habitats and mountainous terrain as well as safety considerations (e.g. UXO avoidance), these methods are not practical or cost-effective. In these areas, the traditional approach to reducing impact (or cost) has been to acquire sparse orthogonal geometries with large station-to-line ratios. The problem with this approach is that although a decent structural image is often attained, advanced geophysical analyses that rely on accurate seismic attributes (e.g., AVO) become less reliable due to the sparse offset and azimuth sampling and low trace density at the near offsets. To address these challenges, in 2020 we began a collaborative research project to examine whether alternative geometries (such as parallel linear geometries) could provide a solution (Naghizadeh et al., 2023). This case study presents the most recent results from over 35 different geometries, all decimated from the same fully sampled grid dataset.

Method

To achieve perfect sampling of the subsurface, a 3D seismic surveys would need to be acquired with a continuous grid of source and receiver stations (full grid geometry) where receiver station interval = source station interval = receiver line interval = source line interval. Although ideal, this method is often cost-prohibitive or impossible due to surface constraints. The resulting interconnected, orthogonal seismic cutlines increase anthropogenic footprint, which can negatively affect sensitive species and habitats (Larson et al., 2020). Additionally, in areas with limited access and various environmental constraints such as sensitive habitats and mountainous terrain, sparse orthogonal geometries with large station-to-line ratios have traditionally been used. Although these can be successful in obtaining an acceptable structural image, advanced geophysical analyses that rely on accurate seismic attributes become less reliable due to the sparse offset and azimuth sampling and low trace density at the near offsets (Crook et al., 2025).

Recent advances in equipment miniaturization (Crook et al., 2021) and acquisition methods (Crook, 2018, 2019) are enabling new 3D survey geometries such as alternative linear geometries to overcome these challenges. For example, parallel geometries have the potential to significantly reduce the land footprint associated with seismic acquisition with some methods, such as EcoSeis™ achieving up to a 50% reduction in seismic cut lines while maintaining subsurface data quality and enabling safe and efficient field operations (Crook, 2022; Naghizadeh et al., 2023, Goodway et al., 2025).

This case study began with the examination of a fully sampled grid geometry that was decimated in both conventional and novel linear-type geometries (Crook et al., 2023; Cova et al., 2023). Conventional (orthogonal) and lower impact geometries were generated from a well-sampled grid seismic dataset via decimation. Lower impact linear geometries were perturbed by varying the shape, amplitude and frequency of line deviations. Each design was measured based on their trace density and linear and areal cut-line disturbances to compare subsurface coverage and surface impact. The full grid and decimated datasets were processed through AVO compliant pre-stack time migration. Interpolation algorithms assist in reconstructing data that fell outside of Nyquist sampling. An independent interpretation of each geometry provided target level horizons and attributes. Attributes from each geometry were compared mathematically via NRMS calculations (Detomo, 2012) to quantify the imaging differences between low impact and orthogonal geometries. To avoid bias, rather than comparing these datasets to standard orthogonal geometries, all datasets (orthogonal, linear, and alternative) were compared back to the fully sampled grid dataset. To date, thirty-five geometries have been evaluated through an identical 5D interpolation, pre-stack time migration (PSTM), and advanced processing workflows to assess their imaging performance.

Results

The intersecting lines of conventional orthogonal surveys result in habitat fragmentation, which is particularly problematic in forested areas with sensitive species that rely on continuous, undisturbed habitat. Linear and alternative irregular geometries help reduce both the total linear km of seismic as well as the habitat fragmentation associated with orthogonal surveys. However, traditional linear geometries (Goodway & Ragan, 1996), can suffer from poor crossline interpolation due to the continuous gaps created in crossline subsurface bin sampling. Therefore, alternative linear geometries were developed. Figure 1 highlights some of the geometry comparisons from the testing. The plots a), c), and e) represent higher resolution designs with orthogonal, straight line linear, and zigzag respectively, all with the same line interval and equal trace density (same number of sources and receivers), but with c) and e) having ~50% fewer linear km than a). The plots b), d), and f) represent end member testing for the same types of geometries, but with lower trace density due to the larger line interval.

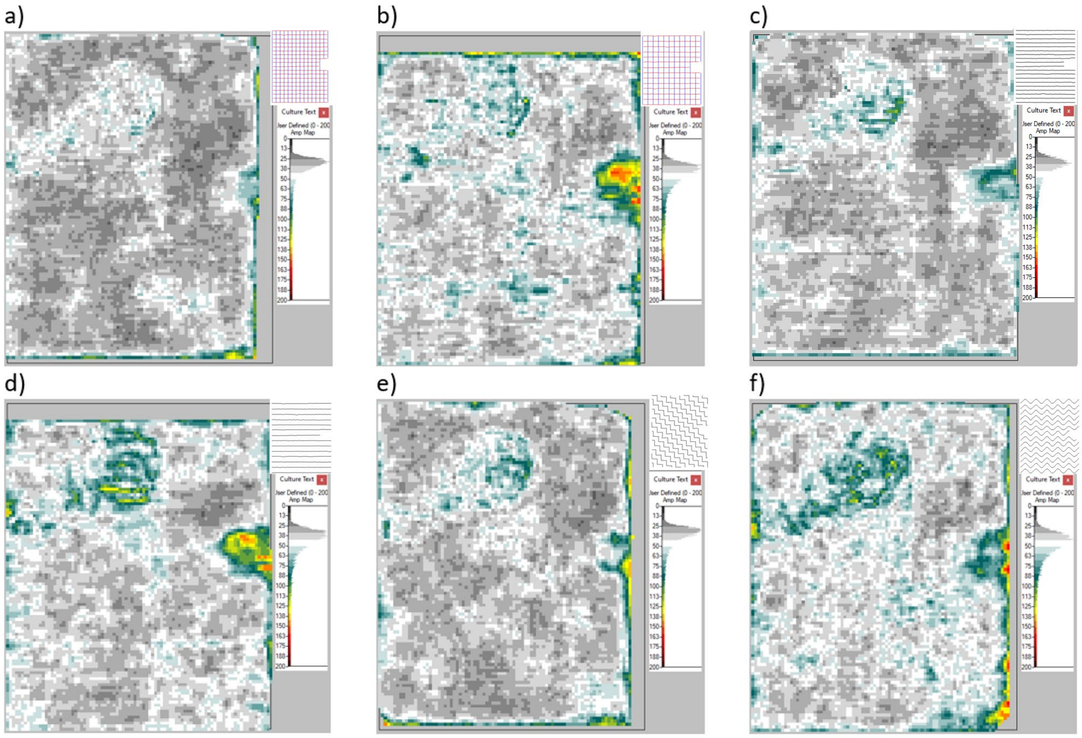

Figure 1: NRMS plots comparing each decimation to the fully sampled grid. Greys, whites, and light greens represent a good fit with the fully sampled dataset, whereas dark greens, yellows, and reds represent areas where the decimated geometry results in deviations from the fully sampled data.

Conclusions

To fully evaluate a new seismic acquisition method, the data must be examined through processing, interpretation, and inversion. Here we present the results from decimation tests of 35 different conventional and alternative geometries as well as more recent results from several successful field trials, which have shown that alternative geometries that minimize the total linear km of seismic can reduce both the environmental impact of clearing seismic lines or disturbing sensitive habitat, and potentially reduce the cost of acquiring the data. Observations from processing and interpretation indicate that in addition to generating comparable 3D subsurface images, the new methods are compatible with time-lapse (4D) over legacy surveys providing a new, cost-effective way of monitoring. However, one must be careful to ensure the trace density of these alternative geometries remains sufficient for accurate target resolution. If carefully implemented, these new methods can provide optimal subsurface imaging that will support sound economic decisions while reducing the overal environmental impact of acquiring land seismic datasets.

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