The Midland Basin field test: Results for the GeoLite/DAS hybrid system and the Surface Linear Vibrator

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Abstract

Mature electrical geophone technologies for active and passive borehole seismic are challenged to address emerging permanent monitoring needs like CO_2 storage, geothermal, production optimization, High Pressure - High Temperature (HP-HT), reservoir surveillance, and induced seismicity detection. Optical technologies (including Distributed Acoustic Sensing (DAS) and Fiber Bragg Grating (FBG) based Optical Point Sensors (OPS)) are investigated as candidates to complement or eventually replace geophones for borehole seismic acquisition (imaging or monitoring). Permanent seismic sources are needed for 4D monitoring. The GeoLite project is designed to evaluate such an innovative approach, combining DAS and FBG based OPS. After an initial shallow borehole prototype test in 2020, stronger downhole tools were built and tested in field conditions in 2024 and 2025 in the Midland Basin to record induced seismicity and to perform seismic borehole imaging. DAS was embedded in the GeoLite cable to combine the two optical technologies in a single array. It was deployed in parallel with a standard geophone wireline tool. It was the first time that such a design was considered for passive and active seismic evaluation. It comprised two observer wells, a hybrid borehole optical system (DAS/slim multicomponent multilevel FBG array), a standard geophone borehole array, a network of surface stations, a Vibroseis source truck, and a permanently anchored automated seismic source. Active and passive seismic data were acquired by all systems. The experiment established the operational feasibility of GeoLite as a wireline tool. Broadband seismic data were acquired across both campaigns. Stronger coupling for this light tool was identified as an improvement for future wireline operations. For permanent deployment inside the casing, the small size of the FBG sensor is an advantage. Surface station records confirmed the limited detectability for small events from surface compared to borehole sensors.

Introduction

Electrical geophones, in boreholes or at the surface, have for decades demonstrated their ability to record accurately acoustic waves propagating in the subsurface. In most cases, sensors are deployed temporarily for days or weeks. They need electrical power, have specific frequency response ranges (a few Hertz [Hz] to a few hundred Hz), and a limited operating temperature range (above freezing to less than 200°C, depending on deployment duration). Their size (up to several inches wide) can limit their deployment in confined spaces such as the annulus between tubing and borehole casing. These limitations present a problem for permanent geophysical monitoring to address emerging challenges like Carbon Capture and Storage (CCS) monitoring (with potential temperatures below 0°C), High-Temperature (HT) wells (deep HT reservoirs or geothermal reservoirs), permanent borehole deployment (long life span), completion compatibility (slim), or microseismic monitoring (high-frequency events), among others. In the case of CCS, surveillance is being imposed by regulators or stakeholders for safety and public acceptance. Reservoir performance and integrity also must be monitored for geothermal projects. It is necessary to deploy deep permanent borehole monitoring networks to achieve optimum detectability. The value of borehole monitoring is established (White et al., 2021), but the cost of dedicated monitoring wells is prohibitive. Flowing wells (injecting or producing) must then be considered as possible deployment locations. Systems deployed on tubing in flowing wells are noisy. Installations cemented behind casing have a limited life span, are not retrievable, present a risk for cement integrity, and may provide a path for leakage. A better solution is to install sensors permanently in the flowing well (injecting or producing) between tubing and casing. Such sensors should be firmly clamped to the inside of the casing but acoustically isolated from the tubing. Independent of an innovative clamping system, the sensors will have to not require downhole electronics and power, have a broad operating temperature range with a large frequency response spectrum, provide multicomponent capabilities, and be slim.

Borehole optical technologies have the potential to be part of the solution. The interrogator (power and electronics) is at surface. Temperature operating range can vary from (–50°C) up to 300°C depending on fiber quality and duration (Haldorsen,

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2025). Their frequency response is broader than geophones. Three main technologies are available:

- Distributed Acoustic Sensing (DAS) measuring the strain variation along an optical fiber. It has the disadvantage of being sensitive to environmental noise, responding only to the component of the acoustic wavefield along the fiber axis and presenting challenges in depth accuracy (Verliac et al., 2015; Dean et al., 2018).
- Optical Point Sensors based on Optical Interferometry (OI). This solution is directive and allows multicomponent measurements, but the sensor, by design, cannot be smaller than a certain size to avoid prohibitive optical losses intrinsic to the concept.
- Optical Point Sensors based on Fiber Bragg Grating (FBG). They are also multicomponent, but the sensor size can be reduced to as small as one inch (Haldorsen et al., 2021a; Bhatti et al., 2024).

Due to these reasons, it was decided to investigate further the FBG technology (embedded with DAS fiber) for a novel sensor design. The GeoLite project addresses this challenge of developing and testing such a tool for active 4D vertical seismic profiling (VSP) seismic imaging solutions and passive seismic permanent monitoring (induced seismicity).

Permanent monitoring for seismic imaging purposes requires a repeatable, affordable, and remotely controlled source. For onshore applications, the Vibroseis truck is the standard solution. However, it is expensive, is not fully repeatable and automated for long-term source operations, and can suffer from shallow ground conditions due to water table fluctuations, winds, or other environmental surface issues. Several sources for automated monitoring were considered, and the Surface Linear Vibrator (SLV) was selected for testing.

The GeoLite project

DAS technology uses an optical fiber as the sensing element, allowing for a massive acoustic sensor antenna that simultaneously records data at thousands of measurement points. Using interferometric processing, one can measure the changes in optical phase as a passing acoustic wavefield induces strains along the optical fiber very accurately.

DAS measures only changes in strain along the axis of the fiber, which is a serious limitation for many seismic applications. However, winding the fiber around a mass-spring that is mechanically constrained to extend in one particular direction allows the extension of the fiber to measure acceleration in this direction. Three of these devices, arranged in mutually perpendicular directions, make a three-component (3C) fiber-optic acoustic sensor.

Around 1990, the U.S. Navy began research on Bragg grating technology, and in 2001, Clarion, a 3C optical sensing system, was made commercially available by Weatherford, allowing up to eight 3C sensors along a single fiber (Bostick et al., 2003; Keul et al., 2005). More recently, several large arrays of ocean-bottom multicomponent optical sensors have been deployed (Maas et al., 2015; Fayemendy et al., 2021). The system described by Maas et al. (2015) has been adapted for borehole deployment. Other borehole systems have been developed by Paulsson Inc. (Paulsson et al., 2019), by Avalon Sciences (Soulas et al., 2024), and by Geospace Technologies Corp. (Bunn and Murray, 2024)

A common problem with fiber-optic acoustic data is a high sensitivity to vibrational noise picked up from the interrogator. It is very important that the two signals that are interferometrically compared be transmitted through the same fiber. Different designs for how to minimize detrimental effects from the segments of the transmission path that are not shared tend to move the problem between different parts of the system.

By fundamentally changing the interrogation architecture and adding new real-time signal-processing steps, the problem with interrogator noise has been solved in the fiber-optic accelerometer GeoLite by MagiQ Technologies (Haldorsen et al., 2021a, 2021b, 2022). Figure 1 shows the 3C GeoLite sensor, with an outer diameter of about 1.1 in. (0.028 m) and a length of about 28 in. (0.7 m). GeoLite is designed to fit in the narrow annulus between casing and production/injection tubing and has a substantially narrower diameter than other fiber-optic tools.

The figure also shows a comparison between data recorded simultaneously by GeoLite and a piezoelectric reference accelerometer, as well as the angular response of the transverse sensor, measured in the laboratory at 100 Hz using a linearly polarized source and a controlled geometry. The response agrees with the theoretical cosine function from the projection of the transmitted compressional signal onto the axis of the accelerometer, corresponding to a "cross-axis suppression" of 41 dB, compared to a typical value of around 20 dB for geophones (Frømyr, 2004). However, the angular accuracy obtained with field data depends critically on the coupling of the sensor to the casing in a wellbore.

The first field test of the prototype GeoLite 3C accelerometers was performed in 2020 at the Aramco Research Center in Houston (Haldorsen et al., 2021a; Verliac et al., 2021). The objectives of the test were to prove the ability of the new 3C optical sensors to record sensible VSP data and compare them to the data acquired by conventional electrical sensors. Two optical 3C tools were tested, one encased in a rigid housing and one in a flexible housing. Both were strapped to conventional 3C geophone tools and deployed into a shallow vertical well. The VSP data were acquired from four source locations using Vibroseis as the source. The analysis of the data demonstrated that the sensors could record meaningful broadband seismic data with a frequency range from sub-1 Hz to several hundreds of Hertz. Because of the small scale of the experiment and the limitations of the tool deployment, which resulted in poor coupling of the GeoLite tool, some important tool characteristics like vector fidelity were not fully assessed. The field test also demonstrated the imperfection of the mechanical design of the tool, which was not suitable for commercial deployment in deep wells. Because of this, it was decided to build a more robust tool that could be deployed in real well conditions. A 12-level

3C prototype array was built and ready for testing at the end of 2023. It was also designed to carry DAS fibers within the system, making it a full hybrid optical DAS/FBG system.

Surface Linear Vibrator (SLV) technology

The SLV electrical seismic source features two vibratory motors mounted on a helical anchor that is screwed up to 100 feet into the ground. Rotation of synchronized eccentric weights in opposing directions generates variable frequency sweeps of linear vertical vibrations like traditional Vibroseis systems (Li et al., 2023).

The SLV can generate very large linear forces of more than 11,000 lb relative to its compact size. The source is controlled remotely or runs semiautomatically with customizable sweeps up to 100 Hz. The helical anchor method of deployment is unique to the SLV and ensures strong source–ground coupling while minimizing or avoiding near-surface temporal changes. This is a critical feature for a permanent seismic source, especially when coupled with deep permanent downhole optical receiver arrays such as DAS or GeoLite for time-lapse 4D seismic. Figure 2 shows the field setup of the SLV source.

The SLV source is monitored continuously using a buried 3C geophone cemented nearby at a depth of 25 feet below ground level. An autonomous data recorder continuously transmits the recorded data to the cloud for correlation with downhole and surface seismic sensors.

The Midland Basin experiment

Following the sensor capabilities test in Houston in 2020, the next priority was to evaluate GeoLite technology in real field conditions for different applications and configurations that meet safety standards and operational requirements. After deploying the GeoLite tool in the well, the objectives were:

1) to assess whether the GeoLite hybrid array, under wireline deployment, can record VSP wavefields and microseismic detections consistent with a conventional geophone array, and to characterize the principal drivers of data quality for a future permanent deployment.
2) to compare borehole measurements from the three types of downhole systems (DAS, GeoLite, geophones) with surface stations for induced and natural seismicity (detectability, location accuracy).
3) to evaluate the SLV as a candidate for a permanent, remotely controlled onshore source, with comparison to conventional Vibroseis for repeatability and imaging consistency under a vision of a fully automated, low-footprint seismic source.

Recorded data would comprise:

1) Passive microseismic from hydraulic stimulation on two new horizontal wells acquired from two vertical observer wells, one with geophones and one with DAS/GeoLite technology and the secondary surface network of buried SensorEra low-frequency sensor seismometer stations.

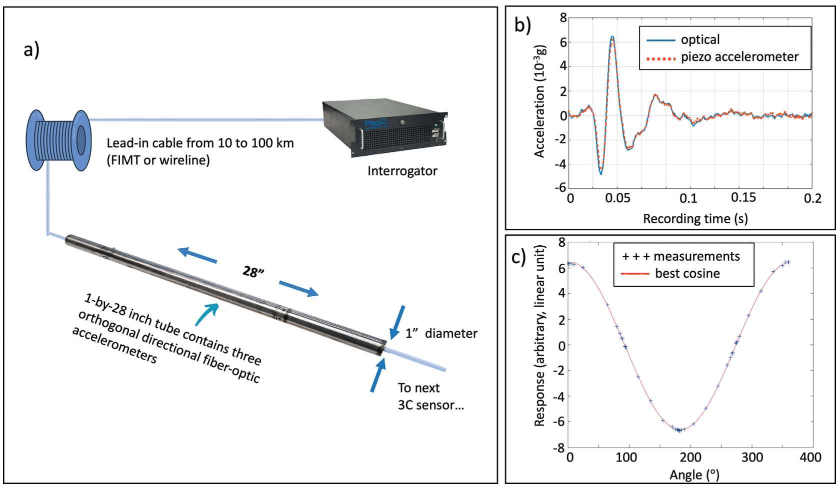

Figure 1. (a) The three-component GeoLite sensor is composed of three mechanical springs, each free to move in mutually perpendicular directions, which are mounted in a 1-inch-diameter tube of 28 inches in length. Two components T1 and T2 are oriented transverse to the sensor axis, and Ax, the third component, is oriented along the sensor axis. (b) Comparison between data recorded simultaneously by GeoLite and a piezoelectric reference accelerometer. (c) The response of the GeoLite transverse component to signal from different azimuths. The response is measured at 100 Hz using a linearly polarized source. The response agrees to within ± 0.5° with the theoretical cosine function from the projection of the transmitted compressional signal onto the axis of the accelerometer, corresponding to a "cross-axis suppression" of 41 dB.

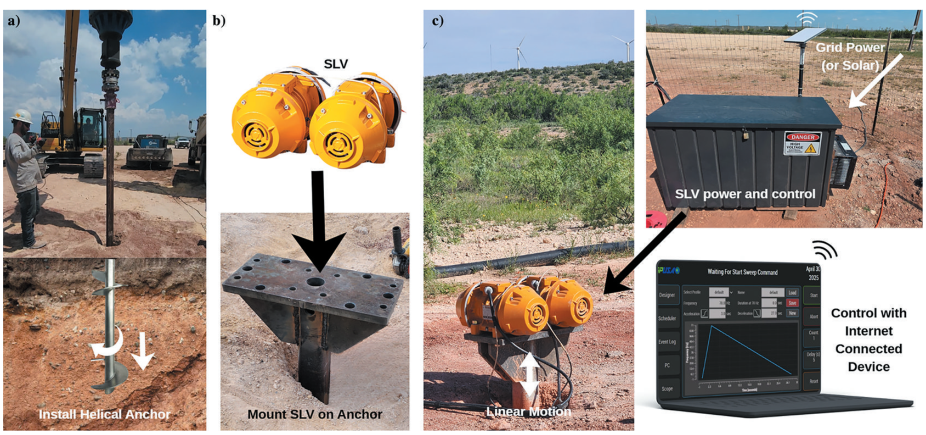

Figure 2. SLV installation at the Midland Basin site, from left to right: (A) Anchor installed to required depth below Caliche layer; (B) SLV installed on anchor; (C) source is tuned via the controller that was powered by the grid and controlled remotely via a laptop.

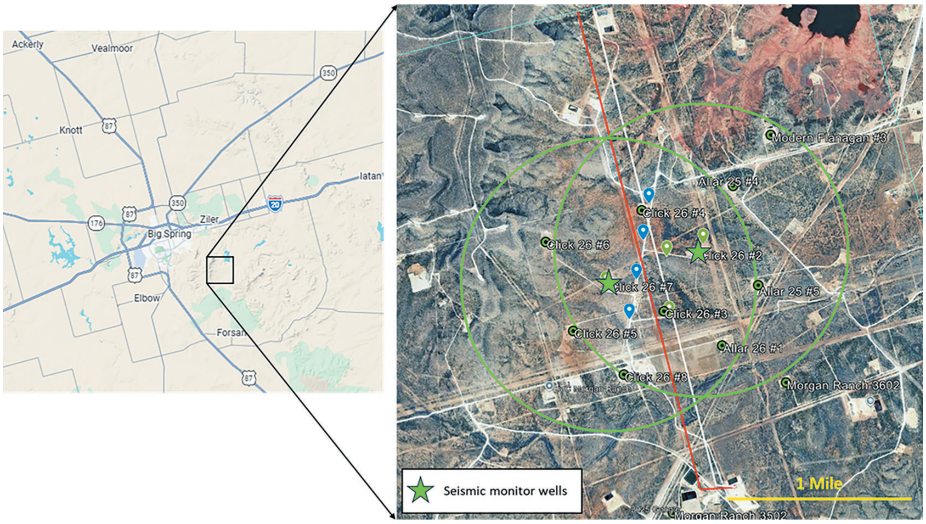

Figure 3. Area map for Howard County, Texas, showing the outline of the field experiment southeast of Big Spring at the Signal Peak field area. Green stars on the enlarged map denote the click 26 #2 and #7 wells that were used for observation wells in the experiment. Blue and green markers show the locations of the SensorEra surface stations. Green circles represent the expected 4000 ft radius of detection limits for microseismic events for both observation wells. The red and white lines are the well trajectories for the MCC wells.

2) Natural regional seismic activity with the same field configuration (far-field events)
3) Vertical Seismic Profiles and multioffset VSPs simultaneously recorded in the two observer wells.

The site selected for the field experiment was provided by HighPeak Energy Inc. at their Signal Peak field area in southeast Howard County, Texas. The field area is currently being developed with horizontal wells in the Middle and Lower Spraberry and Wolfcamp A, B, C, and D formations and has also seen previous development in the Wolfcamp C (Hutto) target zone and Wolfcamp C Sands with vertical wells dating back to the 1990s. The surface conditions are semiarid desert with rolling hills and mesas. The geology is relatively simple with gentle dips and minimal to no faulting in the Spraberry and Wolfcamp formations. The field experiment was designed around a pair of new horizontal wells in the Lower Spraberry Shale (MCC B Unit L3H) and Wolfcamp A (MCC B Unit A3H) that were planned for zipper-fracs in 2024. The location was surrounded by recently drilled vertical wells with excellent casing and cement that were suitable for observation wells for the GeoLite and DS-150 geophone arrays that were deployed during the experiment (Figure 3). The observation wells chosen for the experiment (Click 26 #2 and #7) are denoted with green stars along with the expected approximately 4000 ft radius of detection for microseismic events for this area.

The 2024 and 2025 acquisition surveys

The 2024 survey. The first field test at the Signal Peak field area was performed in May 2024. Two downhole seismic sensor arrays were deployed for the active source VSP program and passive microseismic monitoring. The GeoLite sensor array was deployed in the vertical observation well click 26 #7. The sensor array comprised eleven 3C sensors separated by 50 ft interconnectors. Three different sensor designs were incorporated into the array: five standard and four enhanced sensors with slim encapsulation and two slightly larger diameter sensors with higher sensitivity. In addition to the 3C sensors, the system included dedicated DAS fiber that was interrogated by a FEBUS A1 unit to obtain DAS measurements. A second vertical observation well click 26 #2 was equipped with a standard 25-level 3C geophone array with DS-150 geophones with a separation between levels of 100 ft for the top five shallow levels and 50 ft for the remaining 20 levels.

An AHV-IV Commander Vibroseis truck was used as a source for the VSP test program. A 12-s linear sweep from 6 to 120 Hz was used. The source was positioned near the click 26 #7 and click 26 #2 boreholes, respectively, to acquire Zero-Offset VSP surveys from approximately 6000 ft depth up to surface with the two sensor arrays. The multioffset VSP survey was then acquired from 77 source positions on the roads at a range of azimuths and distances away from the two boreholes with the two sensor arrays located at their fixed positions downhole.

In addition to the conventional Vibroseis truck, the SLV source was tested as part of the active source program. The SLV source was located 128 ft from the wellhead of the click 26 #7 observation well and approximately 2700 ft from the click 26 #2 observation well. It was mounted on a helical anchor installed to a depth of 56 ft.

Passive microseismic monitoring was performed with both downhole sensor arrays during the fracking operation in two horizontal wells as described above.

Additionally, three autonomous offset seismic stations, positioned up to 2875 feet away from the SLV, were equipped with identical 5 Hz 3C geophones and deployed at depths of 1 foot (Figure 4). These offset stations facilitated simultaneous passive seismic monitoring from the surface and recorded all Vibroseis and SLV sweeps. They were installed prior to the 2024 field trial and remained in place after.

The initial program, expected to take 2 weeks, consisted of acquiring Zero-Offset VSP in the click 26 #7 well with the geophone array and then with the GeoLite/DAS tool array. In a second step, the GeoLite/DAS array would remain at depth in the click 26 #7, and the geophone array was moved to the click 26 #2 for a Zero-Offset VSP survey. With both tools recording permanently, it also generated a Fixed-Offset VSP for the offset observation well. The fixed SLV source deployed in click 26 #7 was tested to record a Fixed-Offset VSP with the geophone array deployed in click 26 #2. To complement this, the multioffset Vibroseis positions were acquired when the frac operations were far enough along to prevent contaminating the signal. Active seismic operations started a few days before the hydraulic frac operations were getting close enough to be detectable and were terminated at the end of the frac operations. During the frac operations, all systems were put in passive mode.

Unfortunately, after starting the GeoLite/DAS recording, it became clear that the GeoLite signal was not nominal, and the laser sources were not behaving as planned. Short periods of data were recorded on some sensors but not long enough for a Vibroseis sweep. A transport-related interrogator hardware fault was identified that prevented nominal GeoLite/DAS active-source acquisition during the 2024 campaign. All other equipment worked nominally

The resulting package of data consisted of:

- Zero-Offset VSP and multioffset VSP recorded with DAS and geophones, but no GeoLite
- Frac-induced passive seismic recorded with geophones, DAS, and partial GeoLite, plus the surface stations
- A comparison of Zero-Offset VSP and Fixed-Offset VSP between SLV and Vibroseis

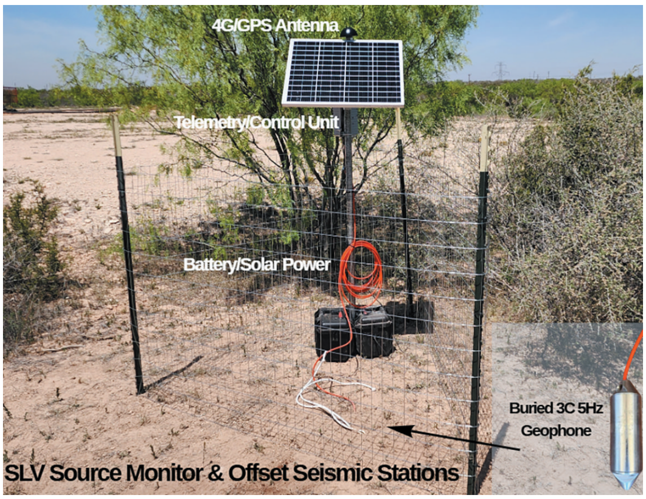

Figure 4. A 3C 5 Hz buried geophone station.

Figure 5 shows the DAS results for the Zero-Offset and Fixed-Offset source positions. At the field site, the data were observed to be extremely noisy due to the poor coupling of the GeoLite/DAS hybrid cable to the borehole, related to the quasiverticality of the well (around 01°). This was confirmed by tap tests at the wellhead. However, after a thorough analysis, the Zero-Offset VSP and Fixed-Offset VSP data sets were of acceptable quality for waveform analysis. A limited number of microseismic events were also detected on the DAS records but could not be located due to the well's near-verticality and poor Signal-to-Noise Ratio (SNR).

The passive seismic data were recorded using the DS-150 geophone array in the click 26 #2 well and the GeoLite array in the click 26 #7 well. The DS-150 array recorded 3396 events during stimulation, and the GeoLite array captured a small subset of 35 events that were integrated with the DS-150 data set for co-location analysis. The seismic events recorded during the stimulation were located using traditional P- and S-wave travel times using a high-resolution velocity model built from well and 3D seismic data at the project location. The arrays were oriented and calibrated using perf shots in the two wells being stimulated, and the back azimuth for each microseismic event was determined using the P-wave polarization of the events. Travel times for the P and S arrivals were then used to determine the distance from the array for each event. For the events recorded on both arrays, the events were colocated using recorded waveforms weighted by SNR and hodogram analysis.

Of the 35 events recorded on the GeoLite array, nine events corresponded to DS-150 recorded events, with seven of those nine events being co-located with their DS-150 counterparts. The remaining 26 events were close to the GeoLite array and did not have corresponding events on the DS-150 array to use in co-location due to the distance between the arrays, the geometry of the two arrays, and the fact that only a few sensors on the GeoLite array were working properly during the frac job. The co-located events had very good depth agreement and generally good agreement of *X* and *Y* coordinates compared to the single-array results for the DS-150 array alone. Misfits in the events were small enough (tens of feet for some of them)

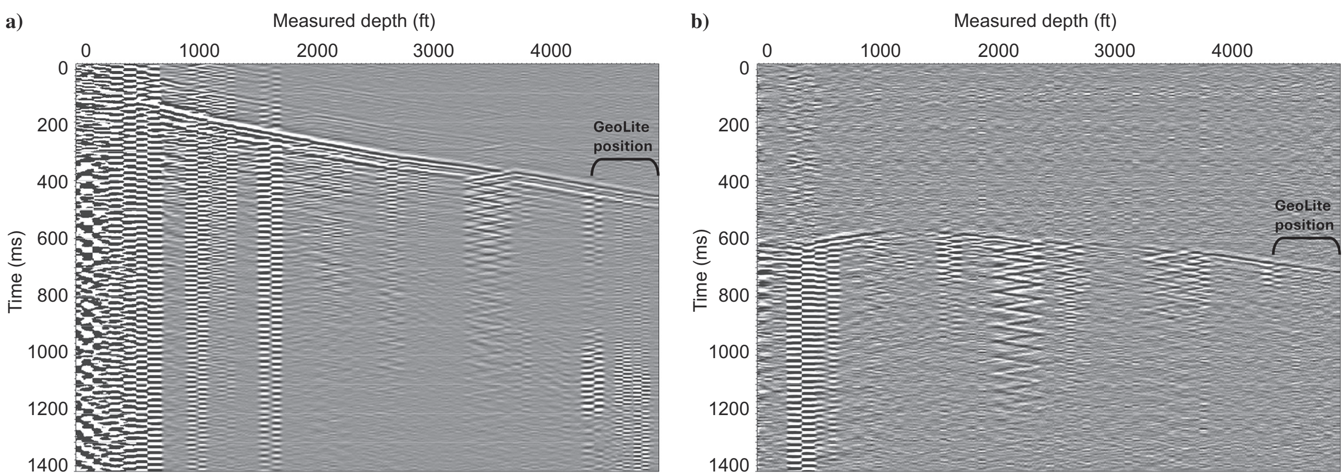

Figure 5. DAS VSP data acquired from (A) zero-offset and (B) fixed-offset source positions. The gauge length is 20 m. The position of the GeoLite array is annotated on the DAS wavefield.

that they demonstrated that the two different arrays can be used together for event colocation without any significant issues. These converging results validate the capability of GeoLite to detect and locate microseismic events accurately. Figure 6 presents examples of microseismic events detected by the GeoLite sensors and the collocation for events detected by the two arrays.

The SLV performed without problem. Vibroseis is significantly heavier than the SLV and couples to the surface through its weight, whereas the SLV couples at depth through the steel helical-anchor method described above. The peak output force of Vibroseis exceeds that of the SLV by approximately a factor of 5. To enable a like-for-like comparison at the receiver, the recorded data sets were normalized by stack count. The 3000 ft offset VSP images in Figure 7 combine 78 stacked SLV sweeps with five stacked Vibroseis sweeps (Lesnikov et al., 2025). SLV and Vibroseis sources differ in ground coupling and output force behavior. Vibroseis uses ramped tapers at the ends of each sweep, whereas SLV force naturally tapers at low frequencies due to slower mass rotation. SLV reaches maximum force near its maximum frequency (typically 100 Hz/ 6000 rpm, depending on type). Therefore, Vibroseis data were high-pass filtered at 30 Hz to mimic the SLV low-frequency taper, ensuring residual differences reflect source character and coupling rather than bandwidth.

Repeatability of the surface-wave arrivals between consecutive SLV sweeps was also evaluated and was found to be high, consistent with the SLV's intended use as a repeatable permanent source. Residual differences between the stacked SLV and Vibroseis images are attributed to differences in sweep frequency content, near-surface ground coupling at the respective source locations, and localized surface conditions in this area.

Another significant result was the detectability of events from borehole sensors compared to surface sensors. During a nine-day period of frac operations, the geophone array recorded and located more than 3300 events with magnitudes between (−3) and (−0.5). During the same period, only 14 of these same events were detected from the surface. All of them had magnitudes above (−1). This is illustrated in Figure 8.

The data acquired in 2024, though not complete for the GeoLite active seismic surveys, demonstrated that the tool could be deployed in real field conditions and was able to acquire reasonable microseismic events. The DAS results showed the limitation of the technology for microseismic from vertical wells and the sensitivity to the cable coupling to the formation. The SLV provided encouraging results as a potential source for a permanent remote-controlled source in an onshore environment.

The 2025 survey. Following the 2024 field test results, it was decided to investigate the interrogator failure, fix it if possible, and return to the Signal Peak field area in 2025 to redeploy the GeoLite system in one of the boreholes to retest its performance and compare the data against the conventional geophone array data acquired in 2024. The second test in the Signal Peak field was performed in July 2025. This time, two GeoLite systems were deployed. The first system included the same 11-level 3C sensor array that was used in the 2024 test. The damaged interrogator was fixed to allow stable recording from three of the 3C sensors. The second system included a single 3C fiber optic sensor with a dedicated interrogator. The two systems were deployed sequentially in click 26 #2 to allow comparison with the data previously acquired with the standard geophone array in that well.

For each of the two systems, a Zero-Offset VSP survey was acquired with the Vibroseis source located at 125 ft distance from the wellhead and a near-offset VSP survey at 900 ft from the wellhead. As in 2024, a multioffset VSP survey was also conducted to assess the data quality from large offsets and vector fidelity of the systems. Multioffset VSP data were acquired from 60 source positions azimuthally around

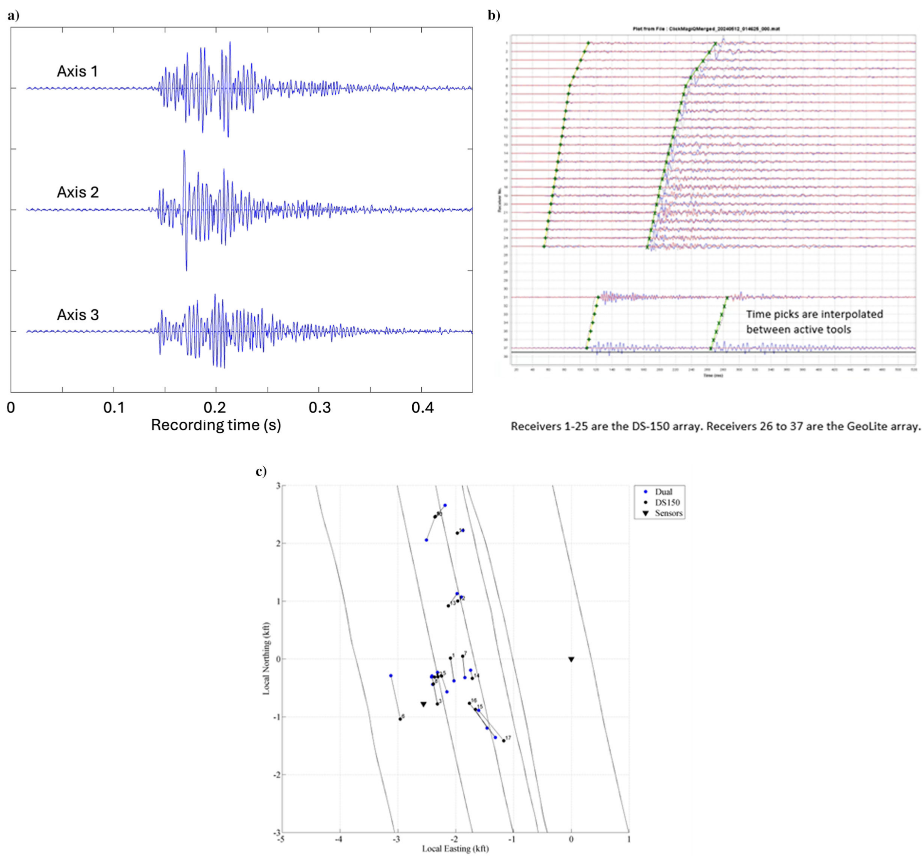

Figure 6. Examples of a 3C microseismic event recorded by the GeoLite system (top left), by both the GeoLite and geophone (top right)and the example of collocation events using two downhole seismic arrays (bottom). The line joins the same event.

the click 26 #2 well with the GeoLite systems and three positions in the wellbore at approximately 5500, 4600, and 2800 ft depths. The positions of the sources at surface and sensors downhole were selected to be equivalent to the 2024 test.

The Vibroseis source type was the same as in the 2024 test with the same sweep parameters. In addition, the SLV source was brought back for additional testing during the VSP program. An accelerated weight drop was also available as a source for parts of the program but was not used after determining that it had insufficient penetration for the testing effort. The active source program was restricted to daytime operations that allowed the recording of continuous passive seismic data overnight.

The entire test program was executed in two runs of three days each. During the first run, a single-level system was deployed downhole and the VSP data were recorded as described above. A Zero-Offset and near-offset VSP data were acquired with a depth spacing of 100 ft. This allowed an overlap between the data from two GeoLite systems and the data acquired with a conventional DS-150 geophone array in 2024 while minimizing the acquisition time with a single-level system. The second 11-level GeoLite system was then re-spliced to the same wireline cable, and the acquisition of VSP data was repeated following the same program during the second run. Both systems were deployed and retrieved from the borehole without any issues, and all components of the systems demonstrated stable performance and operational efficiency during the test.

The data collected from Zero-Offset and near-offset source positions were of good quality and comparable with the data collected in 2024 using the conventional geophone array. Figure 9 shows the vertical component of the data and the interval velocity profile calculated from the picked P-wave arrivals. The interval velocities obtained from the GeoLite system match very well with the velocities calculated from the DS-150 geophone array. Strong tube waves were observed on the GeoLite records, particularly in the Zero-Offset VSP and, to a lesser degree, in the near-offset VSP. Tube waves are fluid-pressure waves. When they arrive at a sensor that is not rigidly fixed to the borehole wall, the pressure field may move the sensor. The sensor may also wobble, so that its instantaneous direction of motion may deviate from the direction of motion of the borehole wall. Postsurvey analysis indicated that the magnetic clamps used for the GeoLite tool in this 2025 campaign provided much weaker coupling to the casing than the magnets on the conventional DS-150 geophone array. The difference reflects sensor-to-casing coupling rather than the intrinsic capability of the GeoLite accelerometer. Therefore, the SNR for the GeoLite data in this campaign was somewhat lower than for the DS-150 data, and future deployment will be with upgraded stronger coupling hardware.

Despite the coupling issues, the GeoLite data compare well with the conventional geophone data acquired in 2024. Figure 10 shows zoomed-in wavefields and the associated frequency spectra for the near-offset VSP survey recorded by DS-150 and two GeoLite systems.

The focus of the analysis of the multioffset VSP data was on the assessment of the vector fidelity of the system. For that purpose, the data acquired from 60 source positions with 3C sensors positioned inside the borehole were analyzed to estimate the azimuth of the P-wave arrival at the receiver and compare it to the actual azimuth of the source at each position. Figure 11 illustrates

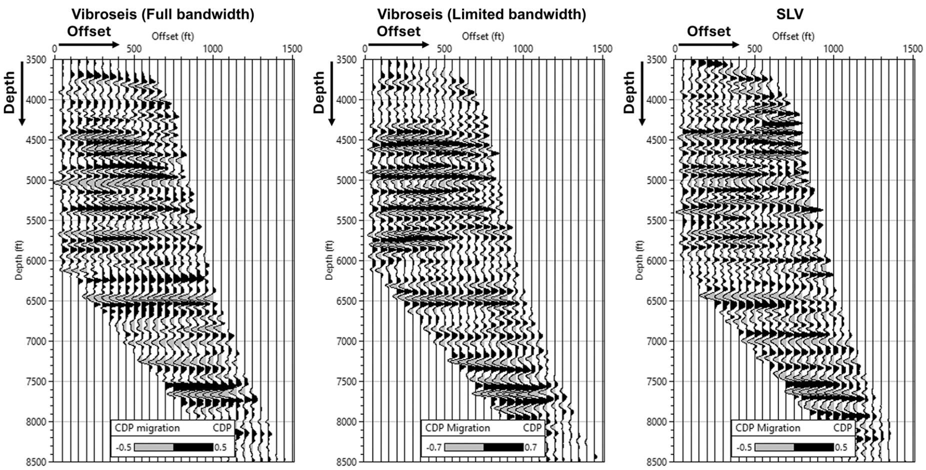

Figure 7. Vibroseis versus SLV data (approximately 3000 ft offset VSP, approximately 6000 ft well). Vibroseis full bandwidth (left) was filtered at the beginning of the processing flow (middle) to match the SLV's reduced centrifugal output below 30 Hz. Processing workflow was otherwise the same for both sources.

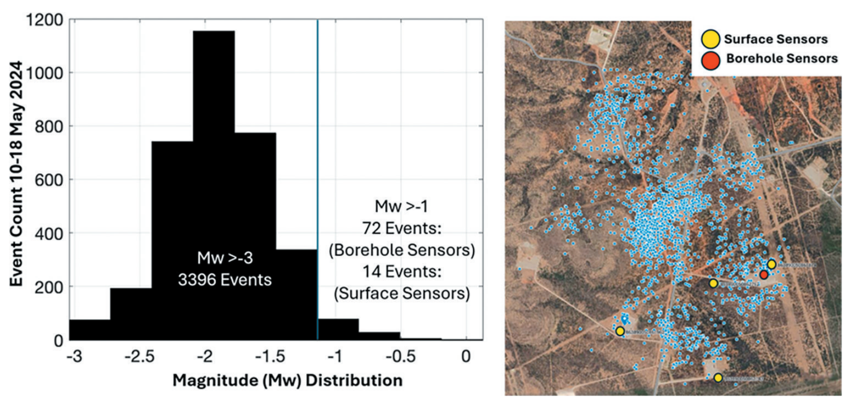

Figure 8. Borehole versus surface microseismic detectability. Left: magnitude distribution (–3.0/0) of the 3396 events located by the geophone borehole array and 14 of those same events detected by the surface array (MW above –1). For events with magnitude (–1), 14 were detected at surface and 72 from the borehole array. On the right is the localization map of the events (blue points) with the surface stations (yellow points) and the observation well (red point).

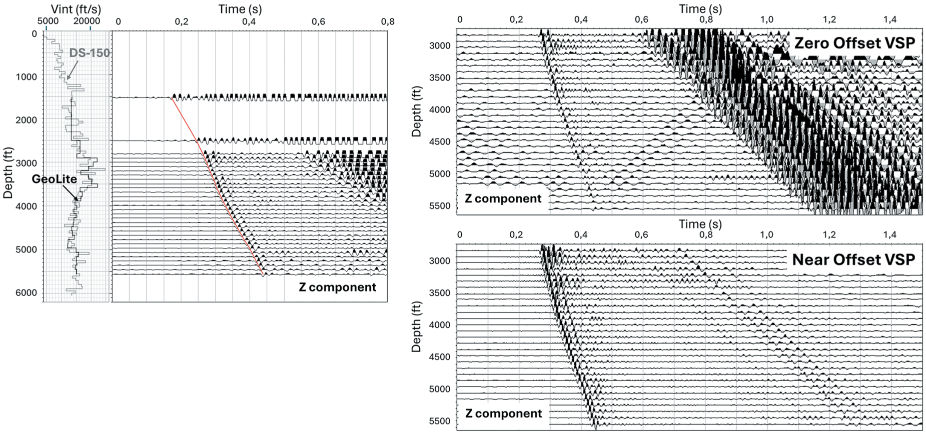

Figure 9. (left) VSP velocity profile: left track shows comparison of interval velocities calculated from DS-150 and GeoLite systems. Vertical component of Zero-Offset VSP data zoomed in around the first arrivals; high-amplitude tube wave was clipped for display purposes. (right) Zero-Offset and near-offset VSP wavefields were recorded by GeoLite.

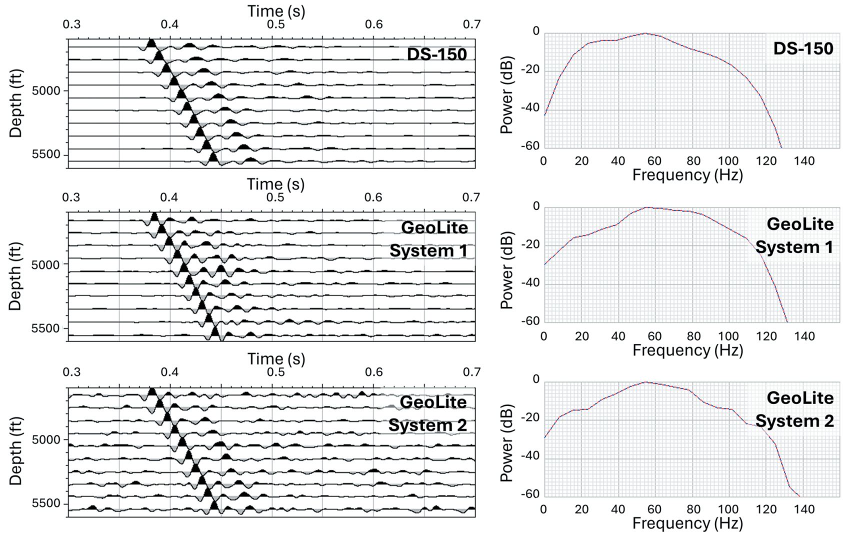

Figure 10. Left: Comparison of selected traces from near-offset VSP for DS-150 and two GeoLite systems (GeoLite data were converted from acceleration to geophone-equivalent traces). Right: associated frequency spectra.

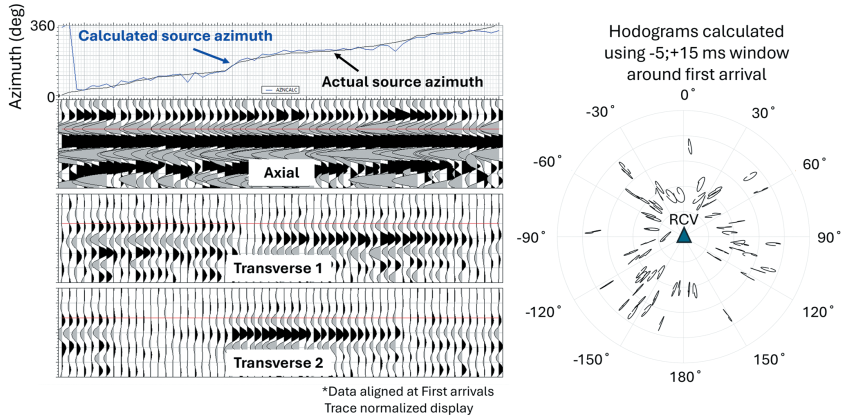

Figure 11. Vector fidelity estimation. Multioffset 3C VSP data aligned at first arrivals and sorted by azimuth (left). The top graph shows calculated and actual source azimuth. Hodograms calculated for each shot position are displayed on the right.

the results of this analysis for one of the receiver positions at approximately 4600 ft depth. The data from the horizontal components were rotated by 161°, which is the angle calculated to minimize the transverse component for each source position. The hodograms in Figure 11 illustrate the direction of the particle motion in a 20-ms window around the P-wave arrival. The particle motion appears to be quasilinear and corresponds well to the azimuth of each source position. The variation between the calculated and actual source azimuths is explained by the weak SNR of the data.

In addition to the recording of the VSP data, passive microseismic data were collected by the GeoLite systems overnight. Several small regional earthquakes were recorded by the GeoLite sensors and SensorEra surface seismic stations with magnitudes in the (−0.3 to 0.5) range. As an example, one event recorded by downhole and surface sensors is shown in Figure 12. The maximum frequency that was determined for this event was 275 Hz for the GeoLite, compared to 100 Hz for the surface stations.

Another opportunistic test was conducted with the SLV source, which was activated in the periods when the Vibroseis source was moving between source positions or during overnight hours. The SLV data recorded by the seismic stations at the surface was used to assess the long-term source repeatability. It was observed that the repeatability between the data acquired during 2024 and 2025 surveys was good and comparable or even better than for the Vibroseis source for the interval around the direct wave arrival. However, the surface wave appearing at approximately 2 s after the direct wave was not repeatable for either the SLV or the Vibroseis data. One of the

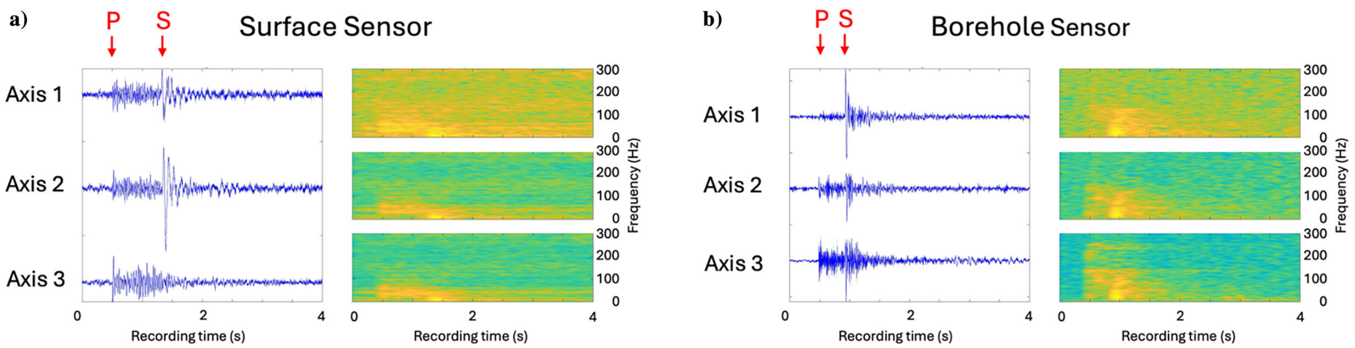

Figure 12. One small regional seismic event recorded by SensorEra surface stations (left) and by the GeoLite system (right).

reasons for that is varying surface conditions because the experiment in 2025 was performed right after a significant flood event, whereas the test in 2024 was performed in normal dry conditions.

Lessons learned and way forward

Across the 2024 and 2025 campaigns, the Midland Basin experiment indicated that the GeoLite technology, combined with DAS in a hybrid cable, is a viable candidate for borehole 3C monitoring. Cable deployment was smooth. Downhole reliability is potentially higher than for an electrical tool because of the absence of downhole electronics, telemetry, or power components. A transport-related interrogator fault in 2024 that prevented nominal active-source GeoLite/DAS acquisition was subsequently diagnosed and resolved, and the system was successfully redeployed in 2025. Clamping solutions (magnetic in the experiment) can be improved.

Main features like imaging capabilities or vector fidelity potential were broadly consistent with expectations, although contaminated by noise due to poor clamping. Sensitivity and full-bandwidth vector fidelity remain to be evaluated in a quieter environment. Microseismic event energy was recorded to approximately 300 Hz, consistent with the broadband character of the 3C fiber-optic sensor. Borehole monitoring was confirmed to be more sensitive than surface monitoring for frack-induced seismicity.

The SLV performed consistently as a candidate for a permanent, remotely controlled onshore source, showing repeatable direct-arrival waveforms across both campaigns and stable operation under automated control, supporting its suitability for 4D monitoring applications. The accelerated weight drop source was not pursued beyond initial trials due to insufficient force coupling into the near surface at this site.

Looking ahead, the project will focus on the next generation GeoLite with a one-inch sensor node to be deployed on tubing in a well using an innovative clamping system. It is expected to confirm vector fidelity and sensitivity by applying a strong coupling force to the borehole casing that should eliminate environmental contamination, like flow noise.

Conclusion

The Midland Basin field test evaluated several possible solutions for future permanent geophysical monitoring systems. Some technical firsts were achieved successfully. The GeoLite/DAS hybrid system was deployed for the first time in real operational conditions. The GeoLite system was also evaluated against geophones. The SLV source was compared with a traditional Vibroseis source while simultaneous recording of natural and induced seismicity from surface and borehole systems was achieved.

Based on the recorded data set, a next-generation interrogator is being designed as well as a one-inch diameter sensor node. The final objective of the project is to evaluate the capability of these technologies to perform permanent monitoring using this slim sensor system embedded in permanent completions. In conjunction with a permanent surface-automated and remote-controlled source, it will allow a fit-for-purpose monitoring system not only for passive seismic monitoring but also for imaging. TLE

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Data and materials availability

Data associated with this research are available and can be obtained by contacting the corresponding author.

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