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Quest Carbon Capture and Storage – 4D Seismic Monitoring and Geologic Controls on Plume Migration

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Abstract

The Quest project is a fully integrated, commercial scale, Carbon Capture and Storage project located near Fort Saskatchewan, Alberta. Quest captures, transports, and stores CO_2 produced by three hydrogen manufacturing units at the Scotford upgrader which provide hydrogen used in the upgrading process of bitumen from the Athabasca Oil Sands Project. The facility is operated by Shell Canada, on behalf of the AOSP Joint Venture (Canadian Natural Upgrading Limited, Chevron Canada Oil Sands Partnership and 1745844 Alberta Limited).

To ensure safe and permanent storage of the CO_2, Quest has implemented a Measurement Monitoring and Verification plan. This plan is updated every three years and is developed based on four main principles: risk-based, site-specific, ensuring regulatory compliance, and adaptive. This paper will review observations from the seismic technologies deployed as part of the subsurface monitoring to verify containment and conformance of the injected CO_2. In addition, the authors propose potential underlying geologic drivers controlling plume development.

Early seismic based plume imaging consisted of Distributed Acoustic Sensing Vertical Seismic Profile (DAS VSP) surveys acquired utilizing single mode fibre cemented behind casing in each of the three injector wells. Shot lines extend radially along eight azimuths from the injection wells to a distance of 2.5 kilometres offset from each of the injector wells (Figure 1). This allows for reliable and repeatable imaging at the storage reservoir depth of approximately 800 to 1000m from the injection wellbores. DAS VSP has enabled robust early plume growth monitoring on a repeat frequency of every one to two years for approximately the first 4 years of injection at each well (Harvey et al., 2021).

In 2021, Quest performed its first repeat 3D surface seismic survey covering 100 square kilometres of the 400 square kilometre baseline 3D seismic survey (Figure 1). This repeat survey covers the northern and central injection wells and was acquired with two primary objectives:

1. Verification of the earlier DAS VSP time-lapse findings
2. Providing a larger, spatially extensive view of the plume growth geometry to inform reservoir model updates.

Simultaneous processing of the 2010/11 baseline and 2021 monitor surface seismic surveys resulted in high image repeatability, subsequently resulting in a strong time-lapse anomaly associated with the injected CO_2 plume. Initial observations of the anomaly verified time-lapse DAS VSP observations of plume elongation in the NE-SW orientation.

In cross section, the vertical extent of the plume at injection wells 2 and 3 can be clearly defined using the 4D difference cubes derived from the 3D surface seismic data. Cross-referencing the observed time-lapse anomalies with well log data supports an interpretation that, despite a Net to Gross ratio close to 1, reservoir heterogeneities in the uppermost facies act as baffles or barriers to CO_2. This is a reminder of the importance of careful reservoir characterisation – while it can be tempting to view high quality reservoirs as simple tanks of sand, relatively subtle permeability contrasts between small-scale lithofacies can act as baffles or barriers to fluid flow.

The geometry of the plume in plan view can be explained by a combination of reservoir porosity trends and top reservoir structure. Recent work indicates that both of these parameters are strongly influenced by the topography and geological history of the underlying granitic basement, showing that a holistic geological model is required to fully understand plume behaviour.

Visualization of the basement fabric is enhanced by sculpting of 3D seismic spectral decomposition volumes. These images reveal basement features that are expressed either as an acoustic impedance anomaly, a structural feature, or both, with a predominant NE-SW trend (Figure 2).

Reservoir porosity maps have been generated from porosity inversion of a subset of the 3D seismic data. These maps indicate that, in places, trends in average reservoir porosity correlate with observed basement features. The genesis of these features is not definitively known but, given the strong influence on reservoir quality on plume migration, it is important to understand the mechanism by which they might influence porosity and permeability in the reservoir.

Top reservoir structure is controlled by the interplay of accommodation space, depositional compaction, and minor syn- or post-depositional faulting. For these reasons, top reservoir structure is often observed to mimic the rugosity of the basement. At Quest, plume migration is observed to follow structural contours as well as reservoir quality trends. Extrapolating these observations to other sequestration projects, areas exhibiting rugose present-day structure can expect a different expression of plume migration to areas of smooth basement.

In summary, time-lapse seismic has enabled Quest to gain critical insights into injected CO_2 plume evolution. Plume development is observed to follow a) trends in reservoir quality and b) top reservoir structure, both of which are shown to be strongly influenced by basement features. The authors propose that interpretation and characterisation of both the reservoir and basement are fundamental to any holistic geological study of carbon sequestration in the Basal Cambrian Sandstone in Alberta.

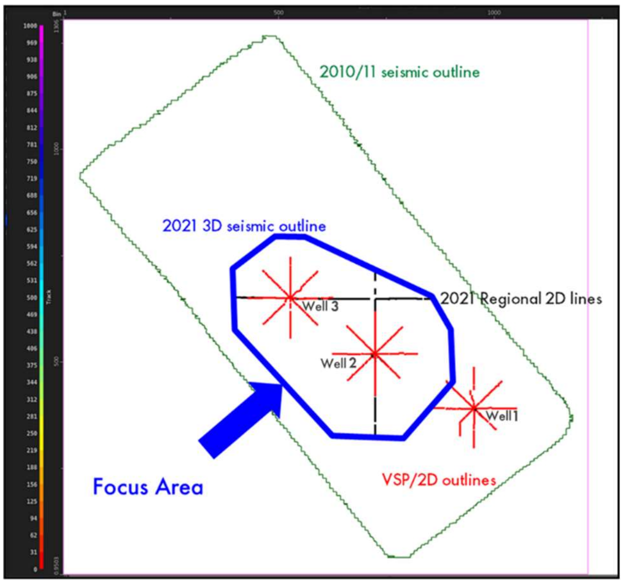

Figure 1: Quest Seismic Dataset Summary- Repeat 3D survey (blue), radial Das-VSP surveys (red). Both methods confirm a NE-SW orientation of plume development.

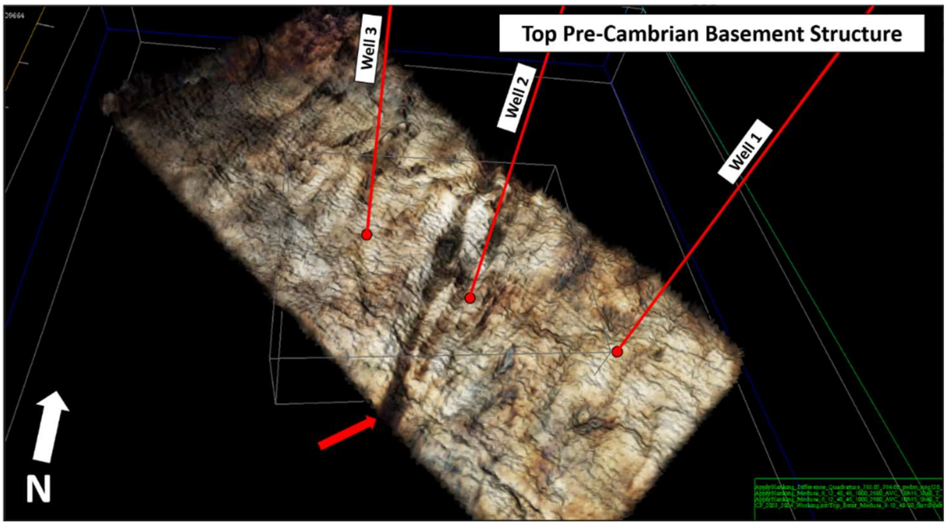

Figure 2: Spectral decomposition of the Precambrian basement, draped over the Precambrian Horizon in time. NE-SW oriented features are observed, with the dark feature directly to the Northwest of Well 2 (red arrow) being a prominent topographic low and acoustic impedance anomaly. This feature correlates to a porosity low in the overlying BCS reservoir.

References:

Harvey, S., Hopkins, J., Kuehl, H., O'Brien, S., Mateeva, A. 2021, Quest CCS Facility: Time-Lapse Seismic Campaigns. Greenhouse Gas Control Technologies Conference