AMPLIFIED GEOCHEMICAL IMAGING LLC

Using Ultrasensitive Detection to Monitor Carbon Capture Sequestration

A primary mode of Carbon Capture and Sequestration (CCS) is geologic sequestration in which carbon dioxide (CO_2) is injected into underground geologic sinks. Critical to the success of geologic sequestration is the need to ensure that underground storage sinks have adequate seal and do not leak to pose a potential threat to human health and the environment.

However, the ability to determine if these subsurface structures have adequate seal prior to CO_2 injection and that those seals remain leak-proof is difficult since there are not many CO_2 monitoring technologies available to provide adequate sensitivity and coverage for underground sequestration. However, ultrasensitive passive geochemical sorbers at the surface **provide the ability to monitor leakage over reservoirs, faults, as well as natural fractures**.

Amplified Geochemical Imaging's (AGI's) proprietary passive surface detection and compound mapping technology provides a unique ability to detect hydrocarbons at parts per billion (ppb) levels **which is 1,000 times more sensitive than traditional methods**.

The AGI passive sampler, **Figure 1**, contains a specially engineered polymeric adsorbent encased in a microporous membrane. These membrane pores are small enough to prevent soil particles and water from entering, but large enough to allow vapor molecules to pass through and concentrate on the adsorbent material.

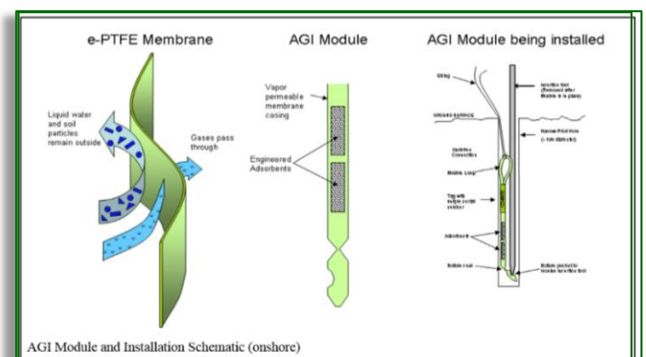

Figure 1.

The first case study took place in the Yibal field located within the Fahud Salt Basin in northwestern Oman, ~310 km SW of Muscat. The Yibal field produces oil from the Cretaceous Natih A Formation, with significant faulting throughout. Field and facilities covered ~115 km^2.

The purpose of the survey was to ground-truth the ability of AGI's high sensitivity surface geochemical imaging to map hydrocarbon seepage along faults, as a proxy for CO_2 tracers, and thus to identify segments of potential fault leakage from the Natih A reservoir.

Approximately 152 samplers were deployed for 20 days over structural closures at depth (i.e. depleted petroleum reservoirs) along specified fault projections to monitor indications of natural leakage pathways. Samples were deployed along single transects and double transects with 200 m spacing (see **Figure 2**).

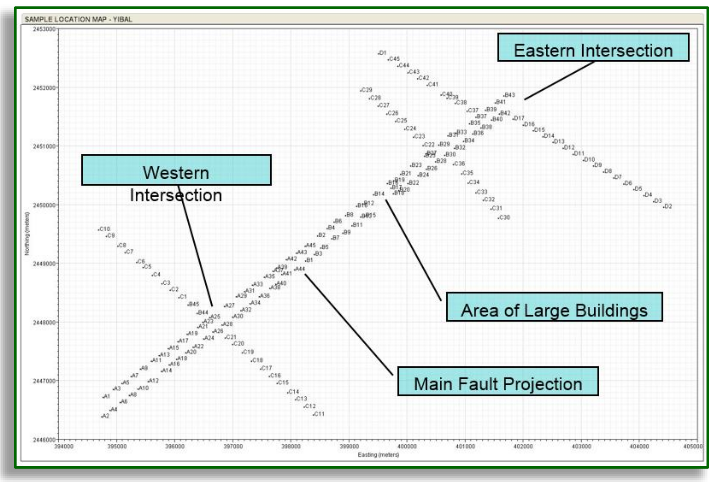

Figure 2.

Statistical evaluation of the data using Hierarchical Cluster Analysis (HCA) indicated three primary signatures: baseline, surface contamination, and sub-surface leakage along faults, see **Figure 3**.

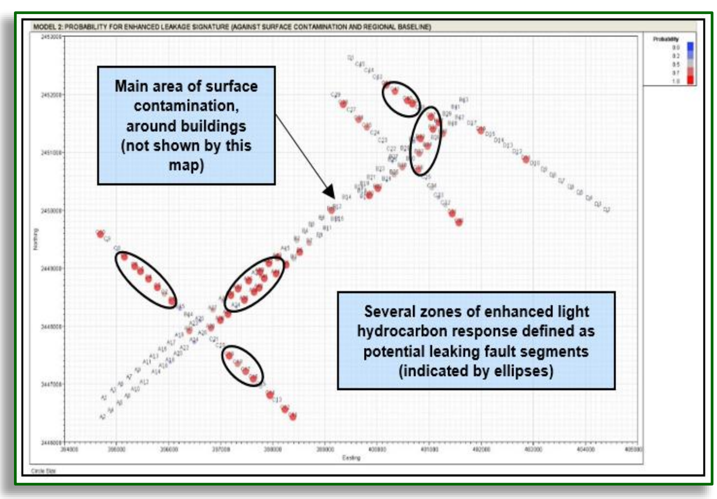

Figure 3.

Detecting Leaks Over Faults & Natural Fractures

Significant mass levels for C_9+ compounds were found primarily around buildings and were attributed to surface contamination. Trace levels ascribed as regional baseline levels showed the lowest relative mass response primarily for C_4 and C_5 compounds emanating from the reservoir. Enhanced light hydrocarbon signatures, primarily C_2 to ~C_7, were mapped along coherent segments of fault projections inferring reservoir leakage along specific fault traces. These segments are encircled by ellipses in **Figure 3. Leaking segments were noted along the main fault** trace near the western intersection, north and south segments off the western intersection, and eastern-most intersection region.

The second case study involves the In Salah CCS program in the Algerian Krechba Field. Gas with high amounts of CO_2 was being produced from a ~20 m thick reservoir at ~1850–1900 m, see **Figure 4**. The reservoir is overlain by ~950 m carboniferous mudstones, siltstones, and limestones which is overlain by ~900 m of Cretaceous sandstone deposits (Ringrose, 2009). The CO_2 was injected into

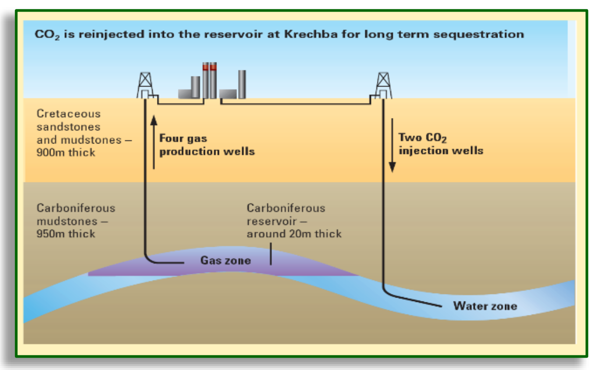

Figure 4.

the~20m thick down-dip water leg of the gas reservoir at ~1.9 km depth. There were five gas producing wells – colored red inside the yellow shaded area, see **Figure 5**, and three injection wells (the KB-1, KB-2, & KB-3 – colored blue).

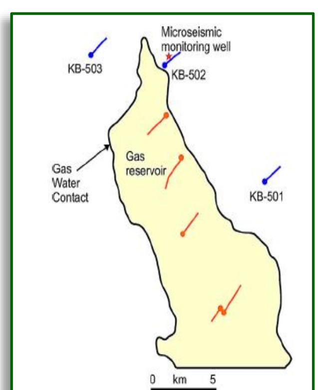

Figure 5.

Response of the reservoir to CO_2 injection had already been observed using geophysical technologies: InSAR (Interferometric Synthetic Aperture Radar), 3D seismic and microseimic. Surface deformation up to several cm was observed above each of the injection wells by InSAR, see **Figure 6**. The 3D seismic survey concluded that the CO_2 injection had activated a deep fracture zone extending several hundred meters wide and extending about 150 m above the reservoir.

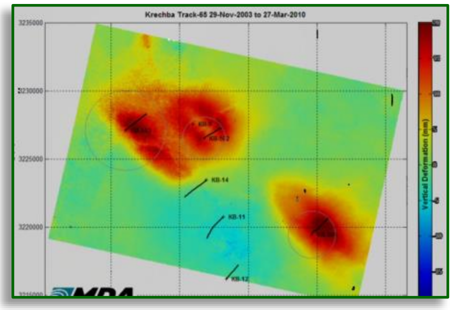

Figure 6.

Thus, an AGI survey, using fluorinated CO_2 tracers and 143 samples, was employed to evaluate subsurface leakage. A different fluorinated tracer, with a detection limit of ~ 5 ppb, was used for each well.

Background hydrocarbons levels were detected above the reservoir and along fractures. None of the samples recorded detectable levels of perfluorocarbons. **No evidence of leakage from the gas storage reservoir or around the injection wells was observed.**

The study demonstrated the ability of the ultrasensitive method to monitor baseline levels of hydrocarbons and potential leakage of perfluoronated tracers, used as a proxy for CO_2.

Compartmentalization:

CO_2 filling of reservoirs varies based upon the characteristics of the reservoir. In homogeneous reservoirs CO_2 rises to the top of the reservoir and fills the reservoir from the top down (**Figure 6**). However, in heterogeneous reservoirs, CO_2 fills the reservoir from the bottom up by filling the lower most sandstone section. The CO_2 moves horizontally until it finds openings to rise and fill the next sandstone layer above **(Figure 7**).

But what happens when compartmentalization exists? Only a small portion of the reservoir is filled **(Figure 8**). This can dramatically reduce the storage capacity of the reservoir and significantly impact the economic viability of the program. Even if additional well perforations can be

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What about Reservoir Compartmentalization

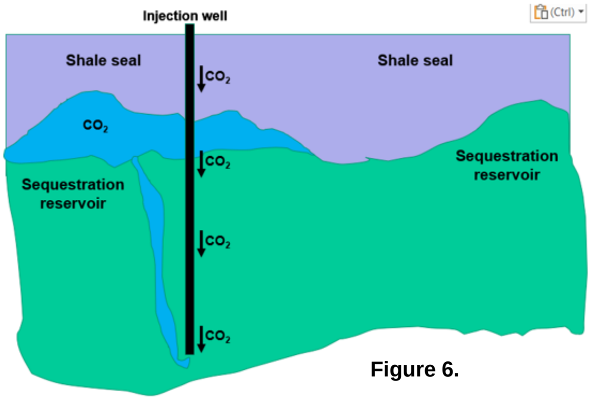

Figure 6.

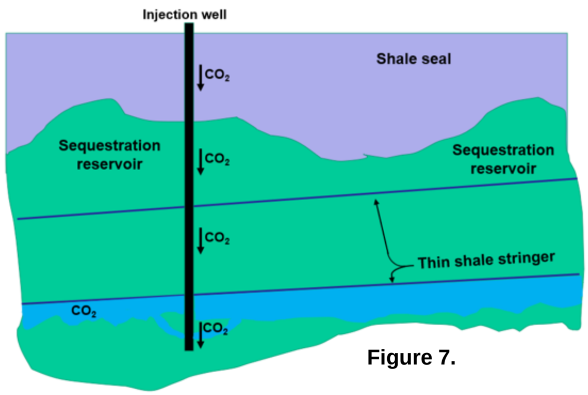

Figure 7.

added along casing, project costs will still increase. So, how do you identify reservoir compartmentalization?

Downhole Geochemical Logging (DGL) can be used to differentiate thin shale seals from compartmentalization. DGL is the analysis of cutting samples collected by the mud logger during the drilling of the well. The samples are then shipped to AGI for analysis by thermal desorption / gas chromatography / mass spectrometry. The analytical methodology allows for the detection of 88 organic constituents, which provides the ability to differentiate multiple hydrocarbon or baseline signatures.

If a seal or compartmentalization does exist, different hydrocarbon signatures will likely exist above and below the seal. For example, in an Eagle Ford case study, the hydrocarbon fingerprint in the Austin Chalk is noticeably different than that of the Eagle Ford (**Figure 9**).

When non-sealing shale stringers exist between sandstone beds, the hydrocarbon fingerprint will be

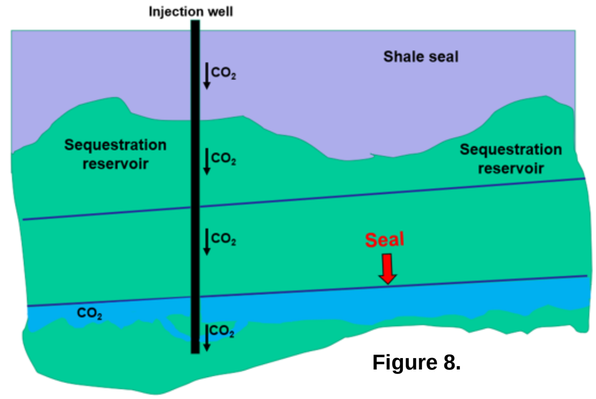

Figure 8.

the same above and below the stringer. The 88 compound target list facilitates the use of multiple interrogative statistical tools, such as hierarchical cluster analysis, principal components analysis, and canonical variates analysis, to distinguish even subtle signature differences.

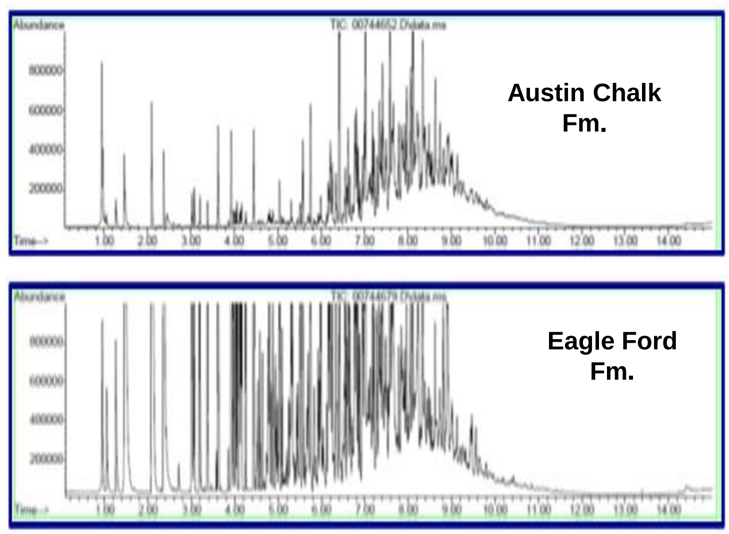

Figure 9.

However, how does one identify compartmentalization in saline aquifers where there is little hydrocarbon presence? With ultrasensitive detection of organic compounds at *ppb* levels, the method may differentiate low concentration baseline signatures.

The example signatures in **Figure 10** illustrate that the AGI DGL method can identify different baseline signatures from saline aquifers, where only trace amounts of hydrocarbons may exist.

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Sequestration in Saline Aquifers

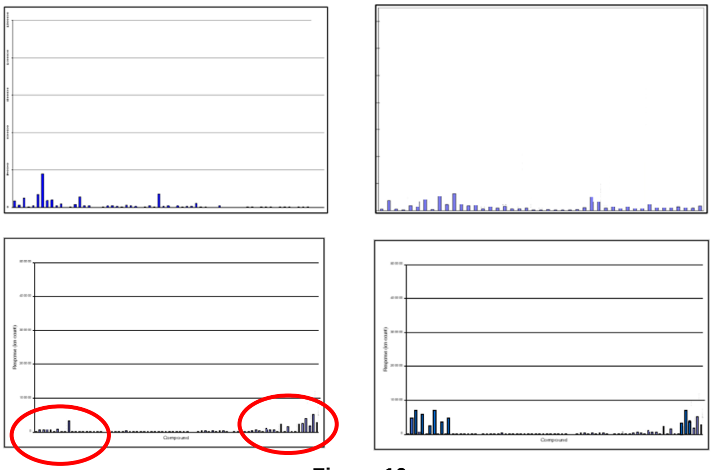

Figure 10.

How does one monitor CO_2 in depleted gas reservoirs and saline aquifers? While the AGI method can measure CO_2, the method cannot currently differentiate between ambient and subsurface CO_2 sources. However, the method can detect and characterize the impurities inherent in CO_2 injection streams. The fingerprints in **Figure 10** highlight typical saline aquifer baseline signatures. **Figures 11, 12, & 13** illustrate impurities from traditional CO_2 emissions.

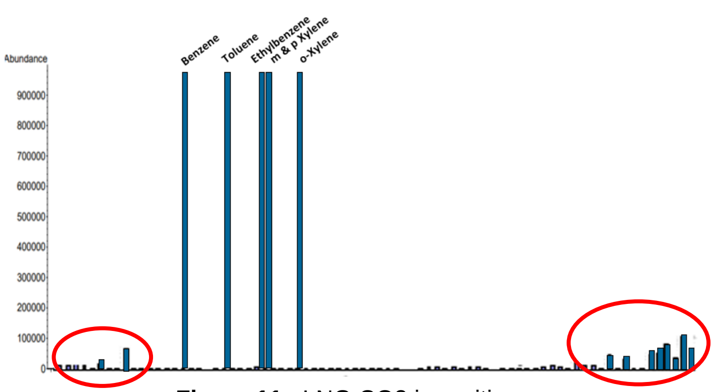

Figure 11. LNG CO2 impurities

Note the dramatic differences in intensity between baseline signatures, highlighted by red ellipses, and CO_2 impurities.

The baseline impurities can be validated and documented during the DGL analyses from the stratigraphic well, as well as the site characterization surface survey performed prior to CO_2 injection.

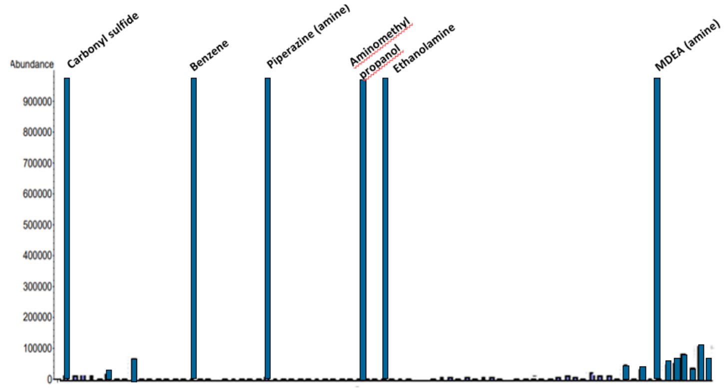

Figure 12. Power plant CO2 impurities

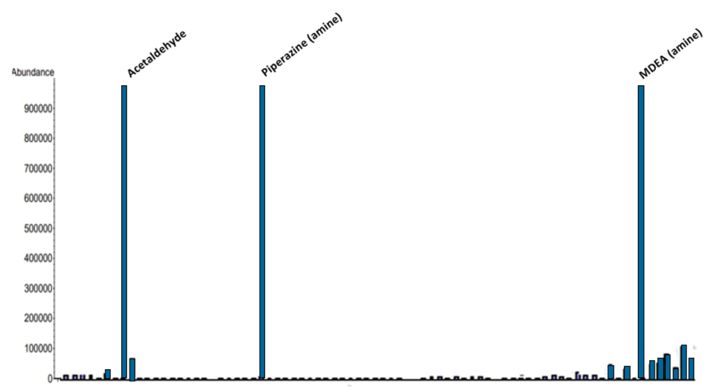

Figure 13. Fertilizer plant CO2 impurities

CO_2 impurities should be documented during project planning since every CO_2 project will have a unique impurity fingerprint. Characterizing CO_2 impurities eliminates the need for special tracer compounds, thereby dramatically reducing the cost of CO_2 monitoring.

Summary:

AGI's proprietary low *ppb* geochemical surveys have utility in studies of subsurface structures for CO_2 injection and storage for:

- Evaluating seal integrity with samples deployed over structural closures (i.e. petroleum reservoirs) as well as around plugged and abandoned wells**;**
- Evaluating compartmentalization in sequestration reservoirs which dramatically affects profitability;
- Long term monitoring of CO_2 through the detection of CO_2 and its inherent impurities that occur at concentrations 1000-times above baseline levels.

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