Passive Seismic Imaging of CO_2 Sequestration at Weyburn

S.C. Maxwell Engineering Seismology Group Canada Inc., D.J. White, Geological Survey of Canada, and H. Fabriol, Bureau de Recherches Géologiques et Minières, France*

Summary

This paper describes a passive seismic imaging case study to track gas movement during CO_2 injection in the Weyburn Field, Saskatchewan, Canada. The project is part of a multi-disciplinary investigation of CO_2 sequestration. A monitoring array of 8 triaxial geophones was permanently deployed in an abandoned well, to monitor induced seismicity in the field. Induced microseismic events were recorded immediately following the start of CO_2 injection in a well 50 m away from the array. The events clustered in a discrete region extending from the injection well to a neighbouring horizontal production well. Production data from this horizontal well indicated significant increases in gas production at the same time. This case study demonstrates the applicability of imaging gas injection with passive seismic monitoring, for both CO_2 sequestration and enhanced oil recovery.

Introduction

CO_2 sequestration in geological reservoirs is being evaluated internationally as a viable means of long-term CO_2 storage and climate change mitigation. In 2000, the International Energy Agency (IEA) Weyburn CO_2 Monitoring and Storage Project was initiated to investigate the technical and economic feasibility of CO_2 storage in a partially-depleted oil reservoir (Government of Canada, 2000). The IEA Weyburn project is exploiting EnCana Corporation's $1.5 billion, 30 year commercial CO_2 enhanced oil recovery operation which is designed to recover an incremental 130 million barrels of oil from the Weyburn field. Specifically, the IEA Weyburn Project aims to comprehensively monitor and verify the progress of the CO_2 flood and establish the likelihood of safely storing the CO_2 in the reservoir for the long-term. Toward this end, a multidisciplinary, integrated program has been formulated to address critical issues central to safe and cost-effective, long-term storage of CO_2. The program includes monitoring of the physical movement and distribution of the CO_2 during injection using seismic, geochemical, isotopic tracers techniques. One of the seismic techniques being evaluated is passive seismic monitoring.

Passive seismic monitoring is a growing technology to image reservoir processes associated with fluid injections in oil and gas fields (Maxwell and Urbancic, 2001). Seismic deformation associated with the reactivation or creation of fractures can result from a number of mechanisms, including hydraulic fracturing, shearing associated with stress or pressure changes, reservoir compaction, or material property changes. During fluid or gas injection, hydraulic fracturing or pressure increases reducing net effective stress and causing shear deformation can both result in discrete acoustic emissions or microearthquakes. Depending on the physical conditions of a particular reservoir, the seismic deformation may be associated with pressure changes associated with gas movements. Nevertheless, the spatial and temporal variations in the microseisms can then be used to track the gas movement, possibly with the need of a geomechanical model to relate pressure changes to gas movement.

Weyburn Field

The Weyburn oil field is located southeast of Weyburn, Saskatchewan within the north-central Williston Basin which contains shallow marine sediments of Cambrian to Tertiary age (Fig. 1). The Weyburn field, which covers ~180 km^2, was discovered in 1954 and hosted an estimated 1.4 billion barrels of oil. Primary production within the field continued until 1964 at which time the initiation of waterflood resulted in oil production peaking at 46,000 barrels/day in 1965. Waterflood has continued since then, with horizontal infill drilling commencing in 1991. Approximately 24% of the original oil in place had been recovered by 2000 when CO_2 injection began.

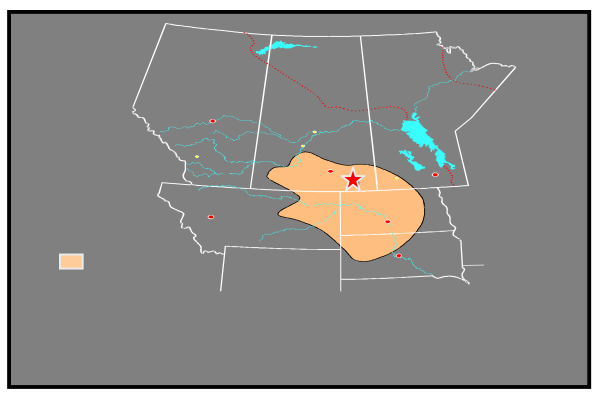

Figure 1. Map of the Weyburn field.

Weyburn oil reserves reside within a thin zone (maximum thickness of 30 m) of fractured carbonates in the Midale beds (Fig. 2) of the Mississippian Charles Formation which were deposited in a shallow carbonate shelf environment. The dominant fracture set within the reservoir is NW-SE perpendicular to the horizontal well direction. The reservoir comprises two intervals; an upper Marly dolostone (0-10 m thick) and lower Vuggy limestone (0-20 m thick) that are sealed by anhydritic dolostones and anhydrites of the Midale Evaporite. The Midale Marly unit ranges from chalky dolomudstone to calcitic biofragmental dolostone with intervening thin beds of biofragmental limestone. The fractured, Vuggy unit includes a lower, peritidal 'shoal' sequence with common secondary (vuggy) porosity, and an upper, shallow marine 'intershoal' sequence dominated by fine grained carbonate sands. The Midale Marly has relatively high porosity (16 to 38%) and low permeability (1 to >50 md), whereas the Midale Vuggy has relatively lower porosity (8-20%) and higher permeability (10 to > 300 md). The higher permeability within the Vuggy unit resulted in preferential recovery of oil from this unit during the waterflood stage of production.

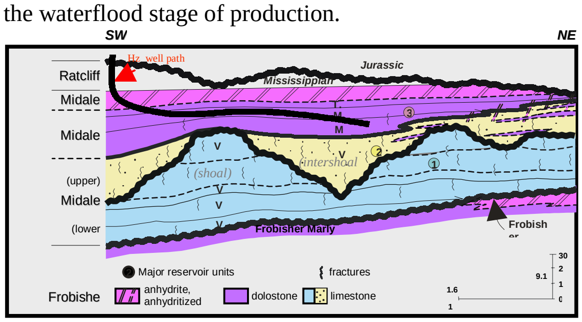

Figure 2. Weyburn lithology.

The CO_2-based enhanced oil recovery scheme was initiated in September of 2000 in 19 patterns of the EnCana Weyburn unit at an initial injection rate of 2.69 million m^3/day (or 5000 tons/day). The present rate of CO_2 injection is 3.39 million m^3/day of which 0.71 million m^3/day is CO_2 recycled from oil production. The CO_2 EOR is contributing over 5000 barrels/day to the total daily production of 20,560 barrels/day for the entire Weyburn unit. As of May 30, 2003, cumulative CO_2 injected was 1.90 billion m^3. The CO_2 flood will be expanded gradually over the next 5 years into a total of 75 patterns with ~20 million tonnes of injected CO_2 anticipated over the lifetime of the project. The source of CO_2 is the Dakota Gasification Company's synthetic fuel plant which is located in Beulah, North Dakota. The CO_2 is transported 320 km via pipeline to the Weyburn field.

Passive Monitoring

An array consisting of 8 triaxial geophones was cemented in a vertical well 101/06-08. As part of EnCana's normal operation, this well was being abandoned and replaced with a new, vertical CO2 injection well (121/06-08) within approximately 50 m of the monitoring well. This offered an unique passive monitoring scenario where a seismic array could be installed close to the reservoir and cemented as part of the normal well abandonment, and then used to monitor injection at close proximity to the array. Once installed, the geophones were connected to an ESG Hyperion Microseismic System, which detects and archives seismic signals. The system could be remotely controlled to make system adjustments and state-of-health assessments. Data was routinely archived from the system for post-analysis.

Background seismicity was recorded with the array between August and December, 2003, prior to the start of injection in 21/06-08. Figure 3 shows a map around the monitoring well, including vertical and horizontal patterns of production and injection wells. Also shown on Figure 3 is an expected detection range (orange circle in Figure 3) of about 400 m, based on previous passive monitoring examples (Maxwell and Urbancic, 2003). As indicated in the figure, there are no specific injection wells close the monitoring well prior to the drilling of the new, 121/06-08 WAG (water alternating gas) injector. Nevertheless, several events were recorded during this background period.

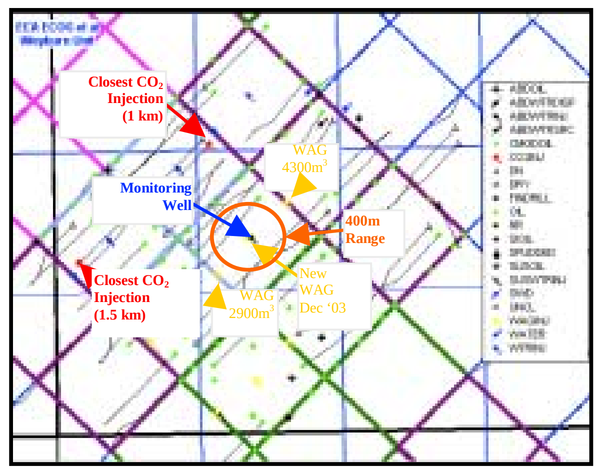

Figure 3. Map of wells in the vicinity of the monitoring well. Horizontal and vertical lines represent township lease boundaries spaced at 1600 m for scale.

During the drilling of the 121/06-08, increased seismic noise levels were found associated with both surface activities and downhole drilling. Several discrete seismic events were also recorded associated with the well completion activities including perforation shots.

In January, 2004, CO_2 injection began in the 121/06-08 well, resulting in microseismicity. Figure 4 shows a map view of events recorded in a three week period following the start of injection. The events concentrate in a region between the injector and the closest active production well (191/11-08). This could be related to the 121/06-08 well being within a depleted region from the 191/11-08 production, and the events may be following the local pressure gradient. The events cluster around the depth of the reservoir, consistent with the location uncertainties.

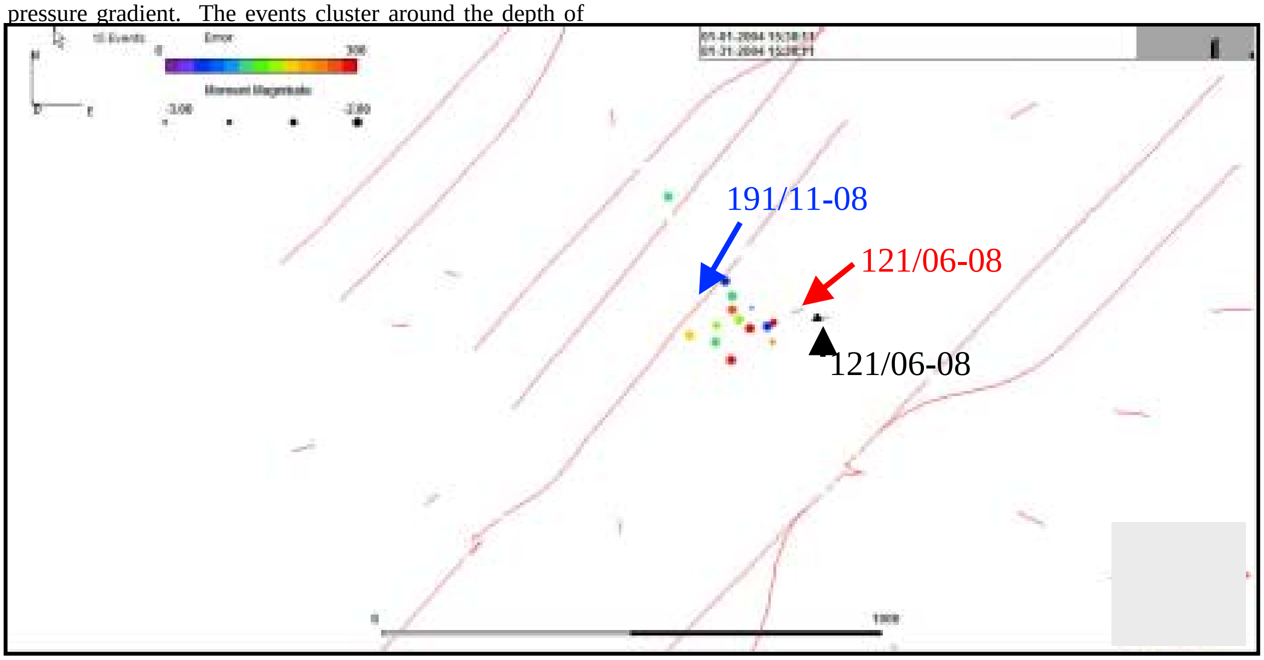

Figure 4. Plan view of microseismic events (circles) recorded during three weeks following the start of CO_2 injection. Geophones are represented by a black triangle.

Passive Seismic Imaging at Weyburn

Figure 5 compares the gas injection and microseismic activity rates. The seismicity corresponds with the start of the CO_2 injection. Figure 6 shows the production data from the 191/11-08, where a significant increase in gas production occurs with the introduction of the CO_2 in 121/06-08.

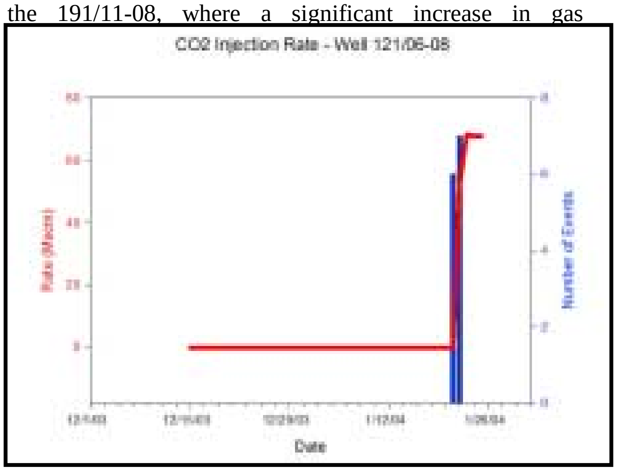

Figure 5. Injection rate and microseismic histogram.

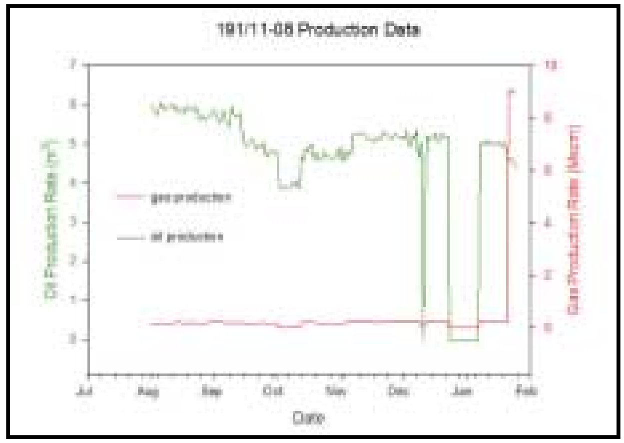

Figure 6. Production data from neighbouring horizontal well.

Conclusions

Passive seismic monitoring has shown that discrete seismic events have been recorded during the CO_2 injection. The location of the events stretch between the injector and a neighbouring production well, where an increase in gas production results. Although the seismic activity could be related to pressure changes, there does appear to be evidence of gas movement between the two wells presumably through the seismically active region. This case study highlights the application of passive monitoring to image CO_2 injection for both sequestration and EOR.

References

Maxwell, S.C., and Urbancic, T.I., 2001, The Role of Passive Microseismic Monitoring in the Instrumented Oil Field, The Leading Edge, 636.

Maxwell, S.C., and Urbancic, T.I., 2003, Passive Imaging of Seismic Deformation Associated with Injection for Enhanced Recovery, SEG Annual Meeting, Dallas, Texas.

Acknowledgements

The authors gratefully acknowledge the Petroleum Research Technology Council and EnCana Corporation for permission to publish this paper.