PTE 790 PHD Research
Real Time MicroSeismic Monitoring

USC Viterbi
School of Engineering

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What is Microseismic Montoring?

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- A geophysical application which involved passive observation of very small scale earth vibrations
- The vibrations occur as a result of hydraulic fracturing , enhanced oil recovery , geothermal operations or undergrund gas storage.

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3D Seismic Vs Microseismic

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- 3D seismic technologies measure acoustic reflections from an energy source
- Microseismic monitor/listen for seismic energy already occurring underground.
- Passive methods provide **a continuous 4D record** of seismicity rather than individual snapshots in time.

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Microseismic Events

- Microseismic events are caused when activities change the stress distribution or the volume of a rockmass.
- When the rock attempts to redistribute the stress within the rockmass , it will suddenly slip or shear along pre-existing zones of weakness such as along faults or fracture networks.
- This results in a release of energy in the form of seismic waves

What can Microseismic Monitoring tell Us?

- When did the microseismic event occur?
- Where did the microseismic event occur?
- What is the magnitude of the microseismic event?
- From the location and magniture of events are observed over time, we can see patterns of seismicity related to production activities

Why Choose Microseismic Monitoring?

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- Increase Safety
- Optimize Production
- Decrease Costs
- Reduce Risks

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Applications of Microseismic Monitoring

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Hydraulic Fracturing:

- Determine Fracture geometry and azimuth
- Identify of out-of-zone events
- Evaluate fracture complexity and intensity
- Optimize injection strategies and staging
- Estimate stimulated reservoir volume (SRV)
- Understand fracture development and stimulation effectiveness using seismic moment tensor inversion (SMTI)
- Evaluate induced seismicity

Life-of-Field Reservoir Monitoring:

- Map steam chest development in EOR activities

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- Casing failure detection
- Observe caprock integrity
- Real-time alerting of vertical steam migration or casing failure

Waste Injection/Underground Gas Storage:

- Evaluate induced seismicity
- Warning of fault activation
- Ensure containment in underground salt caverns or depleted formations

Microseismic Application in Kuwait

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- In 2006, a microseismic monitoring pilot was implemented in Minagish field, Western Kuwait.
- The target zone was the Minagish Oolite, a microporous carbonate reservoir, about 350 ft thick and around 9,600 ft deep.
- The monitoring string, an SST-500 wireline tool of four 3C-geophones, was temporarily deployed in an **abandoned wel**l on the eastern flank of the field. The purpose of the surveillance was:

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Microseismic Monitoring of a Middle East Carbonate Reservoir: Minagish Sesitivity Test Resaults

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- KOC's primary motivation was to test the microseismic technology in 3 main areas of characterization:
  - the sweep efficiency,
  - the water break-through
  - and the fracture mapping.

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Microseismic Application in Kuwait Contd…

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- to assess the occurrence of microseisms induced by the production operations and especially the water injection along the flank;
- to characterize such microseismicity; and
- to measure the effective network sensitivity with depth.

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Microseismic Application in Kuwait

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- During the 50 days of effective monitoring, about 2,000 microseisms were identified and 600 events with a magnitude of -2.0 to 0.3 were located.
- A detailed analysis also highlighted clusters of microseisms between injection-production doublets
- In fact, one doublet was believed to be connected, which was subsequently confirmed.
- Pilot achieved its objectives and was successful
- Hence, it has been proposed to deploy a cost-effective and
- optimized microseismic network suitable to the entire
- Minagish field.

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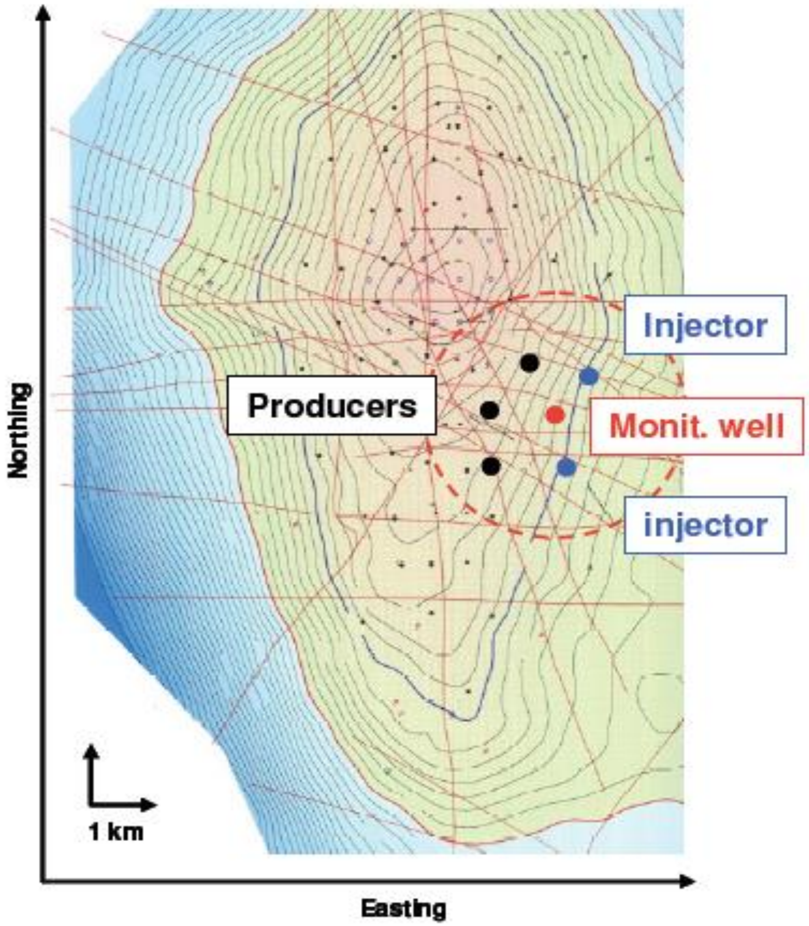
Minagish Field Pilot



- Mingagish is located in West Kuwait and the produced formation, a microporous carbonate, is the Minagish Oolite (MN Oolite) located at a depth of almost 10,000 ft.

- Water injection is carried out at the flank of the anticline structure and production is drawn from its central part.

Sensitivity Test Procedure

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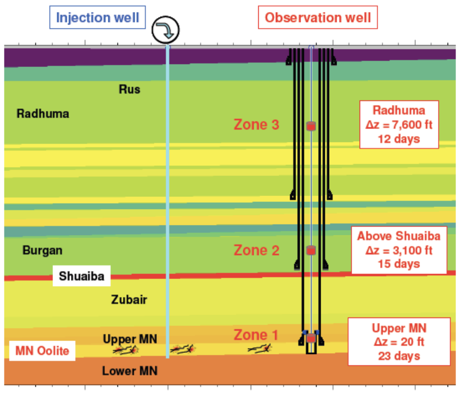

Figure 2: Illustration of the 3 phases of the sensitivity test.

- To achieve a cost effective operation, a 2 month monitoring from a single well was proposed.
- A vertical observation well located at the Eastern flank of the structure, about 1 km away from a powered water injector and a dump flood injector, was selected.
- The technical constraints, especially the well completion, led us to use a SST-500 wireline string.
- It consisted of four three-component geophones evenly spaced over 90 m.
- As its name suggests, the monitoring of the MN Oolite was carried out at 3 different depths.
- The deepest was the closest to the reservoir in the Upper MN formation. A second level was set in the Burgan, above the Shu’aiba

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Sensitivity Test Procedure

- formation in order to assess its possible screen effect on the microseismicity recording.
- And the last one (Zone 3) was relatively close to surface, in the Radhuma formation, about 7,600 ft above the reservoir.
- During each zone monitoring period, which lasted 2 to 3 weeks, the powered injector was shut-in several days and restarted to stimulate the reservoir.
- As a conclusion of the sensitivity test design process, the parameters for assessing the test were chosen and agreed according to previous experiments carried out in relatively similar contexts and according to the mapping objectives.
- The success criteria is mentioned in the next slide.
- Their defining is paramount in deciding on the future of the project: continuation, cancellation or new-design.

Sensitivity Test Criteria

Table 1: Assessment or success criteria table of the sensitivity test.

	STOP		GO ON
Microseismic rate *(Microseisms / month)*	0	1 – 30	≥ 30
Microseisms within reservoir *(Microseisms / month)*	0	1 – 5	≥ 5
Network sensitivity: *Magnitude @ 1 km*	-1	-1 – -1.7	-1.7
Magnitude @ 2 km	-0.5	-1	-1.2
Coverage radius in m	< 500	500 – 1,500	≥ 1,500

Sensitivity Test Phases

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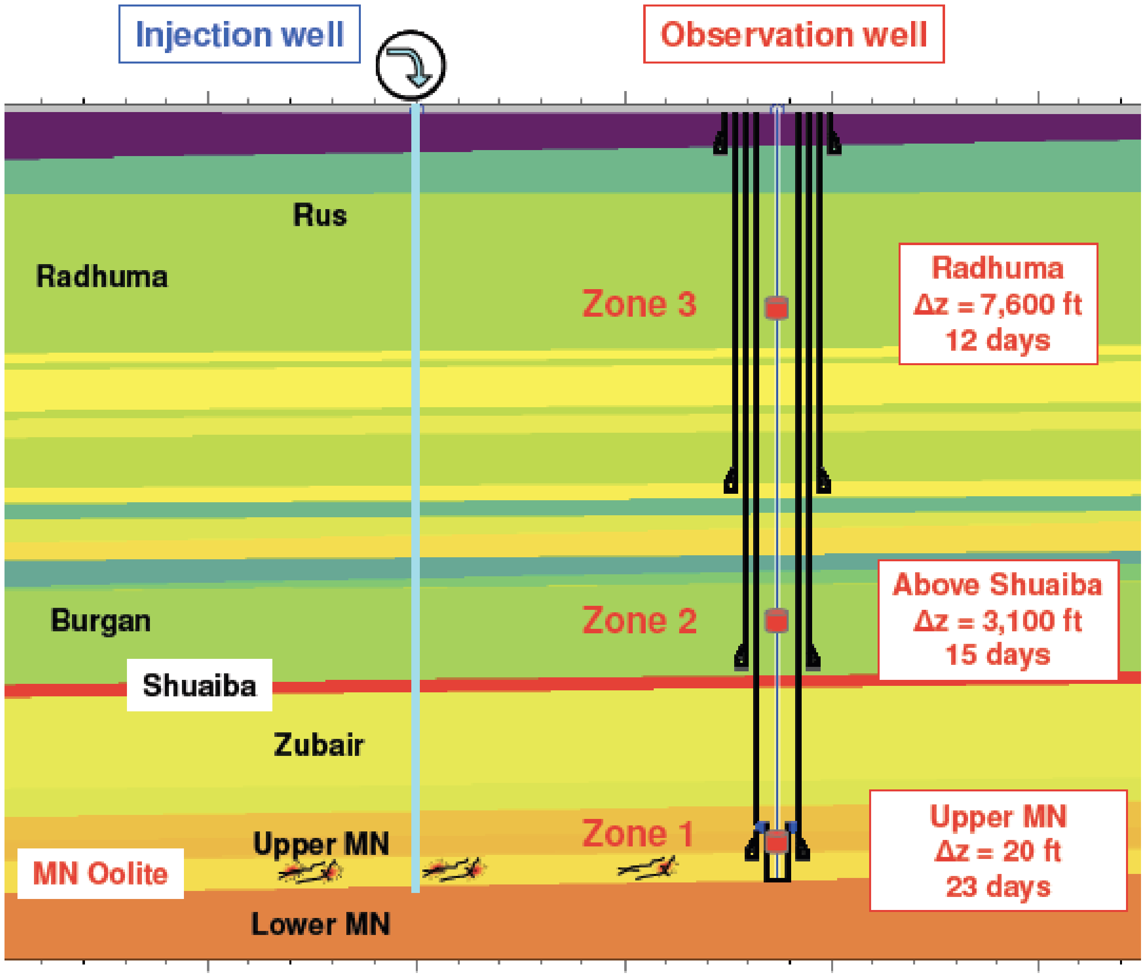

Figure 2: Illustration of the 3 phases of the sensitivity test.

Microseismic Sensitivity Test Operation

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- The microseismic monitoring operation took place in February and March 2006.
- Baker Atlas was in charge of the wireline string deployment for the different monitoring zones, the corresponding vibroseis orientation surveys and the continuous data acquisition.
- Magnitude was in charge of the operation coordination and the data processing: 3Cgeophone orientation and microseismic processing.
- During the 7 week operation, the effective monitoring from Zone 1 reached 63 % that is 23 days.
- It increased to 84 % (15 days) and 87 % (12 days) for Zone 2 and Zone 3 respectively.

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3C geophone string Seismograms Recording in Upper MN Zone and Radhuma Zone

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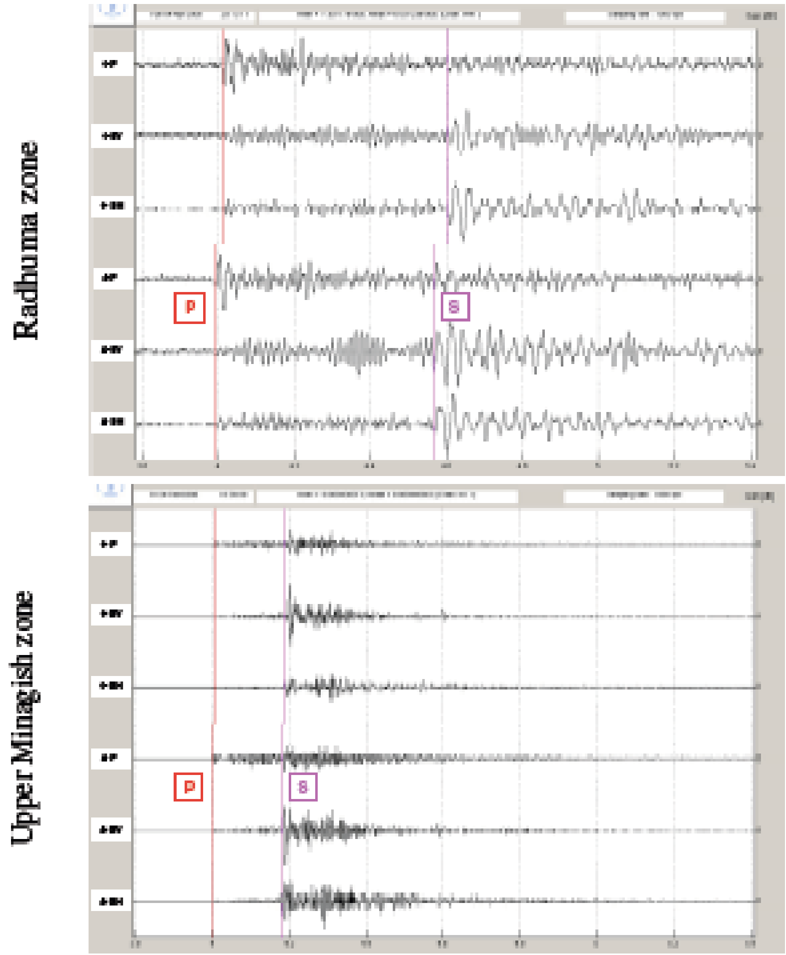

Figure 3: Example of seismograms recorded in the Radhuma zone (top) and in the Upper MN zone (bottom). Each subplot displays the signal in the P-SV-SH system for the upper level (top 3 traces) and the lower level (bottom 3 traces) of the string. The P-wave (red) and the S-wave arrivals (pink) are shown.

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Conclusions

- The sensitivity test was successful as per the criteria:

Table 2: Sensitivity test results per monitoring zone.

	Upper MN	Burgan	Radhuma
Microseismic rate (*Microseisms / month*)	2,600	1,600	150
Microseisms within reservoir (*Microseisms / month*)	660	660	120
Network sensitivity: *Magnitude @ 1 km*	[-2, -2.5]	-2	N.A.
Magnitude @ 2 km	[-1.5, -2]	[-1.5, -2]	N.A.
Coverage radius in m	2,500	2,500	2,500

Conclusions

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- It was shown that the Minagish field exhibits a high rate of microseismicity which can be used for mapping the reservoir.
- Even 7,600 ft above the MN Oolite, microseisms were detected and processed.
- Despite limitations in the location accuracies, clusters of microseisms were observed and gave evidence of injector –producer connection.
- **Design the next phase which is expected to cover between 12 and 24 km2, that is one fourth to one third of the entire field surface, for a minimum monitoring period of 6 months.**

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Research Focus

- Research further uses of Microseismic in light of Hydraulic Fracturing for Kuwait Oil Company in the following aspects:

Hydraulic Fracturing:

- Determine Fracture geometry and azimuth
- Identify of out-of-zone events
- Evaluate fracture complexity and intensity
- Optimize injection strategies and staging
- Estimate stimulated reservoir volume (SRV)
- Understand fracture development and stimulation effectiveness using seismic moment tensor inversion (SMTI)
- Evaluate induced seismicity

References

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