Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Sequestration Policy and Feasibility Studies (1)

Seismic Monitoring of CO_2 Injection at the IEA Weyburn CO_2 Monitoring and Storage Site: What Have We Learned?

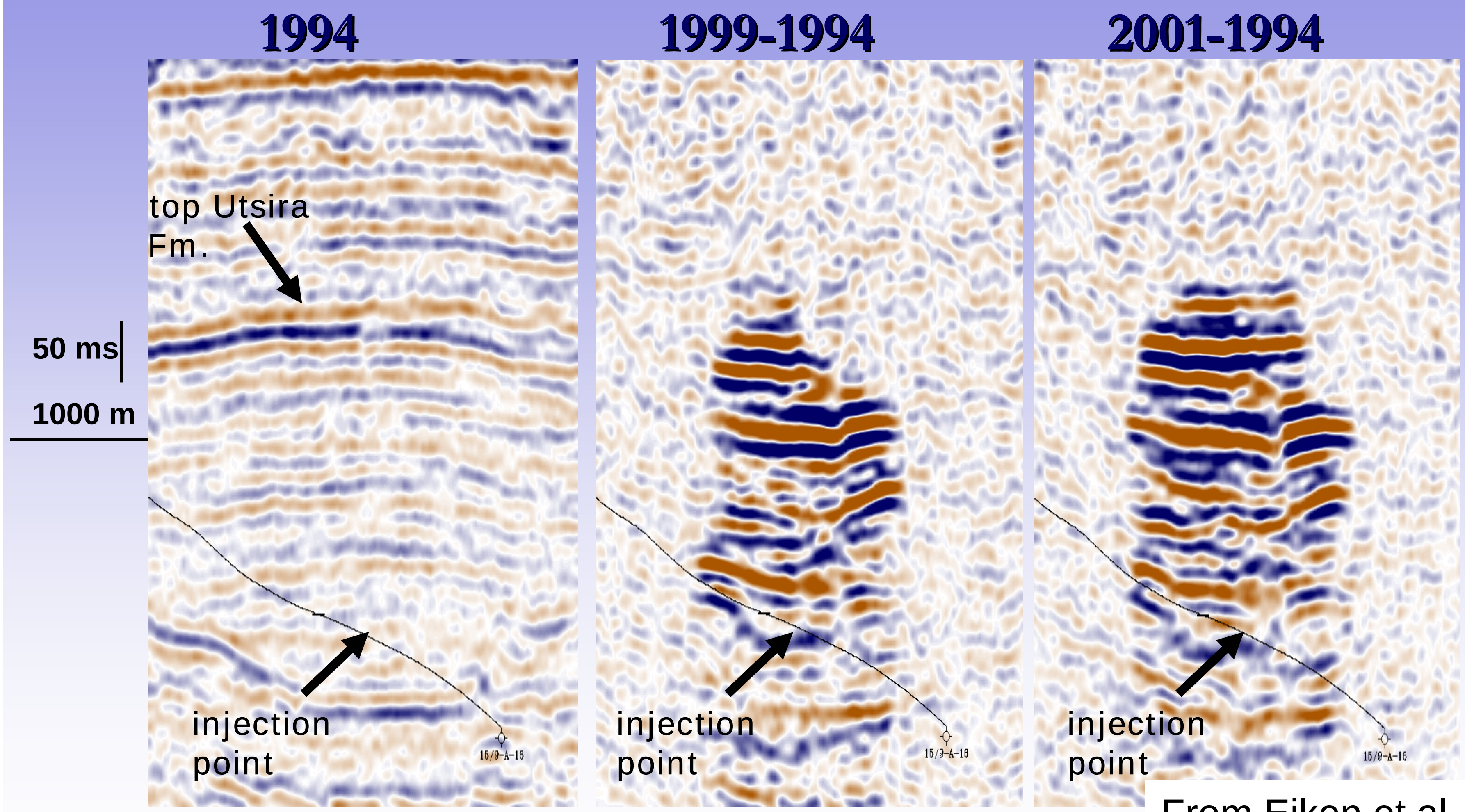
Don White, Keith Hirsche, Tom Davis and Shawn Maxwell

May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia

Pilot Projects

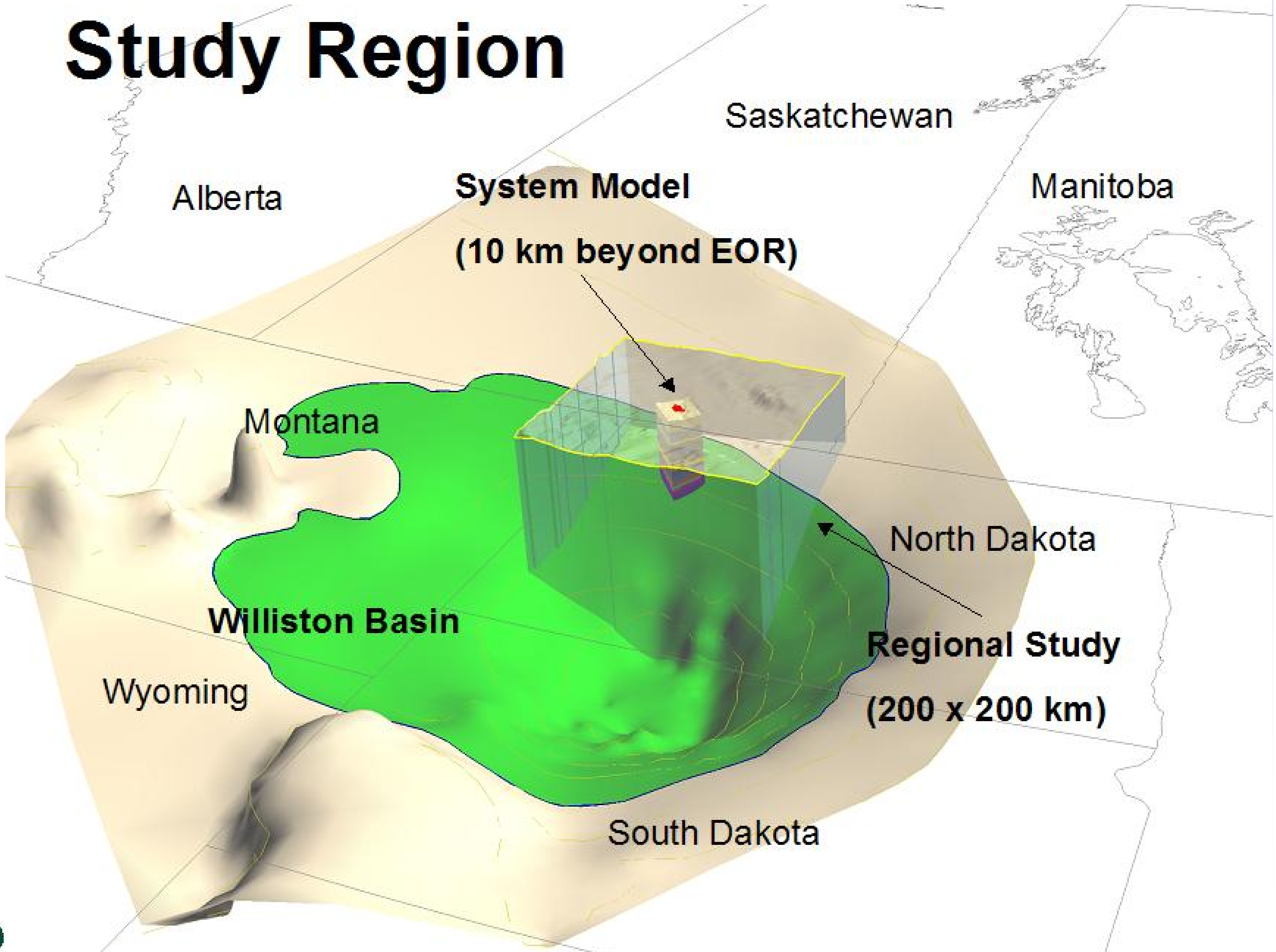
- Frio Brine Experiment (Texas)
- Tea Pot Dome (W. US)
- West Pearl Queen (SW US)
- **Sleipner** (North Sea) 1M tonnes/yr (1996)
- **Weyburn** (Canada): 2M tonnes/yr (2000)

Sleipner Time-Lapse Seismic



From Eiken et al. 2004

Study Region

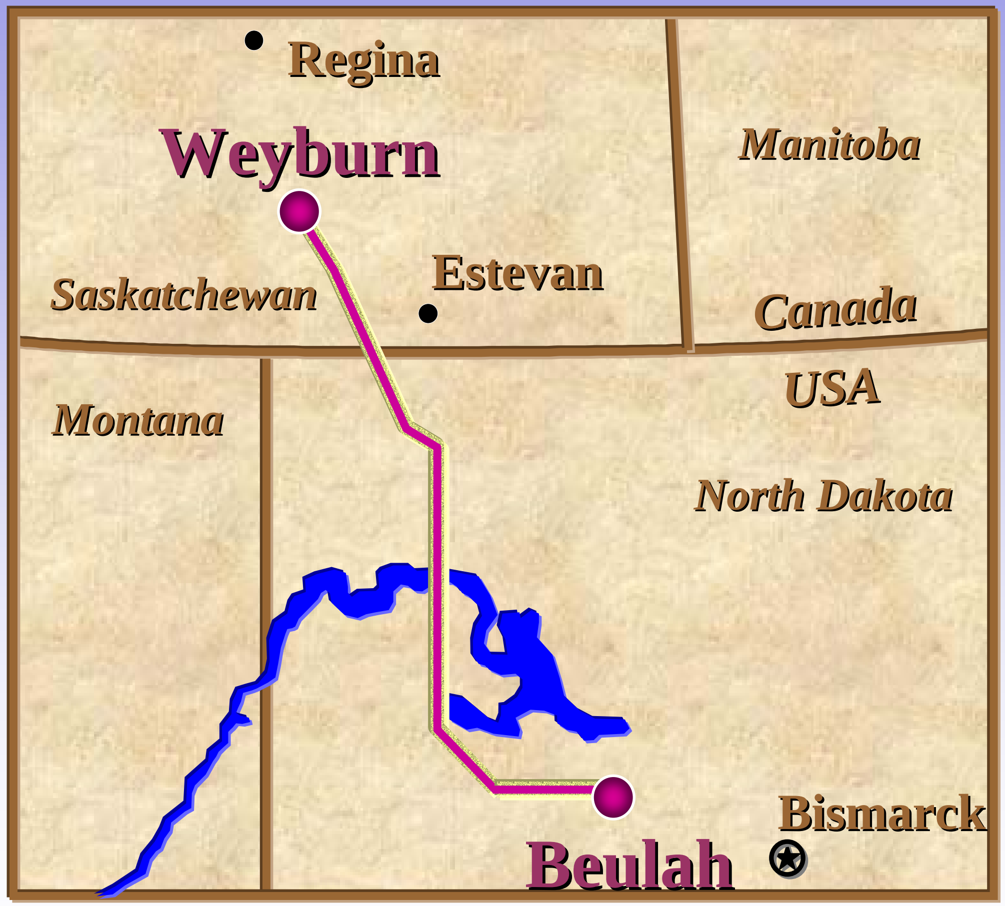


Weyburn Research Themes

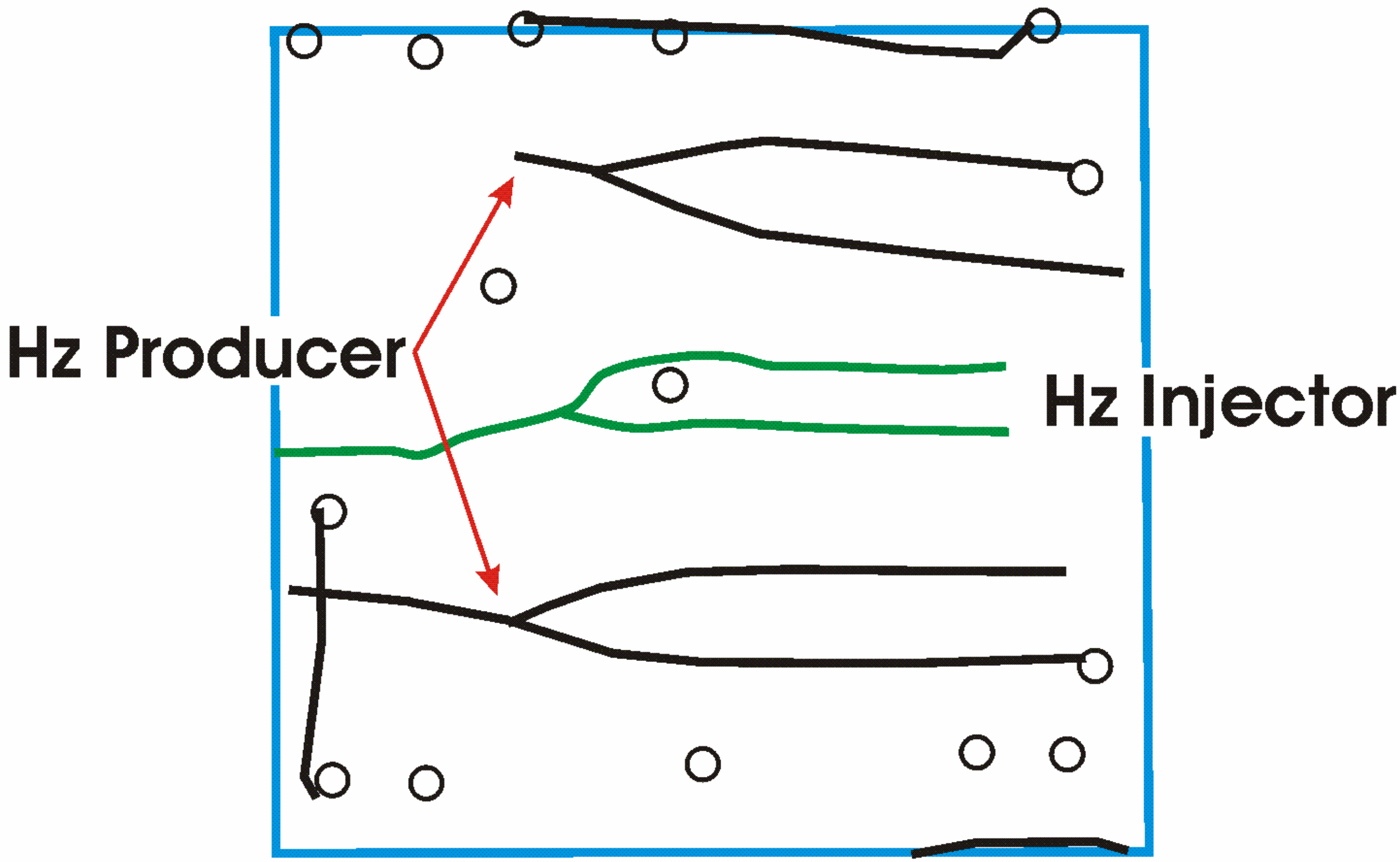
- Geological Characterization
- **Prediction, Monitoring & Verification of CO_2 Movement**
- CO_2 Storage Capacity, Distribution & Economics
- Long-Term Risk Assessment

The Source of CO_2

- Dakota Gasification Company
- 250 mmscfd CO_2 by-product of coal (lignite) gasification
- 95 mmscfd (5000 tonnes/day) contracted and injected at Weyburn
- CO_2 purity 95%
- EnCana currently injects 120 mmscfd (i.e. 21% recycle)



Weyburn Field: Phase 1A EOR Area



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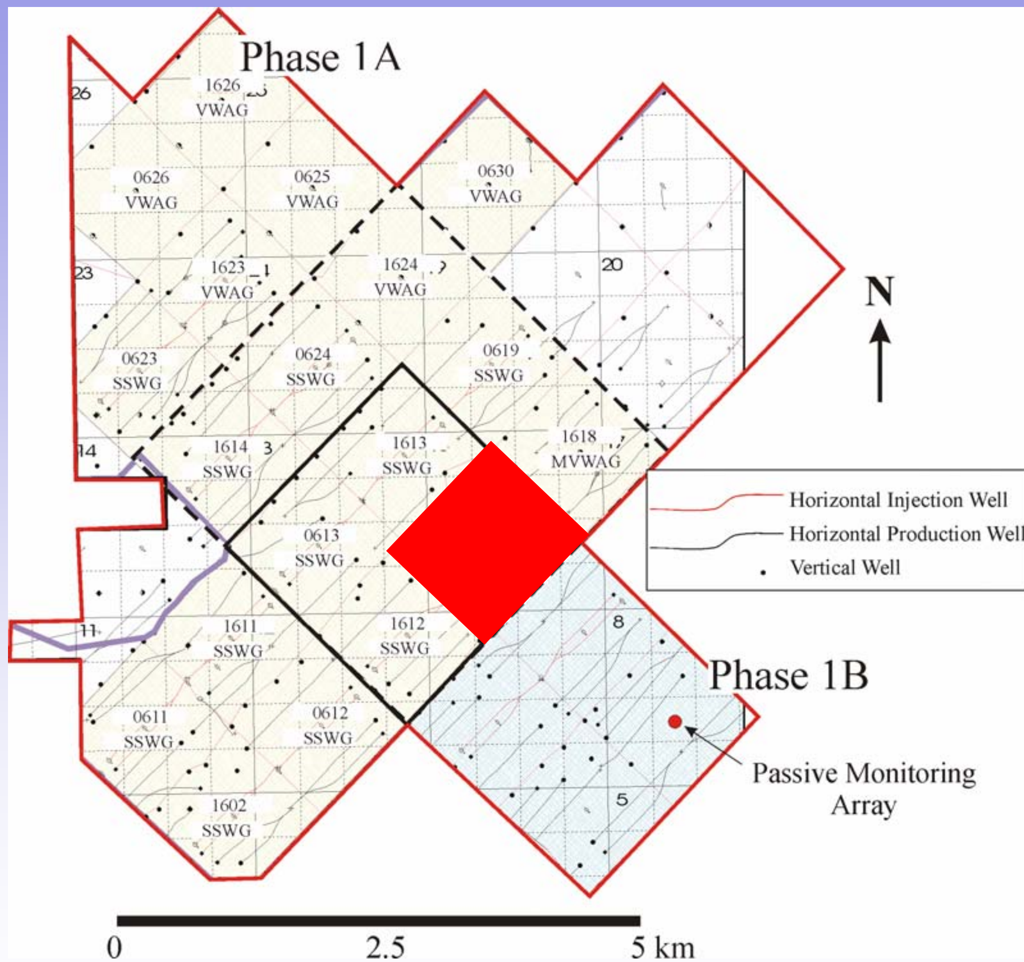
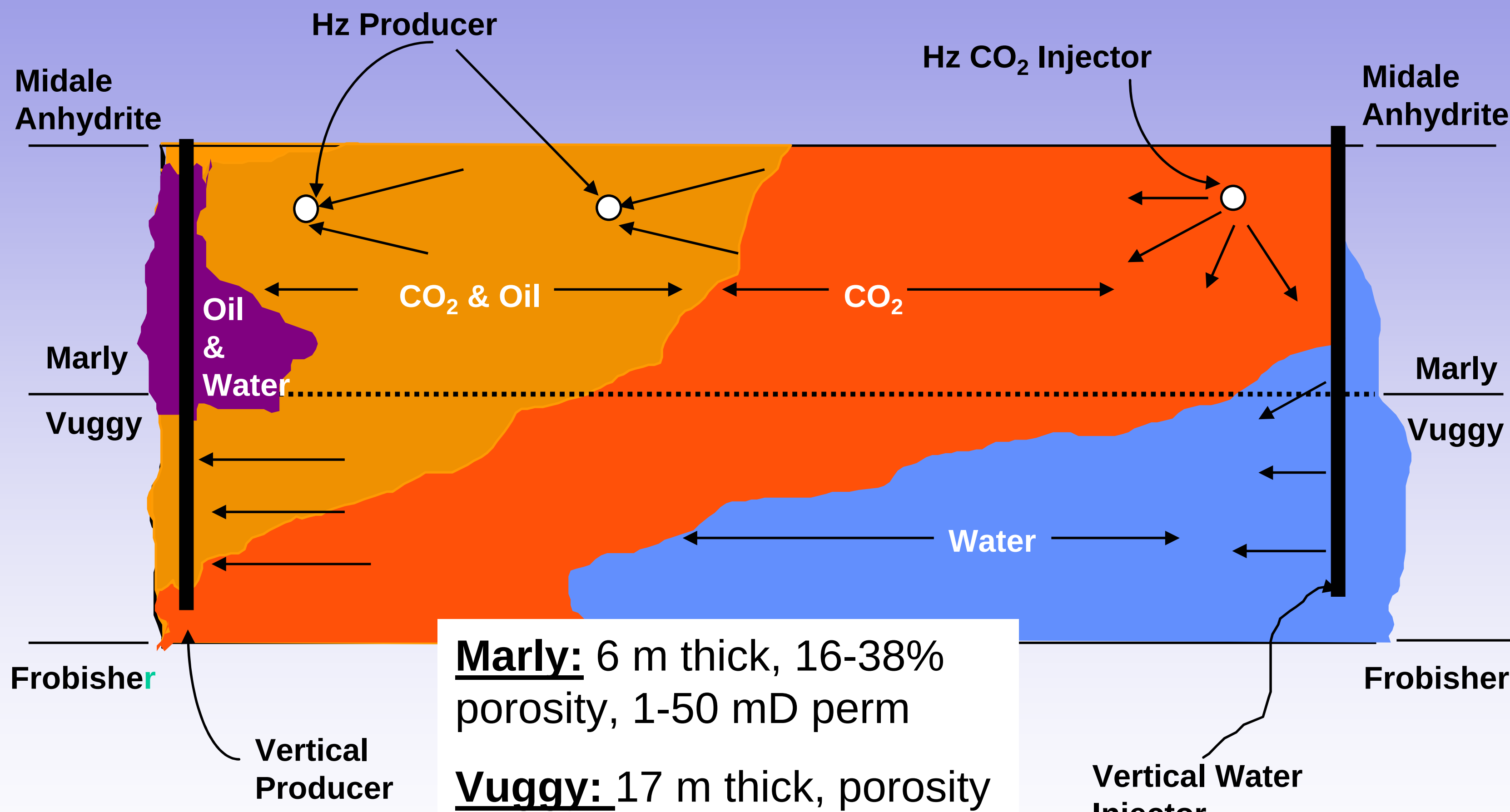


The CO_2 Flood



Marly: 6 m thick, 16-38% porosity, 1-50 mD perm

Vuggy: 17 m thick, porosity 8-20%, 10-300 mD perm

Properties of CO_2

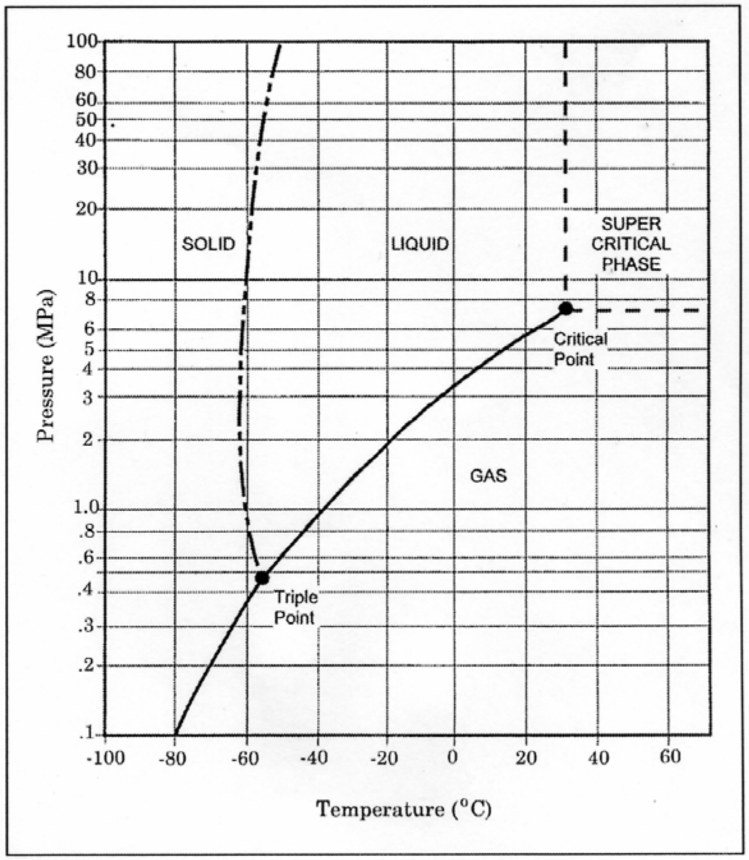


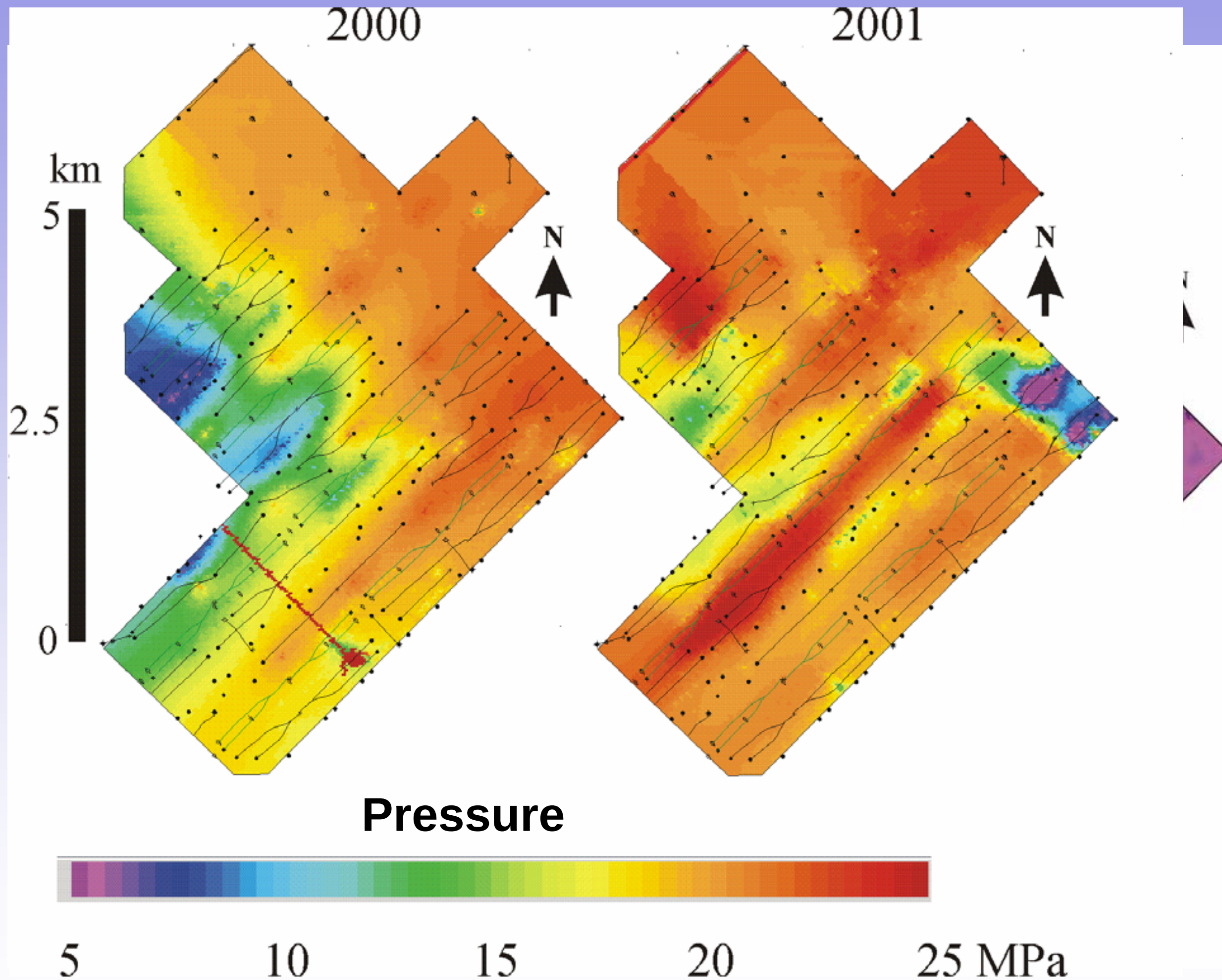
Fig. 4. Phase diagram for carbon dioxide.

Reservoir fluid properties (for P=15-25 MPa; T=63 deg C) summarized from Brown (2002).

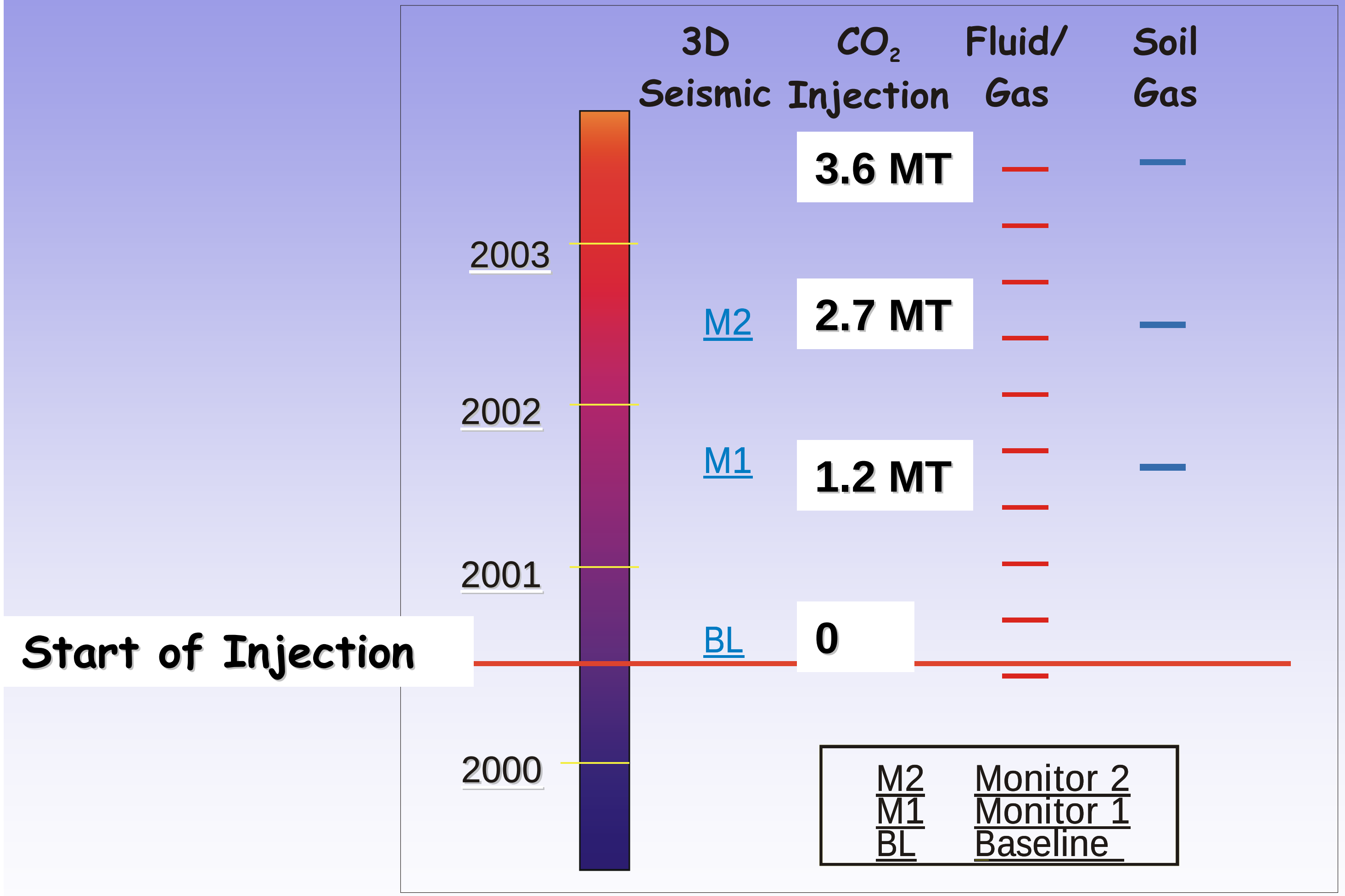
Fluid	Bulk Modulus (GPa)	Density (gm/cc)	Viscosity (relative to oil)	Solubility of CO2 (molar %)
Oil	**1.2-1.7**	0.80-0.88	1	66
Brine	**2.7-3.2**	1.02-1.08	~1/10	1-2
CO_2	**0.05-0.18**	0.58-0.76	1/70	100

Reservoir: T=63^0 C, P>15 MPa

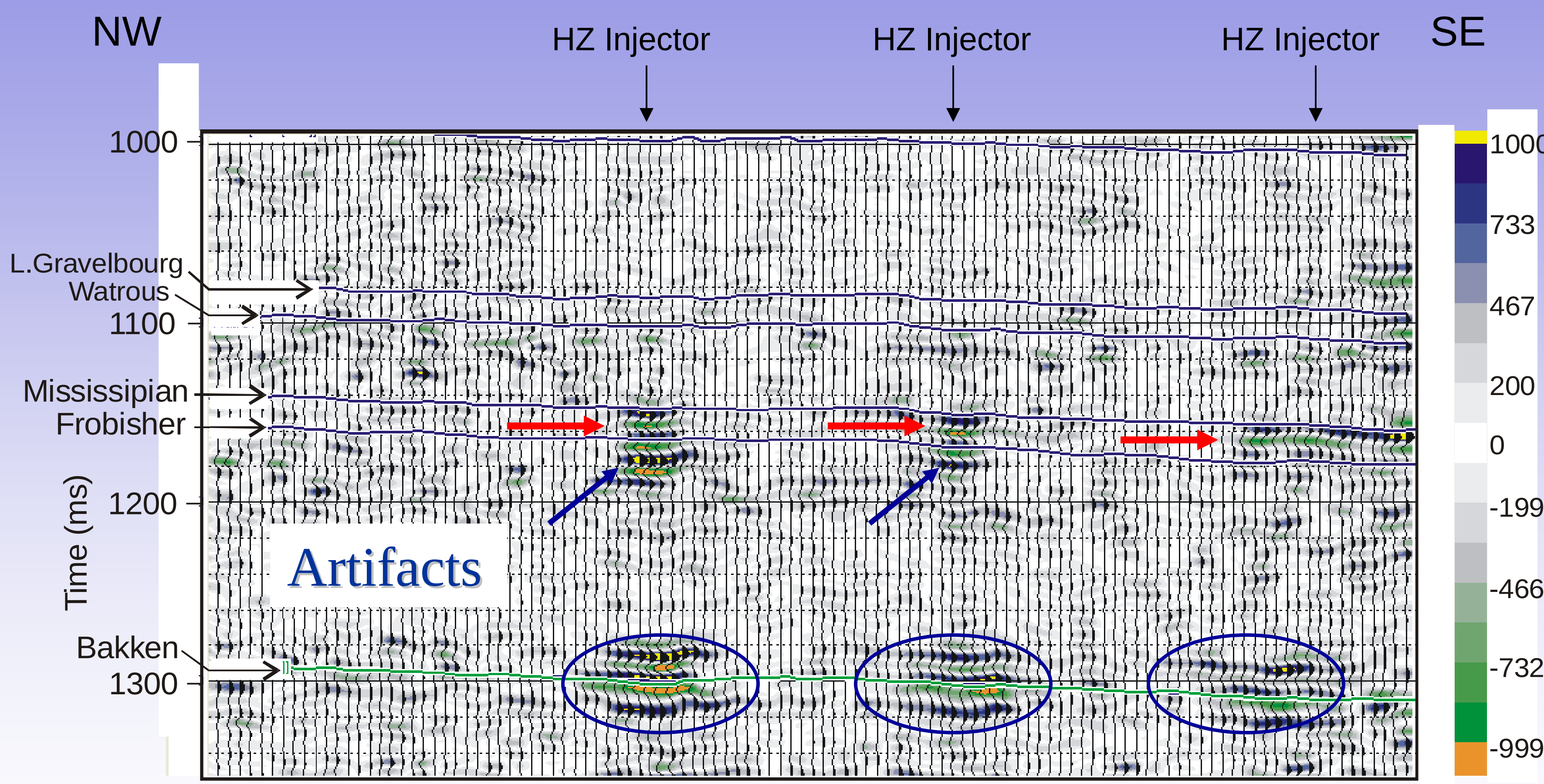
Pre-injection Prediction



Monitoring Schedule

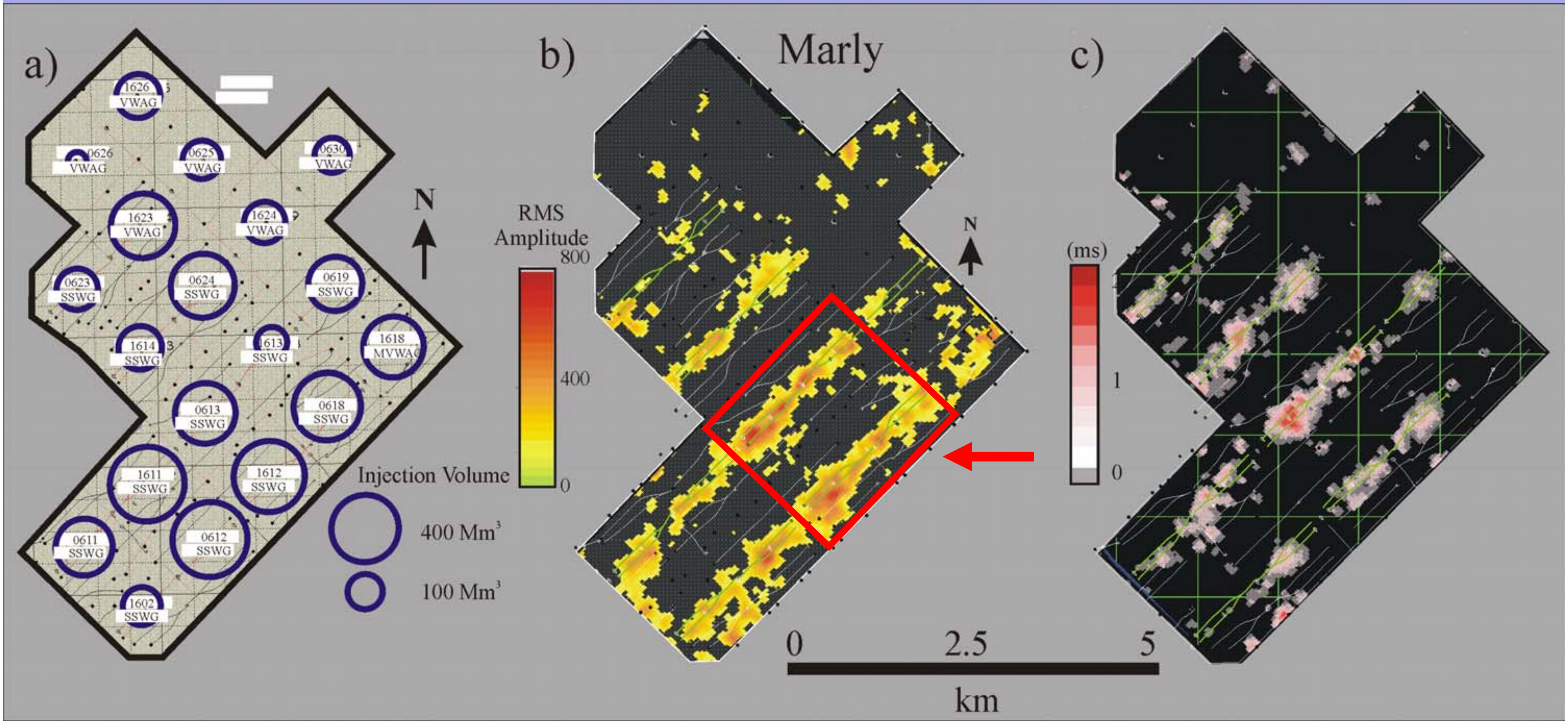


Monitor 2 Time-Lapse Amplitude Difference

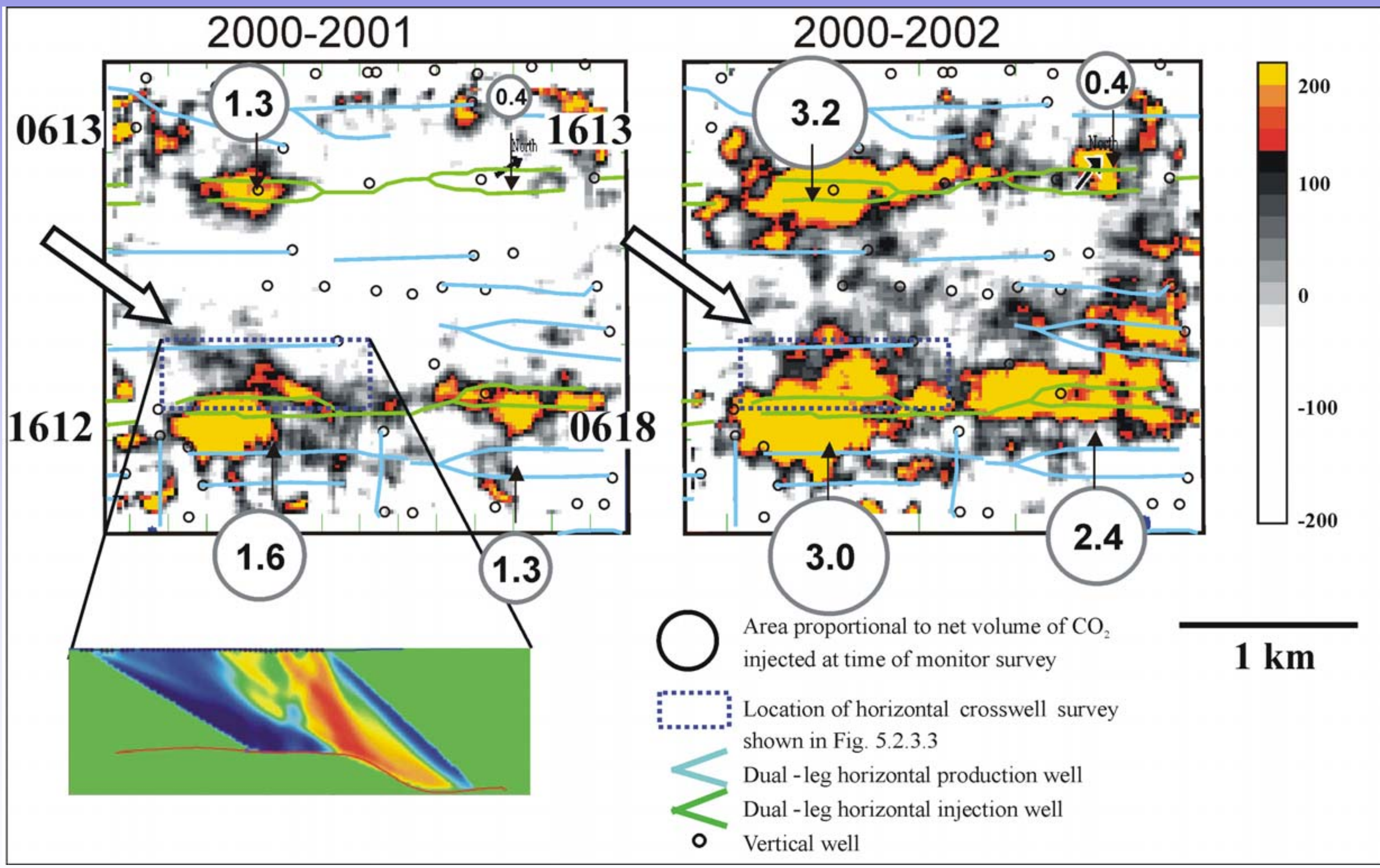


Inline-128

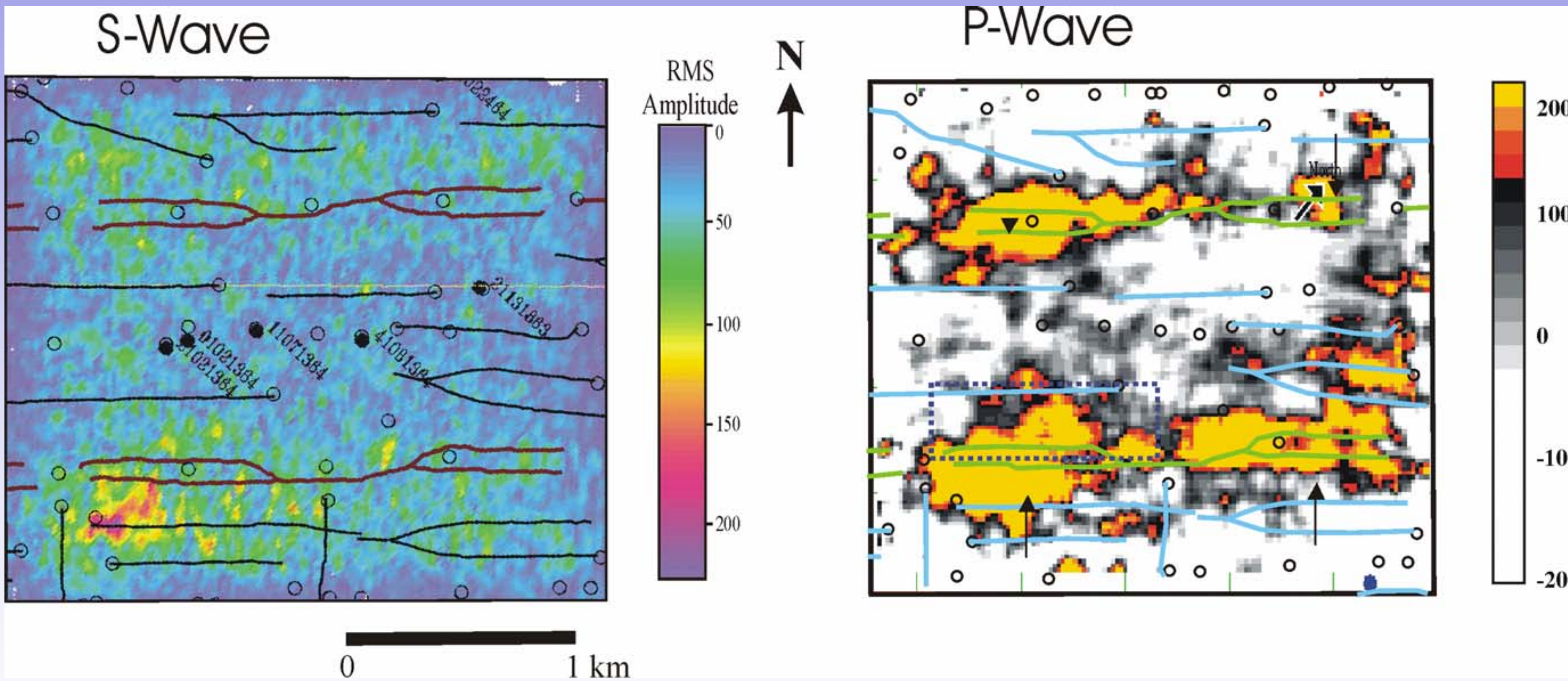
Monitor 2 Production-Seismic Comparison



Amplitude Anomalies at the Reservoir

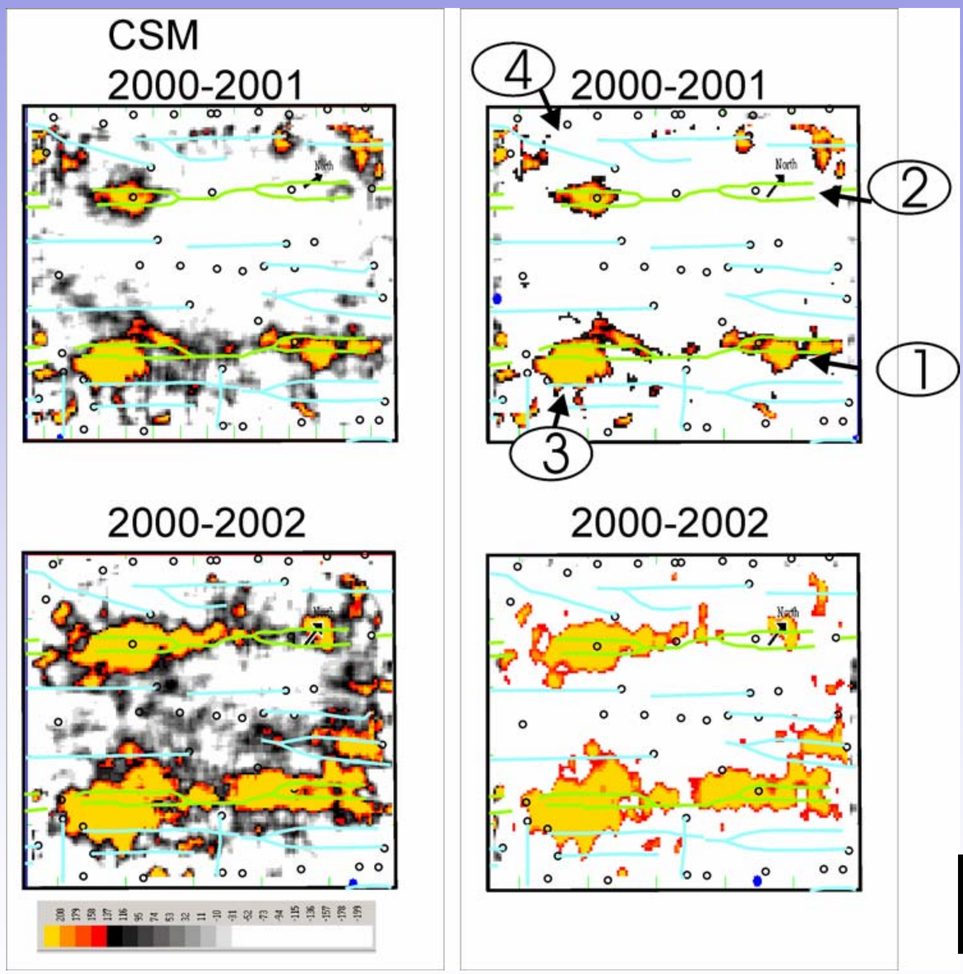


S-wave vs. P-wave Anomalies



Pressure effects are secondary

First-Order Volumetrics



Reservoir Properties:

T=63 deg C

P= 15 MPa

Porosity=0.13

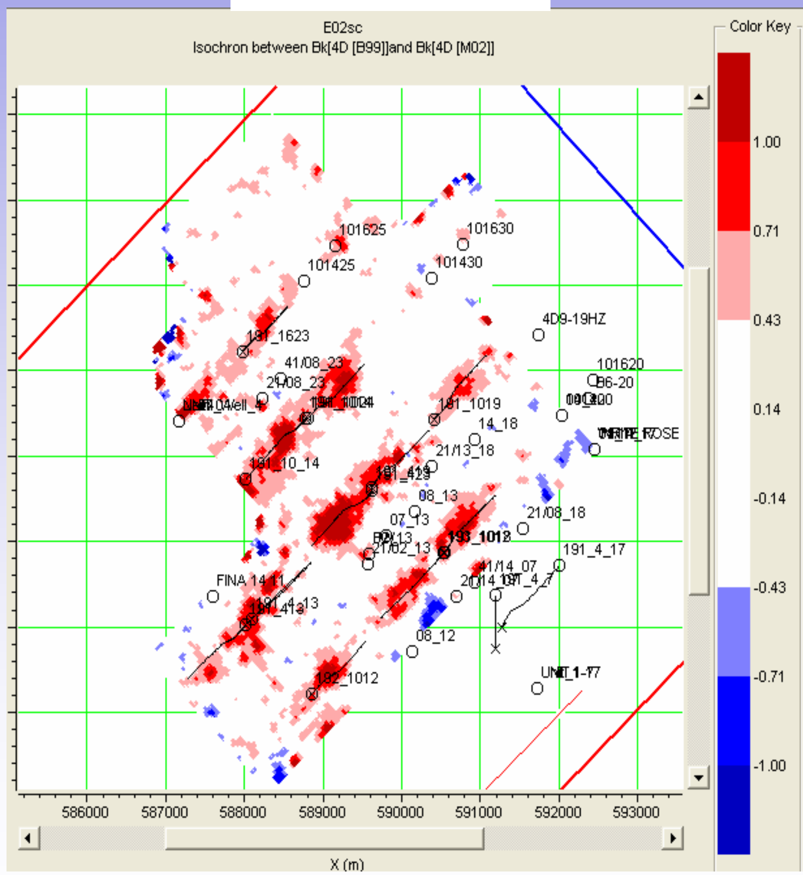
Thickness=23 m

Injector Area	2001 Seismic vol./CO2 vol. Ratio	2002 Seismic vol./CO2 vol. Ratio
1	**5.3**	**6.3**
2	**8.6**	**12.6**
3	**5.4**	**6.2**
4	**3.1**	**4.0**
Total	**4.6**	**5.5**

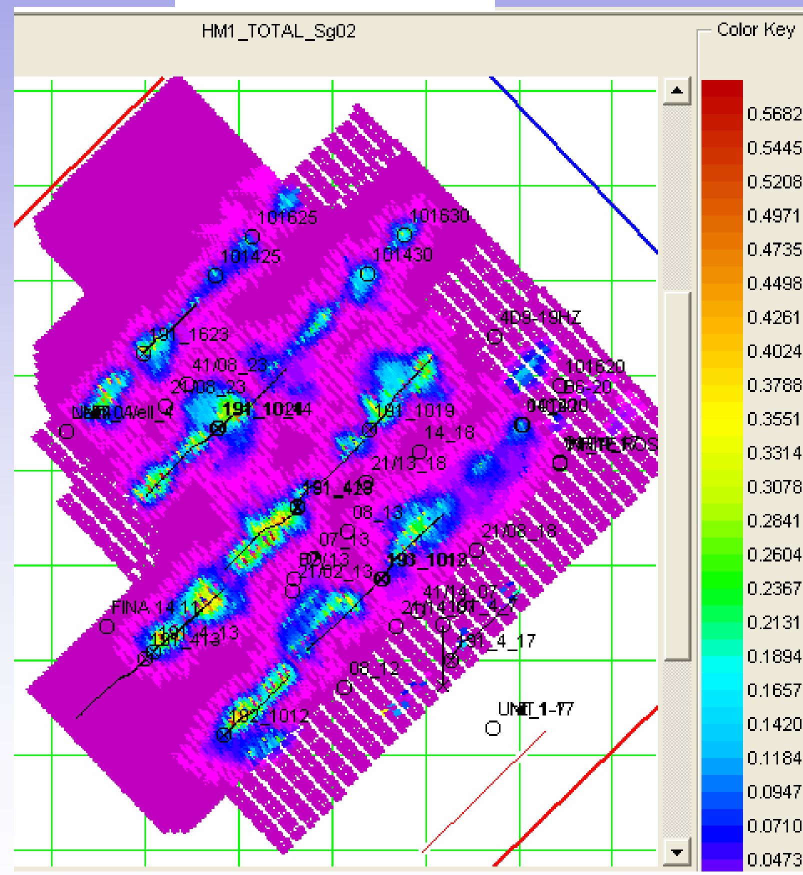
Mean Saturation=0.19-0.23

CO2 distributions from Seismic and Simulator, 1st iteration (Monitor 2 Survey)

Seismic



Simulator



0.5

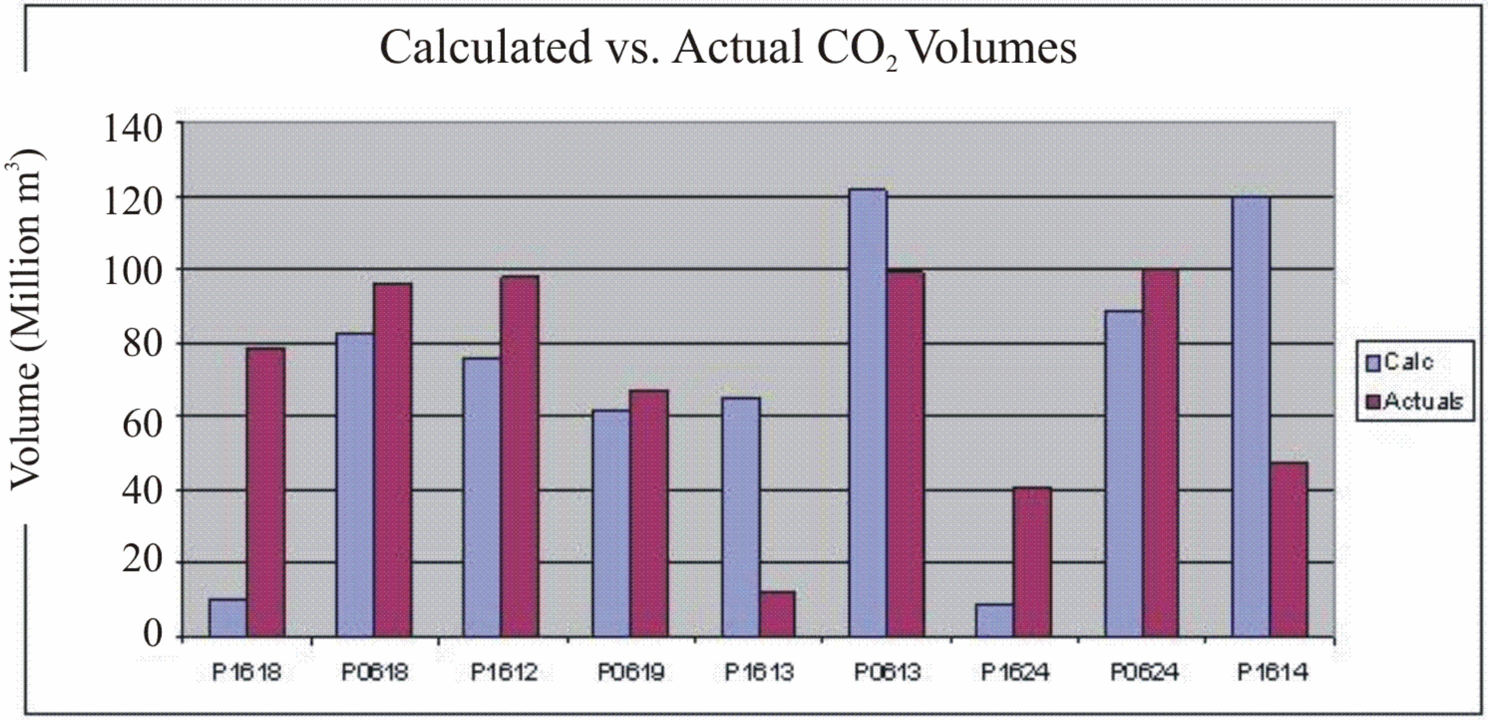
0.4

0.3

0.2

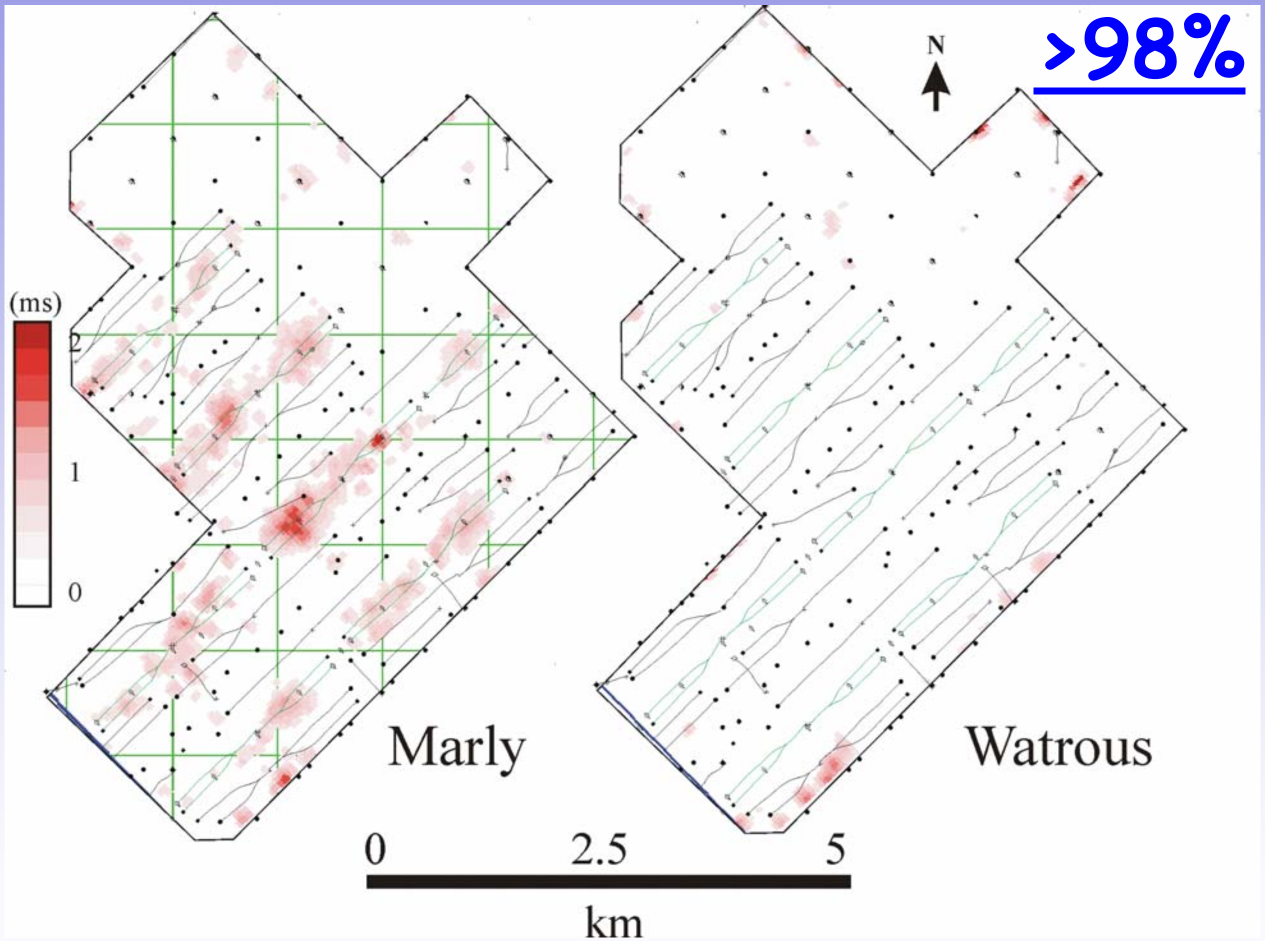
0.1

Net CO_2 injected vs seismic estimate



Assumes average Sg of 0.20

Repeatability



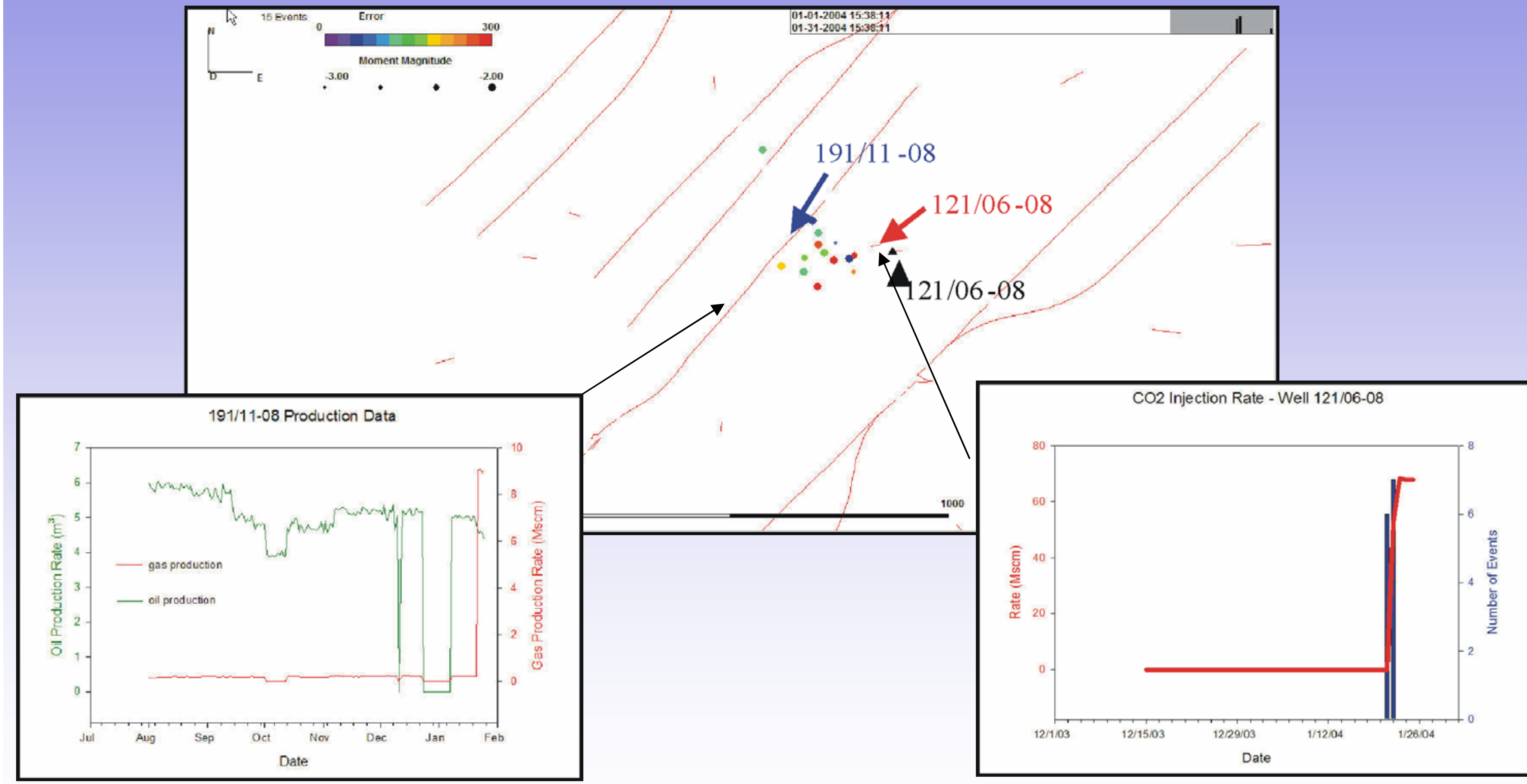
Detection Thresholds

Smallest Amount of CO_2 that can be detected using surface seismic?

Amplitudes: 2500 tonnes
Travel Times: 7500 tonnes

10% CO_2-Rich Phase: 500-1000 tonnes

Microseismicity: Plan View



115 microseismic events with M=-3 to -1 during 15-months.

Summary & Conclusions

- **Monitoring methods** clearly show physical and chemical effects
- **Seismic** methods show **robust time and amplitude anomalies** associated with CO_2 injection.
  - P-wave amplitudes are highly sensitive to CO_2-rich gas phase at low levels of **saturation (5-10%); good for detection**, but makes volume estimation difficult.
  - Volumetric analysis of seismic anomalies: **mean CO_2 saturation of ~20%,** similar to reservoir simulator results.
  - Vp changes of up to 12%: **mainly Sg** with **secondary P effects (2-3%)**.
  - Off-trend anomalies identify areas of **CO_2 channelling.**
  - Sensitivity of amplitude response to upper reservoir changes (Marly unit) allows **partial discrimination of vertical CO_2 distribution.**

Summary & Conclusions

- **1.4 million m³ (2500 tonnes)** of CO_2 is the **minimum detectable amount** using time-lapse surface seismic. This estimate may be overly conservative by an order of magnitude.
- **No evidence for CO_2 escaping** from the reservoir. Based solely on the seismic results, the maximum amount of CO_2 that may have migrated above the reservoir is **<2% of the total injected volume**.
- Contribute to more **accurate reservoir flow simulations.**

- **Microseismicity** is **low** level.
  - 115 microseismic events with M=–3 to –1 during 15-months.
  - Events associated with production/injection changes (*e.g.*, water-to-gas) where **pressure transients** might be expected.
  - Induced microseismicity is **less than for water flooding** that has occurred for more than 30 years.

Role of Seismic Monitoring

- **Reservoir Characterization for Injection Suitability**
  - Structure and properties
  - Reservoir properties required to interpret time-lapse results.
- **Long-Term Monitoring**
  - Justified for EOR, but is it for long-term CO2 injection?
  - Yes. Costs of infrastructure justify reservoir management.
  - Suitable for assessing significant reservoir leakage.

IEA Weyburn CO_2 Monitoring and Storage Project

An International Collaborative Research Program Led by the PTRC Based in Regina, Saskatchewan, Canada

ptrc
Petroleum Technology Research Centre

QUESTIONS ?

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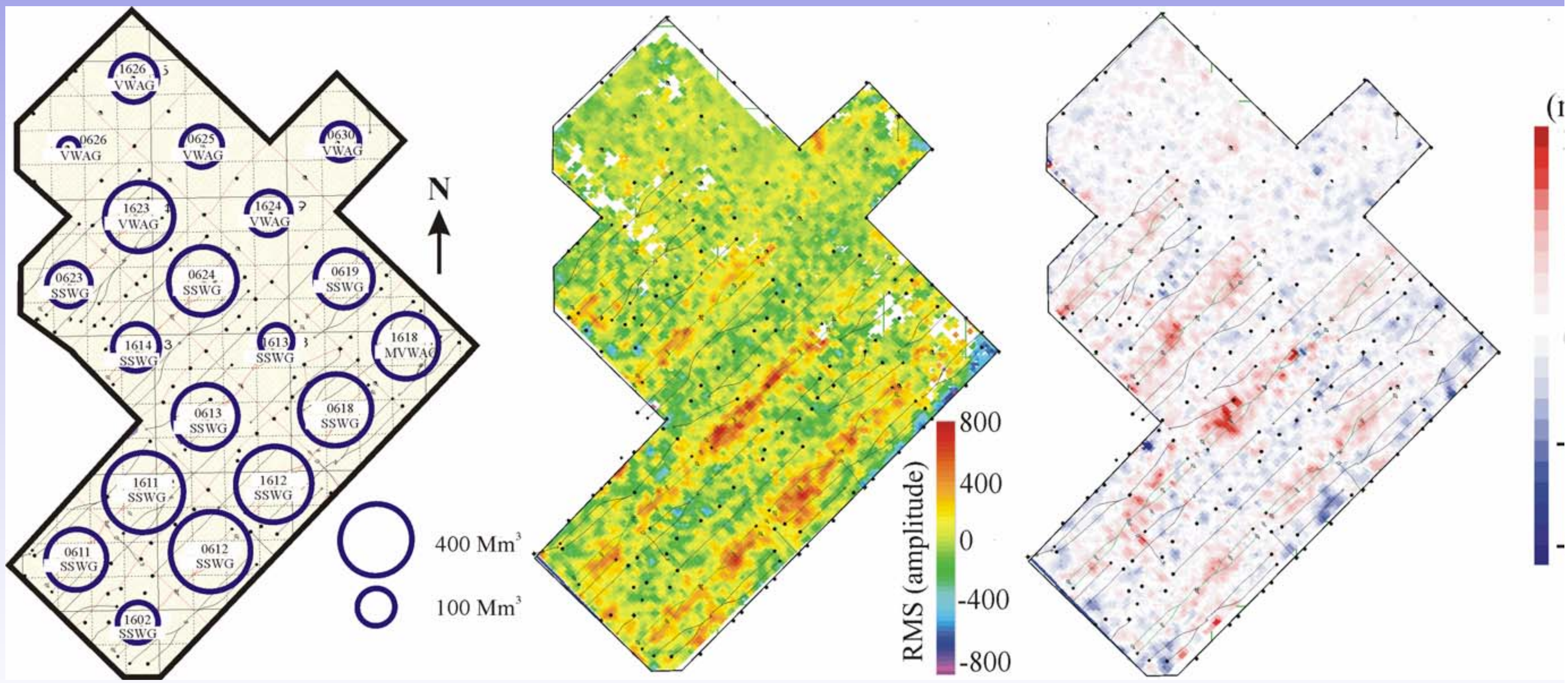
BP, ChevronTexaco, Dakota Gasification Co, Engineering Advancement Association of Japan, Nexen Canada, SaskPower, Total and TransAlta Utilities Corp.

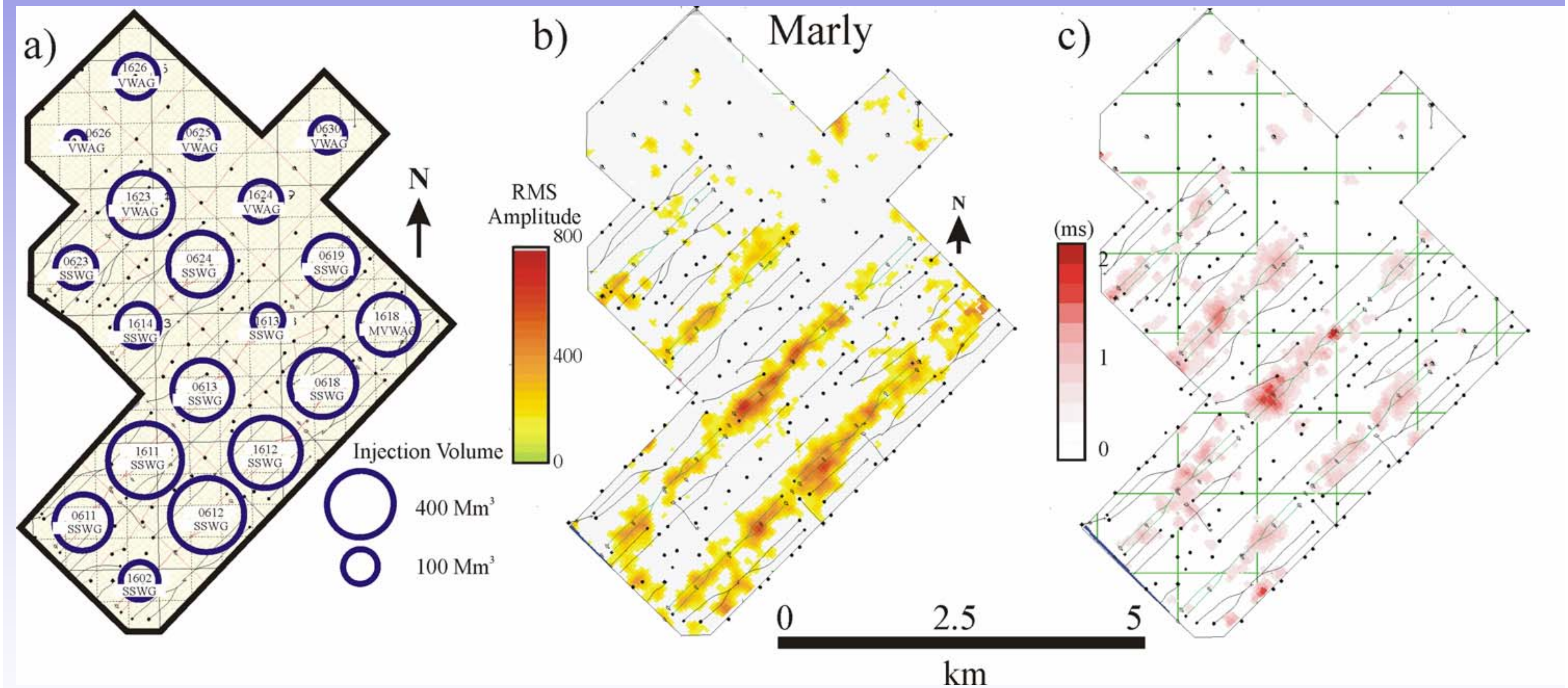
Further Research: Refinement of Techniques

- **In situ measurements for verification of seismic responses.**
- **Improved link between seismic properties, reservoir conditions & reservoir simulation.**
  - **Baseline reservoir characterization for improved CO2 volumetrics**
  - **Beyond thresholding; Quantitative use of seismic anomalies. Requires appropriate rock-fluid physics model.**
  - **Seismic-based dual porosity reservoir simulation**
  - **Testing reservoir simulations by seismic response modelling**
- **New time-lapse seismic monitoring:** Repeatable, efficient, flexible, economic, and continuous 3D multicomponent monitoring. A dedicated seismic array.
- **New analysis of existing data.**
  - **Scenario testing by sub-sampling data sets**
  - **Reprocessing of converted wave (P-S, S-P) and pure-S data**
  - **Revisiting saturation-pressure using prestack analysis**



1626
VWAG
0626
VWAG
0625
VWAG
0630
VWAG
1623
VWAG
1624
VWAG
0623
SSWG
0624
SSWG
0619
SSWG
1614
SSWG
1613
SSWG
1618
MVWAG
0613
SSWG
0618
SSWG
1611
SSWG
1612
SSWG
0611
SSWG
0612
SSWG
1602
SSWG
N
400 Mm³
100 Mm³
RMS (amplitude)
800
400
0
-400
-800

Monitor 2 Production-Seismic Comparison



Monitor 2 Production-Seismic Comparison