EERC Technology… Putting Research into Practice

The Plains CO_2 Reduction (PCOR) Partnership

Zama Field Validation Test

Pittsburgh, PA

December 12, 2007

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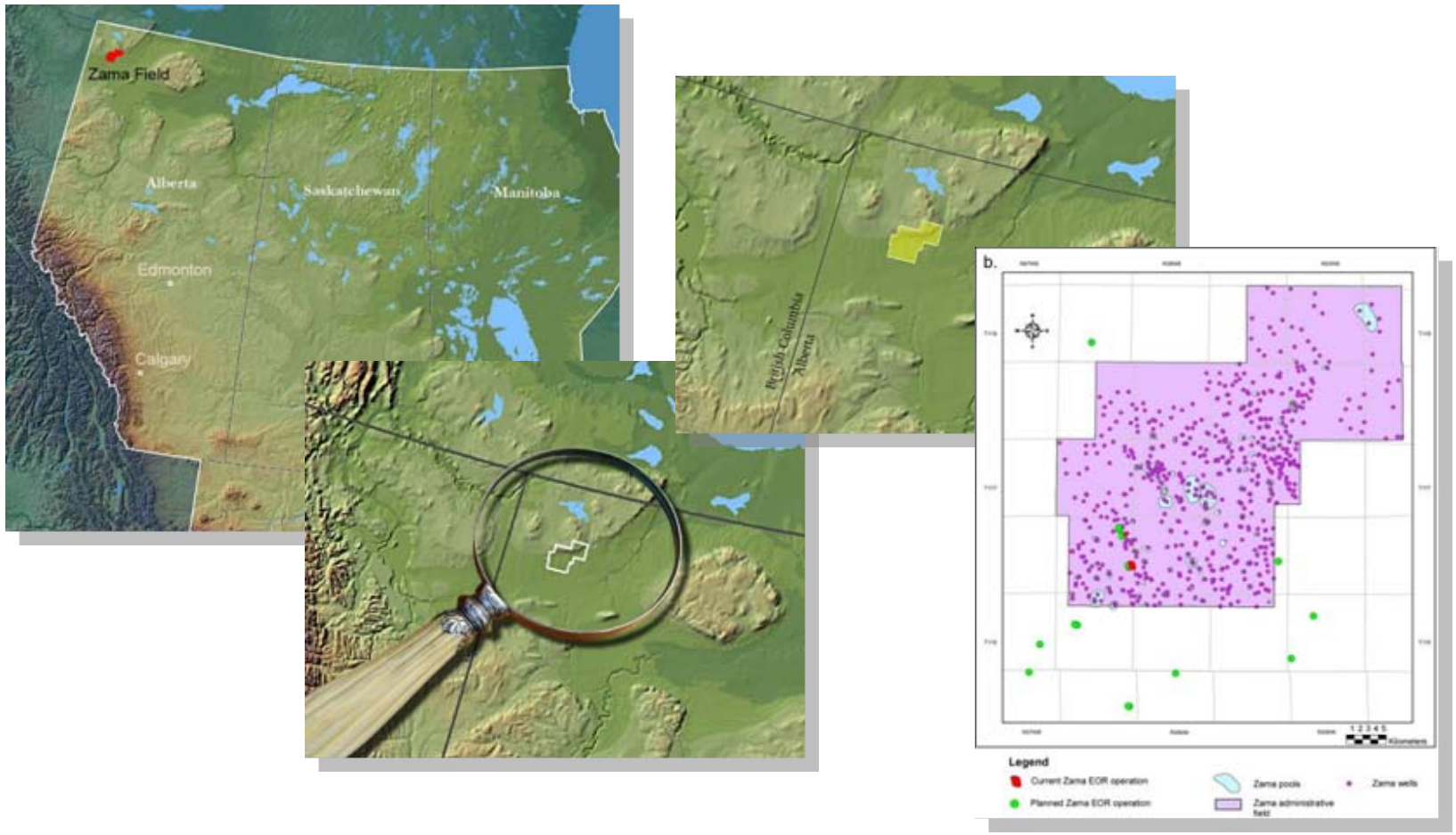
Where's Zama?



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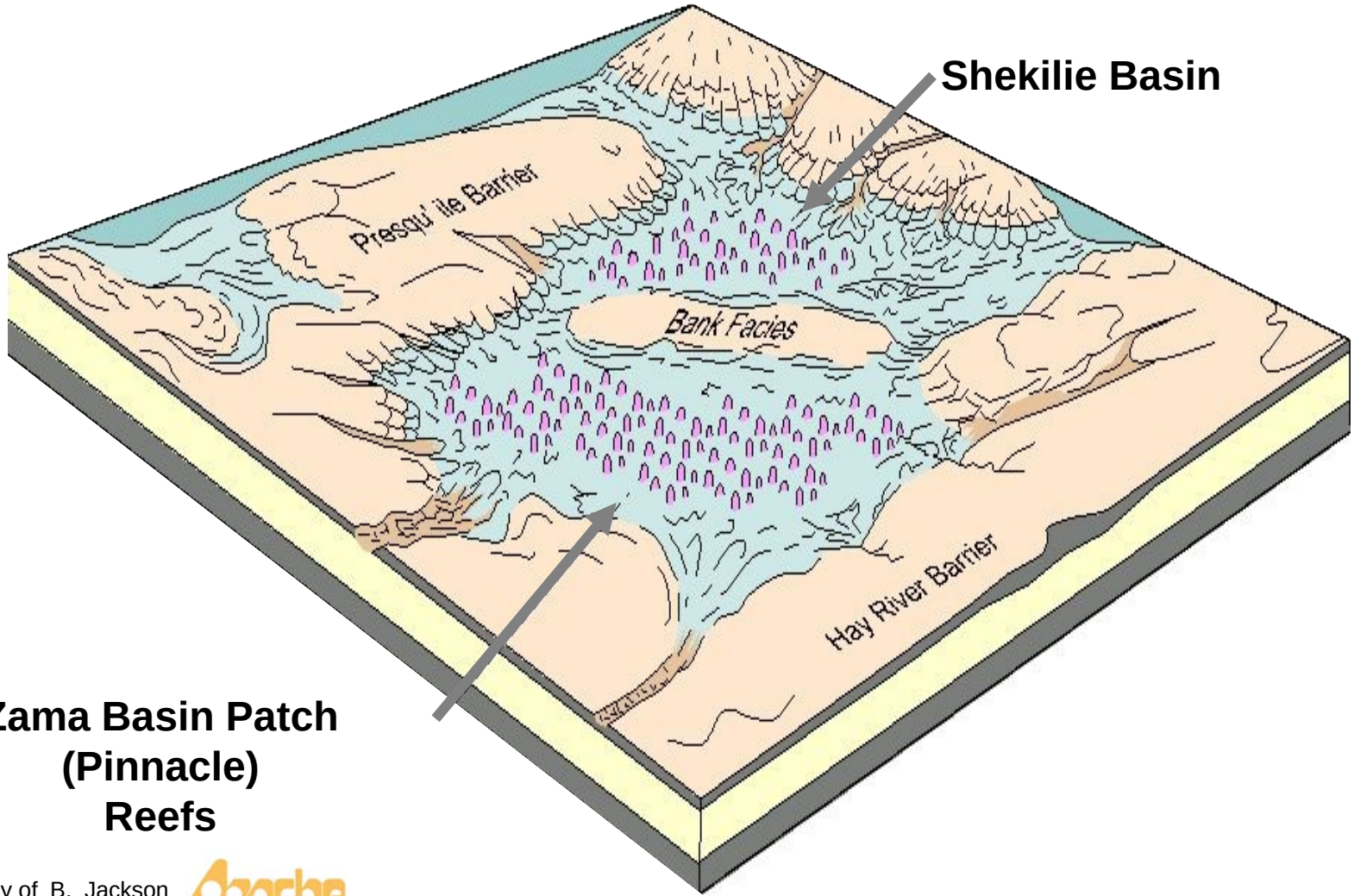
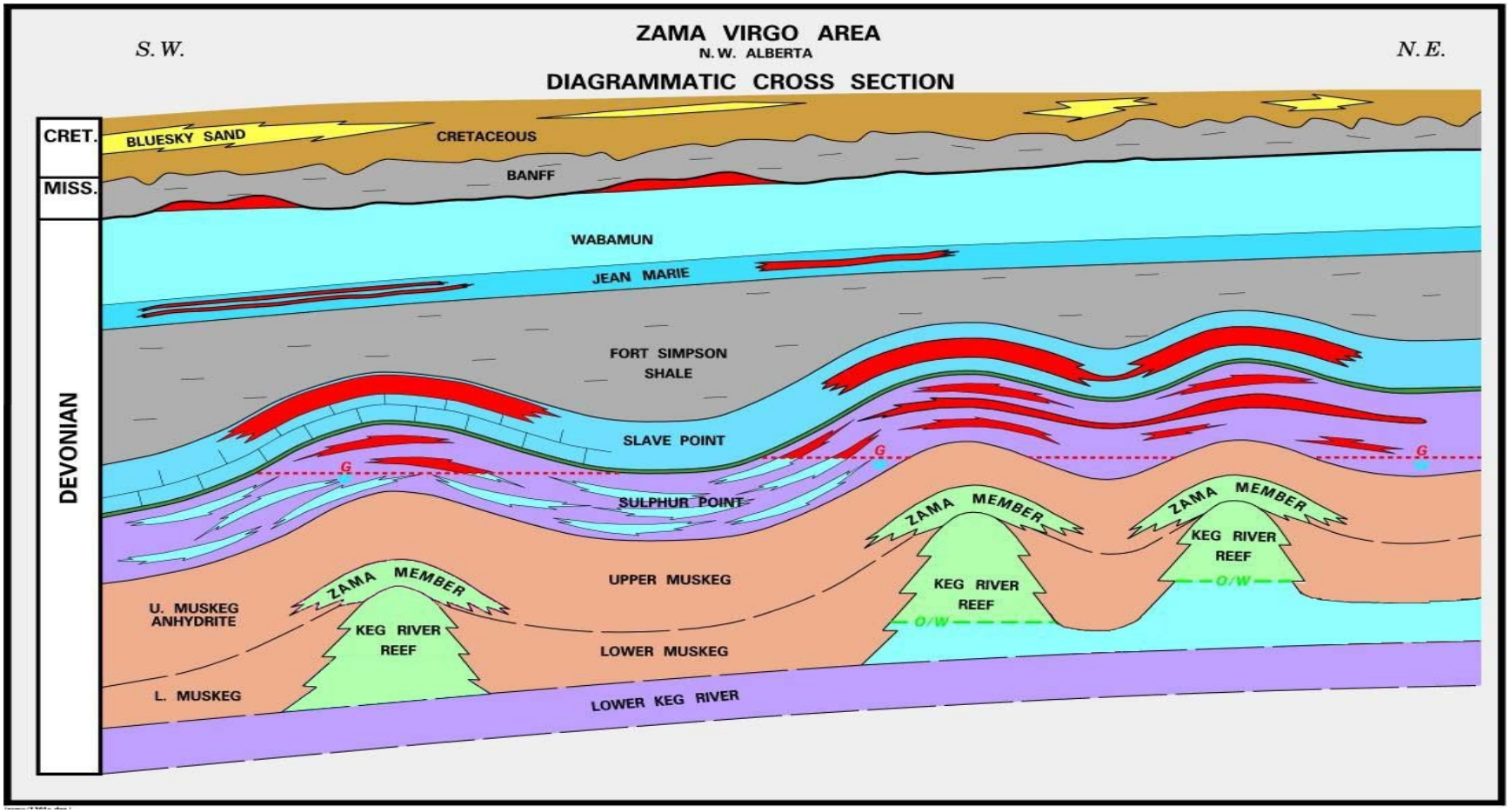
Zama Acid Gas Project – Zama/Shekilie Basins



Slide courtesy of B. Jackson

Pinnacles w/Heterogeneous Reservoir Properties



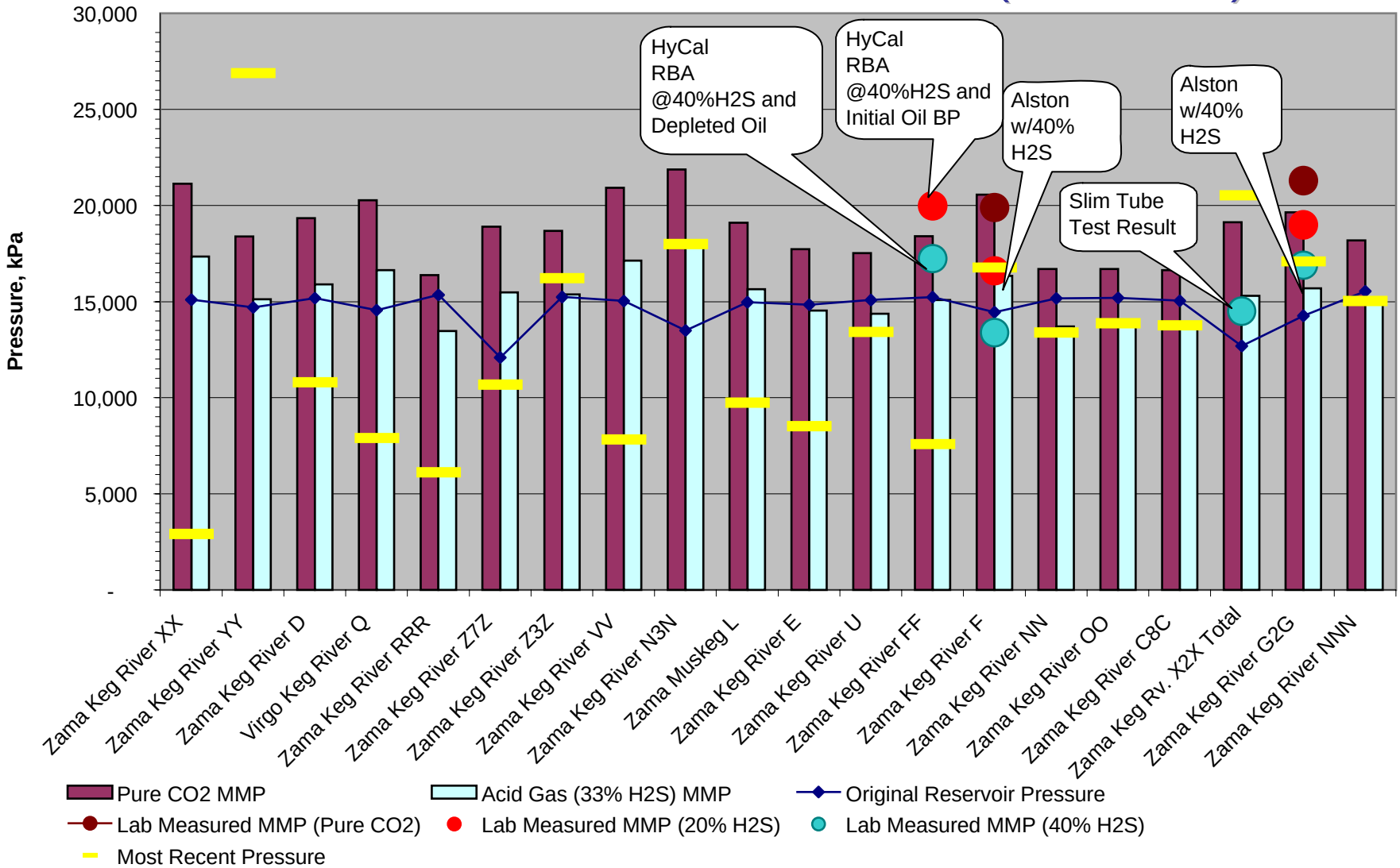
Slide courtesy of B. Jackson

Zama History

Discovery	**1967**
Primary Well Development	**60's-70's**
Waterflood Implementation (selected pinnacle reefs)	**80's - present**
Number of Pools Discovered to Date	**846**
Cumulative oil produced to August 2006	**209 mmstb (17.4% OOIP)**
Current Field Production	**6,550 bopd @ 80.1% water cut**

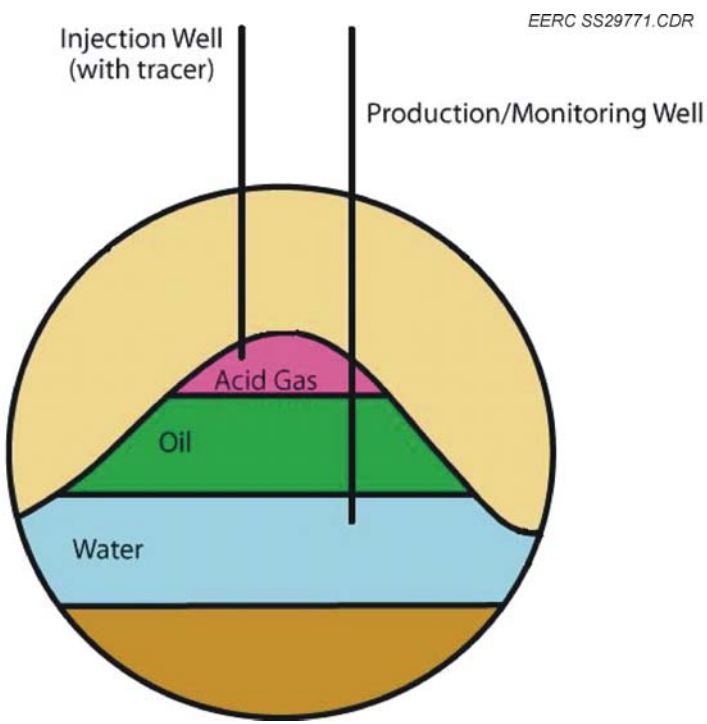
Source: Nimchuck, 2006

Current Reservoir Pressures Vs. Original Candidate EOR Pools Near Zama Gas Plant (6 km radius)



Source: Lavoie, 2005

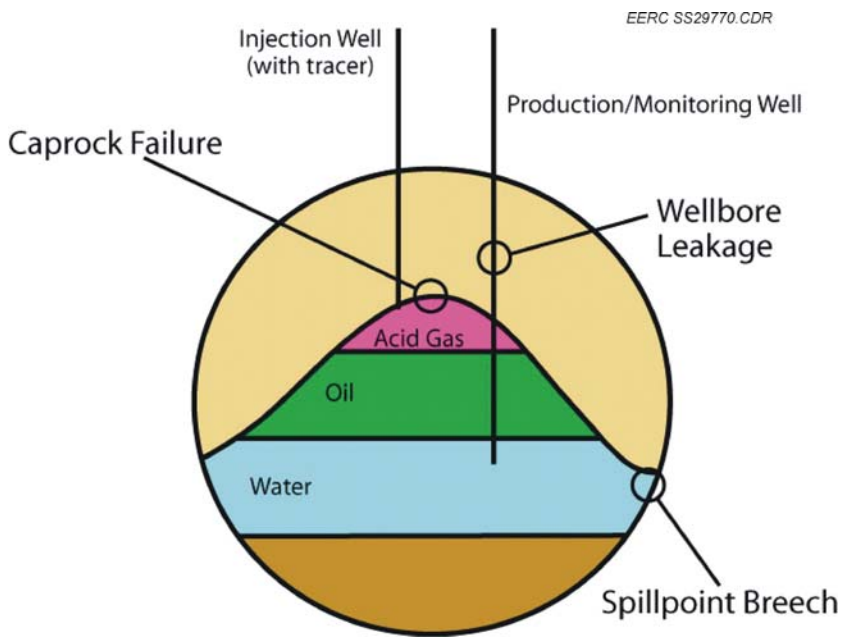
Zama Pinnacle



- Carbonate reservoir
- About 40 acres at the base (.16 km^2)
- 400 feet tall (120 m)
- One production well and one injection well

Technical Goals

- Ensure that acid gas is not migrating to adjacent strata.
- Determine the integrity of the cap rock.
- Understand the effect of acid gas injection on this geological system.



Injection

- Began December 2006
- Rates between 400 Mcf/day and 1 MMcf/day (22 to 60 tons/day)
- 70% CO_2 and 30% H_2S
- Over 8000 tons have been injected to date
- Anticipate between 60,000 and 100,000 tons by project end (2009)

MMV Operations

Monitor the CO_2/H_2S plume through:

- Perfluorocarbon tracer injection.
- Reservoir pressure monitoring.
- Wellhead and formation fluid sampling (oil, water, gas).
- Early warning of reservoir failure.
- Pressure measurements of injection well, reservoir, and overlying formations.
- Fluid sampling of overlying formations.

Injection well conditions:

- Wellhead pressure gauges
- Well integrity tests
- Wellbore annulus pressure measurements

Monitor for leakage up faults or fractures:

- Reservoir and aquifer pressure monitoring

Tracer

- 4 kilograms being injected.
- Gas-phase chemical perfluorocarbon tracer exhibits low detection limits (lower than most radioactive tracers).
- Environmentally friendly, nontoxic, safe to handle, and nonreactive.
- Extremely stable at all conditions in the program.
- Cost-effective (approximately $25,000 for entire program, including sample analysis).

Current Reports

Current Reports Completed on the Zama Project

- Acid Gas–Brine Static Partitioning Study
- A Study of the Reservoir Condition Drainage and Imbibition Permeability
- Displacement Characteristics of Supercritical Carbon Dioxide in the Zama Area, Sulphur Point Formation
- Experimental Study of CO_2 and H_2S Partitioning in a Brine-Saturated Porous Medium
- Evaluation of Zama Field Wellbore Integrity, Part I
- Evaluation of Zama Field Wellbore Integrity, Part II (Evaluation of Leakage Potential by Well)

Current Reports (cont.)

Current Reports Completed on the Zama Project

- Regional-Scale Geology and Hydrogeology of Acid Gas
- Enhanced Oil Recovery in the Zama Oil Field in Northwestern Alberta, Canada
- Reservoir Condition CO_2–Brine Drainage and Imbibition Relative Permeability Displacement Characteristics in the Zama Area, Muskeg Anhydrite Formation (Cap Rock)
- Uniaxial, Triaxial, and Elastic Properties Determinations on Samples from the Zama Field, Northwest Alberta

Zama Characterization

Geomechanical	Geological	Geochemical
Laboratory Testing Program *Compression Tests* • Strength • Static and Dynamic Elastic Properties • Compressibility • Stress-Dependent Permeability *Sonic Tests* • Compressional and Shear Wave Velocities ***Historical Correlation Program and Analytical Work*** *Wireline Logging* • Dynamic Elastic Properties • Stress Regime *Analytical Work* • Correlation of Static-to-Dynamic Elastic Properties • Geomechanical Simulation • Assessment of Rock Integrity	• Baseline geology • Rock mineralogy and composition of formation water • Hydrogeological framework • Mechanical rock properties and stress regime	• Assessment of geochemical interactions between formation and injected fluids and reservoir rock and cap rock • Geochemical modeling

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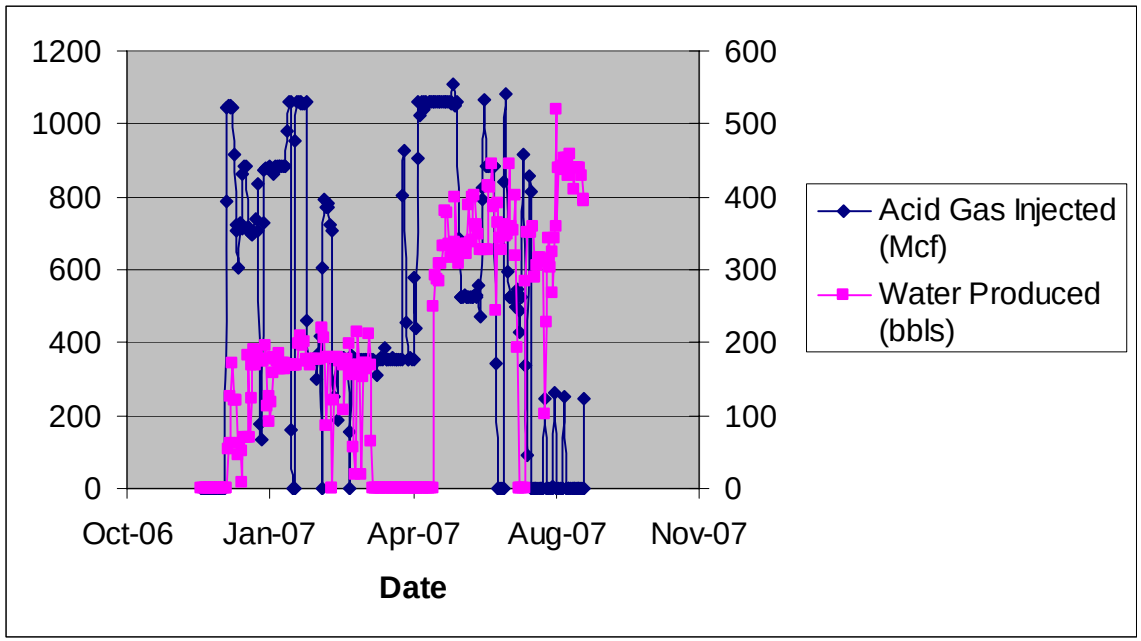
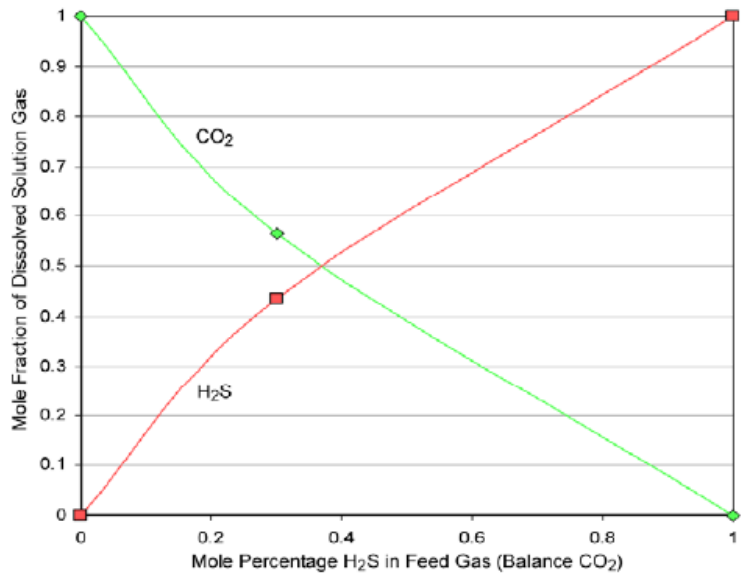
Zama Acid Gas Injection Profile



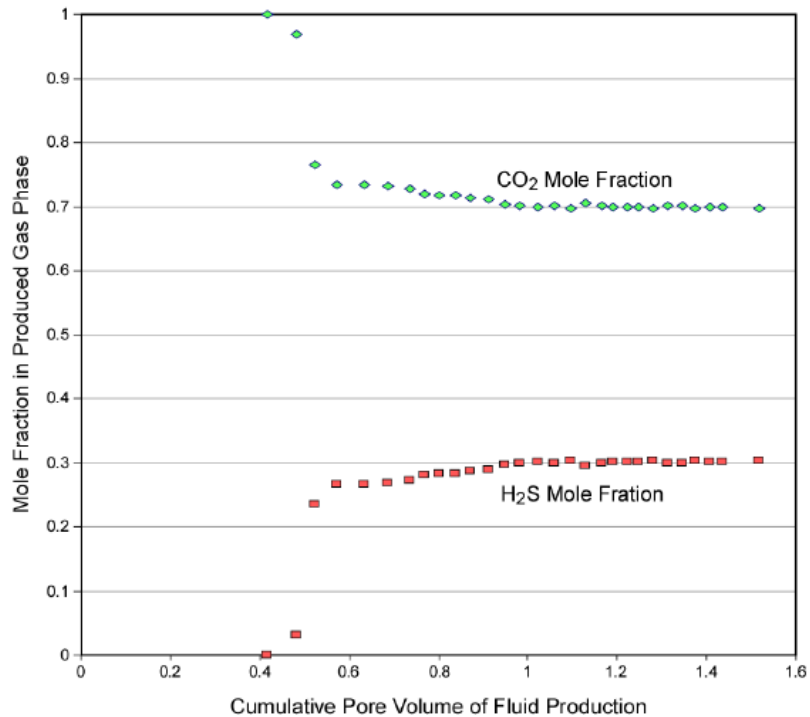
- Injection rates are being varied to match production and maintain pressure.
- No oil production has occurred since acid gas injection started (positive indication that injection is working properly).
- Cumulative injection is now over 8000 tons.

Acid Gas–Brine Static Partitioning Study

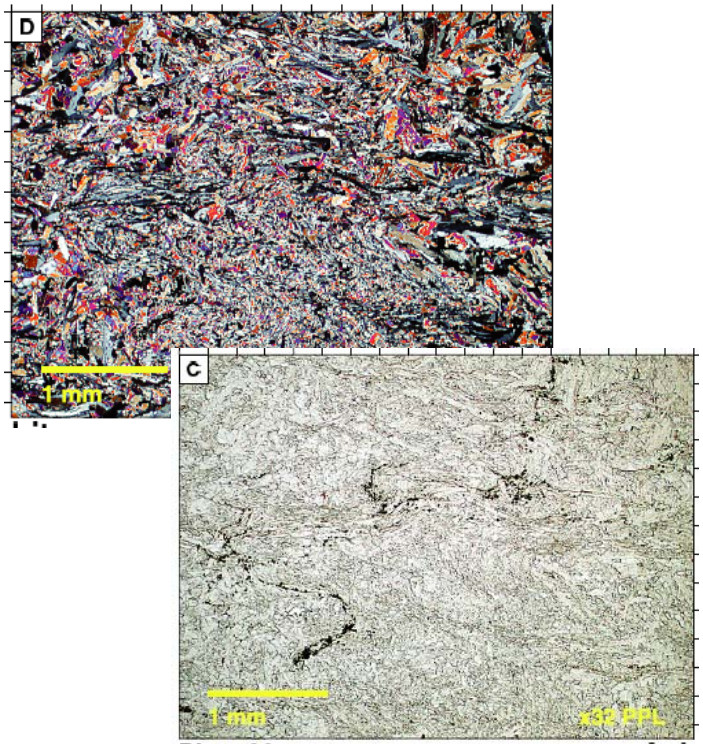


- To determine preferential retention effect of H_2S.
- Performed at 140°F and 1960 psi.
- Brine composition 119,000 ppm TDS.

- Results indicate CO_2 will lead H_2S in the sweep displacement front.
- May provide warning of a potential future breakthrough of acid gas.



Relative Permeability

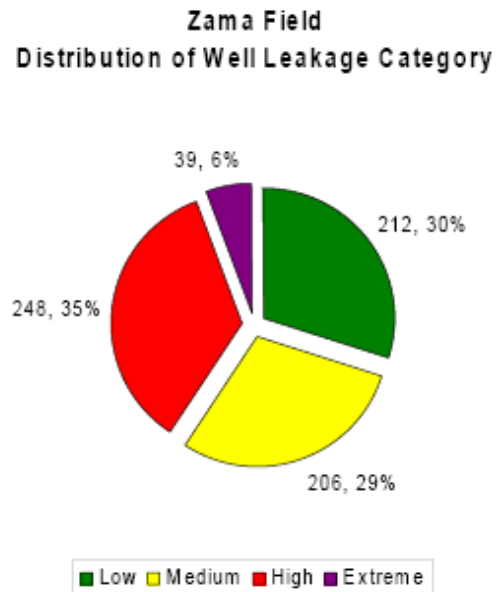


- To determine CO_2 and formation brine displacement characteristics of the pinnacle cap rock (anhydrite).
- Prior to testing:
  - Capillary pressure testing to determine pore throat opening size
  - Petrographic analysis
- Two samples tested using formation brine, CO_2, H_2S, and an acid gas mixture of 70% CO_2 and 30% H_2S.
- Results show very low permeability in the cap rock, indicating low potential for natural fluid flow out of the pinnacle.

Test Phase	Permeability mD	Relative Perm Fraction	Sw Fraction	Sg Fraction
Initial Absolute Brine Perm	0.0001680000	1.0000	1.0000	0.0000
Supercritical Acid Gas Perm	0.0000000050	0.0000298	0.8990	0.1010
Post Acid Gas Brine Perm	<0.0000000010	tstm	0.9050	0.0950

Wellbore Evaluation

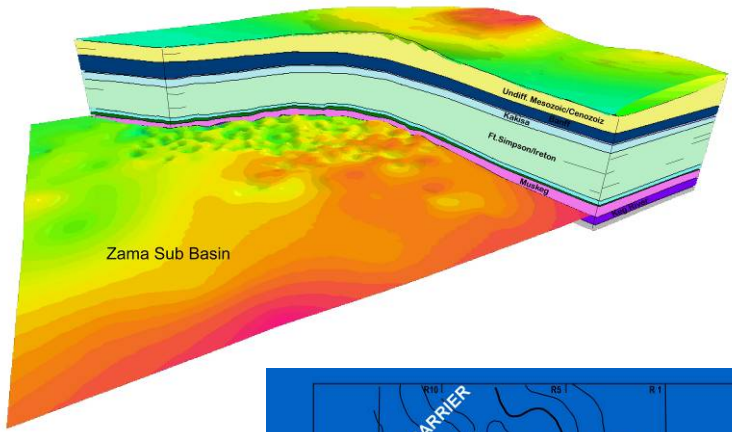
- Wells ranked on several criteria including:
  - Spud date.
  - Abandonment date.
  - Surface casing size.
  - Well type.
  - Location.
  - Depth.
  - Well deviation.
  - Cementing technique.

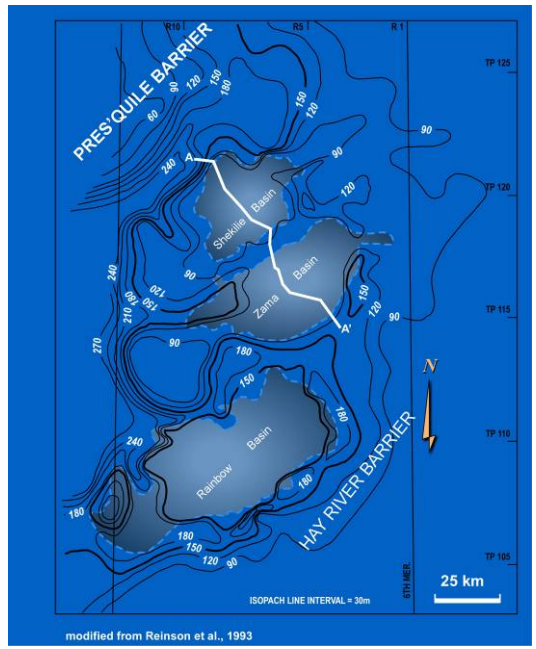


Category	Well Score Range	Description
Low	≤ 200	Typical for D&A wells. Low potential for leakage
Medium	201-600	Generally newer wells. Are typically close to the provincial average for potential for well leakage
High	601-999	Typically cased wells with low cement tops generally abandoned after 1995 or not yet abandoned. Will exhibit leakage potential above provincial average.
Extreme	≥ 1000	Typically cased wells abandoned prior to 1995. Will exhibit leakage potential lower than provincial average due to lack of testing.

Geology and Hydrogeology Results

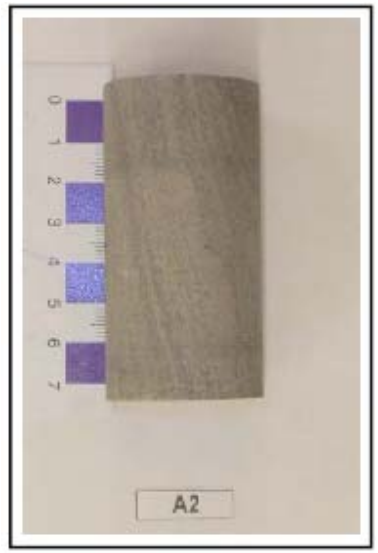
- Conducted to better understand the storage characteristics of regional aquifer systems and the fate of acid gas in case of leakage outside the pinnacle.
- **Results indicate there is minimal potential for acid gas migration to shallower strata and potable groundwater.**
- Leakage migration, should it occur, would be a very slow process (thousands of years) and would likely be limited to much less than a kilometer from the site because of dissolution, dispersion, and residual gas trapping along the migration pathway.





Rock Mechanics Results

- Lab testing of eight core samples has occurred.
  - Primarily dolomite from the Keg River Reservoir and dolomite and anhydrite from the Muskeg cap rock.
- Tests include:
  - Bulk density.
  - Acoustic velocity.
  - Uniaxial strength.
  - Triaxial strength.
  - Residual friction measurements.
- **Results indicate that the cap rock is significantly stiffer than the reservoir rock and is, therefore, a competent seal.**



MMV Results

- Monitoring of reservoir dynamics is ongoing.
- Reservoir dynamics data (pressure and fluid analyses) have shown no evidence of acid gas migration from the pinnacle.
- Monitoring well in overlying Slave Point Formation has been sampled four times since injection and shows no evidence of acid gas.
- Tracer injection is anticipated to occur before the end of 2007.

Zama Path Forward

- Injection of acid gas will continue through Year 4 of Phase II.
- Core samples will be collected from an acid gas disposal zone to examine the mineralogical and geomechanical changes that can occur in a carbonate rock exposed to high-pressure acid gas.
- Geomechanical data will be used to populate a database that will support the creation of a geomechanical model of the pinnacle reef.
- Geochemical modeling activities will be conducted to predict the long-term effects of acid gas injection on the reservoir and caprock formations.
- A Regional Technology Implementation Plan will be developed.

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Project Recognition

Officially Recognized by the Carbon Sequestration Leadership Forum in March 2007 as an Official Geological Storage Project

For more information on the PCOR Partnership please contact:

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