EERC Technology… Putting Research into Practice

Zama Acid Gas EOR, CO_2 Sequestration, and Monitoring Project

Regional Carbon Sequestration Partnership Annual Peer Review Meeting

Pittsburgh, Pennsylvania
October 6, 2008

John Harju
Energy & Environmental Research Center

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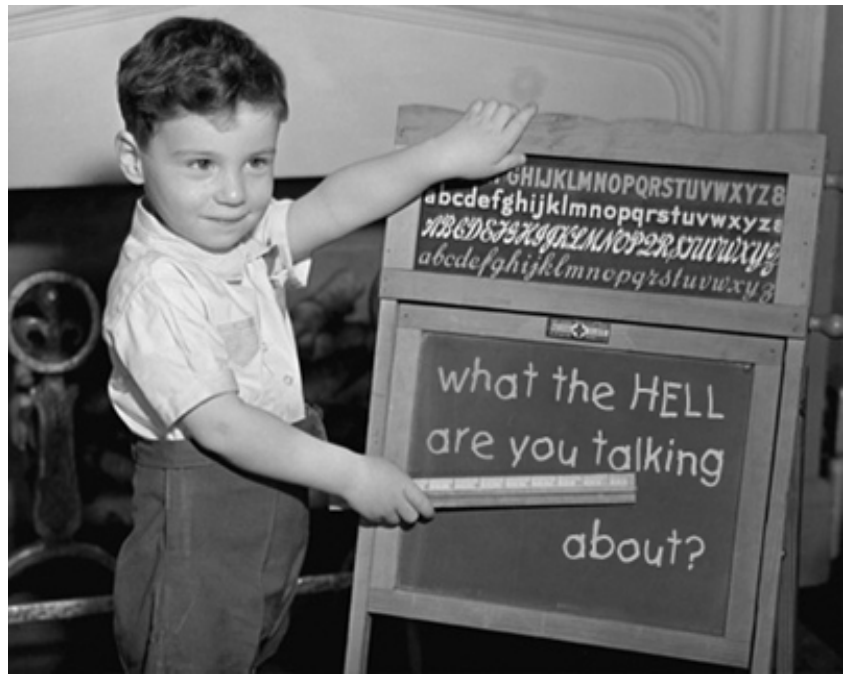
Presentation Outline

- Where are we doing this?
- Why are we doing this?
- What have we done?
- Where are we going?



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Acknowledgments

- Apache Canada, Ltd.
- Natural Resources Canada
- Alberta ERCB
- RPS Energy
- Advanced Geotechnology, Inc.
- U.S. Department of Energy National Energy Technology Laboratory

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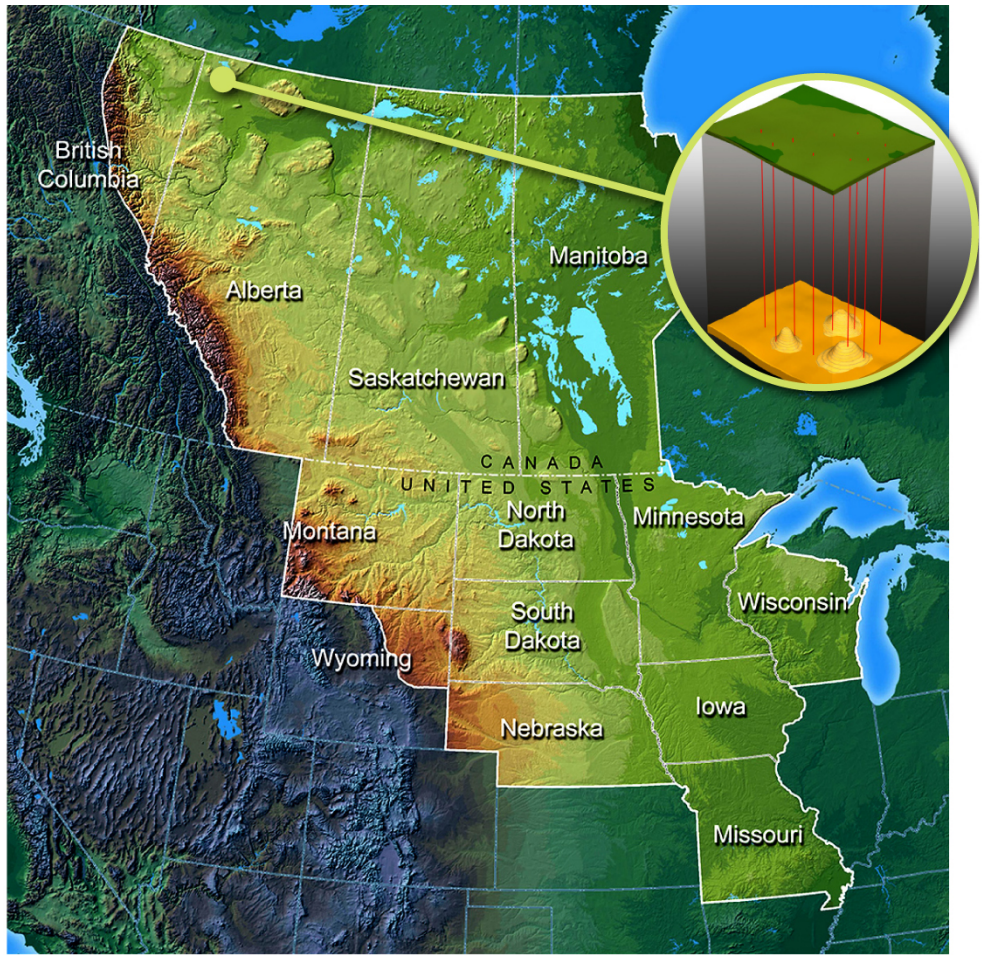
Where's Zama?



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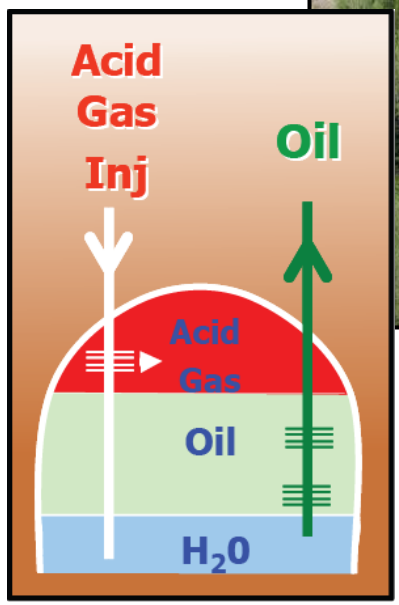
PCOR Partnership Involvement at Zama

Goal

- To validate the sequestration of CO_2-rich acid gas (CO_2 and H_2S) in a depleted oil reservoir.

Objectives

- Determine the effects of acid gas injection on target reservoir and caprock formations.
- Implement a cost-effective approach for monitoring, mitigation, and verification (MMV) for sequestration of a CO_2-rich acid gas stream.



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Zama Acid Gas EOR Project

- One of four Alberta demonstration projects to receive royalty credits for injecting CO_2 for enhanced oil recovery (EOR) in 2004 ($5.0 MM).
- Received $3.1MM NRCan Grant in 2005 for shutting down the sulfur plant and eliminated CO_2 venting which was utilized for injection into EOR pilot project.
- Unique approach combining acid gas disposal and CO_2 EOR.
- Five pinnacles currently accepting acid gas for EOR.
- Potential for expansion into hundreds of additional pinnacles.

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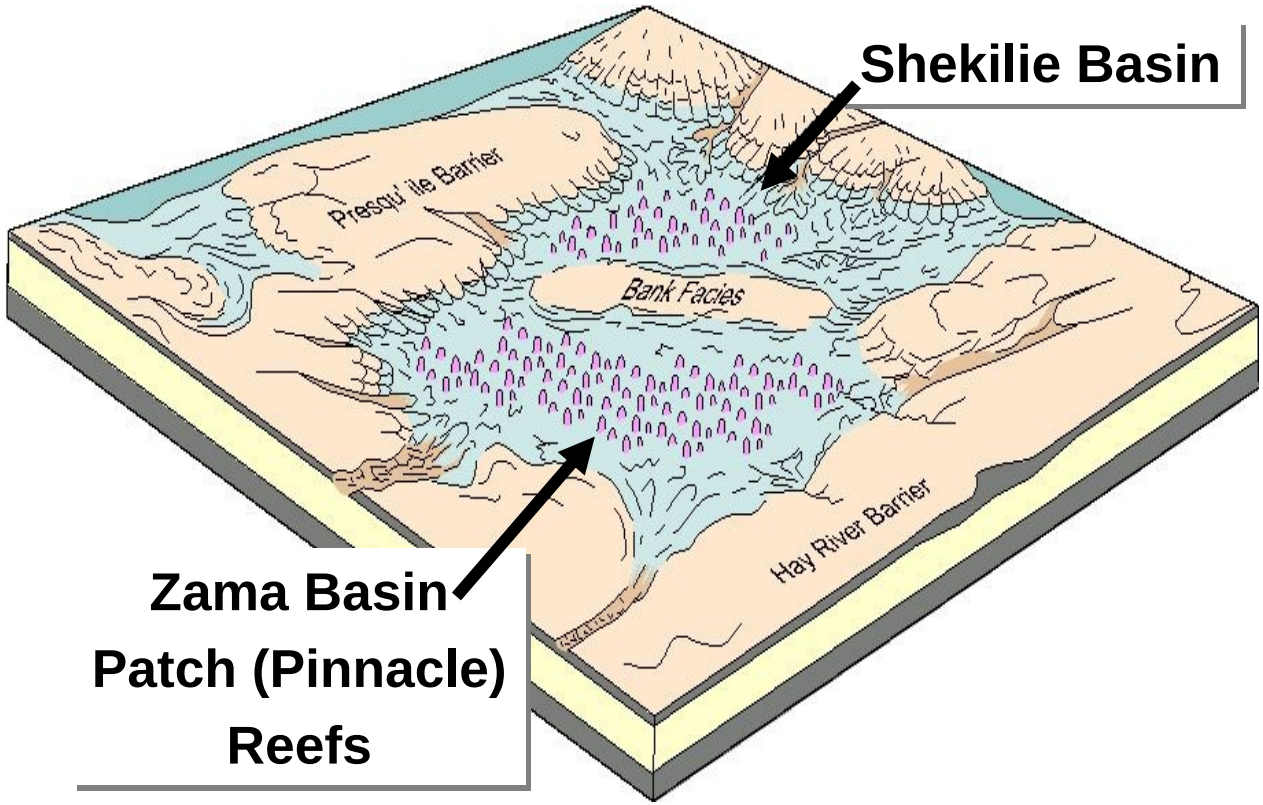
Zama Geological Setting



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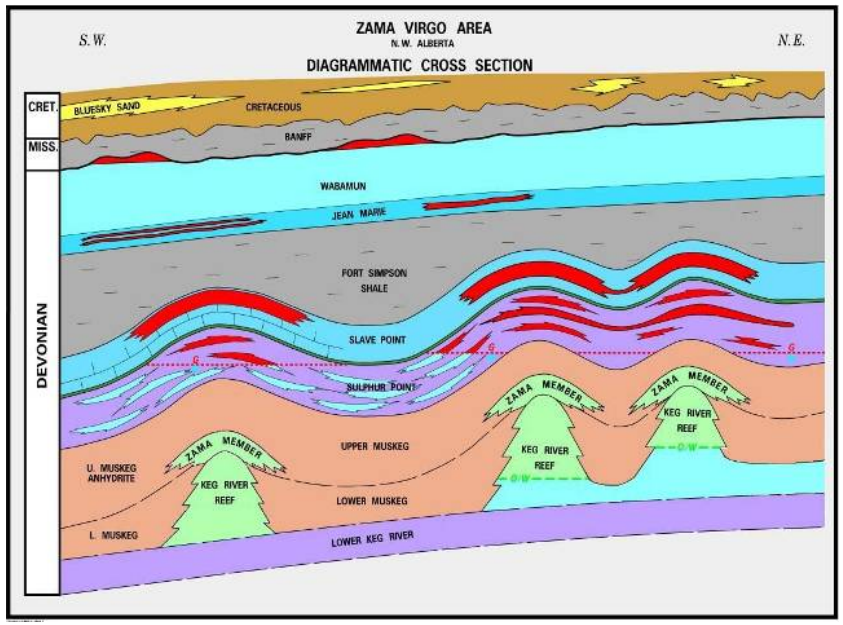
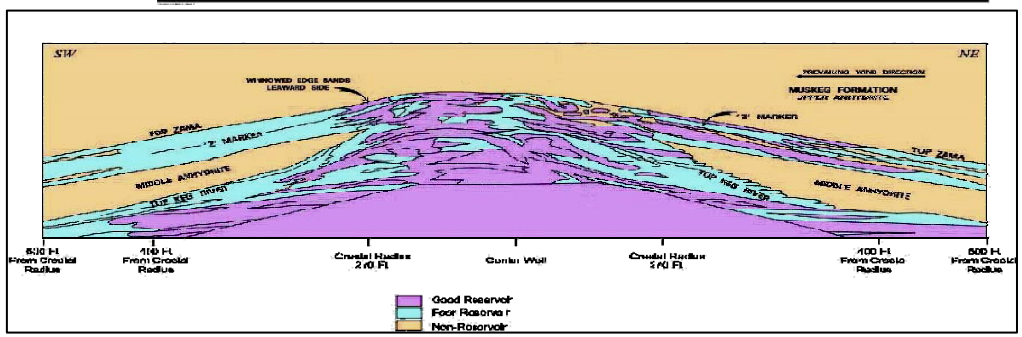
Zama Pinnacle

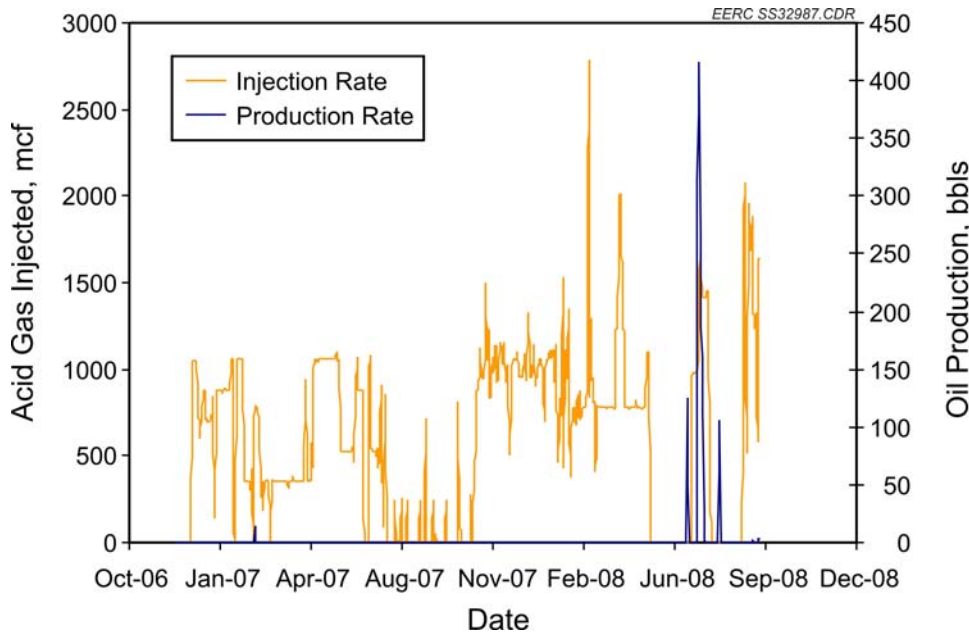
- Carbonate reservoir
- 5300 feet deep
- About 40 acres at the base (.16 km^2)
- 400 feet tall (120 m)
- Two production wells and one injection well
- 10% average porosity
- 100–1000 md permeability
- 2100 psi initial reservoir pressure





Acid Gas Injection

- Began injection December 15, 2006
- 70% CO_2, 30% H_2S
- Average injection rate around 1 MMCF/day
  - Nearly continuous, with brief operational shutdowns
- Second production well completed June 2008
  - Brief period of oil production followed by injected gas production
- Cumulative injection over 20,000 tons



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Philosophy of Monitoring

- Maximize the use of existing data sets in an effort to characterize the baseline conditions of the site.
- Minimize the use of invasive or disruptive technologies to acquire new data.
- MMV data acquisitions will be coordinated with routinely scheduled operation activities.
- Ensure that the monitoring operations are as transparent as possible to the day-to-day field operations.

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MMV Operations

Monitor the CO_2/H_2S plume through:

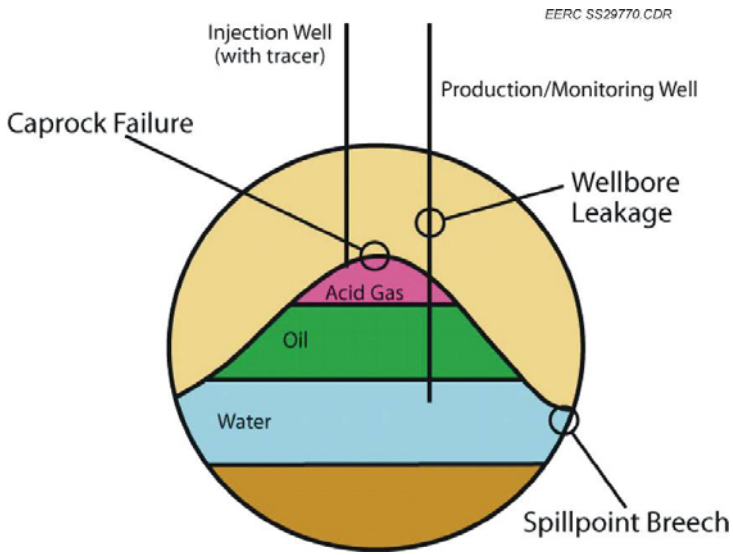
- Perfluorocarbon tracer injection.
- Reservoir pressure monitoring.
- Wellhead and formation fluid sampling (oil, water, gas).

Monitor for early warning of reservoir failure through:

- Pressure measurements of injection well, reservoir, and overlying formations.
- Fluid sampling of overlying formations.

Determine injection well conditions through:

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



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Zama Characterization Activities

Hydrogeology

- Where's the gas going?

Geomechanics

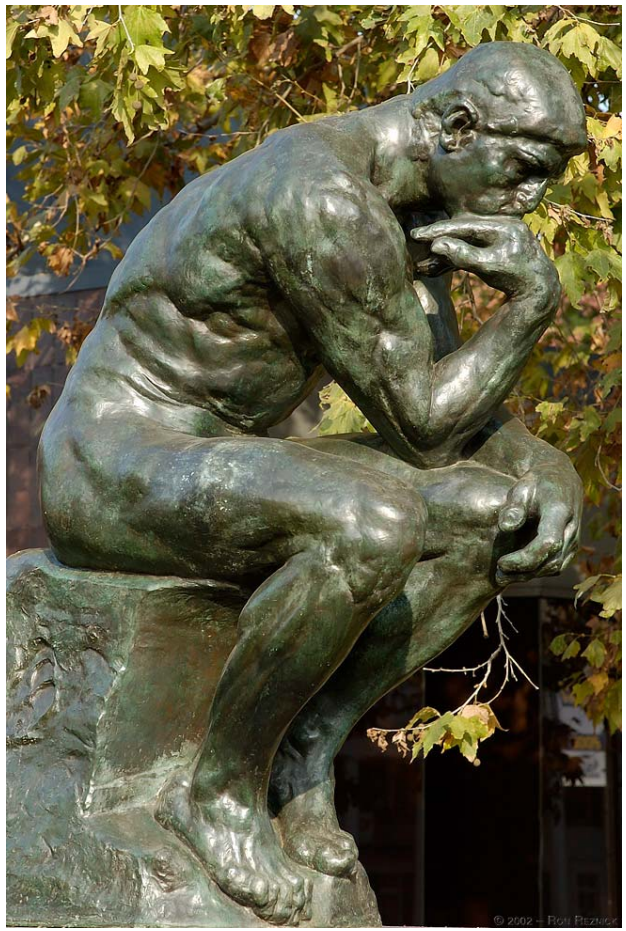
- Is the container going to break?

Engineering

- How did you do that?

Geochemistry

- What's happening down there?



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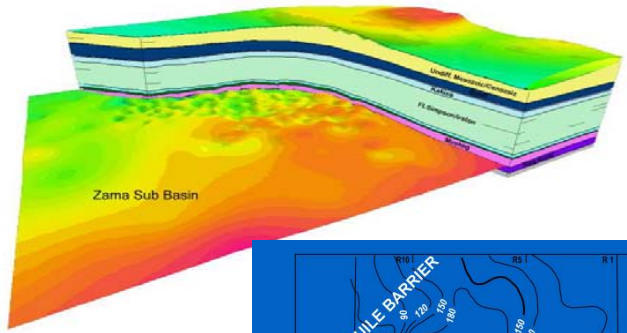
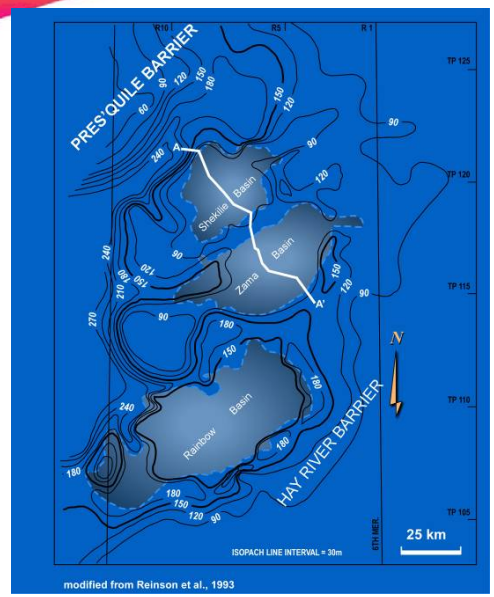
Geology and Hydrogeology Results

- Conducted to better understand the storage characteristics of regional aquifer systems and the fate of acid gas.
- **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.





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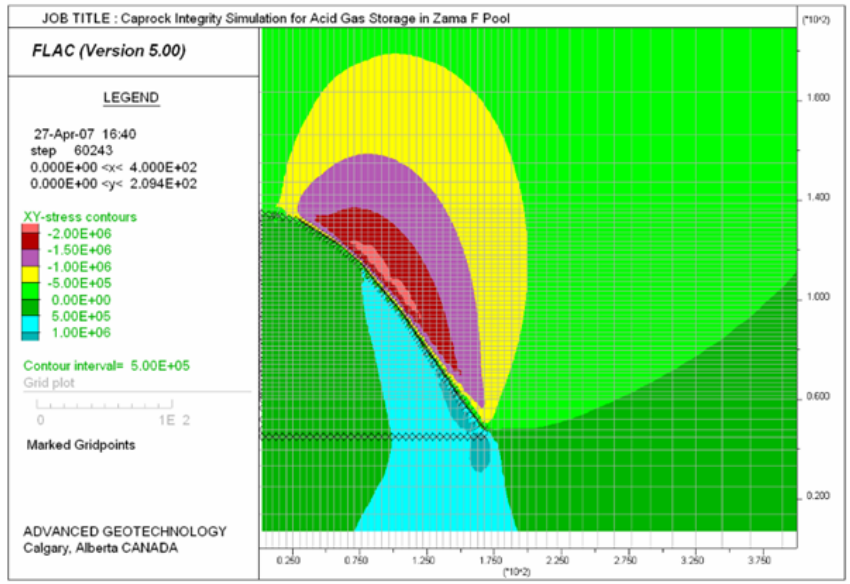
Mechanical Integrity

- Program elements include:
  - Evaluation of possible caprock leakage mechanisms.
  - Triaxial and unconfined compressive strength.
  - Uniaxial pore volume compressibility.
  - Schmidt rebound hammer.
  - Minimum horizontal in situ stress orientations.
  - Vertical stress magnitude.
  - Geomechanical simulation of acid gas injection.



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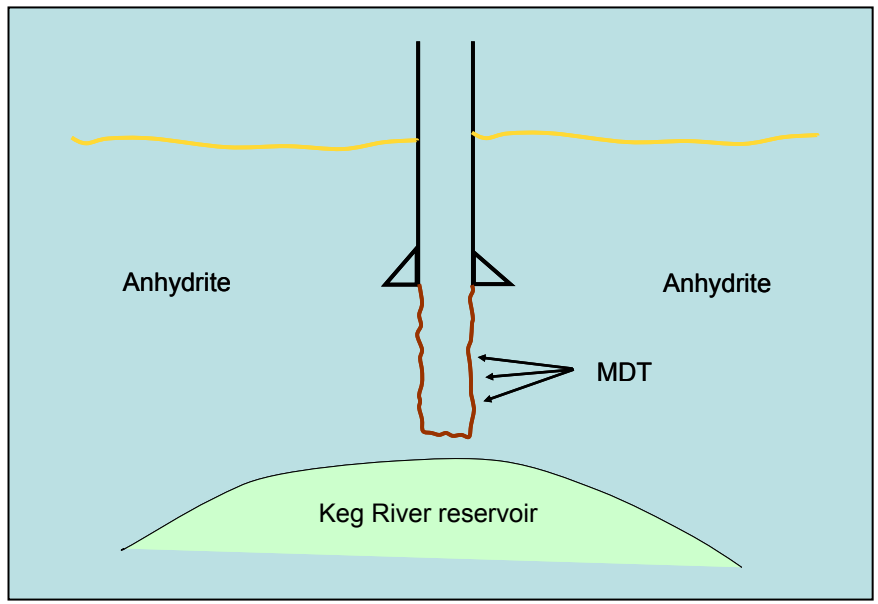
Mechanical Integrity (cont.)

- **Modular Dynamics Test – July 2008**
  - Performed to obtain horizontal stresses in reservoir caprock
  - Tested three intervals
    - Two anhydrite
    - One dolomite stringer (encased in anhydrite)
  - Unable to fracture anhydrite!
  - Fracture attained in dolomite at over 5000 psi
    - Allowable injection pressure approximately 2100 psi
- **All results to date indicate that caprock leakage potential due to a geomechanical mechanism appears to be very low.**



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Engineering

- Catalog the “process” of acid gas injection from cradle to grave
- Pressure-monitoring evaluation
  - Model historical and current pressure regimes in the injection zone
  - Model historical and current pressure regimes in the monitoring zone
  - Quantify pressure difference across zones
  - Determine flux necessary to identify leakage concern
  - May be used to indicate leakage from the reservoir through caprock and or along wellbores
- Evaluate and coordinate:
  - Tracer injection.
  - Sampling procedures.
  - Coring activities.
- Acid gas phase behavior
  - Determine what is happening in the wellbore and reservoir in a multiphase system

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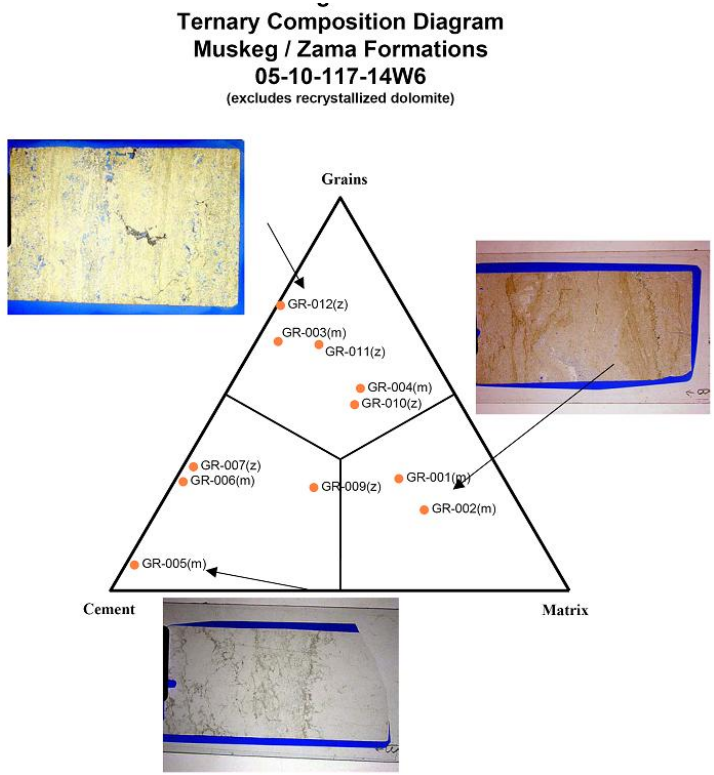
Geochemistry

- New core obtained in 2007
  - Approximately 50 continuous feet from:
    - Muskeg anhydrite.
    - Zama Member (dolomite transition).
    - Keg River Reservoir.
  - Petrophysical evaluation completed
    - Thin sections
    - XRD/XRF
    - SEM
    - Grain size
    - Pore geometry
  - Upcoming/planned work
    - EERC acid gas soak test to determine rates of mineral reactions in carbonates and evaporites



GR Petrology CONSULTANTS Inc.

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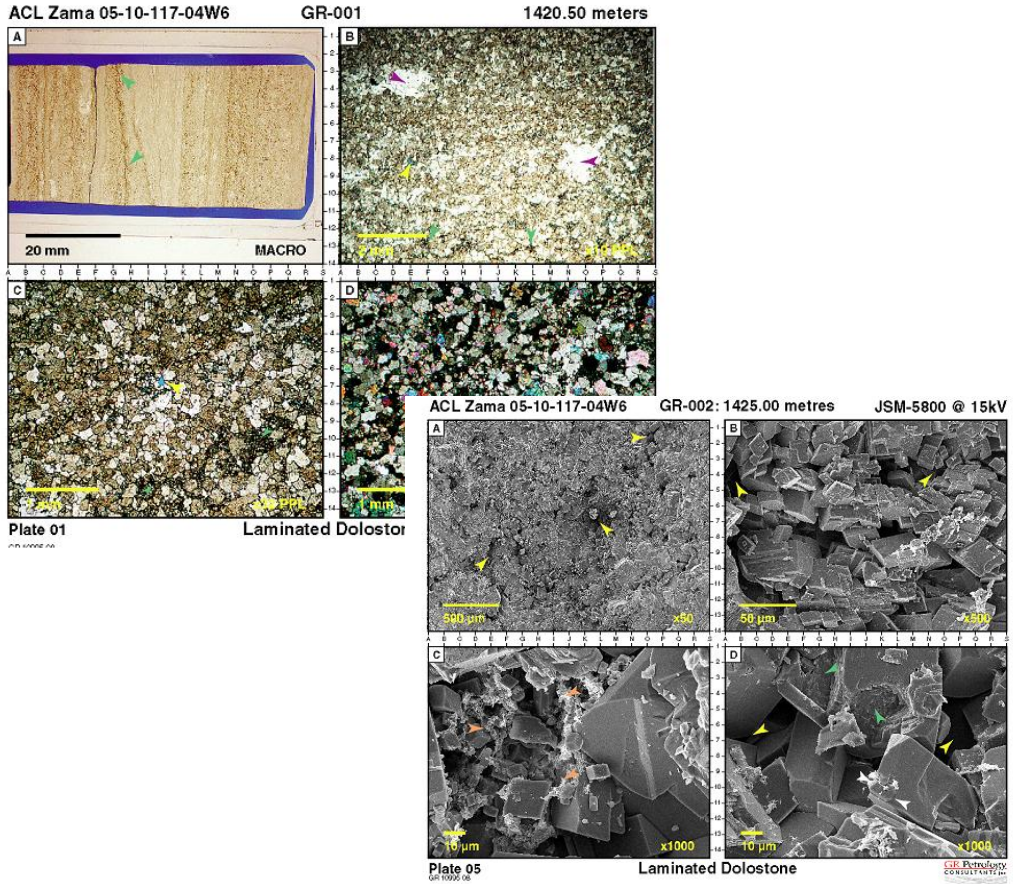
Geochemistry (cont.)

- New core (Oct 2008)
  - Formerly used for acid gas disposal
    - Very unique opportunity!
  - Geochemical models will be created to evaluate reactions in carbonates with respect to:
    - Acid gas.
    - Formation minerals.
    - Formation fluids.
  - Complete petrophysical evaluation will be conducted.
  - **Conclusions will allow direct determination of mineralogical change due to acid gas injection.**



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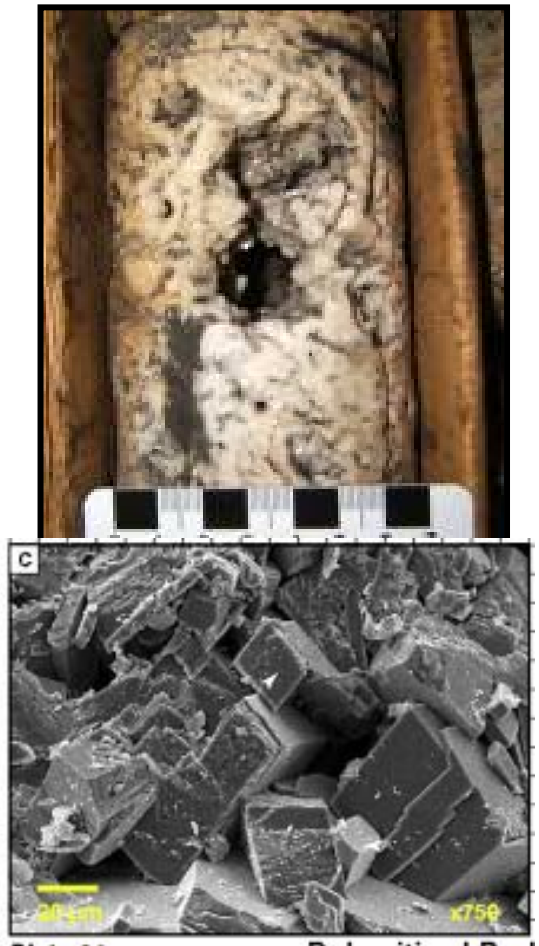
Zama Path Forward

- Injection of acid gas will continue through Year 4 of Phase II.
- Core 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.
- Additional rock mechanical, relative permeability, and capillary threshold pressure measurement of the caprock will be conducted.
- Engineering data and characterization results will be used to develop a Regional Technology Implementation Plan.



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Project Recognition

Officially recognized by the Carbon Sequestration Leadership Forum in March 2007

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Zama Characterization Activities (Questions Answered)

Hydrogeology

Q) Where's the gas going?

A) **Nowhere! Pinnacle geometry, excellent caprock, and extremely slow groundwater flow preclude/minimize migration.**

Geomechanics

Q) Is the container going to break?

A) **No! Safe operating practices and a thorough understanding of the mechanical rock properties at Zama will help prevent this.**

Engineering

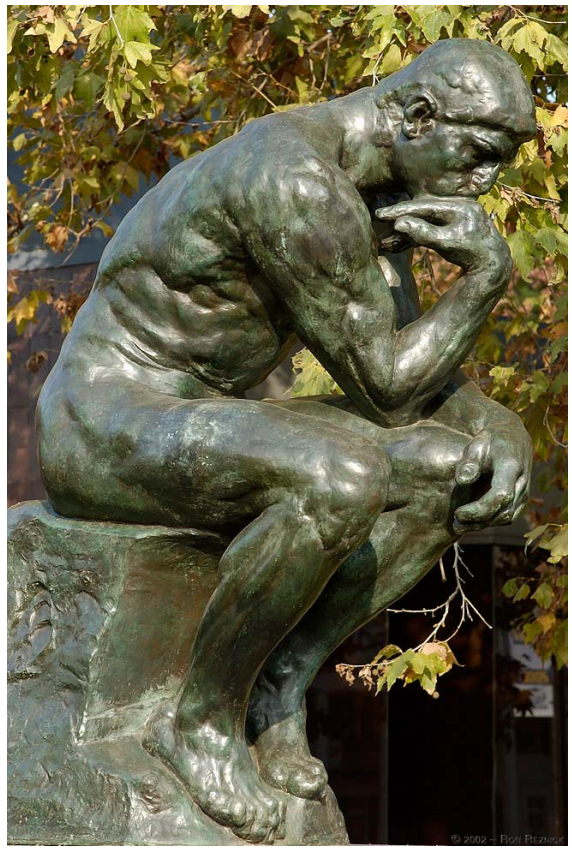
Q) How did you do that?

A) **Comprehensive planning using proven oil field practices.**

Geochemistry

Q) What's happening down there?

A) **Work is in progress during Year 4.**



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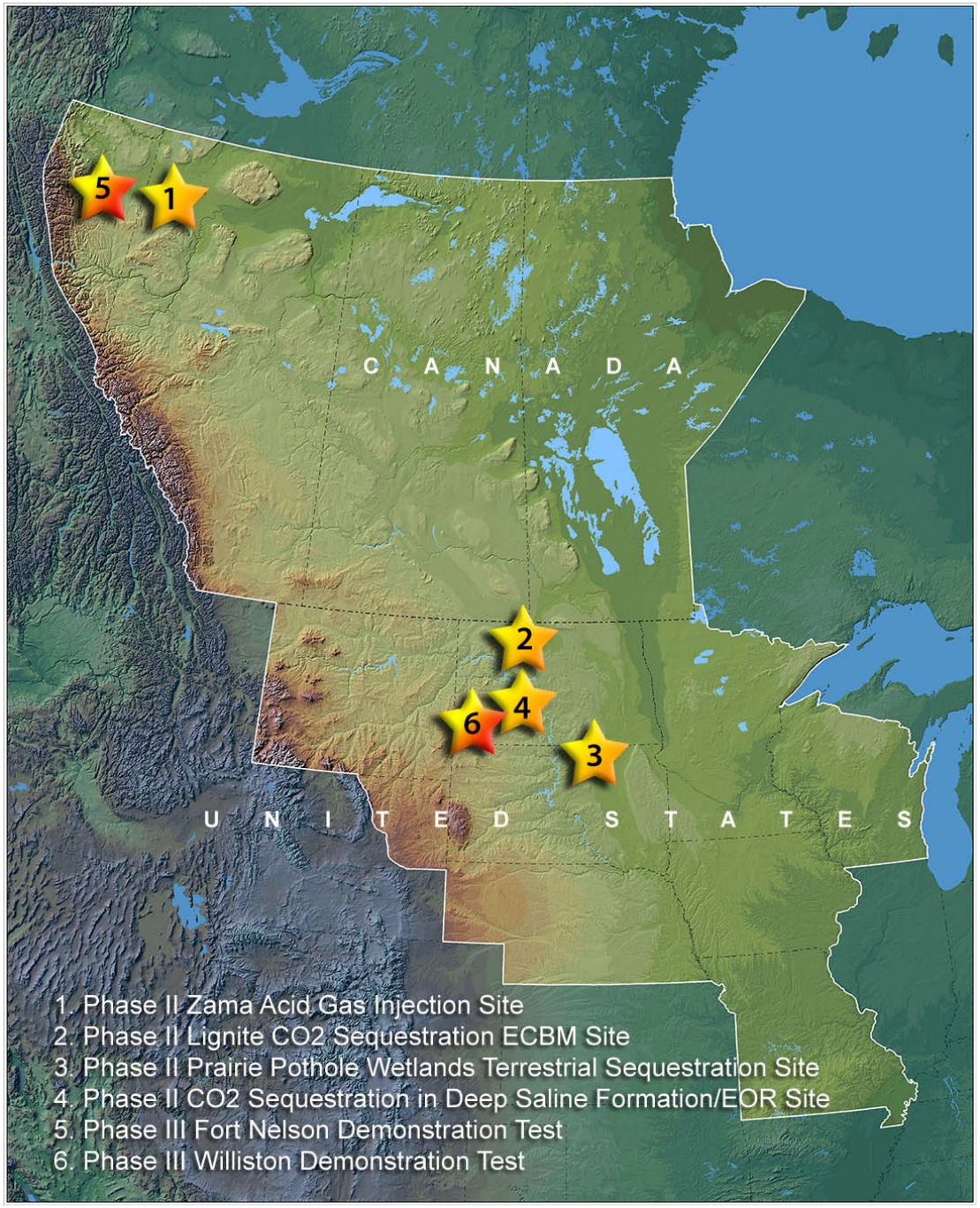

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