Energy & Environmental Research Center (EERC)

RESULTS FROM CSLF-RECOGNIZED PROJECTS: FORT NELSON PROJECT AND ZAMA PROJECT

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Energy & Environmental Research Center

Carbon Sequestration Leadership Forum
CSLF Technical Group Meeting
Venice, Italy
April 23, 2018

Critical Challenges. **Practical Solutions.**

PRESENTATION OUTLINE

- Overview of Plains CO_2 Reduction (PCOR) Partnership Program
- Zama Project
  - Background
  - Key Lessons Learned
- Fort Nelson Project
  - Background
  - Key Lessons Learned

REGIONAL CARBON SEQUESTRATION PARTNERSHIPS

PCOR PARTNERSHIP

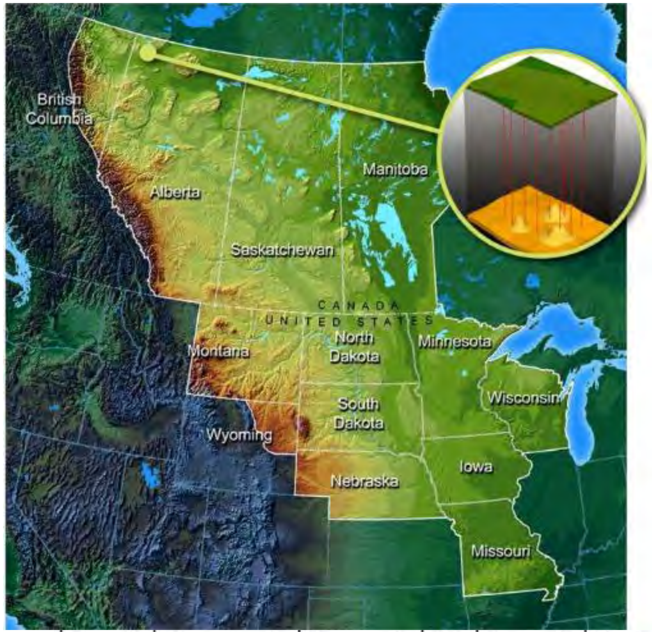
PCOR Partnership 2003 – Present

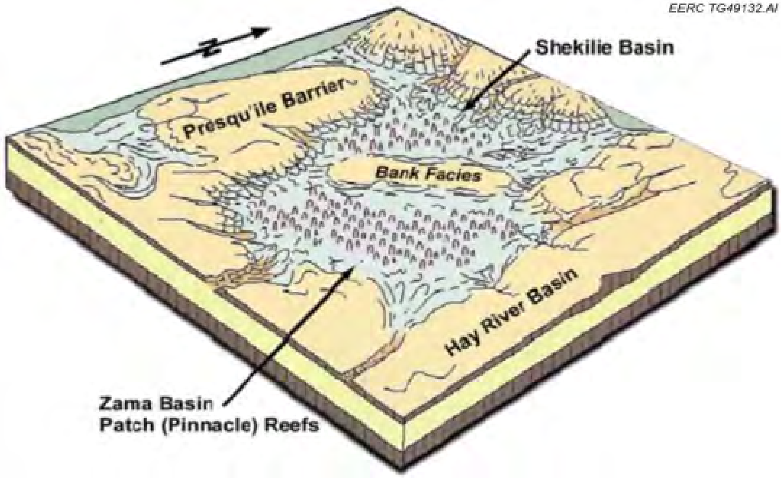
NETL National Energy Technology Laboratory
EERC UND North Dakota
ABENGOA BIOENERGY
AIR PRODUCTS
Alberta Energy
AERI Alberta Energy Research Institute
AGS
Alberta Innovates Technology Futures
ALLETE
Ameren
ACCCE
American Lignite Energy
Apache
Aquistore
Baker Hughes
BALLANTYNE
Basin Electric Power Cooperative
Bechtel
BillyJack Consulting Inc.
Biorecro
Blue Source
BNI Coal
British Columbia
BC Oil & Gas Commission
C12 Energy
The CETER Group, Inc.
CCX Chicago Climate Exchange
CMG
Continental Resources
CO2 Dakota Gasification Company
Denbury
Ducks Unlimited Canada
Ducks Unlimited
Eagle Operating Inc.
EERC
Enbridge
Encore Acquisition Company
ERCB Energy Resources Conservation Board
Environment Canada
Excelsior Energy
Fischer Oil and Gas, Inc.
GE
Great River Energy
HALLIBURTON
HESS
HUNTSMAN
Husky Energy
Indian Land Tenure Foundation
Interstate Oil & Gas Compact Commission
DNR
Kiewit
Lignite Energy Council
Manitoba
Manitoba Hydro
Marathon Oil
MBI Energy Services
MEG Energy Corp
Melzer Consulting
Minnesota Pollution Control Agency
minnesota power
Minnkota Power Cooperative, Inc.
Missouri Department of Natural Resources
Missouri River Energy Services
Montana-Dakota Utilities Co.
Environmental Quality
Murex Petroleum Corporation
National Commission on Energy Policy
Natural Resources Canada
Nebraska Public Power District
Nexant
North American Coal Corporation
North Dakota Department of Commerce
North Dakota Department of Health
Industrial Commission of North Dakota Lignite Research, Development and Marketing Program
Industrial Commission of North Dakota Oil and Gas Research Council
Natural Resources Trust
North Dakota Petroleum Council
NDSU
OPPD
Otter Tail Power Company
Outsource Petrophysics, Inc.
Oxand
Peabody Energy
petro harvester
ptrc Petroleum Technology Research Centre
PTTC
Pinnacle
Prairie Public
Pratt & Whitney
PRAXAIR
RAMGEN
RPS Energy
Saskatchewan Industry and Resources
SaskPower
Schlumberger Carbon Services
SCOUT
Sejong University
Shell Canada Limited
Spectra Energy
Strategic West Energy Ltd.
Suncor Energy
TAQA
Tesoro
TGS
Tri-State G&T
Tundra Oil & Gas
University of Alberta
University of Regina
USGS
WBI Energy
Weatherford
Advanced Geotechnology
Western Governors' Association
Westmoreland Coal Company
Wyoming Office of State Lands and Investments
Xcel Energy

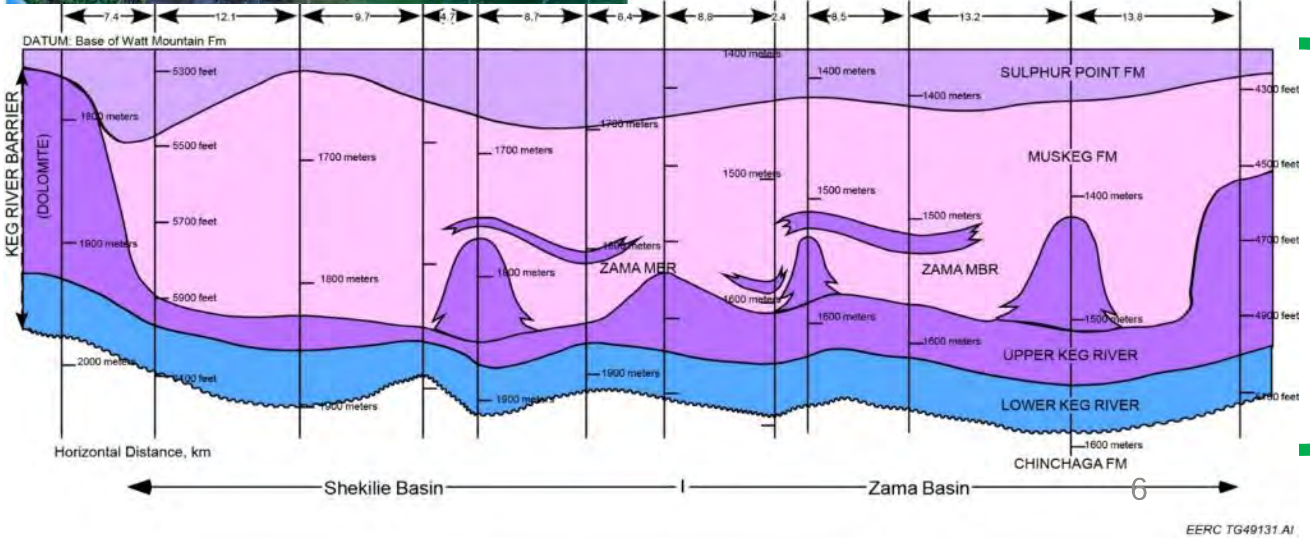
PCOR PARTNERSHIP: PROJECT COMPONENTS

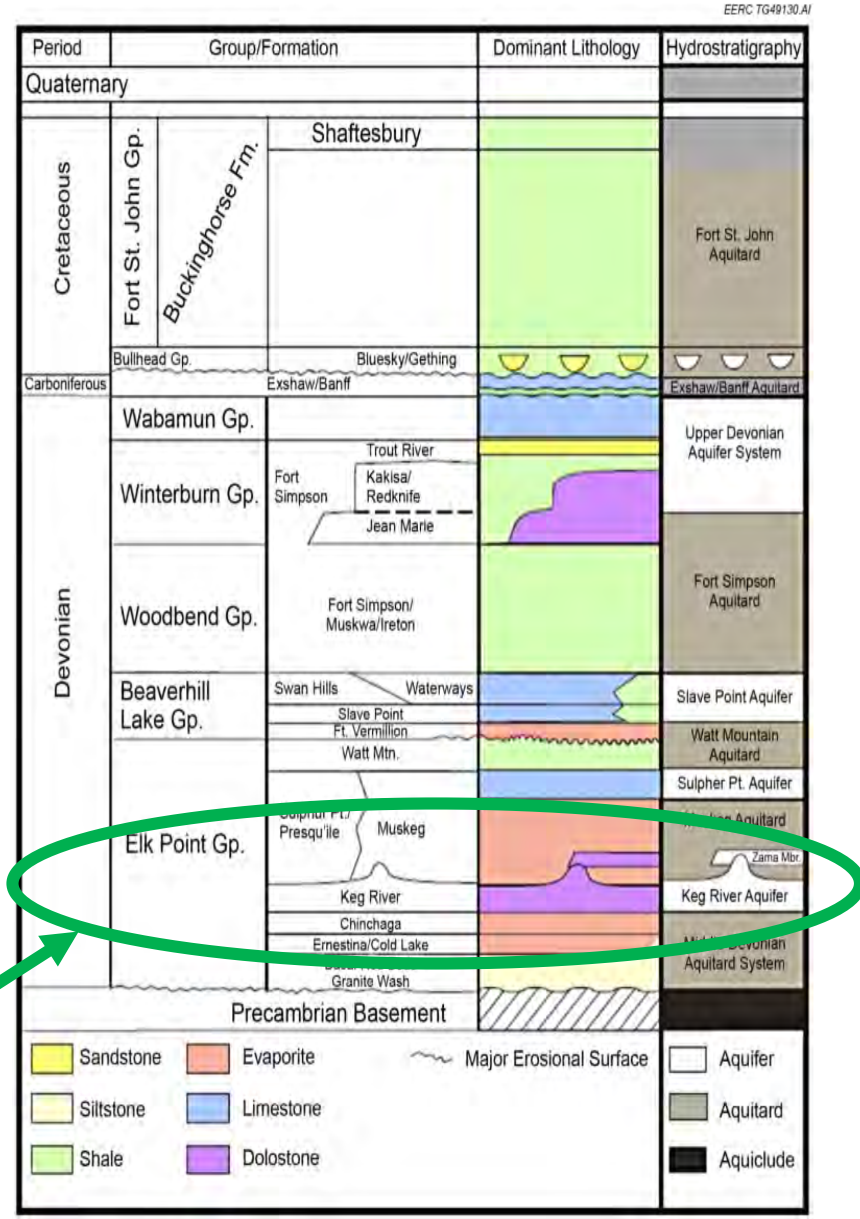
- Bell Creek project
- **Fort Nelson project**
- Aquistore project
- Basal Cambrian project
- **Zama project**
- Regional characterization
- Public outreach
- Regulatory involvement
- Water Working Group

ZAMA BACKGROUND AND SIGNIFICANCE









ZAMA INJECTION SCHEME

Injection stream 70% CO_2 and 30% H_2S.

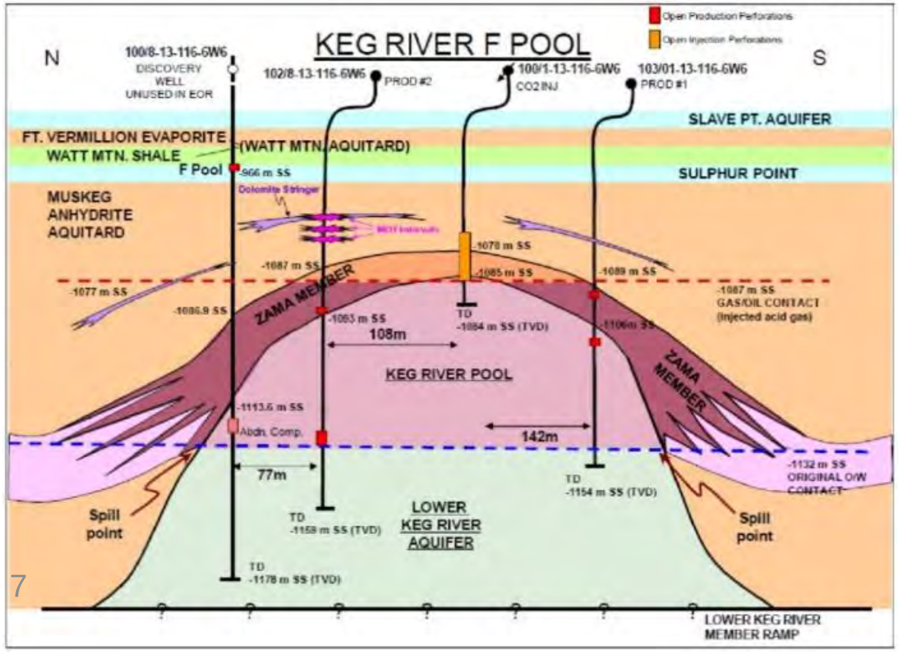
Injection began 2006 in the “F Pool” pinnacle, ultimately expanded to 5 other pinnacles.

85,000 tonnes injected in the “F” pool as of May 2012.

Project addresses the effects of impurities on CCUS.

EERC TG49138.AI

EERC TG49126.AI



ZAMA PVT MODELING PENG–ROBINSON (PR) EQUATION OF STATE (EOS)

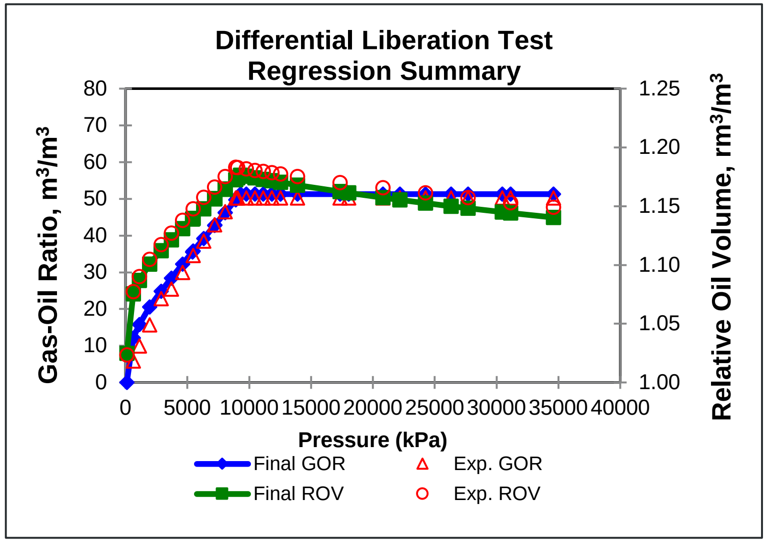
EOS and Tuning

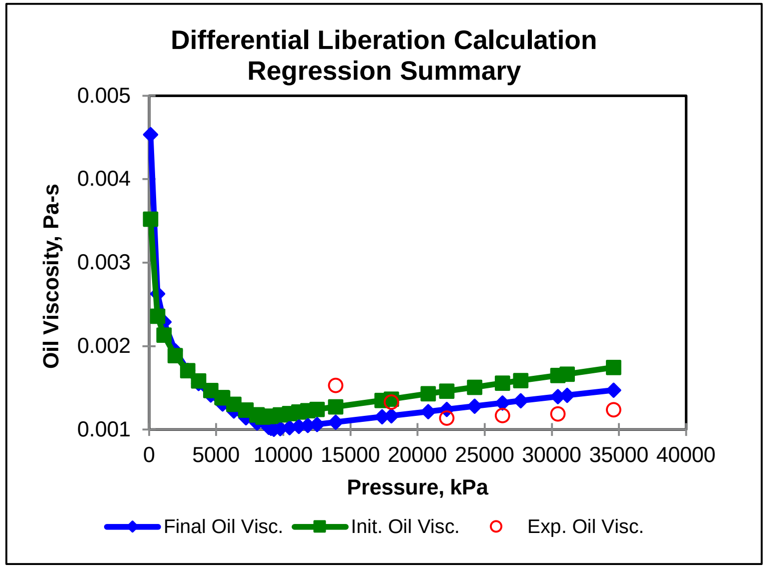
- Seven pseudo-components PR EOS
- Regression: differential liberation, constant volume expansion, swelling, separator, and saturation pressure

Minimum Miscibility Pressure (MMP)

- MMP prediction of pure CO_2
- Different percentage of H_2S

Key Lesson Here – Presence of H_2S lowered MMP, which lowers cost of injection.



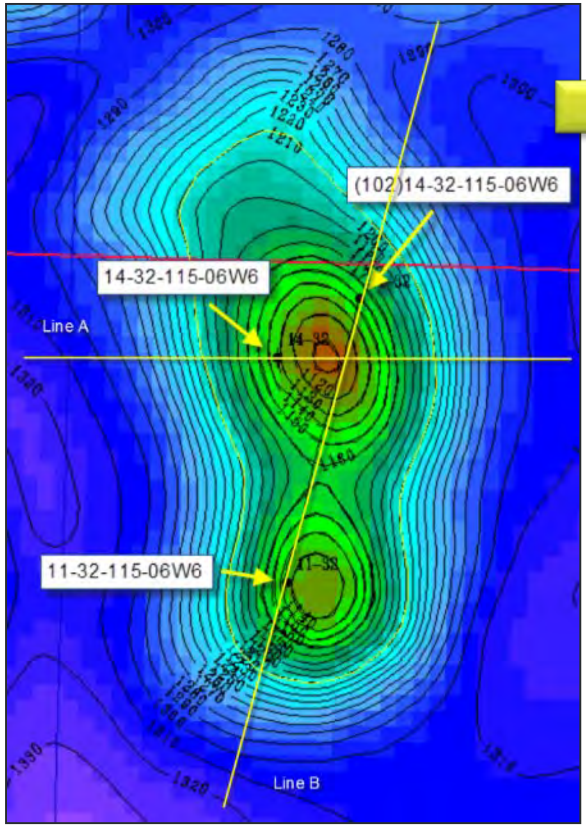


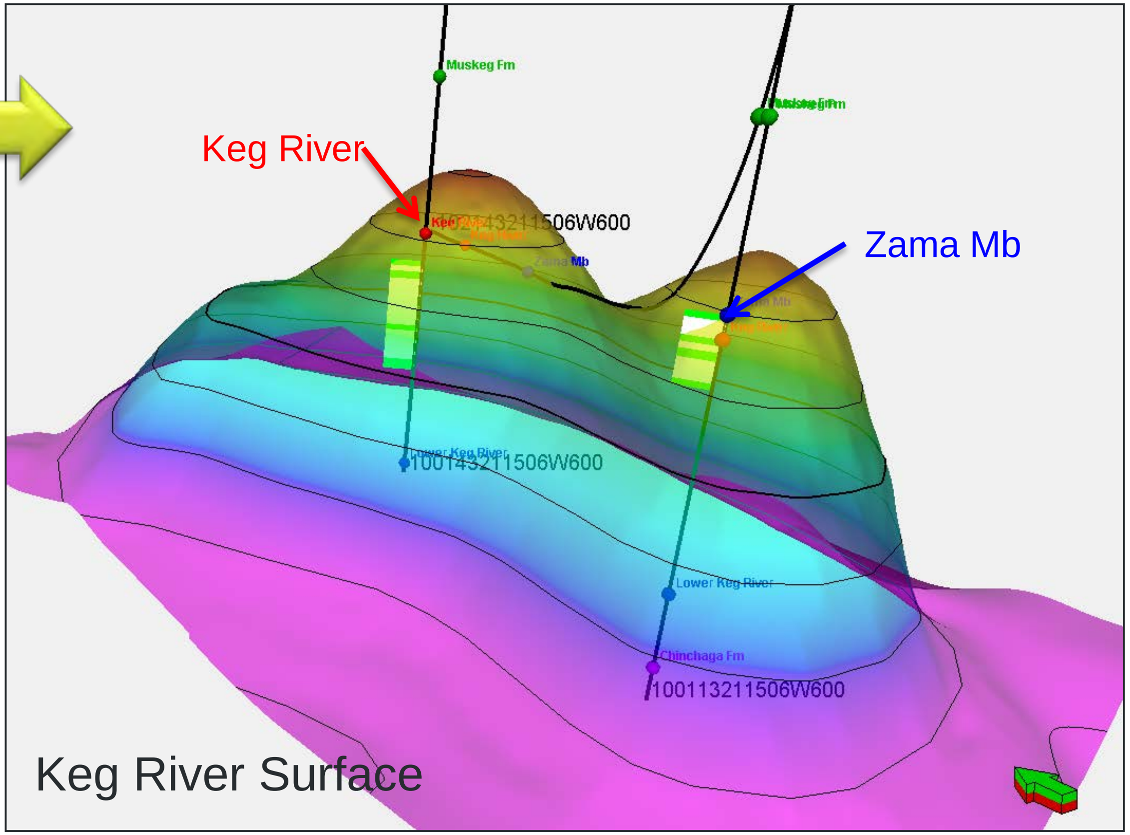
STRUCTURAL MODELS OF ZAMA PINNACLE REEF RESERVOIR

Created models and conducted injection and production simulations on six pinnacle reefs.

Modeling was performed to develop:

- CO_2 utilization factors.
- Estimates of CO_2 storage capacities.

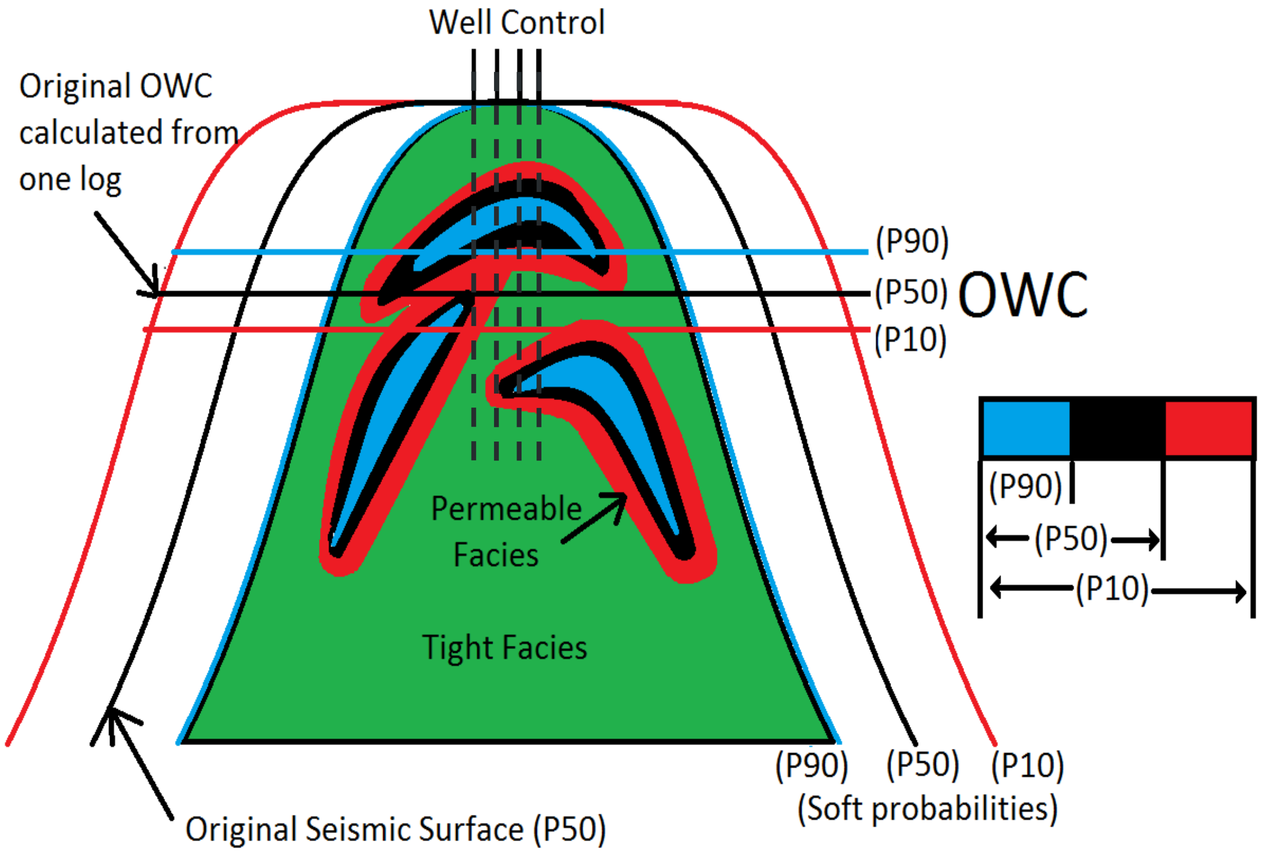




ZAMA PINNACLE REEF STATIC UNCERTAINTY MODEL

- Goals were to assess and quantify the uncertainties associated with existing data.
  - To help CO_2 storage from operational and planning standpoints.
  - To provide insight regarding the design of the CO_2 storage scheme.
  - An improved estimate of recoverable resource (oil) and associated storage.

- Reef properties were allowed to vary between defined ranges for 3-D uncertainty model.



ESTIMATION OF ZAMA CO_2 UTILIZATION FACTORS AND STORAGE CAPACITIES

CO_2 Utilization Factor and Recovery Contribution Based on Simulation Predictions

Pool	E_u, Mscf/bbl		E_rco_2, %	
	Pessimistic	Optimistic	Pessimistic	Optimistic
Keg River F	22.90	9.73	12.60	22.00
Keg River G2G	5.60	4.77	4.40	15.00
Muskeg L	13.15	3.98	1.60	9.80
Average	10.02		6.20	15.60

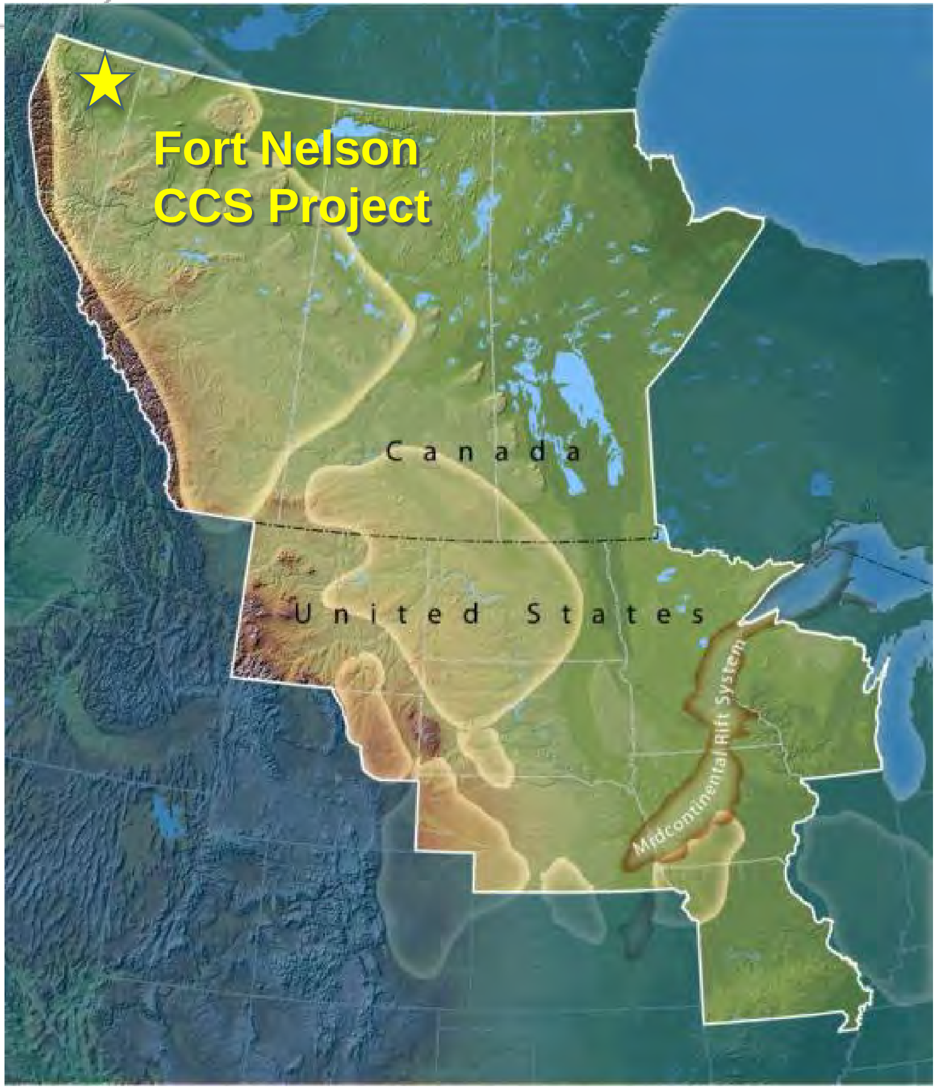
Estimates of CO_2 Storage Capacities for Three Extra Pools

Pool	OOIP, MMstb	CO_2 Utilization (E_u), b/bbl	Recovery Contributed by CO_2 (E_{rCO2}), %		Storage Capacity G, MM tonnes	
			Pessimistic	Optimistic	Pessimistic	Optimistic
Keg River Z3Z	2.380	10.02	6.20	15.60	0.083	0.209
Keg River RRR	4.700	10.02	6.20	15.60	0.164	0.412
Keg River NNN	3.530	10.02	6.20	15.60	0.123	0.310

KEY OBSERVATIONS AND CONCLUSIONS FROM ZAMA

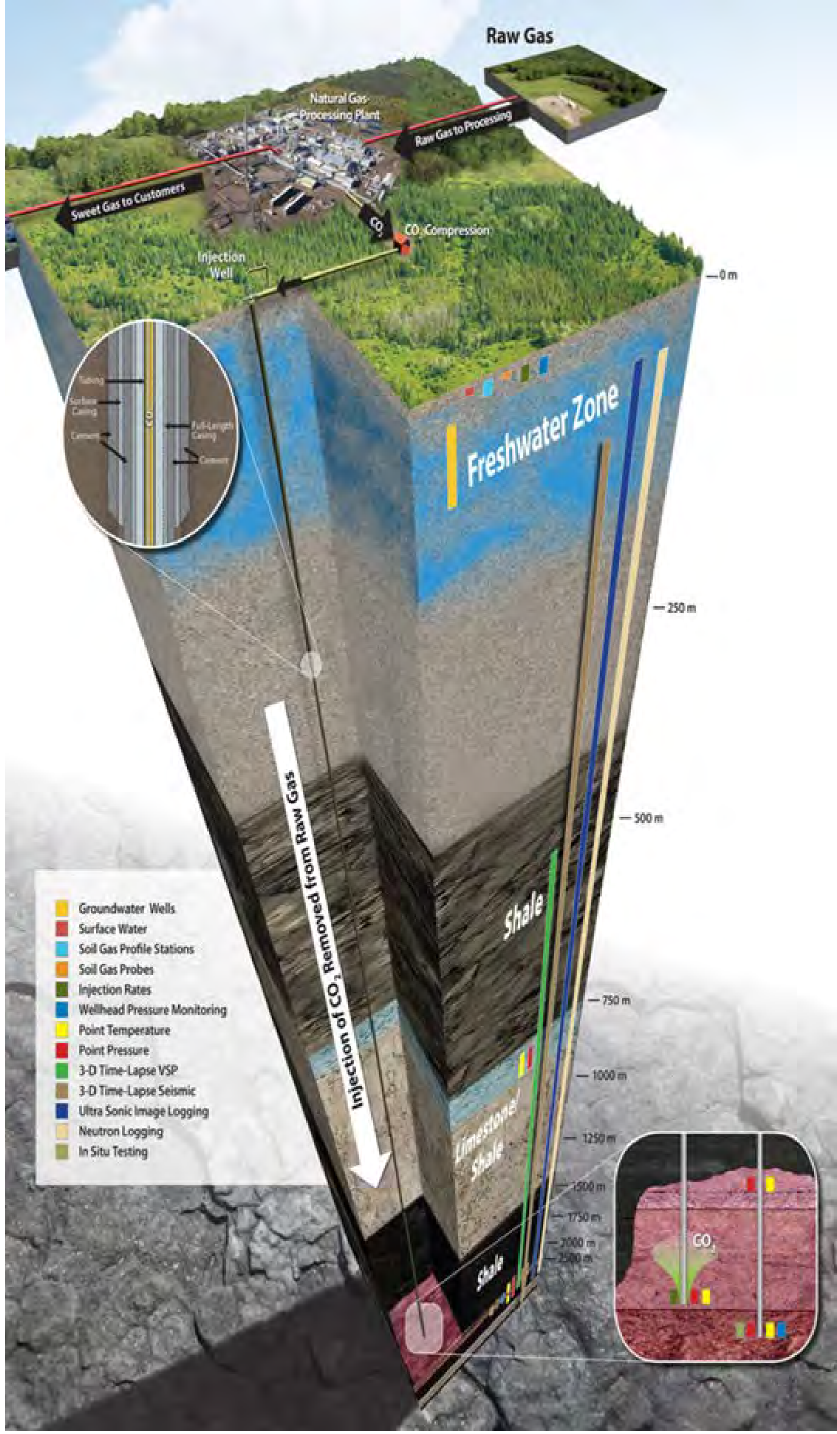
- Results from the 6 pinnacles modeled were applied to the field as a whole (over 800 pinnacles) and **suggest that more than 334 MMt of CO_2 can be stored in the Zama pinnacles** as part of EOR operations.
- H_2S can lower MMP, but does require modifications and specialized equipment to ensure safety and minimize corrosion.
- “Sour” CO_2 injection could yield 15% of original-oil-in-place incremental recovery at Zama.
- Pinnacle reefs are great candidates for CO_2 storage and sour CO_2 can be safely and economically used for CCUS.

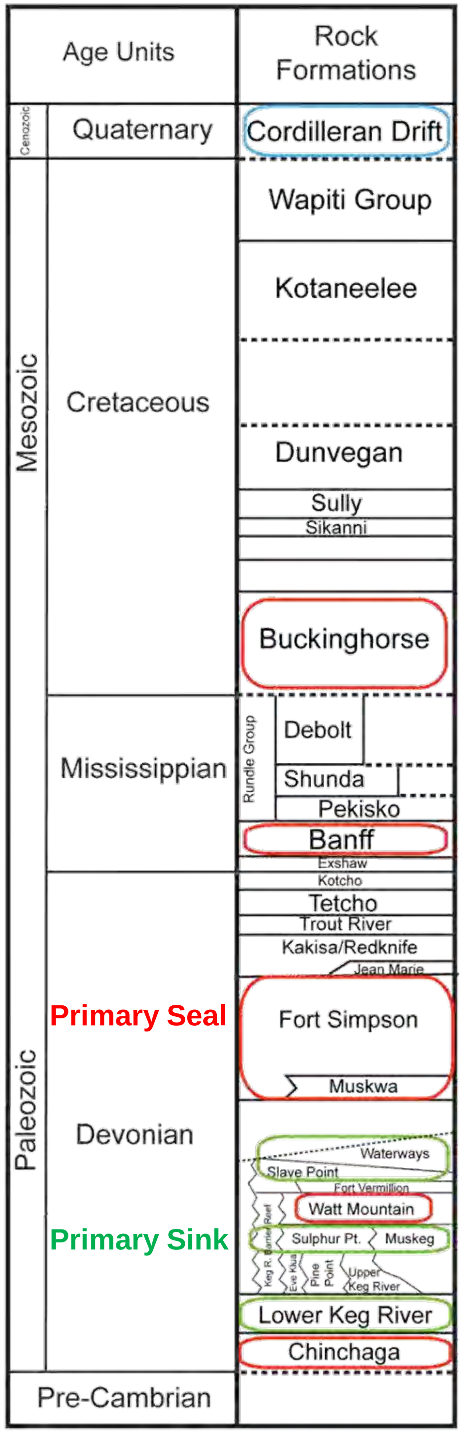
FORT NELSON BACKGROUND AND SIGNIFICANCE



Feasibility study for CCS for a gas-processing plant in northern British Columbia:

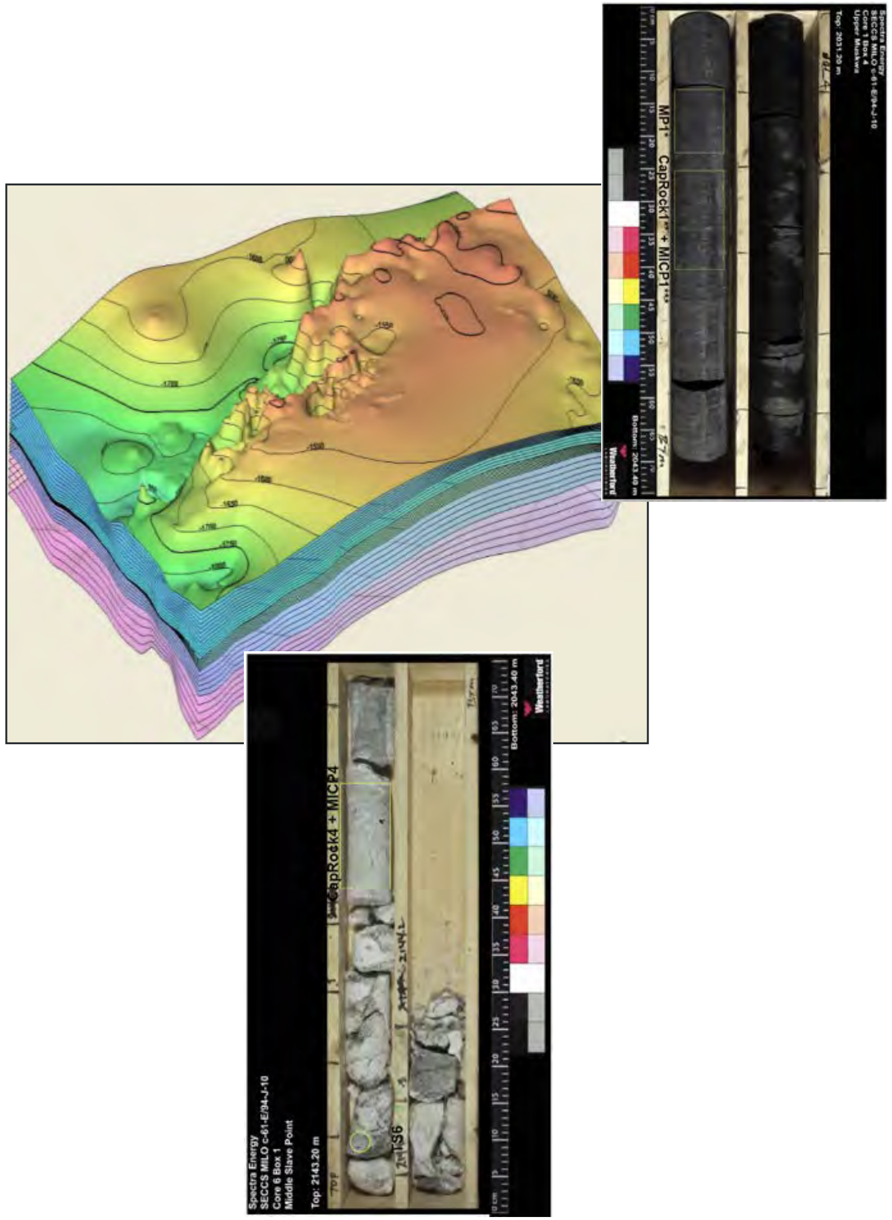
- Risk-based approach to define monitoring, verification, and accounting (MVA) strategy.
- Site characterization.
- Modeling and simulation.
- Risk assessment.
- Cost-effective MVA plan.





FORT NELSON SITE CHARACTERIZATION

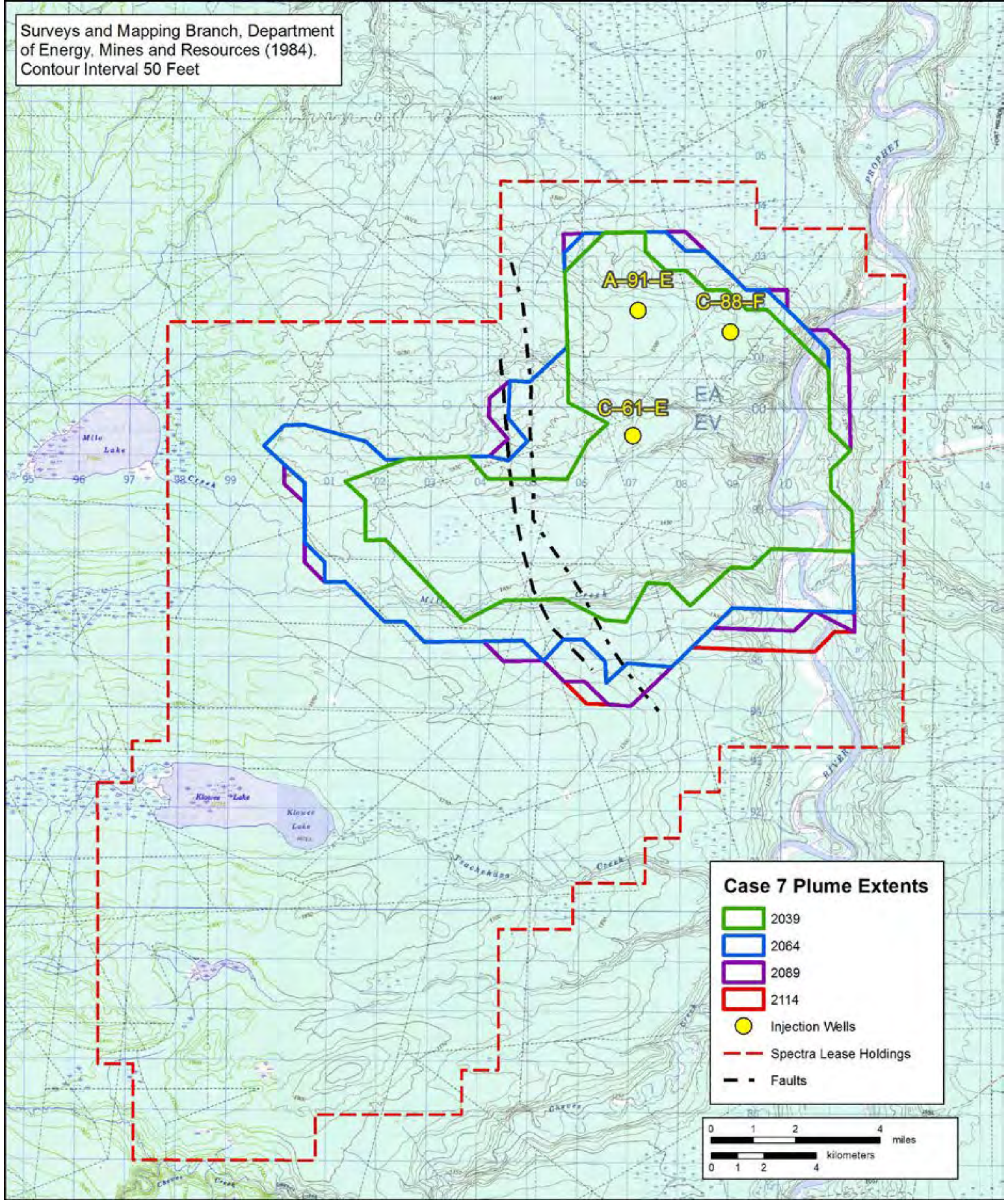
- 93 wells in study area
- Historical 2-D and 3-D seismic
- Hydrogeological studies
- Test Well – C-61-E
  - Core and cuttings
  - Formation pressures
  - Formation fluids
  - Water injection testing
  - Cap rock integrity testing
  - Solubility testing
  - Relative permeability testing
  - Hg injection capillary pressure tests
  - Geochemical reactivity testing



50-YEAR INJECTION SCENARIO

Key Parameters

- Three injection wells
  - Sulphur Point Formation
- 120 MMscf/d injection rate
  - 2.5 MMt/year
- 50 years of injection



RECOMMENDED MVA

Monitoring Elements

- Shallow groundwater-monitoring wells in vicinity of deep monitoring wells and injection wells

- Surface water sampling
  - Lakes
  - Rivers

- Soil gas monitoring in vicinity of deep monitoring wells and injection wells

- Four deep monitoring wells

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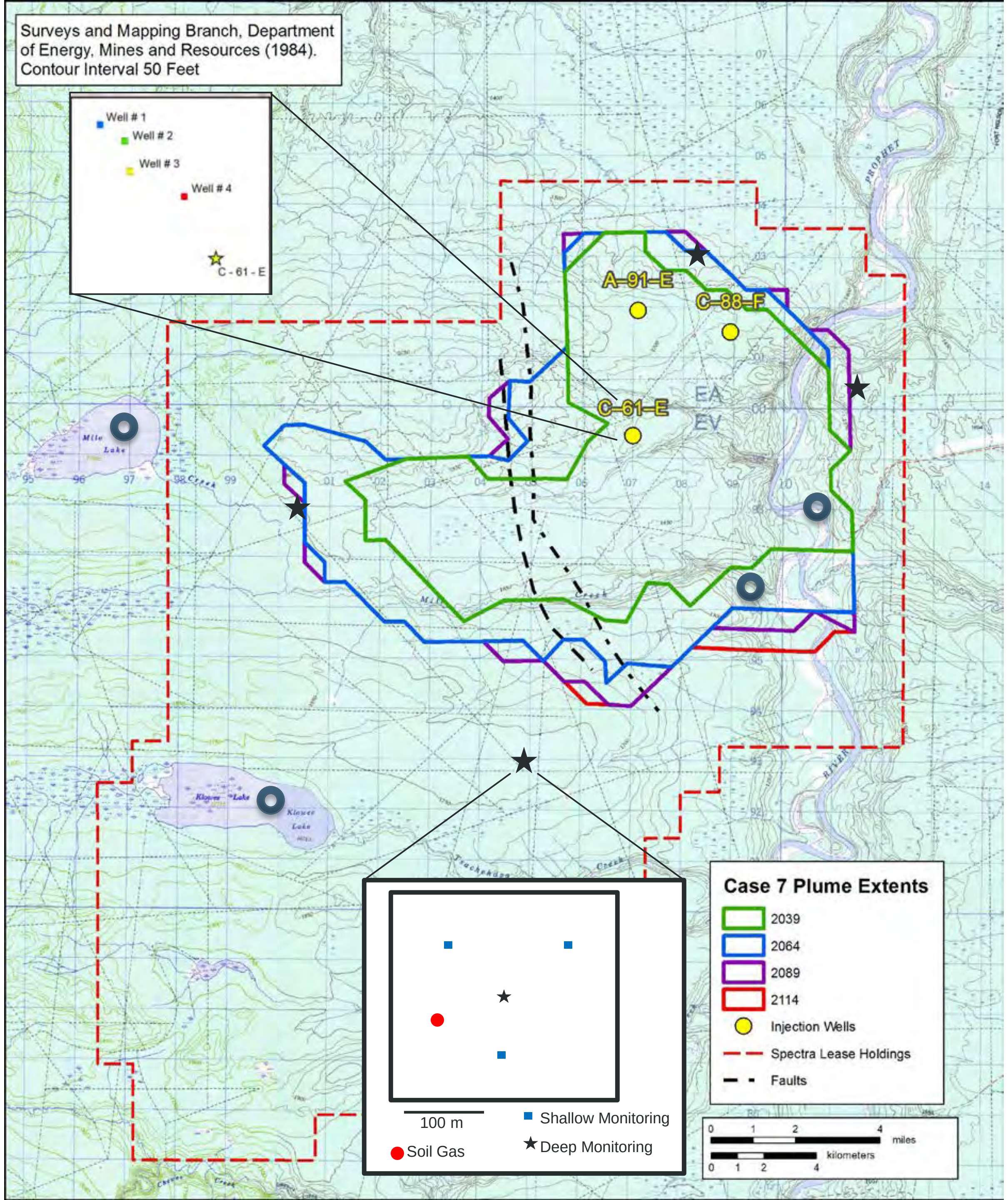
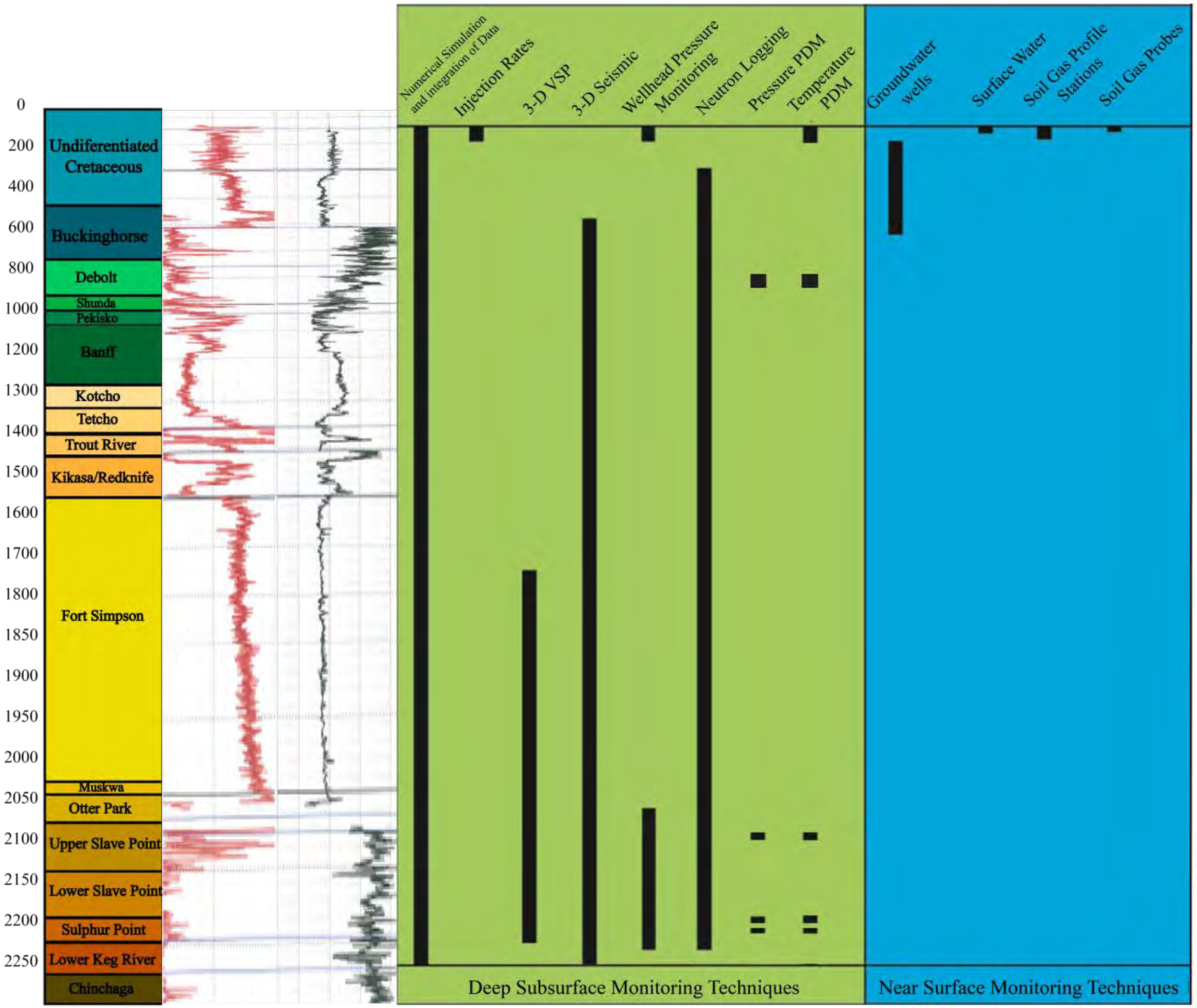
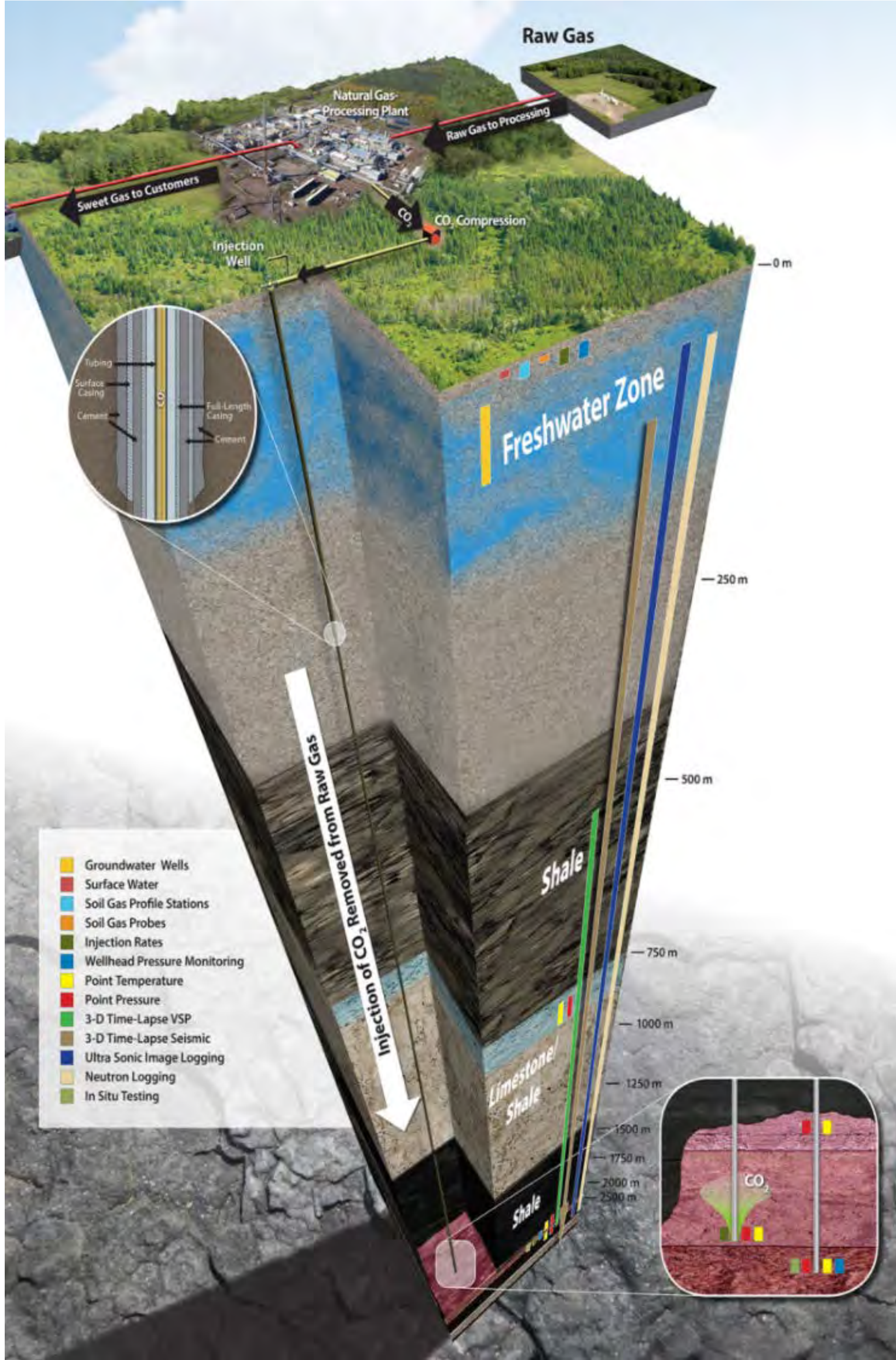


Surveys and Mapping Branch, Department of Energy, Mines and Resources (1984). Contour Interval 50 Feet

RECOMMENDED MVA AT FORT NELSON





DEEP MVA (2014 BASELINE) AT FORT NELSON

FORT NELSON CHARACTERIZATION AND MODELING COMPARED TO CSA GUIDELINES FOR CCS

In 2012 the Canadian Standards Association established guidelines for geologic storage of CO_2 (CSA Z741-12).

Fort Nelson activities were compared to those standards.

Site Screening, Selection, and Characterization

- 🟢 Site screening
- 🟢 Site selection
- 🟢 Site characterization and assessment
  - 🟢 Geological and hydrogeological characterization of the storage unit
  - 🟢 Characterization of confining strata
  - 🟢 Baseline geochemical characterization
  - 🟢 Baseline geomechanical characterization
  - 🟡 Well characterization
- 🟢 Modeling for characterization
  - 🟢 Geologic static model
  - 🟢 Flow modeling
  - 🟡 Geochemical modeling
  - 🟡 Geomechanical modeling

🟢 Thoroughly addressed

🟡 Partially addressed

🔵 SET to determine

FORT NELSON RISK MANAGEMENT COMPARED TO CSA GUIDELINES FOR CCS

🟢 Thoroughly addressed
🔵 Spectra to determine

Risk Management

- 🟢 Objectives
- 🟢 Context
  - 🟢 Elements of concern
  - 🟢 System model
  - 🟢 Identification of context
- 🔵 Risk management plan
- 🟢 Risk assessment
  - 🟢 Risk identification
  - 🟢 Risk analysis
  - 🟢 Risk evaluation
- 🟢 Planning and review of risk treatment
- 🟢 Review and documentation
- 🔵 Risk communication and consultation
  - 🔵 Performance metrics
  - 🔵 Scope of risk communication and consultation activities

FORT NELSON MVA COMPARED TO CSA GUIDELINES FOR CCS

Monitoring and Verification

- 🟢 – Purpose
- 🟢 – M&V program periods
  - 🟢 • Preinjection period monitoring
  - 🟢 • Injection period monitoring
  - 🟢 • Closure period monitoring
  - 🔵 • Postclosure period monitoring
- 🟢 – M&V program objectives
- 🟢 – M&V program design
  - 🟢 • Procedures and practices
  - 🟢 • Required specifications
  - 🟡 • Recommended specifications
  - 🔵 • Contingency monitoring

🟢 Thoroughly addressed

🟡 Partially addressed

🔵 SET to determine

CONCLUSIONS FROM FORT NELSON

- CCS at Fort Nelson is on hold until a business case can be made.
- An integrated approach to site characterization, modeling, and risk assessment can:
  - Lead to an effective site-specific monitoring program.
  - Identify data gaps in site characterization.
  - Increase the likelihood of project success by identifying and mitigating potential project risks.
- The Fort Nelson site has excellent potential, but requires a business case and additional technical work to move forward.

ACKNOWLEDGMENT

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