Geochemical monitoring during CO_2 EOR – applications to CCS MMV

Ernie Perkins

PENNWEST RESEARCH PROGRAM

Initiated in 2004, the research program focussed on 8 areas:

- Geology and Hydrogeology,
- CO2 Leakage Potential,
- Environmental Monitoring,
- Geophysical Monitoring,
- Geomechanical Issues,
- Geochemical Monitoring and **Geochemical Modelling**
- Reservoir modelling.

The **Geochemical Modelling** project used detailed geological information, mineralogical data, produced and injected fluid compositional data, field operational parameters and production data, and reservoir model simulations provided by other researchers in the program and by the operators.

A typical summer day

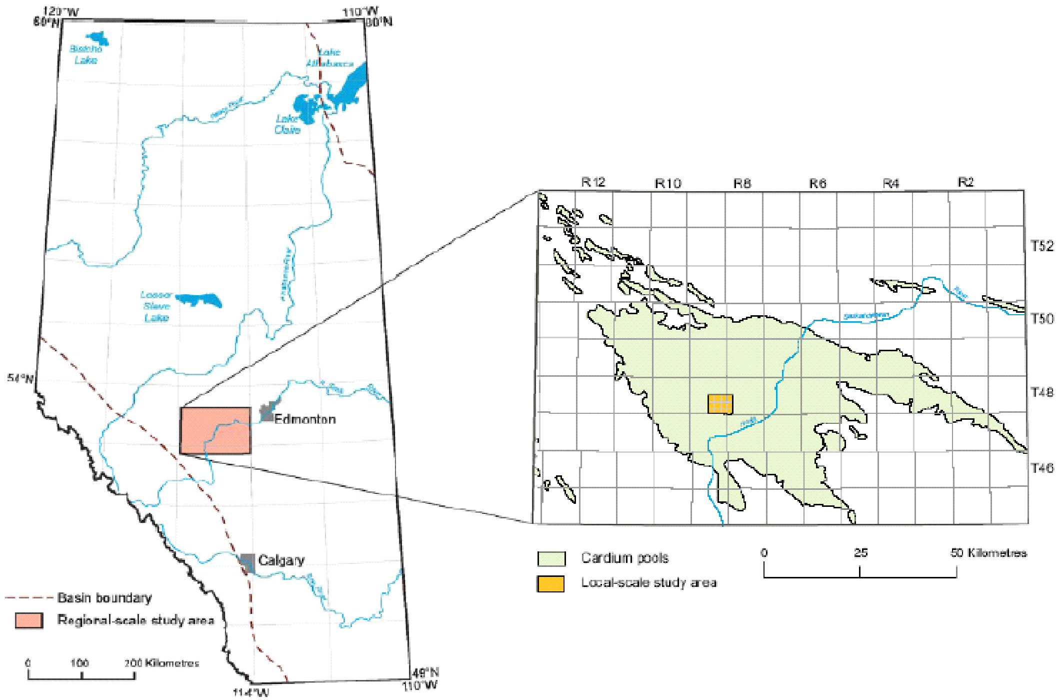
PENNWEST RESEARCH PROGRAM

The research program was lead by The Alberta Research Program, now named Alberta Innovates – Technology Futures.

The geochemical research shown in the following presentation was largely undertaken by S. Talman, M. Shevalier, M. Nightingale and E. Perkins.

Research in other areas was the responsibility of numerous other researchers, technologists and field operators – we thank them for the use of their results.

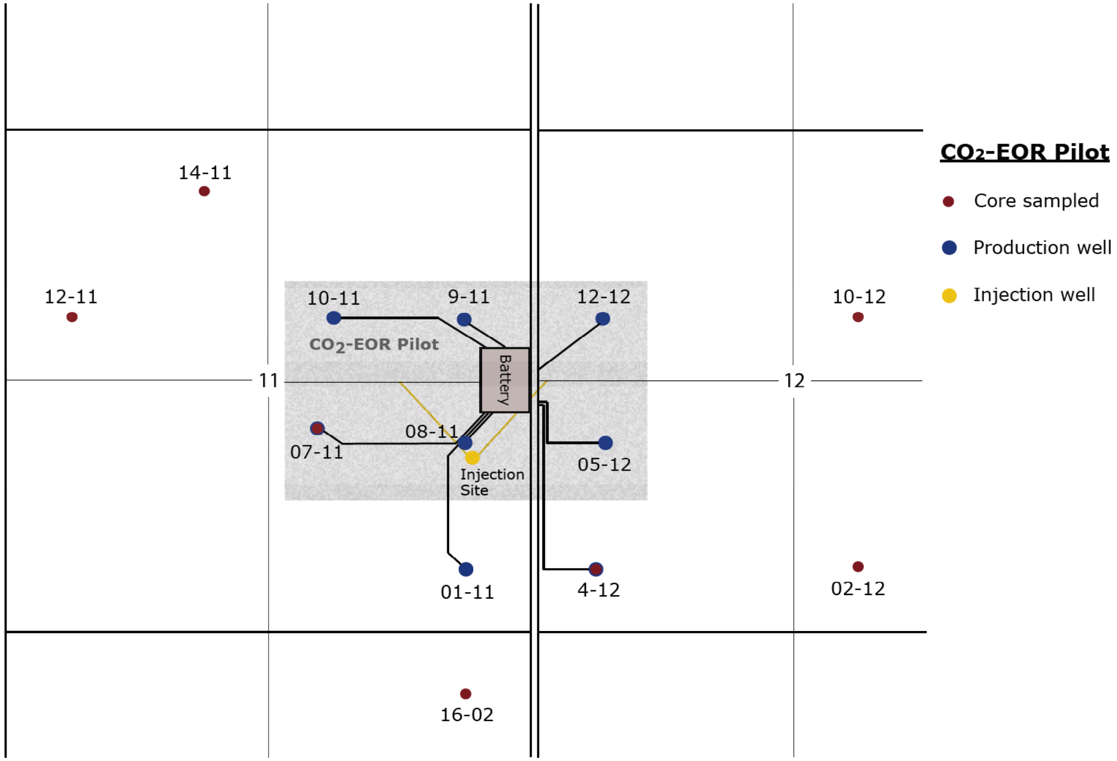
PENN WEST SITE HISTORY



- Discovered in 1953.
- Approximate area is 140,000 km^2.
- Average thickness: 20 m.
- Primary production begins in 1955 from the Cardium formation.
- Water flood begins in 1958.

The Cretaceous Cardium formation consists of stacked sandstone sheets with interstitial shale beds. Unit is capped by the Wapiabi Shale formation and underlayen by the Blackstone Shale formation. Initial reservoir temperature and pressure estimated to be 50 ^{o}C and 19 MPa.

PENN WEST CO_2-EOR SITE



Wells at 10-11 and 8-11 are historic water injectors.

Well 7-11 was converted to observation/downhole sampling well.

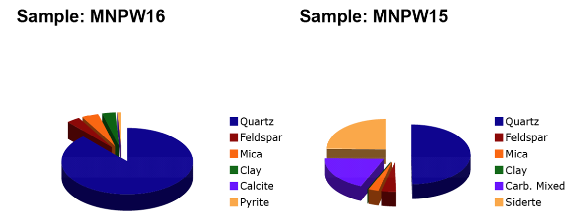
- 2005: CO_2 miscible flood in 2 five spot pattern. Water support used.
- 2007: Converted to WAG operations. Wells switched on monthly basis
- Variable CO_2 source.

SELECTED PORTION OF FLUID MONITORING CHEMISTRY

On a monthly basis, subject to operational constraints,

- Production fluid samples taken and analysed,
- Injection stream samples taken and analysed.

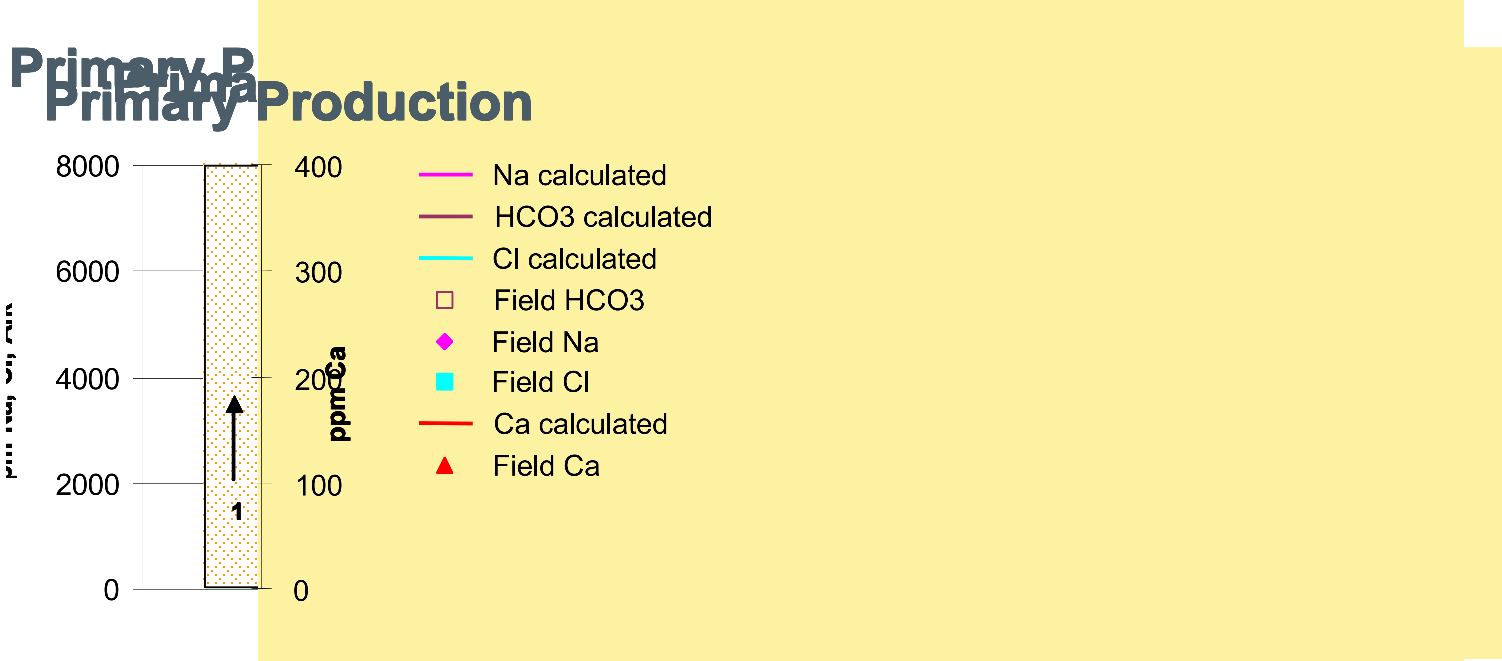
WATER FLOOD CHEMISTRY: SAMPLING VERSUS MODELLING



Geochemical modelling included the effects of supercritical gas, fluid mixing, dissolution, precipitation, ion exchange and gas solubility in oil.

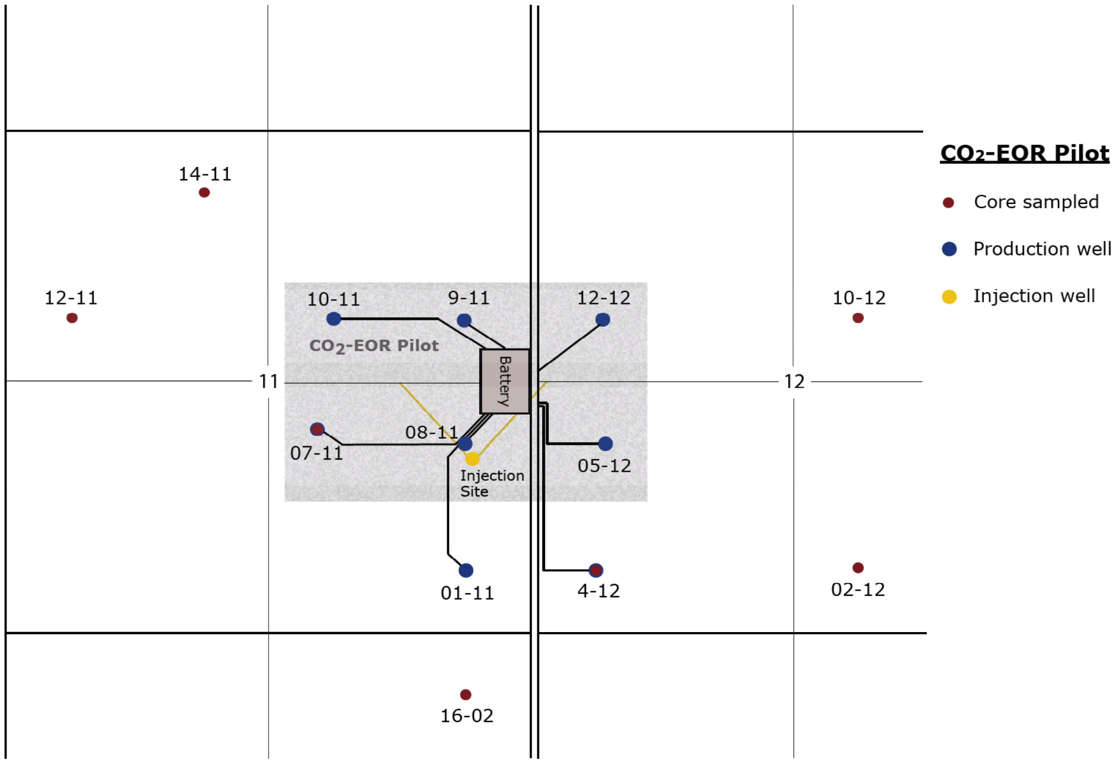
There is a good correlation between historical and predicted values, but not between baseline and predicted values. This is due to operational changes; different make-up water and the increasing use of re-cycled waters.

1-D COUPLED GEOCHEMICAL FLOW SIMULATION



Similar to the previous conclusion, the differences between modelled and the measured fluid composition is due to changing make-up water sources and the increasing use of re-cycled waters.

FLUID SAMPLING LOCATIONS

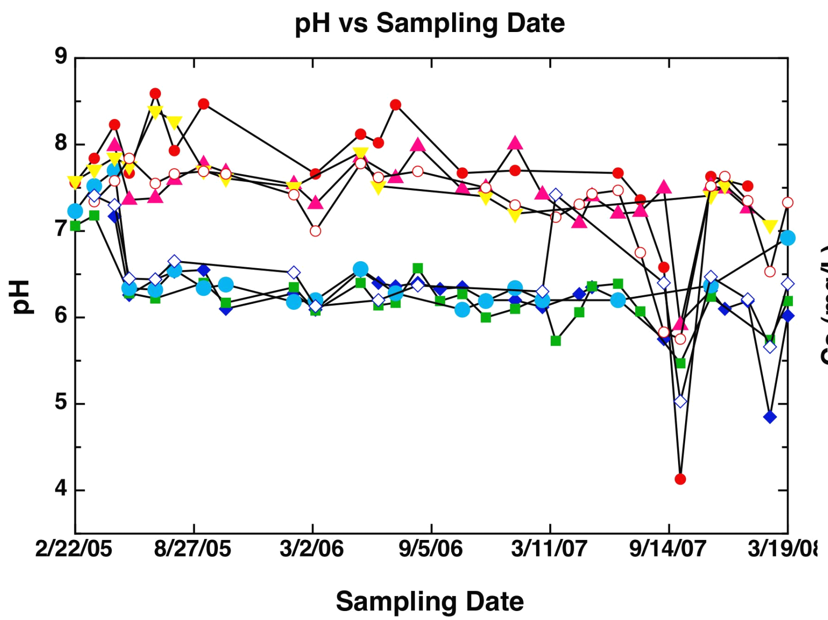


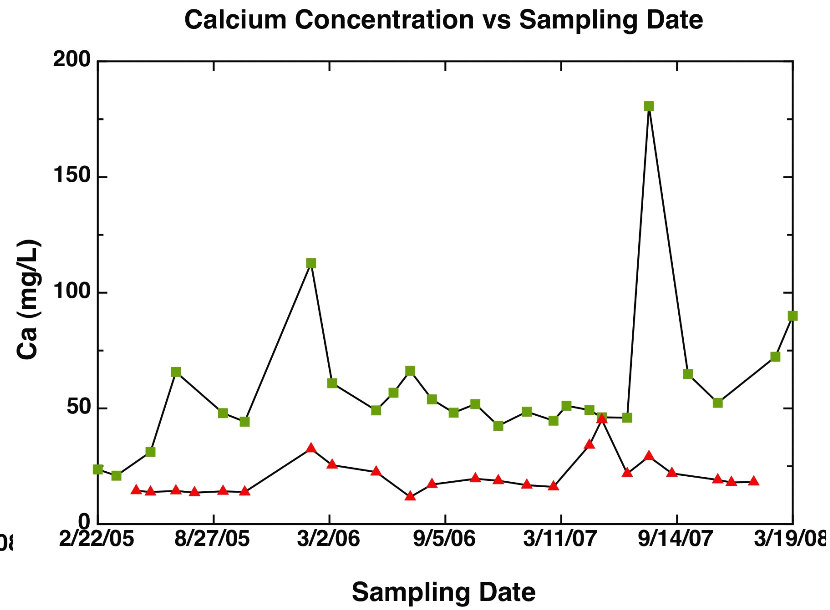
Wells 10-11 and 8-11 have been historically used as water injectors, but are now production wells.

Samples were taken from the production wells around each of the injection wells in the 5 spot pattern.

- The saturation indices of carbonate minerals were calculated for each sample, and examined as a function of time for each well.

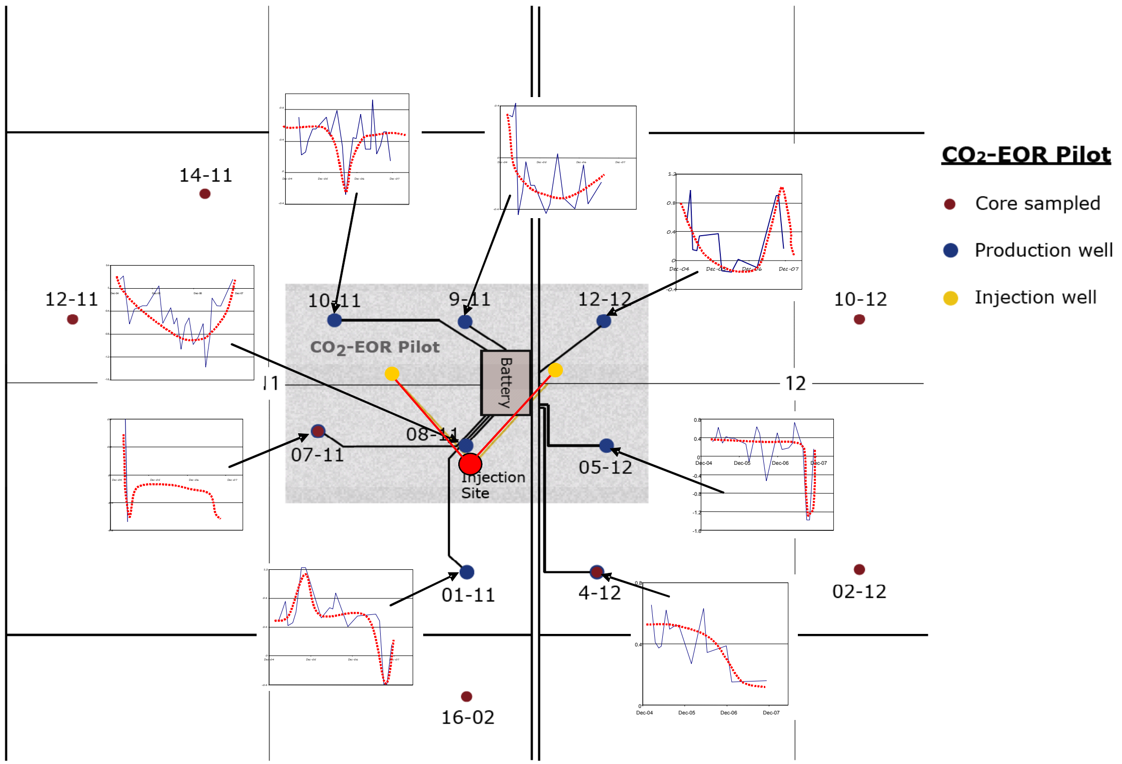
WELL WORK OVER EFFECTS





- The effects of workover fluids can be clearly seen in the spikes of calcium concentration, and to a lesser extent, changes in pH.

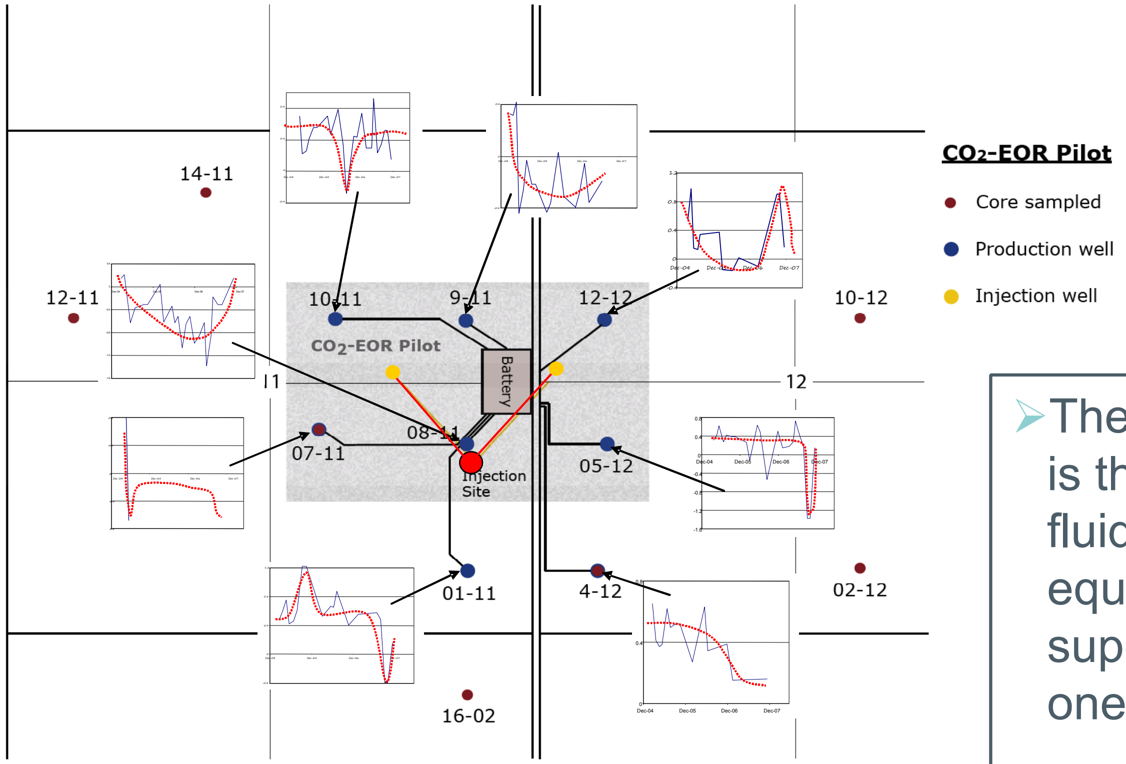
CALCULATED CALCITE SI'S AS A FUNCTION OF TIME FOR EACH WELL

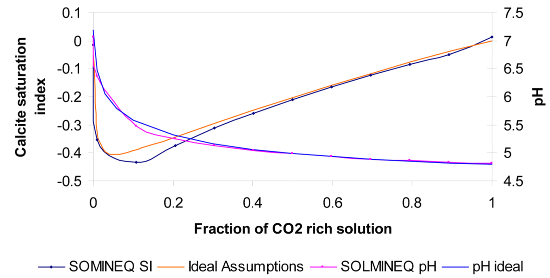


The Observations

- The calcite SI's change significantly with time.
- All are undersaturated significantly for some period of time.
- Fact: the reservoir contains significant amounts of carbonate minerals!
- "On trend" wells behaved quite differently than "Off trend" wells

CALCULATED CALCITE SI'S AS A FUNCTION OF TIME FOR EACH WELL

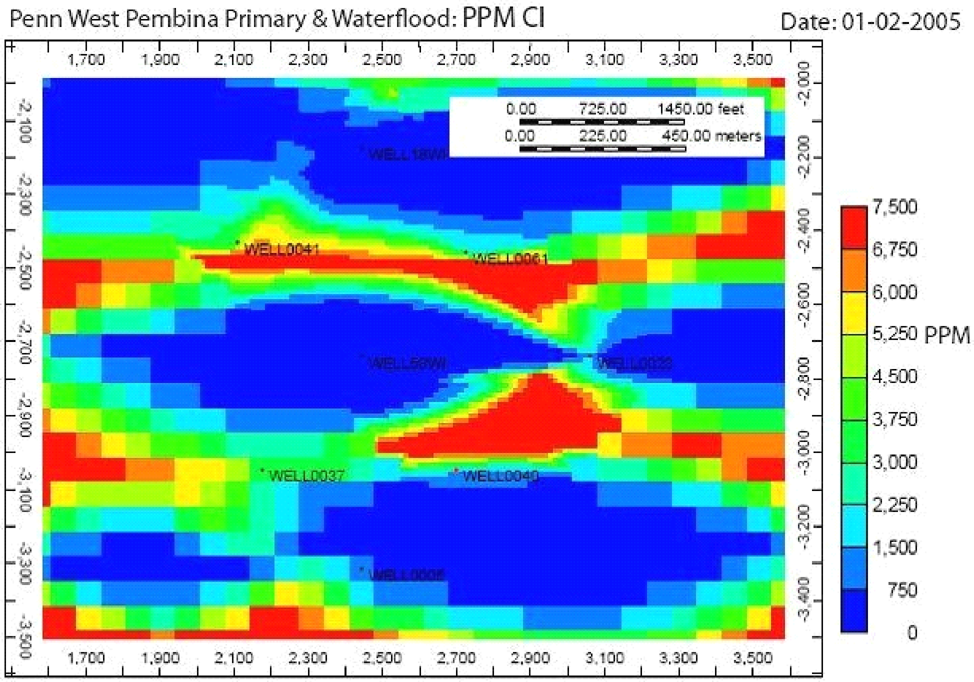




The Conclusions

- The calcite undersaturation is the results of different fluids (waters) mixing, one in equilibrium with the supercritical CO_2 plume and one not.
- "On trend" wells responded quickly to breakthrough.
- "Off trend" wells responded slowly.

3-D COUPLED GEOCHEMISTRY AND RESERVOIR MODELLING –END OF WATER FLOOD



Chloride concentration in the reservoir.

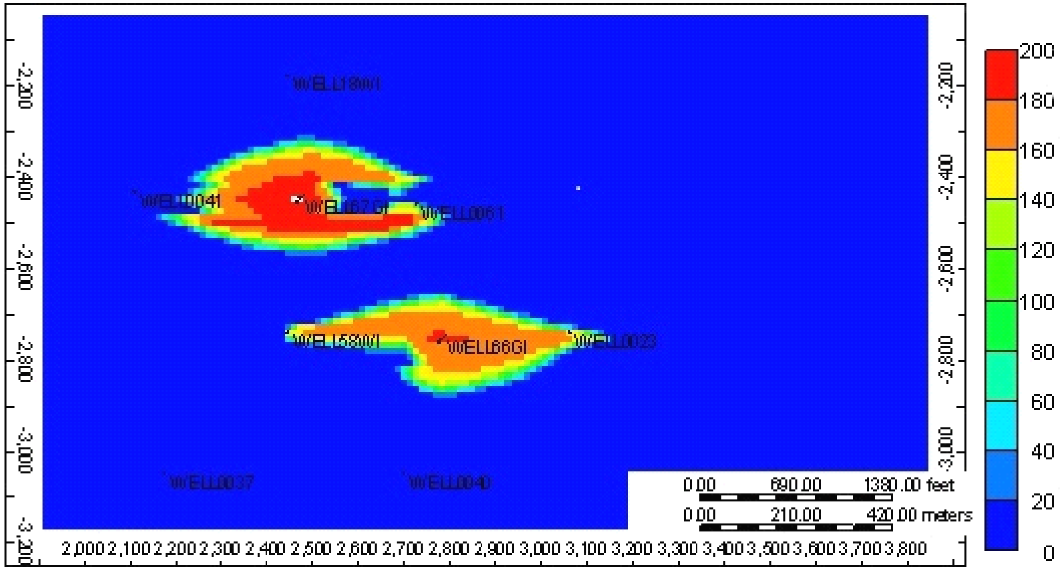
- Modelled using CMG GHG GEM
- 3rd layer in reservoir
- At the end of waterflood

Display is rotated from earlier pattern description.

Conclusions:

- Fracture pattern in the reservoir controls water movement.
- Good match on all dissolved components.

3-D COUPLED GEOCHEMISTRY AND RESERVOIR MODELLING –THE CO_2 FLOOD



Partial Pressure of CO_2 fluid in the reservoir.

- Modelled using CMG GHG GEM
- 3rd layer in reservoir
- 18 months after CO_2 injection began.

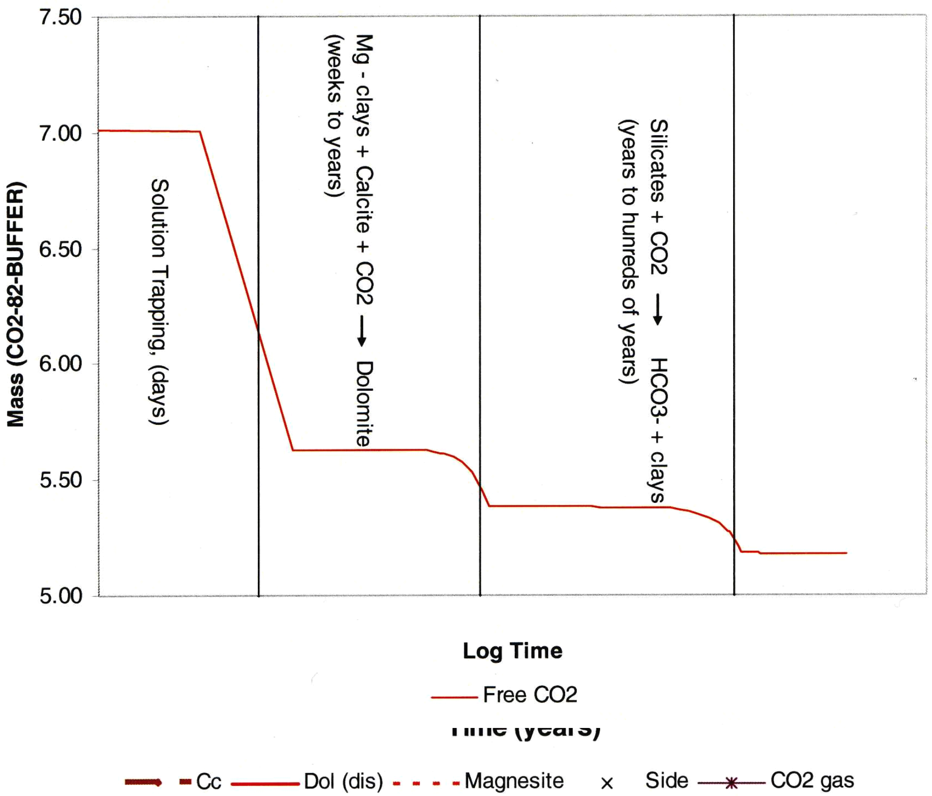
Display is rotated from earlier pattern description.

Conclusions:

- Fracture pattern in the reservoir controls CO_2 and water movement.
- All components behaved in a complimentary fashion.
- As observed previously, modelled concentrations were off-set from analytical values.

DETAILED REACTION PATH MODELLING

- Impacts of changing
  - thermodynamic data
  - fluid chemistry
  - mineralogy
  - chemical processes
- were evaluated.



Calculations shown for the Cemented Cardium Sandstone.

CONCLUSIONS - TRAPPING

CO_2 trapping mechanisms kg/m^3 reservoir	Unit			
	Sandstone	Conglomerate	Interstitial Shale	Cemented SS
CO_2 Dissolved in Oil	1.27	0.59	0.79	0.95
CO_2 Residual Gas	26.12	12.53	14.47	18.47
CO_2 Solution Trapping	5.50	2.55	3.44	4.13
CO_2 Ionic Trapping	1.43	0.35	1.74	1.96
CO_2 Mineralogical Trapping	0.47	0.08	1.31	0.59
Total CO_2 Trapped	34.79	16.09	21.74	26.09

CONCLUSIONS – EOR

- Fluid sampling programs during CO_2 EOR are appropriate to "*chemically*" evaluate the reservoir. The results are necessary input to more numerically complex simulations.

- Coupled 3-D geochemical – flow models are necessary to totally represent the "*physical*" reservoir processes and the coupling to the chemical processes.

CONCLUSIONS - CCS

- *EOR fluid and mineralogical sampling programs allow CO_2 storage amounts to be determined.*
- *EOR fluid sampling program allow the ionic concentration and ithe variation in fluid chemistry to be quantified for monitoring purposes.*
- *Coupled geochemical – reservoir simulators allow long term fate of CO_2 in the reservoir to be determined.*

www.globalccsinstitute.com