Geochemical Evolution of Piceance Basin Groundwater During Heating

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31th Oil Shale Symposium
October 17-21, 2011
Geochemical Modeling Results

**Temperature (°C)**
- Retort Zone
- 3 years
- 2 years
- 1 year
- 0.5 year

**Fluoride**
- Concentration (mmol/L)
- Retort Zone
- Concentration Exceeds Background

**Total Nitrogen**
- Concentration (mmol/L)
- Retort Zone
- Concentration Exceeds Background

**Aluminosilicates**
- Concentration
- Retort Zone
- Analyte
- Ankerite
- Low Albite
- Fe-Mg Saponite
- Weight %

Distance (m)
Mineralogical Changes in Retorted Oil Shale

Powder X-ray Diffraction

Graph showing the concentration of various minerals with temperature.
Objective:

To develop models of the geochemical evolution of groundwaters from the Piceance Basin during heating

Approach:

• Determine the natural groundwater composition and thermodynamic status using Phreeqc-Interactive,
• Simulate chemical evolutions during evaporation,
• Estimate the type and amounts of precipitates that may be formed.
Data Sources

- CSM database,
- Kimball (1984),
- USGS and other reports
Issues

• Many reported pH values are not reliable,
• Aluminum values are often missing or unreliable,

Potential Solutions

• Calculate pH on the assumption of calcite equilibrium,
• Calculate Al activity on assumption of gibbsite equilibrium,
Piper Plot
Mineral Saturation Indices

Based on data from Kimball (1984)
Mineral Saturation Indices

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Based on data from Kimball (1984)

Feldspars

Sample

0  5  10  15  20  25

Saturation Index

-3
-2
-1
0

High Albite
Low Albite
K-Feldspar

Upper Lower Aquifer

Saturation Index

-3
-2
-1
0

Feldspars

K-Feldspar
Low Albite
High Albite

Upper Lower Aquifer

Sample
Mineral Saturation Indices

Based on data from Kimball (1984)

Montmorillonite

Sample

0 5 10 15 20

Saturation Index

-1 0 1 2

Montmor-Ca
Montmor-K
Montmor-Mg
Montmor-Na

Col 5 vs Col 6

Upper Aquifer
Lower Aquifer

Montmorillonite

Based on data from Kimball (1984)
Mineral Saturation Indices

Based on data from Kimball (1984)

Clays

Sample

Saturation Index

Upper Aquifer  Lower Aquifer

Beidellite-K
Montmor-K
Saponite-Mg
Illite
Kaolinite

Sample
Evaporation within Mineral Matrix – Upper Aquifer

Ionic Strength

\[ \text{Ionic Strength (mol/kg)} \]

\[ \begin{array}{c|c|c|c|c|c|c|c}
\% \text{ Liquid H}_2\text{O Remaining} & 1 & 10 & 100 \\
\hline
\text{Ionic Strength} & 0.01 & 0.1 & 1 \\
\end{array} \]

\[ \text{pH} \]

\[ \begin{array}{c|c|c|c|c|c|c|c}
\% \text{ Liquid Water Remaining} & 100 & 10 & 1 \\
\hline
\text{pH} & 5.5 & 6.0 & 6.5 & 7.0 & 7.5 & 8.0 & 8.5 \\
\end{array} \]
Evaporation (Upper Aquifer)

% Liquid $H_2O$ Remaining

Concentration (mol/kg)

$1 \times 10^{-5}$
$1 \times 10^{-4}$
$1 \times 10^{-3}$
$1 \times 10^{-2}$
$1 \times 10^{-1}$
$1 \times 10^{0}$

Na
Cl
C
Mg
Ca
K
Evaporation (Upper Aquifer)

% Liquid Water Remaining

Mineral Reacted (mol/kg)

-0.00010
-0.00005
0.00000
0.00005
0.00010
0.00015
0.00020

Calcite
Disordered Dolomite

-0.006
-0.004
-0.002
0.000
0.002
0.004
0.006

Quartz
Gibbsite
Dawsonite

-4e-5
-2e-5
0
2e-5
4e-5
6e-5

Fluorite
Illite
Experiments

An experimental apparatus has been designed and built to study the evolution of fracture permeability as precipitates form from boiling solutions.
Summary

• We have initiated a modeling study of the groundwater geochemistry in the Piceance basin to determine the thermodynamic state of those waters,

• We have simulated the evolution of Piceance Basin groundwaters undergoing evaporation,

• These simulations will improve our understanding of potential groundwater impacts and permeability evolution,

• Next Steps are to:
  ➢ Simulate the evaporation of other groundwaters in the basin,
  ➢ Determine the effects of temperature on groundwater composition
  ➢ Experimentally investigate evolution of oil shale fracture permeability as waters boil and precipitates form.