POROSITY CHANGES IN THE JANGGI BASIN

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PRESENTATION BY: TAYLOR SEVERANCE

05/01/2025 CHEM 428

AGENDA

Introduction

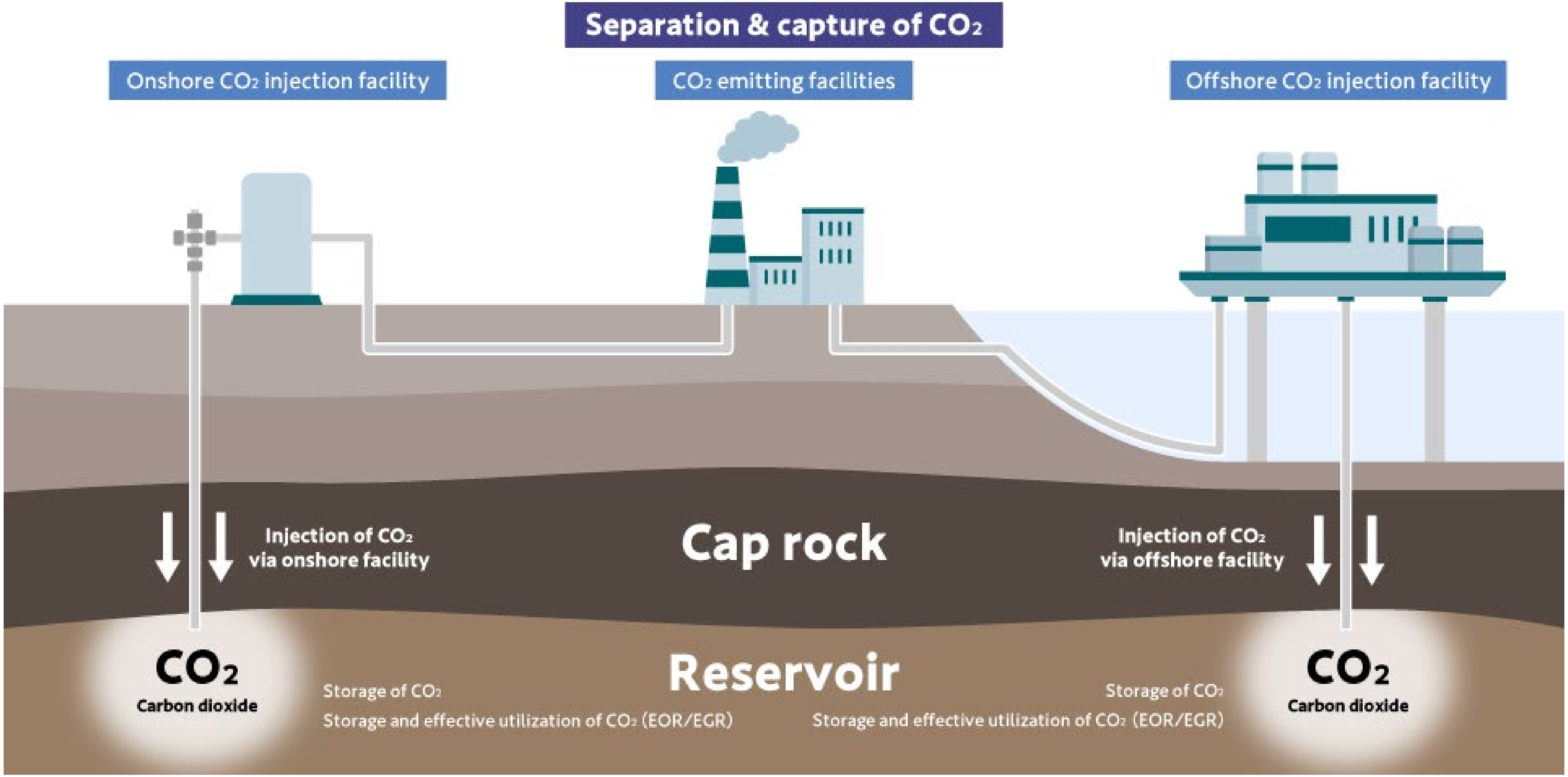
Background

Methods

Geochemical Modeling

Summary

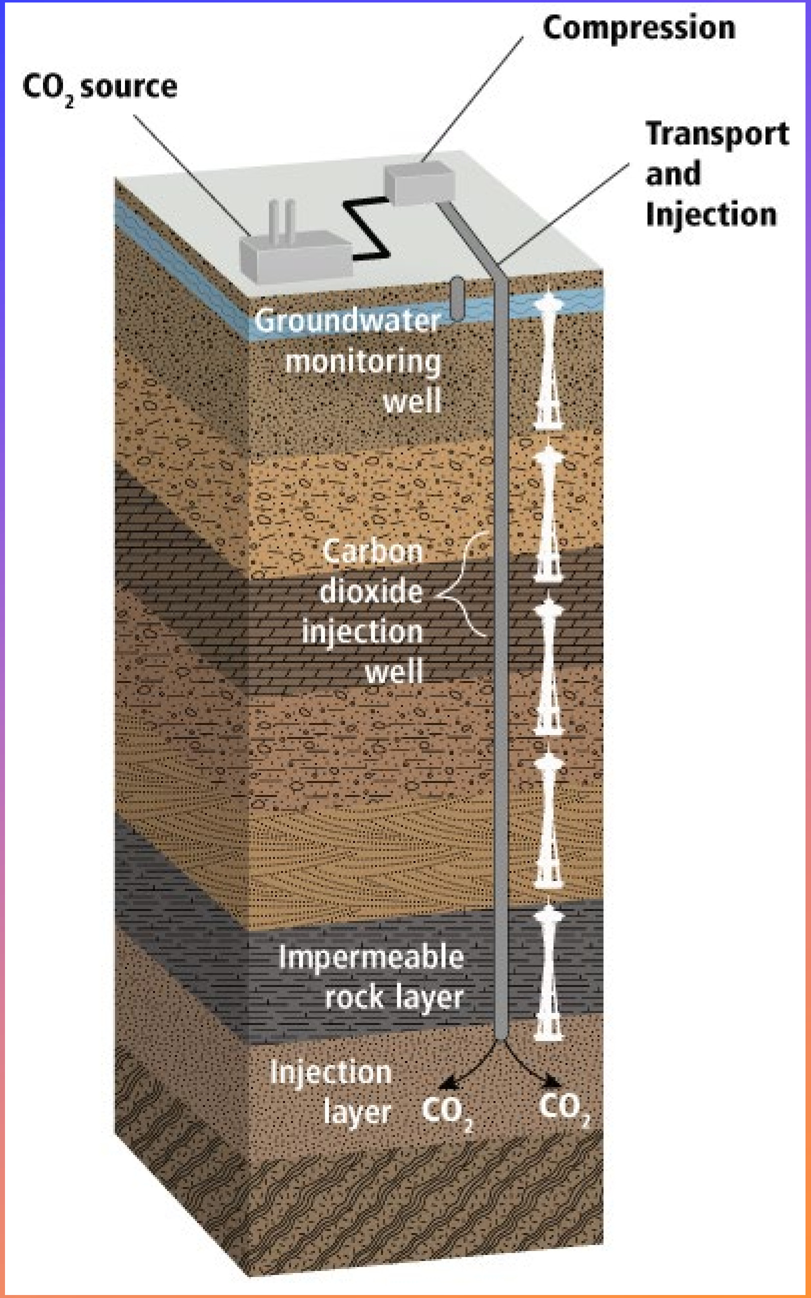
CO2 Capture



Steel, N. (n.d.). Metropolitan Area CCS Project. In *INPEX*. https://www.inpex.com/english/business/project/metropolitan-ccs.html

CO2 Reservoirs

- Places that can securely contain CO2 over long periods of time
  - Depleted Oil and gas reservoirs
    - Layers of porous rock
  - Basalt Formations
    - Solidified lava: potential to convert injected CO2 to solid mineral
  - Shale Basins
    - Sedimentary rock characterized by thin horizontal layers with very low permeability in the vertical direction: Good adsorption for CO2 storage



Herzog, H., & Golomb, D. (n.d.). *Carbon Capture and Storage from Fossil Fuel Use 1*. Retrieved April 28, 2025, from https://sequestration.mit.edu/pdf/enclyclopedia_of_energy_article.pdf

CAP ROCKS

Form over the top of reservoirs and create a layer that is impervious to fluid flow (fluids prevented from escaping the reservoir)

- When a rock that is harder to break down (resists weathering) overlies an easier to break down rock (less resistant to weathering) the rock on top is the cap rock
- Develop from solution of salt from the top of a salt core; leaves a residue of insoluble anhydrite that is later altered to gypsum, calcite and sulfur.

Often formed from shale, anhydrite or salts

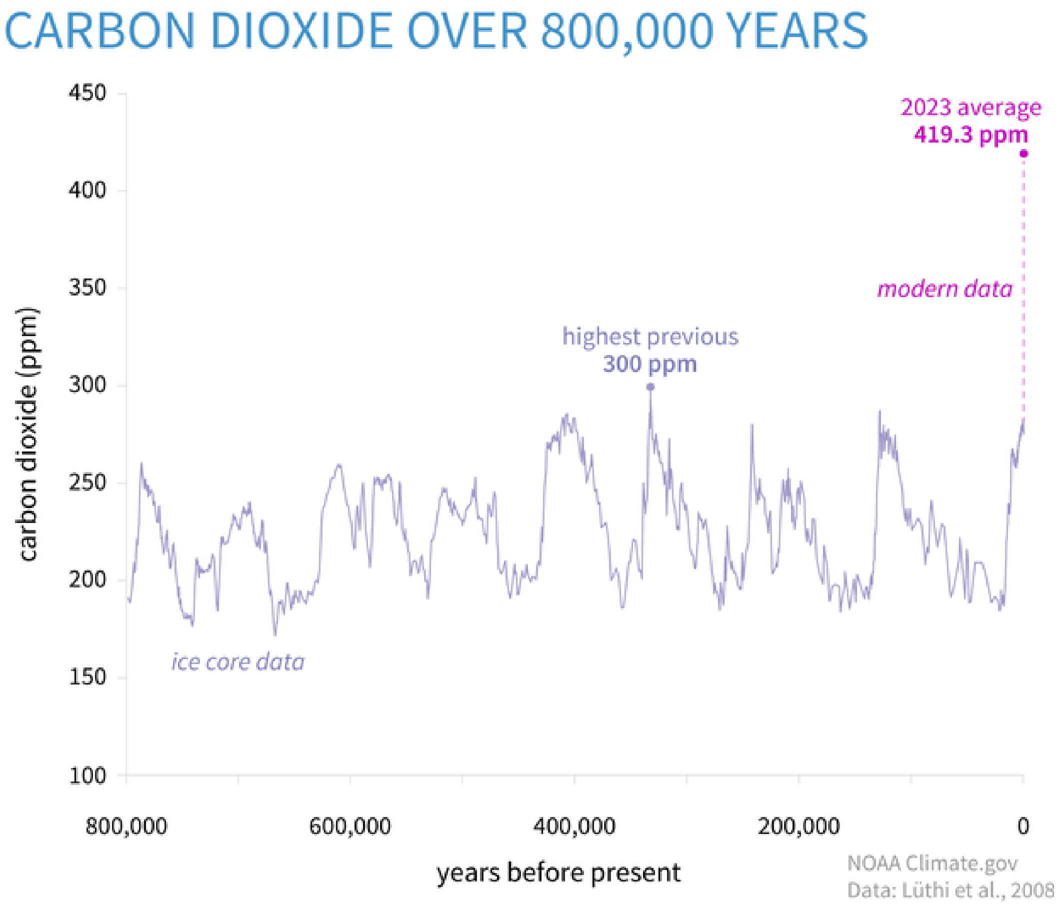
- Ranges from 0 to 300 meters thick

Can protect the more delicate layers from weather and erosion OR cap rock can remain while the more delicate lower layers are weathered and eroded under it.

Editors of Encyclopaedia Britannica. (n.d.). *Salt dome | geology | Britannica*. Www.britannica.com. Retrieved April 28, 2025, from https://www.britannica.com/science/salt-dome

THE ARTICLE

RESEARCH PROBLEM



NOAA Climate.gov
Data: Lüthi et al., 2008

CO2 accounts for 2/3 of Earth warming

- Atmospheric CO2 419.3ppm in 2023

CO2 storage

- Uncertainties of geochemical storage
  - The CO2 injected into reservoirs migrates upward due to its buoyancy, resulting in contact with cap rocks. Acidic conditions promote CO2–water–cap rock interactions.
  - Dissolution of carbonate rocks through acidic CO2-water mixtures
  - These geochemical reactions can affect pore water quality but also shape the pore and pore throat morphologies.

Miller, B. G. (2017, January 1). *13 - Carbon Dioxide Emissions Reduction and Storage* (B. G. Miller, Ed.). ScienceDirect; Butterworth-Heinemann. https://www.sciencedirect.com/science/article/abs/pii/B9780128113653000132

JANGGI BASIN

- Miocene sedimentary basin in southeastern South Korea
- Formed by the opening of the East Sea associated with (NNW)-trending dextral strike-slip faults and (NNE)- to (NE)-trending normal faults
    - Mainly filled with volcanic and nonmarine sedimentary deposits
- Basaltic Rock (mainly basaltic tuff) distributed at various depths depending on the basin structure and was observed to exist at depth of approximately 450 meters below the surface from a borehole
- Identify the geochemical reactivity of basaltic tuff as a cap rock and its effect on porosity changes by CO2–water–rock interactions

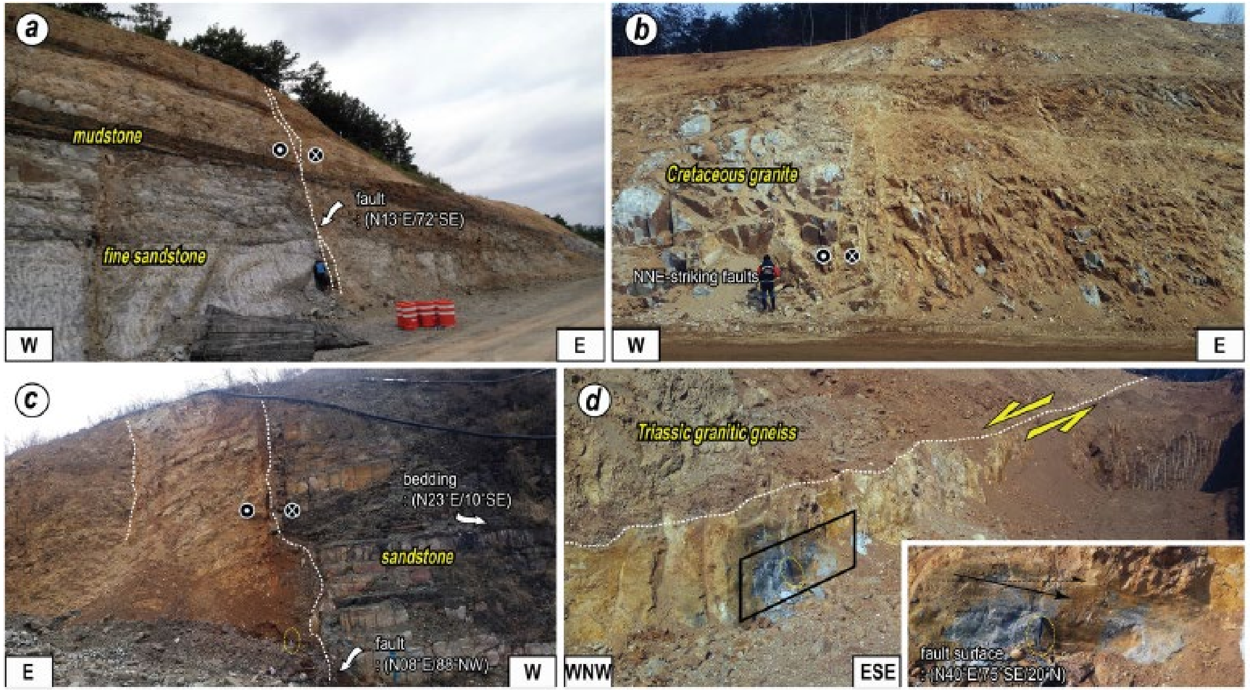
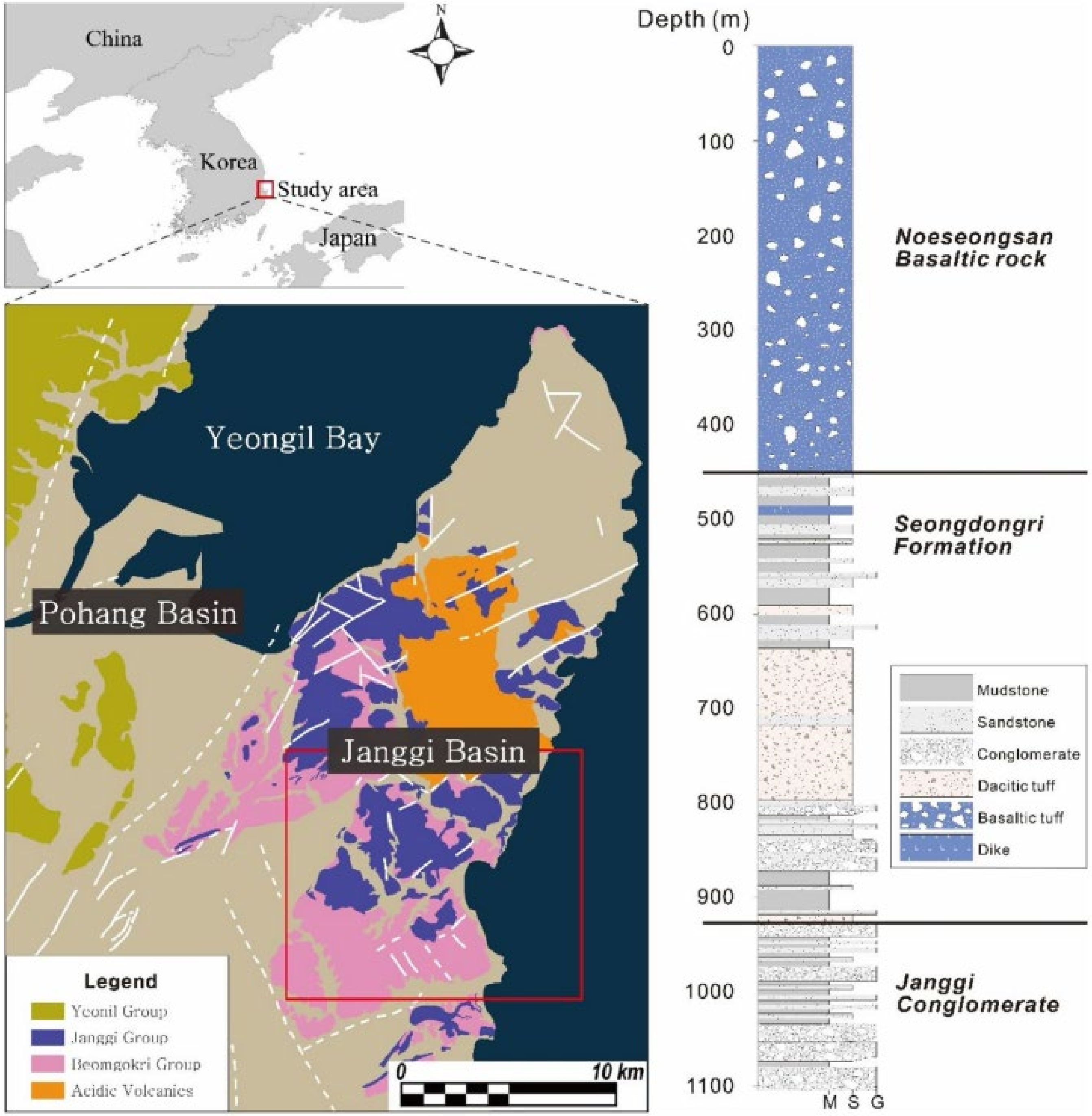


Table 1 Mineral components of the basaltic tuff determined using powder X-ray diffraction (XRD)

Mineral	Weight %
Plagioclase	29.9
Smectite	23.4
Clinoptilolite	22.9
Analcime	6.3
Pyroxene	9.5
Stilbite	6.2
Quartz	1.8

Park, J., Choi, BY., Lee, M. *et al.* Porosity changes due to analcime in a basaltic tuff from the Janggi Basin, Korea: experimental and geochemical modeling study of CO$_2$–water–rock interactions. *Environ Earth Sci* **80**, 81 (2021). https://doi.org/10.1007/s12665-021-09370-


China
N
Korea
Study area
Japan
Yeongil Bay
Pohang Basin
Janggi Basin
Legend
🟨 Yeonil Group
🟦 Janggi Group
🟪 Beomgokri Group
🟧 Acidic Volcanics
0
10 km
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
Noeseongsan Basaltic rock
Seongdongri Formation
Janggi Conglomerate
Mudstone
Sandstone
Conglomerate
Dacitic tuff
Basaltic tuff
Dike
M
S
G

EXPERIMENTAL METHODS

Solid Sampling

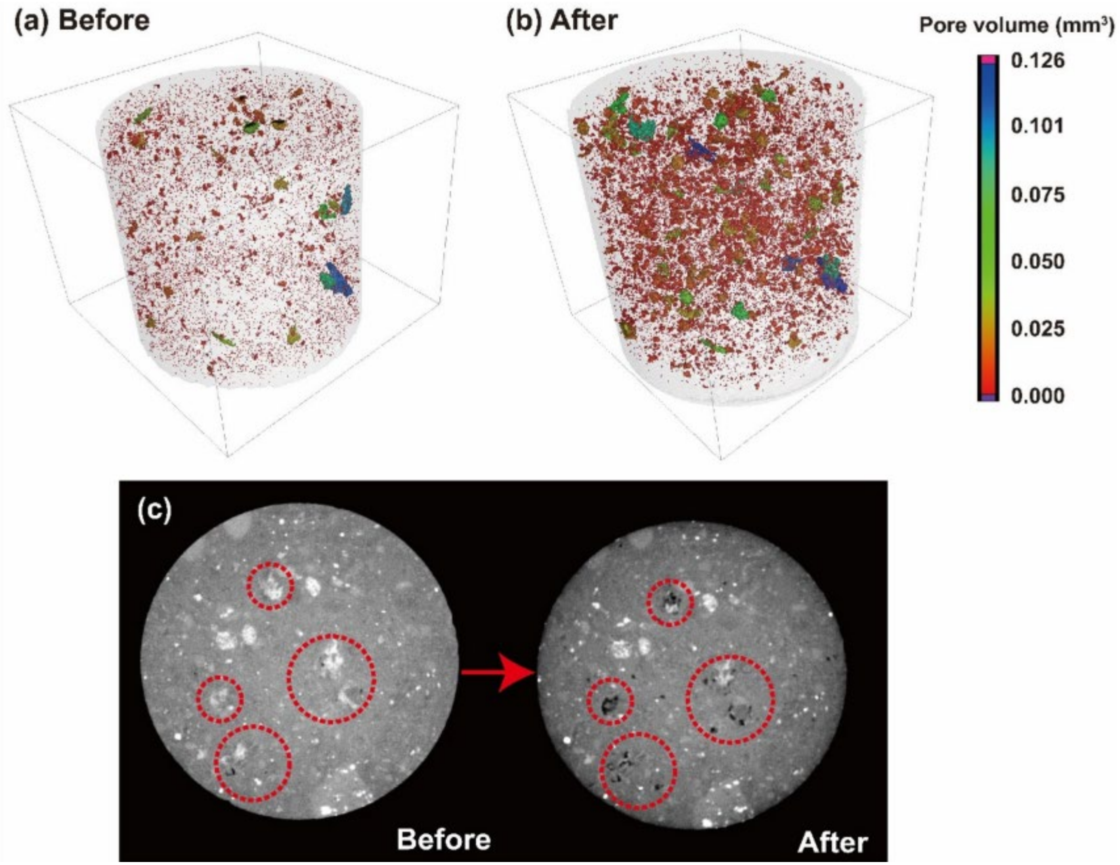
1. Mineralogical analysis with X-ray diffraction
2. Changes in surface area by N2 adsorption
3. Porosity changes by 3D x-ray CT scans

Park, J., Choi, BY., Lee, M. *et al.* Porosity changes due to analcime in a basaltic tuff from the Janggi Basin, Korea: experimental and geochemical modeling study of CO_2–water–rock interactions. *Environ Earth Sci* **80**, 81 (2021). https://doi.org/10.1007/s12665-021-09370-

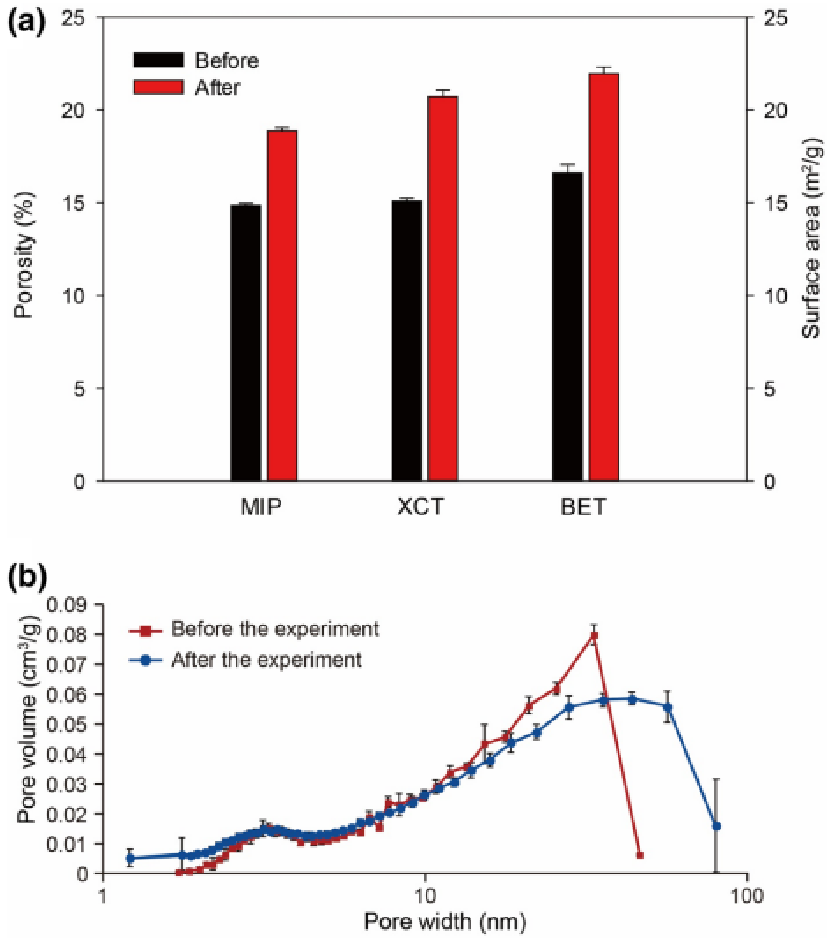
PREPARATION

1. 13.77 g of the total rock samples and 140 ml of distilled water were filled in a reactor.
2. The reactor was purged with gaseous CO2 to remove oxygen from the water and then pressurized to 100 bar of CO2 gas using a syringe pump
3. The experiment was run at 50 °C and100 bar for 84 days without a stirrer.

PHYSICAL RESULTS



Three-dimensional images of pore volume in basaltic tuff after experiment using XCT scan.



Comparison of porosities and surface areas. Error bars are standard deviation of the mean.

GEOCHEMICAL MODELING

Concentration

- Kinetic reaction modeling for CO2–water–basaltic tuff interactions was conducted using PHREEQC.
- Lawrence Livermore National Laboratory (LLNL) database.
- Plagioclase was represented as albite and anorthite in a ratio of 1:2.13 based on the molar ratio of Ca and Na.
- Pyroxene was represented as enstatite and hedenbergite in a ratio of 1:1.15 from the molar ratio of Fe, Mg, and Ca.
- The possible secondary minerals considered were calcite, dolomite, illite, kaolinite, magnesite, magnetite, montmorillonite, siderite, and SiO2 (am).

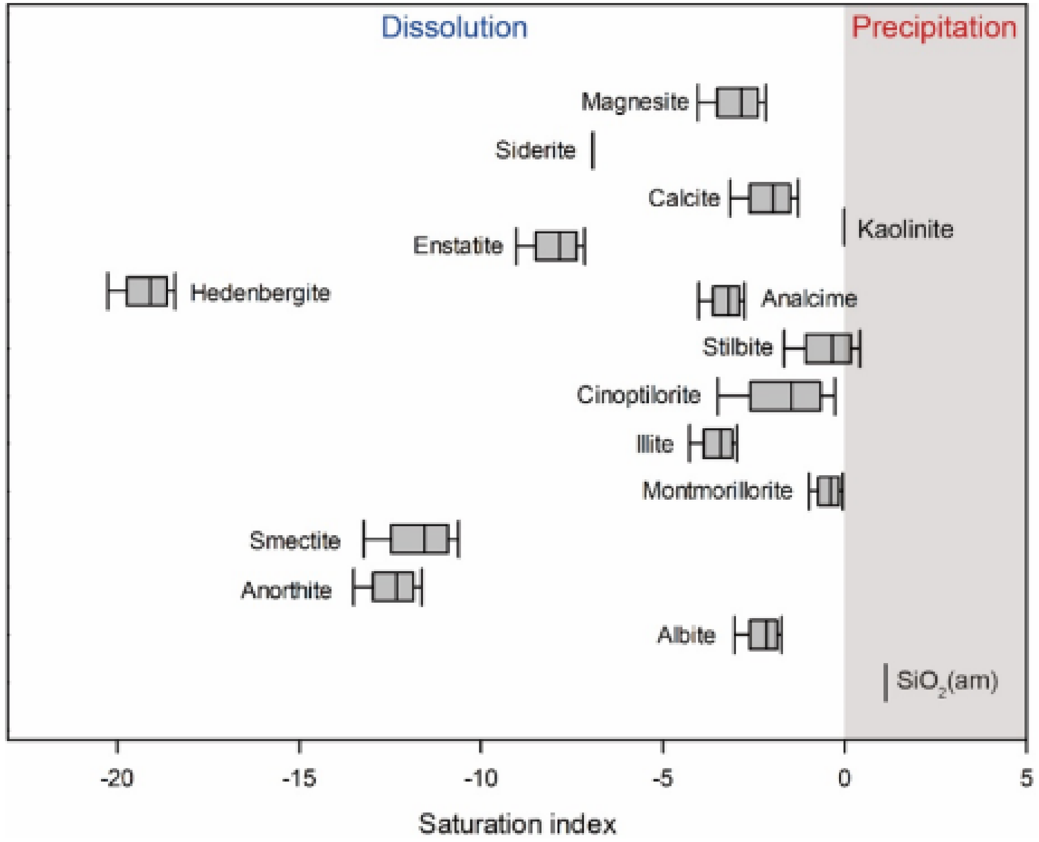
Kinetics

- Rate calculated by rate law equation

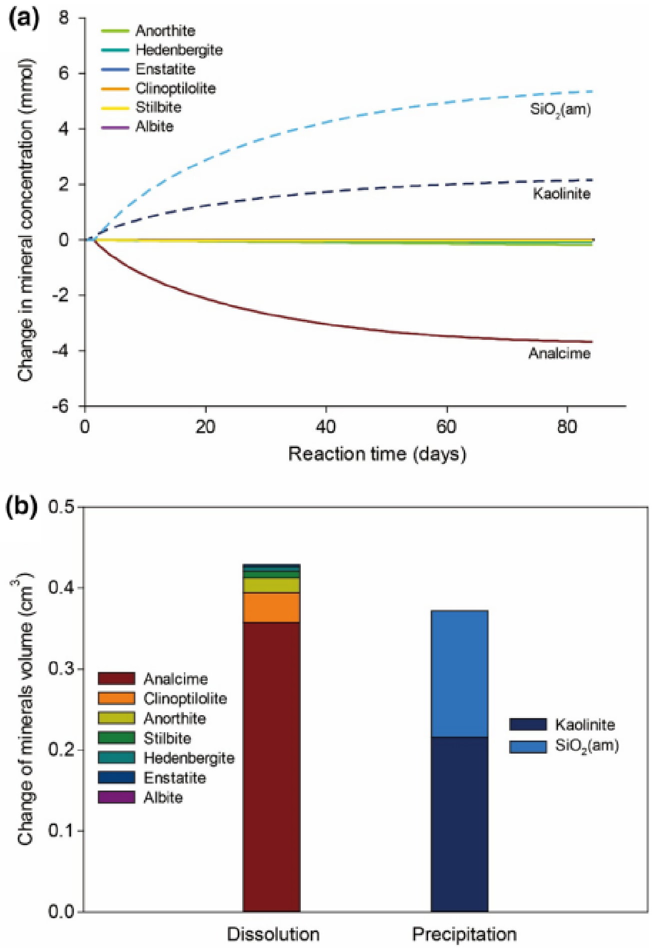
$$
\begin{aligned}
&= A\Big[k_a \exp\left[\frac{-E_a}{R}\left(\frac{1}{T}-\frac{1}{298.15}\right)a_{H+}^{na}\left(1-\frac{Q}{k}\right)\right] \\
&+ k_{nu} exp\left[\frac{-E_n}{R}\left(\frac{1}{T}-\frac{1}{298.15}\right)\left(1-\frac{Q}{k}\right)\right] \\
&+ k_b exp\left[\frac{-E_b}{R}\left(\frac{1}{T}-\frac{1}{298.15}\right)a_{H+}^{nb}\left(1-\frac{Q}{k}\right)\right]\Big]
\end{aligned}
$$

- $E = activation\ energy \mid Q = reaction\ product \mid k = equilibrium\ constant \mid A = specific\ reactive\ surface\ area \mid a = \ activity \mid n = power\ constant \mid R = gas\ constant$
- Calculated for all minerals and then modeled

MODELING RESULTS



Saturation indices of primary and secondary minerals.

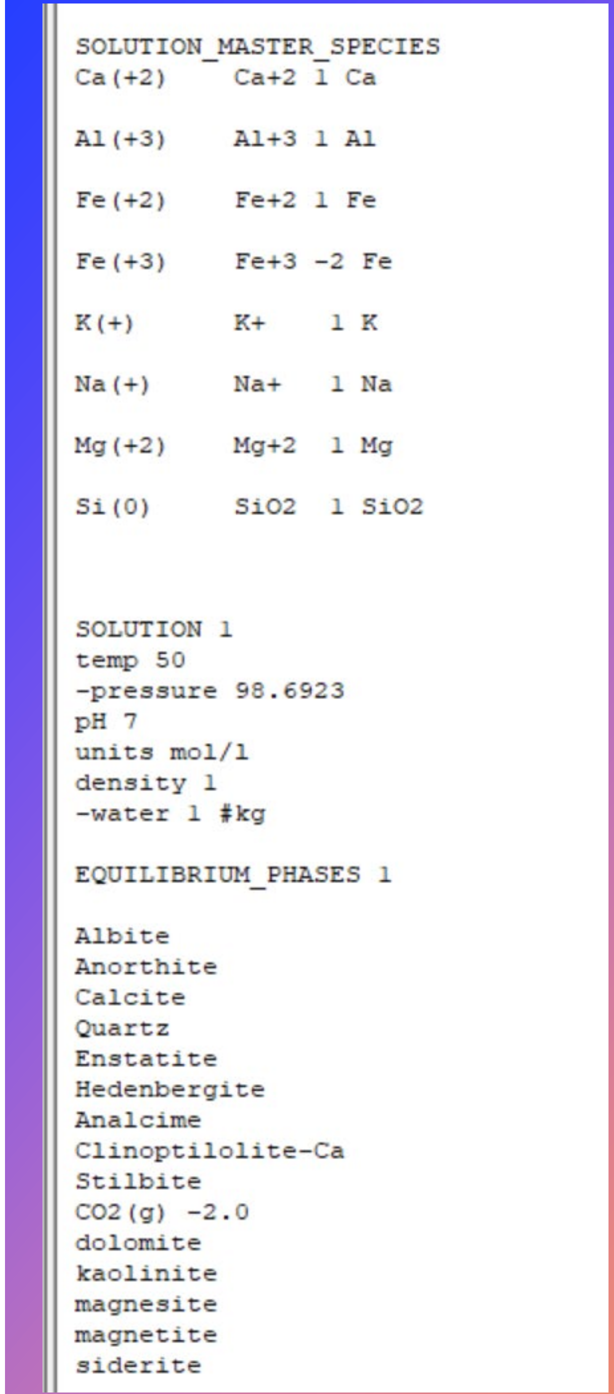


a. Changes in the mineral concentrations in the basaltic tuff sample by CO2–water–rock interaction. **b.** Changes in mineral volumes. Left bar represents dissolved volume of primary minerals. Right bar represents the precipitated volume of secondary minerals.

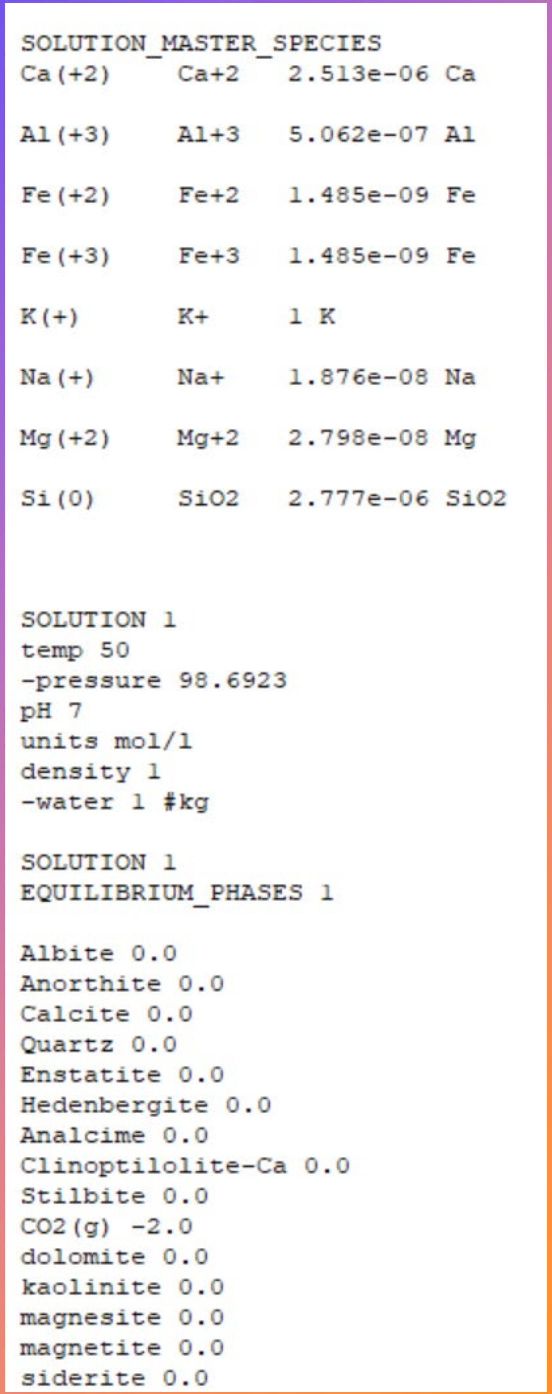
MY GEOCHEMICAL MODELING

My goals:

- Track SI's of the primary and secondary minerals
- Calculate concentration of ions
- Model pH of solution after interactions
- Model kinetics of the system

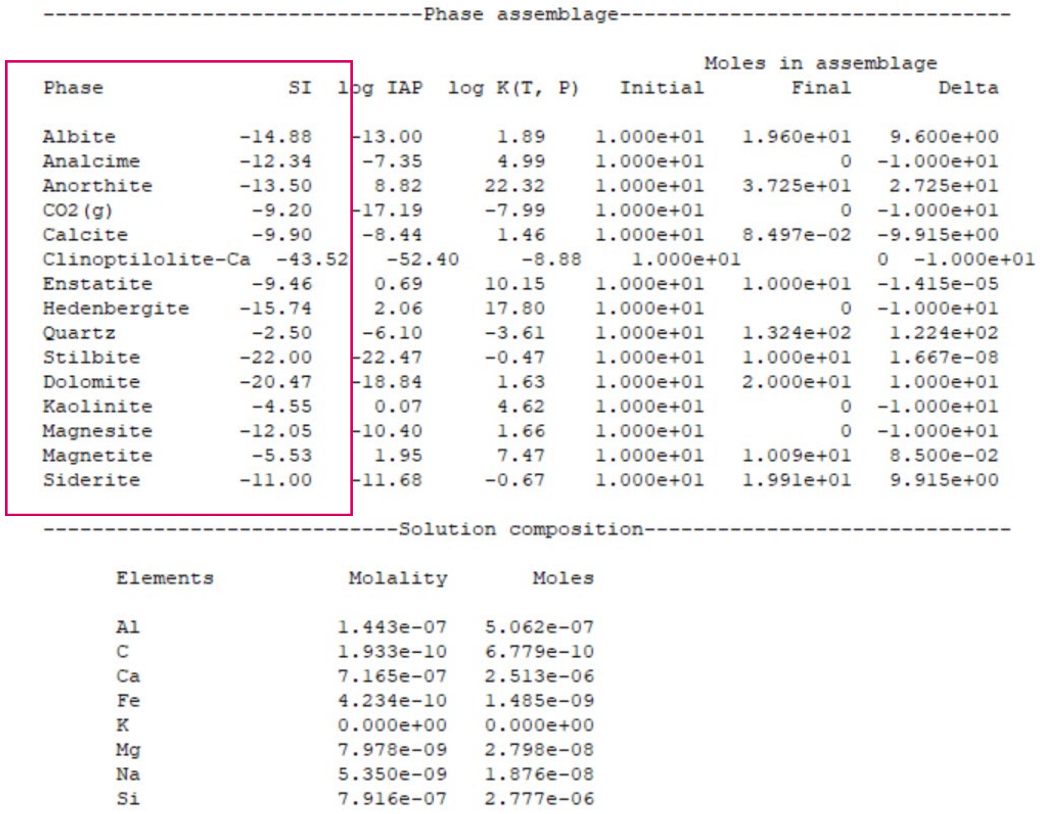


```
SOLUTION_MASTER_SPECIES
Ca(+2)      Ca+2  1  Ca

Al(+3)      Al+3  1  Al

Fe(+2)      Fe+2  1  Fe

Fe(+3)      Fe+3 -2  Fe

K(+)        K+     1  K

Na(+)       Na+    1  Na

Mg(+2)      Mg+2   1  Mg

Si(0)       SiO2   1  SiO2



SOLUTION 1
temp 50
-pressure 98.6923
pH 7
units mol/l
density 1
-water 1 #kg

EQUILIBRIUM_PHASES 1

Albite
Anorthite
Calcite
Quartz
Enstatite
Hedenbergite
Analcime
Clinoptilolite-Ca
Stilbite
CO2(g) -2.0
dolomite
kaolinite
magnesite
magnetite
siderite
```

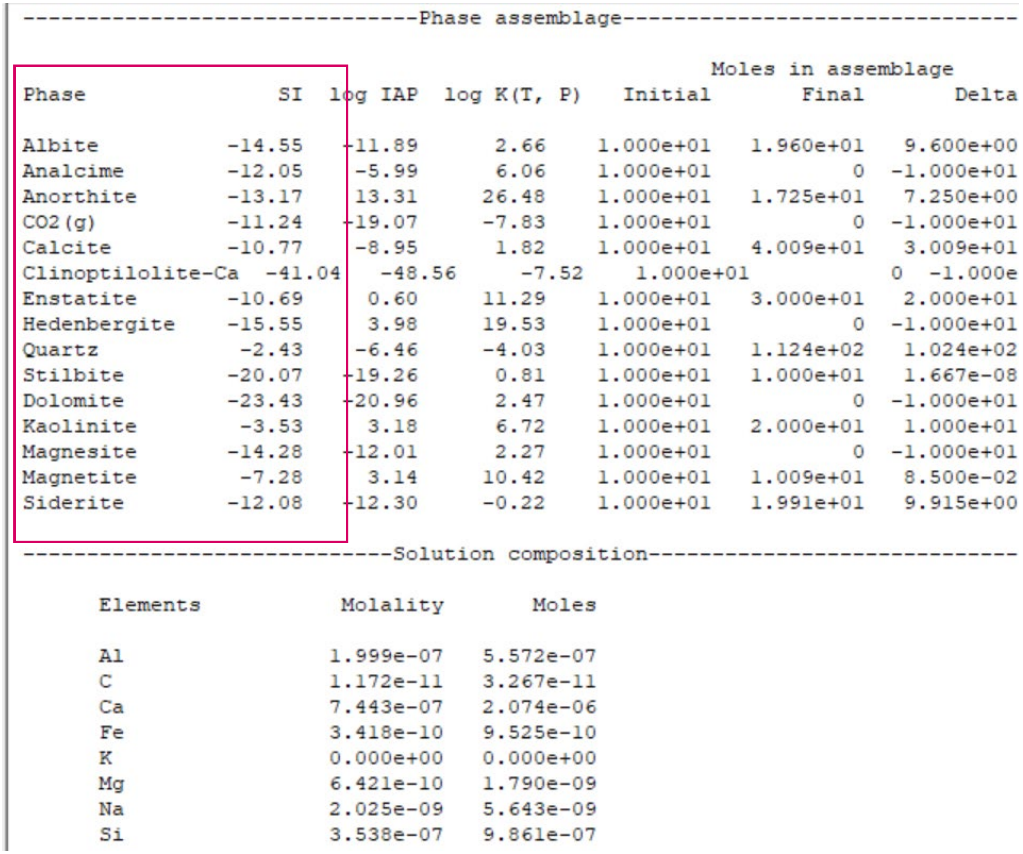


```
SOLUTION_MASTER_SPECIES
Ca(+2)      Ca+2    2.513e-06 Ca

Al(+3)      Al+3    5.062e-07 Al

Fe(+2)      Fe+2    1.485e-09 Fe

Fe(+3)      Fe+3    1.485e-09 Fe

K(+)        K+      1 K

Na(+)       Na+     1.876e-08 Na

Mg(+2)      Mg+2    2.798e-08 Mg

Si(0)       SiO2    2.777e-06 SiO2



SOLUTION 1
temp 50
-pressure 98.6923
pH 7
units mol/l
density 1
-water 1 #kg

SOLUTION 1
EQUILIBRIUM_PHASES 1

Albite 0.0
Anorthite 0.0
Calcite 0.0
Quartz 0.0
Enstatite 0.0
Hedenbergite 0.0
Analcime 0.0
Clinoptilolite-Ca 0.0
Stilbite 0.0
CO2(g) -2.0
dolomite 0.0
kaolinite 0.0
magnesite 0.0
magnetite 0.0
siderite 0.0
```

CONCENTRATION AND SI'S



```
-------------------------------Phase assemblage--------------------------------

                                                      Moles in assemblage
Phase               SI  log IAP  log K(T, P)   Initial       Final        Delta

Albite          -14.88   -13.00      1.89   1.000e+01   1.960e+01   9.600e+00
Analcime        -12.34    -7.35      4.99   1.000e+01           0  -1.000e+01
Anorthite       -13.50     8.82     22.32   1.000e+01   3.725e+01   2.725e+01
CO2(g)           -9.20   -17.19     -7.99   1.000e+01           0  -1.000e+01
Calcite          -9.90    -8.44      1.46   1.000e+01   8.497e-02  -9.915e+00
Clinoptilolite-Ca  -43.52   -52.40     -8.88   1.000e+01           0  -1.000e+01
Enstatite        -9.46     0.69     10.15   1.000e+01   1.000e+01  -1.415e-05
Hedenbergite    -15.74     2.06     17.80   1.000e+01           0  -1.000e+01
Quartz           -2.50    -6.10     -3.61   1.000e+01   1.324e+02   1.224e+02
Stilbite        -22.00   -22.47     -0.47   1.000e+01   1.000e+01   1.667e-08
Dolomite        -20.47   -18.84      1.63   1.000e+01   2.000e+01   1.000e+01
Kaolinite        -4.55     0.07      4.62   1.000e+01           0  -1.000e+01
Magnesite       -12.05   -10.40      1.66   1.000e+01           0  -1.000e+01
Magnetite        -5.53     1.95      7.47   1.000e+01   1.009e+01   8.500e-02
Siderite        -11.00   -11.68     -0.67   1.000e+01   1.991e+01   9.915e+00

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al               1.443e-07   5.062e-07
      C                1.933e-10   6.779e-10
      Ca               7.165e-07   2.513e-06
      Fe               4.234e-10   1.485e-09
      K                0.000e+00   0.000e+00
      Mg               7.978e-09   2.798e-08
      Na               5.350e-09   1.876e-08
      Si               7.916e-07   2.777e-06
```



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-------------------------------Phase assemblage--------------------------------

                                                      Moles in assemblage
Phase               SI  log IAP  log K(T, P)   Initial       Final        Delta

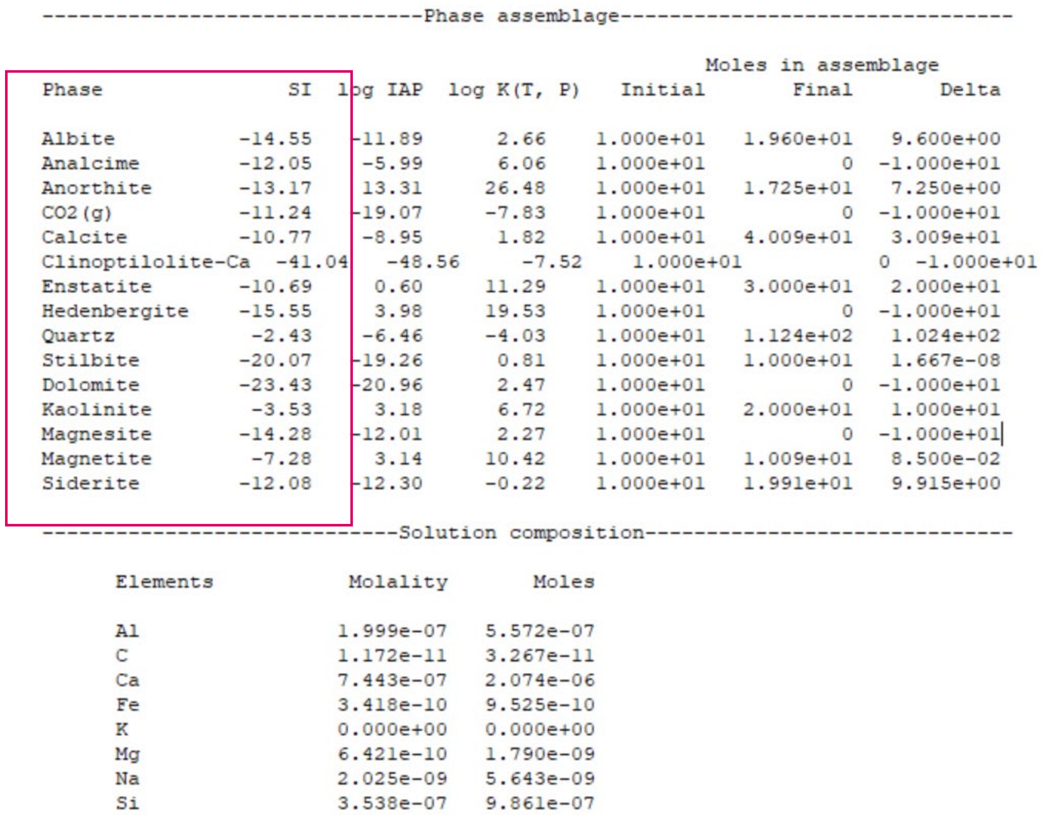
Albite          -14.55   -11.89      2.66   1.000e+01   1.960e+01   9.600e+00
Analcime        -12.05    -5.99      6.06   1.000e+01           0  -1.000e+01
Anorthite       -13.17    13.31     26.48   1.000e+01   1.725e+01   7.250e+00
CO2(g)          -11.24   -19.07     -7.83   1.000e+01           0  -1.000e+01
Calcite         -10.77    -8.95      1.82   1.000e+01   4.009e+01   3.009e+01
Clinoptilolite-Ca  -41.04   -48.56     -7.52   1.000e+01           0  -1.000e
Enstatite       -10.69     0.60     11.29   1.000e+01   3.000e+01   2.000e+01
Hedenbergite    -15.55     3.98     19.53   1.000e+01           0  -1.000e+01
Quartz           -2.43    -6.46     -4.03   1.000e+01   1.124e+02   1.024e+02
Stilbite        -20.07   -19.26      0.81   1.000e+01   1.000e+01   1.667e-08
Dolomite        -23.43   -20.96      2.47   1.000e+01           0  -1.000e+01
Kaolinite        -3.53     3.18      6.72   1.000e+01   2.000e+01   1.000e+01
Magnesite       -14.28   -12.01      2.27   1.000e+01           0  -1.000e+01
Magnetite        -7.28     3.14     10.42   1.000e+01   1.009e+01   8.500e-02
Siderite        -12.08   -12.30     -0.22   1.000e+01   1.991e+01   9.915e+00

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al               1.999e-07   5.572e-07
      C                1.172e-11   3.267e-11
      Ca               7.443e-07   2.074e-06
      Fe               3.418e-10   9.525e-10
      K                0.000e+00   0.000e+00
      Mg               6.421e-10   1.790e-09
      Na               2.025e-09   5.643e-09
      Si               3.538e-07   9.861e-07
```

CONCENTRATION AND SI'S CONT.



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-------------------------------Phase assemblage--------------------------------

                                                          Moles in assemblage
Phase               SI  log IAP  log K(T, P)   Initial       Final       Delta

Albite          -14.55   -11.89      2.66   1.000e+01   1.960e+01   9.600e+00
Analcime        -12.05    -5.99      6.06   1.000e+01           0  -1.000e+01
Anorthite       -13.17    13.31     26.48   1.000e+01   1.725e+01   7.250e+00
CO2(g)          -11.24   -19.07     -7.83   1.000e+01           0  -1.000e+01
Calcite         -10.77    -8.95      1.82   1.000e+01   4.009e+01   3.009e+01
Clinoptilolite-Ca  -41.04   -48.56     -7.52   1.000e+01           0  -1.000e+01
Enstatite       -10.69     0.60     11.29   1.000e+01   3.000e+01   2.000e+01
Hedenbergite    -15.55     3.98     19.53   1.000e+01           0  -1.000e+01
Quartz           -2.43    -6.46     -4.03   1.000e+01   1.124e+02   1.024e+02
Stilbite        -20.07   -19.26      0.81   1.000e+01   1.000e+01   1.667e-08
Dolomite        -23.43   -20.96      2.47   1.000e+01           0  -1.000e+01
Kaolinite        -3.53     3.18      6.72   1.000e+01   2.000e+01   1.000e+01
Magnesite       -14.28   -12.01      2.27   1.000e+01           0  -1.000e+01
Magnetite        -7.28     3.14     10.42   1.000e+01   1.009e+01   8.500e-02
Siderite        -12.08   -12.30     -0.22   1.000e+01   1.991e+01   9.915e+00

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al                1.999e-07   5.572e-07
      C                 1.172e-11   3.267e-11
      Ca                7.443e-07   2.074e-06
      Fe                3.418e-10   9.525e-10
      K                 0.000e+00   0.000e+00
      Mg                6.421e-10   1.790e-09
      Na                2.025e-09   5.643e-09
      Si                3.538e-07   9.861e-07
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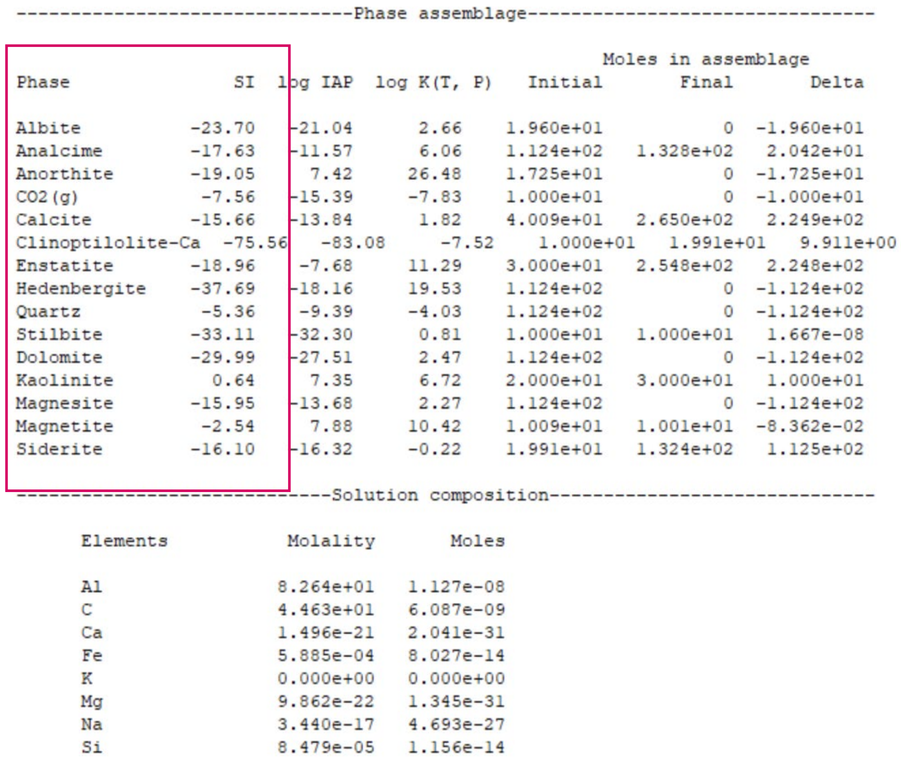

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-------------------------------Phase assemblage--------------------------------

                                                          Moles in assemblage
Phase               SI  log IAP  log K(T, P)   Initial       Final       Delta

Albite          -23.70   -21.04      2.66   1.960e+01           0  -1.960e+01
Analcime        -17.63   -11.57      6.06   1.124e+02   1.328e+02   2.042e+01
Anorthite       -19.05     7.42     26.48   1.725e+01           0  -1.725e+01
CO2(g)           -7.56   -15.39     -7.83   1.000e+01           0  -1.000e+01
Calcite         -15.66   -13.84      1.82   4.009e+01   2.650e+02   2.249e+02
Clinoptilolite-Ca  -75.56   -83.08     -7.52   1.000e+01   1.991e+01   9.911e+00
Enstatite       -18.96    -7.68     11.29   3.000e+01   2.548e+02   2.248e+02
Hedenbergite    -37.69   -18.16     19.53   1.124e+02           0  -1.124e+02
Quartz           -5.36    -9.39     -4.03   1.124e+02           0  -1.124e+02
Stilbite        -33.11   -32.30      0.81   1.000e+01   1.000e+01   1.667e-08
Dolomite        -29.99   -27.51      2.47   1.124e+02           0  -1.124e+02
Kaolinite         0.64     7.35      6.72   2.000e+01   3.000e+01   1.000e+01
Magnesite       -15.95   -13.68      2.27   1.124e+02           0  -1.124e+02
Magnetite        -2.54     7.88     10.42   1.009e+01   1.001e+01  -8.362e-02
Siderite        -16.10   -16.32     -0.22   1.991e+01   1.324e+02   1.125e+02

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al                8.264e+01   1.127e-08
      C                 4.463e+01   6.087e-09
      Ca                1.496e-21   2.041e-31
      Fe                5.885e-04   8.027e-14
      K                 0.000e+00   0.000e+00
      Mg                9.862e-22   1.345e-31
      Na                3.440e-17   4.693e-27
      Si                8.479e-05   1.156e-14
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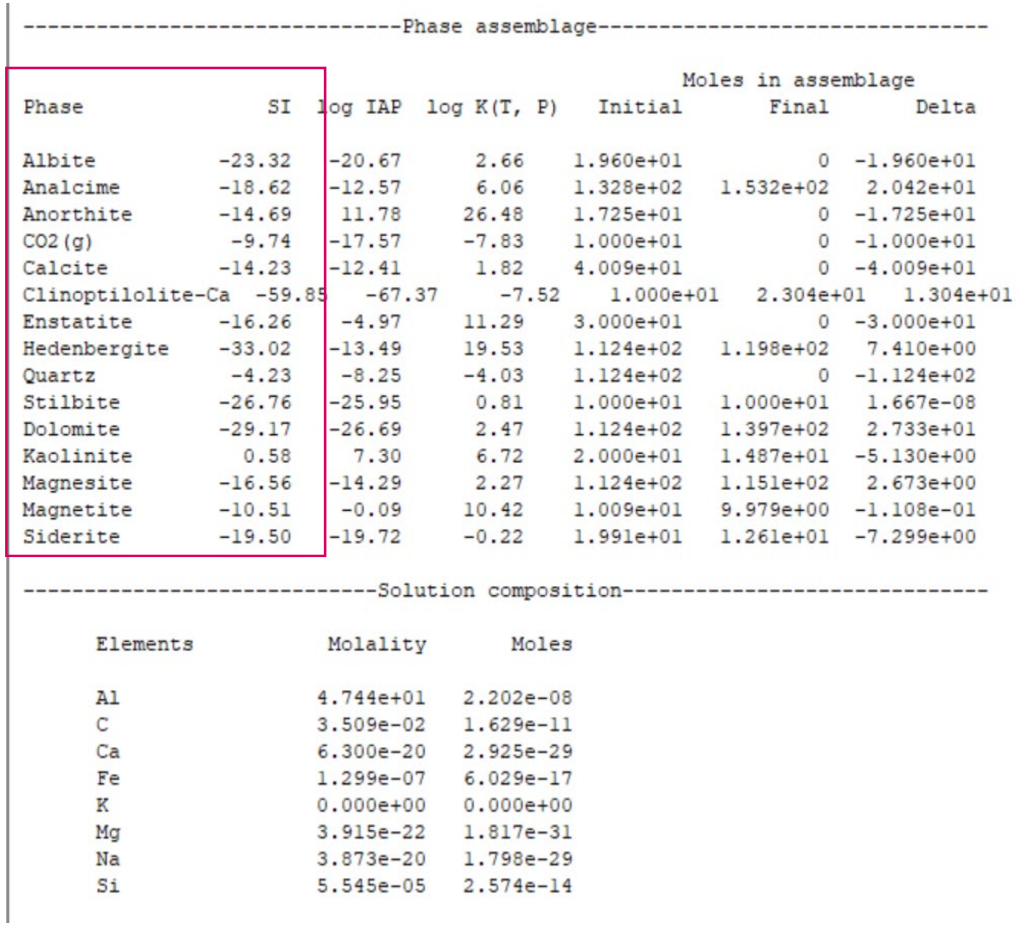
CONT.



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------------------------------Phase assemblage-------------------------------

                                                     Moles in assemblage
Phase               SI  log IAP  log K(T, P)   Initial       Final       Delta

Albite          -23.32  -20.67      2.66   1.960e+01           0  -1.960e+01
Analcime        -18.62  -12.57      6.06   1.328e+02   1.532e+02   2.042e+01
Anorthite       -14.69   11.78     26.48   1.725e+01           0  -1.725e+01
CO2(g)           -9.74  -17.57     -7.83   1.000e+01           0  -1.000e+01
Calcite         -14.23  -12.41      1.82   4.009e+01           0  -4.009e+01
Clinoptilolite-Ca  -59.85   -67.37     -7.52   1.000e+01   2.304e+01   1.304e+01
Enstatite       -16.26   -4.97     11.29   3.000e+01           0  -3.000e+01
Hedenbergite    -33.02  -13.49     19.53   1.124e+02   1.198e+02   7.410e+00
Quartz           -4.23   -8.25     -4.03   1.124e+02           0  -1.124e+02
Stilbite        -26.76  -25.95      0.81   1.000e+01   1.000e+01   1.667e-08
Dolomite        -29.17  -26.69      2.47   1.124e+02   1.397e+02   2.733e+01
Kaolinite         0.58    7.30      6.72   2.000e+01   1.487e+01  -5.130e+00
Magnesite       -16.56  -14.29      2.27   1.124e+02   1.151e+02   2.673e+00
Magnetite       -10.51   -0.09     10.42   1.009e+01   9.979e+00  -1.108e-01
Siderite        -19.50  -19.72     -0.22   1.991e+01   1.261e+01  -7.299e+00

----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al                4.744e+01   2.202e-08
      C                 3.509e-02   1.629e-11
      Ca                6.300e-20   2.925e-29
      Fe                1.299e-07   6.029e-17
      K                 0.000e+00   0.000e+00
      Mg                3.915e-22   1.817e-31
      Na                3.873e-20   1.798e-29
      Si                5.545e-05   2.574e-14
```
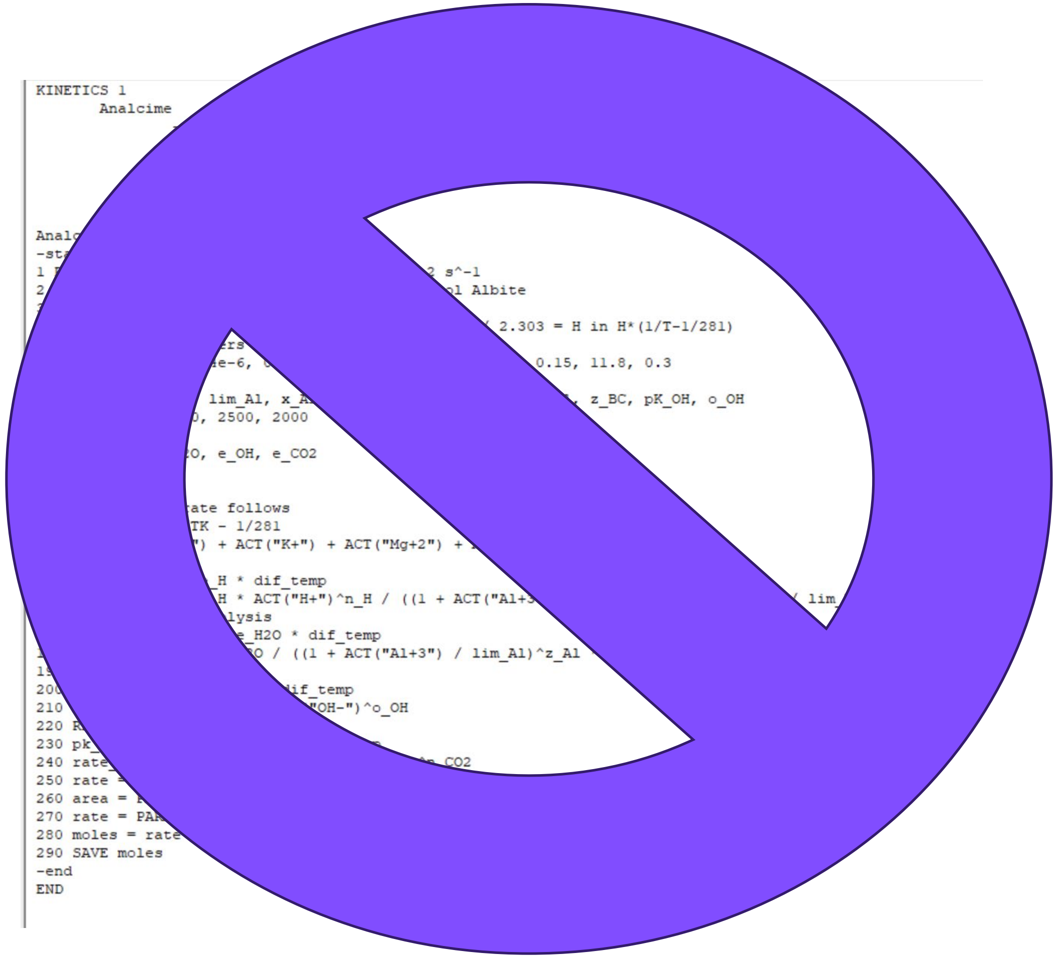

	pH
Iteration 1	7.449
Iteration 2	6.128
Iteration 3	6.128
Iteration 4	5.651
Iteration 5	5.636

KINETICS

```
KINETICS 1
       Analcime
               -m0 0.174              # 6.3% Analcime, 0.1 mm cylinders
               -m  0.174              # Moles per L pore space
               -parms 6.04  0.1      # m^2/mol Albite, fraction adjusts lab rate to field rate
               -time 84 days


Analcime
-start
1 REM Sverdrup and Warfvinge, 1995, mol m^-2 s^-1
2 REM PARM(1) = Specific area of Albite m^2/mol Albite
3 REM PARM(2) = Adjusts lab rate to field rate
4 REM temp corr: from A&P, p. 162 E (kJ/mol) / R / 2.303 = H in H*(1/T-1/281)
5 REM Albite parameters
10 DATA 11.5, 0.5, 4e-6, 0.4, 500e-6, 0.2, 13.7, 0.14, 0.15, 11.8, 0.3
20 RESTORE 10
30 READ pK_H, n_H, lim_Al, x_Al, lim_BC, x_BC, pK_H2O, z_Al, z_BC, pK_OH, o_OH
40 DATA 3500, 2000, 2500, 2000
50 RESTORE 40
60 READ e_H, e_H2O, e_OH, e_CO2
70 pk_CO2 = 13
80 n_CO2 = 0.6
100 REM Generic rate follows
110 dif_temp = 1/TK - 1/281
120 BC = ACT("Na+") + ACT("K+") + ACT("Mg+2") + ACT("Ca+2")
130 REM rate by H+
140 pk_H = pk_H + e_H * dif_temp
150 rate_H = 10^-pk_H * ACT("H+")^n_H / ((1 + ACT("Al+3") / lim_Al)^x_Al * (1 + BC / lim_BC)^x_BC)
160 REM rate by hydrolysis
170 pk_H2O = pk_H2O + e_H2O * dif_temp
180 rate_H2O = 10^-pk_H2O / ((1 + ACT("Al+3") / lim_Al)^z_Al * (1 + BC / lim_BC)^z_BC)
190 REM rate by OH-
200 pk_OH = pk_OH + e_OH * dif_temp
210 rate_OH = 10^-pk_OH * ACT("OH-")^o_OH
220 REM rate by CO2
230 pk_CO2 = pk_CO2 + e_CO2 * dif_temp
240 rate_CO2 = 10^-pk_CO2 * (SR("CO2(g)"))^n_CO2
250 rate = rate_H + rate_H2O + rate_OH + rate_CO2
260 area = PARM(1) * M0 *(M/M0)^0.67
270 rate = PARM(2) * area * rate * (1-SR("Albite"))
280 moles = rate * TIME
290 SAVE moles
-end
END
```



SUMMARY

- Porosity of the basaltic tuff increased predominantly because of the dissolution of primary minerals
  - Primary mineral that contributed most was porosity
  - Continued CO2-water-rock interactions will lead to an increasing acidification which will always influence surface area and porosity
  - More research is needed to properly determine sealing capacity of cap rock because analcime was only 6.3% by weight of the basaltic tuff
- pH will decrease and create a more acidic environment with time in the set parameters
- SI’s were majority primary minerals
- Kinetics is hard to model ☺

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THANK YOU