Controls on the solute geochemistry of subglacial discharge from the Russell Glacier, Greenland Ice Sheet using Phreecq

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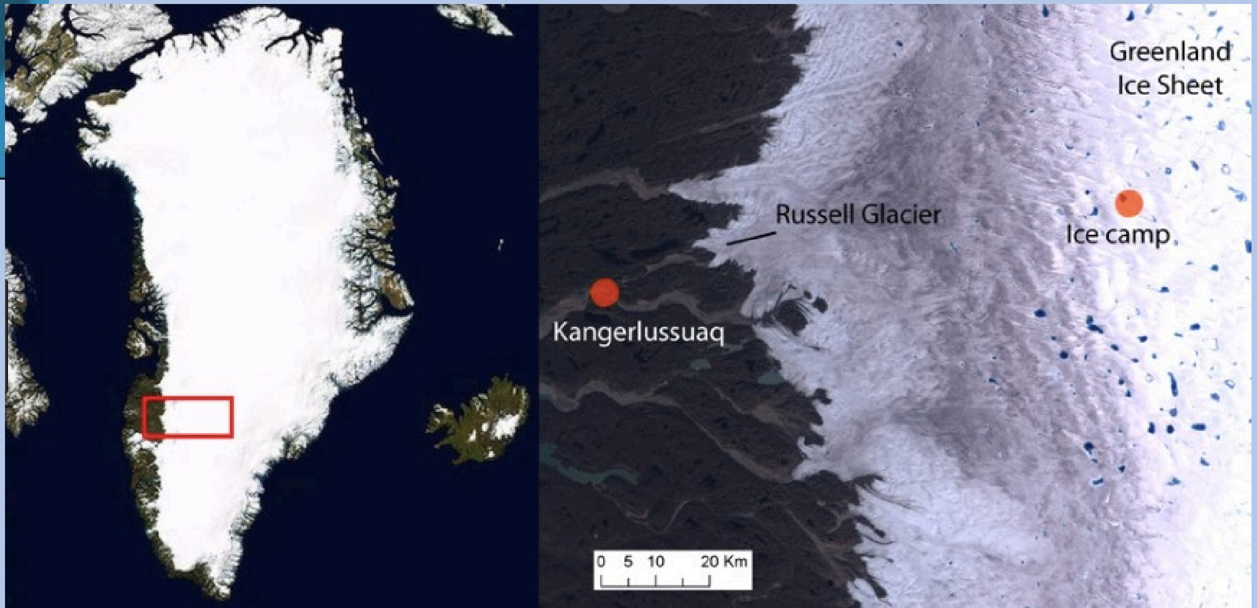
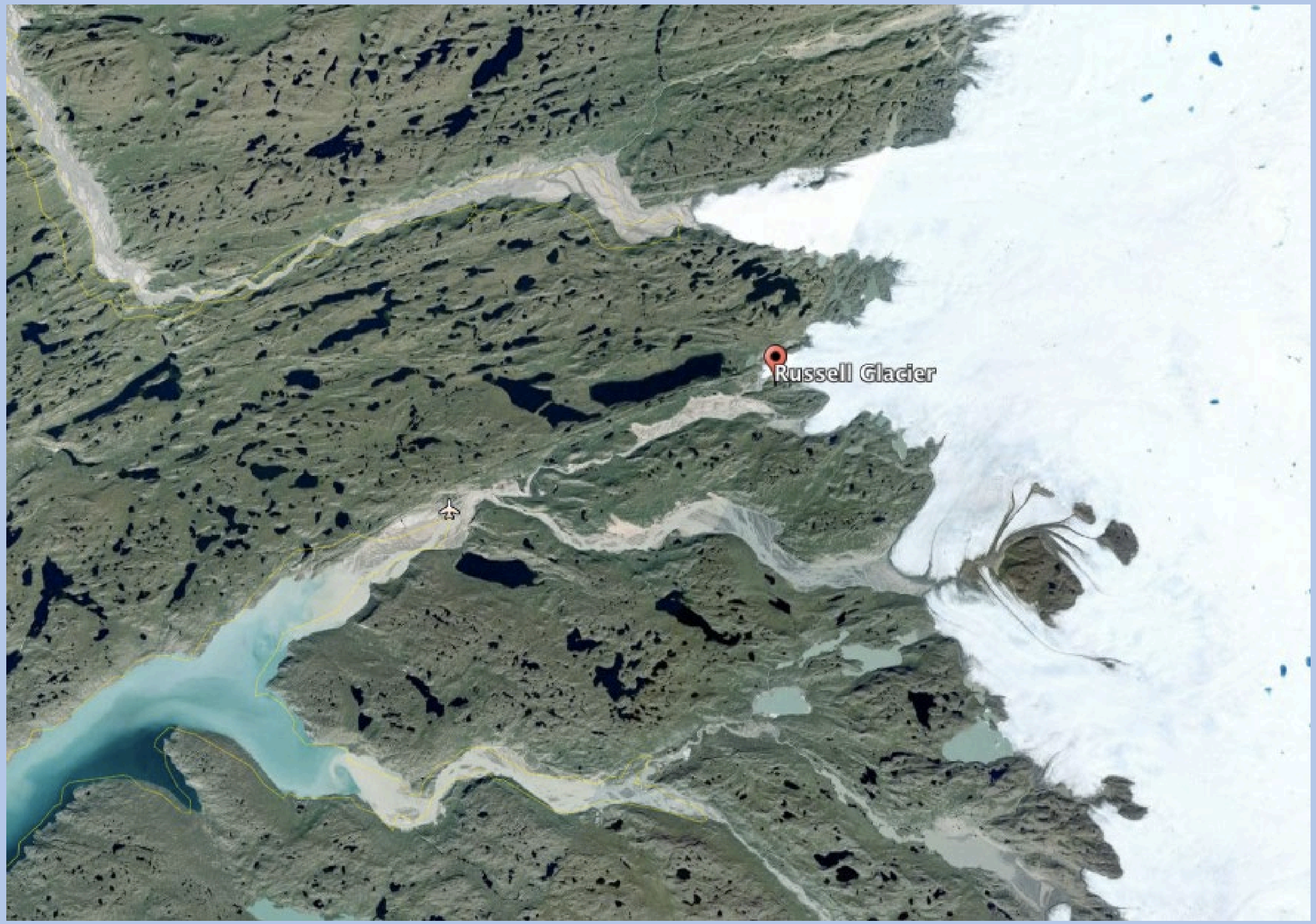
Study Area: Kangerlussuaq region of western Greenland



Study Area: Kangerlussuaq region of western Greenland

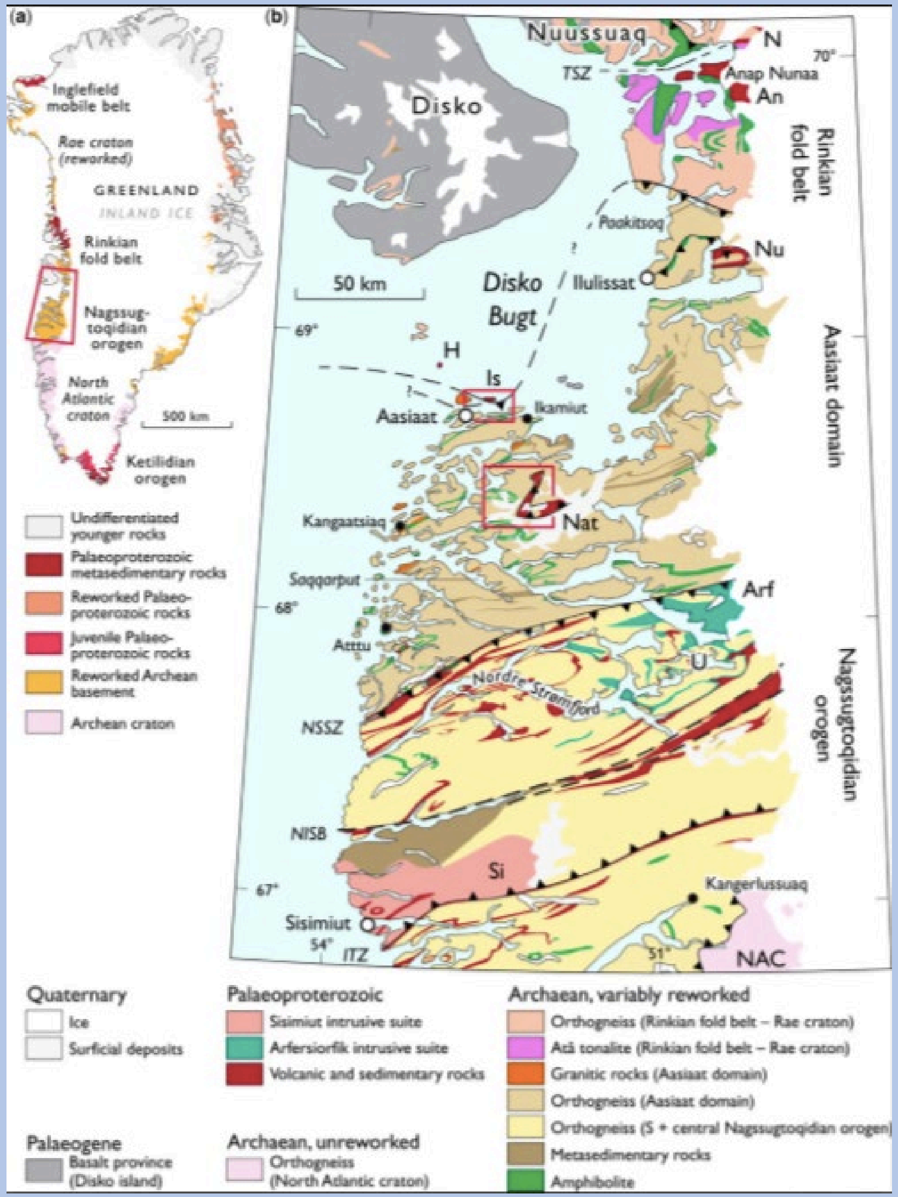
- Akuliarusiarsuup Kuua River (AKR), which drains the Russell Glacier, a land terminating lobe of the Greenland Ice Sheet (GrIS) located in the Kangerlussuaq region of western Greenland
- AKR integrates water from Seashore Lake and another small subglacial discharge tributary
- Climate is low Arctic polar desert
- Mean annual precipitation is low



Google Earth Image

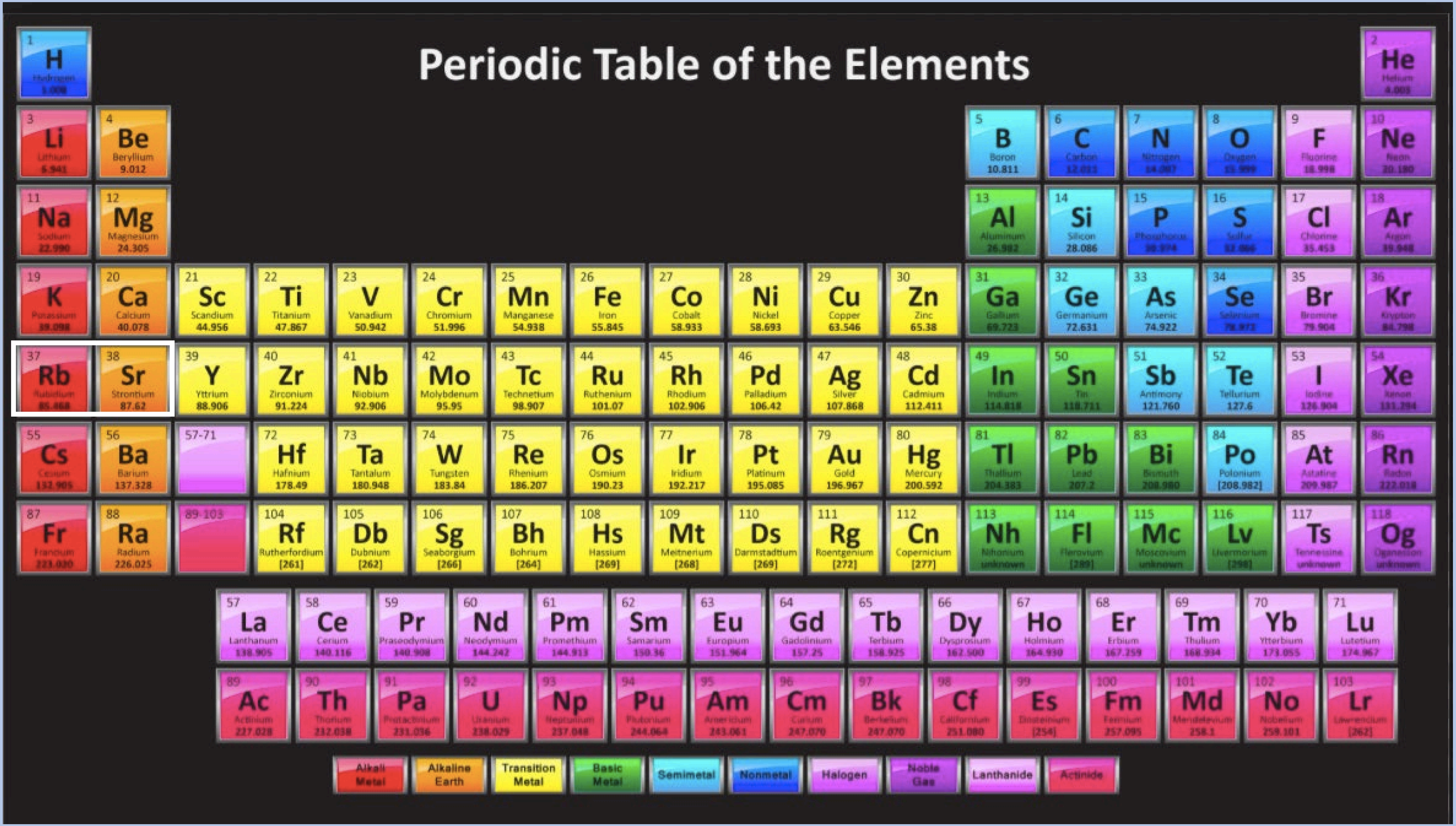
Geologic Background

- Russell and Leverett Glaciers overlie a geologic boundary between the southern Nagssugtoqidian Orogen to the north and the North Atlantic craton to the south
- Regionally dominated by Archaean gneisses
  - Southern Nagssugtoqidian Orogen: amphibolite-facies
  - North Atlantic Craton: granulate facies
- Northward transition from undeformed to deformed Kangamiut dykes marks the boundary between the terranes



Why Did I Chose this Topic?

- Glaciers
- Radiogenic and stable Sr isotope ratios ($^{87}Sr/^{86}Sr$)
- The paper came out just this year
- Has to do with hard-rock geochemistry as well as aqueous geochemistry


Periodic Table of the Elements
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57-71
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89-103
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113 Nh
114 Fl
115 Mc
116 Lv
117 Ts
118 Og
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr
Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Semimetal
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide

$^{87}Sr/^{86}Sr$

- Isotopes are atoms of the same element that differ in the number of neutrons
- The difference between ^{87}Sr and ^{86}Sr is the number of neutrons in the nucleus
  - ^{86}Sr means that the mass number (number of protons plus the number of neutrons) of this isotope is 86
  - ^{87}Sr means that the mass number of this isotope is 87
- The β^- decay of naturally occurring $^{87}Rb_{37}$ to stable $^{87}Sr_{38}$ is the basis for the Rb-Sr method of dating
- Geochronometry equation is written in terms of the isotopic ratio $^{87}Sr/^{86}Sr$
- Used to date Rb-rich minerals such as muscovite, biotite, and K-feldspar in igneous and metamorphic rocks based on assumed values of the initial $^{87}Sr/^{86}Sr$ ratio

Faure, Gunter (1998)

Stable Sr isotope ratios ($^{87}Sr/^{86}Sr$)

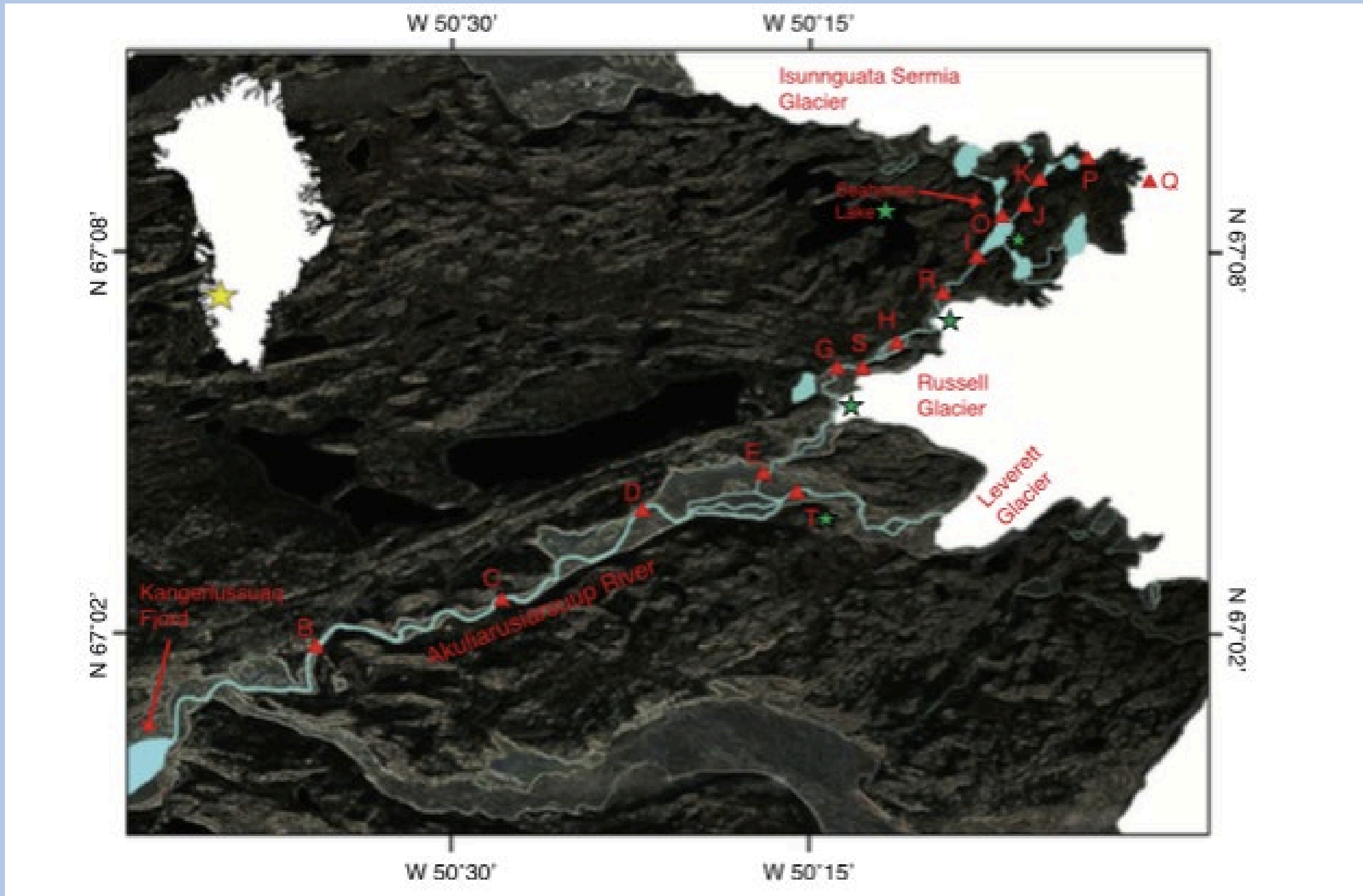
- Strontium has 4 stable, naturally occurring isotopes: ^{84}Sr (0.56%), ^{86}Sr (9.86%), ^{81}Sr (7.0%), and ^{88}Sr (82.5%)
- Important concept for isotopic tracing is that Sr derived from any mineral through weathering reaction will have the same $^{87}Sr/^{86}Sr$ as the mineral
- Only ^{87}Sr is radiogenic
  - Produced by decay from radioactive alkali metal ^{87}Rb
  - Two sources of ^{87}Sr in any material: formed during primordial nucleo-synthesis along with ^{84}Sr, ^{86}Sr, and ^{88}Sr, as well as that formed by radioactive decay of ^{87}Rb

Applications

- Provenance identification
- Global weathering and hydrothermal activity cycles
- Stratigraphy and correlation of marine sediments
- Mixing of seawater and freshwater sources
- Tracing the source and constraining the timing of formation of groundwater pathways and processes
- Forensics (ivory, wood, ceramics, etc.)

Previous Work Objectives

- How does silicate weathering affect the geochemistry of subglacial discharge from the Russell Glacier into the proglacial AKR?
    - How do elemental concentrations and radiogenic and stable Sr isotope affect the geochemistry?
- What is the elemental and Sr isotope geochemistry of suspended sediments, bedload sediments, bulk rocks, and mineral separates?
- What are the solute sources that are determined by $^{87}Sr/^{86}Sr$ ratios?



(Andrews and Jacobson, 2018)

Previous Work

- Using radiogenic and Sr isotope ratios ($^{87}Sr/^{86}Sr$)to examine controls on solute acquisition in subglacial discharge from the Russell Glacier
- Two melt seasons (2014 and 2015)
- Analyses of mineral separates from bulk rocks
- Water samples were collected once per week, from June through August
- Downstream transect samples of the AKR were collected within one week of each other, once per month
- Water temperatures
- Anion, cation, and Si concentration analyses as well as Sr isotope analyses

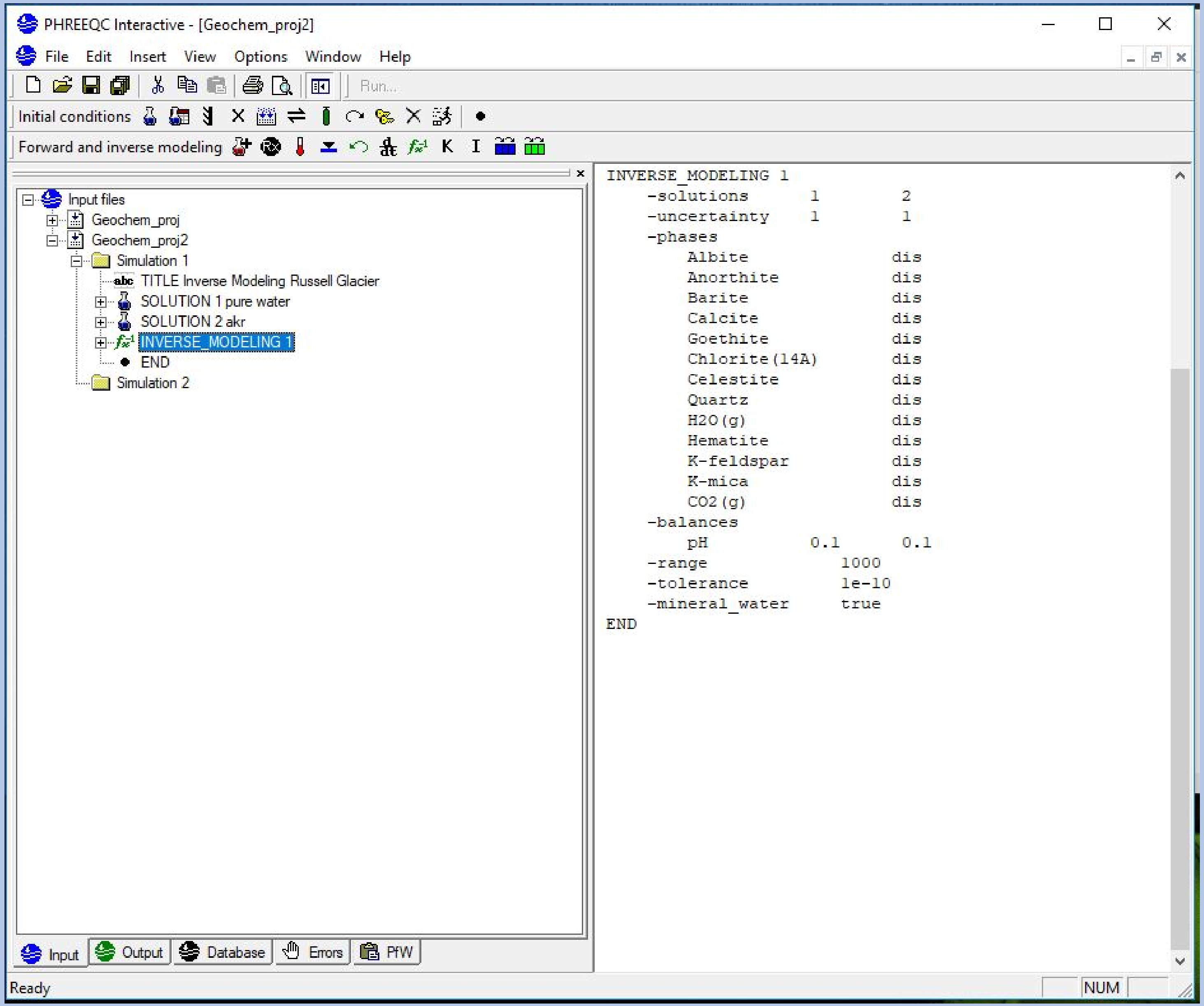
Results of the research

- Silicate mineral weathering dominates the solute geochemistry of the Greenland Ice Sheet subglacial discharge in contrast to valley glaciers
- Ice sheet subglacial chemical weathering may have a greater impact on long-term CO2 drawdown
- Radiogenic Sr isotope ratios of subglacial discharge, sediment, and bulk rocks suggest that minerals with high $^{87}Sr/^{86}Sr$ ratios preferentially weather and elevate $^{87}Sr/^{86}Sr$ ratios of the dissolved load above the background level of bulk bedrock
- Calcite weathering doesn’t appear to be the prevailing control on subglacial discharge $^{87}Sr/^{86}Sr$ ratios

How am I going to improve the project/ my contribution

- Inverse Modeling in Phreecq to:
  - Confirm the idea that the subglacial discharge from Russell Glacier is acquiring elemental geochemistry from the rocks that are within the area.
  - Another modeling approach was done in order to look at the interaction between the AKR and Seashore Lake.

Inverse Modeling



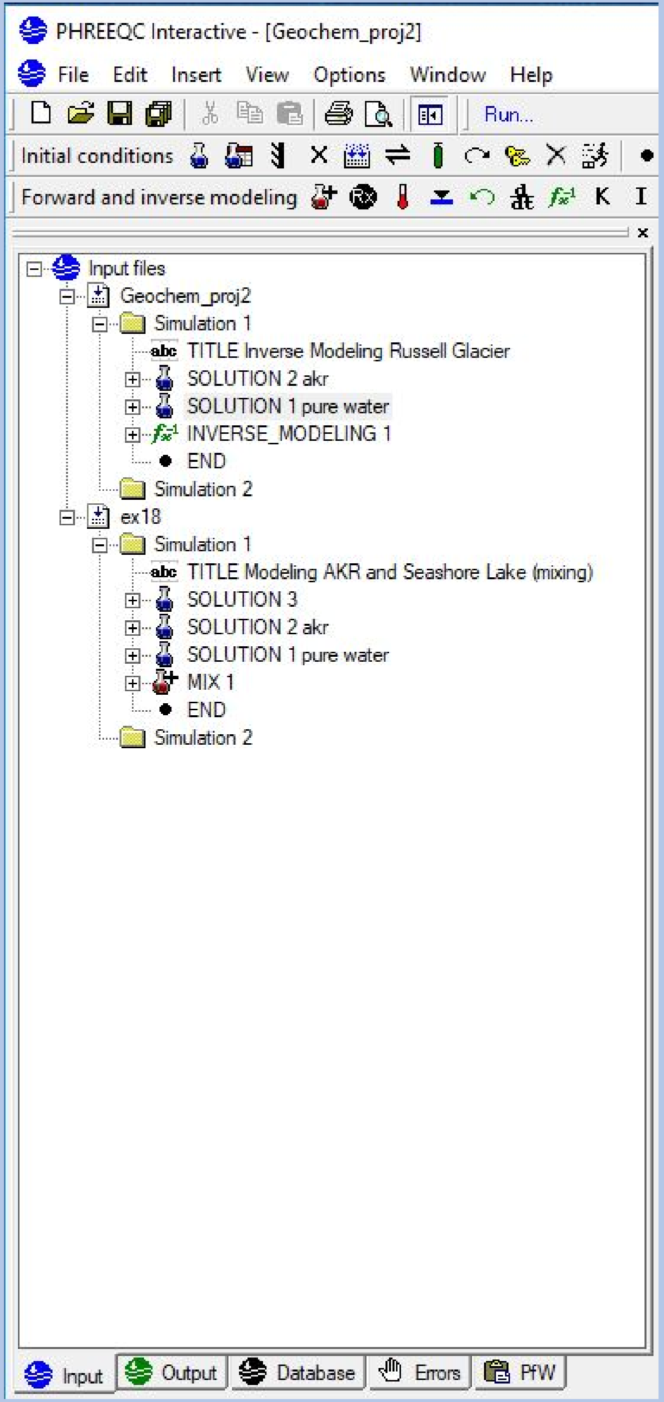


Table 1
Elemental and Sr isotope geochemistry of the Akuliarusiarsuup Kuua River and Seahorse Lake during the 2014 melt season.

Sample ID	Site ID	Distance (km)	Date (m/d)	T (oC)	Ca (μmol/L)	Mg (μmol/L)	K (μmol/L)	Na (μmol/L)	Al (μmol/L)	Ba (nmol/L)	Fe (μmol/L)	Si (μmol/L)	Sr (nmol/L)	SO4 (μmol/L)	Alkalinity (μeq/L)	pH	$^{87}Sr/^{86}Sr$	$\delta^{88/86}Sr$ (‰)	Suspended Sediment (g/L)
Akuliarusiarsuup Kuua River																			
W25	P	0.1	6–17	0.2	25	8.2	10	8.7	3.2	20	1.5	17	56	bdl	85	7.01	0.72596	0.332	0.12
W26	K	1.0	6–17	1.1	22	8.2	7.7	8.7	2.4	17	0.8	15	54	bdl	78	nd	0.72487	nd	nd
W27	J	2.4	6–17	2.1	22	8.2	7.7	8.7	3.0	20	1.0	16	52	bdl	78	nd	0.72496	nd	nd
W28	I	4.4	6–18	3.6	32	8.2	10	8.7	0.7	20	0.2	19	73	11	78	nd	0.72502	nd	nd
W30	H	9.2	6–21	2.3	30	8.2	10	8.7	2.2	17	1.0	16	58	bdl	95	nd	0.73141	nd	nd
W29	G	11.0	6–18	3.2	30	8.2	13	8.7	5.9	26	2.3	24	66	10	78	nd	0.73211	nd	nd
W31	E	15.6	6–21	1.6	32	8.2	15	22	7.0	19	2.3	28	58	11	96	nd	0.74183	nd	nd
W32	D	20.7	6–21	2.0	45	12	31	61	4.1	12	1.3	32	66	21	165	nd	0.74764	nd	nd
W33	C	27.2	6–22	1.5	42	12	28	57	3.3	12	1.0	30	64	20	155	nd	0.74674	nd	nd
W34	B	32.1	6–22	2.0	45	12	28	61	8.5	25	1.8	43	76	18	167	nd	0.74712	nd	nd
W44	P	0.1	6–28	0.1	20	8.2	5.1	8.7	9.6	32	3.9	26	60	bdl	70	6.92	0.71988	0.334	0.05
W55	P	0.1	7–7	0.2	20	8.2	5.1	4.3	1.5	15	0.8	13	49	bdl	66	6.79	0.72330	0.409	0.10
W65	P	0.1	7–22	0.3	10	bdl	2.6	bdl	0.9	7.3	0.6	6.1	27	bdl	23	6.20	0.72127	0.432	0.12
W66	K	1.0	7–23	1.6	10	bdl	2.6	bdl	2.8	13	1.1	10	29	bdl	23	nd	0.72112	nd	nd
W67	J	2.4	7–23	2.6	10	bdl	2.6	bdl	3.7	18	1.3	14	31	bdl	23	nd	0.72109	nd	nd
W68	I	4.4	7–23	5.5	15	4.1	5.1	4.3	1.9	15	0.7	13	38	bdl	48	nd	0.72496	nd	nd
W69	H	9.2	7–24	3.4	20	8.2	7.7	4.3	4.8	24	1.6	20	45	bdl	68	nd	0.72895	nd	nd
W70	G	11.0	7–24	4.0	20	8.2	7.7	4.3	4.4	23	1.4	19	47	bdl	68	nd	0.72914	nd	nd
W71	E	15.6	7–24	3.7	20	4.1	7.7	8.7	2.4	8.7	1.1	12	37	bdl	65	nd	0.73852	nd	nd
W72	D	20.7	7–25	0.9	52	8.2	33	57	4.1	8.7	0.7	29	75	17	177	nd	0.74663	nd	nd
W73	C	27.2	7–25	2.6	60	12	38	61	12	39	3.6	53	98	18	207	nd	0.74643	nd	nd
W74	B	32.1	7–25	3.0	55	8.2	33	57	1.7	8.7	0.5	28	79	22	171	nd	0.74671	nd	nd
W76	P	0.1	7–28	0.3	12	4.1	2.6	bdl	1.8	12	1.2	8.5	34	bdl	36	nd	0.72015	0.408	nd
W89	P	0.1	8–2	0.3	17	4.1	2.6	bdl	0.4	11	1.1	7.8	43	bdl	46	6.42	0.72207	nd	nd
W101	P	0.1	8–12	0.3	20	8.2	5.1	4.3	2.7	17	1.2	16	56	bdl	66	6.91	0.72124	0.403	0.07
W102	K	1.0	8–12	1.6	15	4.1	5.1	bdl	1.4	12	0.6	10	38	bdl	43	nd	0.72229	nd	nd
W103	J	2.4	8–12	2.1	17	4.1	5.1	4.3	1.6	13	0.7	12	42	bdl	53	nd	0.72175	nd	nd
W104	I	4.4	8–13	4.3	20	8.2	5.1	4.3	0.7	13	0.3	12	41	bdl	66	nd	0.72787	nd	nd
W105	H	9.2	8–13	2.7	20	4.1	7.7	4.3	2.1	13	1.1	12	39	bdl	60	nd	0.73158	nd	nd
W106	G	11.0	8–13	2.8	20	4.1	7.7	4.3	1.7	12	0.9	12	40	bdl	60	nd	0.73187	nd	nd
W107	E	15.6	8–14	2.2	30	8.2	13	17	2.7	10	1.1	18	54	bdl	107	nd	0.73960	nd	nd
W108	D	20.7	8–15	0.9	45	8.2	26	39	2.8	11	1.0	27	67	17	137	nd	0.74770	nd	nd
W109	B	32.1	8–15	1.6	47	8.2	26	43	2.0	9.5	0.8	26	73	20	141	nd	0.74841	nd	nd
Seahorse Lake																			
W24	O	3.4	6–16	7.6	35	16	10	13	14	43	4.7	50	75	13	101	nd	0.72992	nd	nd

"nd" indicates no data, "bdl" indicates below instrumental detection limit. Cl concentrations not shown because all samples were bdl (<1 ppm). SO_4 concentrations were bdl when <1 ppm. Site ID and distance corresponds to Fig. 1.

Selected Output 1

Solution 1: pure water

	Input		Delta		Input+Delta
pH	7.000e+00	+	0.000e+00	=	7.000e+00
Al	0.000e+00	+	0.000e+00	=	0.000e+00
Alkalinity	-8.520e-08	+	8.520e-08	=	0.000e+00
Ba	0.000e+00	+	0.000e+00	=	0.000e+00
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	0.000e+00	+	0.000e+00	=	0.000e+00
Ca	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(2)	0.000e+00	+	0.000e+00	=	0.000e+00
Fe(3)	0.000e+00	+	0.000e+00	=	0.000e+00
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	0.000e+00	+	0.000e+00	=	0.000e+00
Mg	0.000e+00	+	0.000e+00	=	0.000e+00
Na	0.000e+00	+	0.000e+00	=	0.000e+00
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	0.000e+00	+	0.000e+00	=	0.000e+00
Si	0.000e+00	+	0.000e+00	=	0.000e+00
Sr	0.000e+00	+	0.000e+00	=	0.000e+00

	Input		Delta		Input+Delta
pH	6.500e+00	+	0.000e+00	=	6.500e+00
Al	1.200e-05	+	0.000e+00	=	1.200e-05
Alkalinity	2.070e-04	+	-1.980e-05	=	1.872e-04
Ba	3.900e-08	+	0.000e+00	=	3.900e-08
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	3.793e-04	+	0.000e+00	=	3.793e-04
Ca	6.000e-05	+	0.000e+00	=	6.000e-05
Fe(2)	3.598e-06	+	-3.598e-06	=	0.000e+00
Fe(3)	1.971e-09	+	0.000e+00	=	1.971e-09
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	3.800e-05	+	-3.080e-05	=	7.200e-06
Mg	1.200e-05	+	0.000e+00	=	1.200e-05
Na	6.100e-05	+	-6.100e-05	=	0.000e+00
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.800e-05	+	-1.786e-05	=	1.370e-07
Si	5.300e-05	+	0.000e+00	=	5.300e-05
Sr	9.800e-08	+	0.000e+00	=	9.800e-08

Solution fractions:		Minimum	Maximum
Solution 1	1.000e+00	1.000e+00	1.000e+00
Solution 2	1.000e+00	1.000e+00	1.000e+00

Phase mole transfers:		Minimum	Maximum	
Barite	3.900e-08	0.000e+00	7.800e-08	BaSO4
Calcite	6.000e-05	0.000e+00	1.200e-04	CaCO3
Chlorite(14A)	2.400e-06	0.000e+00	4.800e-06	Mg5Al2Si3O10(OH)8
Celestite	9.800e-08	0.000e+00	1.960e-07	SrSO4
Quartz	2.420e-05	0.000e+00	1.060e-04	SiO2
Hematite	9.854e-10	0.000e+00	0.000e+00	Fe2O3
K-feldspar	7.200e-06	0.000e+00	2.400e-05	KAlSi3O8
CO2(g)	3.193e-04	0.000e+00	7.586e-04	CO2

Selected Output 2

	Input		Delta		Input+Delta
pH	6.500e+00	+	0.000e+00	=	6.500e+00
Al	1.200e-05	+	0.000e+00	=	1.200e-05
Alkalinity	2.070e-04	+	-5.100e-05	=	1.560e-04
Ba	3.900e-08	+	0.000e+00	=	3.900e-08
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	3.793e-04	+	-3.253e-04	=	5.400e-05
Ca	6.000e-05	+	0.000e+00	=	6.000e-05
Fe(2)	3.598e-06	+	-3.598e-06	=	0.000e+00
Fe(3)	1.971e-09	+	0.000e+00	=	1.971e-09
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	3.800e-05	+	-3.800e-05	=	0.000e+00
Mg	1.200e-05	+	-1.200e-05	=	0.000e+00
Na	6.100e-05	+	-6.100e-05	=	0.000e+00
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.800e-05	+	-1.796e-05	=	3.900e-08
Si	5.300e-05	+	0.000e+00	=	5.300e-05
Sr	9.800e-08	+	-9.800e-08	=	0.000e+00

Solution fractions:		Minimum	Maximum
Solution 1	1.000e+00	1.000e+00	1.000e+00
Solution 2	1.000e+00	1.000e+00	1.000e+00

Phase mole transfers:		Minimum	Maximum	
Anorthite	6.000e-06	0.000e+00	1.200e-05	CaAl2Si2O8
Barite	3.900e-08	0.000e+00	7.800e-08	BaSO4
Calcite	5.400e-05	0.000e+00	1.200e-04	CaCO3
Goethite	1.971e-09	0.000e+00	3.942e-09	FeOOH
Quartz	4.100e-05	0.000e+00	1.060e-04	SiO2

Output of Equilibrium Phases

Phase	SI**	log IAP	log K(275 K, 1 atm)	
Al(OH)3(a)	0.66	13.04	12.38	Al(OH)3
Albite	-3.17	-22.71	-19.54	NaAlSi3O8
Alunite	4.04	5.63	1.59	KAl3(SO4)2(OH)6
Anhydrite	-4.99	-9.04	-4.05	CaSO4
Anorthite	-3.73	-24.13	-20.40	CaAl2Si2O8
Aragonite	-3.87	-12.10	-8.23	CaCO3
Barite	-2.15	-12.23	-10.08	BaSO4
Ca-Montmorillonite	5.92	-42.59	-48.50	Ca0.165Al2.33Si3.67O10(OH)2
Calcite	-3.71	-12.10	-8.39	CaCO3
Celestite	-5.29	-11.83	-6.54	SrSO4
Chalcedony	-0.44	-4.28	-3.83	SiO2
Chlorite(14A)	-23.93	53.47	77.40	Mg5Al2Si3O10(OH)8
Chrysotile	-19.62	15.58	35.19	Mg3Si2O5(OH)4
CO2(g)	-2.55	-3.70	-1.15	CO2
Dolomite	-8.36	-24.89	-16.53	CaMg(CO3)2
Fe(OH)3(a)	-0.47	4.42	4.89	Fe(OH)3
Gibbsite	3.57	13.04	9.47	Al(OH)3
Goethite	4.55	4.42	-0.14	FeOOH
Gypsum	-4.42	-9.04	-4.62	CaSO4:2H2O
H2(g)	-21.02	-24.05	-3.02	H2
H2O(g)	-2.13	-0.00	2.13	H2O
Hematite	11.00	8.83	-2.17	Fe2O3
Illite	3.84	-39.68	-43.52	K0.6Mg0.25Al2.3Si3.5O10(OH)2
Jarosite-K	-12.90	-20.25	-7.35	KFe3(SO4)2(OH)6
K-feldspar	-0.51	-22.92	-22.41	KAlSi3O8
K-mica	12.13	28.37	16.24	KAl3Si3O10(OH)2
Kaolinite	8.00	17.53	9.54	Al2Si2O5(OH)4
Melanterite	-7.75	-10.27	-2.53	FeSO4:7H2O
O2(g)	-49.42	-52.11	-2.69	O2
Quartz	0.06	-4.28	-4.34	SiO2
Sepiolite	-13.14	3.26	16.40	Mg2Si3O7.5OH:3H2O
Sepiolite(d)	-15.40	3.26	18.66	Mg2Si3O7.5OH:3H2O
Siderite	-2.58	-13.33	-10.74	FeCO3
SiO2(a)	-1.36	-4.28	-2.91	SiO2
Strontianite	-5.56	-14.88	-9.32	SrCO3
Talc	-17.13	7.02	24.16	Mg3Si4O10(OH)2
Witherite	-6.58	-15.29	-8.70	BaCO3

Table 1
Elemental and Sr isotope geochemistry of the Akuliarusiarsuup Kuua River and Seahorse Lake during the 2014 melt season.

Sample ID	Site ID	Distance (km)	Date (m/d)	T (oC)	Ca (μmol/L)	Mg (μmol/L)	K (μmol/L)	Na (μmol/L)	Al (μmol/L)	Ba (nmol/L)	Fe (μmol/L)	Si (μmol/L)	Sr (nmol/L)	SO4 (μmol/L)	Alkalinity (μeq/L)	pH	$^{87}Sr/^{86}Sr$	$\delta^{88/86}Sr$ (‰)	Suspended Sediment (g/L)
Akuliarusiarsuup Kuua River																			
W25	P	0.1	6–17	0.2	25	8.2	10	8.7	3.2	20	1.5	17	56	bdl	85	7.01	0.72596	0.332	0.12
W26	K	1.0	6–17	1.1	22	8.2	7.7	8.7	2.4	17	0.8	15	54	bdl	78	nd	0.72487	nd	nd
W27	J	2.4	6–17	2.1	22	8.2	7.7	8.7	3.0	20	1.0	16	52	bdl	78	nd	0.72496	nd	nd
W28	I	4.4	6–18	3.6	32	8.2	10	8.7	0.7	20	0.2	19	73	11	78	nd	0.72502	nd	nd
W30	H	9.2	6–21	2.3	30	8.2	10	8.7	2.2	17	1.0	16	58	bdl	95	nd	0.73141	nd	nd
W29	G	11.0	6–18	3.2	30	8.2	13	8.7	5.9	26	2.3	24	66	10	78	nd	0.73211	nd	nd
W31	E	15.6	6–21	1.6	32	8.2	15	22	7.0	19	2.3	28	58	11	96	nd	0.74183	nd	nd
W32	D	20.7	6–21	2.0	45	12	31	61	4.1	12	1.3	32	66	21	165	nd	0.74764	nd	nd
W33	C	27.2	6–22	1.5	42	12	28	57	3.3	12	1.0	30	64	20	155	nd	0.74674	nd	nd
W34	B	32.1	6–22	2.0	45	12	28	61	8.5	25	1.8	43	76	18	167	nd	0.74712	nd	nd
W44	P	0.1	6–28	0.1	20	8.2	5.1	8.7	9.6	32	3.9	26	60	bdl	70	6.92	0.71988	0.334	0.05
W55	P	0.1	7–7	0.2	20	8.2	5.1	4.3	1.5	15	0.8	13	49	bdl	66	6.79	0.72330	0.409	0.10
W65	P	0.1	7–22	0.3	10	bdl	2.6	bdl	0.9	7.3	0.6	6.1	27	bdl	23	6.20	0.72127	0.432	0.12
W66	K	1.0	7–23	1.6	10	bdl	2.6	bdl	2.8	13	1.1	10	29	bdl	23	nd	0.72112	nd	nd
W67	J	2.4	7–23	2.6	10	bdl	2.6	bdl	3.7	18	1.3	14	31	bdl	23	nd	0.72109	nd	nd
W68	I	4.4	7–23	5.5	15	4.1	5.1	4.3	1.9	15	0.7	13	38	bdl	48	nd	0.72496	nd	nd
W69	H	9.2	7–24	3.4	20	8.2	7.7	4.3	4.8	24	1.6	20	45	bdl	68	nd	0.72895	nd	nd
W70	G	11.0	7–24	4.0	20	8.2	7.7	4.3	4.4	23	1.4	19	47	bdl	68	nd	0.72914	nd	nd
W71	E	15.6	7–24	3.7	20	4.1	7.7	8.7	2.4	8.7	1.1	12	37	bdl	65	nd	0.73852	nd	nd
W72	D	20.7	7–25	0.9	52	8.2	33	57	4.1	8.7	0.7	29	75	17	177	nd	0.74663	nd	nd
W73	C	27.2	7–25	2.6	60	12	38	61	12	39	3.6	53	98	18	207	nd	0.74643	nd	nd
W74	B	32.1	7–25	3.0	55	8.2	33	57	1.7	8.7	0.5	28	79	22	171	nd	0.74671	nd	nd
W76	P	0.1	7–28	0.3	12	4.1	2.6	bdl	1.8	12	1.2	8.5	34	bdl	36	nd	0.72015	0.408	nd
W89	P	0.1	8–2	0.3	17	4.1	2.6	bdl	0.4	11	1.1	7.8	43	bdl	46	6.42	0.72207	nd	nd
W101	P	0.1	8–12	0.3	20	8.2	5.1	4.3	2.7	17	1.2	16	56	bdl	66	6.91	0.72124	0.403	0.07
W102	K	1.0	8–12	1.6	15	4.1	5.1	bdl	1.4	12	0.6	10	38	bdl	43	nd	0.72229	nd	nd
W103	J	2.4	8–12	2.1	17	4.1	5.1	4.3	1.6	13	0.7	12	42	bdl	53	nd	0.72175	nd	nd
W104	I	4.4	8–13	4.3	20	8.2	5.1	4.3	0.7	13	0.3	12	41	bdl	66	nd	0.72787	nd	nd
W105	H	9.2	8–13	2.7	20	4.1	7.7	4.3	2.1	13	1.1	12	39	bdl	60	nd	0.73158	nd	nd
W106	G	11.0	8–13	2.8	20	4.1	7.7	4.3	1.7	12	0.9	12	40	bdl	60	nd	0.73187	nd	nd
W107	E	15.6	8–14	2.2	30	8.2	13	17	2.7	10	1.1	18	54	bdl	107	nd	0.73960	nd	nd
W108	D	20.7	8–15	0.9	45	8.2	26	39	2.8	11	1.0	27	67	17	137	nd	0.74770	nd	nd
W109	B	32.1	8–15	1.6	47	8.2	26	43	2.0	9.5	0.8	26	73	20	141	nd	0.74841	nd	nd
Seahorse Lake																			
W24	O	3.4	6–16	7.6	35	16	10	13	14	43	4.7	50	75	13	101	nd	0.72992	nd	nd

"nd" indicates no data, "bdl" indicates below instrumental detection limit. Cl concentrations not shown because all samples were bdl (<1 ppm). SO_4 concentrations were bdl when <1 ppm. Site ID and distance corresponds to Fig. 1.

AKR Distribution of Species

Ba	3.900e-08					
Ba+2	3.868e-08	3.565e-08	-7.413	-7.448	-0.035	-14.67
BaSO4	2.935e-10	2.935e-10	-9.532	-9.532	0.000	(0)
BaHCO3+	3.068e-11	3.006e-11	-10.513	-10.522	-0.009	(0)
BaCO3	1.704e-13	1.704e-13	-12.769	-12.769	0.000	-11.00
BaOH+	3.898e-15	3.820e-15	-14.409	-14.418	-0.009	(0)
C(4)	3.793e-04					
CO2	1.974e-04	1.975e-04	-3.705	-3.705	0.000	33.22
HCO3-	1.817e-04	1.780e-04	-3.741	-3.749	-0.009	21.91
CaHCO3+	7.322e-08	7.176e-08	-7.135	-7.144	-0.009	8.37
FeHCO3+	5.919e-08	5.800e-08	-7.228	-7.237	-0.009	(0)
MgHCO3+	2.248e-08	2.202e-08	-7.648	-7.657	-0.009	4.43
CO3-2	1.572e-08	1.450e-08	-7.803	-7.839	-0.035	-9.42
NaHCO3	6.862e-09	6.862e-09	-8.164	-8.164	0.000	1.80
FeCO3	1.133e-09	1.133e-09	-8.946	-8.946	0.000	(0)
CaCO3	1.078e-09	1.078e-09	-8.967	-8.967	0.000	-14.69
(CO2)2	3.081e-10	3.081e-10	-9.511	-9.511	0.000	66.44
SrHCO3+	1.163e-10	1.140e-10	-9.934	-9.943	-0.009	(0)
MgCO3	1.082e-10	1.082e-10	-9.966	-9.966	0.000	-17.06
BaHCO3+	3.068e-11	3.006e-11	-10.513	-10.522	-0.009	(0)
NaCO3-	4.856e-12	4.758e-12	-11.314	-11.323	-0.009	-4.72
SrCO3	4.304e-13	4.304e-13	-12.366	-12.366	0.000	-14.25
BaCO3	1.704e-13	1.704e-13	-12.769	-12.769	0.000	-11.00
Ca	6.000e-05					
Ca+2	5.979e-05	5.514e-05	-4.223	-4.258	-0.035	-18.78
CaSO4	1.343e-07	1.343e-07	-6.872	-6.872	0.000	6.27
CaHCO3+	7.322e-08	7.176e-08	-7.135	-7.144	-0.009	8.37
CaCO3	1.078e-09	1.078e-09	-8.967	-8.967	0.000	-14.69
CaOH+	2.954e-11	2.894e-11	-10.530	-10.539	-0.009	(0)
CaHSO4+	2.203e-13	2.159e-13	-12.657	-12.666	-0.009	(0)
Fe(2)	3.598e-06					
Fe+2	3.531e-06	3.258e-06	-5.452	-5.487	-0.035	-24.23
FeHCO3+	5.919e-08	5.800e-08	-7.228	-7.237	-0.009	(0)
FeSO4	6.111e-09	6.112e-09	-8.214	-8.214	0.000	53.38
FeCO3	1.133e-09	1.133e-09	-8.946	-8.946	0.000	(0)
FeOH+	5.442e-10	5.333e-10	-9.264	-9.273	-0.009	(0)
FeHSO4+	1.301e-14	1.275e-14	-13.886	-13.894	-0.009	(0)
Fe(OH)2	1.746e-15	1.746e-15	-14.758	-14.758	0.000	(0)
Fe(OH)3-	1.650e-19	1.617e-19	-18.782	-18.791	-0.009	(0)

Seashore Lake Distribution of Species

Ba	4.300e-08					
Ba+2	4.274e-08	4.015e-08	-7.369	-7.396	-0.027	-14.69
BaSO4	2.438e-10	2.439e-10	-9.613	-9.613	0.000	(0)
BaHCO3+	1.359e-11	1.338e-11	-10.867	-10.874	-0.007	(0)
BaCO3	7.581e-14	7.582e-14	-13.120	-13.120	0.000	-11.00
BaOH+	4.370e-15	4.302e-15	-14.360	-14.366	-0.007	(0)
C(4)	1.495e-04					
CO2	7.802e-05	7.803e-05	-4.108	-4.108	0.000	33.22
HCO3-	7.146e-05	7.035e-05	-4.146	-4.153	-0.007	21.90
FeHCO3+	3.129e-08	3.080e-08	-7.505	-7.511	-0.007	(0)
CaHCO3+	1.714e-08	1.688e-08	-7.766	-7.773	-0.007	8.36
MgHCO3+	1.203e-08	1.184e-08	-7.920	-7.927	-0.007	4.43
CO3-2	6.099e-09	5.731e-09	-8.215	-8.242	-0.027	-9.44
FeCO3	6.019e-10	6.019e-10	-9.220	-9.220	0.000	(0)
NaHCO3	5.807e-10	5.807e-10	-9.236	-9.236	0.000	1.80
CaCO3	2.536e-10	2.536e-10	-9.596	-9.596	0.000	-14.69
MgCO3	5.817e-11	5.817e-11	-10.235	-10.235	0.000	-17.06
(CO2)2	4.811e-11	4.812e-11	-10.318	-10.318	0.000	66.44
SrHCO3+	3.570e-11	3.515e-11	-10.447	-10.454	-0.007	(0)
BaHCO3+	1.359e-11	1.338e-11	-10.867	-10.874	-0.007	(0)
NaCO3-	4.089e-13	4.026e-13	-12.388	-12.395	-0.007	-4.72
SrCO3	1.328e-13	1.328e-13	-12.877	-12.877	0.000	-14.25
BaCO3	7.581e-14	7.582e-14	-13.120	-13.120	0.000	-11.00
Ca	3.500e-05					
Ca+2	3.492e-05	3.281e-05	-4.457	-4.484	-0.027	-18.80
CaSO4	5.897e-08	5.897e-08	-7.229	-7.229	0.000	6.27
CaHCO3+	1.714e-08	1.688e-08	-7.766	-7.773	-0.007	8.36
CaCO3	2.536e-10	2.536e-10	-9.596	-9.596	0.000	-14.69
CaOH+	1.749e-11	1.722e-11	-10.757	-10.764	-0.007	(0)
CaHSO4+	9.625e-14	9.475e-14	-13.017	-13.023	-0.007	(0)
Fe(2)	4.697e-06					
Fe+2	4.659e-06	4.378e-06	-5.332	-5.359	-0.027	-24.25
FeHCO3+	3.129e-08	3.080e-08	-7.505	-7.511	-0.007	(0)
FeSO4	6.059e-09	6.059e-09	-8.218	-8.218	0.000	53.38
FeOH+	7.280e-10	7.167e-10	-9.138	-9.145	-0.007	(0)
FeCO3	6.019e-10	6.019e-10	-9.220	-9.220	0.000	(0)
FeHSO4+	1.284e-14	1.264e-14	-13.891	-13.898	-0.007	(0)
Fe(OH)2	2.347e-15	2.347e-15	-14.630	-14.630	0.000	(0)
Fe(OH)3-	2.208e-19	2.173e-19	-18.656	-18.663	-0.007	(0)

AKR and Seashore Lake Distribution of Species

C(-4)	0.000e+00					
CH4	0.000e+00	0.000e+00	-60.294	-60.294	0.000	33.02
C(4)	2.644e-04					
CO2	1.377e-04	1.377e-04	-3.861	-3.861	0.000	33.22
HCO3-	1.266e-04	1.243e-04	-3.898	-3.906	-0.008	21.91
FeHCO3+	4.819e-08	4.733e-08	-7.317	-7.325	-0.008	(0)
CaHCO3+	4.076e-08	4.003e-08	-7.390	-7.398	-0.008	8.36
MgHCO3+	1.844e-08	1.811e-08	-7.734	-7.742	-0.008	4.43
CO3-2	1.089e-08	1.013e-08	-7.963	-7.994	-0.031	-9.43
NaHCO3	2.912e-09	2.912e-09	-8.536	-8.536	0.000	1.80
FeCO3	9.255e-10	9.256e-10	-9.034	-9.034	0.000	(0)
CaCO3	6.021e-10	6.021e-10	-9.220	-9.220	0.000	-14.69
(CO2)2	1.499e-10	1.500e-10	-9.824	-9.824	0.000	66.44
MgCO3	8.903e-11	8.903e-11	-10.050	-10.050	0.000	-17.06
SrHCO3+	7.216e-11	7.087e-11	-10.142	-10.150	-0.008	(0)
BaHCO3+	2.269e-11	2.228e-11	-10.644	-10.652	-0.008	(0)
NaCO3-	2.058e-12	2.021e-12	-11.687	-11.694	-0.008	-4.72
SrCO3	2.679e-13	2.679e-13	-12.572	-12.572	0.000	-14.25
BaCO3	1.264e-13	1.264e-13	-12.898	-12.898	0.000	-11.00
Ca	4.750e-05					
Ca+2	4.737e-05	4.406e-05	-4.325	-4.356	-0.031	-18.79
CaSO4	9.335e-08	9.336e-08	-7.030	-7.030	0.000	6.27
CaHCO3+	4.076e-08	4.003e-08	-7.390	-7.398	-0.008	8.36
CaCO3	6.021e-10	6.021e-10	-9.220	-9.220	0.000	-14.69
CaOH+	2.357e-11	2.314e-11	-10.628	-10.636	-0.008	(0)
CaHSO4+	1.526e-13	1.499e-13	-12.816	-12.824	-0.008	(0)
Fe(2)	4.148e-06					
Fe+2	4.092e-06	3.808e-06	-5.388	-5.419	-0.031	-24.24
FeHCO3+	4.819e-08	4.733e-08	-7.317	-7.325	-0.008	(0)
FeSO4	6.212e-09	6.213e-09	-8.207	-8.207	0.000	53.38
FeCO3	9.255e-10	9.256e-10	-9.034	-9.034	0.000	(0)
FeOH+	6.352e-10	6.238e-10	-9.197	-9.205	-0.008	(0)
FeHSO4+	1.319e-14	1.295e-14	-13.880	-13.888	-0.008	(0)
Fe(OH)2	2.044e-15	2.044e-15	-14.690	-14.690	0.000	(0)
Fe(OH)3-	1.929e-19	1.895e-19	-18.715	-18.722	-0.008	(0)
Fe(HS)2	0.000e+00	0.000e+00	-112.708	-112.708	0.000	(0)
Fe(HS)3-	0.000e+00	0.000e+00	-168.783	-168.791	-0.008	(0)
Fe(3)	2.304e-09					
Fe(OH)2+	2.018e-09	1.982e-09	-8.695	-8.703	-0.008	(0)
Fe(OH)3	2.811e-10	2.811e-10	-9.551	-9.551	0.000	(0)
FeOH+2	5.094e-12	4.739e-12	-11.293	-11.324	-0.031	(0)
Fe(OH)4-	3.121e-13	3.065e-13	-12.506	-12.514	-0.008	(0)
Fe+3	1.132e-15	9.651e-16	-14.946	-15.015	-0.069	(0)

Seashore Lake and AKR (mixed) Saturation Indices

------------------------------Saturation indices------------------------------

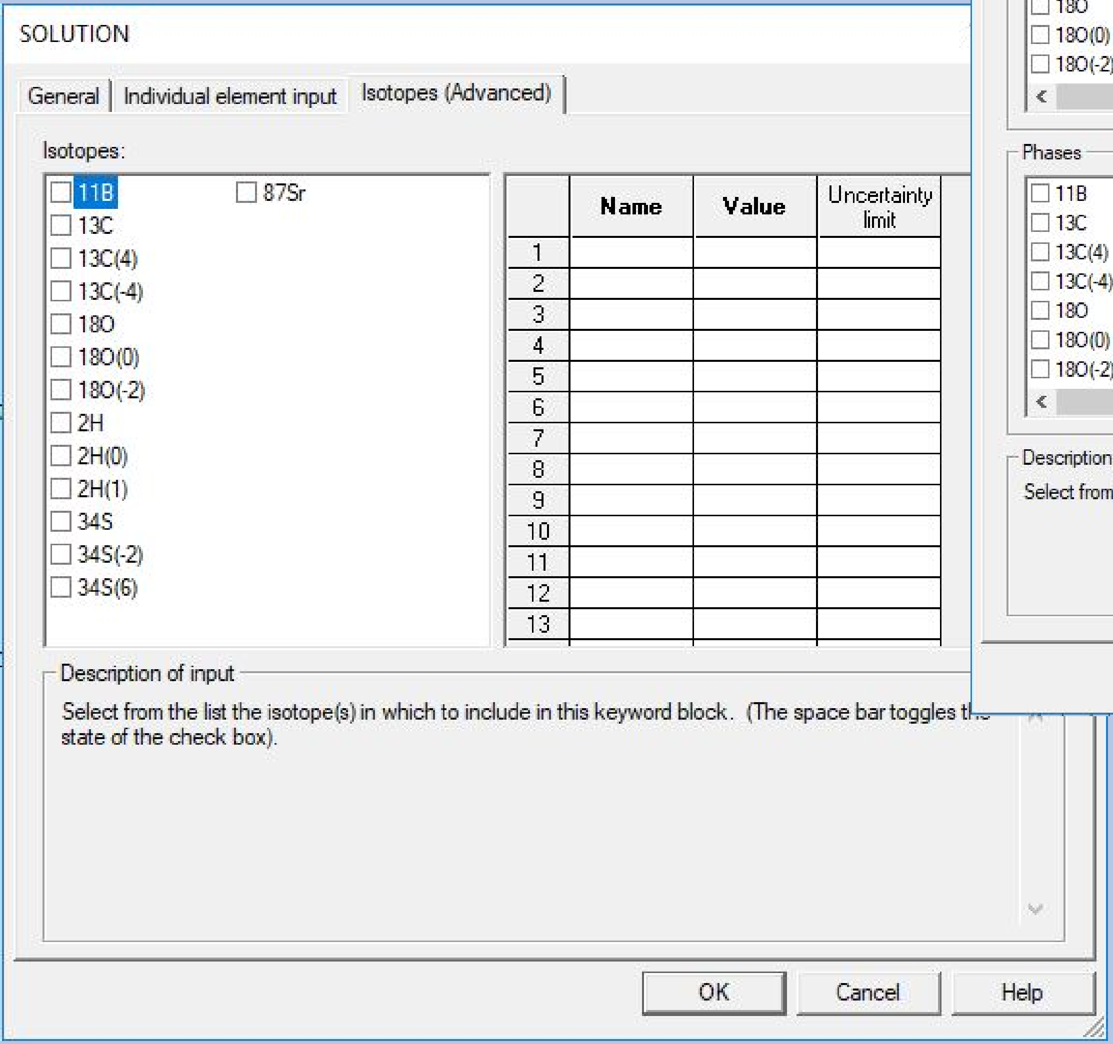
Phase	SI**	log IAP	log K(275 K, 1 atm)	
Al(OH)3(a)	0.70	13.08	12.38	Al(OH)3
Albite	-3.39	-22.93	-19.54	NaAlSi3O8
Alunite	3.83	5.42	1.59	KAl3(SO4)2(OH)6
Anhydrite	-5.15	-9.20	-4.05	CaSO4
Anorthite	-3.78	-24.18	-20.40	CaAl2Si2O8
Aragonite	-4.12	-12.35	-8.23	CaCO3
Barite	-2.18	-12.27	-10.08	BaSO4
Ca-Montmorillonite	5.94	-42.56	-48.50	Ca0.165Al2.33Si3.67O10(OH)2
Calcite	-3.96	-12.35	-8.39	CaCO3
Celestite	-5.40	-11.94	-6.54	SrSO4
CH4(g)	-57.78	-60.29	-2.52	CH4
Chalcedony	-0.46	-4.29	-3.83	SiO2
Chlorite(14A)	-23.54	53.86	77.40	Mg5Al2Si3O10(OH)8
Chrysotile	-19.43	15.77	35.19	Mg3Si2O5(OH)4
CO2(g)	-2.71	-3.86	-1.15	CO2
Dolomite	-8.70	-25.23	-16.53	CaMg(CO3)2
Fe(OH)3(a)	-0.41	4.49	4.89	Fe(OH)3
FeS(ppt)	-53.12	-57.04	-3.92	FeS
Gibbsite	3.61	13.08	9.47	Al(OH)3
Goethite	4.62	4.49	-0.14	FeOOH
Gypsum	-4.58	-9.20	-4.62	CaSO4:2H2O
H2(g)	-21.02	-24.05	-3.02	H2
H2O(g)	-2.13	-0.00	2.13	H2O
H2S(g)	-56.56	-64.62	-8.06	H2S
Hematite	11.14	8.97	-2.17	Fe2O3
Illite	3.78	-39.74	-43.52	K0.6Mg0.25Al2.3Si3.5O10(OH)2
Jarosite-K	-13.01	-20.36	-7.35	KFe3(SO4)2(OH)6
K-feldspar	-0.71	-23.12	-22.41	KAlSi3O8
K-mica	12.01	28.24	16.24	KAl3Si3O10(OH)2
Kaolinite	8.04	17.58	9.54	Al2Si2O5(OH)4
Mackinawite	-52.39	-57.04	-4.65	FeS
Melanterite	-7.74	-10.26	-2.53	FeSO4:7H2O
O2(g)	-49.41	-52.10	-2.69	O2
Pyrite	-81.51	-100.66	-19.15	FeS2
Quartz	0.05	-4.29	-4.34	SiO2
Sepiolite	-13.03	3.36	16.40	Mg2Si3O7.5OH:3H2O
Sepiolite(d)	-15.30	3.36	18.66	Mg2Si3O7.5OH:3H2O
Siderite	-2.67	-13.41	-10.74	FeCO3
SiO2(a)	-1.38	-4.29	-2.91	SiO2

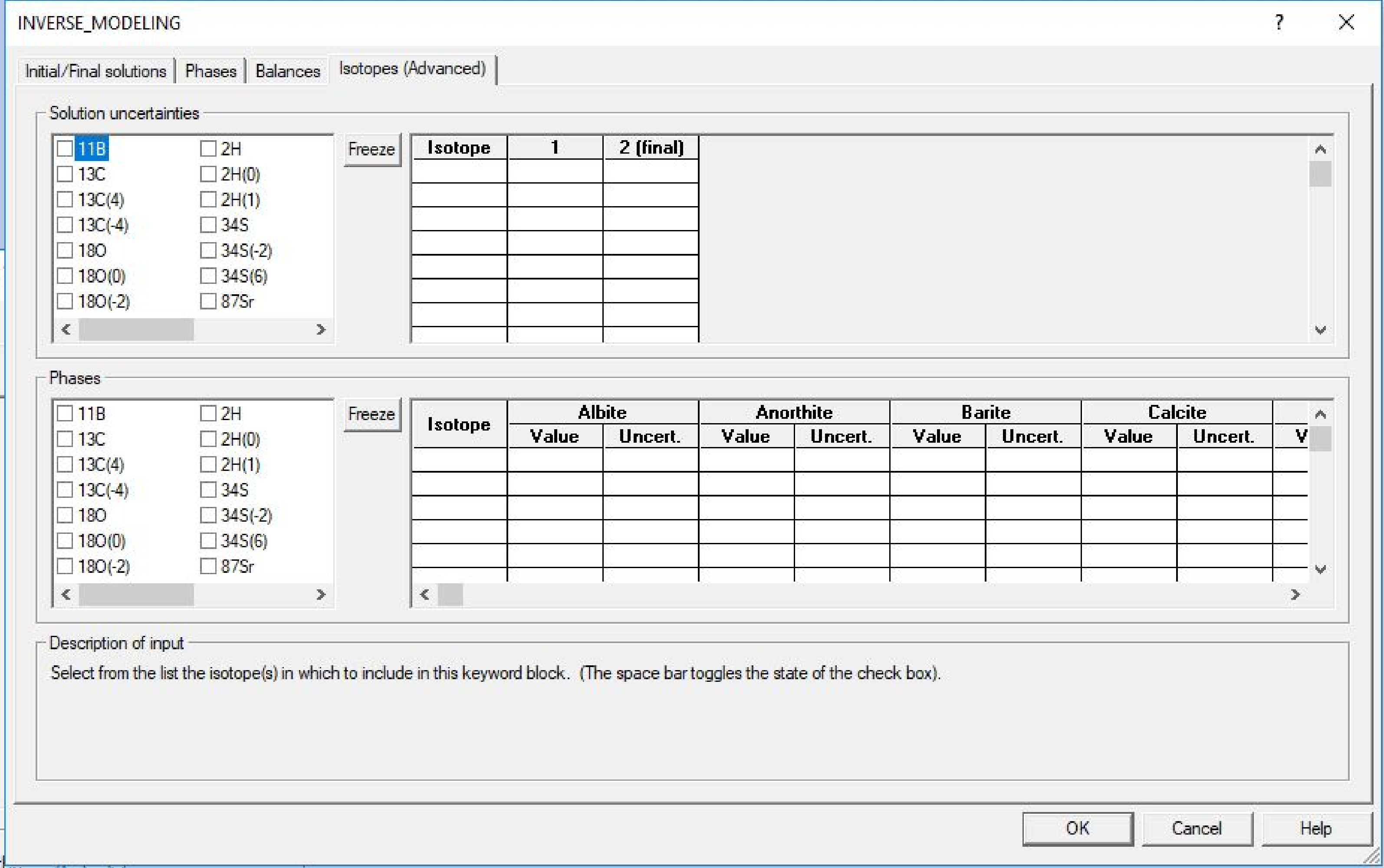
AKR Saturation Indices

------------------------------Saturation indices------------------------------

Phase	SI**	log IAP	log K(275 K, 1 atm)	
Al(OH)3(a)	0.66	13.04	12.38	Al(OH)3
Albite	-3.17	-22.71	-19.54	NaAlSi3O8
Alunite	4.04	5.63	1.59	KAl3(SO4)2(OH)6
Anhydrite	-4.99	-9.04	-4.05	CaSO4
Anorthite	-3.73	-24.13	-20.40	CaAl2Si2O8
Aragonite	-3.87	-12.10	-8.23	CaCO3
Barite	-2.15	-12.23	-10.08	BaSO4
Ca-Montmorillonite	5.92	-42.59	-48.50	Ca0.165Al2.33Si3.67O10(OH)2
Calcite	-3.71	-12.10	-8.39	CaCO3
Celestite	-5.29	-11.83	-6.54	SrSO4
Chalcedony	-0.44	-4.28	-3.83	SiO2
Chlorite(14A)	-23.93	53.47	77.40	Mg5Al2Si3O10(OH)8
Chrysotile	-19.62	15.58	35.19	Mg3Si2O5(OH)4
CO2(g)	-2.55	-3.70	-1.15	CO2
Dolomite	-8.36	-24.89	-16.53	CaMg(CO3)2
Fe(OH)3(a)	-0.47	4.42	4.89	Fe(OH)3
Gibbsite	3.57	13.04	9.47	Al(OH)3
Goethite	4.55	4.42	-0.14	FeOOH
Gypsum	-4.42	-9.04	-4.62	CaSO4:2H2O
H2(g)	-21.02	-24.05	-3.02	H2
H2O(g)	-2.13	-0.00	2.13	H2O
Hematite	11.00	8.83	-2.17	Fe2O3
Illite	3.84	-39.68	-43.52	K0.6Mg0.25Al2.3Si3.5O10(OH)2
Jarosite-K	-12.90	-20.25	-7.35	KFe3(SO4)2(OH)6
K-feldspar	-0.51	-22.92	-22.41	KAlSi3O8
K-mica	12.13	28.37	16.24	KAl3Si3O10(OH)2
Kaolinite	8.00	17.53	9.54	Al2Si2O5(OH)4
Melanterite	-7.75	-10.27	-2.53	FeSO4:7H2O
O2(g)	-49.42	-52.11	-2.69	O2
Quartz	0.06	-4.28	-4.34	SiO2
Sepiolite	-13.14	3.26	16.40	Mg2Si3O7.5OH:3H2O
Sepiolite(d)	-15.40	3.26	18.66	Mg2Si3O7.5OH:3H2O
Siderite	-2.58	-13.33	-10.74	FeCO3
SiO2(a)	-1.36	-4.28	-2.91	SiO2
Strontianite	-5.56	-14.88	-9.32	SrCO3
Talc	-17.13	7.02	24.16	Mg3Si4O10(OH)2
Witherite	-6.58	-15.29	-8.70	BaCO3

$^{87}Sr/^{86}Sr$ Isotope Modeling using Phreecq





Conclusions

- The results from the two models in Phreecq suggest that silicate minerals for the phase mole transfers can be abundant in the AKR.
- Once the AKR and Seashore Lake interact with one another and the AKR is bringing its geochemical properties to the Seashore lake, silicate minerals are precipitating out in abundance
- A difference between the distribution of species can be seen before and after the interaction between the AKR and Seashore Lake.
- Focusing on the interaction between the AKR and Seashore Lake once they meet, it can be seen in the distribution of species that calcium, carbon dioxide, and bi-carbonate values level out compared to before they meet.

References

- Andrews, G.M., Jacobson A.D., 2018. Controls of the solute geochemistry of subglacial discharge from the Russell Glacier, Greenland Ice Sheet determined by radiogenic and stable Sr isotope ratios. *Elsevier, 0016-7037*.
- Faure, Gunter. *Principles and Applications of Geochemistry: a Comprehensive Textbook for Geology Students*. Prentice Hall, 1998.

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