The Inyan Kara Aquifer of the Great Plains

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Geochemistry 428
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- Objectives
- Context and Background (Spatial and Temporal)
- Data Analysis by Phreeq
- Conclusions
- Discussion

Objective

- Learn how to use aspects of Phreeq
- Apply U.S.G.S. data to Phreeq to determine strata composition
- Compare conclusions between Phreeq and the U.S.G.S. report

Context and Background

Ages of the Five Main Aquifers of the Great Plains

- Cambrian-Ordovician aquifer (AQ1)
- Mississippian aquifer (AQ2)
- Pennsylvanian aquifer (AQ3)
- * Lower Cretaceous aquifer (AQ4)
- Upper Cretaceous-Tertiary aquifer (AQ5)

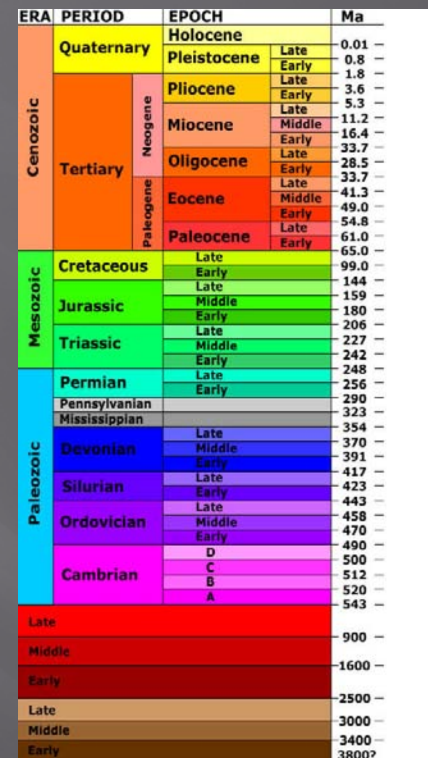


Figure 1. Geologic timescale (Scienceblog.com, 2012).

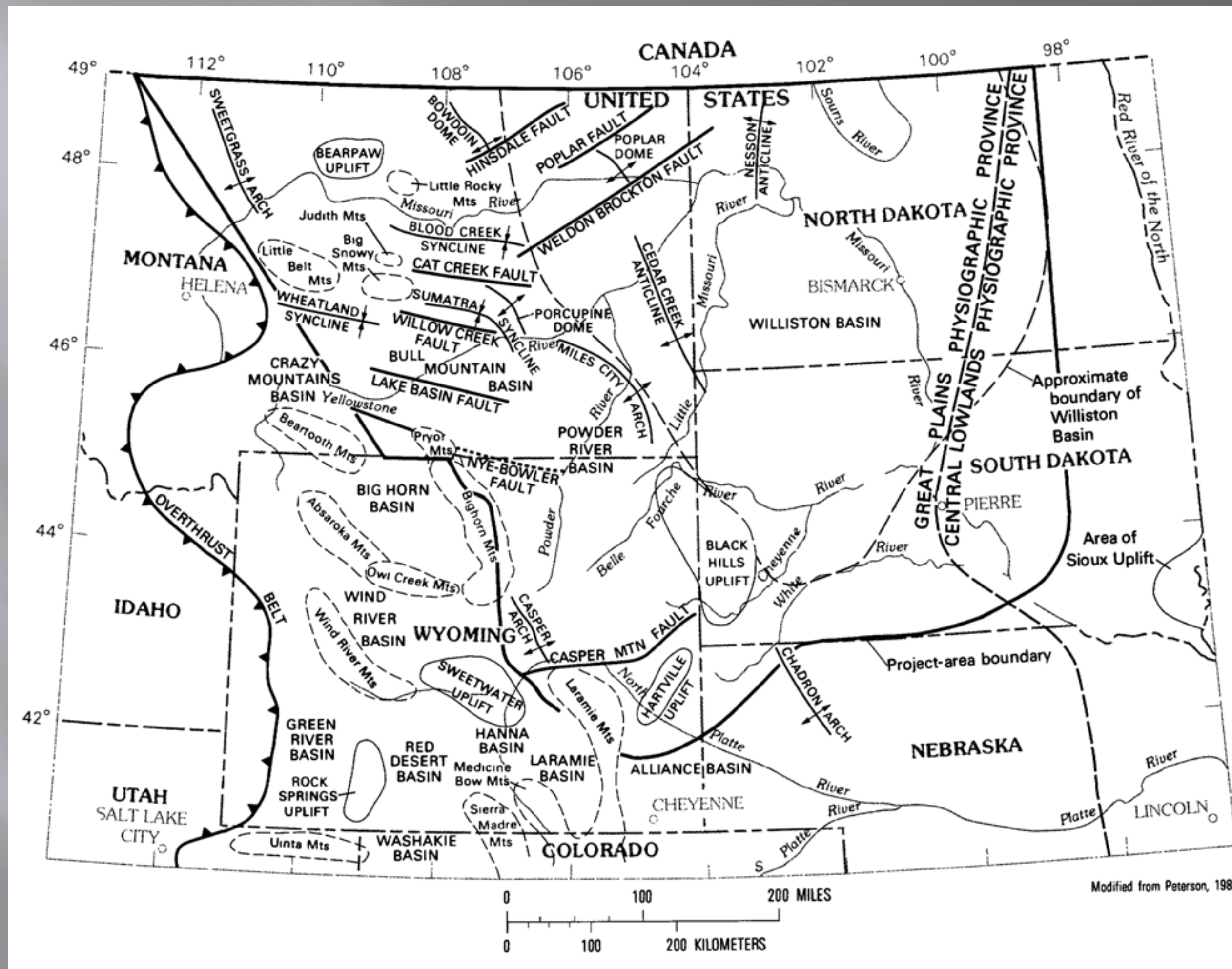


Figure 2: Regional extent of the Great Plains aquifers with major geologic structures. This includes the states of Wyoming, Montana, North Dakota, and South Dakota covering 300,000 sq. miles (Bubsy, et al., 1995).

Various Names

- Lower Cretaceous aquifer (AQ4)
- Inyan Kara Aquifer
- Dakota Aquifer

- AQ4 is sandstone and siltstone
- Confining strata is limestone, shale, evaporites, and halite
- AQ4 consists of mainly marine sediments
- Thickness is1400 ft in Montana tapering to nil in eastern North Dakota
- Recharge area is the Rocky Mountains and the Bighorn Mountains
- This presentation utilizes flow path #6 data only.

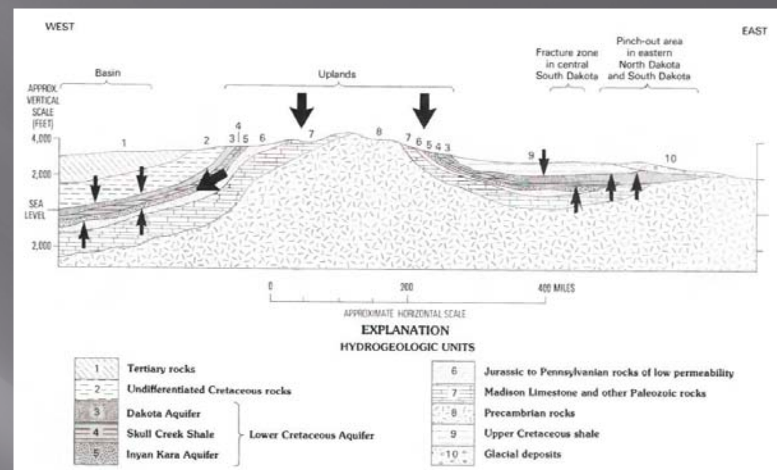


Figure 3. The Lower Cretaceous Aquifer is split into three hydrogeologic areas called the Basin, the Uplands, and the Pinch-out areas (Busby, et al., 1995).

Flow Path #6 of the Inyan Kara

Station identification number	Sample number	Temperature (°C)	pH	Specific conductance (µS/cm)	Dissolved solids, calculated (mg/L)	Dissolved iron (µg/L)	Sodium (mg/L)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Bicarbonate (mg/L)
473832099320201	1	21	8.3	4,210	4,920	60	980	3	5.2	1.2	320	1,300	4,704
472730099295802	2	--	8.2	4,590	6,050	1,200	1,100	4	6.8	3.2	440	1,200	6,707
472724099270501	3	9.4	8.7	4,320	6,050	520	1,000	3	4.0	1.9	350	1,200	7,100
472400099012001	4	12	8.1	4,490	5,390	--	1,000	40	8.0	6.1	430	1,200	5,500
472025098594401	5	10	8.1	4,420	4,980	--	1,000	16	4.0	4.9	300	1,200	5,000
472633097315501	6	--	7.7	4,690	4,210	100	970	24	60	21	930	730	3,000
473418097304401	7	6.0	7.3	6,640	5,370	3,400	1,000	46	370	120	1,400	1,500	1,900
472951097255702	8	9.0	7.8	5,480	4,780	--	800	39	310	110	940	1,500	2,200
472430097220701	9	7.0	7.3	4,520	4,130	--	820	34	140	44	660	1,200	2,500
472430097125301	10	7.0	7.6	5,370	4,860	--	1,100	38	110	30	800	1,400	2,800
474858097134601	11	8.0	7.7	7,190	6,060	--	1,100	33	330	130	1,600	1,200	3,400
474424097130201	12	10	7.1	--	5,400	--	1,000	28	300	92	1,300	1,300	2,800
474905097115001	13	9.0	7.8	7,070	6,130	--	1,200	30	330	100	1,500	1,400	3,200
474537097114001	14	10	8.0	6,210	5,230	--	1,100	39	230	77	1,200	1,400	2,400
474530097101702	15	9.0	7.9	6,740	5,330	--	1,200	35	230	83	1,400	1,400	2,000
474208097071301	16	14	7.4	4,940	5,180	--	780	12	300	130	480	2,000	3,000
474109097034901	17	--	7.6	5,770	6,240	--	900	0	250	86	1,200	1,000	2,800

Table 1. Data acquired by the U.S.G.S. from numerous test wells along the Inyan Kara flow path #6 (Busby et al., 1995).

Phreeq Results

- Inverse modeling function
- 2 solution data set; sample 1 and sample 16
- Uncertainty was set at 0.6 for both solutions
- Resulted in 6 models

Phreeq Results

Name	Phase Mole Transfers	Minimum	Maximum	Chemical Formula
Gypsum	1.71E-02	0.00E+00	0.00E+00	CaSO4:2H2O
Anhydrite	-1.57E-03	0.00E+00	0.00E+00	CaSO4
Aragonite	-1.34E-02	0.00E+00	0.00E+00	CaCO3
Dolomite	5.33E-03	0.00E+00	0.00E+00	CaMg(CO3)2
Halite	-2.70E-03	0.00E+00	0.00E+00	NaCl
Pyrite	-7.21E-08	0.00E+00	0.00E+00	FeS2
Goethite	-1.01E-06	0.00E+00	0.00E+00	FeOOH

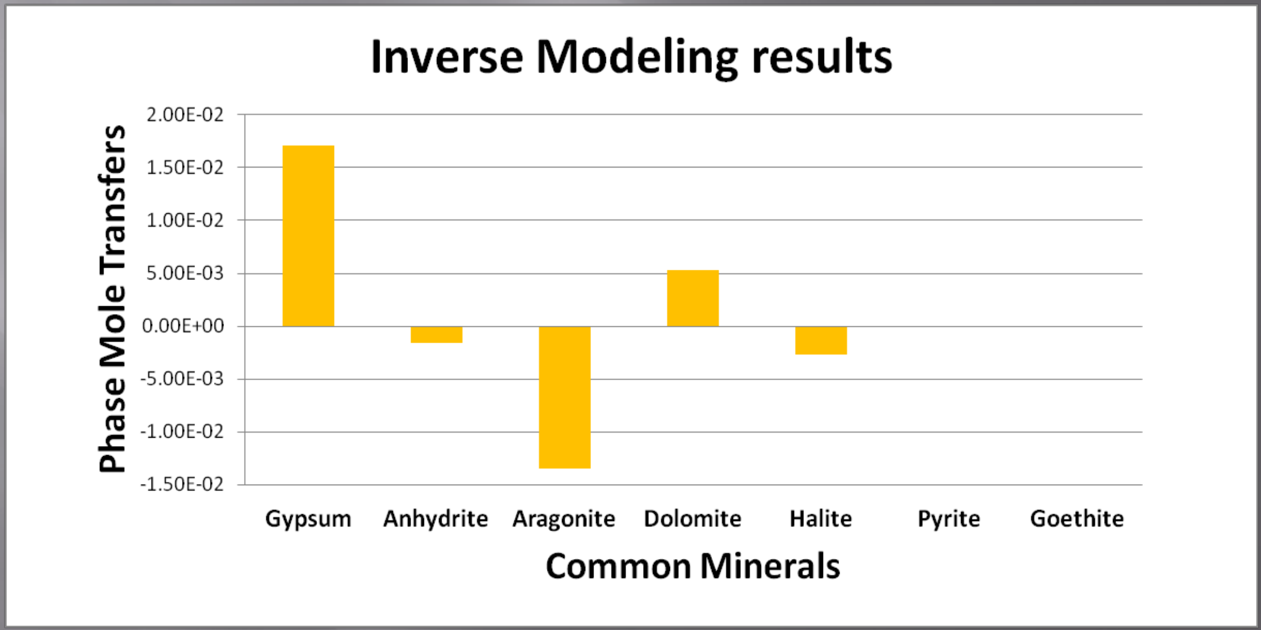
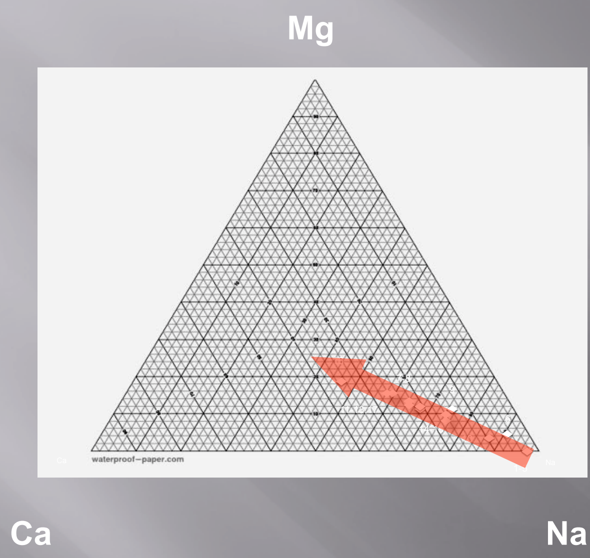


Figure 4. Inverse modeling can be used to determine likely mineral solutes and precipitates resulting from a change in chemistry between two or more solutions.

Piper Plots



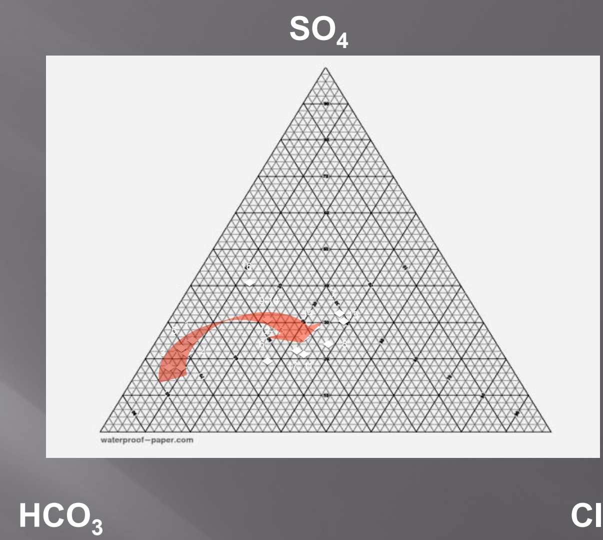


Figure 5. Piper plots are used to determine cation and anion trends within an aquifer. Cations and anions values not utilized are not plotted. Programs exist to plot these values but are not required. This Piper Plot is specific to flow path #6 of the Inyan Kara aquifer (AQ4) and shows relative percentages of an ion in solution.

Conclusions

- Phreeq model results indicate precipitation of Anhydrite ($CaSO_4$), Aragonite ($CaCO_3$), and Halite (NaCl)
- Piper Plots of the well data indicate the trend of ions in solution. They are complementary to Phreeq results
- The U.S.G.S. suspects leakage from a deeper aquifer is contaminating the Inyan Kara. Phreeq model results do not conclusively confirm or deny this hypothesis.

References

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Bubsy, J.K., Kimball, B.A., Downey, J.S., Peter, K.D. (1995). Geochemistry of water in aquifers and confining units of the Northern Great Plains in parts of Montana, North Dakota, South Dakota, and Wyoming.

Geologic Timescale, 2012, http://scienceblogs.com/gregladen/wp-content/blogs.dir/472/files/2012/04/i-bfd305e65b904f946b147b50e1ed1f83-geologic_time_scale_USGS_modified_01.jpg: Date accessed, Dec., 3, 2012

The regional aquifers of the northern Great Plains area of the United States and Canada include the underlying strata of the states of Wyoming, Montana, North Dakota, and South Dakota as displayed in figure 1. Over 300,000 square miles in area, it is bounded on its western perimeter by the Rocky Mountains and its Eastern side by the Central Province. The aquifers of this region are bedded atop each other throughout this area with shared common recharge areas located both in the Rocky Mountains and in the region of the Black Hills of South Dakota.

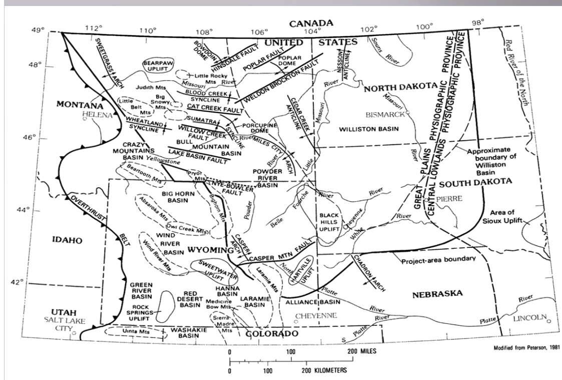


Figure 1: Regional extent of the Great Plains aquifers with major geologic structures

A recent study by the United States Geological Survey (USGS) report five major aquifers and associated confining units that comprise this regional area. These range in age from the ancient Cambrian-Ordovician aquifer (AQ1) through the fairly young Upper Cretaceous-Tertiary aquifer (AQ5). The Lower Cretaceous aquifer (AQ4) discharges to the eastern regions of North and South Dakota. It is known by multiple regional names including the Inyan Kara and the Dakota. AQ4 is comprised of sandstone and siltstone of the Fall River and Newcastle Sandstone Formations and the Lakota and Fuson Formations as shown in figure 2.
The lower confining unit is called TK3 and the upper confining unit is TK4.

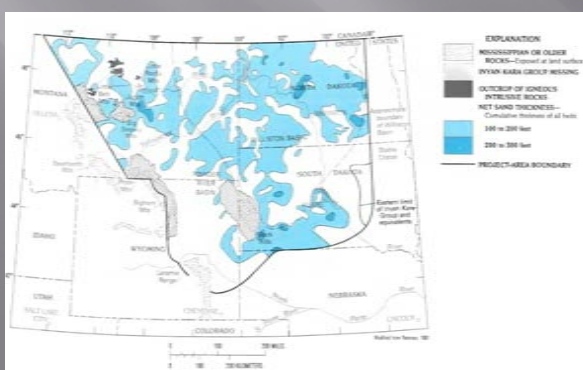


Figure 2: Distribution of sandstone bodies more than 100 feet thick in the Inyan Kara

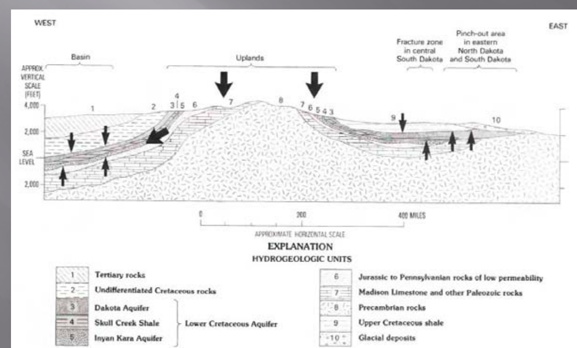
AQ4 consists of marine and clastic nonmarine sediments with a thickness ranging from 1400 ft in Montana tapering off to nil in eastern North Dakota.

The Fall River Sandstone results from the Cretaceous inland sea initial sand deposits with simultaneous silt and shale deposits within Wyoming and Montana indicating a deeper water situation. Regression and transgression of the inland sea dictate the thickness of the Newcastle Formation fluctuating between zero and tens of feet over most of the region.

Waters within the recharge areas generally are present for a limited timeframe and assumptions are made that the dissolved solids including chloride will be minimal. By applying specific criteria to this assumption, the authors of the USGS report also identified the area of the Bighorn Mountains as a substantial recharge contributor to most of the aquifers of this region.

Hypothetical flow paths of AQ4 were established with the assumption that flow paths are at right angles to the equipotential lines derived from a potentiometric surface map. Changes in pH and ion concentration were monitored to determine the evolution of the aquifers geochemistry. The authors acknowledge that while flow path depictions are created under assumptions of a steady-state condition this is not the true condition in every flow path.

Figure 3: Hydrogeologic areas under study



The Inyan Kara aquifer was broken into three hydrogeologic areas (fig.3): The uplands, the basins, and the pinch out areas. Our focus is on flow path six which contains the pinch out area. The authors of the report established evidence of leakage from dissolved solid concentrations. In eastern South Dakota and southeastern North Dakota the dissolved solids concentration is below 3,000 mg/L which range to above 20,000 mg/L generally increasing northward. Sodium concentrations display a similar relationship. They claim that underlying Paleozoic aquifers in eastern North Dakota are more saline than the Inyan Kara. The direct result of this is that calcium, magnesium, sodium, and chloride concentrations increase down gradient. This also forces the anions to transition from a sulfide rich nature to a saline chloride dominant composition.

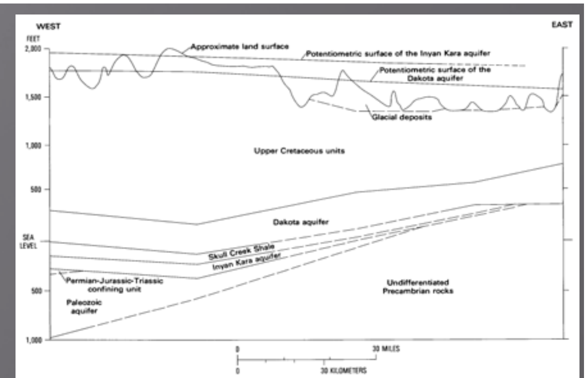
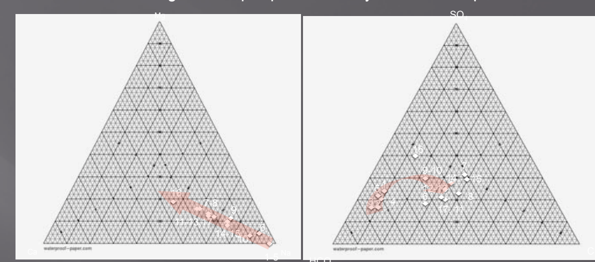


Figure 4: Potentiometric surfaces of North Dakota

Generally speaking the waters of AQ4 are less saline in the uplands areas and more saline in the basins mostly due to a higher residence time of the waters in basins as a function of decreased permeability. At pinch out areas of AQ4 formations, the potentiometric surfaces of the deeper older aquifers are higher than that of the Inyan Kara resulting in upwards leakage (fig. 4). This causes variations in water chemistry within the pinch out area. Water chemistry within the Inyan Kara aquifer is primarily affected by sulfate reduction of the water, recharge water chemistry, and water-rock interactions. Unexplainable changes in water chemistry along a flow path may be indicative of leakage from another aquifer.

Figure 5: Piper plot of the Inyan Kara flow path 6



On our piper plot, wells 1 through 5 were consistent in chemistry but the unit is indeterminate.

A steady increase in Calcium in the remaining wells as well as a general clustering of anions slightly favoring HCO_3, could indicate a path through a gypsum unit.

BUBSY, J.K., KIMBALL, B.A., DOWNEY, J.S., PETER, K.D. (1995). Geochemistry of water in aquifers and confining units of the Northern Great Plains in parts of Montana, North Dakota, South Dakota, and Wyoming.