Appendix C: Geochemistry of Colorado Thermal Springs and Wells

C.1 Contents of Appendix Data Table

This appendix explains the Colorado Geological Survey (CGS) datafile that contains the major and minor constituent chemistry of waters from thermal springs and wells in Colorado, collected to record and understand the geothermal resources of the State. The data table is available in an Excel file located here (Colorado Thermal Springs Geochemistry), and also may be accessed through the CGS website (1) and from the ECMC geothermal library (2). The data file gives the spring or well name, county, location in various formats, temperature at the surface when the sample was collected, date of collection, results of all chemical analyses performed on the sample, results of a radioactive tests on a few samples, and estimates of reservoir temperatures for the samples using chemical geothermometry. This data table contains 400 geochemistry data entries for the 182 distinct and differentiated seeps, springs, and wells.

C.2 Chemical Geothermometry

All minerals dissolve in water very slowly until the water reaches saturation or equilibration with the elements or ions that form the minerals. The rate that equilibration is reached depends on the temperature of the water and the mineral. A household example is sugar in water: the hotter the water, the more sugar dissolves. Even sand or silica (SiO_2) dissolves in concentrations of part per million (ppm) and is useful as a geothermometer. However, different varieties of silica, such as amorphous (no crystalline structure such as glass), chalcedony (the most usual form of silica at low temperatures), and quartz (which is only soluble above 175°C or 347°F) dissolve at different rates and different equations must be used to convert the concentrations of silica to the geotemperature. More complex minerals, such as feldspars, which include at least two other elements (ionic geothermometers) in addition to silicon and oxygen do not dissolve in concentrations directly proportional to their temperature, but rather in complex ratios of the elements that are related to temperature. Equations for these ratios have been developed by "cooking" the minerals in water in the laboratory for extended times and analyzing the water at the end of the experiments. These results have yielded several geothermometers. In the Excel file, results of some of the more common geothermometers are given as estimates of the reservoir temperature for the thermal springs and wells.

There are three inherent assumptions in the use of thermal water geothermometers:

1. The water stays in the reservoir long enough to reach equilibrium with the appropriate minerals in the reservoir, and the minerals are present before the thermal water rises to the surface. Solution equilibrium is very slow and this assumption may not always be satisfied;

2. The thermal water rises to the surface faster than it can re-equilibrate at a lower temperature. Equilibration is slower at lower temperatures, so if the water has not completely cooled at the surface it is unlikely to have re-equilibrated; and

3. The thermal water has not mixed with different, cooler waters with different chemistry before being collected. While it is possible for such a situation to occur, the effects of dilution may also be calculated if the temperature and chemistry of other near–surface waters are known.

Giggenbach (3) devised a technique to determine whether the chemistry of waters from thermal springs were in equilibrium with feldspars. This technique was applied to all the chemistries of the Colorado ionic geothermometers with the result that many were immature (out of equilibrium) and many more were in partial equilibrium. Therefore, in interpreting the results of the ionic geothermometers, they were only given an emphasis if they were in reasonable agreement with the silica geothermometer. The final column of the data file identifies the Colorado Geological Survey's interpretation of the best estimation of the geothermometer results, utilizing the Giggenbach plot technique.

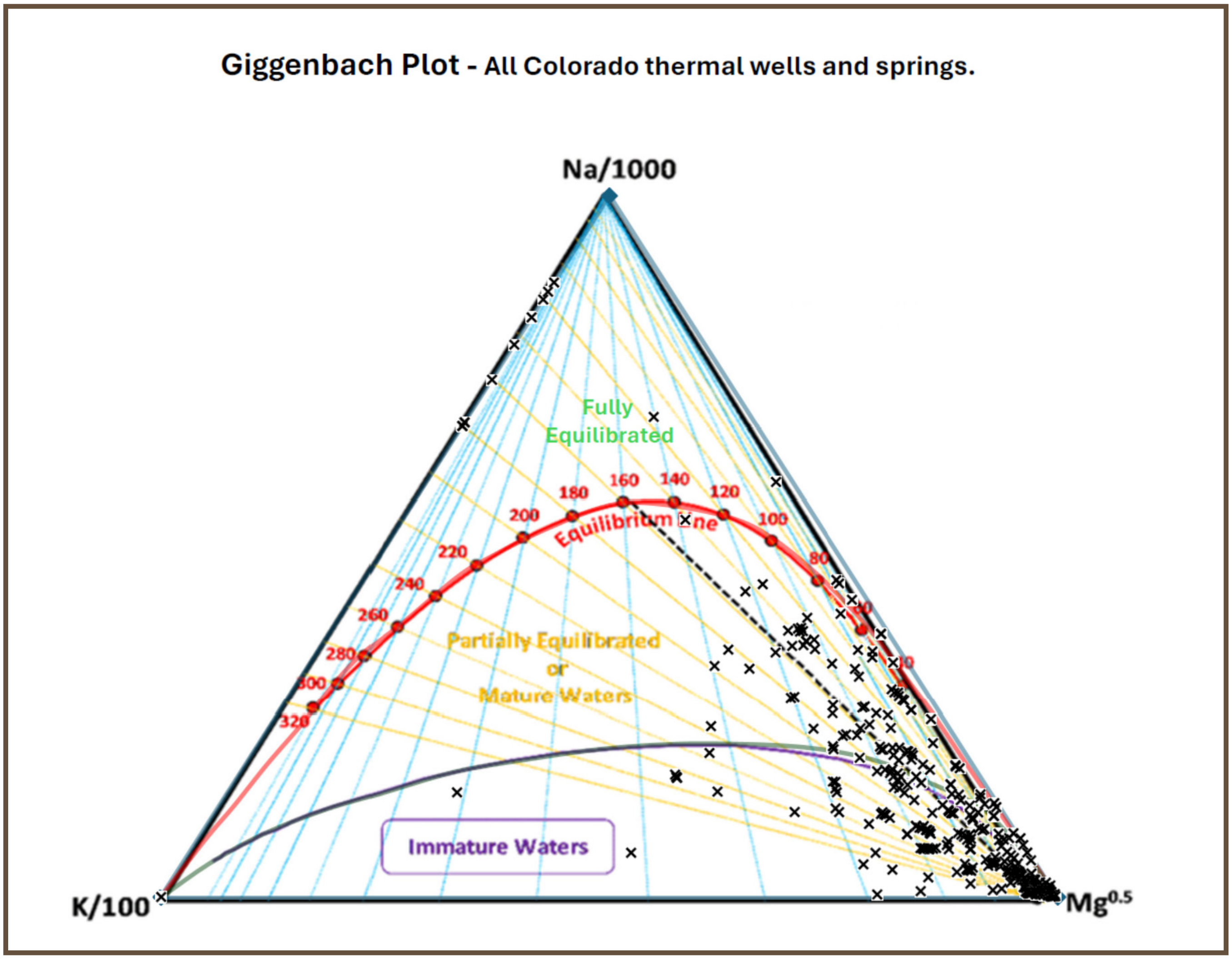

Figure C.1: Giggenbach plot diagram of all Colorado thermal springs and wells.

C.3 References

1. Morgan P, Rogers NT. OF-24-12 Data for 2024 ECMC Geothermal in Colorado Report [Internet]. Denver, CO: Colorado Geological Survey; 2024 [cited 2024 Jun 7]. (Open-File Report). Report No.: OF-24-12D. Available from: https://coloradogeologicalsurvey.org/publications/of-24-12-data-for-2024-ecmc-geothermal-in-colorado-report/

2. ECMC. ECMC (Energy and Carbon Management Commission). 2024 [cited 2024 Jun 12]. ECMC Library: Deep Geothermal, Carbon Capture and Storage (CCS), and Underground Natural Gas Storage (UNGS). Available from: https://ecmc.state.co.us/library.html#/gtccsungs

3. Giggenbach WF. Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. Geochim Cosmochim Acta [Internet]. 1988 Dec 1 [cited 2024 Jun 7];52(12):2749–65. Available from: https://www.sciencedirect.com/science/article/pii/0016703788901433