Water-Quality Principles
QW1022–TEL

Lesson 13—Interpretive Methods

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U.S. Department of the Interior
U.S. Geological Survey

7.2 Graphical Methods and Hydrochemical Facies

An important task in groundwater investigations is the compilation and presentation of chemical data in a convenient manner for visual inspection. For this purpose several commonly used graphical methods are available. The simplest of these is the bar graph. Two examples are shown in Figure 7.3. For a single sample these two graphs represent the major-ion composition in equivalents per cubic meter (or milliequivalents per liter) and in percentage of total equivalents. The same

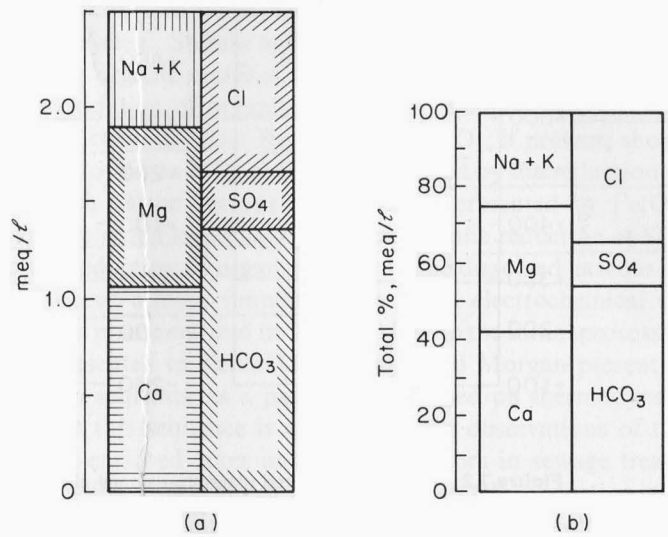

Figure 7.3 Chemical analyses of groundwater represented by bar graphs: (a) milliequivalents per liter; (b) percentage of total equivalents per liter (after Davis and De Wiest, 1966).

analysis is shown on a circular graph in Figure 7.4. In Figure 7.5(a) the analysis is shown in a manner that facilitates rapid comparison as a result of distinctive graphical shapes. This is known as a *Stiff diagram*, named after the hydrogeologist who first used it. Analysis of water with a much different composition is shown in Figure 7.5(b). The bar, circular, radial, and Stiff diagrams are all easy to construct and provide quick visual comparison of individual chemical analyses. They are not, however, convenient for graphic presentation of large numbers of analyses.

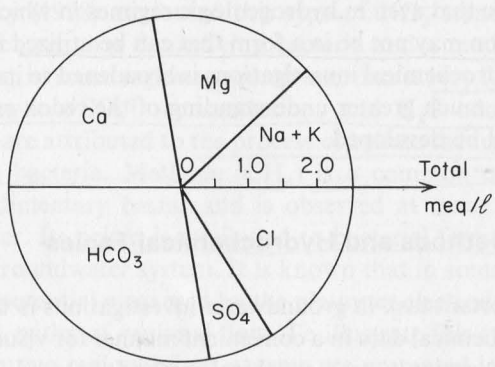

Figure 7.4 Chemical analysis of groundwater represented by a circular diagram. The radial axis is proportional to the total milliequivalents. Same chemical analysis as represented in Figure 7.3 (after Davis and De Wiest, 1966).

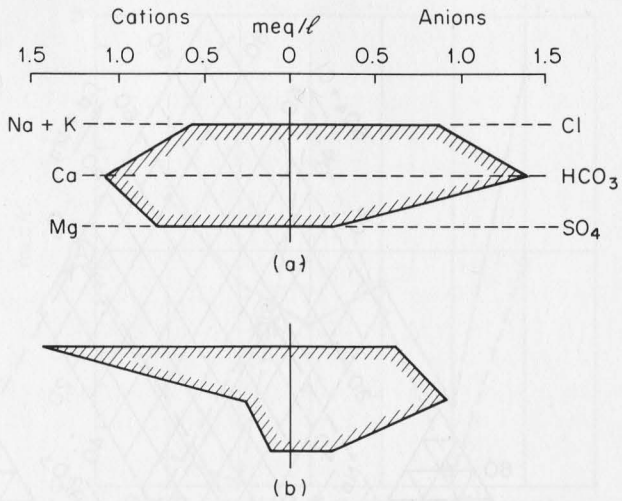

Figure 7.5 Two chemical analyses represented in the manner originated by Stiff. (a) The same analysis as in the previous three figures; (b) second analysis, illustrating contrast in shape of the graphical representation (after Davis and De Wiest, 1966).

For this purpose two other diagrams are in common use. The first one, developed by Piper (1944) from a somewhat similar design by Hill (1940), is shown in Figure 7.6; the second one, introduced into the groundwater literature by Schoeller (1955, 1962), is shown in Figure 7.7. Both of these diagrams permit the cation and anion compositions of many samples to be represented on a single graph in which major groupings or trends in the data can be discerned visually. The Schoeller semilogarithmic diagram shows the total concentrations of the cations and anions. The trilinear diagram represents the concentrations as percentages. Because each analysis is represented by a single point, waters with very different total concentrations can have identical representations on this diagram. A single trilinear diagram has greater potential to accommodate a larger number of analyses without becoming confusing and is convenient for showing the effects of mixing two waters from different sources. The mixture of two different waters will plot on the straight line joining the two points. The semilogarithmic diagram has been used to directly determine the saturation indices of groundwaters with respect to minerals such as calcite and gypsum (Schoeller, 1962; Brown et al., 1972). This approach, however, is often not advisable, because of errors introduced by neglecting the effects of ion complexes and activity coefficients.

Some of the shortcomings of the trilinear graphs of the type developed by Hill and Piper are removed in the diagram introduced into the Soviet literature by S. A. Durov and described in the English-language literature by Zaporozec (1972). The basis of this diagram, shown in Figure 7.8, is percentage plotting of cations and anions in separate triangles, which in this respect is similar to the Piper diagram.

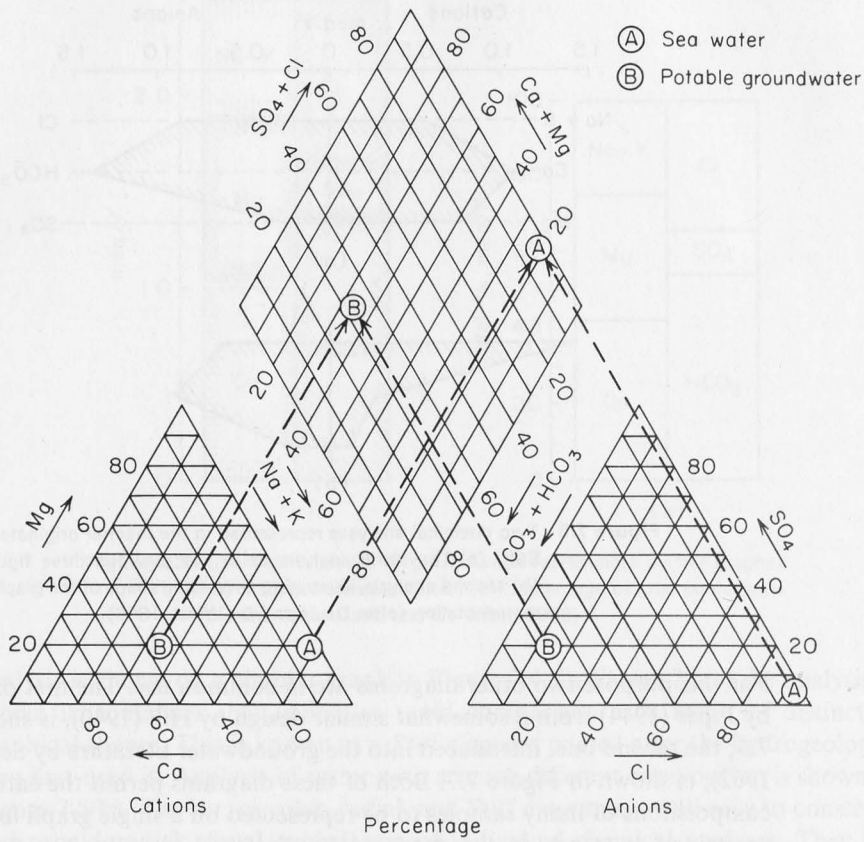

Figure 7.6 Chemical analyses of water represented as percentages of total equivalents per liter on the diagram developed by Hill (1940) and Piper (1944).

The intersection of lines extended from the two sample points on the triangles to the central rectangle gives a point that represents the major-ion composition on a percentage basis. From this point, lines extending to the two adjacent scaled rectangles provide for representation of the analysis in terms of two parameters selected from possibilities such as total major-ion concentration, total dissolved solids, ionic strength, specific conductance, hardness, total dissolved inorganic carbon, or pH. Total dissolved solids and pH are represented in Figure 7.8.

The diagrams presented above are useful for visually describing differences in major-ion chemistry in groundwater flow systems. There is also a need to be able to refer in a convenient manner to water compositions by identifiable groups or categories. For this purpose, the concept of hydrochemical facies was developed by Back (1961, 1966), Morgan and Winner (1962), and Seaber (1962). The definition of *hydrochemical facies* is a paraphrase of the definition of *facies* as used by geologists: *facies* are identifiable parts of different nature belonging to any genet-

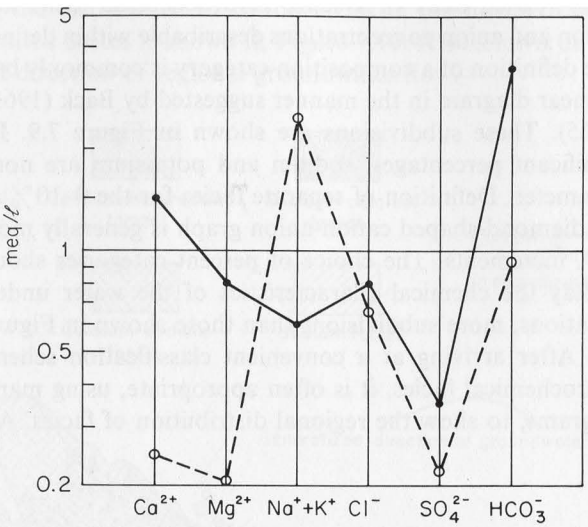

Figure 7.7 Chemical analyses of water represented on a Schoeller semi-logarithmic diagram (same analyses as in Figure 7.6).

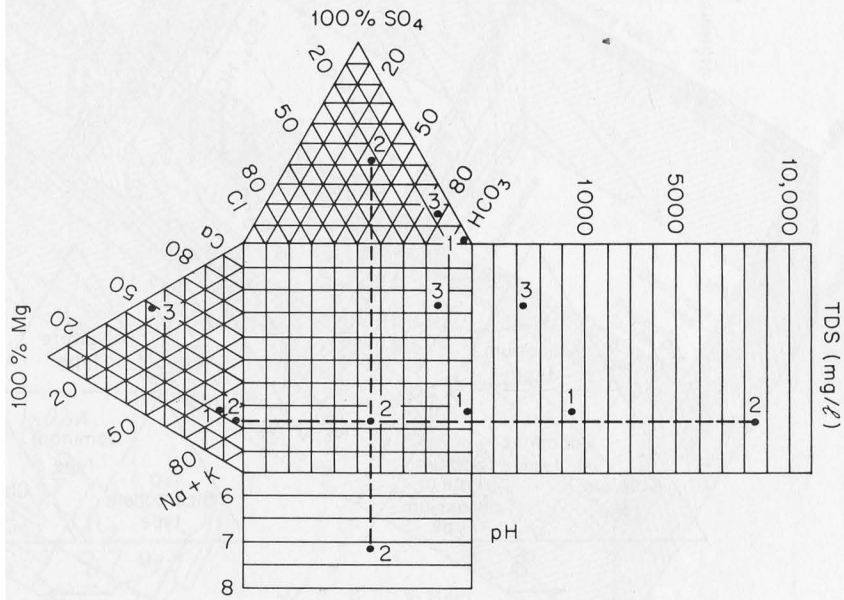

Figure 7.8 Chemical analyses represented as milliequivalents per liter on the diagram originated by Durov as described by Zaporozec (1972).

ically related body or system. Hydrochemical facies are distinct zones that have cation and anion concentrations describable within defined composition categories. The definition of a composition category is commonly based on subdivisions of the trilinear diagram in the manner suggested by Back (1961) and Back and Hanshaw (1965). These subdivisions are shown in Figure 7.9. If potassium is present in significant percentages, sodium and potassium are normally plotted as a single parameter. Definition of separate facies for the 0–10% and 90–100% domains on the diamond-shaped cation-anion graph is generally more useful than using equal 25% increments. The choice of percent categories should be made so as to best display the chemical characteristics of the water under consideration. In some situations, more subdivisions than those shown in Figure 7.9 are useful.

After arriving at a convenient classification scheme for the designation of hydrochemical facies, it is often appropriate, using maps, cross sections, or fence diagrams, to show the regional distribution of facies. An example of a fence dia-

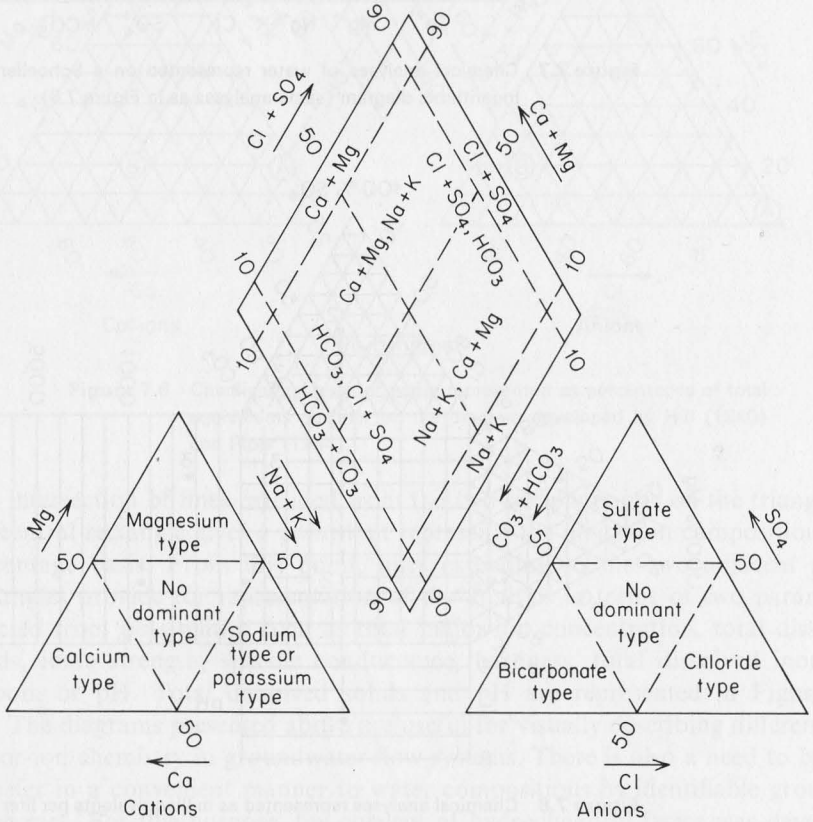

Figure 7.9 Classification diagram for anion and cation facies in terms of major-ion percentages. Water types are designated according to the domain in which they occur on the diagram segments (after Morgan and Winner, 1962; and Back, 1966).

gram showing the distribution of cation facies in the northern Atlantic Coastal Plain of the United States is shown in Figure 7.10. Also shown on this diagram is the generalized direction of regional groundwater flow.

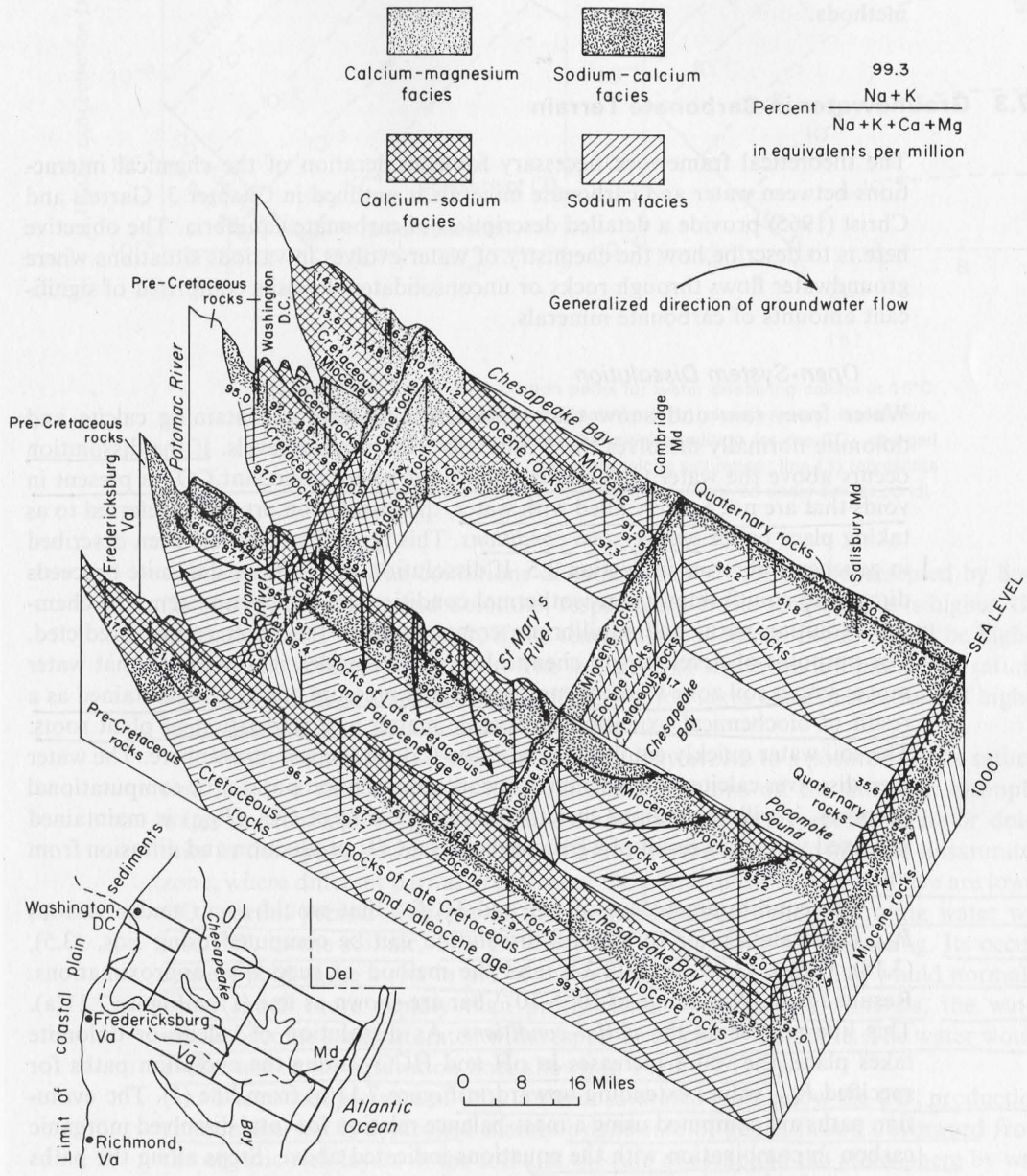

Figure 7.10 Fence diagram showing cation facies and generalized directions of groundwater flow in part of the northern Atlantic Coastal Plain (after Back, 1961).