ORIGIN OF HYDROCHEMICAL FACIES OF GROUND WATER IN THE ATLANTIC COASTAL PLAIN*

By WILLIAM BACK
U.S.A.

ABSTRACT

The application of the concept of facies to the chemical aspects of ground water shows that the kinds of ions in solution and their concentration result from chemical processes responding to the lithology and the hydrologic flow pattern of a particular region. The Atlantic Coastal Plain was selected as a field model in which to study the portion of the geochemical cycle of elements that is controlled by the circulation of ground water. Significant characteristics of hydrochemical facies can be illustrated by methods similar to those used in lithofacies studies—trilinear diagrams that show the types of facies present in any area or formation; panel diagrams that show the overall facies distribution; and maps showing isopleths of chemical constituents within certain formations. Within the Coastal Plain sediments the calcium magnesium facies occurs in areas of high head (areas of recharge); the sodium facies occurs in downgradient areas of lower head. Mapping of these facies demonstrates that the outcrop area of Cretaceous and Eocene sediments in southern Maryland is the discharge area for ground water, rather than a recharge area as is more normally the role of the outcrop of artesian aquifers.

INTRODUCTION

The part of the geochemical cycle of the elements that probably has been studied the least is the portion in which the circulation of ground water controls the concentration and distribution of chemical constituents within particular environments of the earth’s crust. Chemical analyses and interpretative papers pertaining to the hydrosphere are related almost entirely to the fields of oceanography, potamology, and limnology. Ground water has been largely ignored in the geochemical cycle. Although the amount of water stored in, and circulating through, the sedimentary formations is a small percentage of the total water of the earth, it is this water with its contained chemical constituents that is largely responsible for the chemical nature and quantity of the dissolved load carried to the oceans by streams. This paper is concerned with this part of the geochemical cycle and partially summarizes a study by the U.S. Geological Survey, with the purpose of clarifying the relations between the chemical character of ground water and the geology and hydrology of the region in which the water occurs. The Atlantic Coastal Plain was selected as a suitable field model in which to study these relationships.

About 3,000 chemical analyses of ground water and several hundred logs of geologic formations were studied. Stratigraphic classification of well logs were obtained from published ground water reports resulting from investigations of Geological Survey in cooperation with state agencies. Figure 1 and 2 were prepared by

* Publication authorized by the Director, U.S. Geological Survey.
projecting the geologic logs of the wells closest to the lines of profiles for the fence diagrams, to establish the geologic framework for presentation of the hydrochemical facies. Nearly 300 chemical analyses, judged to be typical of a particular area and formation by group plotting on trilinear diagrams similar to that used for figure 3, were used to map the facies distribution. Selected chemical analyses and the locations of wells from which samples were collected are not given in this paper but will be included in the final report of the study.

The part of the Coastal Plain discussed in this paper includes parts of New Jersey, Delaware, Maryland, and Virginia. The Coastal Plain is generally flat to gently rolling and ranges from sea level to about 300 feet above. The highest areas are in the northern part of New Jersey and in southern Maryland south of Washington, D.C. The eastern shores of Maryland and Virginia and the State of Delaware are on the lowest part of the Coastal Plain, where the elevation is generally 50 feet or less.

SUMMARY OF STRATIGRAPHY

As shown on the fence diagrams (figs. 1 and 2) the Coastal Plain consists of a wedge-shaped mass of unconsolidated and semiconsolidated sediments ranging in age from Cretaceous to Recent. Underlying the Coastal Plain sediments is a complex of crystalline rocks of pre-Cretaceous age.

In the southern part of this area the lower part of the Cretaceous sediments consist of interbedded clay and sand, which are of fresh water origin. Overlying these sediments are beds of marine clay and sand. In New Jersey the Cretaceous sediments are essentially all marine sand and clay. In these diagrams (figs. 1-2) the Paleocene sediments are grouped with the Eocene in all the area except Virginia, where the Mattaponi formation contains deposits of both Paleocene and Upper Cretaceous. The Eocene sediments of marine sand, clay and marl which are commonly glauconitic.

As shown in the fence diagrams, the Miocene sediments attain a thickness of more than 1,000 feet along the coast. These sediments are marine and consist primarily of gray and blue sand, clayey sand, and clay. In New Jersey the equivalents of these sediments are subdivided into the Miocene Kirkwood formation and the overlying Miocene (?) Cohansy sand. The Pliocene (?) sediments of the Coastal Plain generally cap the higher hills and consist of slightly cemented silty sand and gravel. The Pleistocene sediments, which are primarily of fluvial origin and are at a lower altitude than the Pliocene (?) sediments, occur over much of the Coastal Plain.

HYDROCHEMICAL FACIES

The notion of hydrochemical facies is used in this paper to denote the diagnostic chemical aspect of water solutions occurring in hydrologic systems. They reflect the response of chemical processes in the lithologic framework and the pattern of water flow in it.

The following terms are used to designate particular cation facies: the calcium-magnesium facies occurs where calcium and magnesium ions comprise 90 percent or more of the total cations (on the basis of equivalents per million, not parts per million); the calcium-sodium facies exists where the calcium and magnesium content exceeds 50 percent but is less than 90 percent of the total cations; and the sodium and potassium cation facies, respectively, apply when more than 90 percent of the total cations are sodium or potassium. The various combinations of calcium, magnesium, sodium, and potassium cations may be used to designate mixed facies.
The rock forming the fence hydrochemical facies in the area and for figure 3, and the locations are in New Jersey, y flat to gently west areas are in ashington, D. C. ware are on the feet or less.

ists of a wedge-
going in age from a complex of ceous sediments rigin. Overlying the Cretaceous as (figs. 1–2) the except Virginia, ene and Upper which are com-
hickness of more visit primarily of valents of these nd the overlying il Plain generally and gravel. The are at a lower xtal Plain.

te the diagnostic They reflect the pattern of water ions: the calcium prise 90 percent on, not parts per ammonium content ; and the sodium

---

**Q** - Quaternary Sediments  
**Tch** - Cohansey sand of Miocene age  
**TkW** - Kirkwood Formation of Miocene age  
**Tc** - Chesapeake group of Miocene age  
**E** - Eocene, undifferentiated  
**T/Km** - Montepello Formation of Paleocene and Late Cretaceous age  
**K** - Cretaceous, undifferentiated

---

**Ca + Mg** exceeds 90% of total cations  
**Ca + Mg** exceeds 50% of total cations  
**Na + K** exceeds 50% of total cations  
**Na + K** exceeds 90% of total cations

**FIG. 1.—Fence diagram showing the distribution of the cation hydrochemical facies in part of the Atlantic Coastal Plain.**

and potassium content exceeds 10 percent but is less than 50 percent; the sodium calcium facies designates the chemical character of water in which the content of the sodium and potassium ions exceeds 50 percent but is less than 90 percent of the total cations; the sodium facies occurs where the sodium and potassium ions exceed 90 percent and the calcium and magnesium are equal to less than 10 percent. Although
other anions exceed chloride sulfate bic.

The distribution facies is generally p greater depth. The farther south in Ma.
In the Eocene ar resented. Near the s common and at pro changes from calciu sodium facies. The formajons in which flow characteristics example the sodium clay minerals and th as natural water so downward the cal continues to move ti materials remove th with sodium ions.
In the calcium m carbonate. The wat Therefore, if more e residence time in th
The anion facies facies and the bicar ions originate from by dissolving carbon
The chloride sulfa modes of origin in v rene of sodium chl sediments of New " solution is so dilute the development of the lithologic materi facies to the bicarbon Plain where these fa due to lack of calcar the sulfide is oxidize.
The distribution c New Jersey and Del and Virginia. The A and have fewer clay it may be that less so

the potassium ion occurs in far lower concentration than the sodium ion, it is included in the facies classification because often it is not separated from the sodium ion in the chemical analysis.

Essentially the same limits are used in figure 2 for the designation of the facies; that is, the bicarbonate facies occurs where the bicarbonate plus carbonate exceeds 90 percent of the total anions; the bicarbonate chloride sulfate facies indicates that bicarbonate is less than 90 percent but exceeds 50 percent, and the content of the
other anions exceeds 10 percent and is less than 50 percent of the total anions; the chloride sulfate bicarbonate facies occurs where the chloride and sulfate content exceeds 50 percent and is less than 90 percent of the total anions. In most areas of the chloride sulfate facies the chloride ion occurs in a concentration greater than the sulfate ion, and this terminology can be simplified to “chloride facies”.

The distribution of cation facies in figure 1 shows that the calcium magnesium facies is generally predominant near the surface and the sodium potassium facies at greater depth. The sodium potassium facies is less common in New Jersey than it is farther south in Maryland and Virginia.

In the Eocene and Cretaceous sediments the full range of cation facies is represented. Near the surface, within these formations the calcium magnesium facies is common and at progressively lower elevations and, therefore, lower head, the facies changes from calcium through calcium sodium and sodium calcium to the complete sodium facies. The occurrence of these facies within one formation or group of formations in which the mineralogy remains essentially constant indicates that the flow characteristics of the aquifer systems control the distribution of the facies. For example the sodium facies is developed by the process of ion exchange in which the clay minerals and the glauconitic sand of the Eocene and Cretaceous formations act as natural water softeners. As the water enters the recharge areas and percolates downward the calcium magnesium bicarbonate facies develops. As this water continues to move through the Eocene and Cretaceous formations, the ion-exchange materials remove the calcium and magnesium ions from the water and replace them with sodium ions.

In the calcium magnesium facies the ground water is not saturated with calcium carbonate. The water has a low concentration of dissolved solids and a low pH. Therefore, if more calcareous material were available, or if the water had a longer residence time in these areas, more calcium carbonate would go into solution.

The anion facies distribution, shown on figure 2, indicates that the bicarbonate facies and the bicarbonate chloride sulfate facies are predominant. The bicarbonate ions originate from the solution of calcium carbonate by ground water made acid by dissolving carbon dioxide gas from the atmosphere and soil.

The chloride sulfate facies and the chloride sulfate bicarbonate facies have several modes of origin in various areas of the Coastal Plain. The major cause, is the occurrence of sodium chloride water in the deep Cretaceous sediments. In the Miocene sediments of New Jersey and Maryland in which these facies occur, the water solution is so dilute (generally less than 2 equivalents per million of total ions) that the development of any particular facies is the sensitive response of minor changes in the lithologic material and a small addition of calcareous material would change the facies to the bicarbonate type. In those areas along the western margin of the Coastal Plain where these facies occur in the Eocene and Cretaceous sediments, the origin is due to lack of calcareous material and the presence of iron sulfide minerals in which the sulfide is oxidized to sulfate.

The distribution of the concentration of dissolved solids shows that the waters of New Jersey and Delaware have generally a lower content than those in Maryland and Virginia. The Miocene formations in New Jersey are composed of cleaner sand and have fewer clay beds than do the equivalent formations farther south. Therefore, it may be that less soluble material is available in the near-surface formations of New
### Table

<table>
<thead>
<tr>
<th>Number</th>
<th>County</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>Anne Arundel</td>
</tr>
<tr>
<td>6-27</td>
<td>Prince Georges</td>
</tr>
<tr>
<td>28-37</td>
<td>Charles</td>
</tr>
<tr>
<td>38-39</td>
<td>St. Mary's</td>
</tr>
</tbody>
</table>

### Diagram

- **Magothy formation**
- **Raritan formation**
- **Patapsco and Raritan formations**
- **Patapsco formation**
- **Patuxent formation**

**Figure 3.**—Water analysis diagram showing the hydrochemical facies in the Cretaceous formations in southern Maryland.

Jersey than is available in Maryland and Virginia. Another possible explanation for the low dissolved-solids concentration of ground water in New Jersey is that the bedrock is much shallower in that area and the water does not have as long a flow path as it does farther south. It would appear that there is less upward leakage into the Miocene beds in New Jersey than in Maryland. Another area of discharge for Cretaceous formations in New Jersey is along the Delaware River under conditions similar to those described for Maryland. In Maryland and Virginia discharge from
Fig. 4.—Map of southern Maryland showing the distribution of the cation facies in the Cretaceous formations.
the Cretaceous sediments occurs by upward leakage that causes a concentration of dissolved solids higher in the shallow formations than would be the case if such leakage did not occur.

Figure 3 shows the characteristic hydrochemical facies of the Cretaceous formations in southern Maryland. The cation facies show the complete range of distribution from the calcium to the sodium facies. Most of these samples represent the bicarbonate facies. The sulfate and chloride facies occur in the more dilute waters. Although these analyses are identified by the formation in which the well is completed, the similarity of the lithology of the formations permits the development of the same facies within each formation. Therefore, the grouping of the analyses in the high calcium and high sodium areas reflects the changes caused by the movement of the water rather than by change in type of geologic materials.

The cation distribution shown in figure 4 results from several different processes. For instance, the sodium facies can occur in areas having no source of calcium carbonate material. In a recharge area that has been functioning for a long time the calcium carbonate material may be leached and the predominate cation may be sodium or potassium derived from the marine clays or weathered feldspars. However, in such an area the dissolved solids will be very low, and it should be possible to identify the recharge areas at those showing the lowest dissolved-solids concentration. On the other hand, an area where the high sodium facies with a high dissolved-solids concentration is likely to be the discharge area, because the amount of dissolved solids in the water would reflect the length of residence time in the aquifers.

The calcium facies shown in figure 4 includes the topographic high southeast of
Washington. This suggests that the topographic high is a recharge area and that part of the water flows westward, up the dip, and part of it flows southward and southeastward, generally down the dip. This hypothesis is further supported in that the water of low dissolved solids content (100 to 150 ppm) occurs in the calcium and calcium sodium facies. The dissolved solid content of the water in the sodium facies ranges from about 200 to 350 ppm.

It follows that in part of the area along the Potomac River the outcrop of the Cretaceous sediments is a discharge area. Therefore, the outcrop area of artesian aquifers need not be an area of recharge but may function also as an area of discharge. Figure 5 is a diagrammatic cross section showing the direction of groundwater flow as interpreted from the mapping of hydrochemical facies.

[Manuscript received September 1, 1959]