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AN EARLY AMERICAN STATEMENT OF THE BADON GHYBEN-HERZBERG PRINCIPLE OF STATIC FRESH-WATER-SALT-WATER BALANCE*

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ABSTRACT. In 1828 the American Journal of Science published a paper by Dr. Joseph Du Commun, a West Point Military Academy teacher of French, which outlined qualitatively and quantitatively the principle of hydrostatic balance of fresh water and sea water in coastal regions (1828). Du Commun's statement antedated by 61 years Badon Ghyben's (1889) statement of this principle and Herzberg's (1901) statement by 73 years. Badon Ghyben and Herzberg have hitherto been credited for the first enunciation of the principle.

In recent years Hubbert (1940) has shown that the fresh-water-salt-water balance is hydrodynamic rather than hydrostatic because a flow system must exist in the fresh water. Wentworth's (1948) demonstration of a zone of diffusion on either side of the fresh-water-salt-water interface has led Cooper (1959) to the hypothesis that a flow system also exists in the salt water near the interface. Cooper's hypothesis and his further deductions have been confirmed by field observations in the Miami area (Kohout, 1960). Glover (1959) and Henry (1959, 1960) have also contributed to this field of inquiry.

INTRODUCTION

The principle of static equilibrium between fresh water and salt water in coastal regions is widely known as the Badon Ghyben-Herzberg principle. The principle was applied to hydrologic problems of seacoasts by W. Badon Ghyben, a Dutch captain of engineers, in 1889. Because there was little interest in coastal ground water at that time his paper on the subject received little attention. Alexander Herzberg's studies of the fresh-water-salt-water balance on the island of Norderney was published in 1901 at a time when coastal water supplies in the Netherlands were of considerable interest to hydrologists. Herzberg apparently had no knowledge of Badon Ghyben's work and arrived at the same conclusions independently. Herzberg's paper was widely acclaimed and it was not until later that the priority of Badon Ghyben was established. The names of both men were then credited for the principle.

The principle states:

$$z = \frac{\rho_f}{\rho_s - \rho_f} h$$

in which z is the depth below sealevel to a point on the fresh-water-salt-water interface vertically below where h is measured, ρ_f is the density of fresh water and is assumed to be 1 g/cm^3, ρ_s is the density of sea water, and h is the head of fresh water above sealevel datum.

PRIORITY OF DU COMMUN

The writer has discovered that credit for the first enunciation of this principle should be given to an American of French birth whose statement in the American Journal of Science antedated the Badon Ghyben paper by 61 years and the Herzberg paper by 73 years. Dr. Joseph Du Commun,[1] a teacher

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[1] According to the records of the West Point Military Academy, Dr. Du Commun was born in France, was appointed to the Academy from New York on March 1, 1818 and served as a civilian Second Teacher of French until his resignation on August 31, 1831.

of French at West Point Military Academy, clearly outlined qualitatively and quantitatively the principle of coastal balance of fresh and sea water in 1828 in the American Journal of Science (Du Commun, 1828).

In May, 1824, Levi Disbrow, the first American water-well driller, bored his first water well at a distillery in New Brunswick, New Jersey (Carlston, 1943, p. 123). By 1827, this well, or a later drilled well, was the subject of discussion in two newspapers of the day, the "National Gazette" and the "Harmony Gazette". Questions were asked as to why this fresh-water well had a water level that rose from eight to fourteen feet above the Raritan River and why the yield of the well varied in exact phase with the rise and fall of the tide.

To explain these phenomena, Du Commun, applying the basic physical principles developed by Archimedes and Pascal, used the analogy of a U-tube. This tube, *ACB*, is shown in figure 1, as copied from Du Commun's illustration. Du Commun's explanation of the ebb and flow of the well followed these logical steps:

1. Water poured into this tube will fill it in part to the same height (*a* and *b*).

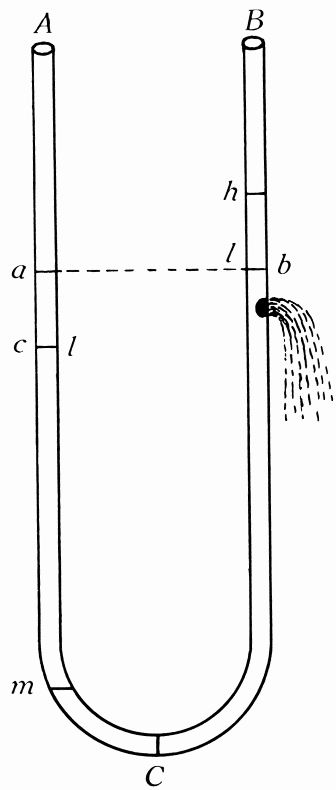

Fig. 1. Du Commun's illustration of density balance of liquids.

2. An inch of mercury at *m* will support, in branch *B*, 13 inches of rain water.

3. A liquid heavier than fresh water, such as salt water in branch *A*, will support, in branch *B*, a column of fresh water rising to a higher level than that of the salt water in inverse ratio to their densities. The height of the fresh-water column is represented by level *b*, and the height of the salt water column is represented by level *c*.

4. Branch *B* can represent fresh water in the rocks under the well, and Branch *A*, the salt water of the ocean lying beneath the fresh water.

Du Commun then states: "If so, it explains why the fresh water in boring by the sea shore is raised and flows above the level of the sea water . . . " (p. 174). He then proceeds to reason in this fashion:

> "Let us suppose that a hole has been opened in the branch *B*, a little below *lb* the level of the water at ebb; the water will then flow with a velocity that may be represented by 1, but at high tide the water might be supported at the height *h*, if the opening in the tube did not permit it to flow out, and it then must flow with the same velocity as if pressed under a column of fluid of that elevation. The quantity of water so running may be as 3, 4, 5, & c, according to the height of the tide; and finally, it must continually and exactly follow its oscillations." (p. 175).

Du Commun described the fresh-water-salt-water balance in the following words:

> "If we calculate the particular case here given, we shall find, the density of fresh water being represented by 1000, that of sea water by 1029 (Dr. Murray), the difference of the levels being 15 feet, we shall find, I say that the depths at which they join underground must be five hundred feet."

Although Du Commun did not give the formula for his computation, he obviously used a form equivalent to the Badon Ghyben-Herzberg equation:

$$z = \frac{1}{1.029-1.000}\ 15 = 517 \text{ feet below sealevel, or rounded off to 500 feet.}$$

Du Commun conceived of ground water as "subterranean streams" and thought that this principle explained springs on high ground and at the top of mountains (p. 175). Such misconceptions are expectable in the context of knowledge of ground-water hydrology in 1828 and should not detract from his principal hydrologic contribution.

Discovery of the very clear priority of Du Commun over both Badon Ghyben and Herzberg adds one more problem in nomenclature. For example, a Lt. Colonel J. Drabbe was the senior author of Badon Ghyben's paper. It has been assumed that Drabbe did not participate in writing the paper, but became senior author by virtue of his military rank. For many years it was thought that Badon was the given name of Ghyben, so that only his last name was used in connection with the principle. Now it is known that Badon Ghyben is a compound surname and that this full name should be used, although habitual usage of only the last name has resulted in strong resistance to adding the name of Badon to Ghyben. Finally, it was thought for many years that Herzberg's first name was Baurat, whereas this was his title, translatable roughly as "State Architect".

RECENT ADVANCES

Since the time of Du Commun, Badon Ghyben, and Herzberg very considerable advances have been made in the formulation of a fresh-water-salt-water interface model in coastal aquifers. Hubbert (1940, p. 872) has stated that the fresh-water-salt-water equilibrium is not hydrostatic but is instead a dynamic equilibrium between flowing fresh water and static salt water. He pointed out that because the fresh-water-salt-water balance is hydrodynamic rather than hydrostatic the Badon Ghyben-Herzberg principle yields results that are more or less in error, depending on the potential gradient. Recently, solutions for the positions of the interface under selected boundary conditions and hydrodynamic balance have been derived by Glover (1959) and Henry (1959).

The rise and fall of the interface in response to tidal fluctuations and variations in recharge creates a zone of diffusion between the fresh water and salt water (Wentworth, 1948). Cooper (1959) has reasoned that, as a consequence of this zone of diffusion, sea water circulates from the floor of the sea to the zone of diffusion and back to the sea, and that this flow tends to decrease the distance from the shore line to the fresh-water-salt-water front. This circulation and the seaward displacement of the front predicted by Cooper have been confirmed by field observations in the Miami area (Kohout, 1960) and are in accord with analytical developments for selected boundary models of the problem (Henry, 1960).

Thus, the principal advances beyond Du Commun, Badon Ghyben, and Herzberg have been Hubbert's demonstration of a hydrodynamic balance between flowing fresh water and static salt water and Cooper's demonstration that the hydrodynamic balance is between flowing fresh water and flowing salt water.

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