Chapter 23

Isotopes

In the next two chapters (chapters 23 and 24), the use of isotopes to identify sources of water and for age-dating water will be discussed. The term “isotopes” sounds very technical, but the concepts are quite simple.

Everything in the world is made up of atoms. More than 100 different types of atoms occur naturally in the world. Each atom is made up of smaller components called protons, neutrons, and electrons. The combination of these smaller components is what makes atoms different.

For example, most people are aware that water is referred to as H_2O. This means that water is made up of two hydrogen atoms and one oxygen atom. Every atom has its own weight, as determined by the number of protons and neutrons (electrons really do not have much weight compared to the protons and neutrons). Hydrogen has one proton and one electron, so the weight is 1. Oxygen has 8 protons, 8 neutrons, and 8 electrons, so its weight is 16.

This relation of the number of protons and neutrons making up the atomic weight works for every atom and it is what makes each type of atom different from other atoms. For example, gold has 79 protons and 79 neutrons, aluminum has 13 protons and 13 neutrons, etc. Of course, the numbers of electrons are equal, but because these do not weigh much, they can be ignored in this discussion of atomic weight.

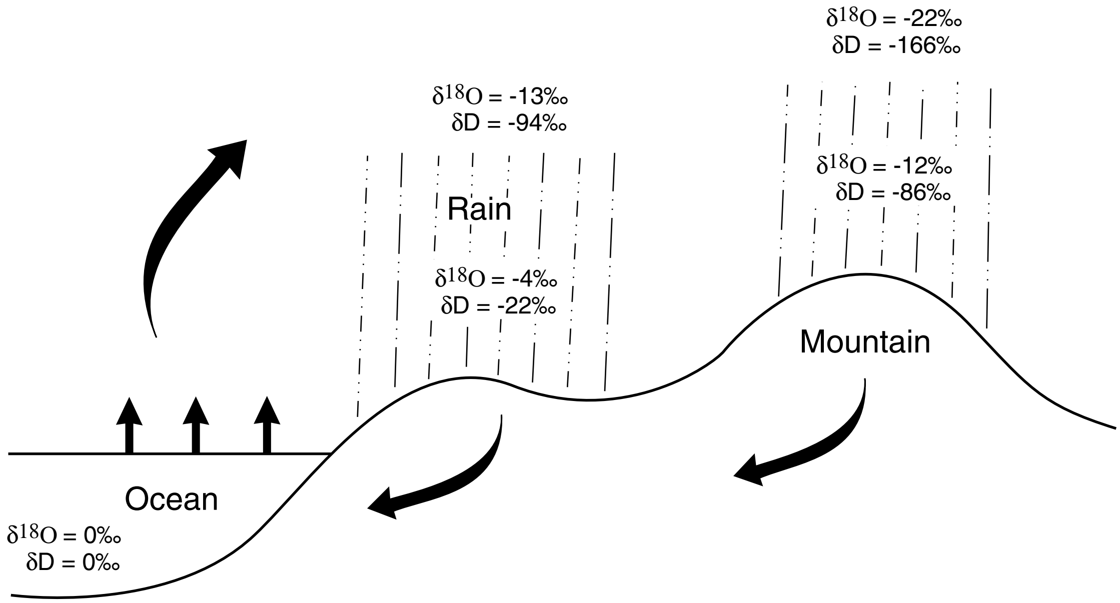
However, nature likes to throw curve balls. In many cases, atoms occur with additional neutrons. This makes these particular atoms heavier than those with equal numbers of protons and neutrons. Atoms with extra neutrons are called isotopes. In the case of hydrogen, there is an isotope with one proton and one neutron. This is called deuterium and it has a weight of 2. Oxygen has an isotope that has 8 protons and 10 neutrons, which has a weight of 18. This does not have a fancy name, rather it is referred to as oxygen-18. In nature, these isotopes of hydrogen and oxygen make up only a small fraction of all of the hydrogen and oxygen, but their occurrence is most important to scientists.

If all water in the hydrologic cycle contained hydrogen, deuterium, oxygen, and oxygen-18, including water held in clouds, the ocean, ground water, etc., then how these atoms get distributed becomes really important.

For example, clouds have water vapor made up of all four of these atoms. As clouds move inland from the oceans and get pushed up over mountain ranges, the clouds will begin to drop their moisture (which is why there is so much rain in Seattle, which is west of the Cascade Mountains, compared to dry Spokane , which is east of the mountains). It seems logical that the heavier atoms (deuterium and oxygen-18) would fall out first and the lighter atoms would hang in there longer.

This is exactly what happens. Heavy isotopes of water tend to drop as rain and snow at lower altitudes and the lighter atoms get deposited further up in the mountains. The same works for temperature. The warmer the temperatures, the heavier the atoms that the clouds can hold. If the atmosphere becomes cooled, the heavier atoms will fall out first. Not only do we see heavier atoms precipitated at lower elevations, but the same generally is true for lower latitudes (the precipitation has lighter isotopes with distance from the equator).

The way isotopes behave really is useful to hydrologists. The ratio of hydrogen to deuterium and the ratio of oxygen-16 to oxygen-18, can be used to help identify where the ground water was recharged.



Schematic showing fractionation of stable oxygen and hydrogen isotopes during rainout. Stable isotope values, which compare isotopic ratios relative to ocean water, are expressed in per mil (‰).

Source: Naus, C.A., Driscoll, D.G., and Carter, J.M., 2001, Geochemistry of the Madison and Minnelusa aquifers in the Black Hills area, South Dakota: U.S. Geological Water-Resources Investigations Report 01-4129, 118 p.

In the case of Nevada, if water collected from springs is compared to precipitation samples in the area, isotopes can be used to tell where the water generally recharged the ground water. For instance, if a spring has water with a hydrogen and oxygen ratio that was much lighter than the water collected from precipitation near the spring, it could be concluded that the water feeding the spring came from a higher elevation (higher in the mountains). Likewise, in a large aquifer system, if the water in a well or spring was much lighter than local precipitation, it can be concluded that the recharge is not from local precipitation.

In many ways, isotopes of hydrogen and oxygen provide a “signature” to the ground water. Well or spring water sampled from different sites but with similar ratios may be from the same recharge area. Isotopes alone can not definitely tell this, but in combination with other tools, such as geochemistry, models, etc., one can make some interpretations about where the water was recharged.

Isotopes of hydrogen and oxygen also can be used to look at interpreting climate during the time when recharge occurred. For example, in many deep ground-water basins in Nevada, the water is lighter than present recharge. One conclusion might be that the water flowed in from higher elevations or latitudes, but another conclusion could be that the water was recharged many thousands of years ago during the Pleistocene (last Ice Age) when many basins in Nevada were covered with lakes. This cooler, wetter period in Nevada history may be observable in the isotopes in the ground water.

The science is complex and one must consider many other things. For instance, isotopes in precipitation change with the seasons and winter snowfall typically is lighter than summer thunderstorms. However, this discussion gives a general idea of how the information can be used to understand ground-water flow.