Chemistry ROCKS

Redox chemistry as a geologic tool

Mary Sue Burns

Rocks may seem like strange adornments for a chemistry lab, but I conspicuously display a collection of sedimentary rocks across the front counter of my classroom. Students like to place the dark, solid-red sample of local sandstone beside the powdery yellow sample of limonite because they resemble our school colors of maroon and gold. One of my favorite rocks is a green and red layered one from the banded iron formations in Minnesota. Another favorite is a green rock with orange swirls that I found in a damp drainage ditch. Students can see additional rock samples of various colors in photographs I have displayed.

So, my students ask, what do all of these colored rocks have to do with chemistry class? I tell them that the influence of many elements and chemical processes can be seen in rock formations. For instance, iron compounds are a common component of many rocks. Iron oxides and iron carbonates can serve as the cement for sandstones, and many rocks contain iron or iron compounds that are oxidized by weathering. So, matching a rock's color to a form of iron allows us to hypothesize what environment was present when the rock was formed. This deductive process allows students to observe firsthand the abstract topics of transition metal chemistry, oxidation states, and oxidation–reduction reactions.

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Teachers can use students' interest in the colors in rocks as a starting point for a redox chemistry lesson.

Integrating Earth science and chemistry allows teachers to address several points of the *National Science Education Standards* for grades 9–12 (National Research Council, 1996). Specifically, I address the physical science content standards of structure and properties of matter and that of chemical reactions, as well as the Earth and space science content standards involving geochemical cycles and the evolution of the Earth system.

Applying chemistry to geology

When compounds of transition elements are present in rocks, particular colors indicate the availability of oxygen and the level of the water table at the time the rock formed. Due to its abundance and striking color variations, iron can be a good indicator of sedimentary environments. Iron-containing shale can be red or green. Iron-containing minerals that were deposited as tidal plain sediments exposed to the air would have quickly been oxidized to a red or rust color. Iron containing minerals that were not exposed to the air, such as deep water sediments or those trapped beneath decaying plant material in a swamp or marsh, like the coal swamps that covered West Virginia 300 million years ago, would have been in a reducing environment. Under these conditions, iron-containing material would appear black or dark green.

Near our school, we have some sedimentary rocks that are mottled or even striped with red and green. These markings can be interpreted as the result of alternating zones of oxidation and reduction produced by variations in groundwater penetration of the original sediment. Many rocks became red due to later oxidation from weathering and staining from iron leaching and oxidizing of nearby materials. The famous Red Wall limestone of the Grand Canyon is actually a gray rock that has been stained red by oxidized iron compounds from overlying rock layers. These facts form the perfect basis for the integration of historical geology and the chemistry of iron compounds. Through a series of short activities, students can explore the relationship between color and oxidation state for iron and then use rock color to describe possible ancient sedimentary environments.

Ironclad chemistry

Safety is an important factor in any chemistry activity. Students must wear full-wrap, splash-proof, safety goggles and aprons throughout these activities. Students should never handle chemicals directly, and caution should be emphasized in all steps.

In this activity, each group of students examines one or more of the rocks and describes the sedimentary environ-

Ubiquitous iron

Of all the elements, iron is arguably the most unique because young students can actually experiment with iron in a sequence of coordinated unit plans throughout their post-primary education. Iron and its many compounds thread not only through the fabric of human existence but also through geologic time, reflecting a myriad of environments of mineral and rock formation.

Geologists have much to contribute to the study of human technological advancement, which is often couched in terms of ages of stone, bronze, and iron. Similarly, for well over a century, the men and women who study the Earth have engaged in vigorous debate, in which iron is central, about the composition of the core of the Earth; the origin of such iron-rich deposits as the Precambrian banded iron formations (BIF); the origin of red beds; the origin of iron ore through igneous, metamorphic, or sedimentary processes; and the origin of color in soils and rocks in response to the redox potential of the environment and the presence or absence of organic matter.

Through activities, students find out that iron is everywhere on Earth—in meteorites, plants, ourselves, and the water we drink. Igneous, sedimentary, and metamorphic rocks and the minerals that form them are studied through an examination of the following:

- Banded iron formation from the Mesabi Range, Minnesota;
- Bog iron ore from the Carboniferous rocks in Appalachia;
- Magnetite from Cornwall, Pennsylvania;
- Red beds of the Ordovician, Devonian, Mississippian, Pennsylvanian, Permian, and Triassic ages;
- Oolitic iron ore of the Silurian age;
- Taconite pellets;
- B-horizon materials from selected soils; and
- Basalt.

Unit plans enhance the ability to compare and contrast goethite, hematite, and magnetite. Additionally, students experience the problems associated with:

- The rusting of metals;
- Acid mine drainage (AMD);
- The staining of items in streams and lakes containing AMD; and
- The amelioration of AMD by chemical treatment and/or wetlands.

Chemical treatments, when handled with appropriate safety precautions, will lead students to discover the nature of Fe(II) and Fe(III) and what lies beneath the coat of iron minerals. Activities could include the use of 3 percent hydrogen peroxide, iron reagent powder pillows packaged with a commercial iron test kit, a dithionite-citrate system buffered with sodium bicarbonate (D-C-B), or Tamm's oxalate solution. A simple color disc method of determining iron concentrations will suffice in these experiments.

The holistic study of iron can expose students to geology, chemistry, physics, and biology, as well as history, geography, social studies, and English. Students can read and write about iron. They can examine various forms of iron and perform laboratory tests to explore the properties of iron and its many, many compounds. Iron exists in and around us every day. It could be said iron has a "magnetic" personality of its own.

—Courtesy of Robert E. Behling, geology professor, West Virginia University

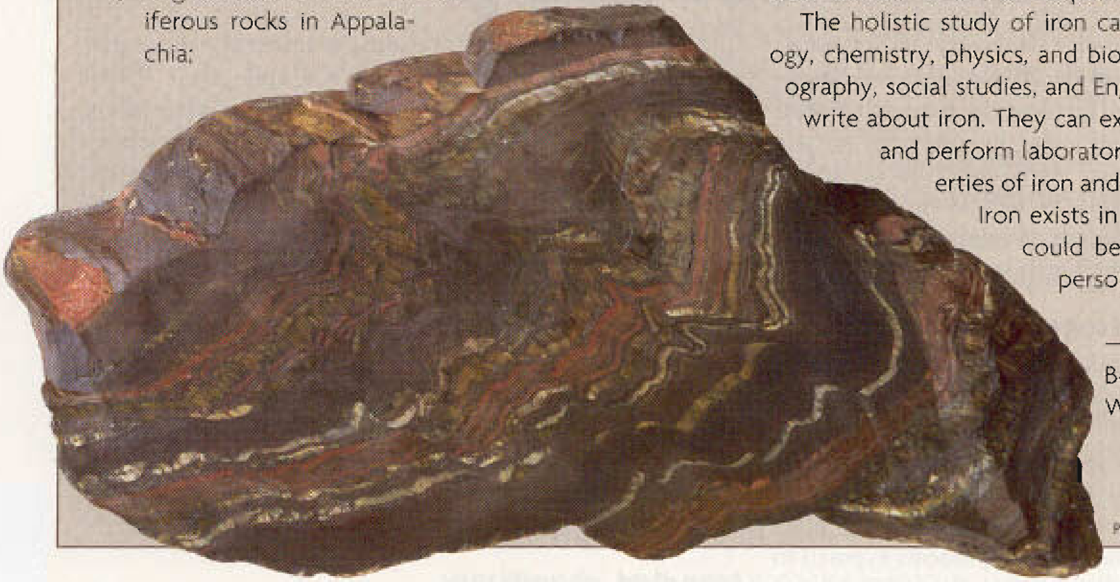

PHOTO BY MICHAEL OLLIVER

ment in which each rock formed. I also ask them to assess the oxygen availability and water table level at the time the rock was being formed. But first, they have detective work to do.

Students begin by exploring samples of various iron compounds. The samples are sealed in transparent vials and labeled with the chemical name of the compound. I include several samples that contain iron(II), such as iron(II) chloride and iron(II) oxide, and several that contain iron(III), such as iron(III) chloride and iron(III) oxide.

We discuss the similarities and differences among the compounds. Students may notice that all are crystalline solids, but the grain size may vary. However, the main focus of this activity is color. Many students will notice a

FIGURE 1

Data table of iron oxides and chlorides. (Other iron compounds may be used.)

Compound	Formula	Oxidation state of iron	Color
Iron(II) oxide	FeO	+2	Green
Iron(III) oxide	Fe_2O_3	+3	Orange
Iron(II) chloride	$FeCl_2$	+2	Green
Iron(III) chloride	$FeCl_3$	+3	Orange

pattern; all of the iron(III) compounds are orange, while the iron(II) compounds are not. Most of the iron(II) compounds will be green, but iron(II) sulfide is black. Compounds containing complex ions exhibit an even greater variety of colors.

This is a good time for students to further develop their skills in formula writing and identification of oxidation states. I usually provide chemical formulas for the compounds used in the exploration and assist students in determining the oxidation state of the iron in each. A table of common oxidation states or a periodic table is useful at this point, and teachers may need to point out that transition metals, like iron, can commonly have more than one charge, or oxidation state, in compounds. Other elements, like oxygen and chlorine, are more predictable, and their charges can be determined using a periodic table. The sum of the charges within a compound's formula is always zero. If students construct a table showing both their observations of color and the oxidation states of iron for each compound, the pattern of orange for iron(III) and green for iron(II) should be clear to all (Figure 1).

In further discussion, I point out that FeO and Fe_2O_3 are both common oxides of iron. I ask students to determine which one has the higher ratio of oxygen atoms to iron atoms (Fe_2O_3). Students can identify that this compound contains Fe^{+3}, which is the source of the orange color. We discuss which of these compounds would be more likely to form under a limited oxygen supply or an abundant oxygen supply.

Application activities

Once students have some experience relating oxidation state to iron compound color, they can apply their knowledge. We do this with two simple activities. The first activity shows the role of water in iron oxidation. I sprinkle iron filings in the bottom of two cups and add a little water to one. After sitting open in the air for at least a day, the wet filings become very rusted while the dry filings appear unchanged. From their previous work, students can now identify the familiar orange-red color as the result of oxidation to iron(III). Therefore, they realize that "rusting," as they normally use the term, is an oxidation process of iron. Although the reaction they observe is readily anticipated, it brings the complex concept of oxidation into a meaningful context for them.

In the second activity, students observe a change from iron(II) to iron(III). This change is brought about by adding a small amount of 3 percent hydrogen peroxide to a small amount of a green iron(II) compound such as iron(II) sulfate. The familiar orange color appears immediately, and the material also "fizzes." This is an important visual clue, which students must try to explain. (It is a release of oxygen gas.)

At this point, students are ready to return to the original challenge of speculating on the presence of oxygen and water in the ancient geologic environments just by looking at a rock specimen. I direct their attention back to the iron-containing rocks on the front desk. Working in small cooperative groups they brainstorm possible scenarios, which they then present to the entire class. The very nature of the investigation means that any plausible explanations for the colors of the rocks are potentially acceptable.

I assess students' understanding of these concepts in the field. Near our school we have a large outcrop of red sandstone, and during a visit and discussion there, the various ideas mentioned in class resurface. Usually one or two prevail as the most popular. At the end of the field trip, I review students' field notes. Their notes, observations, and conclusions provide me with a quick way to assess each student's application and depth of understanding of the connection between geology and chemistry. After this lesson and activities, students can appreciate why rocks are an attractive and relevant adornment for a chemistry lab.

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