Mineral Resources Program

Pyrrhotite Distribution in the Conterminous United States, 2020

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Introduction

In parts of Connecticut and Massachusetts, foundations of some homes are cracking and crumbling. Failing foundations can reduce the market value of a home and lifting a house to replace and repour a foundation is an expensive undertaking. In response, some homeowners are defaulting on their mortgages and abandoning their homes (New York Times, 2016). The culprit is pyrrhotite (fig. 1), which occurs in construction aggregate (crushed stone) that was used as a filler in concrete (Connecticut State Department of Housing, 2020). When pyrrhotite is naturally exposed to water and oxygen, it breaks down to produce sulfuric acid and secondary minerals, including gypsum, which have larger volumes than the pyrrhotite they replace. The expanded volume of the secondary minerals cracks and degrades concrete.

Pyrrhotite occurs in rocks in many areas of the United States. To help assess the national risk of pyrrhotite in aggregate, the fiscal year 2019 appropriations bill for the U.S. Geological Survey's (USGS) Mineral Resources Program allocated funds to develop a map showing the distribution of pyrrhotite across the United States. The purpose of this fact sheet is to (1) present a nationwide map that shows where pyrrhotite may occur in rocks in the United States (fig. 2; Mauk and Horton, 2020), (2) describe and discuss the factors that control the presence and abundance of pyrrhotite in rocks, (3) provide information on geographic information system datasets that deliver more detailed information on these distributions, and (4) describe U.S. and international standards on aggregate that are designed to prevent failing concrete.

While this map and fact sheet provide general information about the possible distribution of pyrrhotite in the United States, they are no substitute for site-specific characterization and quality control programs designed to ensure that aggregate used in concrete is of appropriate quality for its intended purpose.

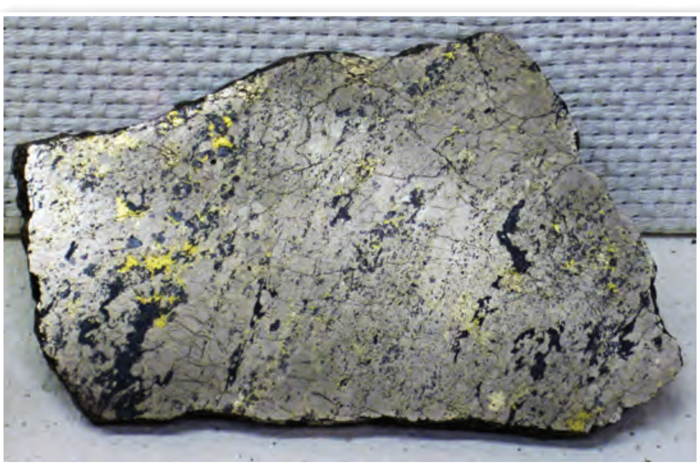

Figure 1. Slab of an ore sample from Canada containing pyrrhotite (cream mineral), and chalcopyrite (yellow mineral). This rock is mined to produce copper and nickel and would not be used for aggregate. Photograph by James St. John.

Pyrrhotite Formation in Rocks

Pyrrhotite and pyrite are both sulfide minerals (a group of minerals that contain sulfur) that require iron and sulfur to form. Both pyrrhotite and pyrite are reactive in concrete, but pyrrhotite is far more reactive, which is why the fiscal year 2019 appropriations bill for the USGS allocated funds to develop a map showing the distribution of pyrrhotite across the United States (Mauk and Horton, 2020). Because iron is the fourth most abundant element in Earth's crust, with an average crustal abundance of 5.6 percent, most rocks have enough iron to form pyrrhotite. However, sulfur is far less abundant, with an average crustal abundance of 0.025 to 0.050 percent (CRC Handbook of Chemistry and Physics, 2017). Therefore, the abundance of iron- and sulfur-bearing minerals is normally controlled by the abundance of sulfur in the rock.

Pyrite is the most common and abundant sulfide mineral in Earth's crust (Ramdohr, 1969). Most pyrite forms either when sulfur is added to rocks by natural processes or when ore deposits form. Pyrite also forms when sulfur is added to sediments by bacterial action in environments with no oxygen, such as black mud in a swamp. The sulfur then combines with iron to produce minerals that evolve over time to become pyrite. How much pyrite forms is mostly limited by the amount of sulfur in the water that is in the mud. Freshwater does not contain as much sulfur as seawater, so pyrite is typically more abundant in sediments in marine environments and estuaries.

Over time, sedimentary rocks can become buried under younger sediments and, if buried deeply enough, can be transformed by heat and pressure into metamorphic rocks. The transformation, or recrystallization, of sedimentary rocks into metamorphic rocks is marked by changes in mineralogy that are due, in part, to the progressive expulsion of volatile components like water and sulfur as metamorphism progresses. Because pyrrhotite has less sulfur than pyrite, the loss of sulfur drives the recrystallization of pyrite into pyrrhotite, which is common in metamorphic rocks that formed from marine sedimentary rocks. Black smoker vents that form with volcanic rocks on the sea floor also contain abundant sulfide minerals, and when these vents and volcanic rocks are later metamorphosed, abundant pyrrhotite can form. Tectonic processes can bring these metamorphic rocks to the surface, exposing rocks that contain pyrrhotite.

Mapping the Possible Distribution of Pyrrhotite in the Conterminous United States

No maps show the distribution of pyrrhotite in the conterminous United States. However, a good approximation can be gained by careful combination of information from three main sources: (1) the State Geologic Map Compilation geodatabase of the conterminous United States (Horton and others, 2017), (2) the USGS Mineral Resources Data System database (U.S. Geological Survey, 2019), and (3) the Mindat.org database (Mindat.org, 2019).

From the State Geologic Map Compilation geodatabase of the conterminous United States, we selected rock units in which pyrrhotite has been reported in other studies, such as the Brimfield Schist in Connecticut, and we also selected rock units that are listed as sulfidic (containing sulfide minerals). Because pyrrhotite forms from the heat and pressure that form metamorphic rocks, we also selected moderately

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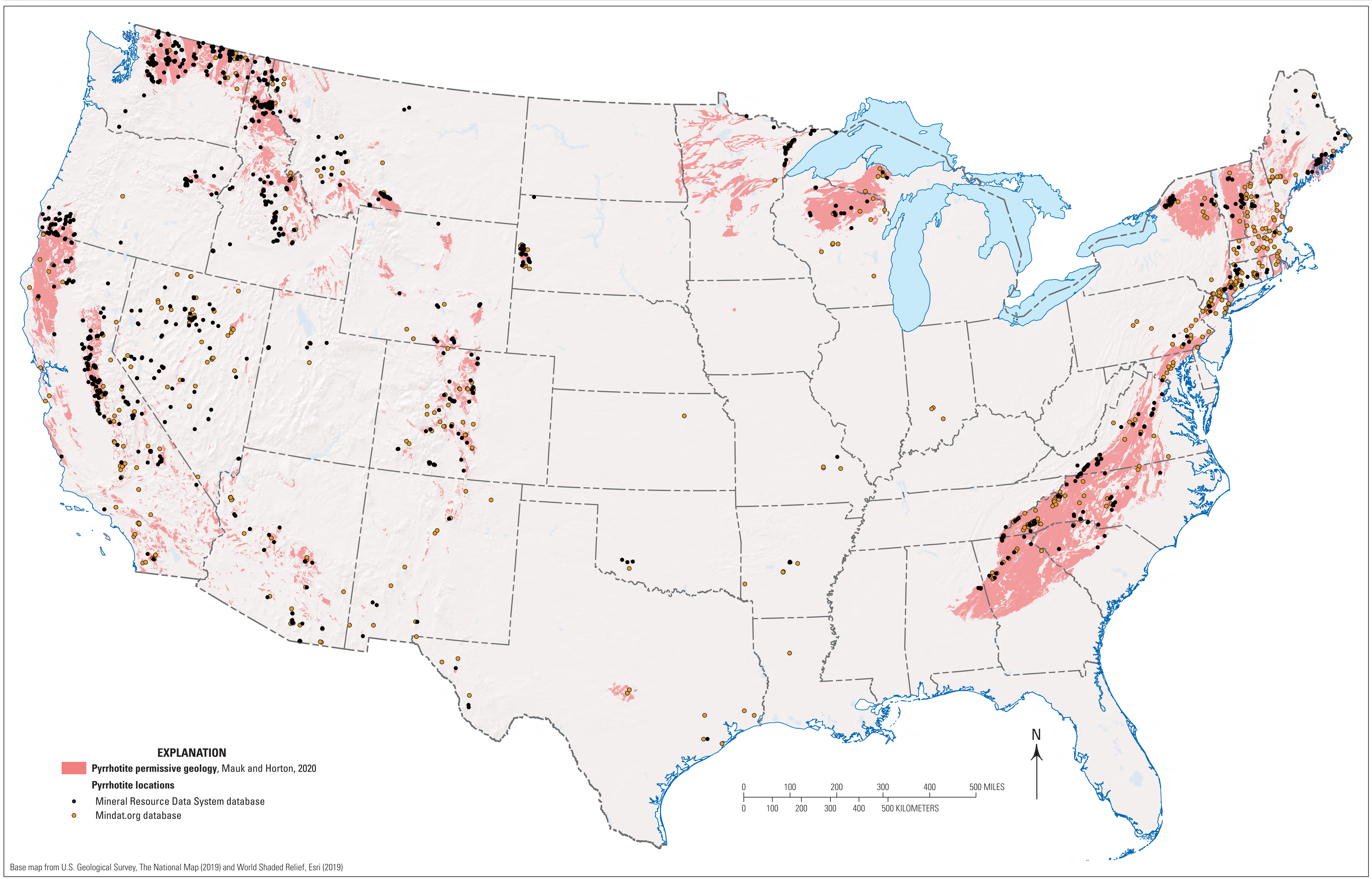

Figure 2. Conterminous United States showing the location of rock units that may contain pyrrhotite (Mauk and Horton, 2020); locations of pyrrhotite from the USGS Mineral Resources Data System database (U.S. Geological Survey, 2019); and locations of pyrrhotite from the Mindat.org database (Mindat.org, 2019).

to highly metamorphosed rocks (Mauk and Horton, 2020). In the eastern United States, these rocks form a belt that lies along the core of the Appalachian Mountains. Most areas of the central United States do not contain rock units that are likely to contain pyrrhotite because that area is generally underlain by sedimentary rocks that have not been metamorphosed. In the western United States, belts of rocks that may contain pyrrhotite are present, but they do not form continuous belts because of the greater complexity of the geology in the western United States.

The USGS Mineral Resources Data System database is a collection of records describing metallic and nonmetallic mineral resources throughout the world (U.S. Geological Survey, 2019). We searched this database for occurrences of pyrrhotite in the conterminous United States, and included all those occurrences on our map (fig. 2).

We also included all occurrences of pyrrhotite in the conterminous United States from the Mindat.org database, except for those from meteorites (Mindat.org, 2019). Many, but not all, of these pyrrhotite occurrences replicate entries in the USGS Mineral Resources Data System database.

Taken together, data from these three databases provide a reasonable landscape-scale indication of where pyrrhotite may occur in the conterminous United States. In general, locations of pyrrhotite from the USGS Mineral Resources Data System database and from the Mindat.org database overlap rock units that may host pyrrhotite from the State Geologic Map Compilation geodatabase of the conterminous United States, but the former databases also show more isolated occurrences of pyrrhotite in mineral deposits and in other localities.

Limitations of the Geologic Map Databases

Selection of geologic units from the State Geologic Map Compilation geodatabase of the conterminous United States to construct our map has several limitations that should be understood by those who intend to use it for informational purposes. (1) Geologic map databases focus on the key characteristics of rock units, such as their most abundant rock types and minerals. Because pyrrhotite is an uncommon mineral, it is rarely reported in these map databases. In our geologic map database, (not including the Mineral Resources Data System database and Mindat.org database records) pyrrhotite is named only 13 times, and sulfide and sulfidic only 106 times in more than 2,000 records (Mauk and Horton, 2020). The remaining records are moderately to highly metamorphosed rock units, so the rock units shown on our map are where pyrrhotite *may* occur, rather than where pyrrhotite *does* occur. The point locations where pyrrhotite does occur in the Mineral Resources Data System database and Mindat.org database records mostly follow the metamorphic rock units that we selected, suggesting that our selection criteria are broadly relevant. (2) The database is based on observed and recorded data. Pyrrhotite may occur where data are incomplete or not available due to a lack of detailed geologic mapping or a lack of detailed descriptions of mapped rock units. (3) The database does not reflect the abundance of pyrrhotite but rather its possible presence. Therefore, the abundance of pyrrhotite in rock units may vary substantially and some rock units in the database may only contain trace quantities of pyrrhotite that would not impair concrete quality. (4) The geologic units were selected to show where pyrrhotite may occur, but other iron sulfide minerals such as pyrite and marcasite, depending on their abundances, can also cause concrete deterioration (Lee and others, 2005). However, pyrite is so common that a nationwide map showing rock units that may contain pyrite would be of little value, and pyrite is less reactive than pyrrhotite.

Standards for Construction Aggregate

For the United States, ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. The ASTM International standards note that the sulfides of iron, pyrite, marcasite, and pyrrhotite are commonly found in natural construction aggregate, and these minerals can react to form a brown stain and volume increase (ASTM International, 2019). The standards note that marcasite is more reactive than pyrite or pyrrhotite, but that marcasite is much less common and is found mainly in sedimentary rocks.

The ASTM International standards acknowledge that the degradation of iron sulfide minerals can cause volume increase, which negatively affects concrete stability. Nonetheless, there are no ASTM International standards for allowable sulfur content or sulfide mineral content for aggregate used in concrete in the United States.

In contrast, European standard EN 12620:2008 specifies that if pyrrhotite occurs in an aggregate, the total sulfur content of that aggregate must be less than 0.1 weight percent (%) sulfur, if the aggregate is to be used in concrete. For aggregate containing other iron sulfide minerals, such as pyrite, the sulfur content must be less than 1 weight %, and this order of magnitude difference underscores the recognition of the greater reactivity of pyrrhotite (Canadian Standards Association, 2019).

The 2019 Canadian standards for concrete provides a detailed three-step performance evaluation protocol for testing natural aggregate that may contain sulfide minerals where that aggregate is intended for use in concrete (Canadian Standards Association, 2019). The first step uses laboratory analyses of total sulfur and rejects all samples that contain more than 1 weight % sulfur. Aggregate with less than 0.15 weight % sulfur may be used without further investigation. Aggregate with 1 to 0.15 weight % sulfur requires further testing that includes additional geochemical data, microscopic investigation to determine mineralogy, and laboratory testing to further evaluate the stability of the aggregate (Canadian Standards Association, 2019).

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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