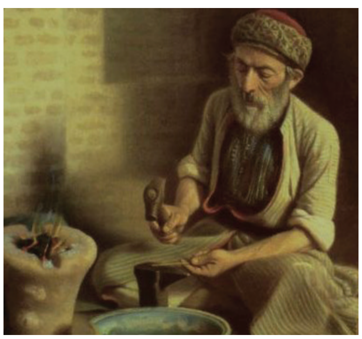
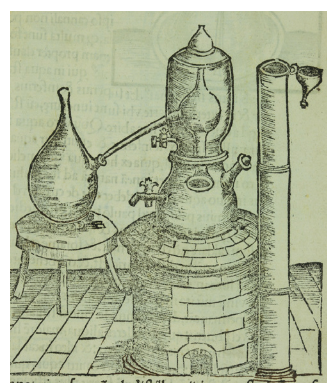
CHAPTER 1: ELEMENTS

People have always been curious about what things are made of. It's obvious that plants are different from animals, and that rocks are nothing like water. Light and air seem to be made of nothing at all. Until just a few hundred years ago, people did not have scientific equipment advanced enough to be able to study the nature of ***matter***. ("Matter" is the scientific name for "stuff." Anything and everything in the universe that is made of atoms and occupies space is matter.) Ancient people were as smart as we are today, but they had no computers, no microscopes, no spectrometers, no thermometers, no telescopes, and often not even any books. The only tools they had were their five senses. They had to come up with theories about how things worked based only on what they saw, heard, smelled, tasted, and felt, combined with some common sense and some religious and cultural beliefs.

The ancients were very clever. They had a good "hands-on" knowledge of the world and discovered and invented a lot of things. They domesticated animals, began farming, and invented ways to make houses out of whatever materials were around them. They wrote stories, poems and songs, made fabrics, pottery and jewelry, studied the stars, made calendars, and kept track of eclipses and comets. Some of these ancient peoples discovered that when you heated certain rocks to a very high temperature, liquid stuff came out that turned into a hard metal when it cooled. The metal could then be shaped into knives, tools, or jewelry. The metals seemed to have been hiding in the rocks until the heat drove them out. Rocks that contained metals were called ***ores*** and became very valuable. Observing the changes that took place when you heated and melted things led people to start wondering what rocks were made of. Why did certain metals always come out of certain rocks and never out of other kinds of rocks? What made some rocks heavier than others? Why did some rocks burn like wood? Why did some rocks smell bad?



About 2,000 years ago, in the city of Alexandria, Egypt, a small group of very curious people started doing what we would call chemistry experiments. One of these curious people was a woman named Mary (or Miriam). Mary was an expert at making a certain purple dye for coloring cloth, and she invented a chemical apparatus for boiling liquids. This apparatus was upgraded and improved over the centuries, but it still bears her name, being called the "bain-marie," which is French for "Mary's Bath." Mary also wrote down some chemical recipes, including one for making gold from certain plants. Gold from plants?! This fired the imaginations of these curious people, and a whole new field of study began. This type of study would eventually be called **alchemy**.



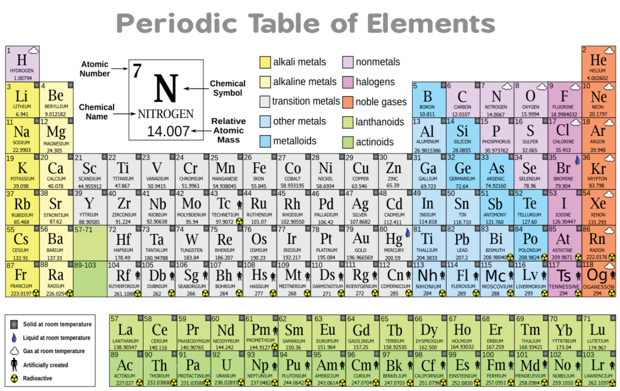
a "bain-marie"

The word "alchemy" came into English from French, which borrowed it from Latin, which borrowed it from Arabic, which seems to have borrowed it from Greek. In Arabic, "al" means "the," and "kimiya" (from Greek "khemia") is such an old word that we don't know for sure what it meant originally. It could be related to the Greek word for Egypt, "keme," or the Greek word for mixture, "chymeia."   Whatever its origins, the word "alchemy" was used right up until the early 1700s.

Jabir ibn Hayyan

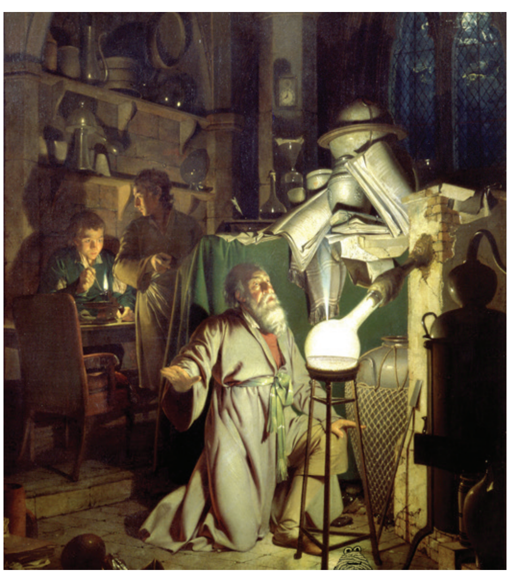
One of the next great alchemists was **Jabir ibn Hayyan**, who lived in Persia (now Iran) in the 700s. Jabir, or "Geber," as the Greeks called him, was an amazing person. He studied mathematics, astronomy, geography, medicine, philosophy, physics and chemistry. As far as we know, he was the first person in history to begin doing scientific experiments. He designed pieces of equipment that could boil and separate mixtures, catch steam, and collect particles. (Oddly enough, one of the main goals of his experimenting was to find out how to create life. He wrote down recipes that he believed would make snakes and scorpions!) He began working with substances that we now call “acids,” and found one that seemed to be able to dissolve gold. He was also the first person to begin to classify rocks and minerals according to their chemistry. He discovered that some substances would turn to steam when they were heated, such as mercury and sulfur. Other substances would melt into a liquid, such as gold, silver and copper. There were also substances, such as ordinary stones, that would neither melt nor turn to steam, and could only be crushed into a powder. Jabir was more interested in the chemical properties of substances, particularly what they did when they were heated, than he was with their color or texture or weight. He had discovered a key to figuring out what matter was made of.

Jabir also studied the writings of the Greeks, and from them he accepted the idea that water, fire, air and earth were essential elements, the “stuff” from which other stuff is made. It might seem silly to think that a tree could be made of a combination of water, air and earth, but that’s what they believed. (However, we need to bear in mind that sometimes true chemistry is odd, too. Doesn’t it sound equally strange to say that water, a liquid, is made of two gases, hydrogen and oxygen?) Jabir’s experiments led him to believe that there were more than four elements. He believed that mercury and sulfur were also elements. No matter what you did to these substances, they always remained the same. They could be combined with other things, but they could not be broken apart. Jabir had made an incredibly important discovery. He had correctly identified two of the basic chemical elements. All of the chemical elements have now been discovered, and the complete list is a chart called the Periodic Table.



Can you find mercury (Hg) and sulfur (S)? Use the large version on page 141.

People had been using copper, iron, silver, gold, lead, mercury and sulfur for a long time. Coppersmiths probably had not given much thought to what their copper was made of. They knew which ore rocks contained copper, they knew how to heat the ore to get the copper out, and they knew how to fashion the copper into useful things. The alchemists were the first to ask the question: “What is copper?”



“The Philosopher’s Stone” by Joseph Wright, 1771

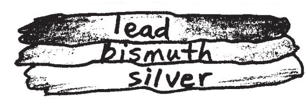
The Arabic alchemists that came after Jabir added “salt” to their list of elements. This was a step backward, but they had no way of knowing this. Salt was not an element, but it would not be separated into its elements, sodium and chlorine, until the 1800s. The early Arabic alchemists made another mistake—they thought that it might be possible to turn one element into another. They still recognized that some substances were basic elements, but thought that perhaps this did not rule out turning one element into another.

In the early days of the Renaissance in Europe (the 1200s), Europeans began reading all these ancient Arabic alchemy texts. They were especially fascinated by the idea that one metal might be turned into another. Perhaps there was a way to turn copper or lead into gold! They began fashioning their own chemistry equipment and thus began the type of alchemy see in paintings: old men surrounded by pots full of strange brews. European alchemists were interested in chemistry, in general, but they were particularly intent upon discovering something they called the “philosopher’s stone.”

To them, a philosopher was exactly what the Greek word meant—someone who loved knowledge. Philosophy to them had nothing to do with morals or ethics; it was simply the pursuit of knowledge of any kind. The stone didn't have to be a literal stone, but any substance that would change one metal into another, and specifically a "base" (not valuable) metal into gold. The reputation of this mythical stone grew over time and it was eventually believed that not only could it change metals into gold, but it could also cure all diseases. In an age without modern medicine, it was no wonder that everyone was so desperate to find this miraculous stone!

While European alchemists were hard at work trying to turn things into gold, they made some interesting discoveries. Like Jabir, they began noticing that some substances seemed very resistant to change, as if they <u>couldn't</u> be changed. The list of basic elements began to grow. The list included the substances that the ancients had already discovered—gold, silver, copper, mercury, lead, sulfur, iron, and tin—plus some new ones that you might not be familiar with: antimony, arsenic and bismuth. Bismuth was usually discovered by miners who were looking for lead or silver. Bismuth would be found sandwiched between lead, on top, and silver, below. Since bismuth was more shiny than lead, but not as shiny as silver, this led the miners to believe that lead would eventually become silver, and bismuth was an intermediate stage, halfway between lead and silver. When the miners found a layer of bismuth they would say, "Oh no, we came too soon!"

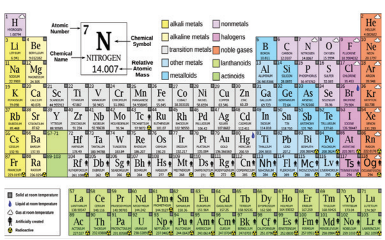
Bismuth sandwich:



The elemental nature of bismuth was first noticed by a German scientist, **Georgius Agricola**, in the early 1500s. Agricola spent a large part of his adult life studying mines and the stuff that came out of them. He wrote one of the first books on mining techniques. Agricola believed that bismuth was a completely different substance from either lead or silver. It was, and always would remain, bismuth.

It was Agricola, and scientists immediately after him, who began to realize that there were actually three levels of classification needed. First was ***rocks***, the most obvious category because everyone could seem them lying on the ground or being carried out of mines. The second was **elements**—the substances that could not be broken down into anything else. But there was also a third category: **minerals**. <u>Mine</u>rals (the stuff that comes out of <u>mine</u>s) were a combination of two or more elements. Sometimes minerals appeared in their pure form, but other times they were hidden in ore rocks, and had to be melted out. A rock might contain several minerals. This concept would become one of the established facts about rocks and minerals: **Elements make minerals, and minerals make rocks.**

ELEMENTS



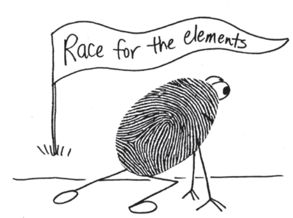
MINERALS

ROCKS

The next great leap in understanding the elements came in Germany in 1669. An alchemist by the name of Hennig Brandt was trying to make gold. Yes, after all those centuries of failure, alchemists were still hoping to change one element into another. By this time, alchemists had tried just about every rock and mineral on the planet. So Hennig decided to boil something that was yellowish-gold but wasn't a mineral. He collected hundreds of gallons of urine and boiled it down until it became a thick paste. (Yes, it smelled really bad.) When he began heating this paste as hot as he could get it, something amazing happened—it began to glow! It glowed with a bright, white light. Hennig had discovered a new element, the element we call **phosphorus**.

This caused a major shift in the thinking of scientists all over the world. Organic things were made of elements, too, not just rocks and minerals. Phosphorus would be found in both living and non-living things. How many other elements were there? The race to discover new elements was on!

In the early 1700s, the word "alchemy" was replaced by the word "chemistry." The new "modern" scientist of the 1700s was no longer interested in trying to turn things into gold. Discovering new elements or inventing a new process for manufacturing chemical products had replaced the search for the philosopher's stone.

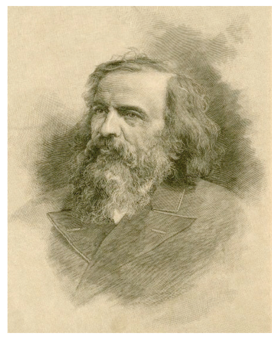


The science of **mineralogy** was born in the 1700s, as there were more men like Agricola who devoted their careers to studying minerals and the elements they were made of. Mineralogists of the 1700s determined that zinc, cobalt and nickel were also elements.

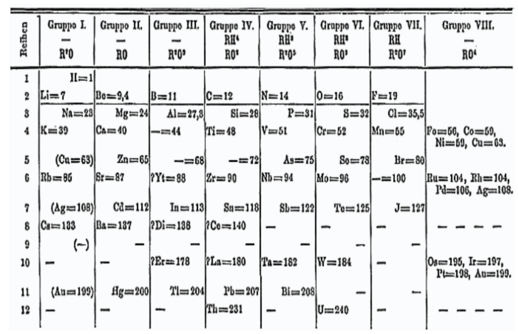
Miners named several elements. "Nickel" means "demon" in German. Ore that contained nickel seemed to be cursed because it would not produce the copper that the miners wanted. "Cobalt" is German for "goblin." The presence of cobalt in silver ore made it harder to extract the silver. The names "copper" and "zinc" came from ancient miners so long ago that no one knows their original meaning.

During the 1800s, chemists tested every mineral sample they could get. They now understood that minerals were made of elements and were eager to discover unknown elements. They improved their equipment and invented new tools and techniques. One of the most important new technologies of the 1800s was electricity. Electricity is the only way that some compounds can be separated into their elements, so these elements could not possibly have been discovered until the age of electricity. The list of elements grew rapidly during this century. By the late 1800s, there were 63 known elements.

In the late 1800s, chemists were starting to make charts of the chemical elements. These elements were the basic building blocks of every type of matter in the universe, so they needed to be printed into a chart for students to study. Several men began working on ways to classify the elements, but only one is well remembered today: Russian chemist **Dmitri Mendeleev**. *(men-dell-LAY-ev)* Mendeleev's stroke of genius was to realize that there were quite a few elements that had not yet been discovered. He made a rectangular chart and left blank spaces in places where he believed there was an element missing. He turned out to be absolutely right in every case. Soon, those missing elements were discovered just as Mendeleev predicted. Today we call this chart the Periodic Table of the Elements, and we've already seen it on pages 2 and 3. There are many more elements today than in Mendeleev's day, but the basic structure of the table has remained the same.



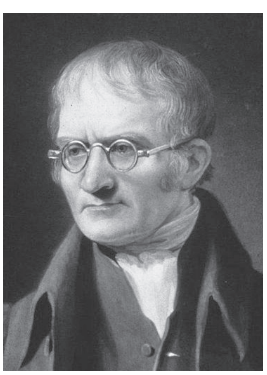
Dmitri Mendeleev



Reihen	Gruppo I. — R^2O	Gruppo II. — RO	Gruppo III. — R^2O^3	Gruppo IV. RH^4 RO^2	Gruppo V. RH^3 R^2O^5	Gruppo VI. RH^2 RO^3	Gruppo VII. RH R^2O^7	Gruppo VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Mendeleev's table of elements

After most of the elements had been discovered, a new question arose: **"What are elements made of?"** This question could not be answered by regular chemists. No amount of boiling or evaporating could tell you what an element was actually made of. The basic building blocks of elements are particles too small to see. This question had to be answered by a new type of scientist—someone who could combine experiments with logic and math. Our knowledge about atoms comes as much from logical reasoning as it does from experiments.

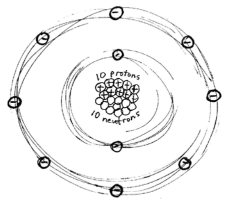


John Dalton

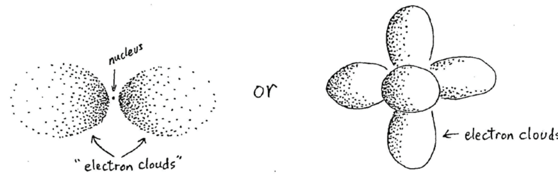
The first scientist to officially propose a theory about elements was **John Dalton**. In 1803, Dalton wrote that be believed that elements were made of individual particles called **atoms**. Every atom of an element was identical. An atom was the smallest piece of an element that could not be divided. In other words, if you start with a lump of gold the size of a marble, you can easily cut it in half. You could easily cut those halves in half again. By this time you might have lumps the size of peas, but you could cut those in half again. If you kept cutting those pieces in half, you would eventually get pieces so small you'd need a magnifier to see them. Let's say you do have a magnifier and can go on cutting them in half. The pieces will keep getting smaller and smaller and smaller. How small can they get? Eventually you will get down to an individual piece of gold that can't be divided any further. That's what Dalton called an atom. Dalton did not have an idea how small an atom might be, but he was right in thinking that you'd reach a point where if you divided it gain, you'd no longer have gold. Dalton didn't have any ideas about what particles might make up an atom, but he was right about the existence of atoms.

Around the turn of the 20th century (early 1900s), the work of three scientists came together to give the world the first theory about what an atom is made of. **Ernest Rutherford***,* **J. J. Thomson** and **Neils Bohr** are all considered to be physicists, not chemists. They each made a different contribution to figuring out the mystery of the atom. If you want to know the particulars, you can easily find more information on the Internet. The end result of their research was a proposal that atoms consisted of a central nucleus made of positively charge **protons** and neutral **neutrons**, surrounded by negatively charged **electrons**. Bohr was the one who came up with a model called the solar system model because it resembled the planets orbiting the sun.

Since then, it has been discovered that electrons don't exactly orbit the nucleus. They move so fast that they occupy a cloud-like area. However, the solar system model continues to be used because it is very helpful in explaining how atoms stick together.

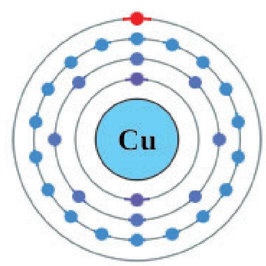


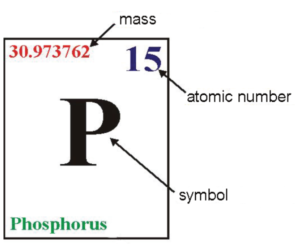
the "solar system" model



electron cloud models

Electrons are arranged in shells around the nucleus. The electrons in the outermost shell are the ones that can interact with the environment, so they are the ones that give the atom most of its chemical properties. In this copper (Cu) atom, the electron highlighted in red is the one that will interact with other atoms.

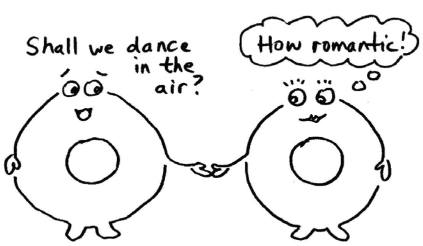




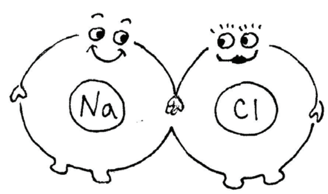
Each atom has a unique number of protons, neutrons and elecrons. It is the number of protons that determines which element it is. If an atom has one proton, it is hydrogen. If it has two protons, it's helium. If it has three, it's lithium, and so on down the Periodic Table. The number of protons is called the **atomic number**. It is the most important number in those squares on the Periodic Table. You will also see a number called the **atomic mass**. This is a lot like weight. Each element also has a unique letter abbreviation called its **symbol**.

Elements in their pure form have the same number of electrons as protons. This is to balance out the positive and negative charges. However, the arrangement of the electrons in those rings is critically important, and some arrangements are better than others. For example, having just one lonely electron in the outer ring is really awful. Even two in the outer ring is less than ideal, and atoms like these will do just about anything to fix their electron problems. The best case scenario is when an unhappy atom finds another atom that is also unhappy, and their problems are exactly opposite. When one atom wants to get rid of an electron and another wants to get one, this works out perfectly and the two atoms stick together and become the solution to each other's problems. A good example of this is table salt, NaCl, where sodium (Na) gives an electron to chlorine (Cl). Sometimes three or more atoms will join together to solve each other's electron problems. We call these clumps of atoms **molecules**.

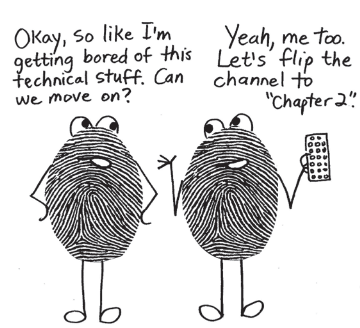
Sometimes atoms of the same element will join together to make a molecule. In the air around us we have two great examples: N_2, a pair of nitrogen atoms, and O_2, a pair of oxygen atoms. When atoms of different elements join to form a molecule, we call this a **compound**. Compounds are always made of at least two different types of elements. NaCl, salt, is a compound. We'll meet lots of compounds in the next chapter.



O_2 is a molecule.



NaCl is both a molecule and a compound.



Activity 1.1 Comprehension self-check

Can you remember the answers to these questions? If not, go back to the text and see if you can find the answers. When you are done, you can check your answers using the answer key at the back of the book.

1) True or false? People started doing chemistry experiments for the very first time during the 1500s. ______

2) If Jabir Ibn Hayyan had found a rock to study, what would he have been most interested in?

a) the color of the rock b) the temperature at which the rock melted c) the location of the rock

3) What four things did ancient peoples consider as elements? ____

4) Is salt an element (listed on the Periodic Table)? _______

5) What two amazing things did people believe the philosopher's stone would do? ___________________________

____

6) What element is often found sandwiched between lead and silver? b______________

7) Georgius Agricola was the first scientist to realize that there are three levels of classification:

_______________ make _______________, and ______________ make _____________.

8) What element did Henning Brandt discover in urine? ______________

9) Nickel is German for _________. Why? ____

10) What did Dmitri Mendeleev invent? ______________________________

11) Who was the first person to use the word "atom"? ______________________

12) What is an atom's atomic number? (What does the number mean?) ____________________________________

13) How many protons does an atom of phosphorus have? ______

14) True or false? Elements in their pure form have an equal number of protons and electrons. ______

15) True or false? All compounds are molecules, but not all molecules are compounds. ______

Activity 1.2 Videos

This book has a playlist on YouTube! Go to **www.YouTube.com/TheBasementWorkshop**. This channel belongs to the author of this book, so the videos on all the playlists have been previewed and chosen very carefully. Find the link that says SHOW ALL PLAYLISTS, if the "Rocks and Dirt" playlist is not visible. Click around until you find "Rocks and Dirt." The videos will be posted in order, with chapter 1 videos first, then chapter 2, etc. Unfortunately, YouTube has not provided any way of adding notes that the viewers can see, so there's no way to let you know exactly what videos go with each chapter. But you can figure it out. The videos about elements go with chapter 1. Then chapter 2 will feature videos on minerals.

Activity 1.3 Elements that make minerals

The crust of the earth is basically made of only a few dozen elements. In fact, if you weighed the planet and then found out how much of that weight came from each element, you'd discover that 75% of the weight comes from just two elements: silicon and oxygen. Of that remaining 25%, 24% is made of aluminum, iron, calcium, sodium, potassium, and magnesium. That means that only 1% is left for all the rest of the elements. (When we look at living things, hydrogen, oxygen and carbon are extremely abundant.) Let's make sure we're familiar with the symbols for these common elements in the earth's crust. Use a Periodic Table (or Google) to find the names that go with these atomic symbols.

1) H ______________	7) P _____________	13) Cu _____________
2) C ______________	8) S _____________	14) Cl _____________
3) O ______________	9) Fl _____________	15) Si _____________
4) Na _____________	10) Ca _____________	16) K _____________
5) Mg _____________	11) Fe _____________	17) Au _____________
6) Al ______________	12) Ag _____________	18) Zn _____________

CHAPTER 2: MINERALS

Now that we understand what an element is, we can explore the world of minerals. Geologists have come up with a very tight definition of what a mineral is. There are five "rules" that must be satisfied in order for something to be considered a mineral:

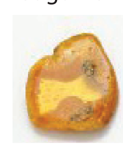
1) It must be inorganic (non-living).
2) It must be naturally occurring (not man-made).
3) It must be a solid (no liquids or gases).
4) It must have a chemical recipe (formula).
5) It must form some kind of crystalline (geometric) structure.

The order of these rules is not important. When you see this list in other books or on websites, the numbers might be different. They can be listed in any order. What's important is to understand what they mean, so let's take a short paragraph to explain each one.

1) It must be inorganic (non-living). This seems pretty obvious. No one has to tell you that a mouse is not a mineral. However, this rule isn't quite as stupid as it sounds. Sugar crystals look very much like the mineral crystals found in sand, but sugar can't be classified as a mineral because sugar is made by plants, which are living things. Pearls also look like they could be minerals. They are hard and shiny and made of the same elements that many minerals are. However, since pearls must be made by a living thing (an oyster), they can't be minerals. Seashells are made of the same elements that are found in calcite crystals, but seashells are not minerals because a little animal (a mollusk) made them. (Sometimes the word "abiogenic" is used instead of the word "inorganic" because "a" means "not," "bio" means "life," and "genic" means "created by.")

There are two notable exceptions to this rule: coal and amber. Coal probably came from ancient plants that were buried under great pressure, and amber is fossilized tree sap. These two substances are often listed in books as "organic minerals." Technically, there's no such thing as an organic mineral, but apparently coal and amber have special privileges. Mineral collectors often have specimens of amber in their collections.

Sugar is NOT a mineral.



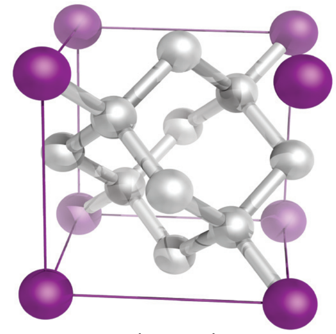
Amber is fossilized tree sap.

2) It must be naturally occurring (not man-made). Metals such as steel and bronze are man-made mixtures of metals, so they can't be minerals even though they are hard, shiny and metallic like many minerals. Plastics can't be minerals, either, since they are made in factories.

3) It must be a solid. Nothing tricky here. Substances like air and water can't be minerals. (However, oddly enough, if you freeze water and make it into a solid (ice) it then qualifies as a mineral under all five rules!)

4) It must have a chemical recipe (formula). Sometimes this rule is phrased like this: "It must have a definite chemical composition." We've substituted the word "recipe" for "definite chemical composition" because it is much easier to understand. A mineral has a unique recipe made from one or more of the elements on the Periodic Table. The best way to understand this is to give some examples. The recipe for the mineral **quartz** is SiO_2. If the atoms were all the same size and could be measured using cooking scoops, you could cook up a batch of quartz in your imaginary chemical kitchen using two scoops of oxygen atoms for every one scoop of silicon atoms. If you wanted to make a batch of the mineral **calcite**, you'd use this recipe: $CaCO_3$. That would be like one scoop of calcium atoms, one scoop of carbon atoms, and three scoops of oxygen atoms. (If you don't see a number listed below a letter, that means the number is 1.) A mineral called **talc** is made with magnesium, silicon and oxygen, using this recipe: $Mg_3Si_4O_{10}$. Recipes can be as simple as one ingredient, such as Cu (copper) or they can be quite complicated, like the recipe for turquoise: $CuAl_6(PO_4)_4(OH)_8 4H_2O$.

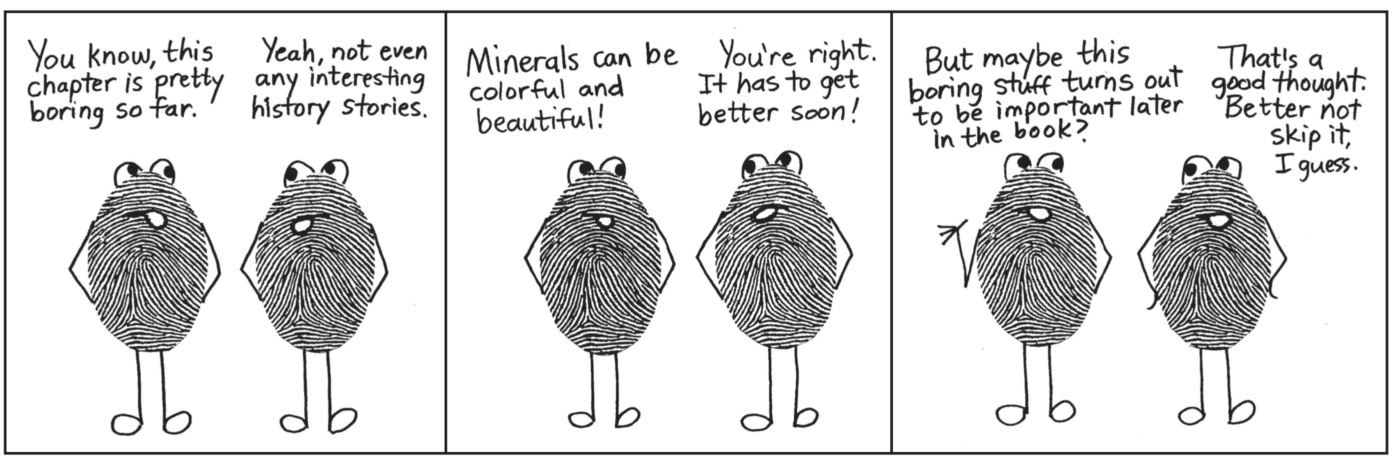
5) It must have a crystalline (geometric) structure. You have probably seen pictures of gemstones such as diamonds, that have beautiful geometric shapes. Perhaps you or someone you know has a mineral collection that includes crystals such as quartz, calcite, amethyst or fluorite. The atoms in a mineral line up in very regular ways, forming a pattern called a **lattice**. Lattice patterns are based on simple shapes such as squares and hexagons, but they can often look quite complicated. Sometimes the overall shape of a mineral specimen will look very much like its lattice structure, but other times it won't resemble the lattice at all. The lattice shown here is made of nothing but carbon atoms locked tightly together to make a **diamond**.



diamond

There are approximately 4,000 kinds of minerals. We've already mentioned some of them: quartz, diamond, calcite, amethyst, talc, turquoise, salt, ice, and elements such as copper, sulfur, silver and gold. Some minerals have names that are thousands of years old, like jasper, onyx, beryl, chalcedony, opal, and agate. Many minerals are named after the person who first identified them, such as Thomsonite, Smithsonite, Allanite and Johannsenite. The rest have names that sound like science words, such as hematite, dioptase, pyrite, and zircon. (Some names even sound a bit funny, like crocoite, wulfenite, apatite, and bauxite.) Mineral books are full of odd names!

Now, 4,000 items is a really large number. Mineralogists had to come up with a way to classify and organize them. Should they sort them by color? By shape? By location? What would be the most useful categories? The best solution turned out to be sorting them by their chemistry. This would not have been possible many centuries ago, but starting in the 1800s, chemists began inventing ways of finding out what elements were present in a given mineral sample. By the 1900s, mineral analysis became very accurate and the "recipe" for every mineral was discovered. Mineral recipes tended to be based on just a handful of common elements, such as carbon, silicon, sulfur, oxygen, phosphorus, chlorine and fluorine. From these elements they formed the names of the mineral groups: silicates, carbonates, sulfides, sulfates, oxides, halides, and phosphates.



Yes, this stuff turns out to be important when we start talking about rocks. Rocks are made of minerals. If we're already familiar with lots of minerals, studying rocks will be much easier.

Minerals are put into groups according to what element their chemical recipes are based on. Quartz, SiO_2, is based on silicon, so it is a silicate. A mineral called pyrite (also known as "fool's gold") has the recipe FeS_2, where S is sulfur, so it is classified as a sulfide. Anything with a recipe that includes (CO_3) is a carbonate. Calcite is made of $CaCO_3$, so it is a carbonate. You may not have heard of the mineral corundum, Al_2O_3, which is an oxide, but you've certainly heard of the gemstones that are made of corundum: rubies and sapphires. This photo shows a famous sapphire, called the Logan Sapphire, which is in the Museum of Natural History in Washington, DC. (Sapphires are blue because there are small amounts of

Minerals are classified according to the elements in their chemical recipes. These are the basic categories you will find in any book about minerals. Some books add a few more categories, these eight are enough for us. Also, we've trimmed the examples down to just minerals that are very well-known and are easy to pronounce. Mineral guide books will give you quite a few more examples.

You don't have to sit and memorize this list! The list is mostly as a source of information you can come back to later. Just skim through it now, and then remember it is here for future reference.

NATIVE ELEMENTS are pure elements.
Examples: sulfur (S), copper (Cu), silver (Ag), gold (Au), bismuth (Bi), diamond (C), graphite (C)

SILICATES are based on silicon, Si.
Examples: quartz (SiO_2), zircon ($ZrSiO_4$), topaz ($Al_2SiO_4(OH,F)_2$), beryl ($Be_3Al_2Si_6O_{18}$), talc ($Mg_3Si_4O_{10}(OH)_2$), and all the different types of feldspar with their various recipes (ex: $KAlSi_3O_8$ and $CaAl_2Si_2O_8$)

CARBONATES are based on the element carbon, but the carbon is attached to three oxygens: CO_3.
Examples: calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), smithsonite ($ZnCO_3$), malachite ($Cu_2CO_3(OH)_2$),

SULFIDES are based on sulfur, S.
Examples: pyrite (FeS_2), chalcopyrite ($CuFeS_2$), galena (PbS), cinnabar (HgS)

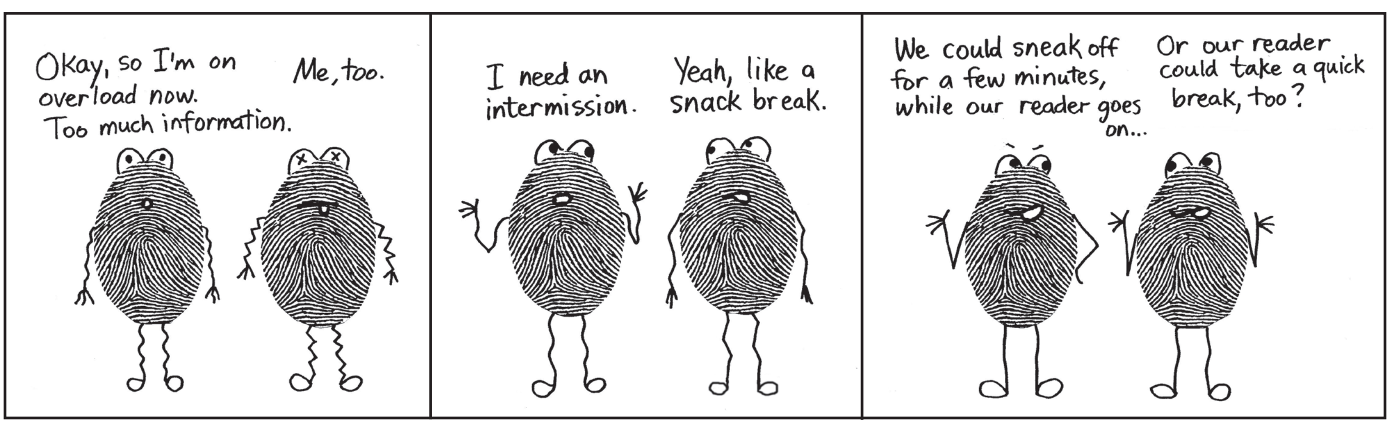
SULFATES are also based on sulfur, but associated with oxygen as SO_4.
Examples: epsom salt ($MgSO_4$), barite ($BaSO_4$), gypsum ($CaSO_4$),

OXIDES are based on oxygen, O.
Examples: hematite (Fe_2O_3), corundum (Al_2O_3), rutile (TiO_3), pitchblende, (UO_2, where U is uranium)

HALIDES are based on elements called "halogens," which include chlorine, Cl, and fluorine, F.
Examples: salt (NaCl), fluorite (CaF_2), sylvite (KCl)

PHOSPHATES are based on the element phosphorus, but attached to four oxygens: PO_4.
Examples: apatite ($Ca_5(PO_4)_3$), turquoise ($CuAl_6(PO_4)_4(OH)_84H_2O$)

The largest of these groups is the silicate group. We'll take an entire chapter to discuss the silicates because they are the most abundant minerals in the earth's crust, and are an important ingredient in the magma that comes out of volcanoes.



When we turn the page, we won't be talking about chemistry anymore. We'll be discussing things like color, texture, hardness, heaviness, and shininess. But don't forget about this chemistry! We'll go back to chemistry again in chapter 3.

Mineral guide books use those chemical categories as their basic organizational structure, sort of like chapters. The order of the chemical categories will be different in each book. Once you are into a category, such as carbonates, the minerals will be listed in seemingly random order, with a short paragraph about each. The paragraphs on each mineral will have exactly the same format: a list of characteristics using some familiar words such as color and hardness, and some less familiar words such as streak, cleavage, and habit. There is also usually a small picture beside each paragraph, showing a geometric shape. The paragraph will also probably tell you where the mineral is found in the world and what it is used for. Though the order of the characteristics is different in each book, the mineral's crystal shape is usually at the top of the list, so we'll tackle that explanation first.

CRYSTAL STRUCTURES (also called "SYSTEMS" or "HABITS")

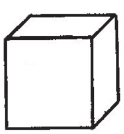
Atoms stick together in different ways. Remember from chapter 1 that the electrons are arranged in shells around the nucleus. The electrons in the outermost shell are the ones that interact with other atoms. The number of electrons in that outer shell will be the most important factor in determining what the interactions will be. Sometimes atoms give away their electrons, and sometimes they share. Certain atoms prefer pairing up with certain other atoms. Given a chance, sodium atoms will always rush to pair up with chlorine atoms. Sulfur and carbon atoms will gladly attach to some oxygens to make little groups like SO_4 and CO_3.

As trillions upon trillions of atoms pair up, the whole mass of atoms starts to be visible as some kind of substance. If trillions of sodiums and chlorines get together, they will interlock into an alternating pattern that will result in a cubic shape. If trillions of hydrogens and oxygens get together they will make lots of little H_2O molecules that can interlock into 6-sided geometric shapes (snowflakes) if the temperature gets cold enough. Trillions and trillions of carbon atoms will interlock to form either flat, gray sheets of graphite, or beautiful, clear diamonds, depending on the pressure and temperature surrounding them.

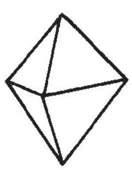
Scientists in the 20th century were able to analyze minerals using techniques (often with x-rays) that allowed them to determine exactly how the atoms were connected. They found that minerals' crystal structures fell into basically six categories. Inside each category, there are some variations (more variations than shown here).

<u>ISOMETRIC</u> ("iso" means "same")

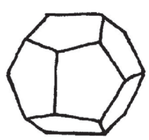
cubic



octahedron

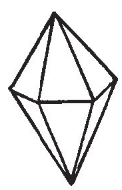


dodecahedron

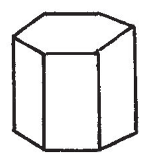


<u>HEXAGONAL</u> ("hex" means "six")

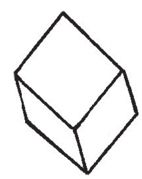
dipyramid



prism

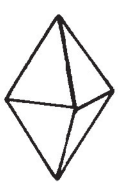


rhombohedron

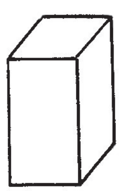


<u>TETRAGONAL</u> ("tetra" means "four")

tetragonal pyramid



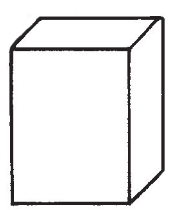
tetragonal prism



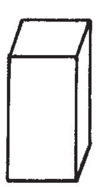
The rectangular prisms look like the same shape, but a mineralogist can see that the sides are different lengths. And that's an important difference.

<u>ORTHORHOMBIC</u> ("ortho" means "straight")

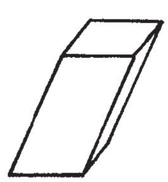
rhombic prism



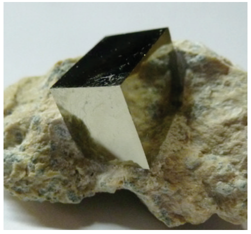
<u>MONOCLINIC</u> prism



<u>TRICLINIC</u> prism



In reality, many mineral specimens don't actually look like these shapes. A few do, however, including pyrite, halite, quartz, fluorite, calcite and galena.


pyrite

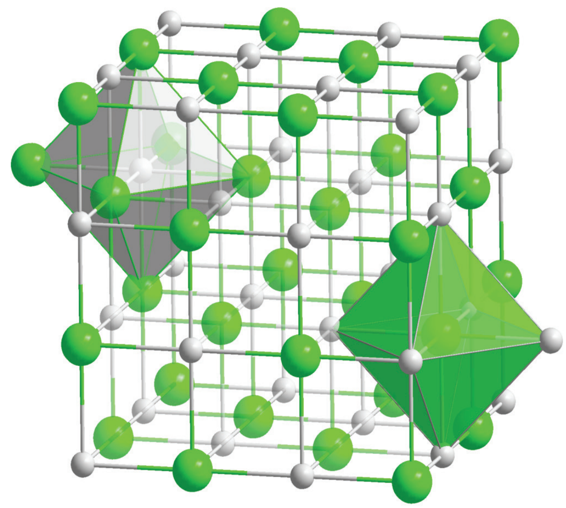

fluorite


quartz


calcite


galena

The reason that minerals make these shapes is due to that interlocking pattern of atoms we keep talking about. Here on the right an artist has drawn the cubic pattern found in NaCl crystals. The green dots are chlorine (Cl) atoms and the gray dots are sodium (Na) atoms. If you look at just the pattern of dots, it is not hard to see how this structure could form a cube. What is harder is to see how this pattern could form other shapes. The artist has helped us out a bit with imagining another shape: an octahedron. Ordinary table salt tends to be cubic, while rock salt can take this octahedron shape. Both shapes result from this cubic lattice pattern. Since an octahedron really doesn't look cubic, we use the more general word, isometric, as our category title. Isometric means that the shape is symmetric (mirror image) from front to back, top to bottom, and side to side.



Most minerals don't have such simple shapes. Or if it does show a simple shape, there are lots of tiny ones, not one large crystal. Some minerals even have shapes with rounded edges, like the form of barite that is often called the "desert rose." Sometimes the same mineral can take different shapes, depending on the temperature, pressure and amount of moisture present when it was formed, or if other elements are mixed in.


barite ("desert rose")


mineral specimens without nice crystals


quartz crystals without distinct sides

Sometimes a mineral's crystal shape is not apparent at all, as is the case with chalk. Chalk is indeed considered to be a mineral, but it is soft and powdery. The mineral called talc is also very soft, so soft, in fact, that you can scratch it with your fingernail! As with everything in life, most things fall into categories pretty well, but you always have your duckbill platypuses that seem to defy classification.

Another mineral that is hard to classify is afghanite. Its chemical recipe is $(Na,K)_{22}Ca_{10}[Si_{24}Al_{24}O_{96}](SO_4)_6Cl_6$. It has so many elements that it's hard to know which chemical group it belongs in. Fortunately, the mineral doesn't care.


afghanite

COLOR

Ruby is red corundum.

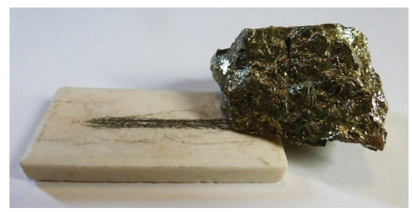
Finally, something easy! Mineral books will always list the color(s) of each mineral. Some minerals are always the same color. Pyrite (fool's gold) is a shiny gold color, galena is dark gray, and pure sulfur is yellow. Other minerals have many color variations. Calcite and quartz have variations that are clear, white, yellow, brown, purple, green or pink. Corundum can be yellow, brown, green, blue or red. (When corundum is blue we call it a sapphire and when it is red we call it a ruby.)

Along with color, the guide will also tell you if the mineral is **opaque**, **transparent** or **translucent**. Opaque means that light cannot pass through it. A piece of wood is opaque. Transparent means that light can go through it and you can also see through it. Glass is transparent. Translucent means that light can go through it, but you can't see through it. A thin piece of paper is translucent. Quartz and calcite can be transparent or translucent. Pyrite and galena are definitely opaque.

LUSTER

Luster is the way the surface of the mineral looks, without respect to color. The luster can be shiny, dull, waxy, glassy, metallic, pearly, greasy, etc.

STREAK



A piece of pyrite leaves a black streak.

"Streak" is the color the mineral makes when it is rubbed onto a surface. Often, a piece of white porcelain (similar to the back of a floor tile) is used to do the streak test. Porcelain seems to be the ideal surface for streaking minerals.

You'd think that the color that rubs off a mineral would be the same as the mineral, but oddly enough, it is often different. For example, if you scratch a surface with a piece of shiny gold pyrite, the mark it makes is black, not gold. (That's a simple way to test your "gold" to see if it is just fool's gold.)
Some minerals are so hard that they don't leave a mark.

HARDNESS

Minerals can be very soft, like chalk, or extremely hard, like diamond. In 1812, a scientist named Friedrich Mohs invented a way to compare the relative hardness of minerals. He chose 10 minerals that would form a hardness scale, which today is called the Mohs hardness scale. The softest mineral on the scale, number 1, is talc. Talc is so soft that, as we previously mentioned, you can scratch it with your fingernail. Just up from that, at number 2, is gypsum. A piece of gypsum can put a scratch into a piece of talc, but a piece of talc can't scratch a piece of gypsum. By trying to scratch a mineral with a mineral, you can evaluate the hardness of each one. Number 10 on the scale is diamond, of course. Right under that, at number 9 is corundum (rubies and sapphires). Here are the others:

1	2	3	4	5	6	7	8	9	10
talc	gypsum	calcite	fluorite	apatite	feldspar	quartz	topaz	corundum	diamond

This scale is not a precise measurement of hardness. If you want an exact measure, you have to use a machine called a sclerometer which measures microscopic scratches cut into the mineral by a diamond blade. A sclerometer still puts talc at number 1, but diamond would be a 1600. Corundum scores only a 400, so you can see how much harder diamond is than any other mineral. Diamond is 4 times as hard as corundum.

Hardness is one clue that can help to identify unknown minerals. Sometimes geologists will also use a penny, a steel knife blade and a steel nail to help them identify hardness, because these items are 3.5, 5.5 and 6.5 on the Mohs scale. Better yet, you can go to websites like geology.com. and get yourself a set of hardness picks. They have conveniently installed the correct hardnesses on the numbered tips and you can just scratch away on your minerals.

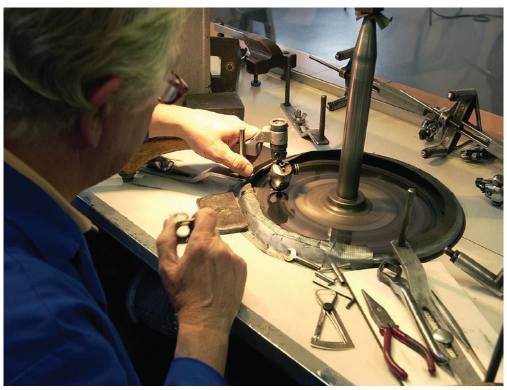
CLEAVAGE

Cleavage means how something cracks or breaks. (A large meat knife is sometimes called a meat cleaver.) Some minerals split into angular little pieces, some break into flat sheets and some just crumble. How a mineral breaks is determined by its atomic lattice pattern. Often the crack will occur right along a line in the pattern.

Calcite is a very interesting mineral to break. Calcite crystals often have a rhombohedral shape. If you smash a calcite rhombohedron, you get a bunch of little rhombohedrons. If you smash those little rhombohedrons you get even smaller rhombohedrons. This would continue on down to the microscopic level because the atomic lattice itself is rhombohedral. You could have a rhombohedral piece so tiny that you can't see it.

Some minerals exist as flat sheets, so they almost peel apart. Biotite and muscovite (forms of mica) look like stacks of paper-thin, almost transparent sheets, pressed tightly together. The sheets come apart easily.

People who cut gemstones take advantage of the natural tendency of crystals to cleave along the weakest planes of the lattice. With a few firm taps in the right places, the crystal's overall shape can be improved, not ruined.



a craftsman working on a diamond

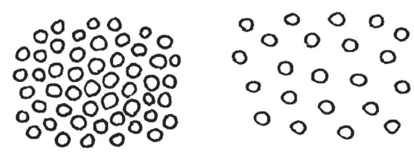
"Sea of Light Diamond" (Iran)

"Hope Diamond" (Washington DC)

DENSITY

Density is another characteristic that gets a number assigned to it. The number 1 on the density scale belongs to liquid water. The density of everything in the world is compared to water. If something is less dense than water, it floats. If something is more dense than water, it sinks. But what, exactly, is density?

The word "dense" basically means a whole lot of something in a given area. ("Sparse" is the opposite of dense and means very few things in an area.) How can we apply this definition to minerals? A dense mineral has many atoms packed into a given area. Sometimes, the size of the atoms factors in, as well, since large atoms take up more space than small ones.



All minerals (except for ice) will sink in water, so they all have a density greater than 1. One of the most dense minerals is gold, which can have a density as high as 19.3. Another heavy mineral (because it contains lead) is galena, but it is only a 7.5. Most minerals have densities between 3 to 6. The least dense minerals are the salts, which can sometimes be as light as 1.5 (which still sinks in water). Density isn't a very exciting property of minerals, but it can be very helpful in figuring out the identity of an unlabeled mineral specimen.

NOTE: Your mineral guide book might use another word for density: specific gravity. Specific gravity is defined as the density of the mineral divided by the density of water. The density of water is 1, so that means you are always dividing by 1, which doesn't change your number. Aren't scientists silly sometimes?

So if someone calls you "dense" just tell them that means you have more brain cells packed into your head!

OTHER PROPERTIES

A few minerals have some very unusual characteristics.

1) MAGNETISM: Magnetite is highly magnetic. Other minerals containing iron can be slightly magnetic, but magnetite takes the prize for magnetism.

3) FIBER OPTICS: A mineral called ulexite demonstrates **fiber optic** qualities. Ulexite is fairly transparent, so if you place it on a piece of newspaper, you can see the words and pictures on the paper. What is odd is that those words and picture look like they come up to the surface of the rock.

2) BIREFRINGENCE: "Bi" means "two" and "re-fringence" has to do with light being bent by the crystal. Birefringent calcite is clear so you can see through it, but what you see is two images, not one. It's like crystal double vision.

4) RADIOACTIVITY: Pitchblende (uranium oxide) contains radioactive elements such as uranium, radium and polonium. The famous scientist Marie Curie discovered the elements radium and polonium by boiling down big pots of pitchblende for months on end. Radioactive means that the nucleus of the atom is falling apart, losing pieces that go flying off. These pieces can be dangerous to the cells of living things.

USES FOR MINERALS

Detailed guide books will often give a sentence or two about what the mineral is used for. Here are a few samples that you might find interesting.

BARITE: a source of the element barium which is used for medical imaging and in the oil drilling industry
BAUXITE: a main source of the element aluminum
BERYL: as a gemstone, also as a source of the element beryllium for aircraft metals, fluorescent lamps, x-ray tubes
CALCITE: lenses, fertilizer, cement, polishing powders, filters,
CINNABAR: a main source of the element mercury (which is a liquid at room temperature)
CORUNDUM: unattractive crystals are crushed and used as abrasives, nice crystals get make into gemstones
DIAMOND: jewelry, tips on cutting and drilling equipment
FLUORITE: used as "flux" in metal manufacturing, also used by industries that make plastics and optical devices
GALENA: an excellent source of lead (Galena was a main source of lead for musket shot in N. America in the 1700s.)
GRAPHITE: pencils, and lubricants (to make things slippery)
GYPSUM: plaster and plasterboard, Portland cement, fertilizer, and in pottery
HALITE (rock salt): used in several ways in the food industry, used to melt ice on roads, used in other industries
HEMATITE: an important source of iron, also used as a pigment for paints
MAGNETITE: an important source of iron (which is used to make steel)
MALACHITE: green pigment for paint, jewelry, decorations
PYRITE: a source of sulfur for sulfuric acid which is used in many industrial processes
SPHALERITE: a main source of the elements zinc, gallium, cadmium and indium, which are used in industry

Activity 2.1   Comprehension self-check

Can you remember the answers to these questions? If not, go back to the text and see if you can find the answers. When you are done, you can check your answers using the answer key at the back of the book.

1) True or false? Since sugar has a crystalline form, it can be classified as a mineral. _____
2) True or false? Salt is a mineral. ___
3) There are two exceptions to the rule about minerals not being organic: __________ and ___________
4) Why is bronze NOT a mineral? ____
5) True or false? Most minerals have a chemical recipe, but some don't.
6) Diamonds are made of nothing but this element: ____________
7) When a mineralogist sends a Valentine card, it might begin like this: Rubies are ____, sapphires are ______.
8) What mineral is made of a square lattice of sodium and chlorine atoms? ________
9) What is the correct name for "fool's gold"? __________
10) What is the correct name for the mineral called the "desert rose"? ___________
11) A quartz crystal has six sides. What category does it belong in: hexagonal or tetragonal? _____________
12) Which one of these is NOT isometric? cube, octahedron, rhombohedraon, dodecahedron? ________________
13) Name a mineral that doesn't appear to have a crystal structure at all: ____________
14) What does "translucent"mean? ____
15) Name a mineral that can be transparent: _______________ Name a mineral that is opaque: ______________
16) What is an easy way to prove that fool's gold is not gold? ____
17) What is the softest mineral on the Mohs hardness scale? _______ The hardest? ______________
18) If you try to scratch a piece of quartz using a piece of calcite, will it work? _______
19) Other than diamond, what is the hardest mineral? _______________
20) The words shiny, dull, waxy and metallic describe what property of minerals? _____________
21) True or false? A mineral will usually break (cleave) right along a line (plane) in its atomic lattice pattern. ______
22) Name a mineral whose cleavage pattern is flat sheets. ____________
23) What has a density of exactly 1? ____________
24) Name a mineral that is extremely dense: ___________
25) The more correct term for density is ___________ ____________.

Activity 2.2   Videos

Go to the "Rocks and Dirt" playlist at: **www.YouTube.com/TheBasementWorkshop**, and watch the videos on minerals. Stop when you get to the quartz videos and save them for the next chapter.

Activity 2.3   "Odd one out"

In each list of four minerals, three belong to the same chemical group and one is the "odd one out." Which one does not belong? Write the correct category for the three others on the line.

1) __________________ copper, silver, turquoise, gold
2) __________________ quartz, apatite, zircon, beryl
3) __________________ gypsum, calcite, dolomite, malachite
4) __________________ pyrite, galena, cinnabar, bismuth
5) __________________ salt, gypsum, calcite, barite
6) __________________ corundum, feldspar, pitchblende, hematite
7) __________________ barite, sylvite, fluorite, salt

Gypsum can sometimes look like this.

Activity 2.4   A word puzzle

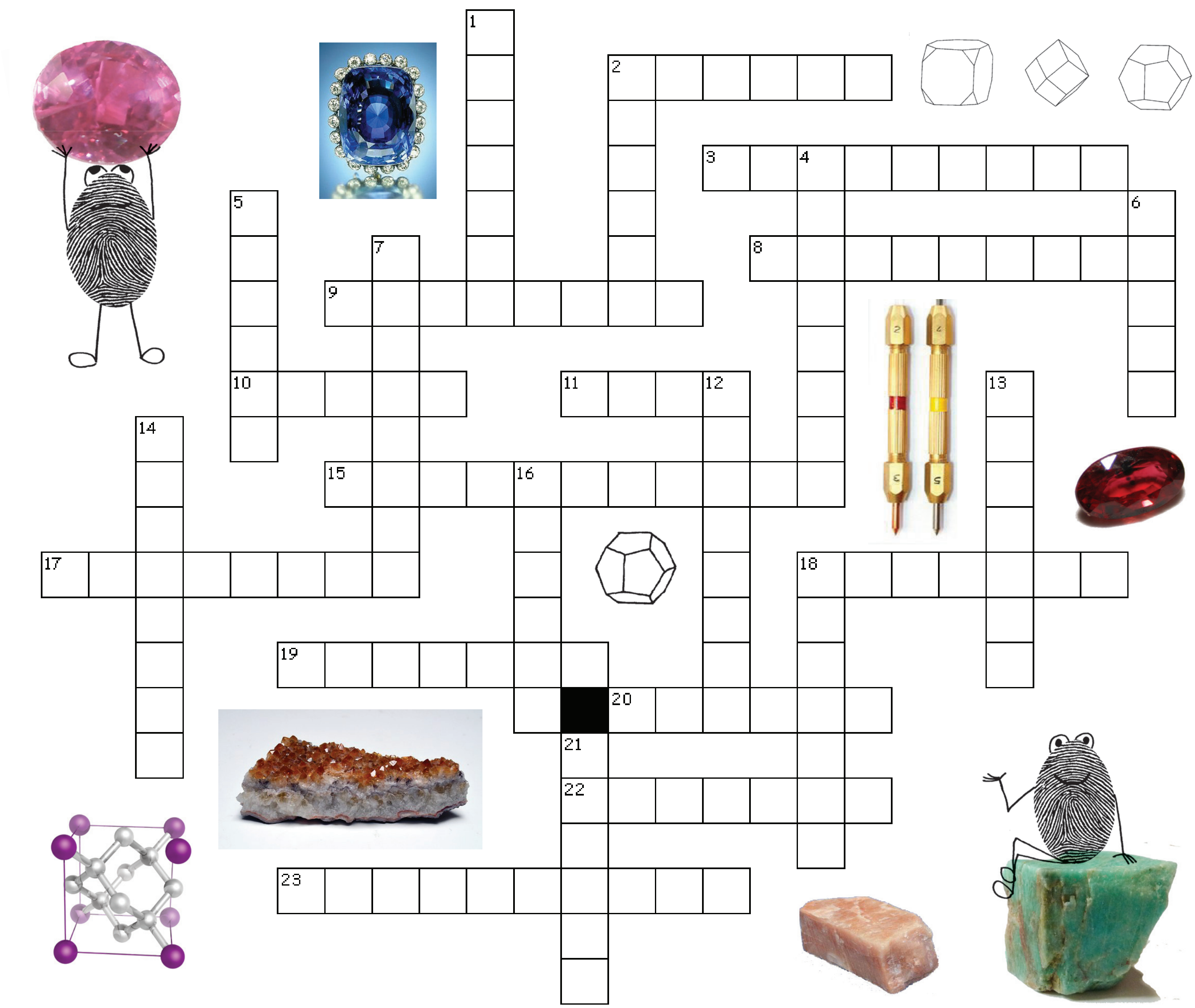
Here is a fun way to do more practice with mineral names. The answers to these clues are all in the chapter.

ACROSS:

2) Used to make plaster, cement and fertilizer
3) The most magnetic mineral
8) A green mineral used for jewelry and as a pigment in paint.
9) Its name means “field stone,” it comes in bluish-green and pink and it is number 6 on the Mohs hardness scale.
10) Number 8 on the Mohs hardness scale
11) One of the softest minerals, number 1 on the Mohs
15) A radioactive mineral that contains uranium.
17) Contains the element fluorine.
18) Most aluminum is extracted from this.
19) Number 5 on the Mohs hardness scale.
20) Has the chemical formula FeS_2.
22) A mineral that contains the element boron and shows the unusual property of fiber optics
23) Is used as a source of zinc, gallium, cadmium and indium.

DOWN:

1) A form of pure carbon, but in hard, clear crystals.
2) A mineral that contains a lot of lead, and was used to make lead ammunition for musket rifles in the 1700s.
4) A form of pure carbon that forms flat sheets. You use this mineral every day when you write with pencils.
5) A source of the element barium.
6) Contains the element beryllium.
7) This red mineral is an excellent source of iron. The first part of its name is Greek for blood (because it is red).
12) A mineral ore for mercury, having the formula HgS
13) Formula $CaCO_3$, pure crystals can look like rhombohedrons.
14) Both sapphires and rubies are made of this mineral.
16) The mineral name for salt.
18) A mineral that comes in flat, shiny, black sheets
21) SiO_2

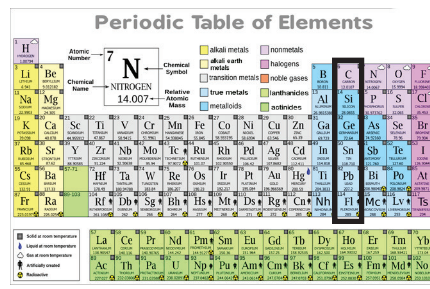


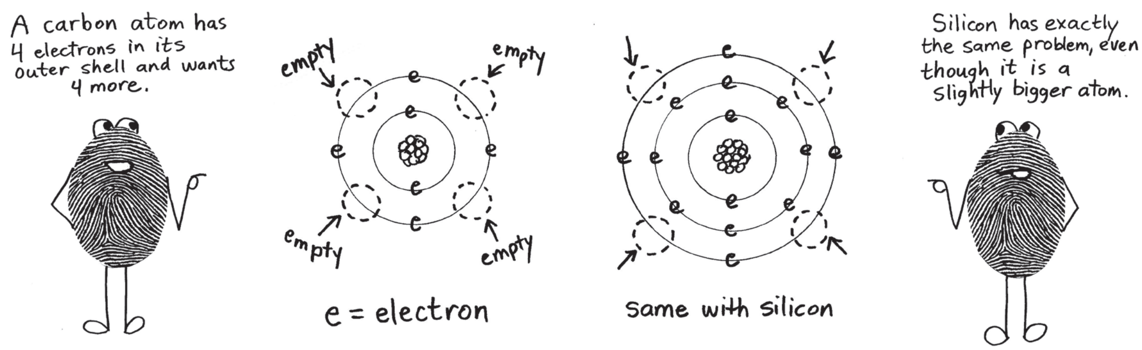
Feldspar is often pink or greenish-blue.

CHAPTER 3: THE SILICATES

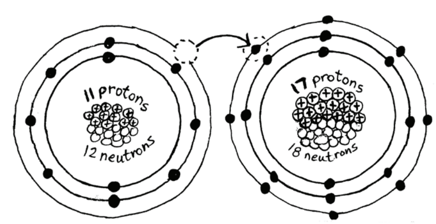
Most of our planet is made of the elements **silicon** and **oxygen**, with help from the elements iron, magnesium, calcium, and carbon. The silicate family of minerals is by far the most abundant, so it deserves an entire chapter. To understand this family of minerals, we'll start by reviewing some facts about atoms.

We'll need to look at a Periodic Table. (You can use the table on page 141, or you can use one from the Internet or in another book; it doesn't matter very much what table you look at because they are all the same.) Look at the element silicon, atomic number 14. The most important thing to notice is that it is directly below the element carbon, number 8. All the elements in this column (up and down) have 4 electrons in their outermost shell. Remember, it is this outermost shell that interacts with the environment, so the elements in this column will behave in a similar fashion. Not identical, but very similar. This outer shell would like to have 8 electrons, but it only has 4. So silicon and carbon will be out looking to share or borrow 4 electrons from other atoms. When they find an atom, or several atoms, that are willing to bond with it, they form very strong bonds called **covalent bonds**. Covalent bonds are hard to break and provide a "backbone" for the mineral structure.

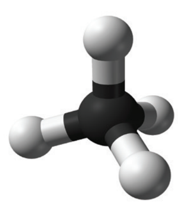




Another type of bonding that atoms can do is called **ionic bonding**. Ionic bonds occur when an atom is willing to share its electrons, but not in such a strong, permanent way. Ionic bonds are more easily broken than covalent bonds are. (In fact, you can break the ionic bonds in salt crystals (NaCl) just by putting the crystals into water. The water molecules themselves are strong enough to break apart these ionic bonds. We call this "dissolving.") A combination of covalent and ionic bonds are found in silicate minerals.

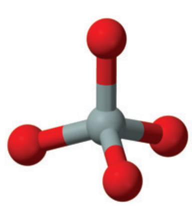


sodium (Na) chlorine (Cl)



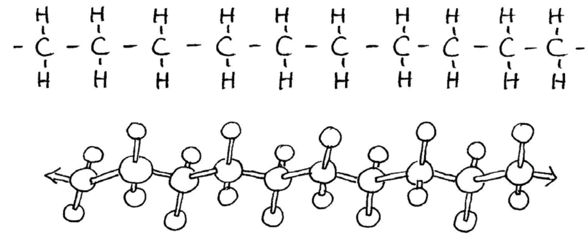
CH_4

The simplest way that carbon and silicon atoms can solve their electron problem (needing to make 4 bonds) is to find 4 small atoms that would like to share 1 electron. In the case of carbon atoms, the element most likely to pair up with them is hydrogen. Hydrogen atoms want to share just 1 electron, so carbon pairs with 4 hydrogens to make CH_4, a molecule that we call methane ("natural gas"). In the case of silicon, the element most likely to pair up with it is oxygen. A silicon atom will attract 4 oxygens to make SiO_4. The SiO_4 molecule doesn't have a nice name, like methane does. We simply call it the **silicon tetrahedron**. The word tetrahedron means "4-sided." (A tetrahedron might remind you of the pyramids of Egypt, but if you count the sides (including the bottom) of the pyramids, they have 5 sides, not 4.)

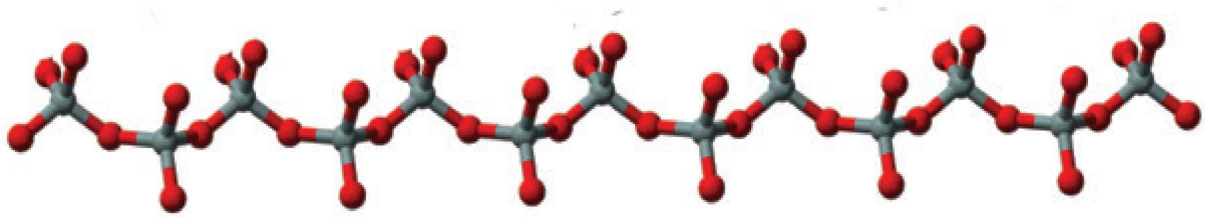


SiO_4

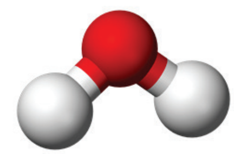
Both these molecules have 1 central atom connected to 4 other atoms. They both form a tetrahedron shape. They both have strong covalent bonds. They both can form long chains, too. Methane molecules can drop some of their hydrogens in order to bond to other carbons, forming chains we call hydrocarbons. Hydrocarbons can be just a few carbons long, or up to thousands of carbons long. Small hydrocarbon chains include propane, gasoline (petrol), diesel fuel, and wax. Longer hydrocarbon chains are found in plastics, starches and fats.



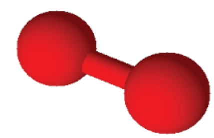
In a similar fashion, a silicon tetrahedron can drop one of its oxygens in order to bond with another tetrahedron. They can keep doing this and form a long line of silicon tetrahedrons.

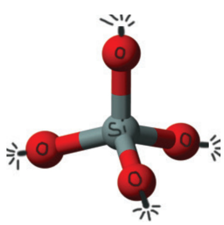


Let's take a closer look at what is going on here. We need to look at the oxygen atoms. Unlike hydrogen, oxygen atoms want to make 2 bonds. Oxygen is number 8 on the Periodic Table. (Find oxygen on the table.) All the elements in this column (under oxygen) have 6 electrons in their outer shell. They'd like to have 8, so they are out looking to borrow 2 electrons from one or more atoms in their neighborhood. When an oxygen atom solves its problem by bonding with two hydrogen atoms (who each have 1 electron to share) we call that molecule H_2O, water. If there are no other atoms around, oxygens will pair up with themselves and each share a pair of electrons with the other. This isn't ideal, but it is better than nothing. The oxygen in the air around is doing this, making molecules of O_2. Bearing in mind that oxygen atoms want to borrow 2 electrons, not 1, how does this affect the chemistry of the silicon tetrahedron?

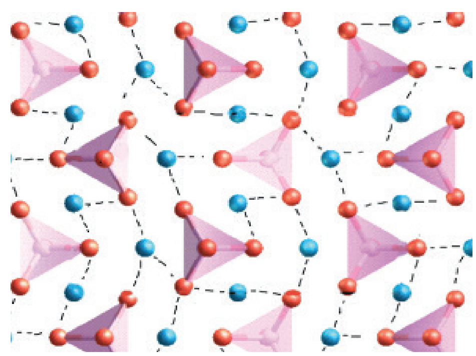


Oxygen is always red.

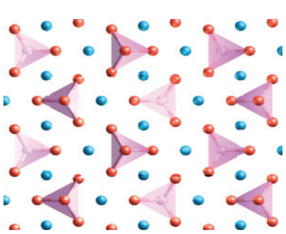




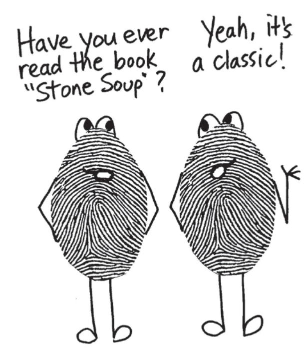
Those oxygens at each corner of the tetrahedron are sharing 1 electron with silicon. That means that the oxygen atoms would like to find 1 more electron. Very often there are atoms of iron, Fe, and magnesium, Mg, floating in the environment. (Magma, hot liquid rock, often contains the elements iron and magnesium.) Fe and Mg atoms have an electron arrangement that allows them to share 2 electrons with other atoms. (Iron can even share 3 sometimes.) An Fe atom can share its electrons with one or more of the oxygens in a silicon tetrahedron. This makes the oxygens very happy and they create ionic bonds with the Fe and Mg atoms. Remember, ionic bonds are not as strong as covalent bonds, but they are strong enough to hold all these atoms together and make the resulting substance as hard as rock.



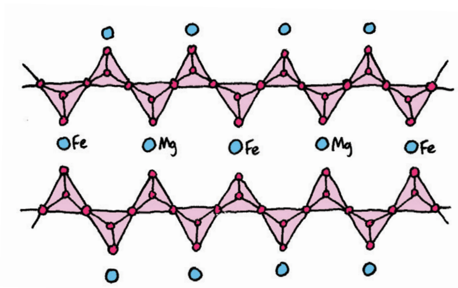
The tetrahedrons are shown in pink with red oxygens at the points. The blue balls represent metal atoms, perhaps Fe or Mg. The dashed lines represent electrical attraction keeping the atoms in place.

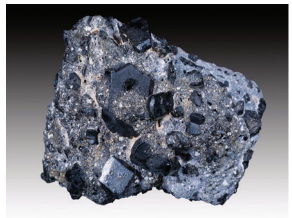


If the silicon tetrahedrons stay separate, we get a mineral called **olivine**. It looks a little bit like a soup, if you imagine the tetrahedrons and the atoms to be bits of chopped vegetables. However, it can't be a soup because it is a solid, not a liquid. Chemists call this type of chemical structure a **solid solution**. (Stone soup!) Olivine is a very easy mineral to remember because it is olive green. Sometimes it is clear, sometimes it is translucent or even opaque. Why is it this color? The arrangement of the atoms just happens to absorb all the colors of the rainbow except for olive green. This color of green light gets reflected back, so we can see it. (The exact details of how the light interacts with the atoms is very complicated. It is enough to know that green light bounces back at you, and all the other colors are absorbed and thus disappear.)



Now let's put some tetrahedrons into long lines—many long lines, like the strong metal rods they put into concrete to reinforce it. All those iron and magnesium atoms will be like the concrete that keeps the metal bars in place. Minerals that have this structure are called **pyroxenes**. *(pie-rocks-eens)* There are different types of pyroxenes, each one defined by tiny "impurities" of other elements mixed in, such as aluminum, titanium, chromium, sodium, calcium, zinc and lithium. The only type of pyroxene you may have heard of is jadeite, from which the gemstone jade is made. (Augite and diopside are shown below but you don't need to remember their names.)





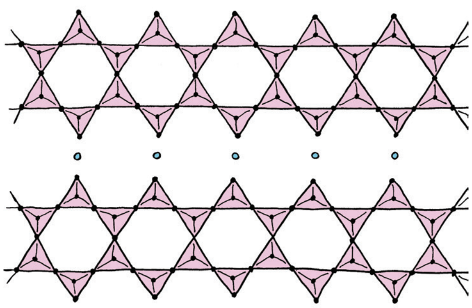
augite in a volcanic rock
(Wikipedia: Rob Lavinsky iRocks.com)

diopside
(Rob Lavinsky)

jadeite

jade carving

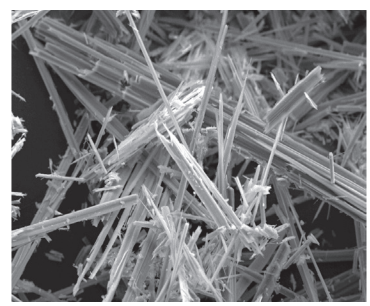
The next thing we can do with the silicon tetrahedrons is to put two chains together to make a double chain. In our picture, below, you can see that when the two chains link together, they look like a series of hexagons. We still have atoms of iron and magnesium in the spaces between the chains. Minerals with this structure are **amphiboles**. *(am-fih-boles)* The Greek word root "amphi" means "ambiguous, " (hard to tell what it is). Amphiboles are hard to identify, even for geologists. The only amphiboles you may have heard of are **hornblende** and **asbestos**.



Long lines create the needly texture of asbestos.

hornblende

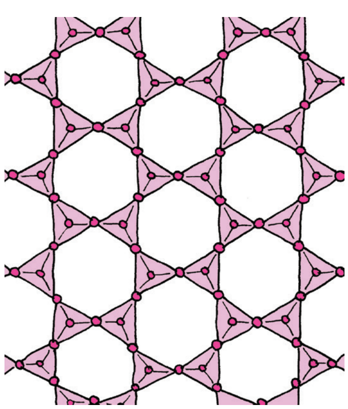
asbestos
(Wikipedia: Aram Dulyan, London)



microscopic view of asbestos fibers

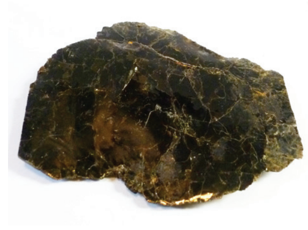
Mineral identification kits often contain a sample of hornblende. It's one of those samples you hardly notice in the collection—just a dark rock that does not look like anything special. What is significant about hornblende is that is often a main ingredient in a very important rock: granite.

Asbestos is one mineral you definitely won't find in a mineral kit. It was discovered in the 1980s that asbestos fibers can get into your lungs and cause lung diseases including cancer. The cells that are your clean-up crew in your body can't get rid of asbestos—it is indigestible. Worse yet, its shape is like sharp little needles so it is constantly poking and irritating your cells. The nice thing about asbestos is that it is fireproof, which is why it had become so popular as insulation in public buildings and wrapped around electrical wires. Billions of dollars have been spent trying to safely remove asbestos from buildings and appliances.



Now we can take a bunch of double chains and connect them together to make a flat sheet, then stack the sheets. We will still have iron and magnesium and other kinds of elements in the middle between these sheets, helping them to stick together, but they won't stick very well, and will peel. You are probably already guessing that biotite might belong to this group, and you are right. Minerals made of sheets of silicon are called **micas**. Biotite and muscovite are types of mica. Biotite is always dark because it contains iron and magnesium, and muscovite is always clear or light-colored because it has lots of aluminum and potassium. (The potassium atoms in muscovite form an entire layer by themselves, helping the silicon layers to peel apart. If you've ever seen cheese slices packaged with pieces of paper between the slices, think of the paper as the layers of potassium atoms.)

Unlike asbestos, the mica minerals are harmless. They have physical characteristics that make them useful in many branches of technology. They are used to make parts for navigation compasses, optical filters, helium-neon lasers, missile systems components, medical electronics, optical instrumentation, radar systems, radiation detectors, and electronic insulators. Very high quality sheet mica can sell for as much as $2000 per kilogram (two pounds).



Biotite is dark.

Muscovite is light.

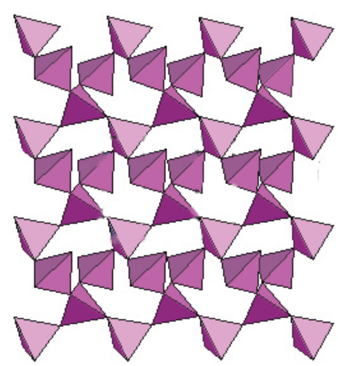
The last variation of silicate structure is called a **framework**. As the name suggests, a framework structure looks like it has supporting beams going in every direction. We can't build a framework, however, by just putting a bunch of sheets together. To make a framework out of the sheets, we would have to take apart all the silicon tetrahedrons and completely redesign them. Ideally, every tetrahedron is joined to four other tetrahedrons. In reality, there are often some other elements, such as potassium and sodium, lurking in and around the tetrahedrons.

Minerals that fall into the framework category include **feldspar**, **quartz** and a number of **gemstones**. The word feldspar is German for "field stone." Apparently this mineral is very common in the fields where the Germanic peoples settled in Europe. Centuries ago, those Germanic peoples discovered that these field stones did not contain any useful ores. You could heat those field stones all day long and not a drop of any metal came out of them—very disappointing. Feldspar could be used as building stone, but that was about it. Nowadays, feldspar is a bit more useful. Modern industries can grind up some types of feldspar and use the powder for making ceramics, paints, rubber, glass and plastics. A few types of feldspar can also be a source of aluminum.

Feldspars are also rich in the elements potassium, K, and sodium, Na. Geologists have a theory that while the minerals were forming in a pool of cooling magma, all the Fe and Mg atoms were used up by the olivine. As long as there was Fe and Mg available, olivine and pyroxenes could form. Once the Fe and Mg were gone, the silicon tetrahedrons had to start forming sheets and frameworks. There were still K and Na atoms floating around, and some of them got incorporated into the frameworks. All this information shows up in the chemical recipe for feldspar: $(K,Na)AlSi_3O_8$. The K and Na inside the parentheses means that it could be either one. There is some aluminum, Al, and, of course, the silicon framework, Si_3O_8. (Si_3O_8 means that we have fewer oxygens per silicon, since the tetrahedrons are connected. SiO_4 can be expressed as Si_2O_8, so we can compare fractions.)

To identify feldspar, there are three things to look for: 1) The color is usually white, pink or greenish-blue. 2) It has a cleavage pattern that makes the chunks similar in shape, looking like a box that has one or two sides folded in slightly. 3) There are usually parallel lines running down at least one side.

Quartz is also a framework silicate. The word quartz comes from an old German word for "hard." In its most pure form, its formula is SiO_2. Why not SiO_4, like olivine? In quartz, the tetrahedrons are all surrounded by other tetrahedrons, so oxygen atoms double up, attaching to more than one silicon atom. The framework geometry requires fewer oxygen atoms per silicon atom. When you see very large quartz crystals it can be hard to believe that they just came out of the ground that way. They are so perfect, with their 6-sided hexagonal shape. Yet, they do naturally form that way. (The YouTube playlist has a video of people finding huge crystals.)



If there are no impurities (other elements) in quartz, the crystals are very clear. If you add a tiny amount of certain other elements, quartz can take on many different colors. The most well-known example of colored quartz is purple amethyst. It is thought that small amounts of iron cause the purple color. Iron is also the coloring agent in citrine quartz. Rose quartz gets its pink color from the elements titanium and manganese. Brown quartz, often called smoky quartz, gets its color not from extra elements, but from radiation. Being near a source of radioactivity causes little holes to open in the framework structure and this changes the way that light is absorbed and reflected.


clear quartz


amethyst

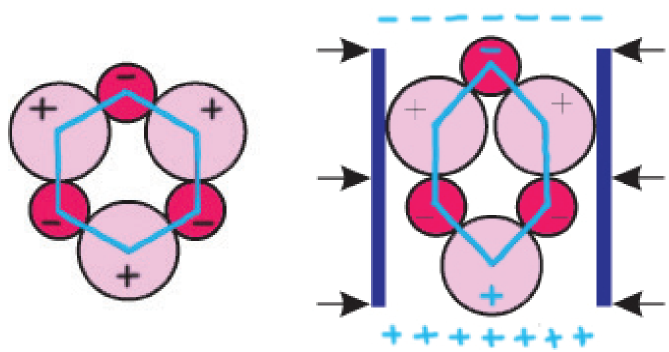

citrine


rose quartz


smoky quartz

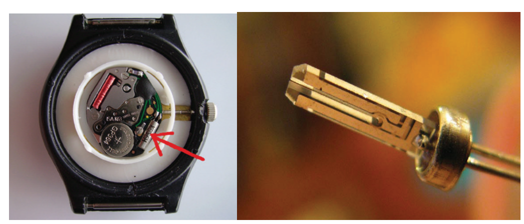
Quartz is not only beautiful as a gemstone, it is also very useful in modern technology. Quartz has a characteristic that the other silicates do not, called the **piezoelectric effect**. (*pie-EE-zo*, or *pea-AY-zo*) "Piezo" means "pressure." When the crystal framework is squeezed, is produces a small amount of electrical charge. Also, the converse is true—when a small amount of electrical voltage is applied to it, the crystal changes shape. This phenomenon was first discovered several hundred years ago, but not officially documented until the year 1880, by Pierre Curie, husband of Marie Curie, who discovered several radioactive elements.

This is just one small piece of a quartz framework crystal. We see just 3 Si atoms (pink with a + charge) and 3 O atoms (red with a - charge). This hexagon would be connected to many others. The hexagons are electrically balanced, even though some of the atoms themselves are more positive or negative.



In this picture, the crystal is being squeezed very hard. The hexagon is bent out of shape slightly. One end of the hexagon becomes more negative, and the other becomes more positive. This allows electrical current (moving electrons) to flow from one side to the other. This happens to all the hexagons in the crystal.

Quartz crystals are used in devices such as sonars, clocks, and ultrasound machines. Small electrical voltages are sent through a tiny quartz crystal. The crystal's lattice changes shape, back and forth, about 30,000 times per second, generating a high-pitched sound wave that can be used for sonar (like a dolphin does) or for medical imaging (like those baby pictures everyone gets during pregnancy). Also, since quartz crystals vibrate at exactly the same rate every second, these vibrations can be used in small time-keeping devices such as watches.


The red arrow shows where the quartz crystal is located inside a watch. It looks like a tuning fork.

Quartz is definitely the most useful framework silicate. Some other types aren't really much good for anything except sitting there and looking pretty. However, people will pay a lot of money for these do-nothing gemstones, so we'd better mention them! When you start adding aluminum to the silicate framework, it seems to make the crystals harder. For example, the mineral **topaz**, number 8 on the Mohs hardness scale, has this chemical recipe: $Al_2SiO_4(F,OH)_2$. You know what that SiO_4 is in the middle—the silicon tetrahedron. The aluminum atoms tuck in and around those tetrahedrons, and there are also either fluorine (F) atoms or OH's. (An OH is like a "broken" water molecule, with one H missing.) When you see letters in parentheses, that means it can be either one. Sometimes you might find fluorine and other times you might find OH's. Topaz naturally comes in clear, yellow, blue, pink, purple and

orange. Clear topaz can be treated with heat or radiation to produce strong colors. If you buy a topaz gemstone in a jewelry store nowadays, it has probably been heated or exposed to radiation. Naturally brilliant colors are rare.

If you mix both aluminum and beryllium (atomic number 4) into a silicon framework, you get a mineral called **beryl**, $Be_3Al_2Si_6O_{18}$. If the piece of beryl is green and transparent, it is worth a lot of money because what you have is an **emerald**. Beryl comes in other colors, too, but they are not as well-known. Beryllium is a rare element, so there are not too many places in the world where you can find emeralds.

Garnet is the name for a whole group of gemstones. You can play "mix and match" with quite a few elements and still have a garnet. The recipe for garnet allows for this mixing and matching. They use the letters X and Y to stand for the elements you can choose. The recipe looks like this: $X_3Y_2(SiO_4)_3$. For X, you can choose one of these elements: iron, magnesium manganese, or calcium. (Notice that there are two elements with similar names: magnesium and manganese.) For Y, you can choose one of these: iron, aluminum, manganese, vanadium, or chromium. There are many possible combinations of these elements, so there are many types of garnets with a wide range of colors. Very clear, brightly colored garnets are used for gemstones in jewelry. Garnets that are not so pretty get ground up and made into industrial sandpaper.

A red garnet attached to the piece of quartz where it grew. This type of garnet is $Ca_3Al_2Si_3O_{12}$.
(credit: Rob Lavinsky, iRocks.com, Wikipedia)

Tourmaline is another group of crystals that are based on silicon but have added elements. Tourmalines always have the element boron, number 5 on the Periodic Table. In addition to boron, they might also have iron, magnesium, manganese, calcium, sodium, aluminum, chromium, vanadium and lithium. Lots of options to choose from! The recipes lets you choose: $XY_3Z_6Al_6(Si_6O_{18})(BO_3)_3(F, OH)_4$. You can see your silicon framework in there, as (Si_6O_{18}). You've got some aluminum to make it hard, and some boron (B) to make it officially tourmaline. You've got the same ending that topaz does, with your choice between fluorine and OH (a "broken" water molecule). At the beginning, you get to choose not two, but three different elements. The list of elements is similar to the choices for garnet, but you use 1 "scoop" of whatever X is, 3 "scoops" of Y and 6 "scoops" of whatever Z is. That's how you cook up a batch of tourmaline.

When corundum has a bit of chromium (Cr) mixed in, it turns red. Blue is caused by small quantities of iron (Fe) and titanium (Ti).

We've already met **corundum**. You may remember that when corundum is red we called it a ruby and when it is blue we call it a sapphire. Sometimes corundum is brown or tan or a yucky in-between color that no one wants as a gemstone. These ugly bits of corundum end up as industrial sandpaper. It makes a great abrasive because it is very hard, number 9 on the Mohs scale.

Corundum doesn't actually belong in this chapter because its chemical formula is Al_2O_3. The silicon has been completely replaced by aluminum! Remember, when aluminum is added to a silicate it makes it harder. Here we have nothing but aluminum. Is it harder? Yes. Corundum is the hardest substance on earth, except for diamond. (And diamond is made from nothing but carbon—no silicon at all.)

We end this chapter with the most colorful members of the silicate family: the **cryptocrystalline** silicates. Many of the shiny, colored rocks you find in gift shops fall into this category. "Crypto" means "hidden." The crystals in these silicates are so small that they are hidden from our eyes. You won't see any 6-sided shapes or flat sheets. The crystals might be made of only a few dozen or a few hundred atoms. They still have the general formula, SiO_2, like quartz, but they also have some added elements ("impurities") that give them various colors. They are classified mainly by their colors or by what their patterns look like. Cryptocrystalline silicates are sometimes called by their ancient name: **chalcedony** (*KAL-seh-done-ee*, or *kal-SED-on-ee*).

Agates *(AG-its)* have rings of various colors, going from the outside into the center. (Although some agates do have a hole in the center.) Agates probably formed in the same was as geodes, starting as an empty air bubble in hot lava, into which seeped hot water saturated with silcon, oxygen and other elements. Each time a little more seeped in, another ring was added.

Geodes probably began as an air bubble inside hot rock. The bubble was surrounded by hot liquid that was rich in silicon. The silicon liquid leaked in gradually and cooled inside the bubble, making crystals.

Chrysoprase gets its color from small amounts of the element nickel. (The formula is still SiO_2, because the amount of nickel is so small.) "Chyrso" is Greek for "gold," and "prase" comes from the Greek word "prasinon" meaning "green."

(Photo: "Xth-floor" Wikipedia)

Carnelian was used in ancient times for signet rings that were pressed into hot wax. Hot wax does not stick to carnelian, and fine details can be carved into it, making it ideal for this purpose.

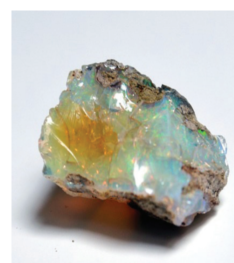
Landscape jasper can have all kinds of fantastic patterns. If you see a rock with swirls and rings and interesting patterns, it is probably jasper.

Banded jasper comes in many colors. This one is called tiger jasper for obvious reasons. This particular sample is not polished, just dipped in water to make the colors show up well in the photo.

Onyx ***(awn-ix)*** often comes in black, though this sample is red. Oddly enough, the name comes from the Greek word for fingernail.

Heliotrope (also known as "bloodstone") is dark green with specks of red hematite. In ancient times it was said to have magical powers, even invisibility.

(Photo: Benutzer Ra'ike,Wiki)



Opals have water as part of their chemical recipe. They came from magma that had a lot of water mixed into it. Opals are the national gemstone of Australia.

Chalcedony is the stone of which **petrified wood** is often made. Water that was saturated (completely filled) with silicon seeped into the dead tree and filled in the spaces where the living cells had once been. This process occurred not too long after the tree died, but before it had time to rot. The trees had to have been immersed in mineral-rich liquid. It's not a process that can occur in a dry environment as far as we know.

Activity 3.1 Comprehension self-check

Can you remember the answers to these questions? If not, go back to the text and see if you can find the answers. When you are done, you can check your answers using the answer key at the back of the book.

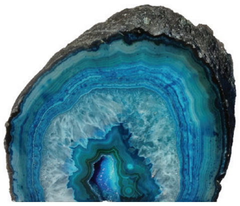
1) The crust of the earth is made of mostly these two elements: _____________ and _____________.
2) Both carbon and silicon have how many electrons in their outer shell? _____
3) How many electrons would carbon and silicon like to have in their outer shell? ____
4) When silicon bonds to oxygen, it makes this type of bond: _____________
5) When sodium bonds to chlorine they make this kind of bond: ____________
6) What element does carbon bond with to make a methane (natural gas) molecule? ___________
7) How many electrons are in oxygen's outer shell? ____ How many electrons does it want to gain? _____
8) Name two metal atoms that might bond with the oxygens on a silicon tetrahedron: _________ and ___________
9) Name a type of mineral that is a solid solution, having tetrahedrons surrounded by metal atoms: _____________
10) What group of minerals has as its basic structure, long lines of tetrahedrons? p______________
11) Name a mineral from this double-chain group that you would never find in a mineral collection: ____________
12) Name a mineral from this double-chain group that would likely be found in a mineral collection: _____________
13) Name the group of minerals that has as its structure sheets of tetrahedrons: ________
14) A mineral from this sheet group that is dark in color is: ___________ And light in color? _____________
15) Do these sheet silicates have any uses in technology? ____
16) True or false? Ancient peoples used feldspar as a source (an ore) of metals such as iron and aluminum. ___
17) Besides silicon and oxygen, feldspars have these elements: __________ , ___________ and __________
18) Do feldspars contain any iron or magnesium? _____ What is a possible reason for this? ___________________
____
19) Feldspar and quartz have this basic structure: f____________
20) True or false? The word "quartz" means "hard." ___
21) Which one of these is NOT a type of quartz? a) amethyst b) gypsum c) citrine
22) What happens if you squeeze a quartz crystal? ____
23) When you add this mineral to a silicon crystal, it seems to make it harder: ______________
24) This gemstone is number 8 on the Mohs hardness scale: ________
25) This gemstone has both aluminum and beryllium added to the silicon structure. Its mineral name is __________ and when it is a green gemstone it is called _____________.
26) What happens to garnets that are not good enough to be gemstones? __________________________________
27) What type of gem always has the element boron in it? t________________
28) Rubies and sapphires are actually this mineral: ___________
29) What is the very old name for what we call cryptocrystalline silicates? c___________
30) What does "crypto" mean? ____________
31) Which one of these probably started out as an air bubble? a) jasper b) onyx c) carnelian d) geode
32) Which cryptocrystalline sometimes has patterns that look like imaginary landscapes? _________
33) Which cryptocrystalline has water as part of its chemical recipe? ________
34) Which cryptocrystalline was used for signet rings because wax would not stick to it? ______________
35) In ancient times this was called the "invisibility stone." ______________

Activity 3.2 Videos

Go to the “Rocks and Dirt” playlist at: **www.YouTube.com/TheBasementWorkshop**, and watch the videos on quartz and other silicates.

Activity 3.3 Recipe review

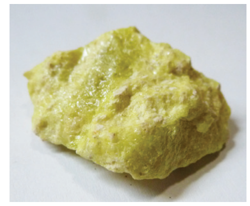
Can you match each picture to its chemical recipe? (You can use information in the text to help you.)

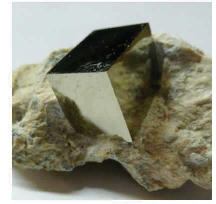

A


B


C

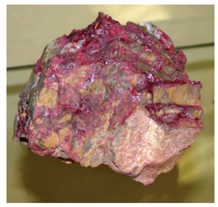

D


E


F


G

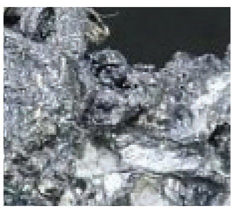

H


I (cinnabar)


J


K (graphite)


L (diamond)


M


N


O (halite)


P


Q


R

1) Au ______
2) Ag ______
3) S ______
4) C ______
5) C ______

6) FeS_2 ______
7) $BaSO_4$ ______
8) HgS ______
9) NaCl ______
10) CaF_2 ______

11) $(Fe,Mg)SiO_4$ ______
12) $KAlSi_3O_8$ ______
13) $Ca_3Al_2Si_3O_{12}$ ______
14) SiO_2 ______
15) SiO_2 ______

16) SiO_2 ______
17) $CaCO_3$ ______
18) organic ______

Activity 3.4 A picture puzzle

Look carefully at the ends of these petrified logs then look at the picture at a living branch that was cracked. Then think about how stone splits. When did these logs break—before or after they were petrified?

Activity 3.5 Read about talc

Talc is a member of the silicate family, but isn't like any of the others. You'll remember that talc is number 1 on the Mohs hardness scale. You can scratch it with your fingernail. It also feels "soapy." If you pick up a mineral specimen and it feels soapy and you can scratch it, it must be talc. Gypsum is also very soft, but doesn't feel soapy. The reason talc feels soapy is because it is related to clay, and you know how slimy wet clay feels. Talc is classified as a "clay mineral," which is a subset of the silicate group. Like the cryptocrystalline silicates, talc has extremely small crystals. Strangely, these crystals can be tiny pieces of sheets, like we find in mica. The microscopic sheets can slip around above and below each other.

Talc's recipe is $Mg_3Si_4O_{10}(OH)_2$. Geologists think that the (OH) on the end came from water molecules (H_2O) as the talc was forming. It may have come from olivine or pyroxene or amphibole that was under pressure, and had lots of water and carbon dioxide in the environment.

The word "talc" is very old. It can be traced back centuries, through Latin, Arabic and Persian. The name doesn't mean anything; it is simply the name for this mineral. Ancient peoples sometimes carved it (since it was so soft) or used it as a lubricant, since it is slippery. In modern times, many more uses have been discovered for talc. The most well-known use is as bath powder or "baby powder." (This use for talc is being discouraged now, as there are concerns about long-term effects on the lungs.) It is used to make paper, plastics, paint, medicines, cosmetics, ceramics and even as an ingredient in some foods.

Recently, there has been some concern over whether powdered talc can cause lung disease such as lung cancer. Lab rats were forced to breathe talc dust for six hours a day, five days a week, for over a year. Only then did some of them start to get lung cancer. So yes, talc can cause health problems if you breathe enough of it, like the rats did. However, talc is still considered to be "generally safe" because the amount of talc a human would be exposed to is extremely small.

Activity 3.6 What is a carat?

If you decide to learn more about gemstones, you will certainly run into this word: **carat**. Gems are measured in carats, not in ounces or grams. The word carat is very old. English borrowed it from Italian, which borrowed it from Arabic, which borrowed it from Greek. The original meaning seems to have been "carob seed." Carob seeds were used as a standard of weight in the ancient world. In modern times, a carat has been defined as 200 milligrams, which is the same as 0.2 g (two tenths, or one fifth of a gram). That means 1 gram equals 5 carats.

So, could you measure other things in carats? Sure, why not? How many carats would these objects be?

1) An ice cube that weighs 25 grams: ______ carats
2) A carrot that weighs 100 grams: ______ carats
3) A marble that weighs 10 grams: _______ carats
4) A banana that weighs 235 grams: _________ carats
5) A piece of talc that weighs 6 ounces: ________ carats (1 ounce is about 28 grams)

Carat is one of the four ways that gems are evaluated. All four ways start with the letter C: carat, color, clarity, cut. Carat is how much it weighs, color is important because some are more rare than others, clarity means how transparent it is (clear is good), and cut means the shape of the gem and how perfect its facets (sides) are.

ANSWER KEY

Chapter 1

1.1

1) False 2) b 3) Fire, water, air, earth 4) no 5) turn things into gold, cure any disease 6) bismuth
7) Elements make minerals, minerals make rocks. 8) phosphorus 9) "demon" (Because the nickel ore would not produce copper. Not understanding why, the miners thought the ore was cursed.) 10) Periodic Table 11) John Dalton
12) number of protons 13) 15 14) True 15) True

1.3

1) Hydrogen	7) Phosphorus	13) Copper
2) Carbon	8) Sulfur	14) Chlorine
3) Oxygen	9) Fluorine	15) Silicon
4) Sodium	10) Calcium	16) Potassium
5) Magnesium	11) Iron	17) Gold
6) Aluminum	12) Silver	18) Zinc

Chapter 2

2.1

1) F 2) T 3) coal, amber 4) Bronze is man-made, not naturally occurring. 5) F 6) carbon 7) red, blue 8) salt
9) pyrite 10) barite 11) hexagonal 12) rhombohedral 13) chalk or talc (or another if you know of one)
14) Lets light through but you can't see through it. 15) diamond, quartz, calcite, others you know of/ any opaque mineral
16) Rub it on a streak plate and it will leave a black mark. 17) talc, diamond 18) no 19) corundum 20) luster
21) T 22) biotite 23) water 24) gold 25) specific gravity

2.3

1) native elements, turquoise does not belong 2) silicates, apatite does not belong
3) carbonates, gypsum does not belong 4) sulfides, bismuth does not belong
5) sulfates, calcite does not belong 6) oxides, feldspar does not belong 7) halides, barite does not belong

2.4

ACROSS:
4) sphalerite 5) hematite 8) gypsum 11) beryl 14) corundum 17) pyrite 19) topaz 20) magnetite
23) talc 24) feldspar
DOWN:
1) halite 2) cinnabar 3) biotite 6) barite 7) malachite 8) galena 9) pitchblende 10) graphite
12) fluorite 13) diamond 15) ulexite 16) quartz 18) bauxite 21) apatite 22) calcite

Chapter 3

3.1

1) silicon and oxygen 2) 4 3) 8 4) covalent 5) ionic 6) hydrogen 7) 6, 2 8) iron (Fe) and magnesium (Mg)
9) olivine 10) pyroxenes 11) asbestos 12) hornblende 13) mica 14) dark: biotite light: muscovite
15) yes 16) false 17) aluminum (Al), potassium (K), and sodium (Na) 18) No. Possibly because all the olivine, pyroxenes, amphilboles, and mica used up all the Fe and Mg when they were forming. 19) framework 20) true
21) b) gypsum 22) It produces a small electrical current. (piezoelectric effect) 23) aluminum 24) topaz
25) beryl, emerald 26) They are used as abrasives. 27) tourmaline 28) corundum 29) chalcedony
30) hidden 31) d) geode 32) jasper 33) opal 34) carnelian 35) heliotrope

3.3

1) J 2) M 3) E 4) K or L 5) K or L 6) F 7) R 8) I 9) O 10) N 11) Q 12) G 13) C
14) A or D or P 15) A or D or P 16) A or D or P 17) H 18) B

3.6

1) 125 2) 500 3) 50 4) 1175 5) 840

Chapter 4

4.1

IGNEOUS

1) extrusive 2) lava 3) plutonic, Pluto 4) a 5) iron, Fe, and magnesium, Mg 6) olivine 7) feldspar, silicon
8) T 9) b 10) andesite, Andes 11) c 12) b 13) b 14) d 15) a 16) b 17) c 18) b 19) d 20) a
21) a 22) felsic, mafic 23) c 24) b 25) d

SEDIMENTARY

26) cobble 27) clay 28) T 29) b 30) F 31) T 32) more 33) F 34) shale 35) siltstone 36) sandstone
37) sandstone 38) c 39) smooth, angular 40) T 41) T 42) b 43) a 44) F 45) halite 46) d 47) c
48) F 49) 2 50) a 51) c 52) F 53) F 54) T 55) F 56) c 57) It makes sparks (good for lighting fires).
58) egg 59) T 60) a

METAMORPHIC

61) change, shape 62) gneiss 63) schist 64) heat 65) heat and pressure 66) granite, slate
67) a 68) split 69) d 70) T

4.3

IGNEOUS PAIRS don't have to be the order listed. They can be reversed, except for number 10.
1) gabbro, granite 2) pumice, obsidian 3) scoria, pumice 4) basalt, rhyolite 5) granite, obsidian
6) diorite, andesite 7) basalt, tuff 8) gabbro, basalt 9) tuff, obsidian 10) Continents are granite, ocean is basalt.

4.4

1) G 2) E 3) F 4) B 5) C 6) J 7) D 8) I 9) A 10) H

4.5

1) coal 2) chert 3) slate 4) cobbles 5) gypsum 6) flint 7) halite (salt) 8) marble 9) limestone
10) granite 11) quartzite 12) scoria 13) sandstone 14) pumice
What is not so useful? I vote for siltstone, mica schist, travertine and conglomerate.
A lot of the lesser quality ingenous rocks, such as tuff or rhyolite, can be used as building stone if nothing better is in the area. They are not ideal but they have been used in the past.

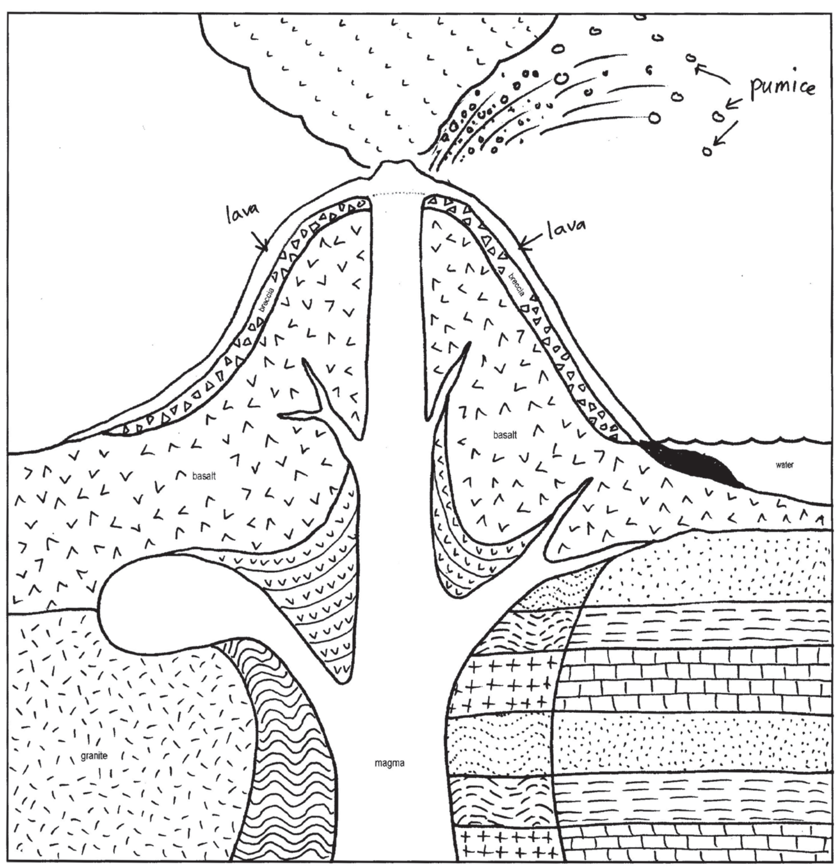
4.9

Students may use colors as well as patterns. Sometimes geologists use both at the same time, putting a light layer of color on top of the patterns.

Notice that magma is called lava after it comes out of the volcano.

The order of the layers of sedimentary rock is variable.

This does NOT represent an exact location that a geologist actually observed. It is only intended as a way to practice lithologic patterns and to apply general concepts learned in the chapter.



CHAPTER 1

1) PERIODIC "SCAVENGER HUNT"

Copy the following page and have the students use a Periodic Table to solve the clues. (The Periodic Table at the top of the page will not be sufficient. It does not contain enough information.) There are lots of very nice Periodic Tables online. Just Google "Periodic Table."

Answer key:
1) 79 2) Cf, californium 3) uranium, 92 4) tellurium 5) 3
6) K, Na, Fe, Ag, Au, Sn, Sb, W, Hg, Pb 7) 43 technetium 8) Br, bromine, and Hg, mercury
9) Ge, germanium, Sn, tin, and Pb, lead 10) Rn, radon 11) I, iodine, and At, astatine
12) U, uranium, Np, neptunium, Pu, plutonium 13) Po, polonium and Fr, francium, Cm, curium 14) Mg, magnesium, and Ca, calcium 15) Er, erbium, Tb, terbium, Y, yttrium and Yb, ytterbium 16) Z: 2 A: 7 P: 9 J: 0
17) N, nitrogen, O, oxygen, P, phosphorus, S, sulfur 18) 99 19) Pb, lead 20) Sn, tin

2) "POINT TO THE ELEMENT" laser pointer challenge (group game)

You will need:
- a Periodic Table poster
- two laser pointers

This is a team game, although you could play it with as few as 2 players. If you can possibly find two laser points with different colors, such as red and green, this is ideal. However, you can make it work even with the same color. The kids will know which dot is theirs.

Divide the students up into two teams. The students will take turns using the laser pointer, one person per team. The adult in charge will call out clues and the first team to land the red laser dot on the correct element wins the round.

Suggested clues:
1) You might want to start out with just finding the letters. Call out the letters of common elements such as carbon, C, or nitrogen, N, or helium, He. For harder elements, choose minerals they are likely to see in this book. Take a look at the poster on page 69 for ideas.
2) If your students are familiar with a lot of the names and letters, call out just the name, such as "Magnesium."
3) If your students know a little more about the elements, you might want to create suitable clues for their knowledge base. Easy clues might be, "I am thinking of an element that you can put into a balloon," or "I'm thinking of the element that the Romans used to make pipes." Tailor the clues to what you think your students might know or be able to figure out.

3) LEARN MORE about a scientist

If you need to lenghten the amount of time you spend on this chapter, you can always ask the students to choose a scientist from the chapter and learn a little more about him/her. Books and websites are fine, but you can also tap into video documentaries via YouTube (with parental supervision). (Or Hulu, or other video services if you have them.)

PERIODIC TABLE SCAVENGER HUNT

hydrogen 1 H 1.0079																	helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]	nihonium 113 Nh [284]	flerovium 114 Fl [289]	moscovium 115 Mc [288]	livermorium 116 Lv [293]	tennessine 117 Ts [294]	oganesson 118 Og [294]

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
**Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

1) If you're digging for gold, you are searching for element number ____

2) The most expensive element in the world is number 98. It is a man-made element and costs about 27 million US dollars per gram to produce. What is the name of this element? ________________

3) In general, elements get larger as the atomic numbers get higher. The largest element (highest number) that is natural and not man-made is _________ at number ____. (HINT: Use the symbol key in the lower left corner.)

4) The element selenium was named after the moon. The scientist who discovered the element right underneath it thought that the moon should be near the earth, so he used the Latin name for "earth" and named it ___________.

5) The best batteries in the world have the element lithium in them. Lithium is a small atom. Its atomic number is ___

6) There are 10 elements with symbols that are different from the first letters of their name. What are the symbols?
__K__, ______, ______, ______, ______, ______, ______, ______, ______, ______

7) What is the smallest (lowest number) radioactive element? ____________

8) Which two elements are liquids at room temperature? ____________ and _____________ *(according to the table in this book)*

9) The elements carbon, C, and silicon, Si, are key ingredients in many minerals. They are both in the same column, so that means that they have similar chemical properties. What other elements are in this column? ____________, ________, and _________.

10) The elements in the column on the far right are called the noble gases. They are the only elements that have no interest in making molecules. All of the noble gases are used in light bulbs except this one, because it is radioactive: ________

11) The column just to the left of the noble gases is called the "halogens" (salt-makers). They combine with the very first column on the left side of the table to make salts. Only two halogens are solids. They are __________ and ___________

12) Three elements are named after planets. Which ones? _______________, _______________, and _______________

13) Marie Curie discovered these elements. She named one after her home country of Poland and the other after her adopted country, France. They are _______________ and ______________ (Which element is named after her? ___________)

14) Iron and magnesium are very important elements in the chemistry of volcanic rocks. Calcium is the key to understanding limestone. Which two of these elements are in the same column? _____________ and ______________

15) Four elements are named after Ytterby, a small town in Sweden: Erbium, Terbium, ______________ and _______________

16) How many element *symbols* begin with the letter Z? _____ the letter A? _____ the letter P? _____ the letter J? _____

17) There is only one place on the table where you will find four elements sitting in a 2x2 square, where all four elements have only one letter in their symbol. What four elements are these? ________, ________, _________, and __________

18) What is the atomic number of the element named after Albert Einstein? ____

19) In radioactive decay, an atom's nucleus falls apart, often spitting out two protons and two neutrons. If a uranium atom decays 5 times (2 protons lost each time) what elements does it end up as? __________

20) Which element has the fewest number of letters in its name? _____

CHAPTER 2

1) "MAKE FIVE" A CARD GAME ABOUT MINERAL RECIPES

NOTE: This game also appears in the curriculum titled "The Elements" by the same author. If you have already done *The Elements* curriculum, and therefore have already played this game, you can decide to skip it here. Or you can get out your old game and play it again! (Your students will find that they have a much better understanding of those chemical recipes than they did the last time they played.)

You will need:
• copies of the pattern pages copied onto card stock (If you purchased a hard copy of this book and would like to be able to print pages directly from your computer printer or take the file to a print shop, use this web address to download digital copies of the pattern pages: www.ellenjmchenry.com/rocks-and-dirt)
(NOTE: Another option would be to cut these pages out of this book and use them.)
• scissors
• white glue (if you are assembling the paper dice)
• If you are using wooden cubes for the dice, you'll also need one or more markers.
(In a pinch, just take a fine point marker (red?) and write on real die. Everyone can just ignore the dots.)

NOTE: If you can get three wooden cubes, this is the best option. Most craft stores sell wooden cubes individually or in small units and fairly inexpensively. If you want this game to be sturdy enough to survive future uses, consider using wooden cubes.

Preparation:
1) Cut out the dice patterns (copied onto heavy card stock) and make into cubes, using small dabs of white glue on the tabs. Or, write the symbols on wooden dice or even regular dice.
2) Cut apart the 16 mineral cards.

How to play:
Place the mineral cards on the table, face up, so they form a 4 x 4 square. Each player will have a turn rolling all three dice at once. The goal is to roll the ingredients to form a mineral. (One roll of the three dice per player per turn.) For example, if the first player rolls Cu, Fe, and S, he should notice that those are the ingredients of chalcopyrite. Therefore, that player picks up the chalcopyrite card. If the next player rolls Ca, C, and WILD, he could make the wild card into O, and be eligible to pick up calcite. (To speed up the game, you can allow players to roll twice on their turn. The second roll can be one, two or all three cubes.)
The first player to collect five cards wins the game.

2) CUT-AND-ASSEMBLE PAPER CRYSTAL SHAPES

You will need:
• copies of the pattern pages printed onto card stock (any color)
• scissors
• white glue (or a really good glue stick, the kind made for adults)
• paper clips or clothespins to hold joints while they dry (optional, but recommended)

Directions:
1) Copy the pattern pages onto card stock. (Tip: Card stock feeds through most computer printers, so if getting to a copy shop is hard, keep a supply of card stock on hand so you can print using your computer's printer.)
NOTE: If you have a hard copy of this book and would like a digital file to print from, go to: www.ellenjmchenry.com/rocks-and-dirt
2) Cut out the crystal shapes. Cut on all solid lines.
3) You may want to "score" the dotted fold lines using a ruler and a very sharp pencil. (Actually, a compass point works the best. But you can also use a nail, a dead ball point pen, or a scissor point if you are gentle.) Run the sharp point along each fold line. Press hard enough so that the paper is slightly dented (scratched). This will make folding very easy.
4) Pre-fold along all the fold lines. (Don't be overly concerned about folding the wrong way because any pre-folding is better than none at all.)
5) Put a SMALL amount of white glue on one or two of the tabs. White glue is very strong and you don't need a lot of it. Press and hold those one or two joints and count to ten slowly. If you don't have the time or patience to hold the joints, clip them with paper clips or clothespins and let them dry for a few minutes.

NOTE: The most common mistake students make when assembling paper projects is to use too much glue. If glue oozes out of the cracks when you press the joint, you've used too much glue. One way to help students avoid using too much glue is to tell them not to squeeze it directly from the bottle onto the tab. Have them put a few drops onto a piece of paper and just dip the tip of a finger into it, or use a toothpick or cotton swab to apply the glue.

TIP: You may want to work on two models at a time. While one set of joints is drying, you can be working on another one.

6) When you get to the last joints, you just have to do the best you can to get the joints to stick. You can try folding the tabs just barely enough to get them in, so that after they are in they will apply a little counter pressure and push back up against the surface. Or, you could resort to using a flattened out paper clip that you can poke into the adjacent corner, giving you an extra "hand" (albeit a skinny one) inside the figure. You might not have to resort to this though. The best tool you've got when doing a project like this is PATIENCE.

Display suggestion: The complete figures make a nice mobile. (They are also less likely to be damaged while hanging up.)

3) OBSERVING TINY MINERAL CRYSTALS

You will need:

• a 40x magnifier (or at least 20x) (TIP: Amazon sells some good magnifiers at reasonable prices.)
• salt
• epsom salt (easily purchased from the pharmacy section of any store, and very inexpensive)
• sugar
• sand (several kinds of sand from different sources is ideal)

What to do:

Look carefully at each type of crystal. The salt should look like little cubes, and the epsom salt should like little 6-sided hexagonal crystals. Sugar crystals might be a bit 6-sided, but they also might have random shapes. Sand is very interesting to look at as long as your magnification is high enough. You should be able to see tiny quartz crystals, bits of pink feldspar, and some black mica, as well as some miscellaneous rounded (and probably unidentifiable) sedimentary rocks. The mix of rocks in minerals in sand is unique to each location on earth. Sand from various beaches around the world have their own particular blend of minerals.

If you don't have a magnifier available, you can use the pictures on the following pages. Real life observation is better, of course, because you can see the crystals in 3D, which is so much better than a flat picture.

4) LAB: MINERAL IDENTIFICATION

Purchase a mineral identification kit from a science supply store. Follow the instructions that come with the kit. If you search Amazon, you can find a wide variety of sizes and prices. The kits start at about $15 USD and go up to $50 USD. If you are on a budget and don't want to spend money on this particular activity, that's okay. You don't absolutely have to do this lab. (Perhaps you can wait until you are done with chapter 4, and then go out in your neighborhood and look at some local rocks and try to identify them.) Another substitute for doing this lab is watching some mineral ID vidoes on YouTube.

5) LAB: MEASURING DENSITY— a lab for older students (See activity 6 for a lab for all ages)

This lab is a bit too tedious for students younger than 11 or 12.

Allow at least an hour. Doing it in a group slows you down A LOT. In a group setting, the entire lab might take 90 min.

Make copies of the following lab pages. (You can print from a digital copy by going to www.ellenjmchenry.com/rocks-and-dirt) If you want to shorten the time needed to do the lab, precut the food cubes ahead of time. If you want to do this lab with younger students (under 12) precutting is highly recommended in order to avoid issues with knives and razor blades. You don't have to cut a set for each student, however. Cubes can be shared around.

NOTE: This seems like a lot of bother just to explain density, but as my group worked through it, I could see several of them having "lightbulb" moments. ("Hey, look! Even if I cut the apple cube in half, the density doesn't change!")

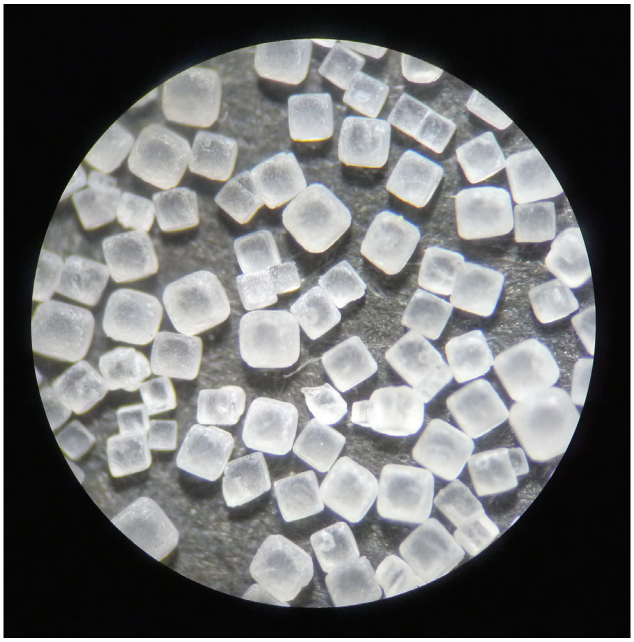
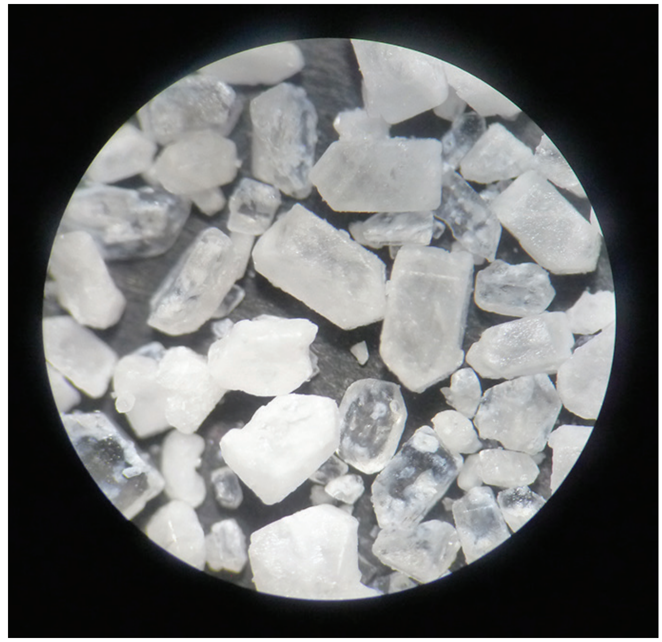
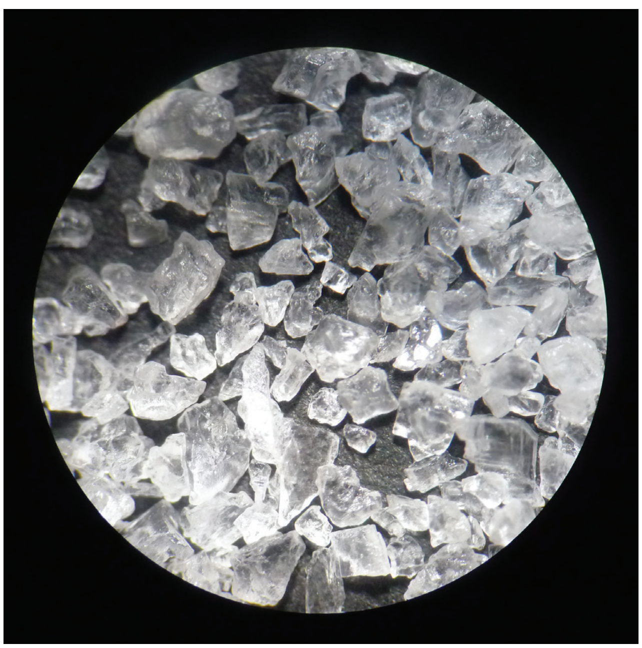


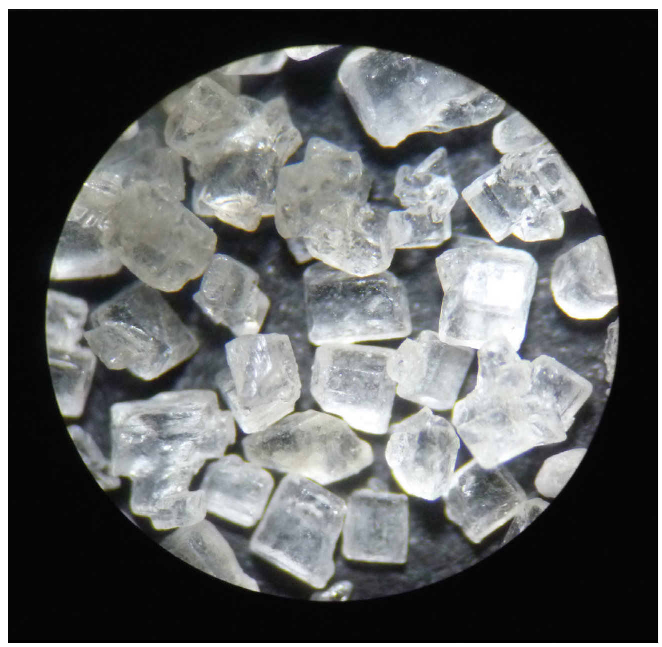
table salt   40x



Epsom salt 20x

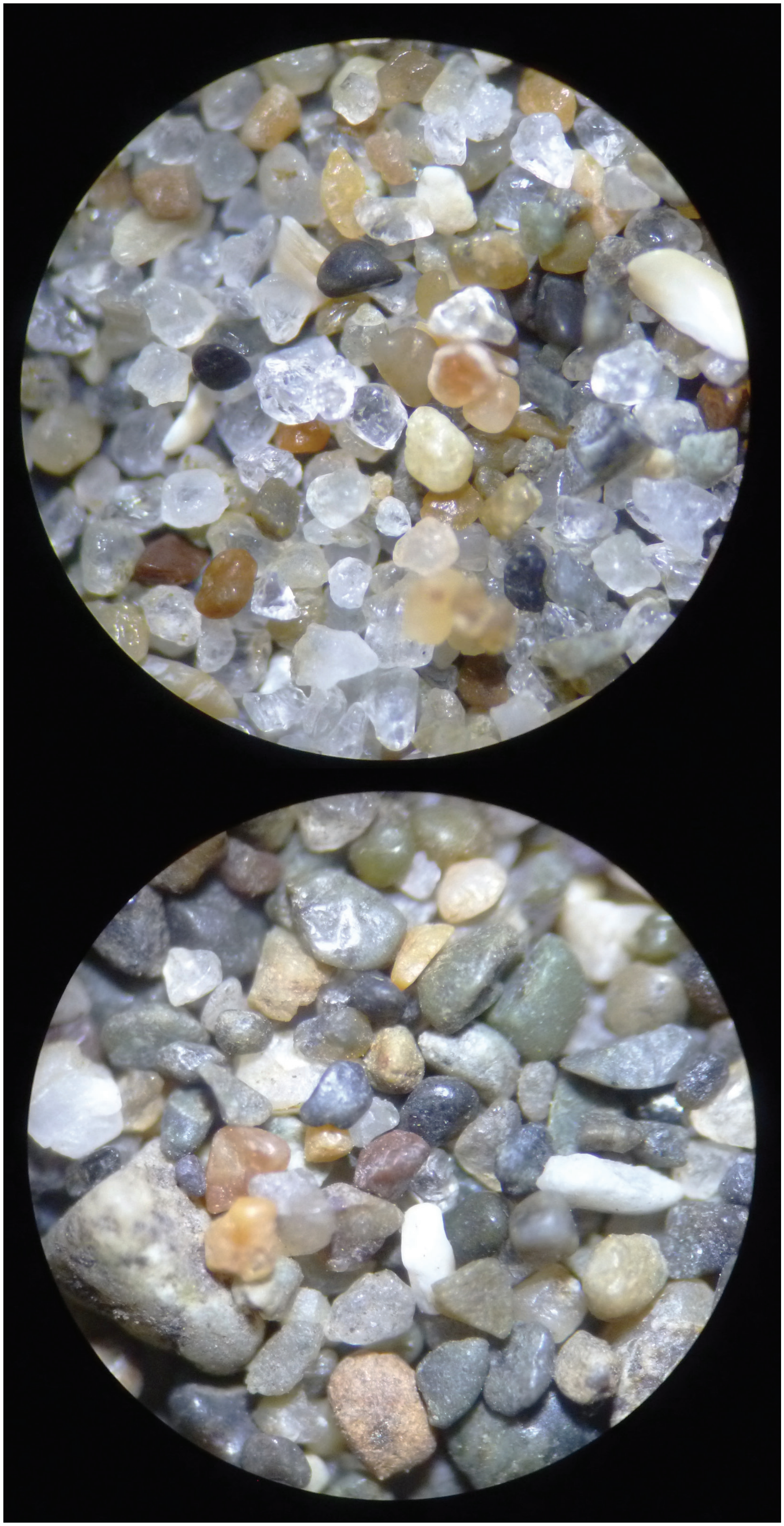


Himalayan salt   20x



raw cane sugar 40x

Sand from two different California beaches   40x



DENSITY LAB

Name ______________________

INTRODUCTION:

Density is the word we use to define how tightly packed the molecules are in a certain substance. Some substances, such as stone, have many atoms packed closely together, giving them a high density and making them feel heavy. Other substances, such as foam, have many fewer atoms in the same amount of space, making them feel light. The size of the atoms themselves also affects the measurement of density. For example, atoms of gold, mercury and lead are very large, much larger than aluminum or copper atoms. The larger atoms have more protons and neutrons in their nuclei, adding to the overall mass and density of the element.

Density is a clue that can help mineralogists figure out the identity of a sample. Two minerals might look exactly the same but have different densities. Therefore, all rock and mineral guide books will list the density along with the other properties of the rock or mineral. However, some books prefer to use the term "specific gravity" instead of density. Specific gravity compares the density of the mineral to the density of water. Since the density of water is exactly 1.0, the specific gravity number is always the same as the density number. It doesn't make any practical difference which term you use. Specific gravity is technically more correct, but you still see the word density, too.

Since we will actually be comparing some substances to water, we'll go ahead and switch over to using the term specific gravity. Don't let it throw you! We are still talking about density.

PART 1: Comparing the specific gravity of various substances to the specific gravity of water

You will need:

- a small graduated cylinder (10 ml is best for this first part, but 25 ml is okay. 50 ml will do if you don't have a smaller one.)
- a balance (digital scale) (Smaller cylinders give you a more accurate measurement.)
- a sharp knife or razor blade (and adult supervision)
- a bowl of water
- vegetable oil
- a pipette (eye dropper)
- a metric ruler
- a variety of solid "waterproof" foods, such as potato, apple, pear, banana, cheese, carrot, squash, cucumber, eggplant, broccoli stem, egg white, cantaloupe (You can use non-food items, too, such as foam. Just make sure anything you choose will be able to go into a bowl of water and not disintegrate. That eliminates bread. Also, make sure you will be able to cut the substance safely. Stay away from nuts or other hard items that might make the knife or razor slip onto your finger.)

You don't have to use this entire list. Just choose a handful of items from what you have around the house.

TIP: Try to use apple, if you can, as it will give an interesting result.

What to do:

1) Choose 4-6 solid items that you will test. Use the metric ruler and the knife or razor to cut cubes of each food that are EXACTLY one centimeter on a side. Be patient and try to get your centimeter cubes cut as accurately as possible. The more accurate you are, the better your measured results will be.

2) Use the balance (set on grams) to record the mass of each cube. Write the name of the substance on the line and then record its mass in grams. (Be sure to keep track of which cube is what, since some of the cubes might look very similar.)

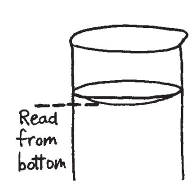
MASSES OF MY CUBES: *(you don't have to use all the lines)*

__________________ = ______ grams __________________ = ______ grams _________________ = ______ grams

__________________ = ______ grams __________________ = ______ grams _________________ = ______ grams

__________________ = ______ grams __________________ = ______ grams _________________ = ______ grams

4) Your cylinder is marked with lines. If you are using a 25 ml or a 50 ml cylinder, those lines will probably represent 1 milliliter (ml). If you are working with another size, figure out what each line represents. Pour water into your cylinder until the top of the water is EXACTLY at 20 ml for the 25 ml size, or 40 ml for the 50 ml size. Use your pipette (eye dropper) to adjust the level of the water until it looks exactly right. (TIP: If you see a slight dip in the surface of the water, this is called the meniscus. Read the level of the water from the bottom of the meniscus (the low point) not from where the water hits the sides of the cylinder.)



5) Put your cylinder onto the balance and then turn it on. The scale might read "0." This is good. If your scale reads somethign other than 0, try hitting the TARE button if you have one. The TARE button resets the starting point for 0. In effect, the TARE button tells the balance to ignore all that weight that is on it, and just weigh what is coming next. If you don't have a TARE button, just write down the mass it is reading right now so you don't forget. You'll just add one to that number in step 7.

6) Take your pipette/dropper and add water until it looks like you have added exactly one ml to the cylinder. Remember to read from the low point of the water (the meniscus).

7) Look at the number of grams the balance is reading now. Did it go up by exactly 1 gram, or very close to that? If you could be perfectly precise, it would go up by exactly 1.

8) Now try the reverse. Don't look at the cylinder while you are dropping in water. Watch the numbers on the balance. When you've added exactly one gram, stop and look at the water level in the cylinder. Did you add 1 ml?
(Don't throw out that water. Leave it in the cylinder.)

1 ml of water has a mass of 1 gram. What is the density of water? Density is calculated like this:

$$\text{Density} = \frac{\text{grams}}{\text{milliliters}}$$

In this case, we have 1 gram/1 ml. 1 divided by 1 is 1, so **water has a density of 1**.

Water is the standard by which all other substances on earth are judged. If a mineral has a density of 2, that means it has a density twice that of water. A substance with a density of 0.5 has a density half that of water. Everything is compared to water.

Substances sort themselves out according to their densities. Higher densities go down, lower densities go up. This principle works in air, in liquids, and sometimes in solids as well. It is easy to see this principle at work in water. Substances with a density greater than 1.0 will sink, and those with a density less than 1.0 will float. Let's test our food cubes!

9) Let's test the density of another liquid. You will add exactly 1 gram of oil to the cylinder of water. Use the pipette/dropper to add the oil drop by drop, as you watch the numbers go up on the balance. Add exactly 1 gram.

10) Now look at the level of fluid in the balance. The oil will be on top of the water. Did you add exactly 1 ml oil? What does that tell you about the density of the oil? (The fact that it is floating on the water confirms what your numbers are telling you.)

11) The size of your cubes was not chosen at random. One solid cubic centimeter happens to have the same volume as one liquid milliliter. That makes calculating the density of these foods very easy! Using the density formula, Density= g/ml, we can put in "1" as the bottom number. That means we'll be dividing by 1, which means our number won't change. So those measurements we did on the cubes ARE the densities. All we need to do is look at those numbers and see which ones are greater than or less than 1.

12) Pick up a cube, check the number of grams, and then predict whether it will sink or float. Then put it into the bowl of water and see if you are right.

13) Lastly, put one of the sinking cubes into the cylinder. How much do you think it will raise the water level? (Make sure you read the cylinder level before you put the cube in.) Do your results confirm that 1 ml = 1 cc? (cc = cubic centimeter)

<u>EXTENSION QUESTIONS</u>:

1) If you cut a food block in half, will half a block have the same density as the whole block? You might want to test two of your blocks, one that floats and one that sinks. Does a very small piece act the same way as the whole piece did? What would happen of you put a whole apple/potato/zucchini/carrot into a large tub of water? Can you accurately predict whether the whole fruit or vegetable will float or sink?

2) Liquid mercury has a specific gravity of 5.43 g/ml. What would happen if you poured some liquid mercury into water? What would happen if you poured the mercury into a glass of vegetable oil?

2) Copper has a density of 8.9. What would happen if you put a piece of copper into liquid mercury? Titanium has a density of 34.5. What would it do in liquid mercury?

PART 2: Calculating the specific gravity of some mineral samples

You will need:
- a small graduated cylinder (25 ml or 50 ml, depending on your sample sizes)
- a balance
- water
- some small minerals or rocks (must fit into your graduated cylinder)
- a calculator

In the last section, our samples were perfect cubes—cubic centimeters that were equal to 1 ml. It was easy to find the density because the number on the bottom of the equation was 1. In this section, we will use things that are not cubic and will need to use the graduated cylinder to help us find their volume, plus a calculator (or your brain) to do the math.

What to do:

1) First, hold your mineral samples and compare how heavy they are. They are probably of different sizes, so comparing densities will be difficult. If you can, try to judge their densities based on their weight and size. Which one would you predict as being the most dense? Which one is the least dense? Take a guess before you measure them. See how good your brain is at estimating density. You might be surprised at how accurate your brain turns out to be!

2) Weigh each of your mineral samples. Keep track of which is which by numbering them or giving them names if you know what they are (calcite, granite, etc.). Write the name or number on a line and then now many grams it weighs. Include the number to the right of the decimal point, such as "19.45." (You might not need all these lines.)

________________ = ______ grams ________________ = ______ grams ________________ = ______ grams

________________ = ______ grams ________________ = ______ grams ________________ = ______ grams

2) Now choose one of the mineral samples and a graduated cylinder. You want to choose the smallest size cylinder that the sample will fit into. Smaller cylinders always give you a more accurate measure.

3) Fill the cylinder about halfway full with water, but make sure that the water line is exactly at a nice even number such as 20 or 30. Use the dropper to get the water line (the bottom of the meniscus) exactly at the mark.

4) Slide the sample gently down into the cylinder. You don't want water splashing out because you just carefully measured the level of the water. Make sure the sample is completely covered by the water. You will get an incorrect reading if it is sticking up out of the water. The sample will "displace" a volume of water equal to its volume. In other words, the amount that the water rises is the volume of the sample. Record the volume of each sample.

________________ = ______ ml ________________ = ______ ml ________________ = ______ ml

________________ = ______ ml ________________ = ______ ml ________________ = ______ ml

Remember, 1 ml equals 1 cubic centimeter, so this ml measure is also giving us the volume of the sample in centimeters.

5) Finally, calculate the density of each one by dividing the grams by the mls. Density = g/ml

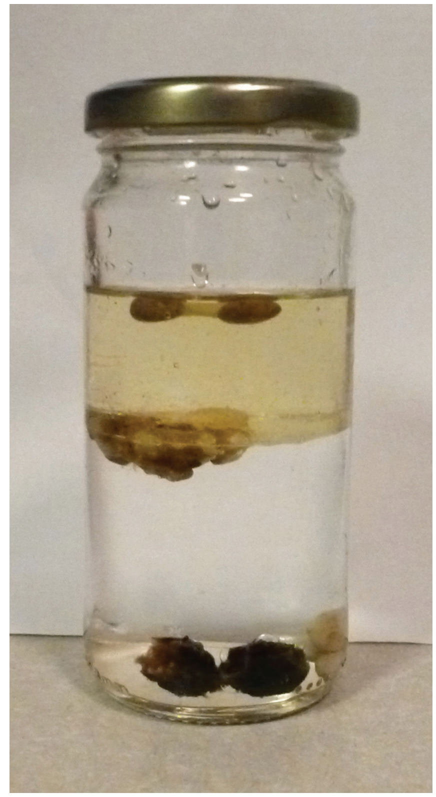
________________ = ______ density ________________ = ______ density ________________ = ______ density

________________ = ______ density ________________ = ______ density ________________ = ______ density

6) Calculate the specific gravity of each sample. This is a no-brainer. The specific gravity of a sample is its density divided by the specific gravity of water, which is 1. Any number divided by 1 stays the same. So the density and the specific gravity are the same. No calculations needed!

7) Compare your results to your original guesses. Did you get any right?

6) LAB: OBSERVING DENSITY (a qualitative lab for all ages)



You will need:
- a tall glass jar (I used an old olive jar-- perfect size and shape, and has lid)
  TIP: Tall glass jars will come in handy in future chapters, too.
- water
- vegetable oil
- various small items from around the kitchen, such as dried beans, raisins, nuts, dried fruit, carrot, apple, pasta noodles, etc. (TIP: Include walnuts, if possible.)
- optional: empty gel caps (oblong capsules that powdered vitamins and medicines come in) If you have vitamin gel caps, you can pull the capsules apart and empty them.

What to do:

1) First, fill the jar halfway with water. Then add an inch or so of oil.

2) Screw on the lid and turn the jar upside down. Then turn it back again. Students should notice that no matter which way you turn it, the oil always goes to the top. This is because the oil is less dense than the water. Less dense things will always rise (if they can) and say above more dense things. This principle holds for solids, liquid, and gases.

3) Begin adding small items, one at a time. You might even want them to predict what will happen. Things that are more dense than water will sink to the bottom. Things that are less dense than water, but more dense than oil, will float at the dividing line between the oil and the water. Things that are less dense than oil will float on top of the oil.

Raisins, carrots and dried beans are guaranteed to sink. Apples, fresh or dried, should float. Nuts of various types will behave differently. Peanuts and almonds will sink. Walnuts seem to be more oily and will float at the dividing line. Try many items and see what happens!

NOTE: If you had an object that was exactly the same density as water, it would be able to stay right in the middle of the water. Neutral buoyancy is very hard to accomplish. If you happen to have an empty gel cap, fill it with water and see if you can get it to float in middle of the water. Fill another one with oil and see what happens. Fill one with a little oil and a little water. This last one will be interesting to watch. The capsule will hang right at the water/oil line with the water half down and the oil half up. The dividing line between the oil and water inside the capsule will exactly match the line in the jar.

ALSO NOTE: Some objects will want to stick to the oil. Almonds, for example, will hang at the water/oil dividing line for a few minutes before sinking. The oily surface of the nuts will be attracted to the oil and might be able to overcome gravity, at least for a while. To really test their density, shake the jar a few times and let everything settle out again.

7) LAB: CRYSTAL GROWING KIT

If you want to further explore crystals, consider purchasing a crystal growing kit. These kits usually give you everything you need to grow several kinds of mineral crystals. Kits are available in any well-stocked toy store, or any online science store.

barite

$BaSO_4$

Often found in limestone or hot spring areas. Usually white or light brown. Sometimes crystalizes into rose shapes, which are popular with collectors.

zircon

$ZrSiO_4$

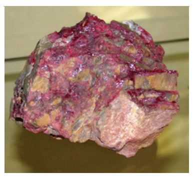
Found in nearly all igneous rocks, although in very small amounts. Because it is so hard, it is often used as a gemstone in jewelry.

hematite

Fe_2O_3

Hematite is a major ore (source) of iron. The name “hematite” comes from its blood-red color (“hema” means blood).

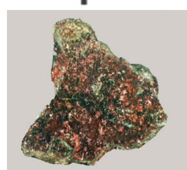
cinnabar



HgS

Cinnabar has a reddish color and is very dense (heavy) because of the mercury (Hg). Pure mercury is a liquid at room temperature, but it is a solid when bound to sulfur.

cuprite



Cu_2O

Cuprite forms cubic crystals. It is sometimes called “ruby copper” because of its color. When exposed to air it changes to CuO.

fluorite

CaF_2

Fluorite is used in the production of steel. It has a glassy luster and can look similar to a quartz crystal, except for its tetragonal (4-sided) shape.

quartz

SiO_2

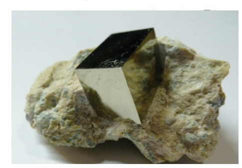
Quartz is used in electronics, as a gemstone, and in the manufacturing of glass (where it is the main component). Sand is made of very tiny pieces of quartz.

galena

PbS

Galena is very dense (heavy) because of the lead in it. During the era of musket rifles, galena was used as the source of lead to make musket balls.

pyrite



FeS_2

This mineral is often called “fool’s gold” because of its golden color and shiny luster. It has no actual gold in it. It leaves a black streak, not gold.

Cards for "Make Five"
Copy onto card stock and cut apart.

corundum

Al_2O_3

Corundum is very hard. It is so hard that it is used in industry as an abrasive (like sand paper). Blue corundum is called a sapphire and red is a ruby.

talc

$Mg_3Si_4O_{10}$

Talc is extremely soft. In fact, you can scratch it with your fingernail! Talc is the main ingredient in talcum powder (used to dry off after a shower).

calcite

$CaCO_3$

Calcite is the main ingredient in limestone. It is one of the most common minerals in the world. Caves are made of limestone.

gypsum

$CaSO_4$

Gypsum is a soft mineral. It is one of the main ingredients in plaster and plasterboard. One type of gypsum is called alabaster and was carved by ancient peoples.

chalcopyrite

$CuFeS_2$

Chalcopyrite is pinkish-purple with flecks of gold. It is found wherever copper is mined. The copper can be taken out of it by using chemical processes.

epsom salt

$MgSO_4$

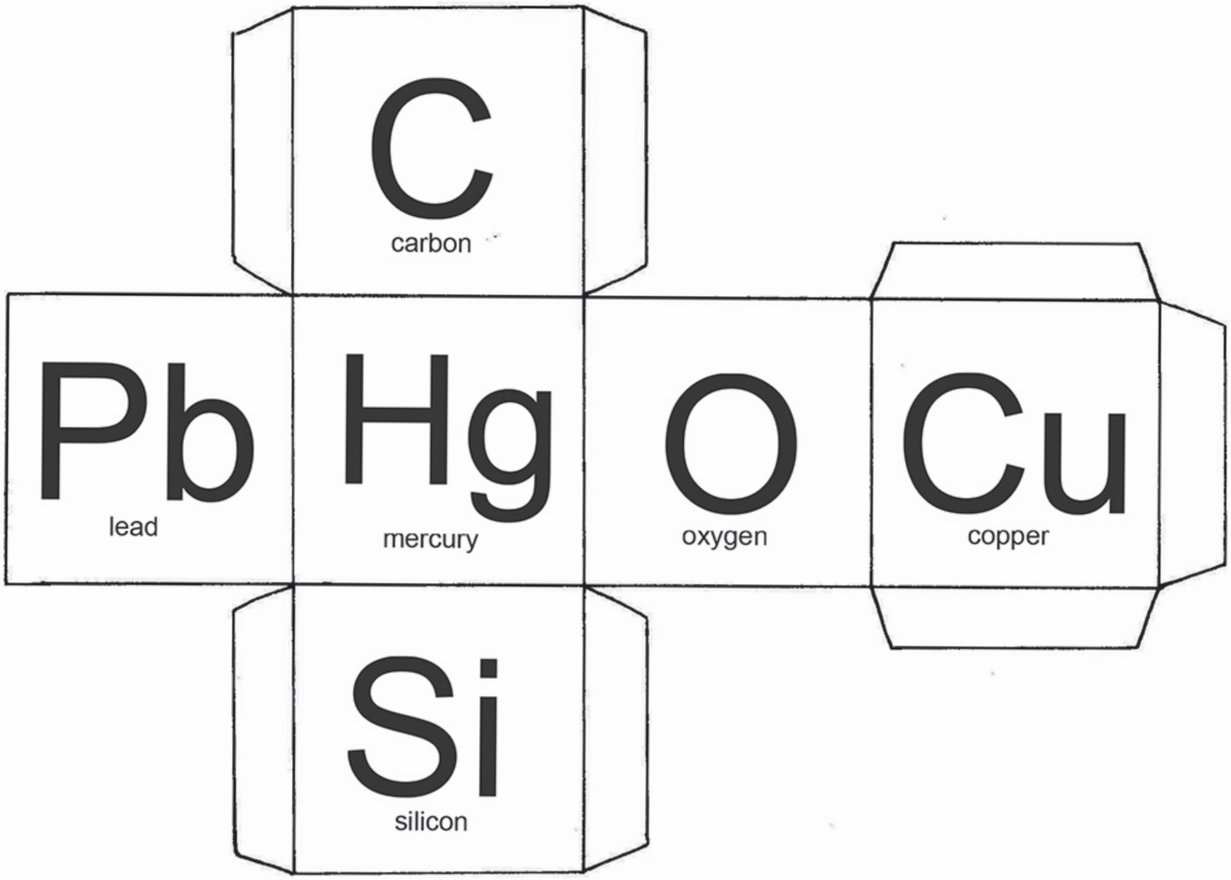
This mineral dissolves into water very easily. It is often used in medical treatment of wounds on hands and feet. It helps in the healing process.

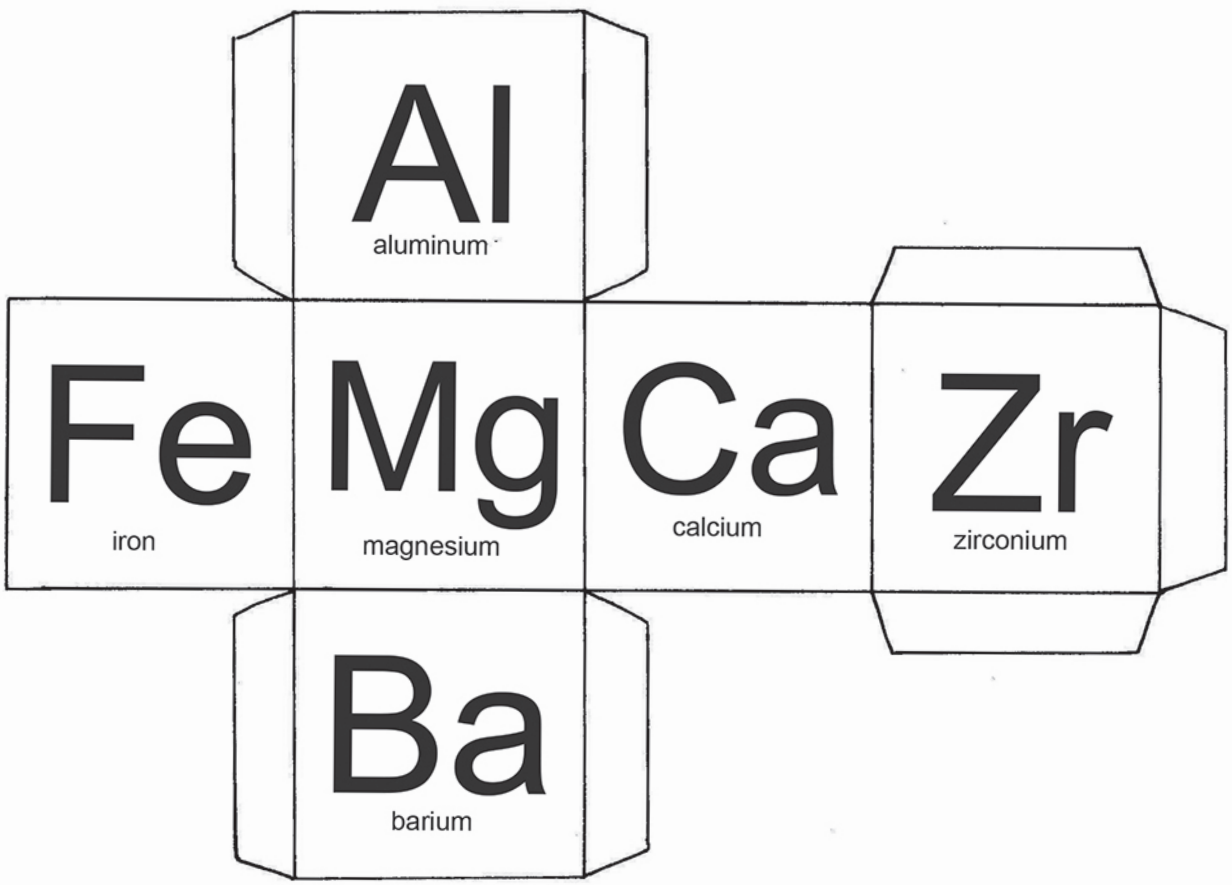
diamond/graphite


C

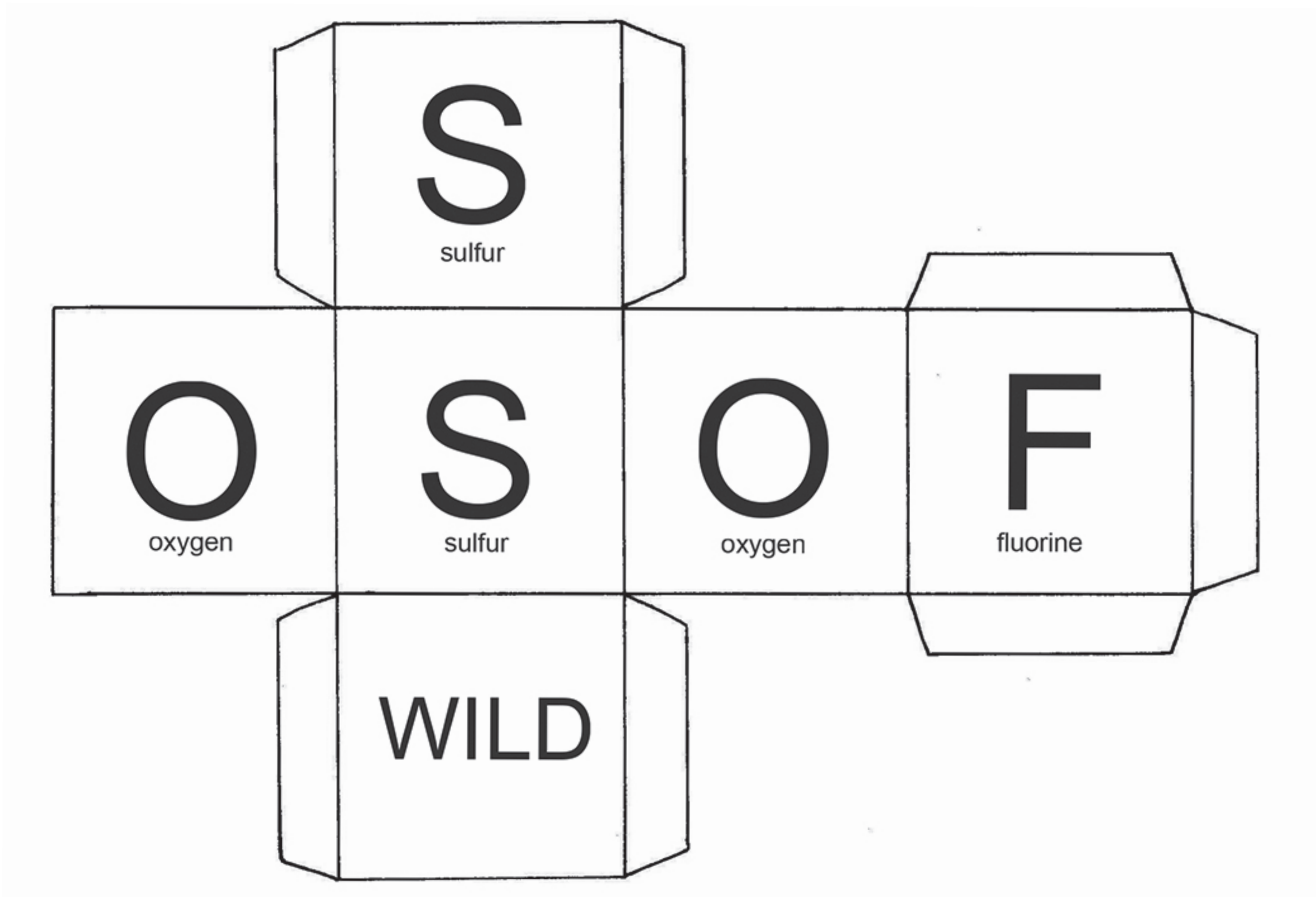
Strangely enough, both priceless diamonds and the stuff in your pencil are made of the same thing: pure carbon. The difference is how the atoms are bonded together.

Cards for "Make Five"
Copy onto card stock and cut apart.

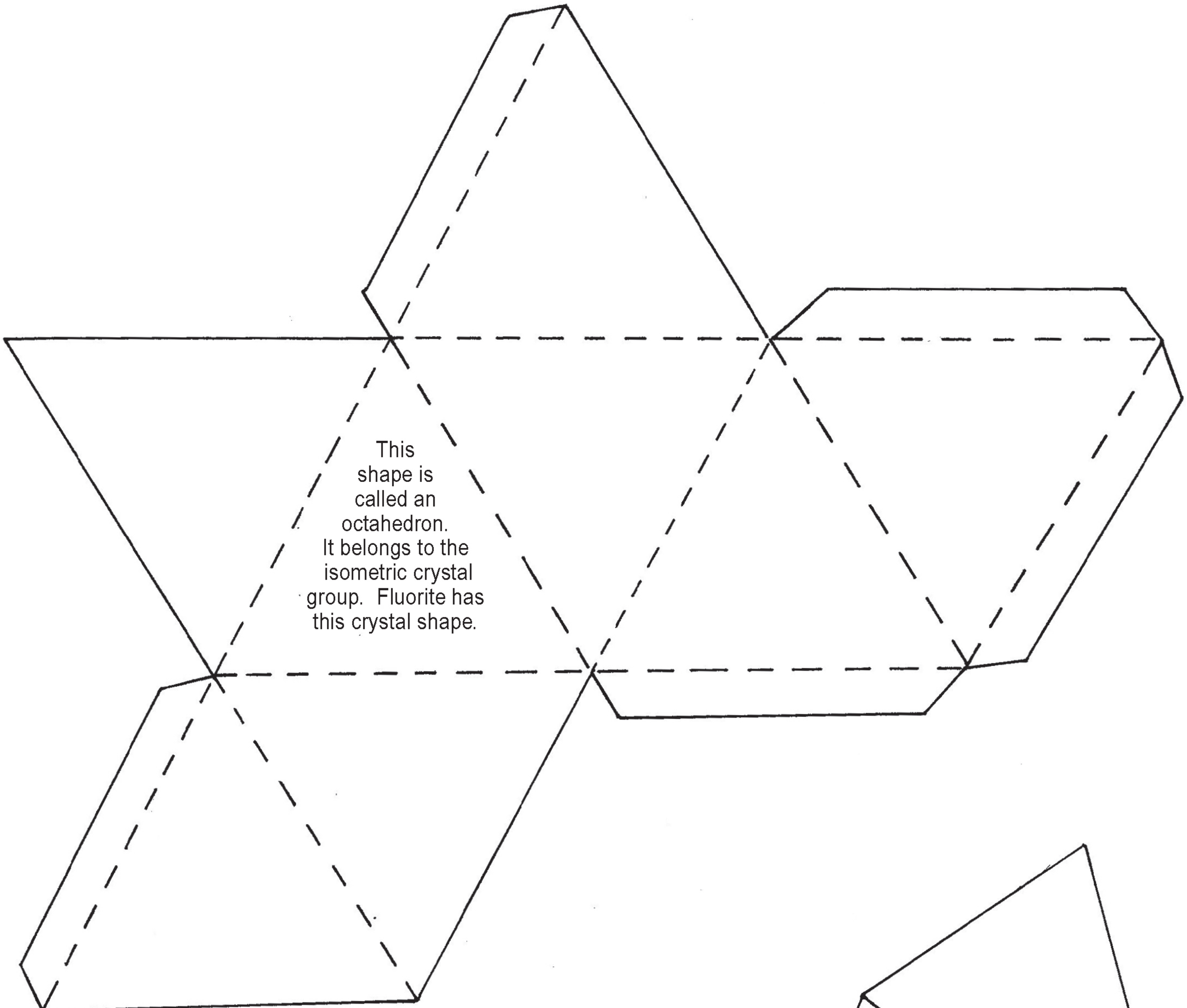


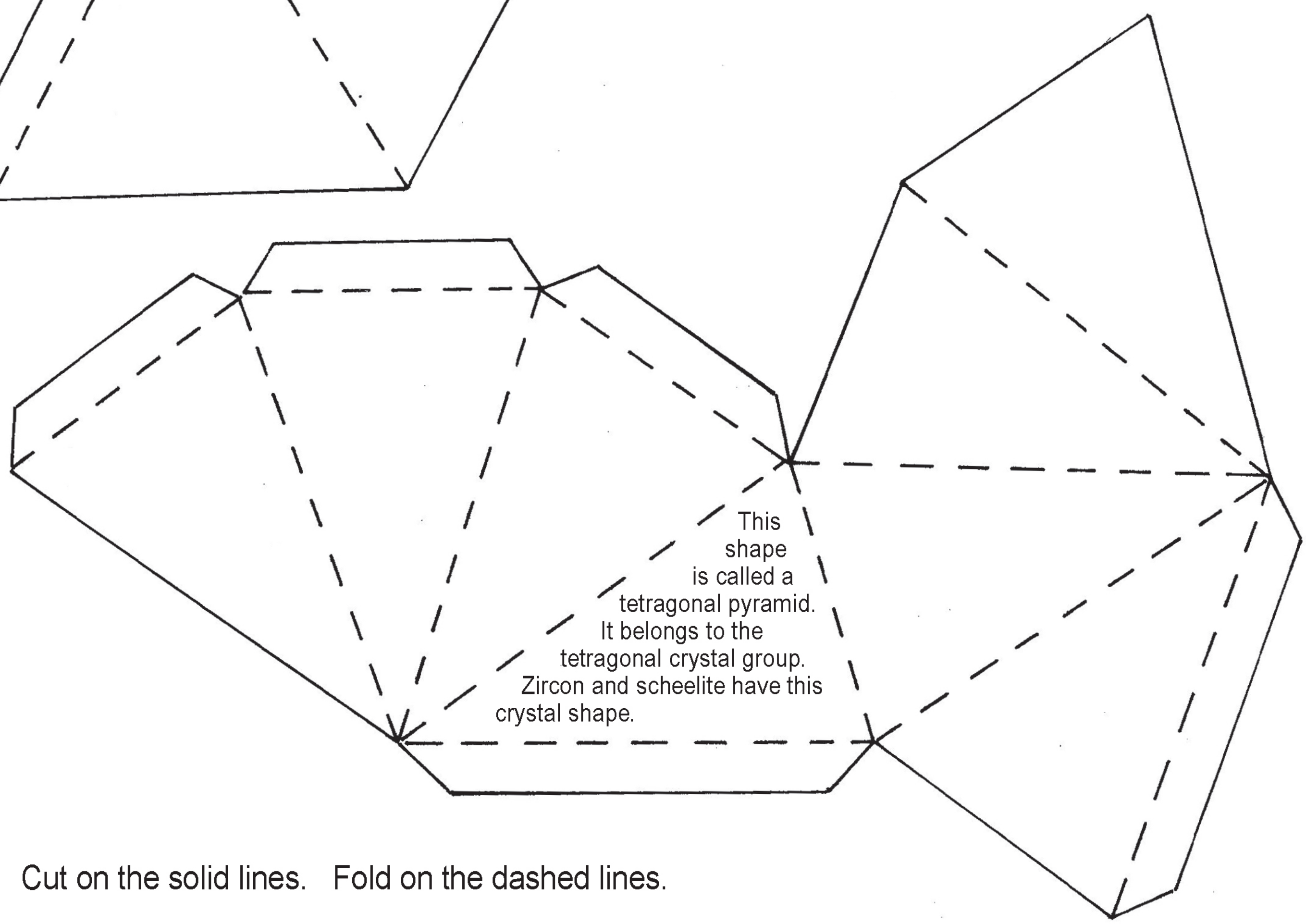


COPY ONTO CARD STOCK ("Make Five" game)

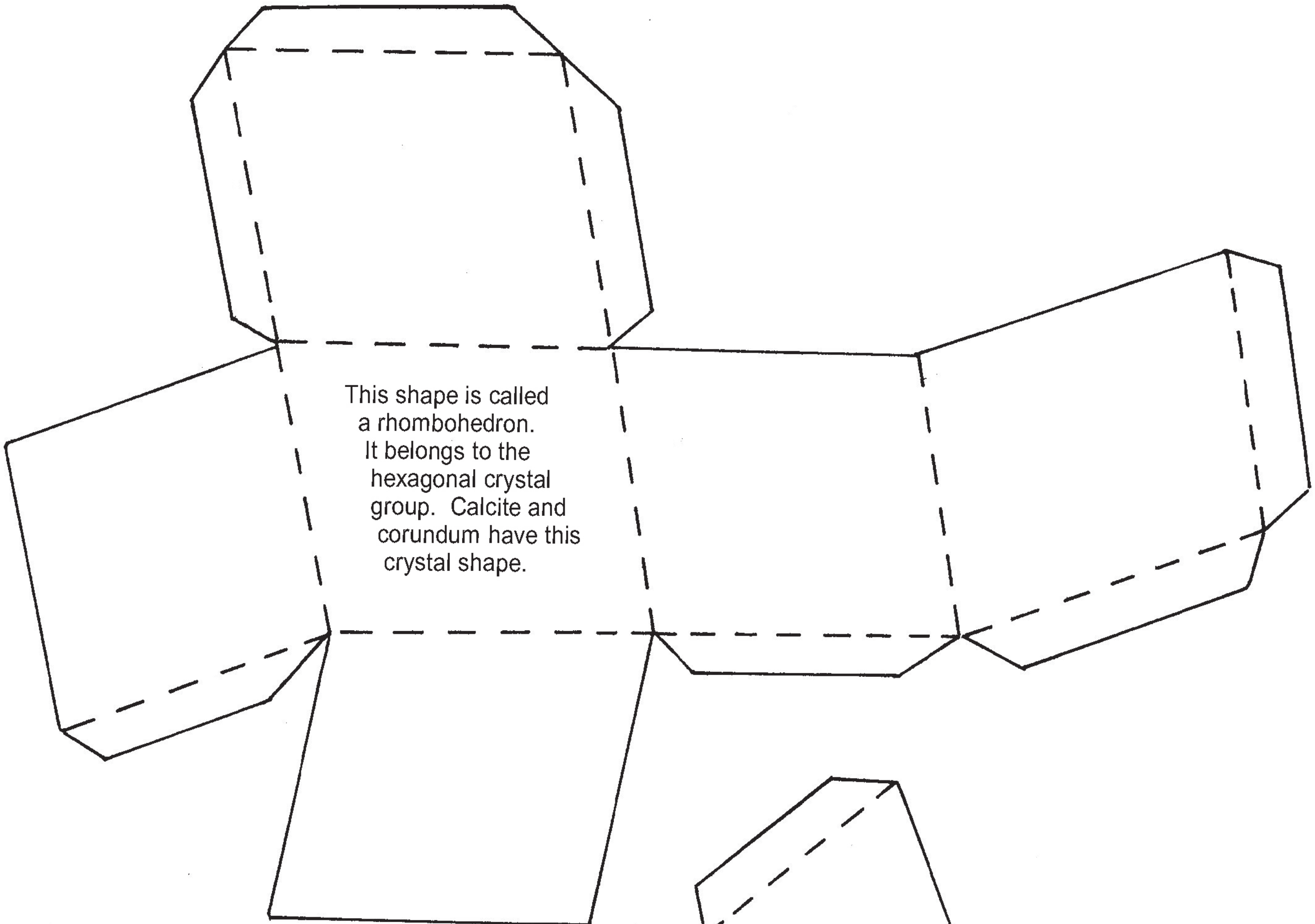


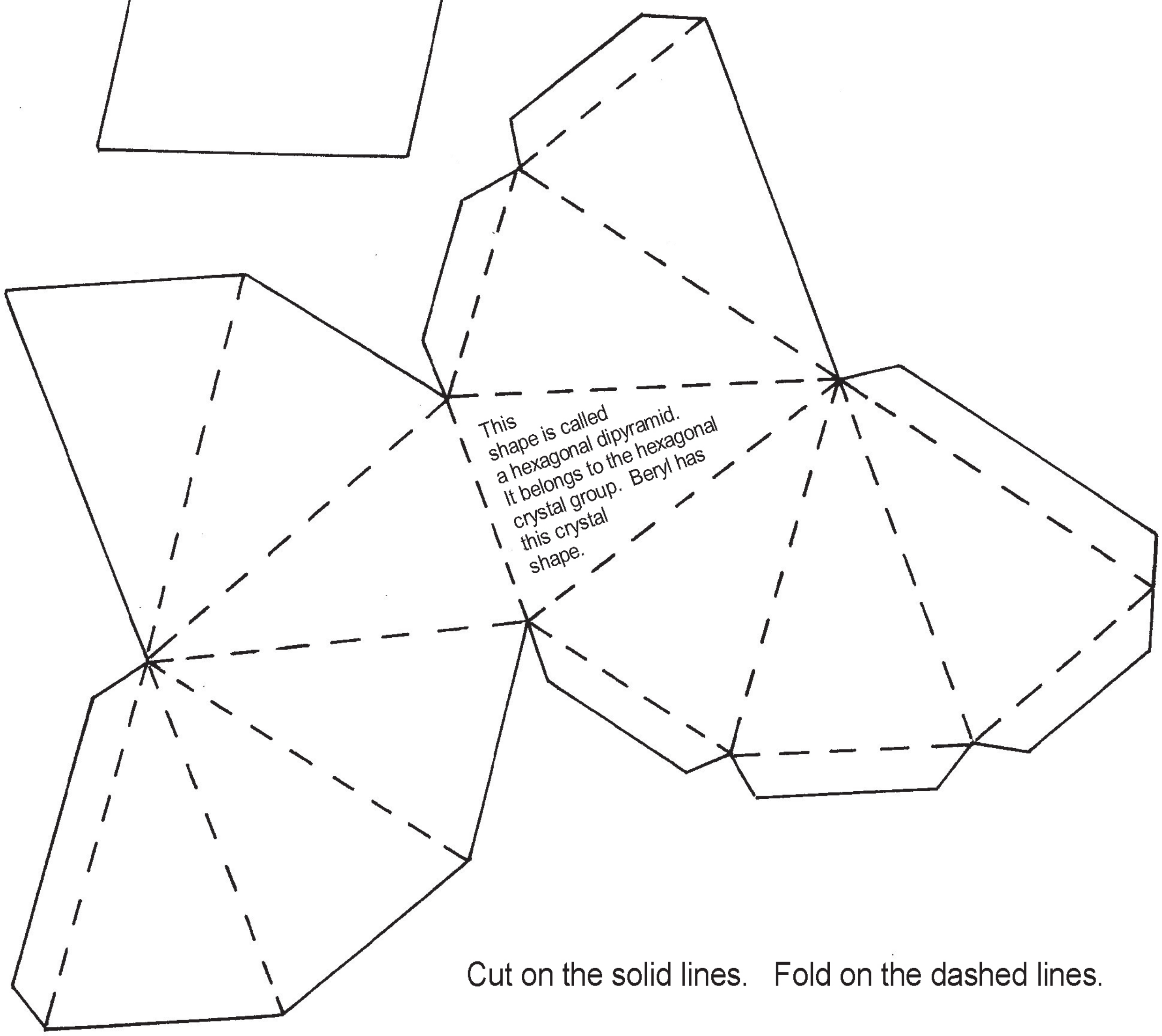
COPY ONTO CARD STOCK ("Make Five" game)





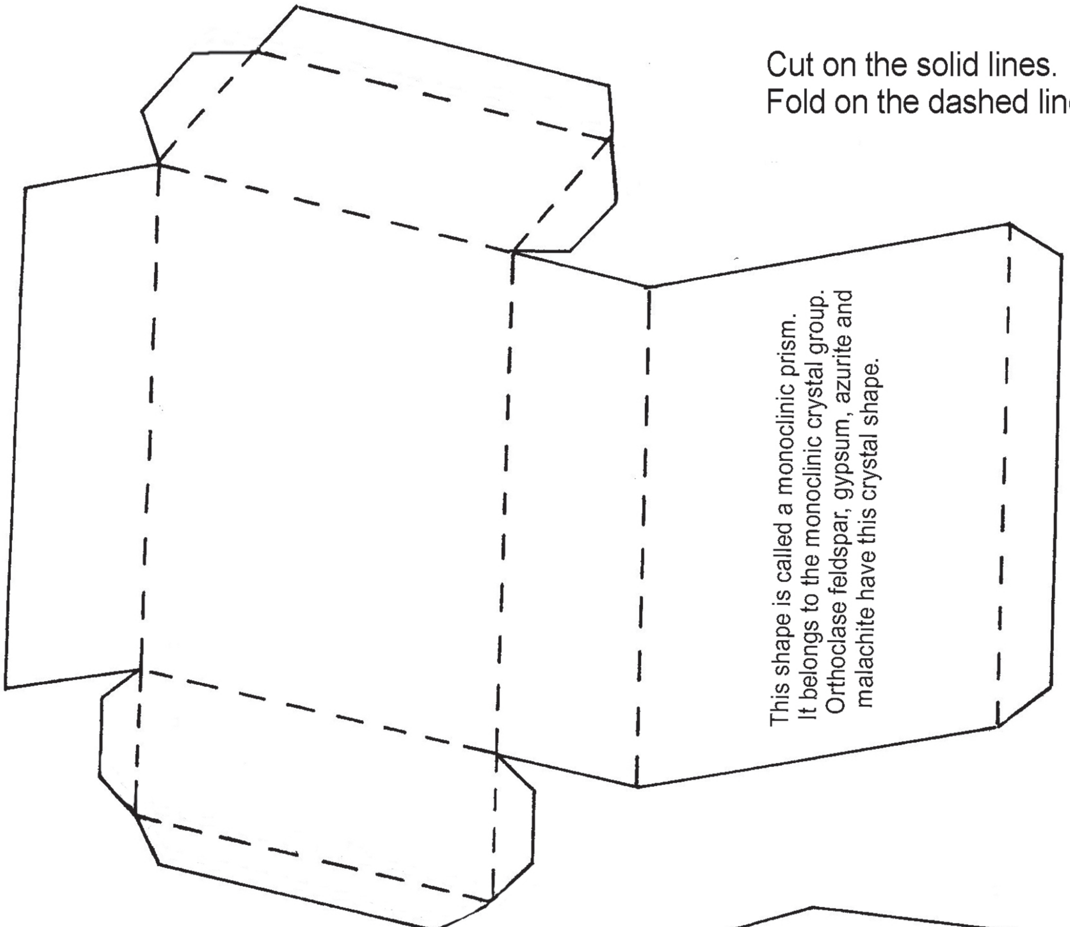
Cut on the solid lines. Fold on the dashed lines.

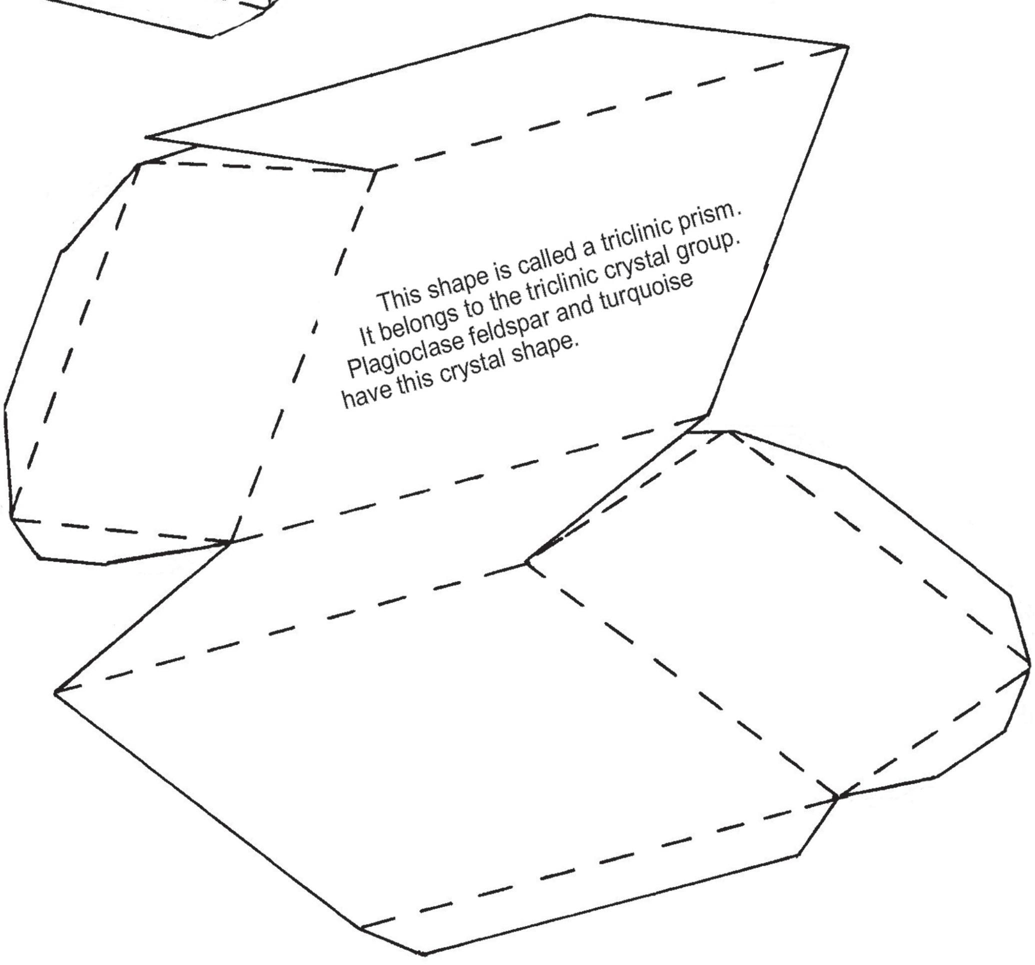


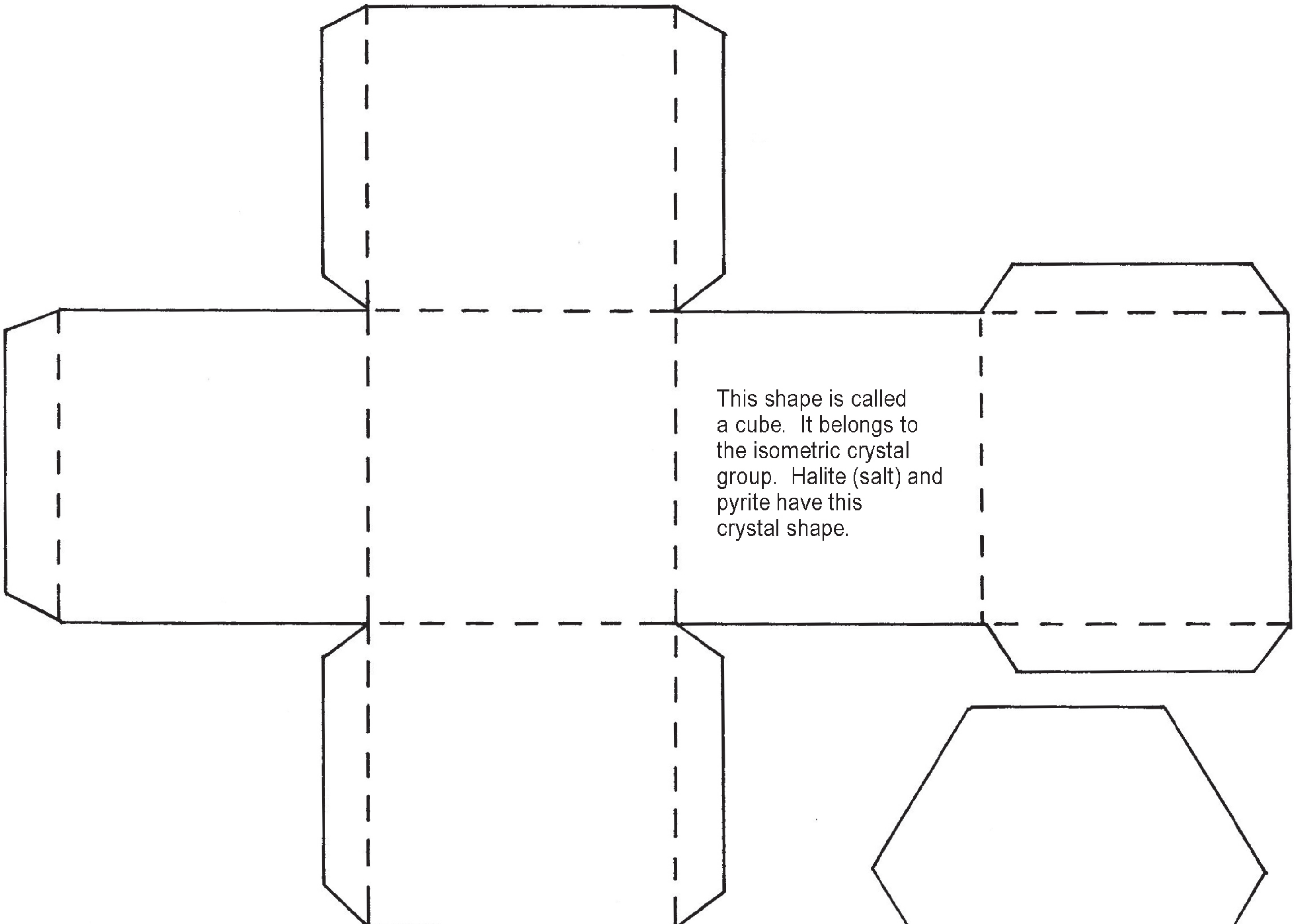


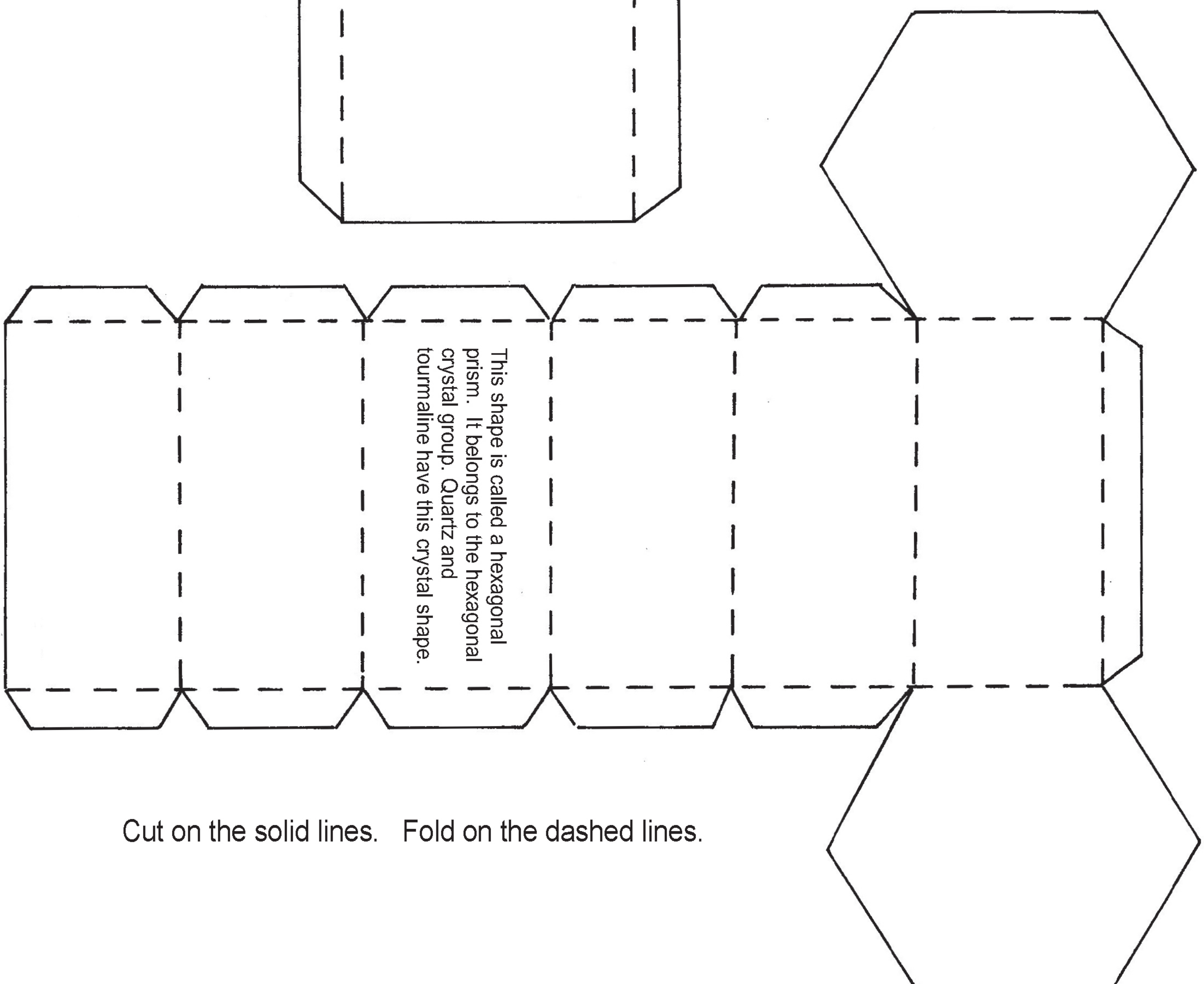
Cut on the solid lines. Fold on the dashed lines.

Cut on the solid lines.
Fold on the dashed lines.

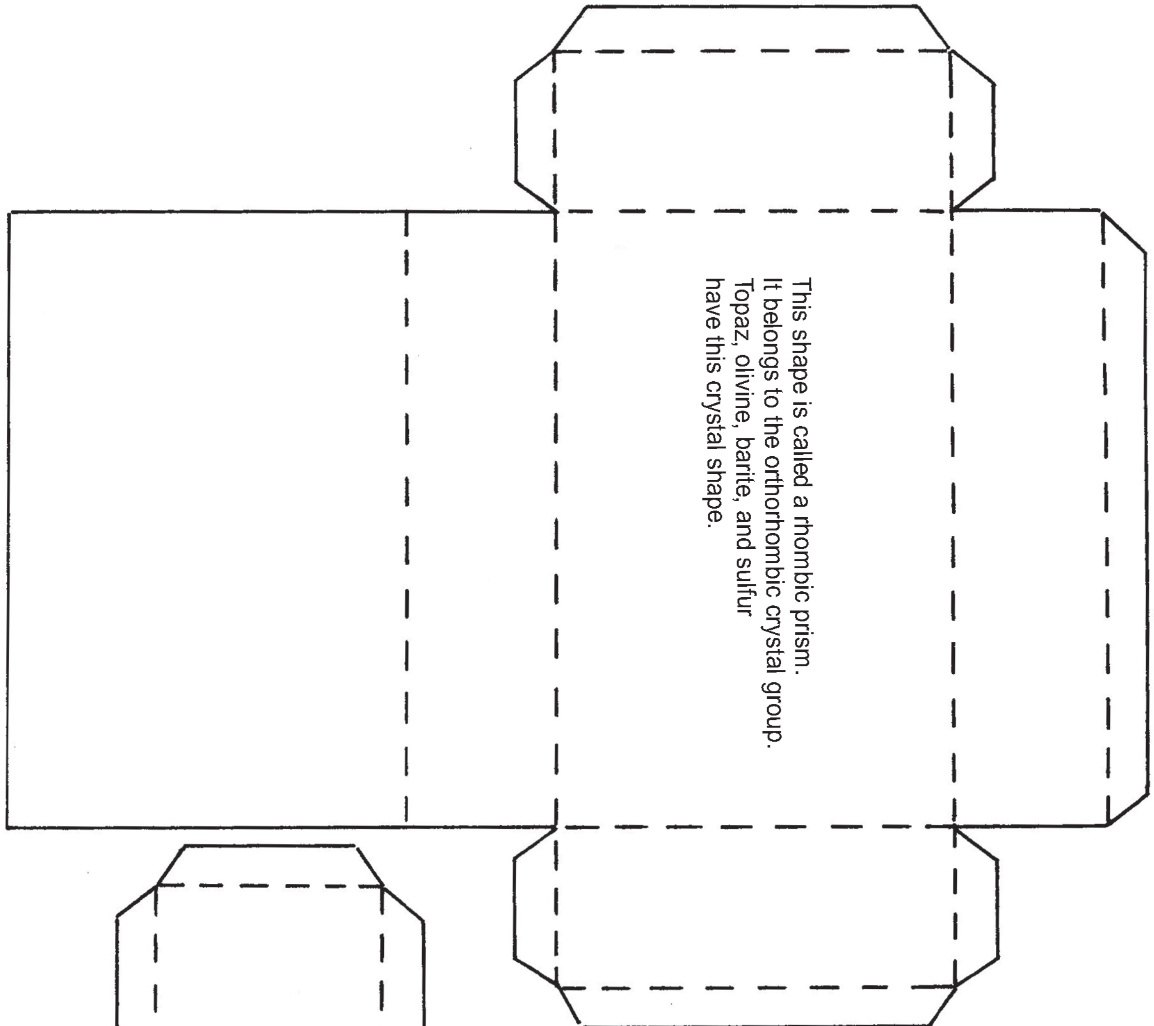


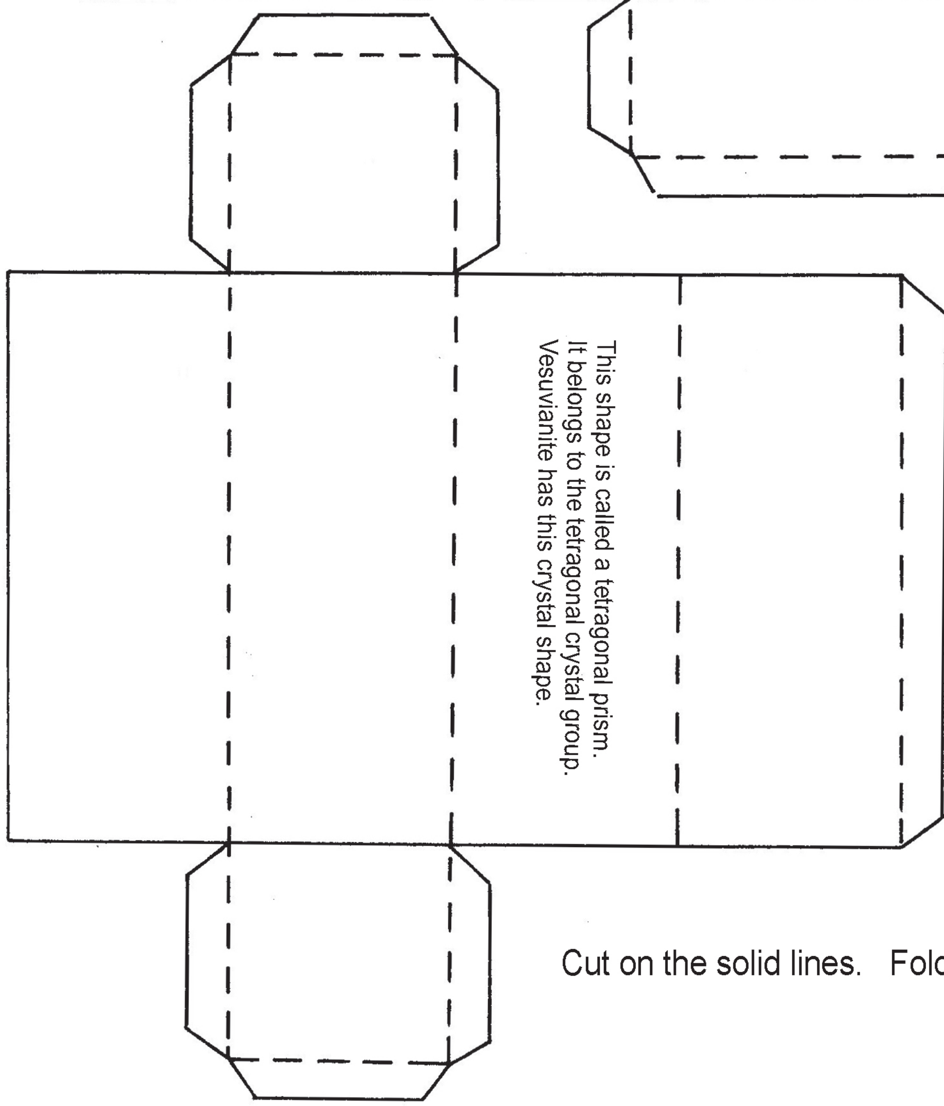






Cut on the solid lines. Fold on the dashed lines.





Cut on the solid lines.   Fold on the dashed lines.

CHAPTER 3

1) MINERAL CARD GAMES

There are 48 mineral cards, with which you can play three different games. You can choose which games are most suitable for your students. You can also add your own tweaks to the games to make them harder or easier (adding clues, increasing number of cards in a set, etc.)

GAME 1: MINERAL BINGO

Goal of the game: get three (or four) in a row
Number of players: any (for larger groups use more than one set of cards)
Time allowance: can adjust the game to fit any amount of time
You will need: the playing cards, the list of clues, and tokens to put on the squares (Edibles are nice, such as cereal bits or candies, because they can be eaten at the end of the game)

How to play:
1) Distribute 9 cards to each player for a 3x3 square, or 16 cards for a 4x4 square.
2) Distribue tokens to the players (to mark the mineral squares).
3) Read the clues and play like standard Bingo. (If you are playing with a 4x4 grid, you could also play "postage stamp" where the winning shape isn't a line across the board, but a 2x2 square.)
4) Feel free to add your own clues.

BINGO CLUES:
1) Is made of just one element (sulfur, copper, silver, gold, graphite, anthracite coal) (Graphite and coal are made of carbon.)
2) Has cubic crystal shape (pyrite, galena, garnet)
3) Contains iron (hematite, magnetite, pyrite, hornblende, jadeite, heliotrope; possibly tourmaline, garnet, biotie, muscovite)
4) Is magnetic (magnetite)
5) Is clear (use pictures to determine this)
6) Is red or has red in it (use pictures to determine this)
7) Begins with the letter A (amber, afghanite, aragonite, agate, amethyst, anthracite)
8) Is organic (amber, anthracite coal)
9) Is purple (use pictures to determine this)
10) Contains carbon (graphite, calcite, anthracite coal)
11) Is green (use pictures to determine this)
12) Has special optical property (calcite-just the clear one, ulexite)
13) Has hexagonal shape (clear quartz, smoky quartz, amethyst, beryl, tourmaline; aragonite is only pseudo-hexagonal, but go ahead and count it)
14) Is yellow (use pictures to determine this)
15) Contains SiO_4 (olivine, topaz)
16) Contains aluminum (ruby, sapphire, feldspar, topaz, beryl, possibly some garnets)
17) Is blue (use pictures to determine this)
18) Begins with the letter F (fluorite, feldspars)
19) Luster is dull (use pictures to judge which ones have a dull, not shiny surface)
20) Have hardness of 8 or higher (topaz, ruby, sapphire)
21) Begins with the letter G (graphite, gypsum, galena)
22) Is a memeber of the cryptocrystalline group (agate, jasper, heliotrope, opal, chalcedony)
23) Contains calcium (fluorite, calcite, gypsum, afghanite)
24) Begins with the letter M (magnetite, muscovite, malachite)
25) Has rhombohedral shape (calcite)
26) Has metallic luster (pyrite, gold, silver, copper, galena, anthracite coal)
27) If you have two of the same mineral, you can put tokens on both of them (gypsum, calcite, feldspar, fluorite)
28) Cleavage is in sheets (biotite, muscovite)
29) Crystal shape resembles needles (gypsum, smoky quartz, clear quartz)
30) Contains sulfur (sulfur, cinnabar, pyrite, barite, gypsum, galena) (Actually, coal probably does, too.)
31) Is orange or has orange in it (use pictures to determine)
32) Doesn't have any flat sides (use pictures to determine)
33) Has vitreous luster (glassy) (use pictures to determine this—they must look really glassy)

<u>GAME 2</u>: MINERAL "DOMINOES"

<u>Goal of the game</u>: get rid of your cards
<u>Number of players</u>: any
<u>Time allowance</u>: can adjust the game to fit any amount of time
<u>You will need</u>: the playing cards

<u>How to play</u>:
1) Distribute 5 cards to each player. The rest go in a draw pile, face down.
2) Take the top card from the draw pile and put it on the table, face up, as the starting card.
3) The first player looks at the cards in his hand to see if any of them have a similarity with the starting card. The criteria for similarity all start with the letter C:

COLOR (must be the same or very close)
CRYSTAL (same shape, such as hexagons, cubes, needles, or cut gemstones
CHEMISTRY (same family group or contain same element, you must name the group or element)

If the player doesn't have a matching card, he must take one from the draw pile. (If the draw matches, he can lay it down.)
4) Play continues like this, with each player attempting to get rid of a card in their hand by matching to one already on the table. If they don't have a match they take a card from the draw pile. The cards on the table need not be in a straight line. However, the cards must match every card they touch. For example, orange calcite could be touching both another orange mineral and another calcite.
5) To make the game harder, add a rule that says the cards must form a straight line and you can only lay down a card at either end. In this case, you might also want to allow players to lay down more than one card on a turn.

<u>GAME 3</u>: "MINERAL AUCTION"

IMPORTANT:

This game gives the players a chance to use a lot of the information they've learned in the past two chapters. There aren't any rules for what makes a set. The players have freedom to think creatively and make their own choices. The goal is collect a set of three cards that have something in common. Simple criteria might be that they are all the same color, or have sharp crystal shapes, or are transparent, or even that they start with the same letter. Students can be encouraged to use criteria such as belonging to the same mineral classification group (carbonates, sulfates, etc.), containing a certain element such as iron or aluminum, being cryptocrytallines, having approximately the same hardness (within 2 points on Mohs scale) or being hexagonal or cubic. Two criteria that you can't use, however, are "ending in -ite" or "contains silicon," because too many of them would fall into these categories. You can have the adult in charge be the official judge of categories, or you might want to have a group vote and if everyone agrees then it's okay.

<u>Goal of the game</u>: to collect sets of three cards.
<u>Number of players</u>: 2 to 6
<u>Time allowance</u>: One game might only take 5-10 minutes, so you can play multiple rounds. You can require two or three sets to be collected in order to win. Adjust the rules to fit your time restrictions.
<u>You will need</u>: the playing cards, plus 5 pennies for each player

<u>How to play</u>:
1) Shuffle the cards and give each player two cards, then put the rest in a draw pile, face down.
2) Give each player five pennies.
3) If you are playing with only two players, you won't have an auctioneer; you will both play every round. If you have more than two players, each player will take a turn being the auctioneer. That means when it is your turn to be the auctioneer, you are the only one who won't be playing during that round. Kind of backwards. The autioneer turns over the top card on the draw pile and asks if anyone wants to bid on it. The players look at the cards in their hand and decide if they'd like to have that card. This is when they need to think about possible categories and guess what they might like to collect. The goal is collect three of a kind.
4) Any player who would like to bid on the mineral up for auction puts out a penny. If only one person bids, they get the card for one penny. The penny can either go back into the bank, or it can go to the auctioneer. (My 11-13 year olds liked the extra craziness of having the auctioneer get the money. Sometimes large numbers of pennies changed hands quickly and they thought this added a lot of fun. However, your group might like the bank option better.)

5) If two or more players bid, the autioneer asks if anyone would like to increase their bid to 2 pennies. If only one person increases their bid, they get the card and their 2 pennies go back into the bank (or to the auctioneer). Everyone else keeps their pennies.

6) If there is a tie, with two or more players bidding the same amount, then the auctioneer uses a coin toss to determine who wins the card. (If there are three people bidding, just have them choose a number between 1 and 10.)

7) After the auction is over, there will then be a chance to trade. Any player who would like to trade a card, puts that card out onto the table. No one has to trade; this is completely voluntary. If two players can agree to a trade, then they may trade cards. (One of my groups asked about trading pennies for cards. You can make your own rule about this if it comes up.)

8) After an auction and a chance to trade, that round is officially over, and it is the next player's turn to be the auctioneer. This sounds like it would make for very long turns, but, in fact, the game moves rather quickly. Often there will be only one bidder, or no one interested in trading.

9) Players may accumulate any number of cards in their hand. (I never ran into any problems with this. If you experience problems because of players having too many cards in their hand, you can add a rule about it, limiting the number.)

10) When someone has three of a kind, the round is over. Those three cards are then out of play and get set aside. The players who did not win are allowed to keep two of their cards if they wish, but have to put the others back into the draw pile. Or they may take two fresh cards. The player who won has to draw two new cards. Everyone gets their 5 pennies back again.

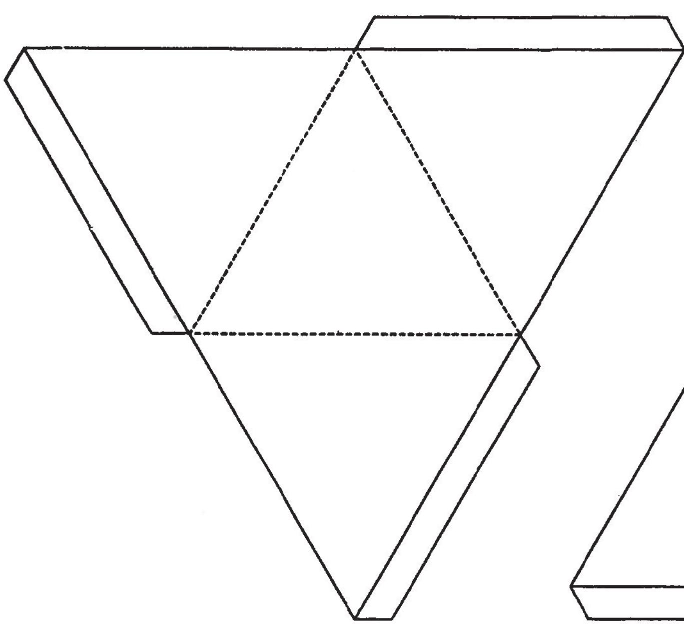
11) Play several rounds, maybe until someone gets two sets. Whoever gets the most sets of three is the winner. (But everyone wins if they had fun and learned something!)

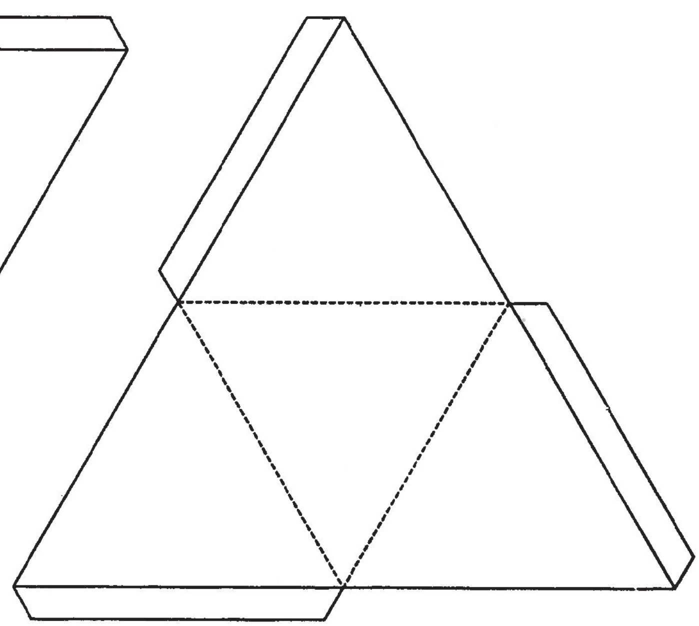
NOTE about using LUSTER as a category:

GLASSY: (or "vitreous") means it is really shiny, like glass (gemstones, quartz, agate, polished jaspers, etc.)
SHINY: still shiny but not as shiny as glassy. (Fluorite or calcite would be in this category as well as others.)
WAXY: still slightly shiny, but much less so than "shiny" (Unpolished chert, flint, jaspers have waxy luster.)
METALLIC: shiny in a metallic way. (Galena and anthracite can look metallic, as well as the metals.)

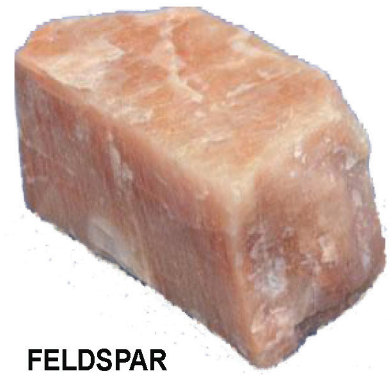
OPTIONAL EXTRA:

Just in case you feel the need to make tetrahedrons, either for demonstrating the science, or as a craft for the students, here is an easy pattern you can use.





FELDSPAR



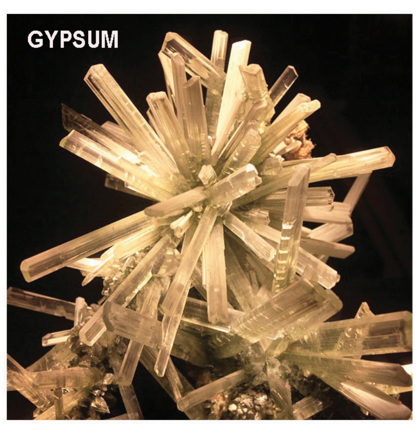
FELDSPAR

SAPPHIRE

RUBY

TOPAZ

ARAGONITE




AMBER


FLUORITE


FLUORITE


ROSE QUARTZ

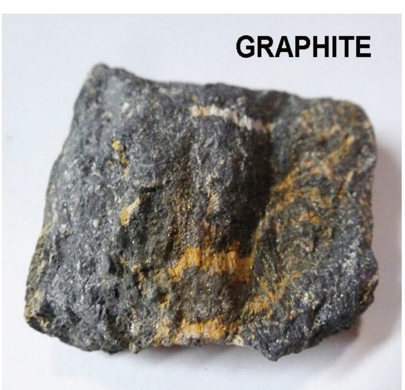

QUARTZ


AMETHYST


TOURMALINE

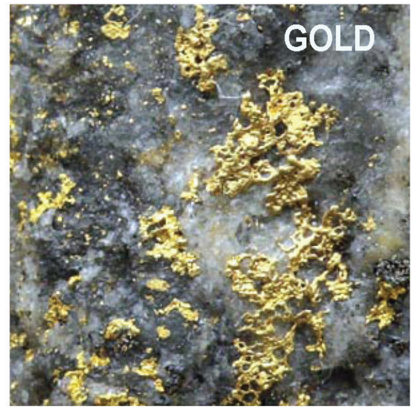

CALCITE


TALC


GRAPHITE

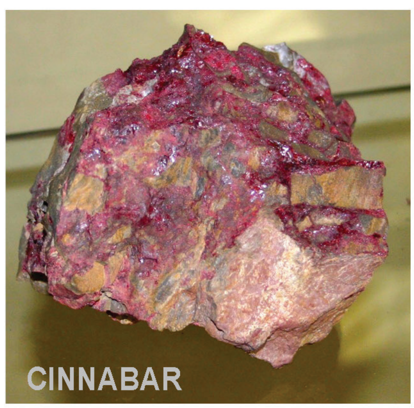

MAGNETITE

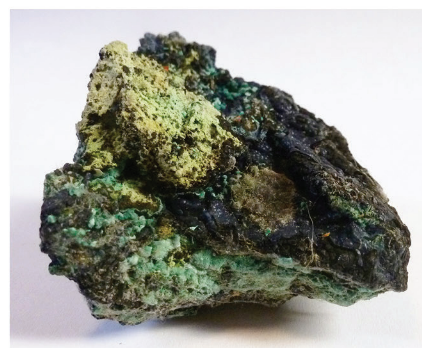
ULEXITE

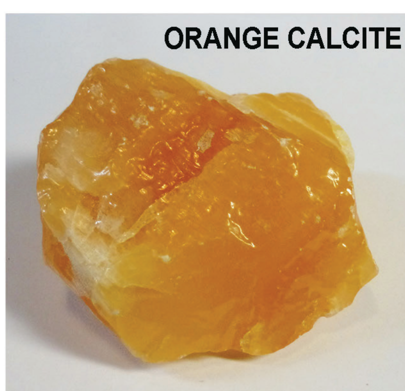



BIOTITE


LANDSCAPE JASPER




MALACHITE



HEMATITE

GALENA

HORNBLENDE

BERYL

HELIOTROPE

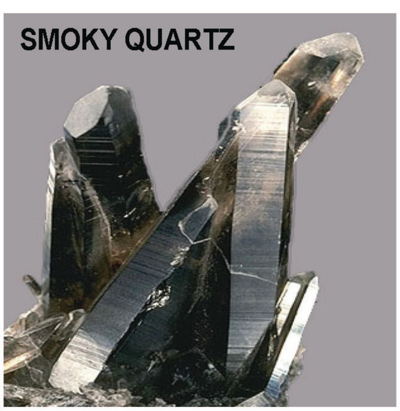
JADEITE

GARNET

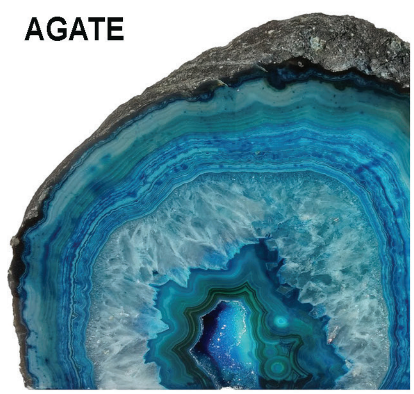
OPAL

TIGER JASPER

SMOKY QUARTZ



AGATE



CHALCEDONY

2) CRAFT: PAINT YOUR OWN AGATE


sample of student work

Agates are made of silica, SiO_2. ("Agate" rhymes with "bag it.") Glass is also made of silica so it is not surprising that agates look smooth and glassy when polished. This name was given by Theophrastus, a Greek philosopher and naturalist who discovered this type of stone along the Achates River.

Most agates are found in volcanic rock, especially basaltic rock, although some are found in metamorphic rock. They started out as empty bubbles in the rock, then the space eventually filled in with SiO_2 that was mixed with hot water. Some bubbles filled in completely and others only partially, leaving an empty space at the center. Therefore, agates can be completely solid, or can have a hole in the center. Agates are not always round. They can also be found as stripes filling long gaps and cracks in volcanic rocks. These are known as banded agates or striped agates.

Agates usually come in shades of red and brown, gray, or blue. Bands of chalcedony often alternate with bands of crystalline quartz. If there is a hole in the center, it is often not smooth, but has large crystals around the edge. Agates are very resistant to weathering. In some places, they are found as hard, round balls, called "geodes" which must be cracked open with a hammer in order to see the beautiful minerals inside. One of the largest geodes ever found was in Brazil. It weighed 35 tons and the inside was lined with amethyst crystals (another form of silica, often light purple in color).

Agates are primarily used for decorative purposes such as jewelry, book ends, and other crafts. Two practical uses that have been documented (in just a few parts of the world) are burnishing leather, and using very thin agate slices as panels for stained glass window

<u>You will need</u>:
- 8.5" x 11" sheet of clear plastic, one per student (copier transparencies are ideal and can be purchased at the printing department of any office supply store)
- the following pattern pages copied onto white paper (each student will need one pattern and one title page)
- acrylic craft paints in various colors (use Google image search to get ideas for color schemes)
  NOTE: Paint markers work well for thin stripes.
- small brushes
- paper clips to hold the pattern pages in place
- white or clear craft glue (such as "Tacky Glue")
- a small amount of sand
- also have paper towels on hand, and some scrap paper to cover your work surface
- hairdryer to speed up drying time if you are working with a group that has limited work time

<u>What to do</u>:

1) Copy (or print out) the agate pattern pages onto white paper. Each student will need one agate pattern and one copy of the title page that says AGATE at the top. The final project will get cut out and glued to the title page. (Card stock is nice for the title page if you have some available.) If you want to extend this project and make it more challenging, have the students draw their own black and white agate patterns instead of using these patterns.

2) Place the sheet of plastic over one of the pattern pages. Use some paper clips or small pieces of tape to keep the plastic sheet in place while you paint.

3) Use acrylic paints to paint colored stripes. (TIP: Limit the number of colors you use. Your agate will look more genuine if it is in shades of just blue, or just red and brown, or just gray, or just purple.) Bear in mind that the agate will be seen from the reverse side. You are painting on the back. If you paint a stripe on top of a stripe, only the first stripe will be seen on the front side. If you are using paint markers for thin stripes, do all the thin stripes first.

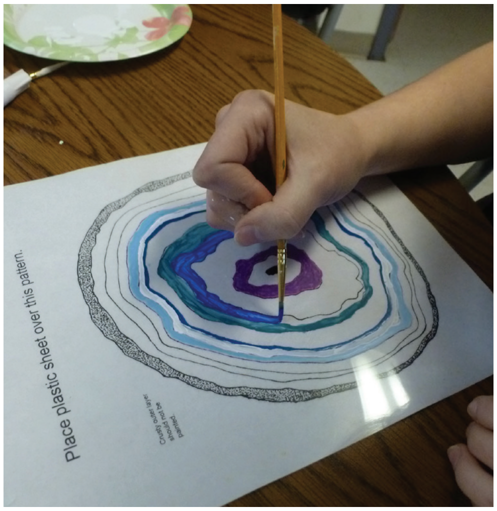
4) Notice that the outer (crusty-looking) layer will be covered with sand. You can trace around this with a permanent marker or with a layer of paint if you are worried that they'll forget about this strip while cutting it out (and accidentally trim it off).

5) When the paint is dry, cut out the agate, including that unpainted strip (for the sand) on the outside.

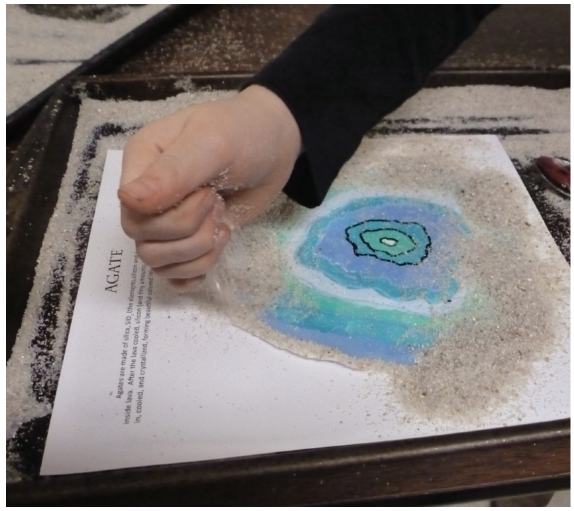
6) Turn your agate over and put craft glue on the outer edge. Then dust with sand, making sure the sand is firmly embedded in the glue. Let it dry.

7) Glue your agate (shiny side up!) to the title page sheet that says AGATE at the top. sheet.

NOTE: The brightly colored agates you find in gift shops might have been dyed artificially. If you are interested in how this is done, here is a website that describes the process in great detail:
http://dyeingagate.com/dyeing-agates/

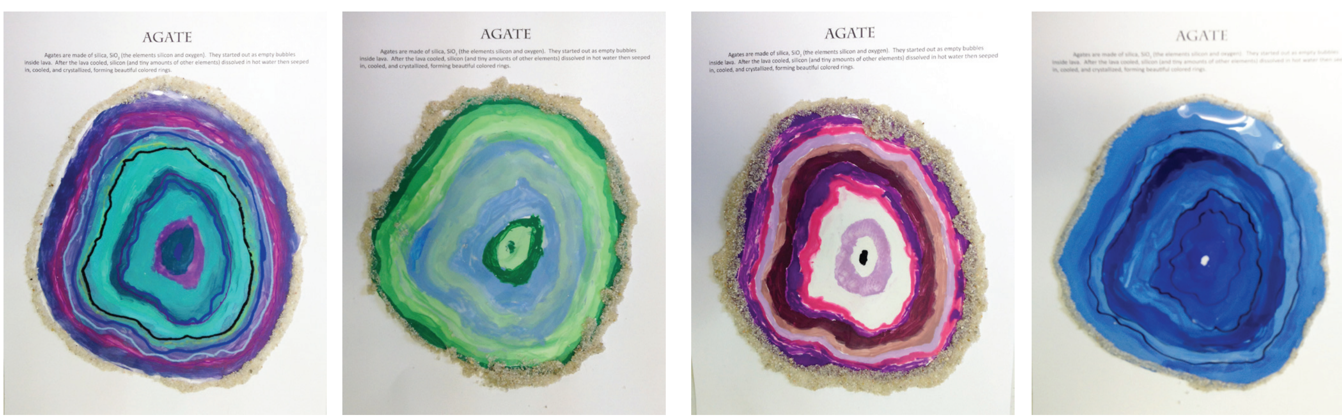


STEP 4

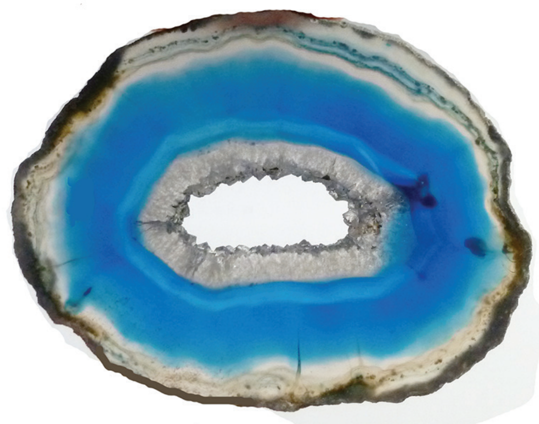


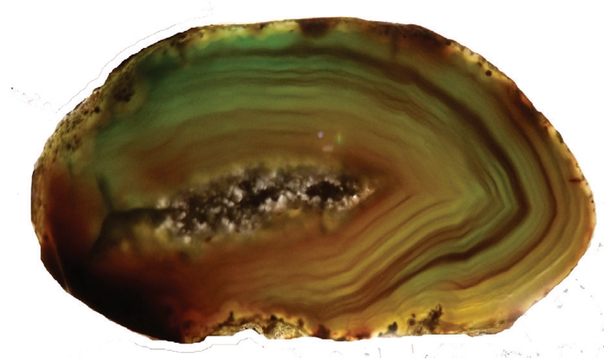
STEP 6

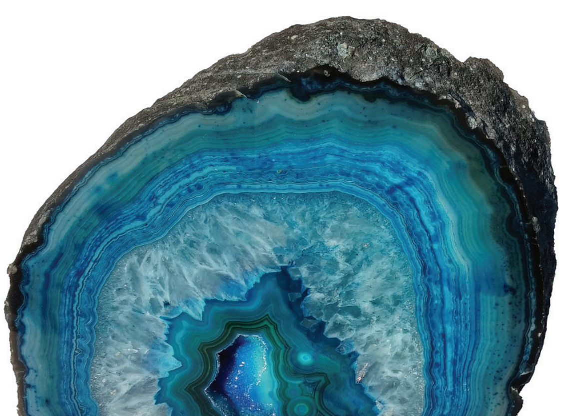
MORE STUDENT WORK:



SAMPLES of real agates (to inspire student creativity!)



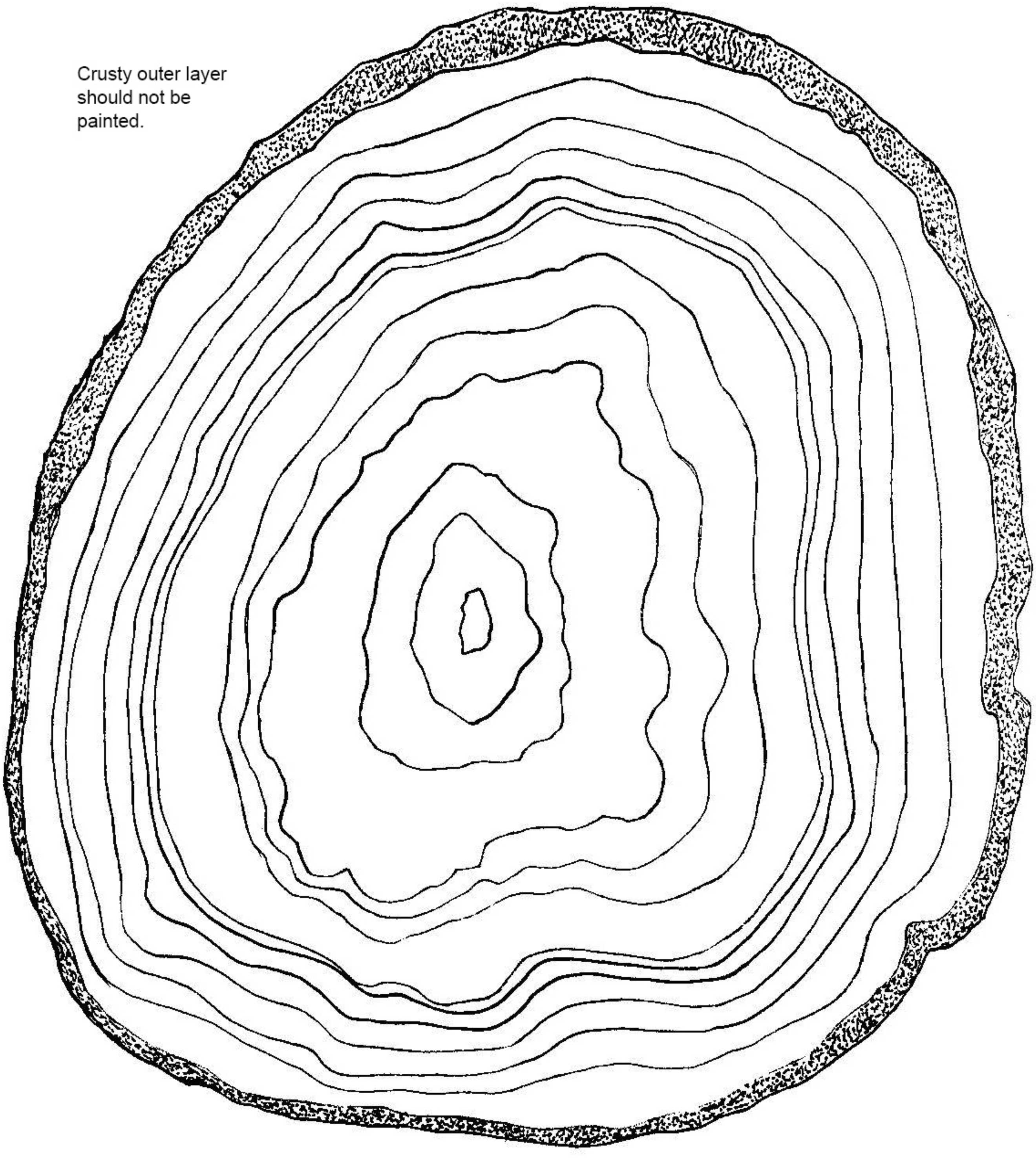




AGATE

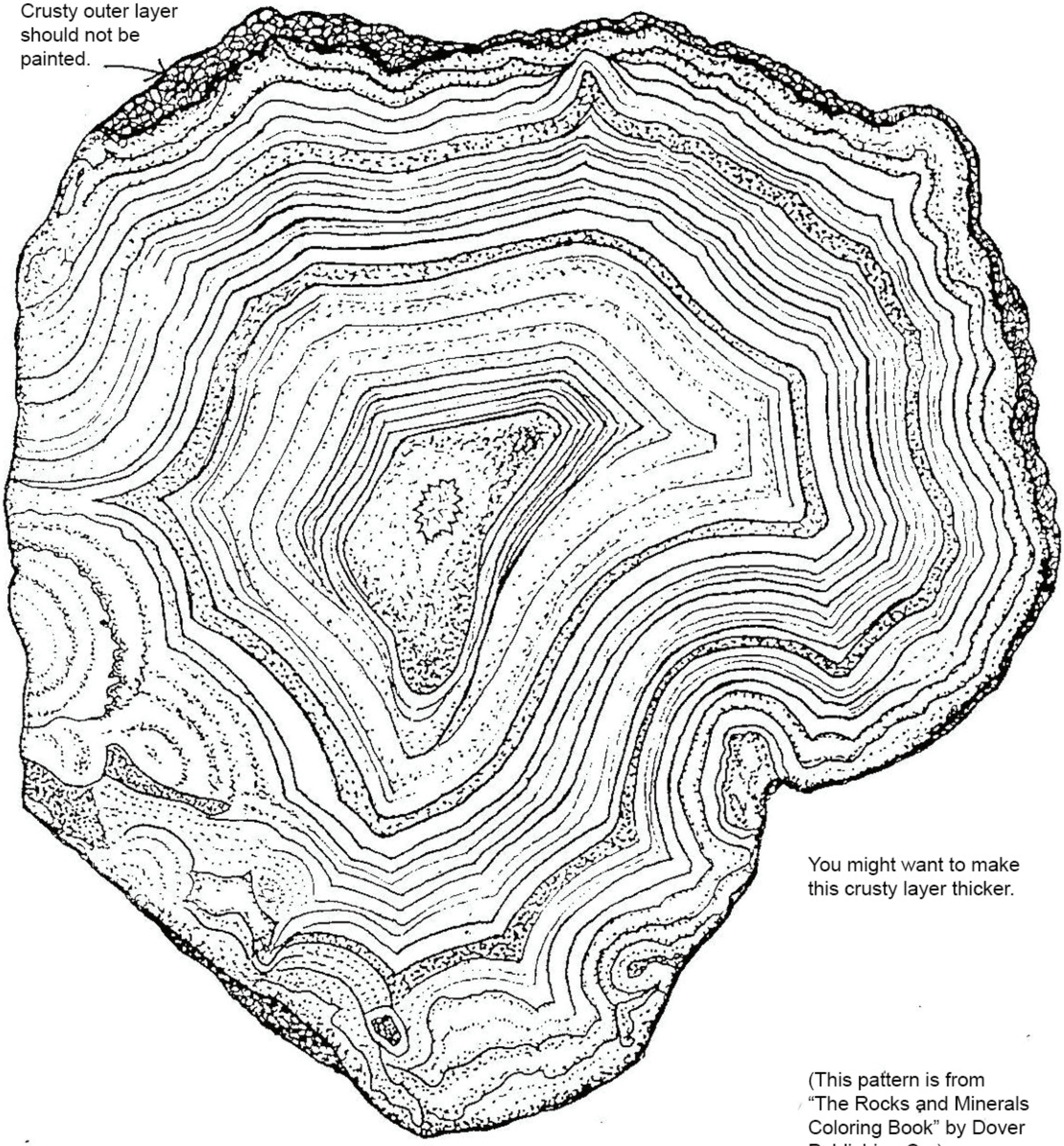
Agates are made of silica, SiO_2 (the elements silicon and oxygen). They started out as empty bubbles inside lava. After the lava cooled, silicon (and tiny amounts of other elements) dissolved in hot water then seeped in, cooled, and crystallized, forming beautiful colored rings.

Place plastic sheet over this pattern.



Place plastic sheet over this pattern.

NOTE: You don't need to use all the lines in this pattern. Feel free to simplify it a bit.



Crusty outer layer should not be painted.

You might want to make this crusty layer thicker.

(This pattern is from "The Rocks and Minerals Coloring Book" by Dover Publishing Co.)