Mineral Resources of the Northeastern US:
a brief review

A mineral is a naturally occurring solid with a definite chemical composition and crystalline structure that is formed through inorganic processes. Minerals are literally the foundations of our everyday world. Not only do minerals make up the rocks we see around us in the Northeast, they are used in nearly every aspect of our lives. The wide variety of minerals found in the rocks of the Northeast, are used in industry, construction, machinery, technology, food, makeup, jewelry, and even the paper on which these words are printed.

Luster refers to the appearance of the mineral surface in reflected light. Metallic minerals have a luster like an aluminum pan or a dull metal like a rusty nail. Metallic minerals are vital to the machinery and technology of modern civilization. Geologists seek out ores that contain significantly more metal than is normal in the crust. Many metallic minerals occur in extremely small amounts in the crust. It is almost always necessary to process ore minerals in order to get the useful element. A mineral is called an ore when one or more of its elements can be profitably removed. For example, ***chalcopyrite***, which contains copper, iron and sulfur, is referred to as an ore when the copper can be profitably extracted from the iron and sulfur.

Non-metallic minerals do not have the flash of a metal, though they may have the brilliance of a diamond or the silky appearance of gypsum. Generally much lighter in color than metallic minerals, non-metallic minerals can transmit light, at least through pieces or edges.

What distinguishes a regular mineral from a gem? Beauty, durability and rarity of the mineral qualify it as a gemstone. Beauty refers to the luster, color, transparency and brilliance of the mineral, though to some degree it is dependent on the skillfulness of the cut. Most gems, including tourmaline, topaz and corundum, are durable because they are hard (scratch-resistant). On the Mohs Scale

Minerals provide the building blocks for rocks. For example, granite, an igneous rock, is typically made up of crystals of the minerals feldspar, quartz, mica and amphibole. Sandstone may be made of cemented grains of feldspar, quartz and mica. The minerals and the connections among the crystals define the color and resistance to weathering of a rock.

Elements:
the building blocks of minerals

Elements are the building blocks of minerals. The mineral quartz, for example, is made of the elements silicon and oxygen. Most minerals present in nature are not composed of a single element, though there are exceptions such as gold (Au). Eight elements make up (by weight) 99% of the Earth's crust, with oxygen being by far the most abundant (46.4%). The remaining elements in the Earth's crust occur in very small amounts, some in concentrations of only a fraction of one percent (Figure 6.1). Since silicon (Si) and oxygen (O) are by far the most abundant elements in the crust by mass, it makes sense that quartz (SiO2, silicon dioxide or silica) is one of the most common minerals in the Earth's crust and is found all over the Northeast.

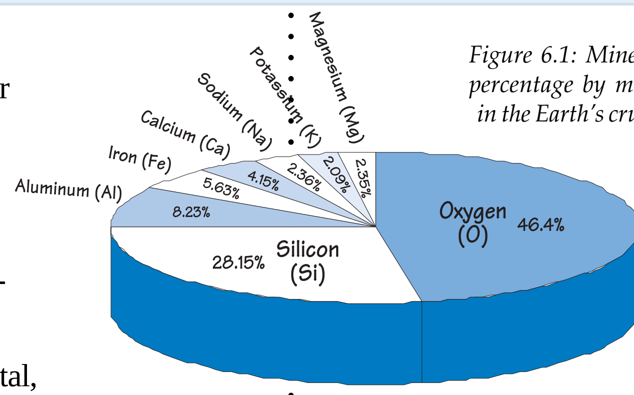
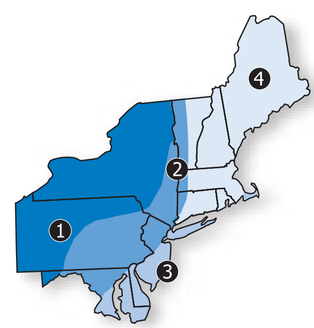


Figure 6.1: Mineral percentage by mass in the Earth's crust.

chalcopyrite: *$CuFeS_2$*



Mohs Scale of Hardness

In 1824, the Austrian mineralogist, F. Mohs, selected ten minerals to which all other minerals could be compared to determine relative hardness. The scale became known as Mohs scale of hardness, and is very useful as a means for identifying minerals or quickly determining hardness. A piece of glass has a hardness of approximately 5 on the scale; your fingernail is just over 2; and a pocketknife blade is just over 5.

1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

of Hardness, the majority of gemstones are greater than 7.

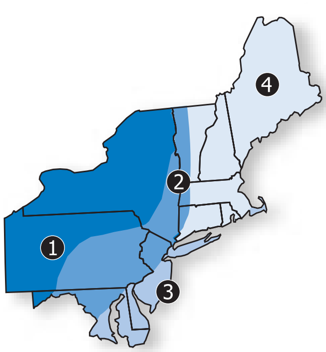
Hardness is important because it helps us understand why some rocks are more or less resistant to weathering and erosion. Quartz (7 on Mohs scale) is a relatively hard mineral, but **calcite** (3 on Mohs scale) is significantly softer. Therefore, it should be no surprise that a quartz sandstone is significantly more resistant to erosion and weathering than a limestone, the primary constituent of which is the mineral calcite. Quartz is a very common mineral in the Earth's crust and very resistant due to its hardness and relative insolubility. Thus, quartz grains are the dominant mineral in nearly all sands.

calcite: $CaCO_3$

A gem's value is also dependent on the rarity of the mineral. With limited supply (commercially or in nature), the value of a gem increases significantly, such as with rubies or diamonds. Quartz may have a brilliant luster and be quite durable, but it is hardly rare. Therefore, quartz has significantly less value as a gemstone, though some microcrystalline and colored varieties of quartz are of moderate value.

Geologists looking for particular minerals do not make haphazard guesses as to the location of ore bodies. The occurrence of minerals in the Earth's crust is due to the geologic processes that formed certain rock types in a given area. An understanding of the environments in which minerals form, the minerals that make up different rocks, and the geologic history of an area, helps the geologist to ascertain with a higher probability where minerals of interest are concentrated. Metallic minerals are often associated with igneous and metamorphic rocks, which typically occur in either very ancient rocks (Precambrian) or in areas of severe deformation of the crust (such as where continents have collided) *(Figure 6.2, 6.3)*.

Non-metallic minerals are found associated with sedimentary, igneous and metamorphic rocks of all ages, and in both deformed and undeformed crust *(Figure 6.2, 6.4)*. The apparent concentration of non-metallic minerals along the east coast



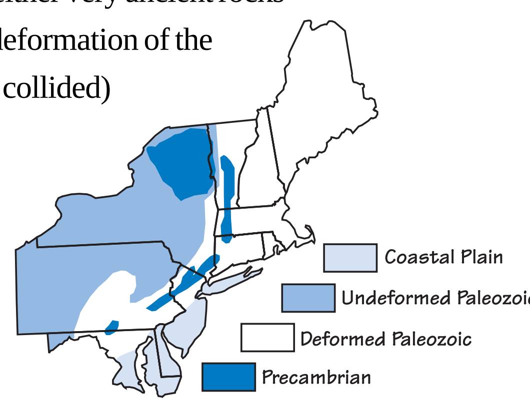


Figure 6.2: Generalized geology of the Northeast.

Figure adapted from USGS 1998 Mineral Resource Evaluation of the Northeastern U.S.

of the United States reflects the high demand for non-metallic minerals in a densely populated region that has led to intense mining of the immediate area.

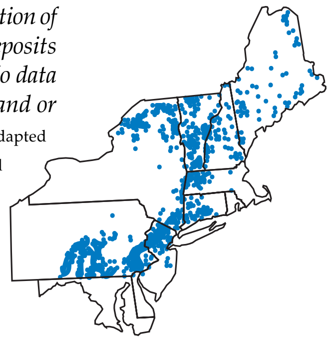


Figure 6.3: Distribution of metallic mineral deposits of the Northeast. No data available for Maryland or Delaware. Figures adapted from USGS 1998 Mineral Resource Evaluation of the Northeastern U.S.

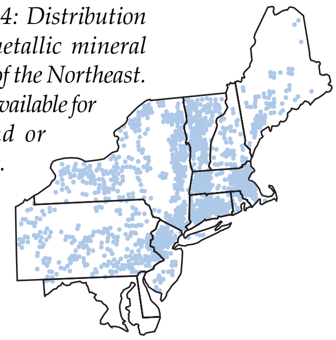


Figure 6.4: Distribution of non-metallic mineral deposits of the Northeast. No data available for Maryland or Delaware.

Mineral deposits may be formed in one of several ways: evaporation of water; crystallization of magma or lava; or the dissolution and later precipitation of minerals by hot water moving through cracks and openings in the rock well below the surface. A mineral is not necessarily restricted, however, to one method of concentration or environment of formation. For example, gypsum may form as a precipitate from evaporating water, but is also associated with volcanic regions where limestone and sulfur gases from the volcano have interacted.

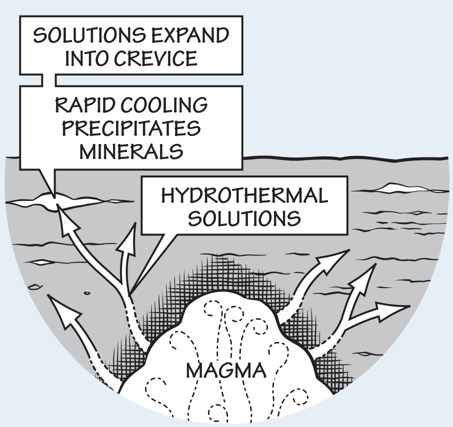
Common rock-forming minerals

There are over 3,500 different minerals identified in the world, and a wide variety occur in the Northeast. However, the number of common rock-forming minerals is much smaller. The most common minerals that form igneous, metamorphic and sedimentary rocks (and the ones that you will most commonly see) include quartz, feldspar, micas, pyroxenes and amphiboles. Though quartz occurs in several colors, it is most commonly white, gray or clear. Feldspar may be a variety of colors, including pink, white, and black or gray. Mica, a thinly sheeted, flaky mineral, is most commonly either light in color (muscovite) or black (biotite). Pyroxene and amphibole are dark green to black, generally needle-like crystals.

In the discussions of each region to follow, the focus is on: currently mined and other significant minerals; where the minerals are most common (though they may occur in other places as well); and how the minerals formed in each particular area relate to the surrounding rocks and geologic history.

What are hydrothermal solutions?

Hot water moving through rocks, also known as hydrothermal solutions, is always enriched in salts (such as sodium chloride NaCl, potassium chloride KCl, and calcium chloride $CaCl_2$) and thus is called a 'brine'. The brine is as salty or even saltier than seawater. Salty water, surprisingly, may contain minute amounts of dissolved minerals such as gold, lead, copper and zinc. The presence of salt in the water suppresses the precipitation of the metallic minerals from the brine because the chlorides in the salt preferentially bond with metals. Additionally, because the brine is hot, minerals are more easily dissolved, just as hot tea dissolves sugar more easily than cold tea. These hot water brines, or hydrothermal solutions, can have varying origins. As magma cools, hydrothermal solutions form because water is often released into the surrounding rock. The water is hot because the nearby magma is still hot (though cooling). Rainwater becomes a hydrothermal solution by picking up salt as it filters through rocks. And seawater (already enriched in salt) is often a hydrothermal solution in the vicinity of volcanic activity on the ocean floor where tectonic plates are pulling apart. Rapid cooling of the hydrothermal solution over short distances allows concentrations of minerals to be deposited. Water moving quickly through fractures and openings in the rock, experiencing changes in pressure or composition, and dilution with groundwater can rapidly cool a hydrothermal solution. Figure by J. Houghton.



Mineral Resources of the Inland Basin

Region 1

The Inland Basin is rich in a variety of minerals, though only a few are mined commercially *(Figure 6.6)*. The sedimentary rocks, making up the thick sequences of the Queenston and Catskill Deltas, formed from sediments eroded off of the Taconic and Acadian Mountains into the inland ocean during the Ordovician and Devonian. The Adirondacks, strikingly different from the surrounding sedimentary rock, are made of billion-year-old Grenville rocks.

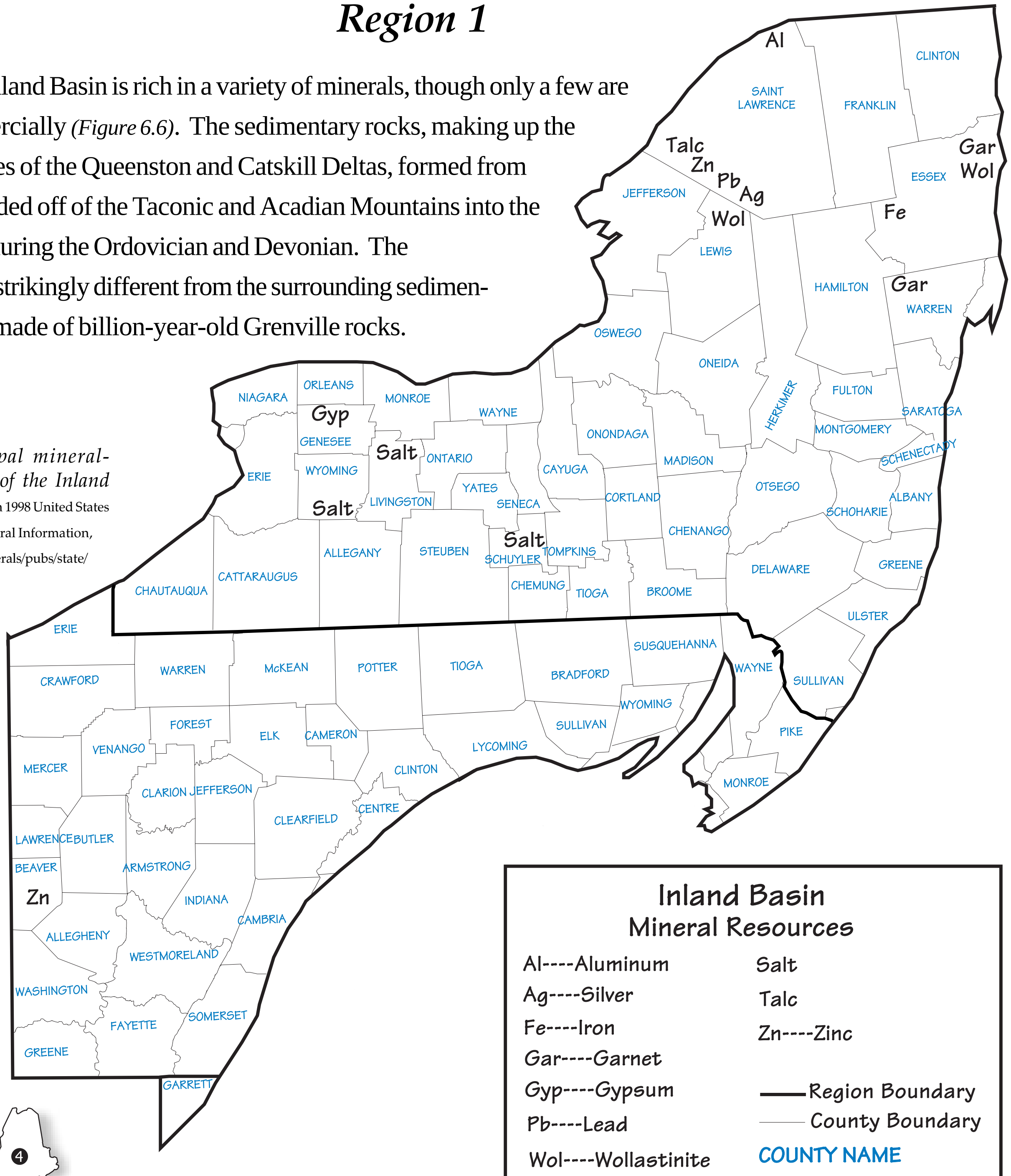
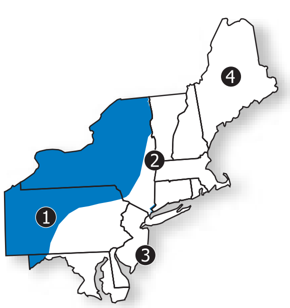


Figure 6.6: Principal mineral-producing localities of the Inland Basin. Figure adapted from 1998 United States Geological Survey State Mineral Information, http://minerals.usgs.gov/minerals/pubs/state/



Between the sedimentary rocks of the basin and the igneous and metamorphic rocks of the Adirondacks, there is a wide diversity in the principal mineral resources found in the region, including metallic minerals such as iron, zinc and illmenite, and non-metallic minerals such as gypsum and salt.

Metallic Minerals

in Grenville Rocks:

The Precambrian ***Grenville rocks*** of the Adirondacks, formed as the Grenville marine sediments were compressed and tacked on to North America, are seen poking through the younger sedimentary rock cover in the Adirondack region of New York *(Figure 6.7)*. The Grenville rocks include metamorphosed sedimentary rocks such as marble, gneiss, and quartzite, as well as anorthosite, an igneous rock crystallized from asthenosphere magma. With a mineral assemblage unique in the Inland Basin, the Adirondacks produce most of the metallic minerals in the region. The principal metallic mineral resources of the Adirondacks include iron, zinc, lead, silver, aluminum and titanium.

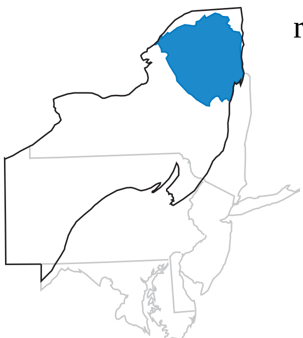


Figure 6.7: Precambrian Grenville rocks of the Adirondacks.

see *Geologic History*, *p. 3, for more on* **Grenville Rocks.**

see *Rocks*, *p.32, for more on* **Grenville rocks.**

Iron in the Adirondacks is mined from the ore ***magnetite***. Though geologists disagree on the origin of the iron, it may possibly have formed as deposits of iron in sedimentary rock that were later metamorphosed, or from concentration and later precipitation of magnetite crystals by ***hydrothermal solutions***. Though iron may also be mined from other minerals, including ***hematite*** and ***siderite***, and was at one time or another mined from every state in the Northeast, the only profitable site currently being mined for iron is in the Adirondack Precambrian gneiss.

magnetite: Fe_3O_4
hematite: Fe_2O_3
siderite: $FeCO_3$

see *Minerals*, *p. 131 for more on* **hydrothermal solutions.**

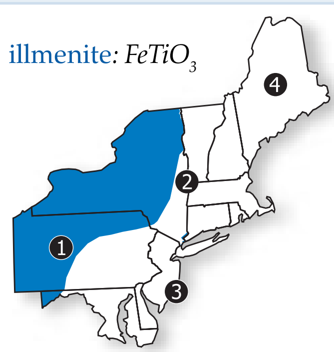
Zinc, lead, and ***silver*** are often found in association with each other. Sphalerite is the most important ore mineral of zinc; galena is nearly the only regional source for obtaining lead; and silver is found in small amounts with galena. Both sphalerite and galena are found in commercial quantities in the Adirondacks. The minerals were initially concentrated by hydrothermal solutions and recrystalized through metamorphism when the Grenville sediments were compressed a billion years ago.

sphalerite: *ZnS*
galena: *PbS*
silver: *Ag*

Zinc *is typically used in metal alloys and galvanized steel. Lead is necessary for batteries, communication systems, and building construction. Silver is used in photographic film emulsions, utensils and other tableware, and electronic equipment.*

Until recently, ***illmenite*** was mined in the northeastern section of the Adirondacks where anorthosite rocks are found. Illmenite is an ore of titanium and was produced for use as a white pigment in paint. Titanium is also an important metal because of its lightweight nature, strength, and resistance to corrosion. As the Grenville rocks were compressed and metamorphosed, magma from the

illmenite: $FeTiO_3$



asthenosphere welled up through overlying rocks. The magma crystallized to form the igneous rock, anorthosite. Crystallization, however, did not happen all at one time. In a process known as crystal settling, the dense, heavy minerals crystallized first and sank to the bottom. Illmenite, being a heavier mineral, became concentrated at the bottom of the crystallizing magma to form the large deposits of the ore that we see today.

kyanite, sillimanite *and* **andalusite** *all have the same chemical composition:* Al_2SiO_5

Aluminum is also mined in the northernmost part of the Inland Basin. Aluminum is a common component of high-grade metamorphic minerals such as ***kyanite, sillimanite*** and ***andalusite***.

The ready availability of **iron** *at the surface made iron one of the earliest mined mineral resources in the US. Iron by itself is extremely rare, usually only occurring in meteorites. Iron is more often found in combination with other elements to form ores of iron, such as hematite, magnetite, siderite and pyrite (FeS), among others.*

The mineral name **hematite** *has its origins in the Greek word* haimatos*, meaning blood. The vivid red pigment that iron lends to the mineral is valuable as a commercial pigment. Iron from hematite is also used in the manufacture of steel.*

in Other Rocks

Iron is also found in Pennsylvania and other parts of New York besides the Adirondacks. In particular, layers of limestone in the Clinton Group of rocks, located in the Silurian deposits at the edge of the Appalachian Plateau, contain deposits of ***hematite*** and siderite. These iron-rich layers stretch as far south as Alabama and are important indicators of sea level rise and fall. Hematite forms in shallow ocean water and siderite forms in relatively deeper water.

Non-Metallic Minerals

The Inland Basin also has a diverse assemblage of non-metallic minerals, from the wollastonite, garnet, tourmaline, and beryl of the Adirondacks to the salt and gypsum of the sedimentary rocks further south.

wollastonite: $CaSO_3$

Wollastonite *is primarily mined for use in ceramic tiles, porcelain, and paints. It is also used as a replacement for asbestos in brake linings.*

in Grenville Rocks

The mineral ***wollastonite*** is currently mined in the Adirondacks in Lewis and Essex County, New York. Wollastonite formed in the Adirondacks when the Grenville limestone was metamorphosed and intruded by magma. Ninety-nine percent of the wollastonite produced in the US comes from New York.

Gore Mountain *garnets are used primarily as abrasives, not gemstones.*

The Adirondacks have also been a leading producer of ***garnets***. Spectacular crystals, as large as 1 m across (though typically 2-2.5 cm across) have been found at the famous ***Gore Mountain*** garnet mine. Though the Gore

Mountain mine is now closed, the mine at nearby Ruby Mountain continues to be a leading producer of industrial garnet for use as an abrasive. When the Grenville sediments were compressed and metamorphosed over a billion years ago, the heat and pressure melted the deeply buried rocks to magma. As the magma pushed up through the overlying Grenville marble, gneiss and quartzite, it gradually crystallized to form anorthosite and other igneous rocks. When these igneous rocks were also metamorphosed, the heat and pressure recrystalized some of the rock to form the famous garnets.

garnet: *$A_3B_2(SiO_4)_3$ in which A and B may be substituted by different elements to produce a given variety of garnet.*

in Evaporite Rocks

The Inland Basin was part of an inland ocean for hundreds of millions of years as the continents pulled apart and pushed together. A shallow restricted sea is the ideal environment for the evaporation of water and deposition of evaporite minerals. ***Halite*** (salt) and ***gypsum*** are examples of ***evaporite*** minerals. The Silurian, in particular, was a time of especially shallow seas with poor circulation in the region. It makes sense, therefore, that salt and gypsum are both found in Silurian sedimentary rocks exposed across central New York *(Figure 6.8)*. The salt is at the surface, as natural salt springs, around Syracuse, New York. The gentle tilt of the Silurian rocks to the south means that salt is also found and mined underground south of the exposed salt beds, buried beneath Devonian rocks.

salt: *NaCl*

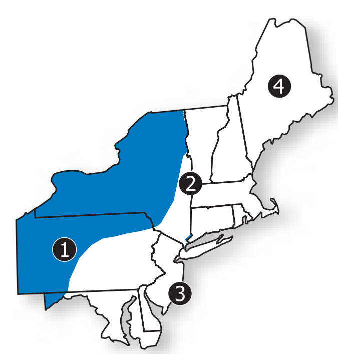
gypsum: *$CaSO_4 \cdot H_2O$*

*see Rocks, p.35, for more on the formation of **evaporite** minerals.*

Figure 6.8: Silurian rocks of the Inland Basin.

Salt has played a key role in the economy of upstate New York, and was the reason for the founding of cities like Syracuse, NY. The Retsof Mine near Geneseo, NY was the largest underground salt mine in the world before its collapse in 1993.

***Salt** is used throughout the Northeast for de-icing roads in winter and is also an important part of the chemical industry. Gypsum is mined for use in plaster and wallboard.*



Gemstones

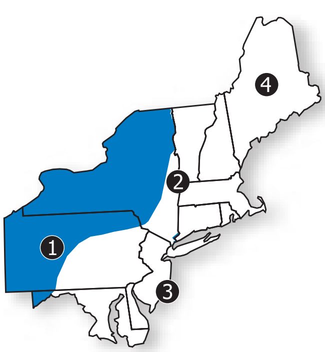
In addition to the abundance of metals and non-metallic minerals produced for industrial use in the Adirondacks, the Grenville rocks also contain the minerals tourmaline and beryl, prized as gemstones. Further south in Herkimer County, New York, in a patch of Cambrian rocks southwest of the Adirondacks, gem collectors seek out 'Herkimer diamonds.' Herkimer diamonds are not in

quartz: *SiO_2*

fact diamonds at all. Rather, they are very well formed, clear crystals of quartz found in the Little Falls dolostone. Dolostone is made in part of calcite, a mineral that is highly susceptible to reacting chemically with acids. The weakly acidic nature of rainwater and groundwater commonly dissolve away parts of dolostone, leaving open cavities in the rock. As groundwater, rich in silica, moved through the Little Falls dolostone, ***quartz*** crystallized in the cavities to form Herkimer diamonds.

The many faces of quartz

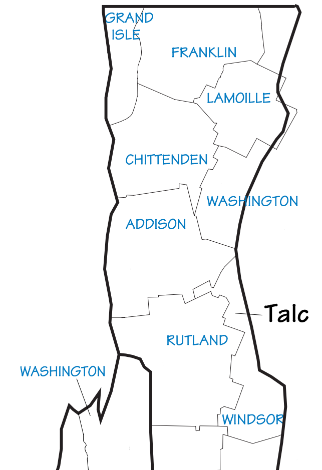
Quartz may be one of the most common minerals in the crust, but it does not always appear in the same form. There are a wide variety of different types of quartz, including coarsely crystalline and microcrystalline quartz. Several common minerals, including chert, agate and jasper, are actually varieties of quartz. Onyx, agate and petrified wood are fibrous, microcrystalline varieties of quartz known as chalcedony. Though agate is naturally banded with layers of different colors and porosity, commercial varieties of agate are often artificially colored. Flint, chert and jasper are granular microcrystalline varieties of quartz, with the bright red color of jasper due to the inclusion of small amounts of iron within the mineral structure. The most common, coarsely crystalline varieties include massive quartz veins, the distinct, well formed crystals of 'rock crystal', and an array of colored quartz, including amethyst (purple), rose quartz (pink), smoky quartz (gray), citrine (orange) and milky quartz (white).



Mineral Resources of the Appalachian/Piedmont

Region 2

Though most of the mineral mining in the Appalachian/Piedmont stopped before the early 1900's, there are still several principal mining localities in the region producing zinc, aluminum, titanium, talc and mica *(Figure 6.9)*. Other important mineral resources of the Appalachian/Piedmont (though not currently mined) include: the kaolin of the Precambrian Grenville rocks; the Ultramafic Belt chrome and asbestos, formed from metamorphosed serpentinite when the Taconic volcanic islands collided with North America; and copper and magnetite deposits of the Triassic Rift Basin.



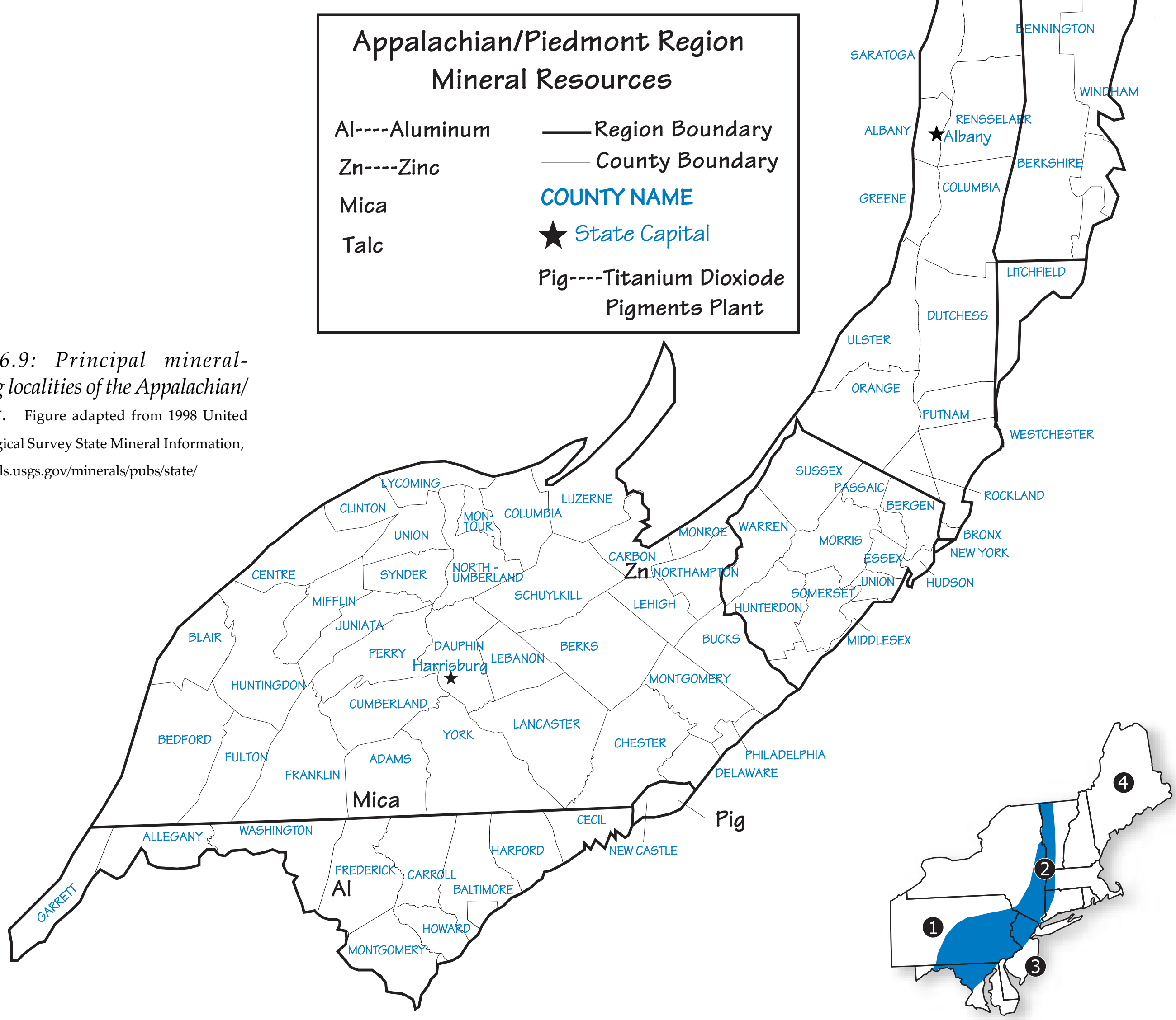


Figure 6.9: Principal mineral-producing localities of the Appalachian/Piedmont. Figure adapted from 1998 United States Geological Survey State Mineral Information, http://minerals.usgs.gov/minerals/pubs/state/

see Rocks, p.39, for more on the **Grenville rocks.**

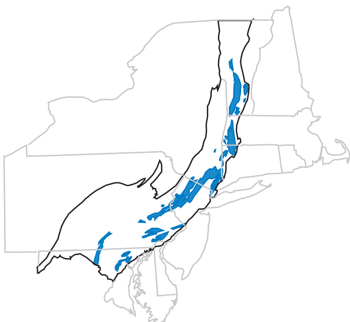


Figure 6.10: Precambrian Grenville rocks of the Appalachian/Piedmont region.

sphalerite: *ZnS*

***Zinc** is used in galvanized steel.*

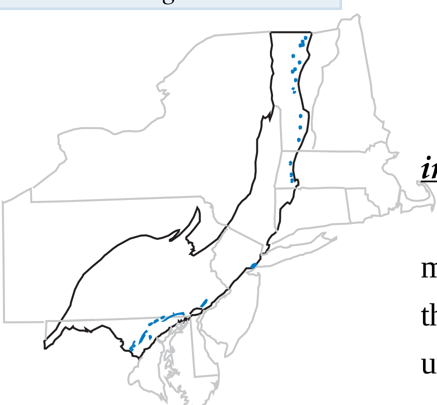
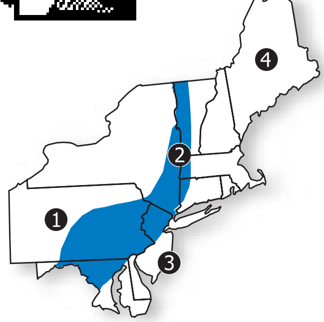


Figure 6.11: Ultramafic Belt rocks in the Appalachian/Piedmont.

see Rocks, p.42, for more on the **Ultramafic Belt.**



Metallic Minerals

in Grenville Rocks

The Precambrian ***Grenville rocks*** of the Appalachian/Piedmont region, located along the spine of the Appalachians, peek through the sedimentary rock cover such as in the Adirondacks of the Inland Basin region *(Figure 6.10)*. Associated with the Grenville rocks in Pennsylvania and Maryland are significant deposits of ***zinc*** ore, in its most common form, ***sphalerite***. At ***Franklin Furnace*** and ***Sterling Hill***, New Jersey, zinc ore in the Grenville rocks is also found, though the ore minerals are unusual.

The Franklin-Sterling Hill mining district

The Franklin-Sterling Hill mining district of northern New Jersey has yielded more than 340 different kinds of minerals, more than any other known place in the world. Franklin is known as the fluorescent mineral capital of the world because 80 of the 340 minerals fluoresce, or give off light, under ultra-violet light. The two large deposits of zinc, iron and manganese contain the ore minerals franklinite (Zn, Fe, Mn)(Fe, Mn)$_2$O$_4$), unique to the area, willemite (Zn_2SiO_4), and zincite (ZnO). The ore deposits at Franklin are found in Precambrian Grenville marble.

in Serpentine Rocks

The ***Ultramafic Belt*** that extends the length of the Appalachian/Piedmont region from Vermont to Maryland contains a variety of minerals unique to the serpentinite rock found in the belt *(Figure 6.11)*. The serpentinite rock itself is unusual, produced from the alteration of peridotites by metamorphism. The peridotite, derived from magma from the upper mantle of the Earth, was originally part of the oceanic crust. However, as the North American tectonic plate and the Taconic volcanic islands gradually drew closer together, the intervening oceanic crust was being pushed beneath the North American plate. Some of the oceanic crust was scraped off and welded onto the side of North America as the rest of the oceanic crust was shoved down into the mantle. The peridotite of the oceanic crust was metamorphosed to form serpentinite, a rock rich in minerals not often found as part of the continental crust. A metallic mineral of note in the serpentinite rocks is chromite. The only ore of chromium, chromite was at one time mined in the Ultramafic Belt serpentinite rocks of Pennsylvania and Maryland. A dense, heavy mineral, chromite is one of the first minerals to crystallize and settle to the bottom of a cooling magma. It was thus concentrated in the serpentinite rocks in quantities sufficient to be profitably mined.

Chromium *is used as a component of certain pigments; as a component of steel, providing resistance and hardness; and in the production of chrome and stainless steel.*

in Rift Basin Rocks

The Newark and Gettysburg Triassic rift basins of the Appalachian/Piedmont region stretch through southeastern New York, New Jersey, Pennsylvania and Maryland. Formed during the rifting of Pangea away from North America, the rift basins contain alternating layers of igneous and sedimentary rocks *(Figure 6.12)*. The resistant, ridge-forming igneous rocks, produced from lava flows (basalt) or igneous intrusions (diabase), contain mineral resources of economic importance to the region.

Figure 6.12: Triassic rift basins in the Appalachian/Piedmont.

see Rocks, p.5

In particular, ***magnetite*** is an important mineral resource in the Pennsylvania and New Jersey diabase rocks, concentrated and subsequently precipitated by hot flowing water through the rocks. Magnetite is one of the common ores of iron. ***Copper*** deposits are also associated with the basalt lavas of the rift basins.

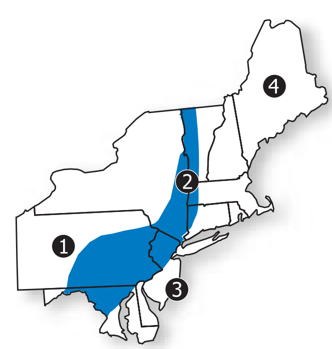
magnetite: Fe_3O_4

Copper *is used extensively as wiring in the electrical industry as well as in alloys such as brass and bronze. Brass is a combination of copper and zinc; bronze combines copper, tin and small amounts of zinc.*

in Other Rocks

Other important metallic minerals in the Appalachian/Piedmont region include nickel, molybdenum, titanium, manganese, cobalt, and graphite. In northern Delaware, titanium is an important mineral resource associated with the igneous rocks of the area, mined commercially for use as a paint pigment. In the Piedmont, gold is found in small quantities associated with quartz veins and fault zones in the metamorphic rocks of the region. ***Sillimanite***, Delaware's state mineral, is found in the Appalachian/Piedmont region of northern Delaware as large crystals produced from aluminum-rich rocks that were deeply buried and subjected to intense metamorphism. Though the mineral is not limited to Delaware, the unusually large crystals of sillimanite found there are rare elsewhere.

sillimanite: Al_2SiO_5



Mineral Resources

Non-Metallic Minerals

The Grenville and Serpentine rocks of the Ultramafic Belt, and the Rift Basins of the Appalachian/Piedmont, host a plethora of non-metallic mineral resources in addition to the metallic minerals discussed above.

kaolinite: $Al_2Si_2O_5(OH)_4$

Brandon, Vermont is famous for its large deposit of the white clay **kaolinite** *used in paint, kaopectate, linoleum, porcelain and fillers.*

in Grenville Rocks

There is an abundance of non-metallic mineral resources in the billion-year-old Grenville rocks, including mica, feldspar and quartz. Mica, a common mineral in igneous, metamorphic and sedimentary rocks, is mined in southern Pennsylvania in Adams County from the Precambrian Grenville rocks that form South Mountain. ***Kaolinite***, a white clay formed from the weathering of feldspar, is mined in Vermont.

asbestos: $Mg_3Si_2O_5(OH)_4$
talc: $Mg_3Si_4O_{10}(OH)_2$

Asbestos *is a very slow conductor of heat, and thus was commonly used as a fireproofing material and electrical insulation. Concerns over the health effects on the lungs of this fibrous mineral have led to its removal from most common uses.*

Used in talcum powder, paint, ceramics, rubber and paper, **talc** *is an economically valuable non-metallic mineral.*

in Serpentinite Rocks

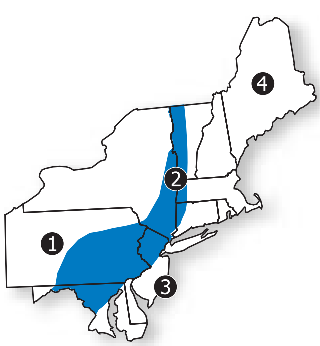
The Ultramafic Belt of serpentinite contains at least two important associated non-metallic minerals, which commonly form through the metamorphism of the magnesium-rich rocks: ***asbestos*** and ***talc***. At one time, Vermont produced the most asbestos in the United States, though it is no longer mined there. Talc continues to be mined in Vermont today. An extremely soft mineral, talc can be scratched easily with your fingernail and has a soapy, greasy feel typical of very soft minerals.

in Rift Basin Rocks

The Triassic Rift Basin of the Appalachian/Piedmont also has its share of non-metallic minerals. Basalt, formed as lava broke out of the crust and flowed across the surface of the basin, cooled quickly, trapping gas bubbles within the rock that left small cavities. Later, as water flowed through the rock, minerals were precipitated in the cavities, forming crystals such as the green mineral ***prehnite***. Paterson and Bergen Hill, New Jersey are known for this mineral.

prehnite: $Ca_2Al(AlSi_3O_{10})(OH)_2$

Prehnite *is used as a gem mineral.*



Gemstones

In addition to the non-metallic minerals discussed above, the Appalachian/Piedmont region produces several types of gemstones. The very common mineral ***feldspar*** has several relatively rare varieties found in Pennsylvania that are sold as the gemstones sunstone and moonstone. Amethyst, smoky quartz, agate, garnet and ***beryl*** are also found in the region. Beryl is common in granites and pegmatites and comes in a variety of colors.

Feldspars

Feldspar is an extremely common, rock-forming mineral found throughout the Northeast in igneous, metamorphic and sedimentary rocks. There are two groups of feldspar: alkali feldspar (which ranges from potassium (K)-rich $KAlSi_3O_8$ to sodium (Na)-rich $NaAlSi_2O_8$) and plagioclase feldspar (which ranges from sodium (Na)-rich $NaAlSi_3O_8$ to calcium (Ca)-rich $CaAl_2Si_2O_8$). Potassium feldspars of the alkali group are commonly seen as pink crystals in igneous and metamorphic rocks, or pink grains in sedimentary rocks. Plagioclase feldspars are even more abundant than the alkali feldspars, ranging in color from light to dark. Sunstone and moonstone, gem varieties of plagioclase feldspar, are found throughout the Appalachian/Piedmont region, particularly in Pennsylvania.

beryl: $Be_3Al_2(Si_6O_{18})$

Though not found in the Northeast, the precious stone emerald is the green variety of beryl.

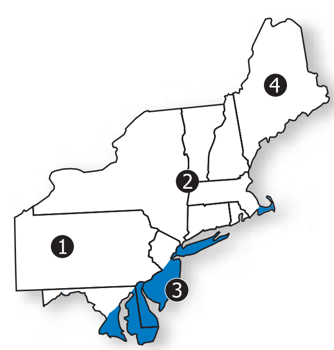
Feldspars are commercially used in ceramics and scouring powders.

Mineral Resources of the Coastal Plain

Region 3

The Coastal Plain region of the Northeast has very few mineral producing localities. Gypsum and magnesium compounds are the extent of the current mineral production, and kaolin was produced in the past in Maryland. The Coastal Plain, made entirely of a wedge of loose sediments (not cemented or compacted sufficiently to have become sedimentary rock), does not have the abundance of valuable minerals and ores found in igneous and metamorphic rocks, nor the proper conditions to create such minerals. Unlike the other regions, minerals are concentrated in the Coastal Plain only through density separation by streams and wave action along the shoreline.

see Rocks, p.46, for more on the **Coastal Plain sediments.**



Mineral Resources of the Exotic Terrane

Region 4

The formation of the igneous and metamorphic rocks that dominate the Exotic Terrane region provided the perfect conditions for spectacular concentrations of metallic and non-metallic minerals. The first chartered mining company in the US started in the Exotic Terrane region in 1709 at the Simsbury Copper Mine, Connecticut (now East Gransby, CT). Other very early mines were located in the Blue Hills along coastal Maine.

Metallic Minerals

With the collision of the Taconic volcanic islands in the Ordovician, Baltica and Avalonia in the Devonian, and the final collision with Africa during the Permian, the various slices of the Exotic Terrane region have undergone significant periods of compression, deformation, metamorphism and intrusion by magmas. These dynamic geologic conditions gave rise to the formation of many metallic minerals (often associated with igneous and metamorphic rocks). Granite pegmatites, common in this area, often include uranium, gold, antimony, graphite, and iron. ***Gold***, lead, silver and copper are associated with the metamorphic rocks in the region and commonly found in association with one another.

Gold

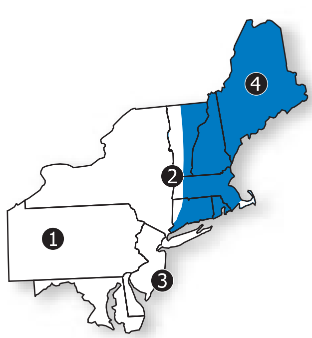
Gold (Au) has been found throughout the Exotic Terrane region as well as the Appalachian/Piedmont. However, having an average abundance in the crust of only 0.004 parts per million, gold can be profitably mined only where hydrothermal solutions have concentrated it. Gold is not found in high concentrations in the Northeast. Most often occurring in its native state (not combined with other elements), gold has been found in stream sediments in very small amounts.

Exceptionally fine quality crystals of ***pyrite***, 'fools gold,' are found in Chester, Vermont. A very common and widespread mineral, pyrite forms in igneous, metamorphic and sedimentary environments as well as through the chemical alteration of other minerals. Other metallic minerals and ores found in the Exotic Terrane region include molybdenum, cobalt, nickel, tin, and tungsten.

pyrite: *FeS*

The largest manganese deposit on the North American continent is found in Maine in Silurian rocks of Aroostook County. The mildly metamorphosed Silurian rocks were once sediments at the bottom of the Iapetus Ocean. Concentrations of manganese commonly form on ocean bottoms today.

Manganese *(Mn) is used in the production of steel.*



Non-Metallic Minerals

The primary non-metallic minerals of the region are metamorphic and pegmatite minerals, which are so common in the Exotic Terrane area because of the foundation of igneous and metamorphic rock.

in Metamorphic Rocks

The process of metamorphism ranges from low grade (with only mild increases in pressure and temperature) to high grade (with severe increases in pressure and temperature). Mildly deformed rocks may be subjected to very low grades of metamorphism and outwardly exhibit little change in appearance. Severely deformed rocks, on the other hand, have usually been subjected to very high grades of metamorphism and appear distinctly different. The higher the degree of metamorphism, the greater the change is to the original rock. The changes include, to varying degrees, the alignment of minerals within the rock, recrystallization of minerals, and, in many cases, the crystallization of new minerals.

Geologists have determined that specific minerals will form at specific temperature and pressure conditions when a given type of rock is metamorphosed. Low-grade metamorphism of clay-rich rocks such as shale, produce the mineral chlorite. Higher-grade increased metamorphism produces the minerals kyanite and sillimanite. The minerals associated with certain grades of metamorphism are known as index minerals, indicative of the combination of the temperature and pressure conditions a rock has undergone *(Figure 6.13)*.

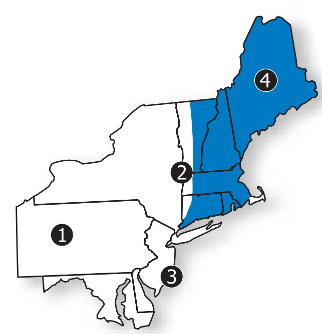
METAMORPHIC GRADE	Clay-rich rocks	Limestone	Mafic igneous rocks
low ↓ high	chlorite biotite staurolite kyanite sillimanite	chlorite garnet hornblende augite	chlorite garnet hornblende

resulting metamorphic minerals

Figure 6.13: Minerals formed through varying degrees of metamorphism in different types of rocks.

Thus, by examining the minerals found in the Exotic Terrane region, it is clear that the rocks have been metamorphosed to varying degrees. Chlorite is found in northern Maine, indicating that the rocks were only mildly deformed because they were not the center of the collision between continents and have fewer igneous intrusions. Eastern New Hampshire and southern Maine, however, clearly show evidence of high-grade metamorphism by the presence of minerals such as sillimanite and kyanite.

Considering the plate tectonic history of the Exotic Terrane region, the



The Taconic, Acadian and Alleghanian mountain-building events repeatedly compressed and deformed the rocks of the Northeast.

The grade of metamorphism generally decreases to the west, with variation due in part to contact metamorphism by intrusions of magma.

see Minerals, p. 134 for more on **garnet.**

presence of ***high-grade*** metamorphism in the rocks is no surprise. The rocks with high-grade metamorphic minerals indicate the area of greatest stress during the episodes of mountain building throughout the Paleozoic, as well as areas that have been intruded by magma.

Garnet, a metamorphic mineral indicative of moderate metamorphism, is found throughout the Exotic Terrane region. Connecticut has spectacular garnets in the metamorphic rock, mica schist. Garnet is used as a gemstone and an abrasive in sandpaper and polishing. The substitution of different elements into the crystal structure produces several common types of garnets, all of which have the same basic chemical composition: uvarovite, pyrope, andradite, almandite, grossularite and spesartite. Almandite is particularly common in Connecticut.

Gemstones and Other Non-Metallic Minerals

The plate tectonic history of the Exotic Terrane region provided the right conditions to produce slow-cooling magmas far below the surface. Volatiles escaping from those deep magma chambers, enriched in water and rare elements, led to the creation of outstanding pegmatites: lithium pegmatites in Massachusetts; phosphate pegmatites in New Hampshire; and the famous gem-quality tourmalines and beryl of Maine. The first Maine tourmaline, and the start of gemstone production in the United States, was mined at Mt. Mica, where crystals have been found as large as 39.4 cm long, 17.8 cm wide and weighing 14.3 kg. Many minerals in a pegmatite are common and not gem quality, such as quartz, mica, and feldspar. However, gemstones frequently are found in association with ***pegmatites***. Other gemstones found in the Exotic Terrane region include garnet, zircon, topaz, corundum, feldspar, and quartz varieties including jasper, rock crystal, amethyst, and smoky, rose and clear quartz.

see Rocks, p.52 for more on **pegmatites.**

Pegmatites *often contain rarer minerals such as lithium, beryllium, uranium, lepidolite, spodumene, apatite, and fluorite, in addition to the more common quartz, feldspar, and mica.*