Northwest
Micro   Mineral
Study   Group

MICRO PROBE

SPRING, 2015   VOLUME XII, Number 1

SPRING MEETING . . . . MILWAUKIE, OREGON

May 2, 2014   9:30 am to 4:30 pm

Fire Station Meeting Room
2930 SE Oak Grove Boulevard
Milwaukie, Oregon

We will be meeting again in the room beside the Fire Station that is a block west of McLoughlin Boulevard at the corner of SE Oak Grove Boulevard and SE East Street

From the south, take I-205 and use exit 9 just across the bridge over the Willamette River onto McLoughlin Blvd. Oak Grove Blvd. is about 3 miles north along McLoughlin.

*From the north along I-5, it is best to take the Broadway exit, then turn south on Martin Luther King Blvd. This will eventually become McLoughlin Blvd. The total distance from the Broadway exit to Oak Grove Blvd. is about 8 miles. Do **not** get shuffled off onto the Milwaukie Expressway!*

From the north, the best way to go is along I-205. Take exit 12 and go west onto SE Roots Road. When it ends, jog south on SE Webster Road to Jennings Avenue, which crosses McLoughlin Blvd. in about 1.5 miles. Turn right and go about 1 mile to Oak Grove Blvd. If you miss exit 12, you can alternatively use the Gladstone exit (#11) onto Oatfield Road, which crosses Jennings Avenue after about 1 mile. Turn left and proceed to McLoughlin Blvd.

There is a sketch of all this on the last page of this issue.

Schedule for the day;

Please note that we will be setting up for the day starting a little before 10am. Don't forget to bring a box or two of pieces with identification and/or location information to put on the give-away table

In the afternoon after a short business meeting, **Doug Merson** will be talking and showing pictures of the minerals he has accumulated from *Mt. Ste. Hilaire.* If you have pictures that you would like to share with us, we will have computer and projector available for your use.

This meeting, let's put together what we have in our collections from Mt. Ste. Hilaire so that we can pass them around and learn from them. Doug will have representative pieces for us to compare to, so maybe we can identify some of the material that we have been unsure about. Make certain that things are properly boxed with your name on them so that they get back to you safely before the end of the day.

Lunch will be the usual pot-luck, with the Group supplying basic sandwich material. Please bring chips, condiment, salads, and desserts to add to the feast.

Dinner plans will be made at the meeting. Please join us if you are able.

Miller Indices revisited

Don Howard

Since the articles in this issue, and the last one as well, refer over and over to Miller Indices, I thought that a quick review of what they are and how they work might make some of what is being said make more sense. First and foremost, *a Miller Index is the name of a particular face in a crystal*. Knowing how to name a face is the first step in recognizing it, just as knowing the name of your friend immediately brings their features to mind.

The planes of a crystal are named according to their intercepts along the three crystallographic axes. Consider the diagram at right. The plane shown in red intersects the x-axis at 1 unit, the y-axis at 2 units, and the z-axis at 4 units. Instead of using the intercepts directly, we use their reciprocals: $(1, ½, ¼)$. Then we clear the whole thing to whole numbers by multiplying by the least common denominator, in this case 4 : (421) . If this were a face on a cubic crystal, its name would be (421).
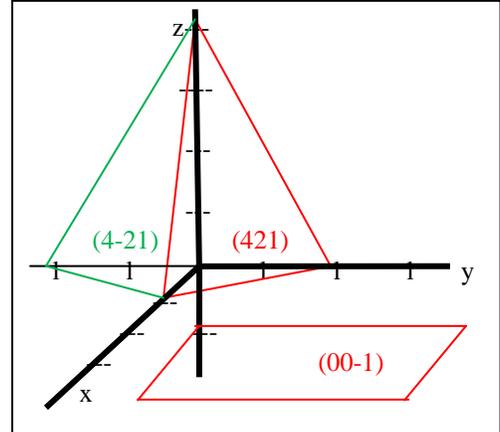
Why, you might ask, go to the trouble of taking reciprocals? There are basically two answers to that question, one practical and one theoretical. The practical one can easily be seen if you consider a plane one unit down parallel to the xy plane. The intercept on the z-axis is -1 unit. But it does not cross the x- or y-axis. We say that the intercept is infinitely far from the origin. If we used the intercepts directly, we would need a bunch of infinity-symbols, like this ∞ . My computer happened to have one, but you sure wouldn't find one on a typewriter keyboard! However, the reciprocal of an infinitely large number is an infinitely small number, namely 0. So this lower face shown in the diagram goes by the name (00-1). By the way, the minus sign is often drawn above the number rather than in front of it, but my computer is not that smart (I'm surprised it had ∞.)

The second answer is that the three numbers obtained using the reciprocals are really the coordinates of a vector perpendicular to the plane they represent. It is convenient in a branch of mathematics called Vector Analysis to represent plane by their normal vector. Using that normal, it is relatively easy to calculate things like the angle two plane make where they intersect, and the direction of the line the intersection, which would be a crystal edge. Those are nice things to be able to do, but we are not going to have reason to resort to that in the discussions in this issue.

One thing we will have occasion to examine is the meaning of what symmetry operations really involve. The symbolism looks mathematical, but in reality it falls more into the realm of symbolic logic. *Symmetry operations are in reality simple rules for interchanging the numbers in a Miller Index*. Let's look at an example. Suppose that the xz-plane was a shiny surface – a mirror. The reflection of the red plane in that mirror would be the image shown in green. We can specify what we have done by saying, "reverse the coordinate along the y-axis but leave the other two unchanged. In symbols, this would look like a recipe for an operation: (x,y,z) ⇨ (x,-y,z) ;   (421) ⇨ (4-21)

Rotations can be specified in the same sort of way. A 90° rotation about the z-axis would shift all coordinates along the x-axis to lie along the y-axis, and all those originally along the y-axis to lie along the negative x-axis. Symbolically: (x,y,z) ⇨ (-y,x,z)   Doing this four time ought to return use to where we started:

(421) ⇨ (-241) ⇨ (-4-21) ⇨ (2-41) ⇨ (421)

Read on in the next article to see how this can be used to deduce crystal shapes.

The Role of Point Groups in Cubic Crystal Shapes

Donald Howard

In the last issue of the Microprobe, Herwig Pelckmans has given a beautiful explanation of the many forms of fluorite crystals. The description is so extensive and detailed, one might be led to think that that was a complete description of the range of forms a cubic mineral could form. But with a little reflection, you will soon come to realize that some forms are missing; in particular the tetrahedron and the pyritohedron are reasonably common forms that are not represented. Why not? Where do such forms fit into the overall picture? In order to answer that question, we have to delve a little deeper into what exactly constitutes a crystal structure, and into what we mean by symmetry operations.

The Group

One of the logical mathematical sub-fields is called group theory. A group is formed around one or more logical operations. We then define one member of the group, apply the operation(s) repeatedly, and in that way generate the members of the group, all of whom are related by those operations.

Let's try an example. Suppose that our operations are multiplication and division by 2. Let's pick the number 1 as a member of the group. Multiplication by 2 then yields 2, 4, 8, 16, 32, 64, ….. Division yields 0.5, 0.25, 0.125, 0.0625, ….. In this way we generate an infinite number of members, and we can start with any of the numbers in the group and reach any other by repeated application of one of the operations.

The concept of a lattice is another example of a group. The operations involved are a set of three translations; in the case of a cubic lattice, these are along the three orthogonal directions x, y, and z. The one member that we start with is the unit cell, which in this case is a cube. Performing the allowed operations generates an infinite group of cells that cover all space with no parts left out or overlapped.

The set of faces that compose a given crystal form, say a dodecahedron, form such a group, in this case a finite group with twelve members. The operations involved are the symmetry operations that pertain to the particular crystal structure. Let us review those first.

The Symmetry of a Cubic Lattice

Let us consider what we mean by a symmetry operation. Consider first a four-fold rotation axis along the x direction. The basic rotation of 90° transforms the y-axis into the z-axis and the z-axis into the negative y-axis. We represent this symbolically as:

$$(x,y,z) \Rightarrow (x,-z,y)$$

Doing this four times returns us to the original position. Suppose we pick as our original member the face {010}. Then operating successively will give:

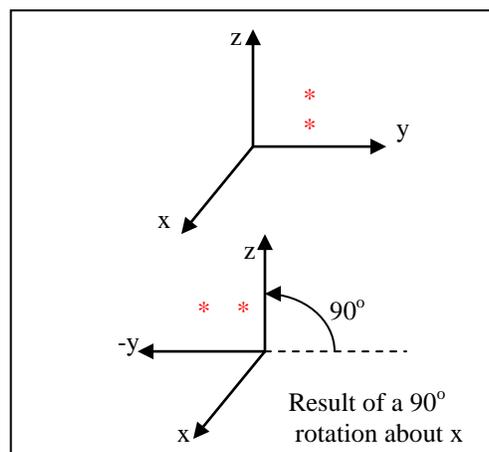$$(010) \Rightarrow (001) \Rightarrow (0\text{-}10) \Rightarrow (00\text{-}1) \Rightarrow (010)$$

Now there are actually two more four-fold rotation axes, one around y and one around z. The z-axis rotation would be: $(x,y,z) \Rightarrow (-y,x,z)$

$$(010) \Rightarrow (\text{-}100) \Rightarrow (0\text{-}10) \Rightarrow (100) \Rightarrow (010)$$

The y-axis rotation would be: $(x,y,z) \Rightarrow (-z,y,x)$

$$(010) \Rightarrow (010)$$

Result of a 90° rotation about x

Taken together, they generate as a group the six faces of the cube:

(100)   (010)   (001)   (-100)   (0-10)   (00-1)

But wait. There are other symmetry operations possible that also generate faces in the same group. One is a mirror plane perpendicular to each of the three four-fold rotation axes.

Perpendicular to x: (x,y,z) ⇒ (-x,y,z)   (100) ⇒ (-100)
Perpendicular to y: (x,y,z) ⇒ (x,-y,z)   (010) ⇒ (0-10)
Perpendicular to z: (x,y,z) ⇒ (x,y,-z)   (001) ⇒ (00-1)

The combination of a fourfold axis and perpendicular mirror is given the symmetry symbol   " **4/m** ".

There are in addition four threefold rotation axes, one along each body diagonal. Rotation around these axes interchanges the principal directions:

About [111]:   (x,y,z) ⇒ (y,z,x)
About [-111]:   (x,y,z) ⇒ (-y,z,-x)
About [1-11]:   (x,y,z) ⇒ (-y,-z,x)
About [11-1]:   (x,y,z) ⇒ (y,-z,-x)

There is also the inversion operation: (x,y,z) ⇒ (-x,-y,-z)

The combination of a threefold axis and inversion is given the symmetry symbol   " **-3** " .

Finally, there are six twofold rotation axes together with their perpendicular mirror planes:

About [110]   (x,y,z) ⇒ (y,x,-z)   mirror   (x,y,z) ⇒ (-y,-x,z)
About [101]   (x,y,z) ⇒ (z,-y,x)   mirror   (x,y,z) ⇒ (-z,y,-x)
About [011]   (x,y,z) ⇒ (-x,z,y)   mirror   (x,y,z) ⇒ (x,-z,-y)
About [-110]   (x,y,z) ⇒ (-y,-x,-z)   mirror   (x,y,z) ⇒ (y,x,z)
About [10-1]   (x,y,z) ⇒ (-z,-y,-x)   mirror   (x,y,z) ⇒ (z,y,x)
About [0-11]   (x,y,z) ⇒ (-x,-z,-y)   mirror   (x,y,z) ⇒ (x,z,y)

The combination of a twofold axis and perpendicular mirror is given the symmetry symbol   " **2/m** ".

Overall, therefore, the symmetry symbol for the full cubic lattice is " **4/m-32/m** " .

The Point Group

However, a lattice is just a mathematical construct. To make it into an actual crystal structure, we must add a basis of one or more atoms into the unit cell. The combination of basis and lattice becomes the crystal structure. And depending on exactly how we arrange these basis atoms, it will also have a particular symmetry to add to that of the lattice. The combined symmetry will be limited to those operations that ***both the lattice and the basis have in common***. This combine symmetry is what we refer to as the point group.

The simplest basis we could add would be just one single atom in the unit cell. Since a lone atom would possess spherical symmetry, the resulting point group would be identical to that of the lattice, namely 4/m-32/m . This is sometimes called ***Simple Cubic***. But this is not very interesting, since no natural material crystallizes in this way.

The next simplest basis is two identical atoms, one at the corner and one at the body center, [1/2,1/2,1/2]. The resulting point group is often referred to as ***Body-Centered Cubic***. Once you combine this basis with the cubic translations you see that each corner of the unit cell is occupied, and each body center is filled. That means that every atom is surrounded by eight nearest neighbors. Full cubic symmetry is satisfied, so the structure belongs to the point group 4/m-32/m . Numerous elements


The Body-Centered Cubic basis
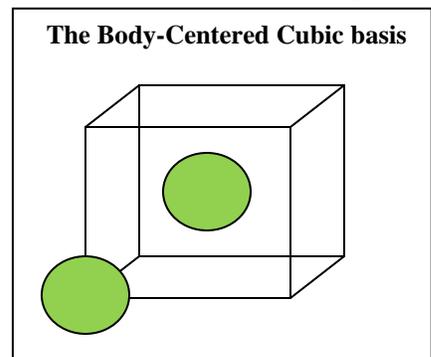
crystallize in the BCC structure, but the only one that I know of that occurs naturally is native iron.
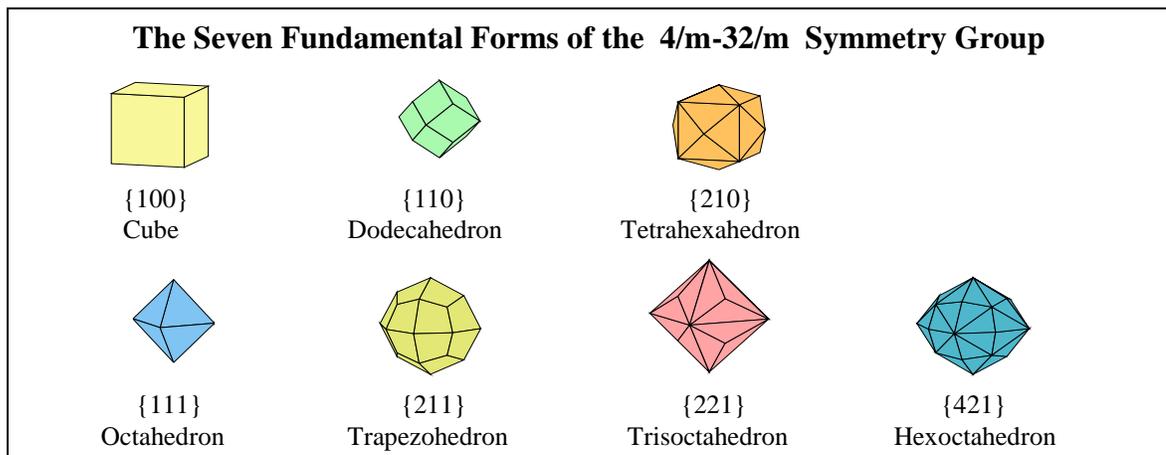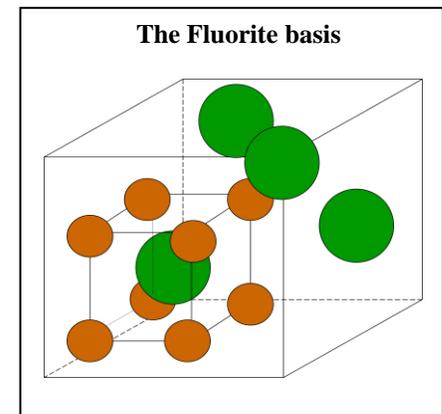
Another common basis included four atoms, one at the corner of the unit cube and one each at the three surrounding centers of the faces. Naturally, this is the ***Face-Centered Cubic*** structure. Again, when combined with translation, each corner of the unit cell and each face center will be occupied. Each atom will have six nearest neighbors. Once again, full cubic symmetry is satisfied, so the structure belongs to the point group 4/m-32/m . Numerous other elements prefer this structure, among them the native metals copper, silver, and gold.
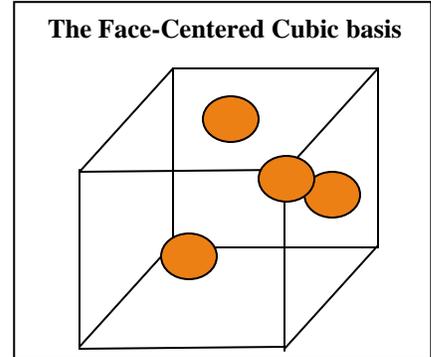
Most naturally occurring minerals are made up of more than one type of atom. Several of the simplest of these are closely related to the FCC structure. Imagine one type of atom occupying the corner and face centers, while a different type of atom occupies the body center and the midpoint along each of the edges. These eight atoms form a smaller cube, with corners alternately occupied by each type of atom. This is usually referred to as the ***NaCl*** structure, which again belongs to the point group 4/m-32/m. Many ionic compounds of the type AB crystallize in this way. Among them are minerals such as halite and galena.
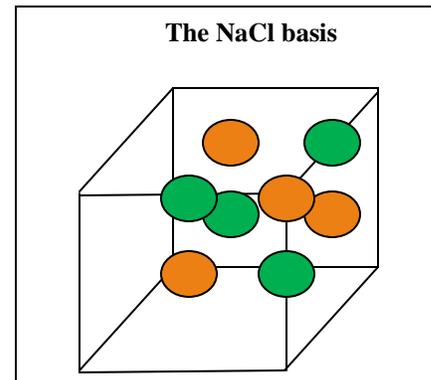
Ionic crystals of the type AB_2 often form in another config-uration related to the FCC structure. This is the arrangement that fluorite adopts. Here the calcium atoms take on a FCC array, with the fluorine atoms arranged at the (1/4,1/4,1/4) points in such a way that they form about each calcium atom a cube whose side is just half the size of the unit cell. There are twelve atoms in the basis, four of one type and eight of the other. The fluorine atoms form a simple cubic array where half of the "cells" are occupied by a calcium atom and half are empty. Again, just as with the other structures introduced above, full cubic symmetry is maintained, so that we have the 4/m-32/m point group. All the forms of crystals discussed for fluorite in the last issue are going to be possible for any mineral that crystallizes under the 4/m-32/m symmetry.

The Face-Centered Cubic basis

The NaCl basis

The Fluorite basis

The Seven Fundamental Forms of the 4/m-32/m Symmetry Group

{100}
Cube

{110}
Dodecahedron

{210}
Tetrahexahedron

{111}
Octahedron

{211}
Trapezohedron

{221}
Trisoctahedron

{421}
Hexoctahedron

The Sphalerite Point Group and -43m Symmetry

Not all point groups are going to exhibit full cubic symmetry. Consider first the structure of sphalerite , Zn S . This is really rather closely related to the fluorite structure, but with half of what were fluorine atoms replaced by sulfur and the other half removed. The removal is of every other corner of the small cube, so that only a tetrahedral arrangement of atoms remain. The zinc is located at the middle of a tetrahedron of sulfur atoms and the sulfur is at the middle of a tetrahedron of zinc atoms.

The Sphalerite basis

The resulting structure still has all four three-fold rotation axes remaining, but overall inversion is gone. The mirror plane parallel to the cube faces are gone, though the mirror planes perpendicular to the [110] directions remain. The normal four-fold rotation axes are gone, though they are replaced by what are called four-fold rotary-inversion axes who operation can be written:
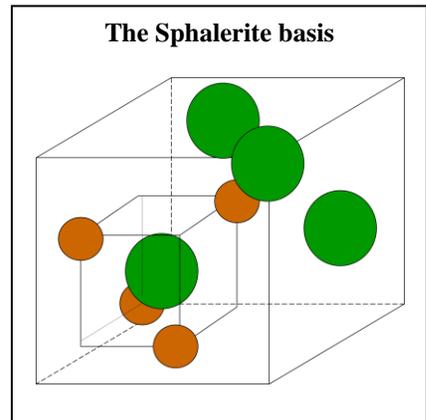
$(x,y,z) \Rightarrow (-x,z,-y)$
$(x,y,z) \Rightarrow (z,-y,-x)$
$(x,y,z) \Rightarrow (y,- x,-z)$

These are abbreviated **-4** , so the overall point group is given the symbol **-43m** . This then is the class that sphalerite belongs to. Other minerals, such as tetrahedrite and helvite also belong to this symmetry class.

To see what effect this has on the shape of crystals, let us apply some of the symmetry operations to the seven fundamental forms illustrated above. We have already shown that the three-fold rotations are sufficient to generate all the faces of the cube, so that remains unchanged. Let us next consider the octahedron. We start with one face, (111), and apply the three-fold rotations:

$(x,y,z) \Rightarrow (y,z,x)$ (111) $\Rightarrow$ (111)
$(x,y,z) \Rightarrow (-y,z,-x)$ (111) $\Rightarrow$ (-11-1) $\Rightarrow$ (-1-11) $\Rightarrow$ (111)
$(x,y,z) \Rightarrow (-y,-z,x)$ (111) $\Rightarrow$ (-1-11) $\Rightarrow$ (1-1-1) $\Rightarrow$ (111)
$(x,y,z) \Rightarrow (y,-z,-x)$ (111) $\Rightarrow$ (1-1-1) $\Rightarrow$ (-11-1) $\Rightarrow$ (111)

Notice that only four group members are generated:
(111), (1-1-1), (-11-1), and (-1-11).
A quick look at the three rules for rotary-inversion above shows the same set of faces. And if you apply the rules farther above for the six mirror planes, you get the same result. So instead of the eight faces of the octahedron, we have here only four faces, and these make up a tetrahedron.

Now that is not to say that the other four faces do not exist. Rather, they belong to a different group   (-111), (1-11), (11-1), and (-1-1-1) . These two groups are different; they may have a different arrangement of atoms on their surface and therefore grow at a different rate. So these two different groups may develop differently and the crystal may end up with different sized faces for each of the two groups. (See for example the sphalerite crystal from New Zealand illustrated below.)
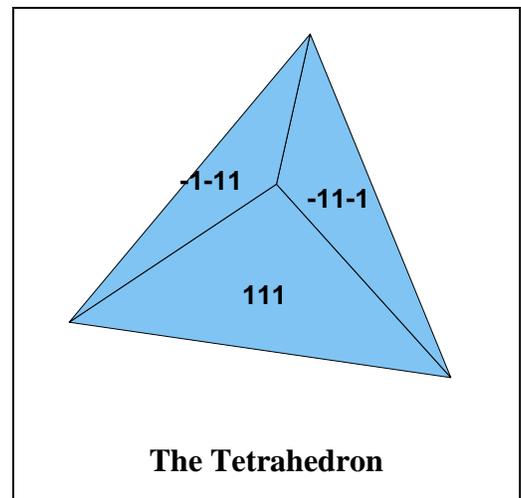
The Tetrahedron

You can go through the other five basic forms, applying the rules just as above, to see what happens in each case. For the sake of simplicity, we will not do that in detail, but only give you the bottom line. The dodecahedron (110) and the tetrahexahedron (210) will generate the full set of faces. All the others come out differently. The appropriate set of seven basic forms for -43m symmetry are given at the top of the next page.

The Seven Fundamental Forms of the -43m Symmetry Group

{100}   {110}   {210}

{111}   {211}   {221}   {421}
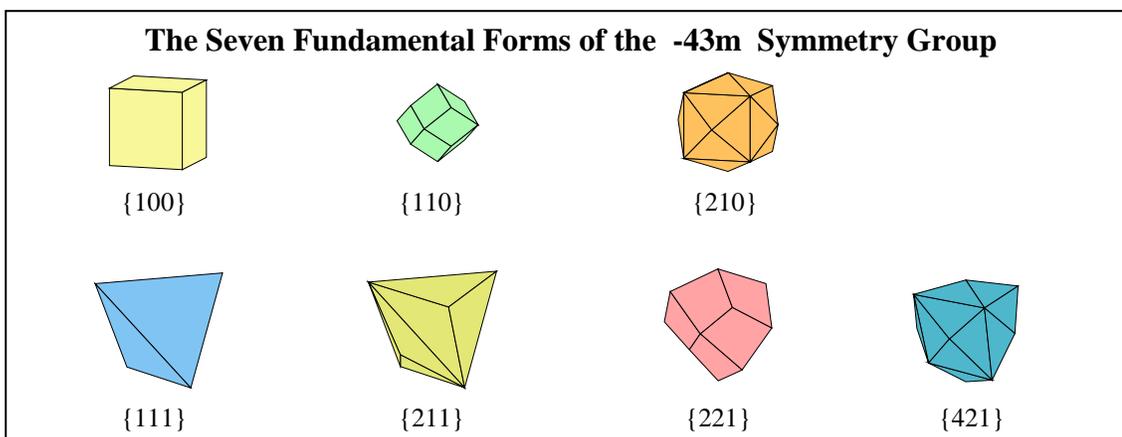
Some minerals that belong to the -43m symmetry group preferentially form as simple tetrahedra. One of those, *tetrahedrite*, actually derives its name from this tendency. It has a considerably larger basis – $(Cu,Fe)_{24} Sb_8 S_{26}$ – for a total of 58 atoms. A crystal of tetrahedrite is shown at right.
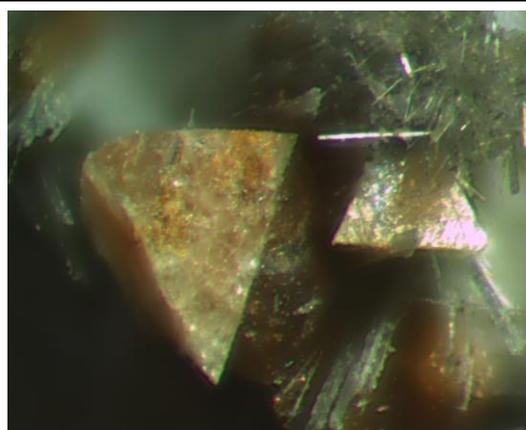
Another mineral in this symmetry group is *helvine*, $Mn_4 (Be_3Si_3O_{12}) S$. Again, the basis is quite large, but the atoms are arranged to preserve cubic symmetry. The fundamental shape of the crystals are simple tetrahedral, as shown at the bottom of the page.

Though *sphalerite*, ZnS, has a much smaller, simpler basis as given above, the crystals tend to incorporate several of the basic shapes, and therefore can become very complicated, just as we found in the last issue for fluorite. We show three examples of sphalerite crystals on the next page, together with diagrams to show what faces are involved.
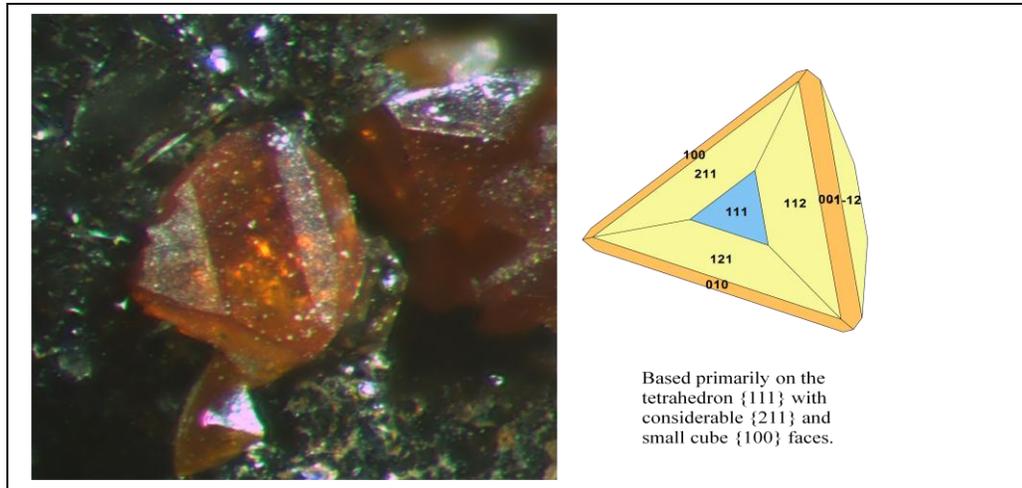
Sphalerite is one of the harder minerals to identify. The crystals do not have the obvious appearance of a cubic mineral. That is compounded by the fact that the color of the mineral is very variable. Pure ZnS would be nearly colorless, but in natural material, some iron normally replaces zinc atoms. As the iron concentration increases, the color ranges from yellow through orange into darkening shades of brown, and if enough iron is present, may be nearly black. In high iron varieties, nearly half of the zinc atoms have been replaced. The structure does not appear to be stable for higher iron concentration.
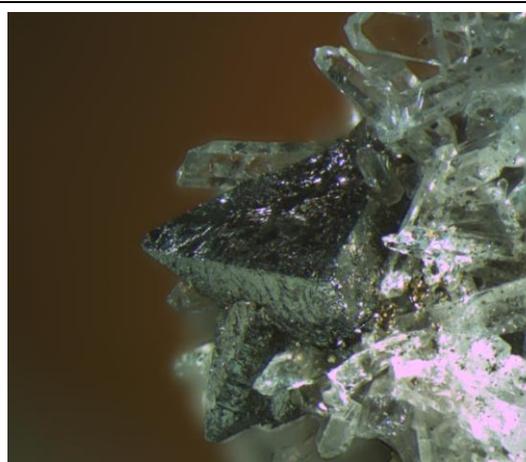
Tetrahedrite on Quartz
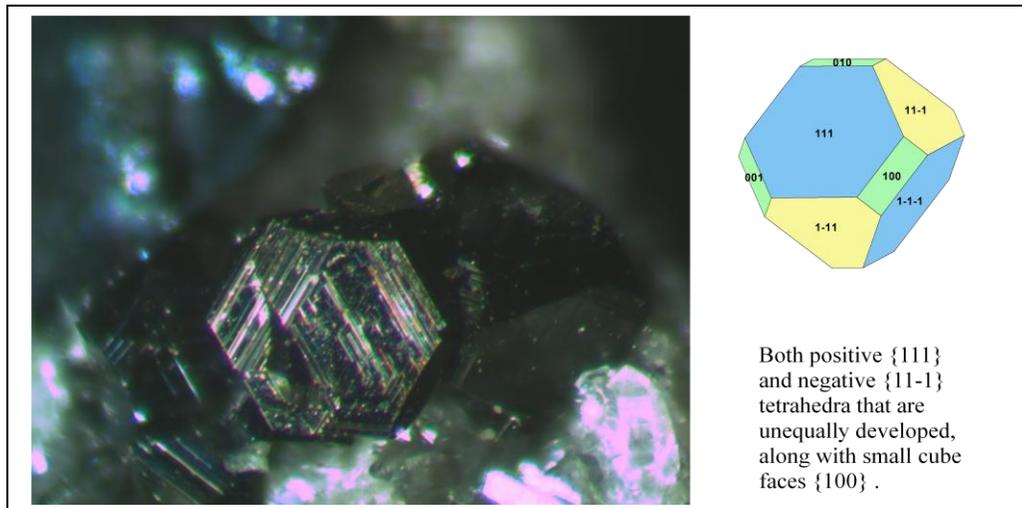Ophir Hill Mine, Tooele Co., Utah
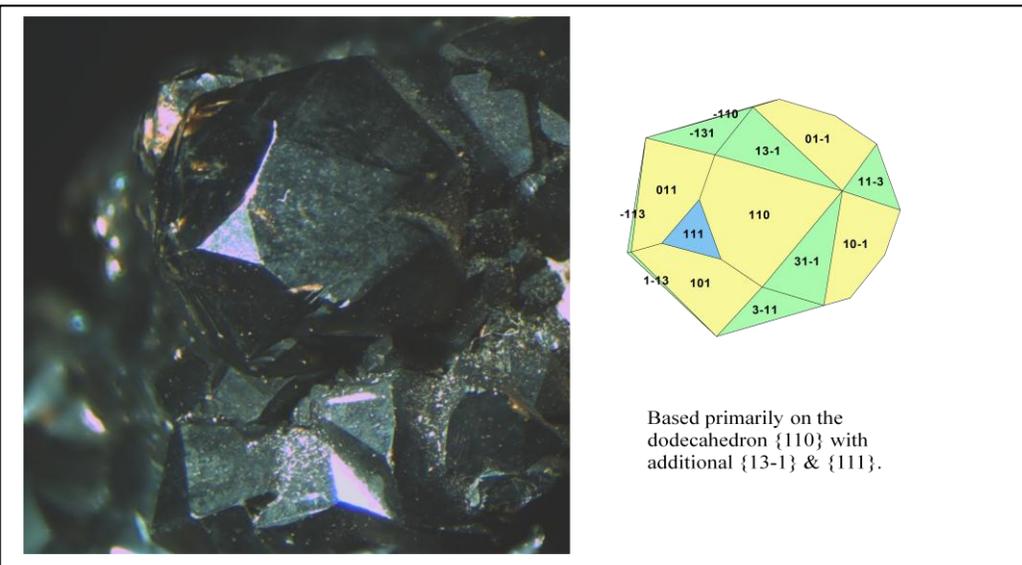

Helvine
Tungsten Hill Shaft, Luna Co., N.M.

8

Based primarily on the
tetrahedron {111} with
considerable {211} and
small cube {100} faces.

Sphalerite   **Joplin, Jasper Co., Missouri**

Both positive {111}
and negative {11-1}
tetrahedra that are
unequally developed,
along with small cube
faces {100} .

Sphalerite   **Kauri Mtn., Whangarei, New Zealand**

Based primarily on the
dodecahedron {110} with
additional {13-1} & {111}.

Sphalerite   **Cumberland, England**

The Pyrite Point Group and 2/m-3 Symmetry

The structure of pyrite is also closely related to that of fluorite. Remember that half of the smaller cubes of fluorine atoms had no atoms inside them. Now imagine the green spheres as representing iron atoms and the orange spheres sulfur atoms. Suppose that the diametrically opposite corner atoms (shown in red in the diagram at right) are attracted and move toward each other. This will distort the inner cube into a rhombohedron. The six atoms at the other corners will have to move out as the cube is squished, and will themselves be attracted to sulfur atoms in adjacent cubes to form their own sulfur-sulfur bonds. A view of the resulting structure looking along one of the cubic (100) directions is shown undistorted (fluorite) in the middle of the page and fully distorted (pyrite) at the bottom of the page.

The resulting sulfur-sulfur bond lie along the {111} directions and preserve the three-fold rotation symmetry of the overall lattice. Unlike with the sphalerite lattice as described above, this distortion maintains the inversion symmetry. However, the fourfold rotation symmetry is now gone irretrievable. A two-fold rotation symmetry still exists along the [100] direction, together with the mirror plane that is perpendicular to it. The two-fold rotation axis along the [110] direction together with its mirror plane are no longer present. To sum up the remaining symmetry, the symbol for this particular kind of point group is **2/m-3** .

As we have seen, the three-fold rotation axes are sufficient to guarantee that the six faces of the cube are an acceptable group, so the cube is one structure in this point group as well. For the octahedron, the presence of the inversion symmetry operation: $(x,y,z) \Rightarrow (-x,-y,-z)$
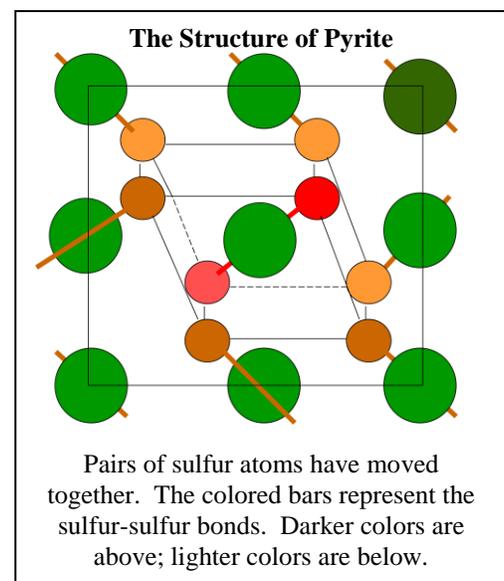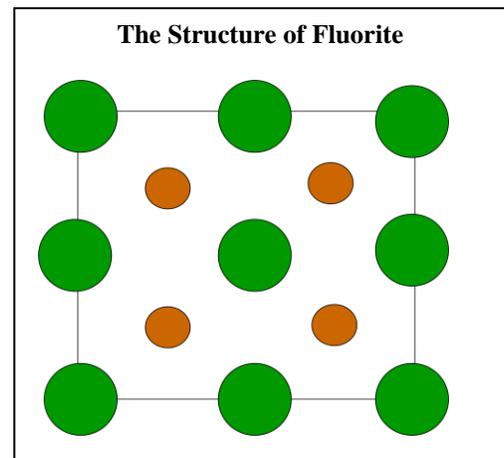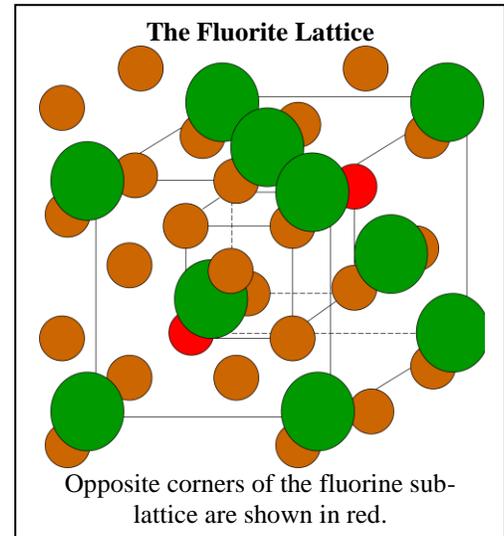Will restore the other four members to the group:

(111)   (1-1-1)   (-11-1)   (-1-11).
(-1-1-1)   (-111)   (1-11)   (11-1).

So the octahedron is a possible structure in the point group. The dodecahedron works as well.

However, consider the (210) group. We start with the three-fold rotations:

$(x,y,z) \Rightarrow (y,z,x)$
(210) $\Rightarrow$ (102) $\Rightarrow$ (021)
$(x,y,z) \Rightarrow (-y,z,-x)$
(210) $\Rightarrow$ (-10-2) $\Rightarrow$ (0-21)
$(x,y,z) \Rightarrow (-y,-z,x)$
(210) $\Rightarrow$ (-102) $\Rightarrow$ (0-2-1)
$(x,y,z) \Rightarrow (y,-z,-x)$
(210) $\Rightarrow$ (10-2) $\Rightarrow$ (02-1)

The mirror operation along x and y will add three more faces: (2-10), (-210), (-2-10)

The Fluorite Lattice

Opposite corners of the fluorine sub-lattice are shown in red.

The Structure of Fluorite

The Structure of Pyrite

Pairs of sulfur atoms have moved together. The colored bars represent the sulfur-sulfur bonds. Darker colors are above; lighter colors are below.
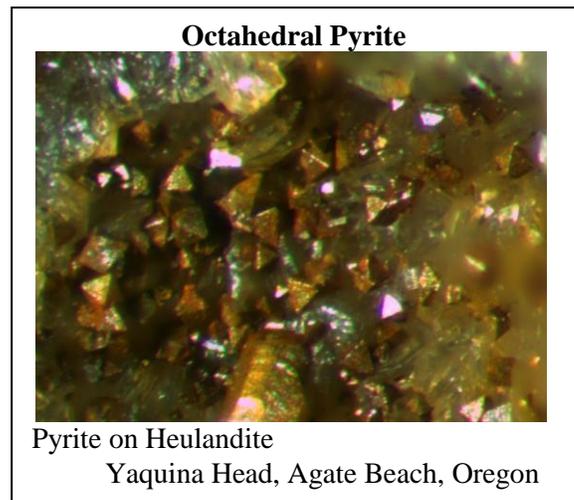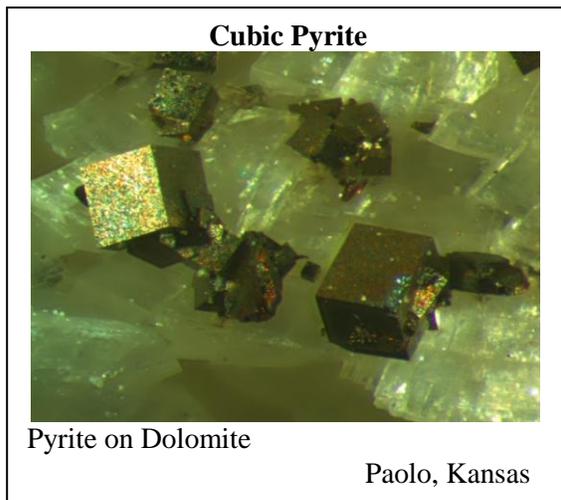
Taken together, these give twelve of the twenty four faces that were previously the tetrahexahedron. Moreover, the two-fold rotations and the inversion operation will change signs but will not rearrange the order of the sequence of numbers. So the {210} group and the {120} group are different in this symmetry. The resulting crystal form with twelve faces is called a pentagonal dodecahedron, or usually a pyritohedron.
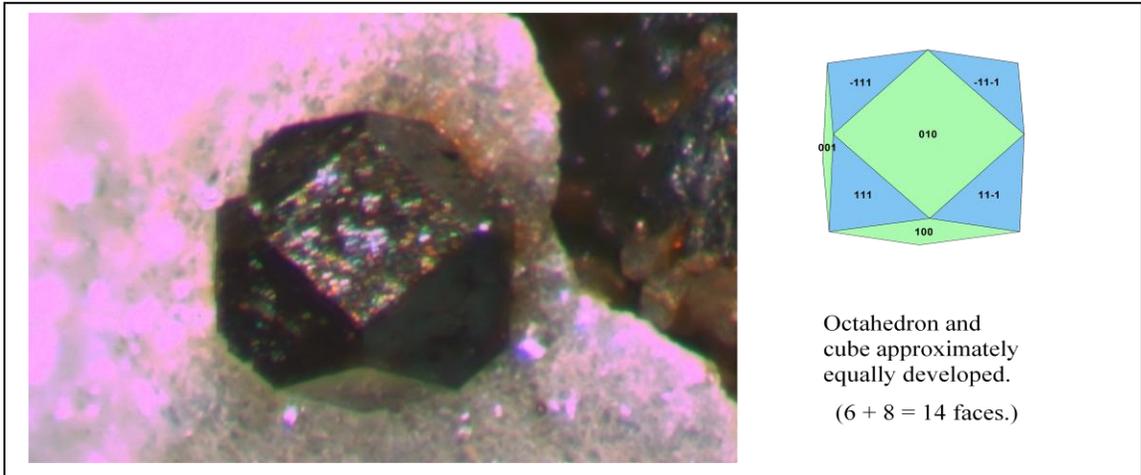
The only other group similarly affected in this symmetry is the hexoctahedron {421} which has no repeating indices. So the entire set of forms under 2/m-3 symmetry is given below.
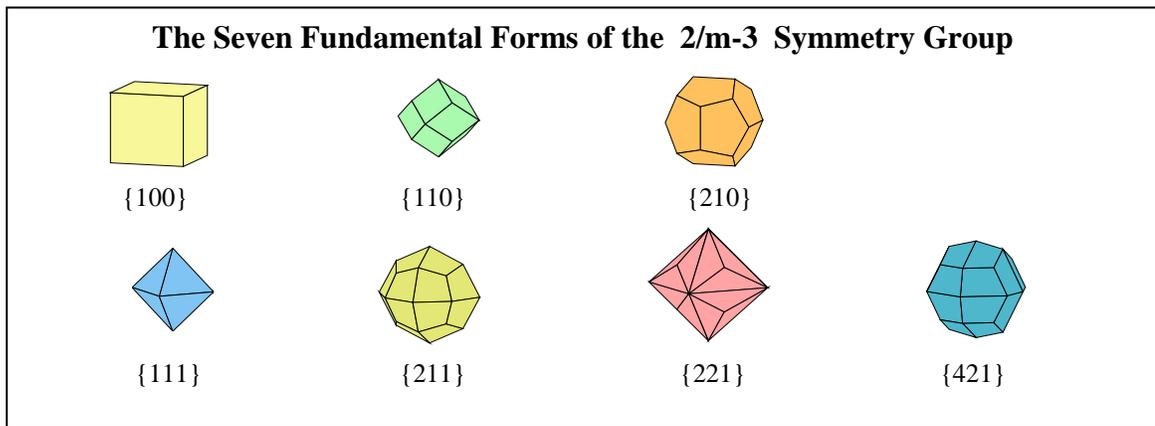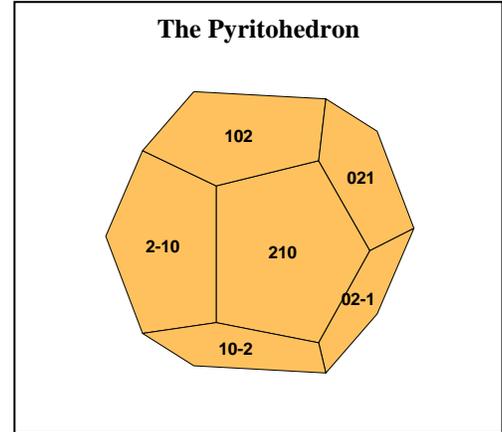
The Pyritohedron

For pyrite, the primary forms are the pyritohedron, octahedron, and the cube, and these are seen individually and in combination with each other. Pyrite octahedra are usually small and very often are truncated by cube faces.
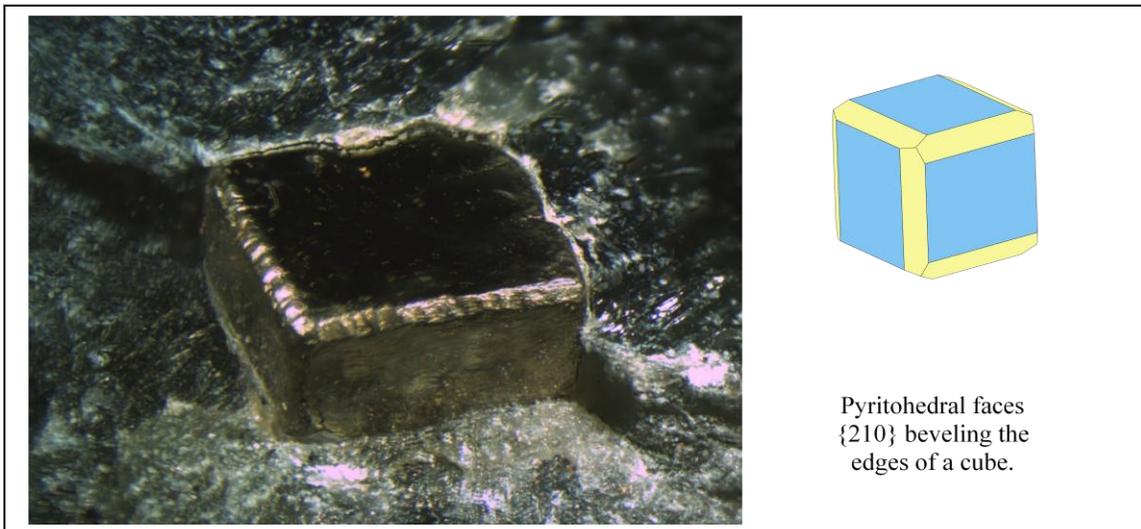
Simple pyritohedral crystals are not uncommon. While cubes with smooth faces do occur (as shown below), many cubic crystals show modifications of combine faces, from crystals that are nearly equally developed to those with only small edge beveling. The striations so often seen on pyrite cubes are the result of repeated switching from the {100} face to the {421} face and back again. Notice that the direction of the striations are mutually perpendicular, maintaining three-fold symmetry.

Cubic Pyrite

Pyrite on Dolomite

Paolo, Kansas

Octahedral Pyrite

Pyrite on Heulandite

Yaquina Head, Agate Beach, Oregon

The Seven Fundamental Forms of the 2/m-3 Symmetry Group

{100} {110} {210}

{111} {211} {221} {421}

Octahedron and cube approximately equally developed.

(6 + 8 = 14 faces.)

Pyrite on Heulandite   **Rock Island Dam, Chelan Co., Washington**

Pyritohedral faces {210} beveling the edges of a cube.

Pyrite in Talc   **Cow Creek, Glendale, Douglas Co., Oregon**

Pyritohedral and cube faces approximately equally developed.
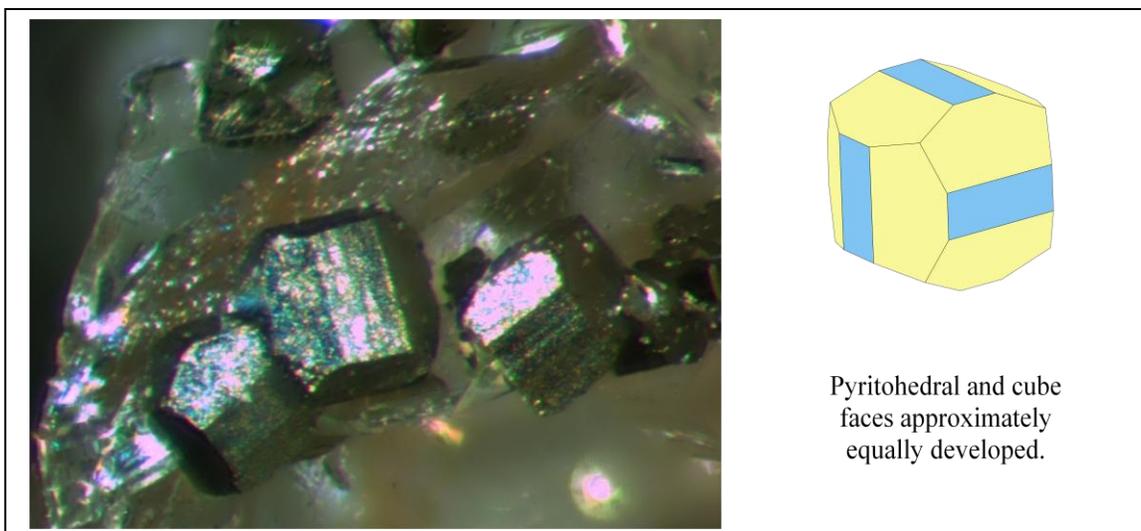
Pyrite on Celestine   **Briar, Arkansas**
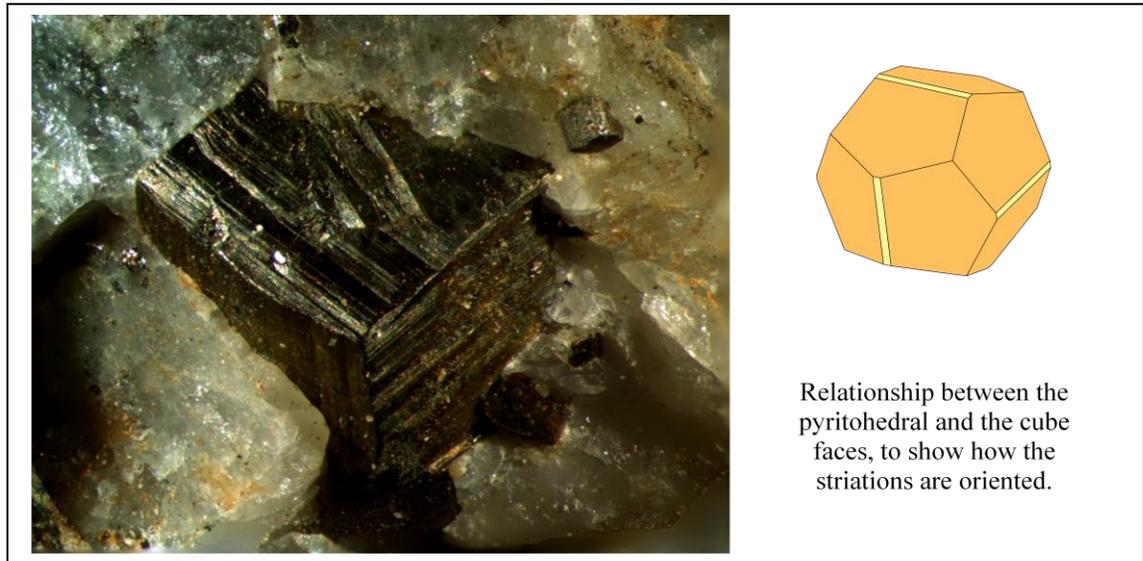
Pyrite in Quartz   **Darwin, California**

       Another mineral that also has a structure that places it in the 2/m-3 point group is bixbyite, $(Mn,Fe)_2O_3$. The iron content can be anywhere from very low (1%) to dominant (60%). The crystals are normally cubes with small trapezohedral (211) faces modifying the corners. We complete the survey of this symmetry group with the illustration below of such an iron-rich crystal from Utah.
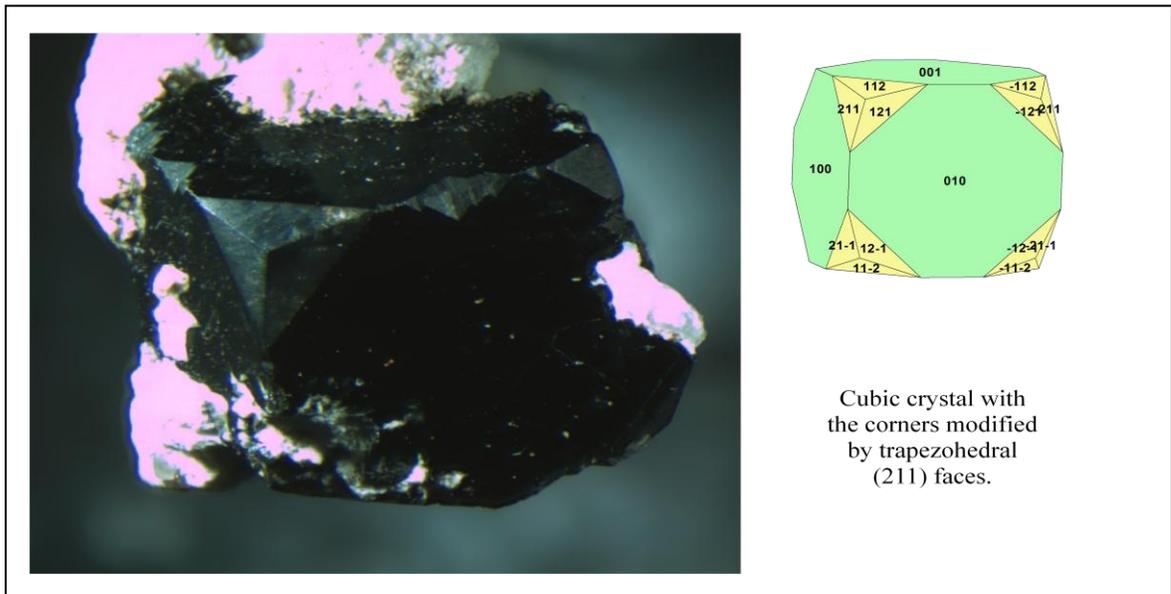
Bixbyite   **Thomas Range, Juab Co., Utah**

Conclusion

       Several other lower symmetry point groups have been identified, but may not have naturally occurring mineral representatives. There are, after all, many compounds that have been prepared and crystallized but that have not been found naturally. The three important symmetries for natural minerals are 4/m-32/m , -432/m, and 2/m-3 . We hope this explanation of what to look for in your cubic crystals will help in identification and appreciation of cubic crystals.

Distinguishing between Adamite and Austinite from the Gold Hill Mine, Utah

Don Howard

At last year's NCMA meeting there were quite a number of specimens on their free table from Gold Hill, Utah. Judging from the size, the quality, and the labels, they appear to have been collected many years ago and kept by a dealer for future sale. There were sufficient left unclaimed that found their way to our give-away table and were subsequently claimed. The material was very nice. However, in looking over a number of the pieces, I found that what was written on the label and what was actually on the specimen was not very closely correlated. Since many of these claimed to be cuprian Adamite or cuprian Austinite, I thought a few words and pictures might help the new owners to verify their finds.

Adamite and Austinite can be very hard to tell apart. Both are zinc arsenates, and they can be mutually present in the same specimen. Both form orthorhombic crystals, and both can vary from colorless into shades of green as copper substitutes in the zinc site.

Habit of Adamite
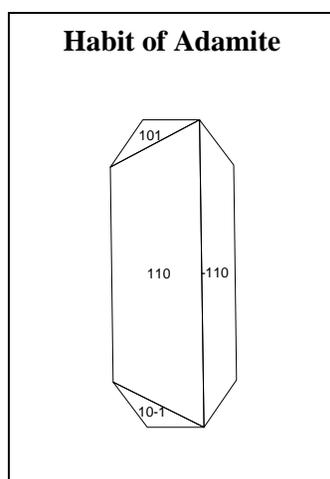
Adamite, $Zn_2(AsO_4)(OH)$, is the more common mineral. In pure form, it is clear and colorless, but as copper substitutes for zinc, it takes on various shades of green. Chemically, it is isostructural with Olivenite $Cu_2(AsO_4)(OH)$, and a continuous series appears to extend between the two end members. Both minerals are found at Gold Hill together with a wide range of intermediate concentrations, referred to by modifiers, such as cuprian Adamite and zincian Olivenite. Crystallographically, adamite is orthorhombic and exhibits full orthorhombic symmetry, *crystals* belonging to the *2/m2/m2/m* space group. Crystals are elongated along the c-axis, with a basic diamond-shaped cross-section formed by the four {110} faces. The termination usually involves {101} faces, which appear to be triangular. On small crystals and clusters, it is often these tiny triangular faces reflecting the light that are the best indication that you are looking at Adamite.

Fig. 1 Colorless Adamite

Habit of Austinite
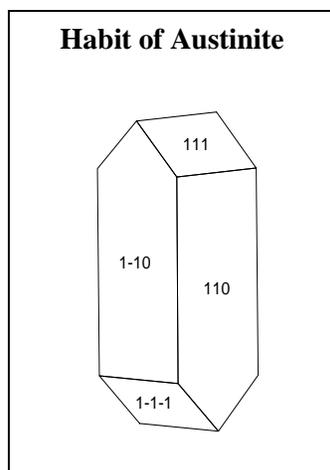
Austinite, $CaZn(AsO_4)(OH)$, was first described from Gold Hill. It also forms as clear, colorless crystals when pure, and takes on varying shades of green as copper replaces zinc. It is isostructural with Conichalcite, $CaCu(AsO_4)(OH)$, in a continuous series. Again, both ends of this series occur at Gold Hill.

A major difference between Adamite and Austinite comes in their crystal structure. Austinite is also orthorhombic, but by replacing half the zinc with calcium, the mirror planes vanish, putting Austinite in the
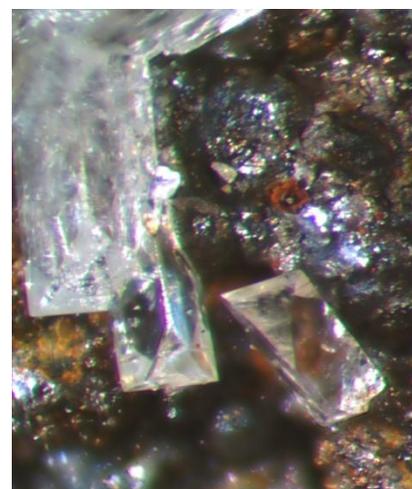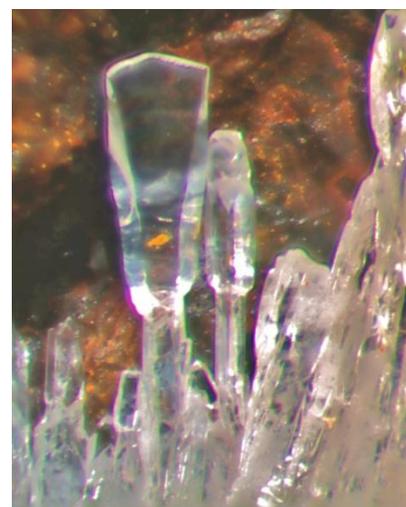
Fig. 2 A Scepter of Austinite

222 space group. The terminal planes are of the forms {111} and related forms {nn1} that blend into the prism faces rather than cut across them. The general appearance of Austinite is therefore of blades. Twinning on (110) is common, leading to a tendency to form sheaves of thinned, parallel blades. In fig. 3, two of the blades can be seen edge-on at upper right; the chunky crystal to the right of them is actually Adamite. In fig. 4, the nearly parallel nature is evident.

Clear, colorless crystals of both minerals are found primarily in the upper regions of the Gold Hill Mine where few copper minerals are present. The matrix is generally oxides of iron that may contain manganese minerals such as chalcophanite,an oxide of zinc and manganese. In other regions, both minerals take on increasingly rich green colors as the concentration of copper increases. Figures 6 through 8 show a variety of these differing shades.

Fig. 5 shows a specimen with the other two end members of these series. Olivenite, as the name implies, is more of as olive green than cuprian Adamite. At Gold Hill, crystals of Olivenite tend to be fibrous with especially irregular, brushy ends. If the fibers are fine enough, they appear almost white. Conichalcite is always in small spheres with smooth surfaces. In fact, if the surface of the balls begin to show evidence of crystal faces, you are probably have at least a surface layer of cuprian Austinite.

Generally speaking, color is not a good indicator of whether you are looking at Adamite or Austinite. The habit of the crystals is a much surer way to tell the two minerals apart. When the clusters become too small to see the faces of crystals, the only sure way to differentiate is by detecting the presence or absence of calcium, such as using XRF in a Scanning Electron Microscope.

All the pictures used in this article have been taken of specimens in my own collection from Gold Hill Mine, Tooele Co., Utah.
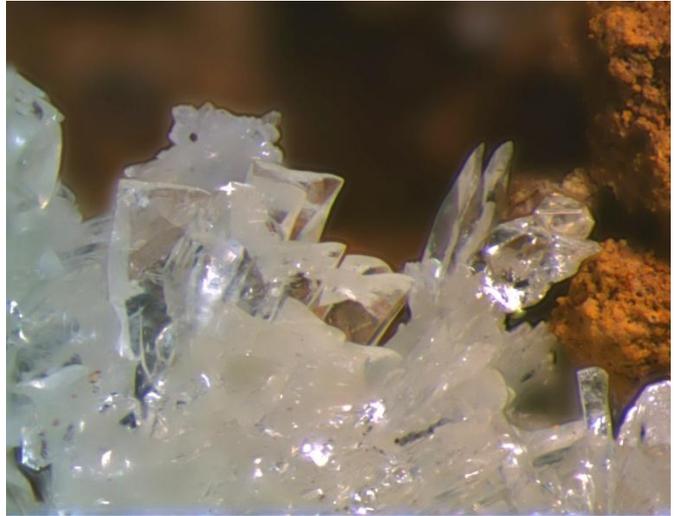
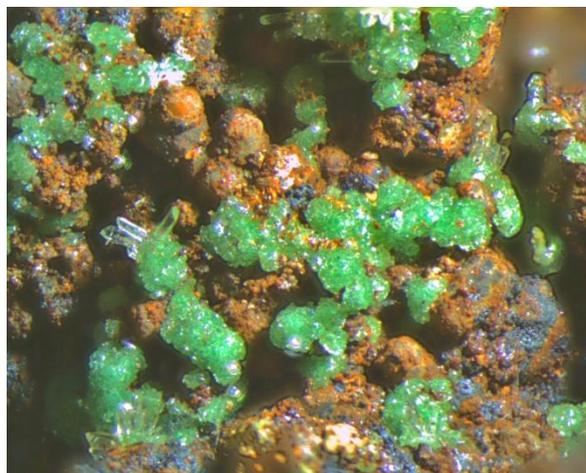*Fig. 3 Thin blades of Austinite*

Fig. 4 Sheaves of parallel growth Austinite blades
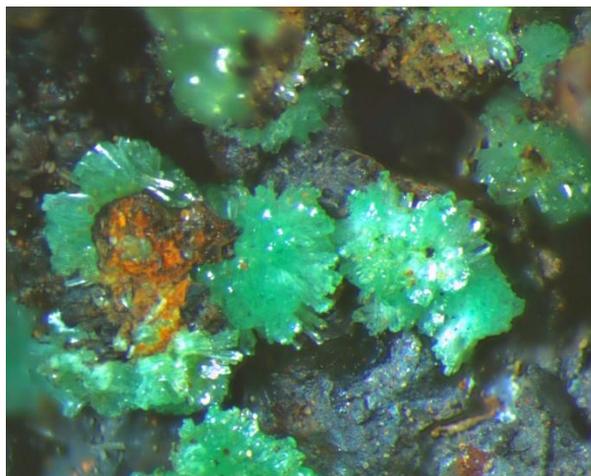

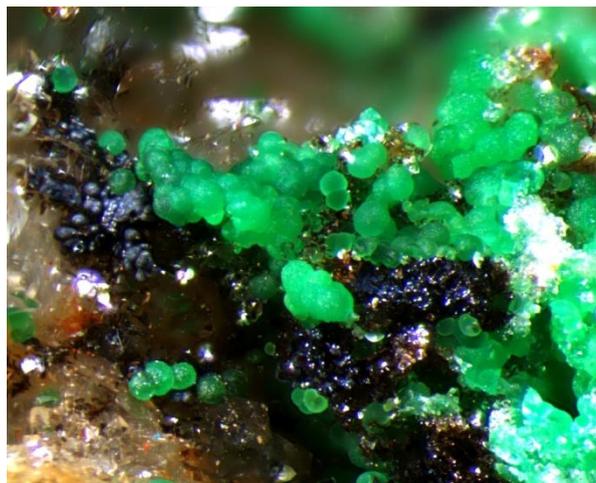*Fig. 5 Conichalcite balls on fibrous Olivenite*

Fig. 6 Cuprian Adamite crystals

Fig. 7 Clusters of cuprian Adamite

Fig. 8 Clusters of cuprian Austinite

Fig. 9 Conichalcite balls on Beudantite

Map to the Oak Grove Blvd. meeting site

2930 SE Oak Grove Boulevard

82nd St.

Clackamas
Town Center

Milwaukie

Expressway

224

Exit #13

Lake Rd

Oak Grove
Blvd.

Thiessen Rd.

Exit #12

212/224 to Estacada
and Sandy

Roots Rd.

Jennings Av.

Webster Rd.

I-205

99 E

Oatfield Rd.

Mc
L
O
U
G
H
L
I
N

B
L
V
D

Exit #11

W
i
l
l
a
m
e
t
t
e

R
i
v
e
r

Clackamas River

Exit #10

Exit #9

Oregon City

213 to Mollala