FALL MEETING . . . . .VANCOUVER, WASHINGTON

November 16, 2002   9:30 am to 6:30 pm

**Clark County P. U. D. Building
1200 Fort Vancouver Way
Vancouver, Washington**

Once again we have a day to talk rocks and share collecting stories. Bring the new finds that you have come up with this summer. Microscopes are a must as usual, and don't forget to bring your extra material for the give-away table so that others will have treasures to look over and take home. There will be ample free material from Summit Rock.

Morning:
Bob Smith will talk and show slides of collecting in the Black Hills. Don Howard will talk and show slides of Summit Rock, Klamath Co., Oregon. Anyone who has slides to share with the group should bring them along to show at this time.

Afternoon:
We will have a short business meeting that will include election of new offficers. And we will have our usual review of the collecting status of locations in the Northwest.

The kitchen area is available as usual and we will provide lemonade, coffee, hot water, etc. There will be a snack table, so bring makings for lunch and we will plan to have a sort of "pot luck" at noontime.

Restaurants are available in the local area. Some of us will plan to eat dinner together, so please plan to join us.
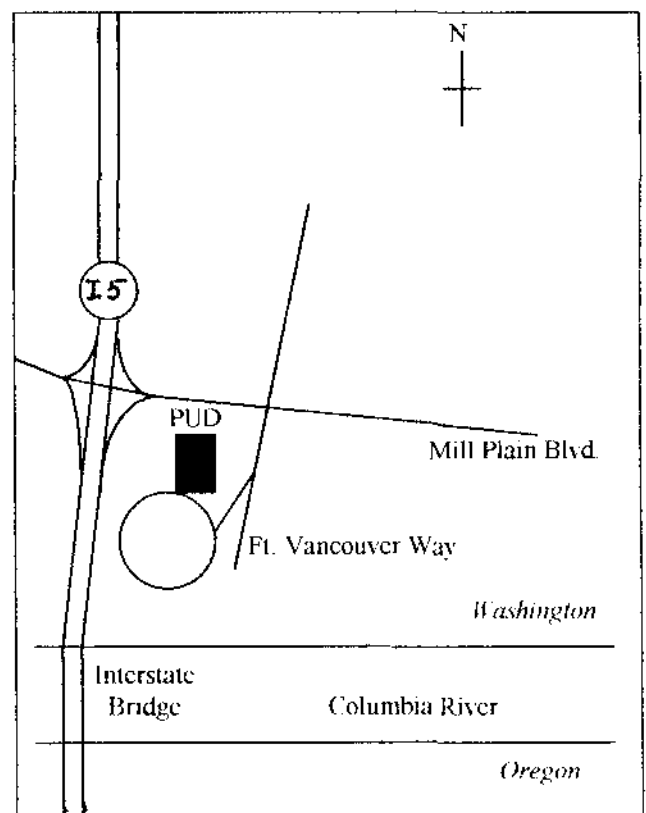
A Study of Crystal Forms — Borax and Halite

Don Howard

In the last issue, we discussed the mechanisms of crystal growth on an atomic scale. Growth was described as a dynamic balance between atoms arriving and sticking on a crystal face as opposed to those that were freed by the agitation of random thermal energy and left the face. In a simple material like the crystal of an element, that is sufficient to describe the process. But most minerals are composed of more than one kind of atom or atom complex — often half a dozen or more building blocks are involved. So the relative rates at which faces grow will be affected by the rate at which each of these atoms or groups of atoms arrive and stick onto the crystal. As an example of what can happen, I have done some experimenting with borax crystals grown from water solutions.

Borax crystals grow naturally in some of the saline deposits in lake beds of the Southwest. Searles Lake, for instance, is a source of such crystals. As originally grown, the mineral borax has eight water-of-hydration molecules: $Na_2 [B_4O_5(OH)_4] (H_2O)_8$. In this state, the water is in dynamic equilibrium with the water molecules in the solution. When removed from the solution, however, water molecules are lost to the air faster than they can be replenished, and the mineral dehydrates to a mineral called tincalconite, which has only three water-of-hydration molecules: $Na_2 [B_4O_5(OH)_4] (H_2O)_3$. Most specimens in collections are therefore tincalconite pseudomorphs after borax, and are milky white instead of being clear, as borax crystals are originally.

The habit of the borax crystals that form in Searles Lake is nearly equant and composed of several classes of faces. Borax is a monoclinic mineral, with parameters:

$$a = 12.22 \text{ A}$$
$$b = 10.67 \text{ A} \quad \beta = 73.4°$$
$$c = 11.88 \text{ A}$$

The dimensions are such that the lengths along the b- and c-axes are about equal and about twice the length along the a-axis. The crystals have prominent (100) faces. Four (110) faces complete the prism. The terminations show small (001) faces and somewhat larger (112) and (111) faces, as shown below:
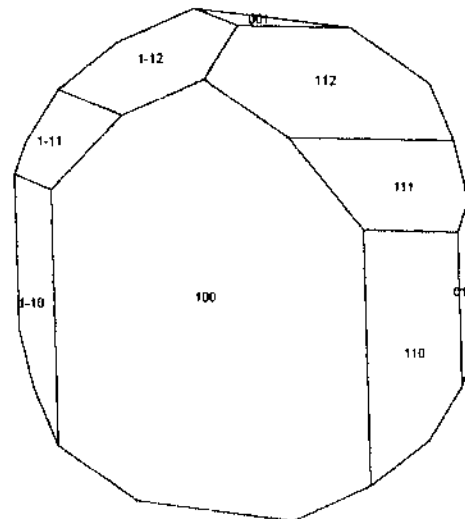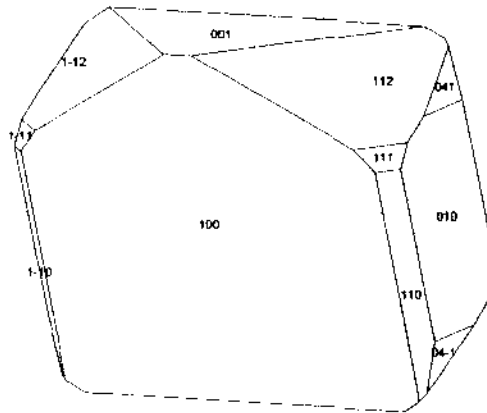
Figure 1.
Typical habit of
a tincalconite
pseudomorph after
Borax, Searles Lake,
San Bernardino Co.,
California

Figure 2
Habit of a Borax
crystal grown from a
pure water solution
of Na_2 [$B_4O_5(OH)_4$] .

Now it is a relatively easy matter to grow borax crystals from water solution (see below). From a solution that contains only borax dissolved in water, a similar but slightly different crystal form is obtained. The (100) faces are still dominant. The prism is now completed primarily by (010) faces, however, and the (110) faces make only a small bevel on the edges. The termination is again mostly (001) and (112) faces, now with rather diminished (111) faces. Small (041) faces appear in the corners. We would say that from pure solution, the (010) grows more slowly and the (111) more rapidly than for the crystal that formed in Searles Lake. Why the difference? Well, in nature it is not reasonable to suppose that the solution contains only sodium borate. Surely a lot of other ions are also present, and they can affect the relative growth speed of the various faces.

Before exploring how impurities in the solution affect the morphology, let us take a moment to understand the crystal structure on an atomic level. As seen in figure 3, the Na atoms are surrounded in octahedral symmetry by six water molecules. By sharing two water molecules with the next group, they form a somewhat zigzag chain along the c-axis. The borate groups are formed of tetraborate [$B_2 B_2 O_5 (OH)_4$]$^{-2}$ ions that are isolated. There are two different boron sites that form a distorted hexagon of alternate B and O atoms. The remaining O bridges between the two opposite B atoms. Each B is attached in addition to the O-end of an OH group so that the H points outward to be able to form hydrogen bonds with the water molecules of the zigzag Na-water chain and with other borate complexes.
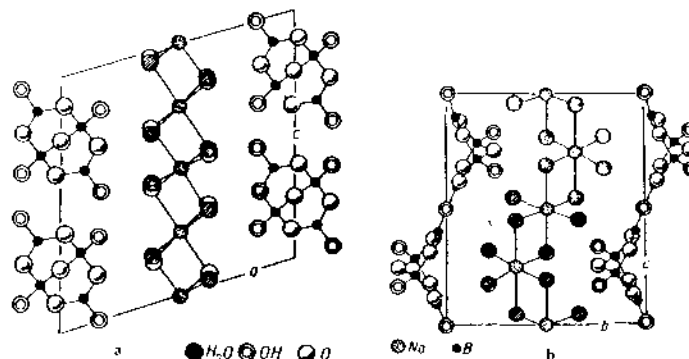

Figure 3   The structure of borax as seen looking along the b-axis (left) and the a-axis (right).

From this structure, we can see some interesting things. Sodium atoms are normally surrounded by water molecules octahedrally when in solution, so they are ready to bond into the crystal. Growth along the c-axis amounts to lengthening the chains. Growth in the other directions requires starting new chains. From the shape of the crystals above, we can see that apparently it is easier to start new chains on the (010) face than it is on the (100) face. Nucleating new chains on the (100) face is particularly difficult; hence the very large a-face on the crystals shown above.

Boric acid has the formula $H_3 BO_3$. In solution, the structure is a B atom connected to three O atoms in the form of a triangle. The three H atoms then stick out and are rather easily removed. So the basic building block is BO_3^{-3}. However, it is a weak acid, so most of the hydrogens stay attached in water. As solutions get more concentrated, the borate groups polymerize into larger and larger complex ions. Since bond angles for boron and for oxygen are both around $120°$, two-boron configurations are not formed. The simplest polyborate is $B_3O_6^{-3}$, a planar hexagon with three O atoms sticking out (some with H attached unless the solution is very basic). Next is the complex $[B_2 B_2 O_5 (OH)_4]^{-2}$, described above. At higher concentrations, even larger polyborate ions form. The times required to establish equilibrium between the various forms can be quite long. That is, once formed, it may take a large complex several hours or even days to break back down when the concentration is lowered by dilution.

The point here is that the $[B_2 B_2 O_5 (OH)_4]^{-2}$ ion must be incorporated into the crystal as a unit, and therefore needs to be present as a unit in the solution. Since it is in equilibrium with BO_3^{-3}, $B_3O_6^{-3}$ and larger polyborates, its concentration in the solution is rather sensitive to temperature and total dissolved salt content. So with that as a rather lengthy and technical introduction, let us look at the effect of adding other things to the solutions from which we are growing our borax crystals.

The most likely compound to be in a saline lake is salt: NaCl. Adding NaCl to the borax solution should make a proportional increase in the Na concentration relative to the tetraborate ions. Crystals were grown in the usual way and again showed slight modifications, as depicted in figure 4. These probably have the simplest form of all the borax crystals grown. They show only the basic prism plus (112) faces on the termination; (110) and (111) have completely grown out.
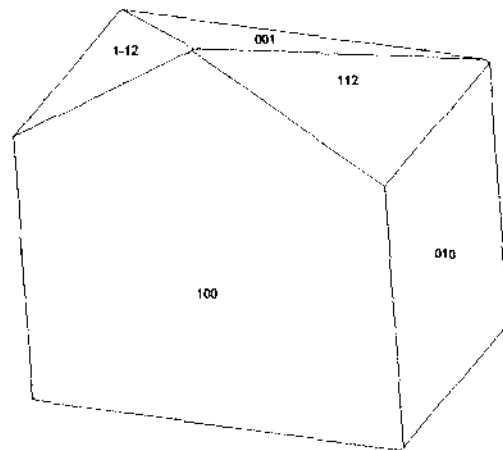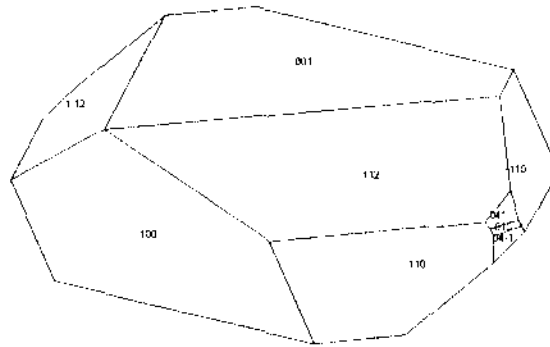
Figure 4
Habit of a Borax crystal
grown from a solution
containing a considerable
concentration of NaCl
in addition.

Figure 5
Habit of a Borax crystal
grown from a very basic
solution containing a
considerable concentration
of NaOH in addition.

The excess sodium seems to complete edges of the prism, leaving the (100) and (010) faces as the slowest growing. The terminal faces (001) and (112) are little effected, and the overall proportions of the crystals are about the same as those grown from pure water. Whether the presence of the chloride ions effect the relative growth of the faces is not clear.

A way to add sodium ions without other anions is to use NaOH instead of salt. Hydroxide ions are already in solution from the dissociation of water. Crystals grown from such solutions, however, produced some surprises. As shown in figure 5, the growth in the (010) direction is considerably speeded up, while that along the c-axis is somewhat slowed. (110) faces again become prominent, and new (041) faces appear. The basic shape is elongated along the b-axis rather than being nearly equant.

So why is this shape so much different than that of figure 4? A clue to this is seen in the fact that adding NaOH actually *increases* the amount of borax that will dissolve in a given amount of water. By shifting the pH so drastically basic, the balance of borate ions shifts; $B_3O_6^{-3}$ becomes much more stable than $[B_2 B_2 O_5 (OH)_4]^{-2}$ and the concentration of the tetraborate ion is therefore reduced in such a basic solution. The result is a slower growth rate on all the major faces except (010). So in actuality, this is a case of modifying the borate part of the equilibrium rather than the sodium part.

Figure 6
Habit of a Borax crystal
grown from an acidic
solution containing a
considerable concentration
of $H_3 BO_3$ in addition.
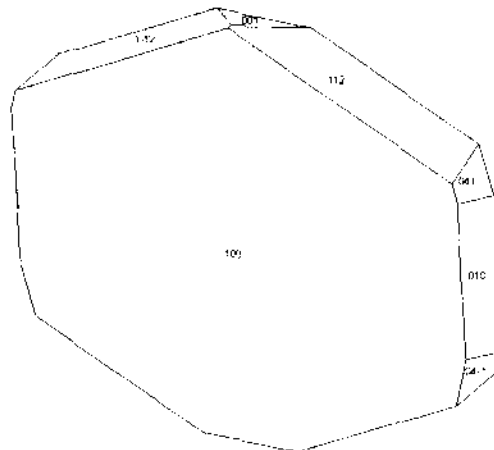
A much more straightforward way to modify the borate concentration relative to the sodium concentration is to add boric acid, H_3BO_3. And again, this has a pronounced effect on the shape of the crystals. Growth is drastically slowed on the (100) face so that the crystals become plate-like, as shown in figure 6. The (041) faces are again present, and the (112) is much more pronounced (ie., slower growing) in relation to the (001). The (100) is slowed so much that the (110) faces are again absent. Again, as with the base, excess acid affects the most probable species to be found in solution., and it becomes difficult to interpret exactly what is going on.

In an attempt to vary the borate concentration without varying the pH, potassium tetraborate, $K_2[B_4O_5(OH)_4](H_2O)_6$, was added to the borax solution. Potassium borates are rare in nature because their solubility is great. Here, the potassium salt is more than ten times as soluble in room temperature water as the corresponding sodium salt. Thus, the borate concentration can be increased considerably in relation to the sodium concentration.

As figure 7 shows, the crystals that grow from this mixture are very similar to those that grow from pure water. The small (111) and (041) faces are missing, but the (110) bevel on the edges are present. The proportions of the crystal are also about the same as for those grown from pure water.
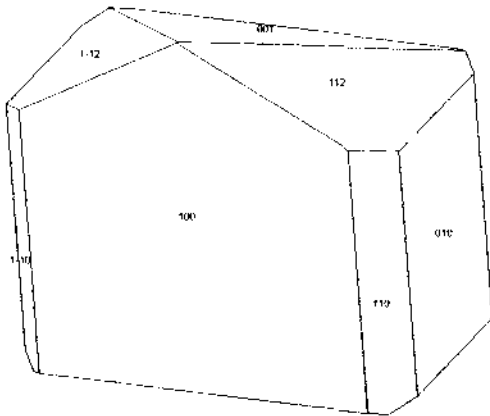

Figure 7
Habit of a Borax crystal grown from a solution
also containing a considerable concentration of
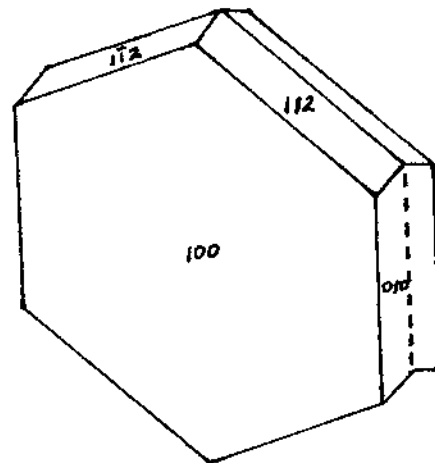the compound $K_2[B_4O_5(OH)_4](H_2O)_6$.

Figure 8
A crystal twinned on (100)
of the same habit as shown
in figure 6.

If the concentration of potassium borate is increased even more, the crystals begin to thin in the a-direction, and they do an interesting thing: they twin on the (100) face! The (001) disappears, so the termination is four (112) faces and the prism is (100) and (110) faces. What happens on the bottom is unclear, since the crystals tend to grow in clusters outward in the form depicted in figure 8. Clearly, the potassium is altering the nature of the original nucleation process of the borax crystals, since excess borate from boric acid thins the crystals but does not cause them to twin. I do not know of natural borax crystals twinned in this way.

Clearly, exactly how the changes in concentration affect the faces present in borax crystals is beyond our ability to analyze in detail. With the variety of borate ions in solution, there are too many variables to deal with. The purpose here was to illustrate how other things in solution can influence the shape of the crystals that grow. The most influential factor is the pH of the solutions. The basic shape is the same for most solutions that are near neutrality. Only crystals grown in

strong base (elongated along the b-axis) and excess acid (flattened along the a-axis) have different overall proportions. The natural crystals resemble those grown from neutral solutions, implying that the lake beds in which they grew are themselves nearly neutral. Apart from that, the additional faces present and their extent are probably a complex function of the composition of the solutions in the lake, and perhaps depend on temperature as well.

   *   *   *   *   *   *   *   *   *   *

Whereas borax is a rather complicated crystal easy to grow but difficult to analyze, halite, NaCl, is a simple crystal difficult to grow but easy to analyze. The difficulty in growing salt crystals comes from the fact that the solubility in hot water is virtually identical to that in cold water, so that the warming and cooling method does not work. This leaves evaporation as the method of growth, so that instead of a few hours to grow crystals, it takes many days to get anything to nucleate and grow. Often the growth then is at the surface, and numerous fine grains result rather than a single large seeded crystal.

As a glance at figure 9 will show, the atomic structure consists of alternating ions of Na^+ and Cl^- along the [100] directions. This yields (100) faces that are electrically neutral. When, say, a Na^+ ion approaches the surface, it sees a Cl^- ion surrounded by four Na^+ ions, and is not strongly attracted electrically. Nucleation on this face is therefore rather slow. The (111) face, by contrast, is composed of alternating sheets of the same ions, so the Na^+ ion will be strongly attracted electrically, and nucleation of new faces will be speedy. The (111) faces would be expected to grow out speedily, leaving the (100) faces as the dominant form. The (110) face is composed of alternate lines of the same ions, so a Na^+ ion approaching the surface will see three Cl^- ions and two Na^+ ions and will be at least weakly attracted, so the (110) face could be expected to grow at an intermediate rate. In fact, from a water solution containing just NaCl, the resultant crystals are all cubes.
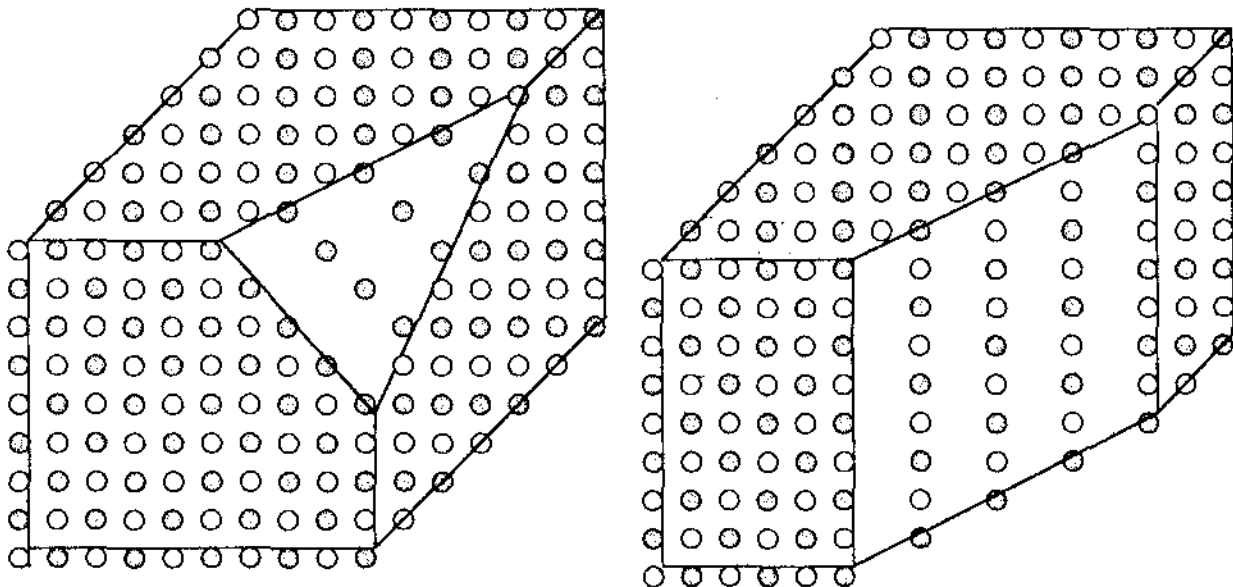

Figure 9

The atomic structure of NaCl, showing the alternating positions of the Na ◯ and Cl ⊙ ions on the (100), (010), and (001) faces. The (111) face (left) has only one kind of atom present. The (110) face (right) has alternating lines of atoms. Atoms are most densely packed on the (100) faces.

In nature, halite normally grows in cubic blocks. Most collected crystals will have this form. However, there are unusual examples of halite where the corners are beveled by (111) faces! That seems to go directly against the argument we have just made.

Once again, the way out lies in the fact that the solutions in nature are seldom pure. Suppose that the solution from which the halite is growing also contains a fair concentration of Ca^{++} ions. $CaCl_2$ is very soluble in water. The calcium ions, bearing twice the charge of the Na^+ ions, are more strongly attracted to the sheets of Cl^- ions. They collect there, but the crystal structure of $CaCl_2 \cdot 6\ H_2O$ is quite different from NaCl and cannot form on the face. So all the Ca^{++} ions do is adsorb onto the face; the Na^+ ions no longer see a large negative surface charge, so the nucleation of new faces is greatly slowed. If enough Ca^{++} ions (or Mg^{++} ions, for that matter) adsorb onto the (111) faces, the rate of growth will be so greatly slowed that they will nucleate new layers at about the same rate as the (100) faces and beveled corners will result.

*   *   *   *   *   *   *   *   *   *

So the bottom line is that the morphology of many of our minerals is quite variable. Crystals such as pyrite and garnet come in a wide variety of forms that undoubted reflect the impurities present in the "solutions" from which they form, be they water based or some other molten rock. Even our zeolites, such as thomsonite, come in a wide variety of habits reflecting the compositions of the solutions from which they form.

*   *   *   *   *   *   *   *   *   *

You might like to try your hand at growing crystals. Below I show the setup I have been using to grow crystals of borax, and on the next page I give some directions and suggestions about exploring this fascinating phenomenon. Let us know what you discover.

Figure 10
Setup used to grow the
various habits of borax.

GROWING YOUR OWN BORAX CRYSTALS

For those of you who would like to try your own hand at growing crystals, borax is a perfect salt to start with. Twenty Mule Team borax is inexpensive and easy to find in your local supermarket. It is quite pure borax, certainly pure enough for our purposes. One of its greatest advantages is that while only moderately soluble at room temperature, the solubility increases greatly as it is warmed, so we can make use of temperature differences to grow reasonably large crystals in just a few days.

I recommend starting with a stock solution. Use a jar that has a quart or more capacity. Fill it most of the way up with tap water and start adding borax. When stirring does not seem to get more to dissolve, warm it up until all the borax present is in solution, and set it aside to cool in a place where it will not be disturbed.. By the next morning, some crystals will probably have formed on the glass. If not, add another spoonful, warm to dissolve, and let stand. Eventually you will have a saturated solution of borax in contact with a few crystals.

Get a clean pint jar and fill it about 80% full of the saturated solution. Add a teaspoonful of borax powder and warm until all is dissolved. I find setting the jar in a pan of hot water works quite well. Again, set it aside in a place where it will not be disturbed, but this time hang a thread down into the center of the jar (using a thin piece of wood or a large nail to suspend it from). With luck, after a few hours, crystals will form, some floating, some on the glass, and hopefully some attached to the thread.

To get the crystals to grow bigger, I use the thread as a "seed" crystal. I knock off all but one or two of the crystals that have formed and set the thread with its crystals aside. I again warm the solution just enough to get all the borax to dissolve. Then I set it aside for perhaps half an hour until it has cooled somewhat. I carefully put the thread with its crystals back in and leave the jar undisturbed. If I have done it just right, by the next morning the crystals on the thread will be considerably larger.

It may take some practice to get the hang of doing this. If there is too much solids in the solution, new crystals will form all over the thread and on the "seeds". If not too bad, they can be knocked off and the procedure repeated. However, getting the concentration just right, and cooling the solution just enough before reinserting the "seeds" makes this procedure rather an art.

It is possible to grow crystals by simply letting the water evaporate. However, this takes a good deal of time to accomplish, and I find the crystals tend to grow on the surface rather than on the thread. It is an alternative that you may want to try.

Once you have got the hang of crystal growing, you may want to try adding other chemicals to the solution to see how they affect the shape of your crystals, much as I have done in the article. There is a lot of room for experimentation here.

Another possibility is to grow crystals of other materials. Some things that are reasonably easy to obtain are:

$Na_2 CO_3$	washing soda.
$Na HCO_3$	bicarbonate of soda.
$NH_4 Al (SO_4)_2$	alum (used in pickle-making)
$Mg SO_4$	Epsom salts

Ordinary salt works very poorly because its solubility is almost the same hot as cold, so it has to be grown by evaporation.

Try other materials. And above all, have fun and tell us about your successes!

Minerals of Summit Rock, Klamath Co., Oregon

Don Howard

We have probably all seen material from Summit Rock: cavities filled with little brown and black crystals scattered everywhere. This material is quite different from the sorts of things we usually collect. These are primary minerals rather than secondary ones. They form at high temperatures rather than from low temperature solutions. They can be somewhat confusing since they are not minerals we are familiar with. On the other hand, the location is easy to reach, easy to collect, and the minerals are not too hard to identify.

Summit Rock is located very close to the line between Douglas and Klamath Counties just north of the East Diamond Lake Highway #138. The county line is actually on the Cascade Crest and is the "summit" on this road, which is clearly marked. The summit is about 10 miles west of the turnoff from US highway #97.

The road to Summit Rock comes off of highway #138 about one mile east of the county line. A well-graded dirt road slants northwest, crosses a horse trail, and proceeds to the quarry area itself. You can drive up into the quarry with no difficulty. The road is good enough that 4-wheel drive is not required. Total distance off the highway is about one mile.

There is an extensive Forest Service campground at Diamond Lake, with hundreds of sites, hookups, water, etc. There are some motel and eating accommodations near the lake, and more at the town of Chemult.
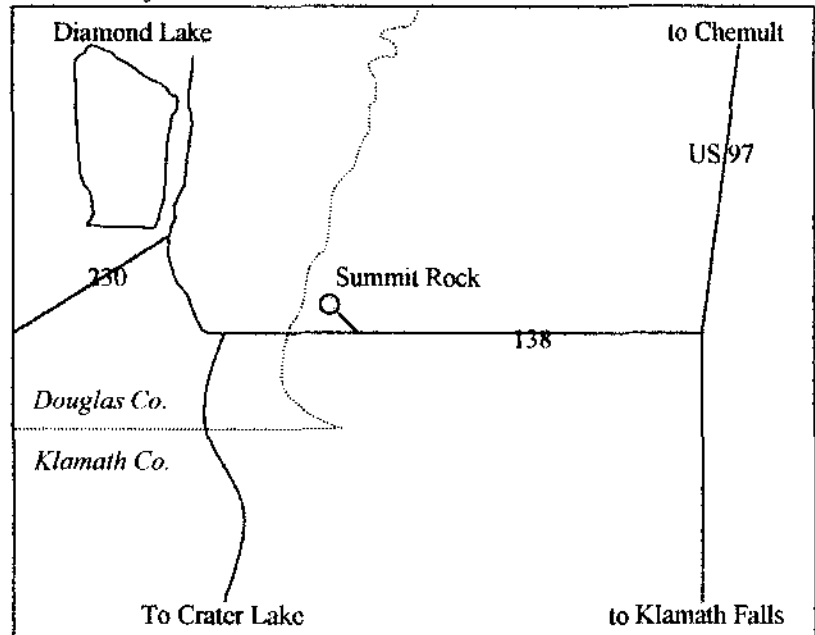
View of what is left of Summit Rock from the short road leading to it.

The whole top of Summit Rock has been quarried, and there is abundant rock exposed and ready to work. Not all of the rock is filled with the flattened vugs that are rich in minerals. Rock on the west side of the quarry is mostly more oxidized, while the rock in place on the east side is considerably fresher. The rock is not too difficult to break, but a broad chisel and a heavy hammer are recommended collecting tools. Since you can drive all the way into the top quarry, carrying equipment is not needed.


East side of the quarry top, showing the rock still in place.

MINERALLOGY:

This is a plug dome that was originally about 60 meters high and 200 meters in diameter. The inside of the dome is composed of a light gray andesite, which was surrounded by a red scoria. Most of the minerallization is in flattened voids that are only a millimeter or two thick but may be several centimeters in diameter. The minerals are primarily those that crystallized out of the magma phase. 95% of the mineral assemblage is composed of feldspars and pyroxenes. The light-colored minerals are difficult to tell apart.

Dark Minerals:

Enstatite (hypersthene) is the most common dark mineral in the cavities. The crystals are clear beer-bottle brown when fresh and somewhat darker when oxidized. They vary from thin blades to rather blocky crystals. They tend to have numerous faces present on the terminations. Some crystals appear cavernous. Almost all of the brown crystals in the cavities are enstatite. The name hypersthene is no longer in use. It referred to an orthopyroxene with a considerable but not a majority component of iron. This mineral in current nomenclature would be an iron-rich enstatite. The formula would then be written as $(Mg,Fe)_2 Si_2 O_6$
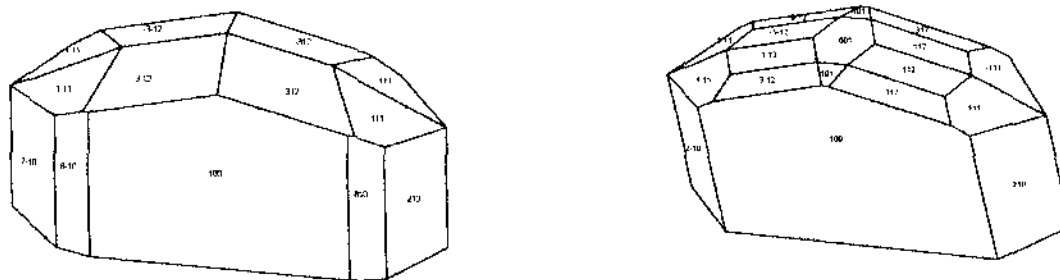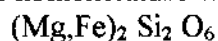
Examples of the faces present on the termination of the enstatite (hypersthene) crystals from Summit Rock.

Ilmenite is also common in the cavities. It forms small rhombohedral platelets that often look rather hexagonal because of the large c-faces. When fresh, ilmenite has a silvery metallic look. In many cavities, however, it appears black, often with c-faces that look blistered. The hexagonal platelets are often grouped in parallel growths, especially when overgrowing magnetite.
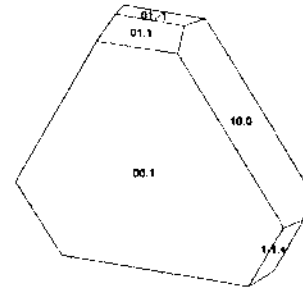
Ilmenite

Magnetite generally forms as rough-faced blobs, usually thoroughly embedded in the matrix with only a bit exposed. Often the surrounding light-colored minerals will show a rusty stain in the vicinity of the magnetite.

Augite also forms crude crystals embedded in the surrounding light-colored minerals. Its color varies from green to olive brown. The augites are always small and seldom show clear faces.

Hematite is present in the form of very thin sheets that appear red due to transmitted light through them. They can often be seen as inclusions in the enstatite blades.

Aegirine (acmite) is a rare mineral, yellow in color, seen growing on oxidized enstatite or ilmenite in weathered regions in the rock. The crystals are acicular with blunt terminations.

Hornblende is a rare mineral, forming slender brown prisms with blunt terminations.

Pseudobrookite is a rare mineral, forming tiny platy crystals, generally on corroded ilmenite. They are a deep red with a submetallic luster.

Light Minerals:

Plagioclase feldspars form the bulk of the background against which the dark minerals are shown off. In composition they range from albite to bytownite, and individuals are typically zoned. In form they are tabular, flattened on (010), and many are twinned. They are small and colorless.

Fluorapatite forms as clear, acicular needles with hexagonal cross-section. They are often thickly scattered in the cavities, usually randomly oriented rather than in tufts.

Zircon occasionally forms as tiny crystals. These are a delicate pink color, so they show up better against the white background than the other light colored minerals in spite of the fact that they are transparent.. In the original article, they were misidentified as rutile. In shape, they are short prisms with pyramidal terminations.

Tridymite is an occasional mineral, forming colorless, thin six-sided plates or twinned, wedge-shaped crystals. It is very hard to differentiate from the plagioclase.

Cristobalite rarely forms colorless, spherical aggregates.

Hyalite is also rare, forming colorless colloform masses.

Copper Minerals:

Several copper minerals have recently been identified from Summit Rock. These all appear to be secondary minerals of later origin than the primary minerals listed above.

Cuprorivaite is a rare calcium copper silicate that has been identified from the quarry. It formed as scattered, tiny, thin, azure-blue tetragonal platelets in a cavity in oxidized material.

Chrysocolla has not previously been reported from Summit Rock. It forms tiny sky-blue blebs and clusters in the cavities of primary minerals. The small masses are irregular and often in contorted shapes. These do not display any macroscopic crystal structure. The fact that even the thinnest blades are blue in color shows that they contain a considerable concentration of copper. Though not seen in large masses, they are present in a good proportion of the cavities on the freshest rock.

Unidentified copper aluminum silicate. This material forms a thin green crust on seams in the rock. It is a malachite green in color, and looks vitrious in the microscope, though there is no obvious crystal form. It gives a weak x-ray pattern, so it is not clear whether it is a gel of some sort or an actual compound. The uniformity of color tends to suggest the latter.

Volborthite forms yellow to yellow-green areas on some of the copper aluminum silicate seams. It is very finely crystalline. The material seems to be nearly pure basic copper vanadate.

The last two minerals were found on surface seams on large blocks of andesite that were fine-grained and without vugs. These blocks were located on the west side of the top quarry in a region that would not be of interest to collectors looking for the usual primary minerals ascribed to Summit rock, though they were easy to spot because of the green color. Several surface seams are present in that part of the quarry, and they are worth further investigation.

Summit Rock is an easy place to reach and an easy place to collect, even though the range of minerals is rather limited. For any one traveling along US Highway 97 north of Klamath Falls, it would be an hour well spent to take the short side trip off on the East Diamond Lake Highway and check out the quarry. The view is teriffic and there is certainly plenty of good material left to collect. And who knows, you might turn up with something new.
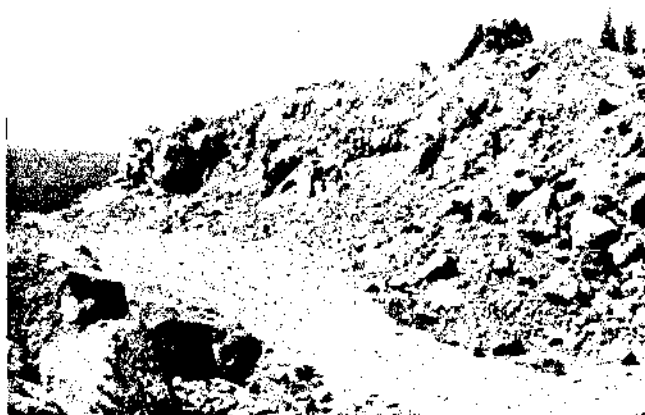
Broken rock fragments on the west side of the quarry top. The seams of copper minerallization are on the large boulders in the center of this view.

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Vanadium and chromium minerals

Don Howard

Last issue, we included Bill Wise's list of vanadium minerals. In this issue we supplement it with a list of known chromium minerals. One might ask: Why list these particular mineral sets? There can be several different rationales offered. These minerals occur over a wide range of locales – wakefieldite at Yellow Lake, mottramite from the mines along the Washougal River, volborthite from Summit Rock. Some of our most colorful minerals – crocoite, uvarovite, vanadinite, cavansite – contain chromium or vanadium. Many of the minerals are rare and unusual, and therefore capture our attention. Also, the lists are fairly short; can you imagine how many pages would be necessary to list all the copper minerals, or all the iron minerals?

So where do the chromium and vanadium originate? Mercury minerals are usually associated with hydrothermal activity. Copper, lead, and zinc minerals are usually found in intrusive veins where the concentrations have built sub-surface and then been injected. But the minerals of chromium and vanadium are seldom in high concentrations. Rather they are widespread, a little here and a little there. Why?

Chromium and vanadium are actually fairly common elements in the Earth's crust. However, they do not often accumulate in very heavy concentration. The reason for this is that they tend to substitute for iron, particularly ferric iron, in a variety of common minerals, particularly the oxides hematite and magnetite. In this form they are widespread but seldom in very high concentration. They can do this because they both have a trivalent state with the size of the ions not very different from the ferric ion, as can be seen from the table. For the other common trivalent ions, aluminum is much smaller and titanium is considerably larger; both do not easily substitute because they would distort the lattice.

RADII OF TRIVALENT IONS	
Al^{+3}	0.50 A
Ti^{+3}	0.69 A
V^{+3}	0.66 A
Cr^{+3}	0.64 A
Mn^{+3}	0.62 A
Fe^{+3}	0.60 A

When these iron minerals break down, the impurities are released. Both chromium (Cr^{+6}) and vanadium (V^{+5}) have higher oxidation states that change their chemistry away from that of iron, so they then can concentrate and form the more colorful chromate and vanadate minerals that we love to collect.

Another place that chromium "hides" in low concentration is the olivines. These are formed well below the Earth's surface, and are not particularly stable when brought to the surface and attacked by meteoric water. Olivine is converted into serpentine, at which time the chromium ends up in one of the spinel minerals, normally chromite.

In metamorphic environments, chromium often follows the iron into garnets or one of the micas. Again, normally the concentrations are only a few percent, but they can give color to the mica (such as fuchsite). Occasionally, such as the case of uvarovite, they constitute the major trivalent ion.

So the result is that usually only small amounts of the unusual mineral are present. Vauquelinite is normally found in a few scattered tufts on other copper minerals. Hemihedrite seldom is a common mineral even in the locations where it is found. Cavansite certainly does not occur in large amounts anywhere; at Goble it was in trace amounts.

But that, plus their color, is what makes them fun to collect.

List of Chromium Minerals

Compiled by Don Howard

A. Elemental

1. Chromium	Cr	white, metallic

B. Sulfides

1. Brezinaite	$Cr_3 S_4$	gray, metallic
2. Kalininite	$Zn Cr_2 S_4$	black, metallic
3. Florensovite	$Cu (Cr,Sb)_2 S_4$	black
4. Daubreelite	$Fe Cr_2 S_4$	black, metallic
5. Caswellsilverite	$Na Cr S_2$	yellow gray, metallic
6. Schollhornite	$Na_{0.3} Cr S_2$	gray, metallic

C. Oxides and Hydroxides

1. Eskolaite	$Cr_2 O_3$	black
2. Bracewellite	$Cr O (OH)$	black
3. Guyanaite	$Cr O (OH)$	reddish brown
4. Grimaldite	$Cr O (OH)$	deep red
5. Mcconnellite	$Cu Cr O_2$	dark red
6. Chromite	$Fe Cr_2 O_4$	black
7. Nichromite	$(Ni,Co) (Cr,Fe)_2 O_4$	dark green
8. Cochromite	$(Co,Ni) (Cr,Al)_2 O_4$	black
9. Zincochromite	$Zn Cr_2 O_4$	brownish black
10. Magnesiochromite	$Mg Cr_2 O_4$	black
11. Manganochromite	$(Mn,Fe) (Cr,V)_2 O_4$	black
12. Chrombismite	$Bi_{16} Cr O_{27}$	yellowish brown
13. Dukeite	$Bi_{24} Cr_8 O_{57} (OH)_6 (H_2O)_3$	yellow

D. Carbonates
1. Petterdite $Pb\ Cr_2\ (CO_3)_2\ (OH)_2\ (H_2O)$ gray to pink violet

E. Halides
1. Woodallite $Mg_6\ Cr_2\ Cl_2\ (OH)_{16}\ (H_2O)_4$ purple

F. Sulfates
1. Bentorite $Ca_6\ (Cr,Al)_2\ (SO_4)_3\ (OH)_{12}\ (H_2O)_{26}$ bright violet
2. Redingtonite $(Fe,Mg)\ (Cr,Al)_2\ (SO_4)_4\ (H_2O)_{22}$ white to purple

G. Simple Chromates
1. Tarapacaite $K_2\ CrO_4$ canary yellow
2. Phoenicochroite $Pb_2\ (CrO_4)\ O$ dark red
3. Lopezite $K_2\ Cr_2\ O_7$ orange red
4. Crocoite $Pb\ CrO_4$ orange red
5. Chromatite $Ca\ CrO_4$ citron yellow
6. Hashemite $Ba\ (Cr,S)\ O_4$ brown
7. Wattersite $Hg^+_4\ Hg^{+2}\ (CrO_6)$ dark reddish brown
8. Santanaite $Pb^{+2}_9\ Pb^{+4}_2\ Cr\ O_{16}$ straw yellow

H. Compound Chromates
1. Edoylerite $Hg\ Hg\ (CrO_4)\ S_2$ yellow
2. Deanesmithite $Hg\ Hg\ (CrO_4)\ S_2$ orange red
3. Vauquelinite $Pb_2\ Cu\ (CrO_4)\ (PO_4)\ (OH)$ green
4. Fornacite $Pb_2\ Cu\ (CrO_4)\ (AsO_4)\ (OH)$ olive green
5. Embreyite $Pb_5\ (CrO_4)_2\ (PO_4)_2\ (H_2O)$ dull orange
6. Cassedanneite $Pb_5\ (CrO_4)_2\ (VO_4)_2\ (H_2O)$ red orange

I. Titanates
1. Olkhonskite $(Cr,V)_2\ Ti_3\ O_9$ black
2. Redledgeite $Ba\ Cr_2\ Ti_6\ O_{16}\ (H_2O)$ black
3. Mathiasite $(K,Ca,Sr)\ (Ti,Cr,Fe,Mg)_{21}\ O_{38}$ black, metallic
4. Lindsleyite $(Ba,Sr)\ (Ti,Cr,Fe,Mg)_{21}\ O_{38}$ black, metallic

J. Silicates
1. Rilandite $(Cr,Al)_6\ Si\ O_{11}\ (H_2O)_5$ dark brownish black
2. Kosmochlor $Na\ Cr^{+3}\ (Si_2\ O_6)$ dark emerald green
3. Uvarovite $Ca_3\ Cr_2\ (SiO_4)_3$ deep rich green
4. Knorringite $Mg_3\ Cr_2\ (SiO_4)_3$ blue green to lilac
5. Krinovite $Na\ Mg_2\ Cr^{+3}\ Si_3\ O_{10}$ emerald green
6. Shuiskite $Ca_2\ (Mg,Al)\ (Cr,Al)_2\ (SiO_4)\ Si_2O_7\ (OH)_2\ (H_2O)_2$ dark violet brown
7. Volsonskoite $(Ca_{0.5})_{0.33}\ (Cr,Mg,Fe)_2\ (Si_{3.5}\ Al_{0.5}\ O_{10})\ (OH)_2\ (H_2O)_4$ deep green
8. Chromceladonite $K\ Cr\ Mg\ (Si_4O_{10})\ (OH)_2$ green
9. Chromdravite $Na\ Mg_3\ (Cr,Fe)\ (BO_3)_3\ Si_6\ O_{18}\ (OH)_3\ (OH)$ dark green to black
10. Chromphyllite $K\ Cr_2\ (Al\ Si_3\ O_{10})\ (OH,F)_2$ emerald green
11. Muscovite varieties: $K\ (Al,Cr)_2\ (Al\ Si_3\ O_{10})\ (OH,F)_2$ light green
    a. Fuchsite
    b. Mariposite

001 1-11 111 100 010 1-1-1 11-1

001 1-11 111 100 010 1-1-1 11-1
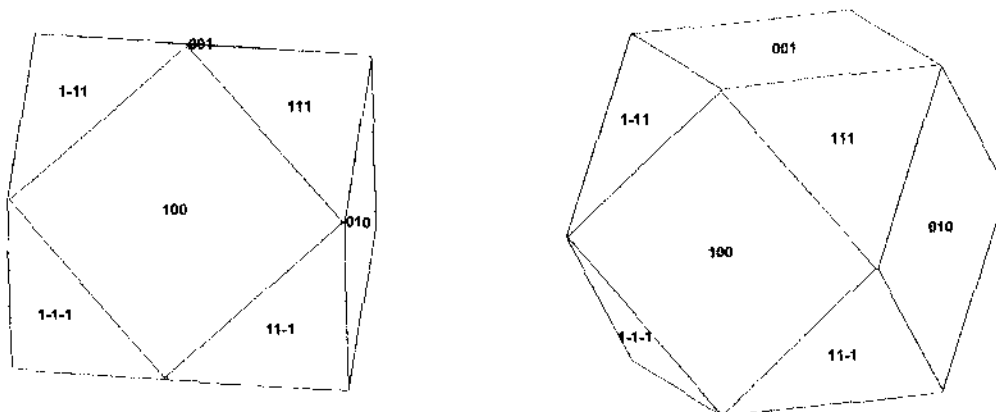
Pyrite Crystals from Rock Island Dam, Chelan Co., Washington

Two views of crystals with nearly equally developed cube (100) and octahedral (111) faces, such that the (100) face is a square and the (111) faces are equilateral triangles. Crystals of pyrite found recently at Rock Island Dam, and illustrated in Micrograph #194, all show exactly this ratio of face development

FIGURE CAPTIONS

For color photographs, the number is on the back in the upper left corner.

 # 13   Tincalconite pseudomorph after Borax   (x2)
Searles Lake, Kern Co., California
The (100) face is uppermost. The small triangular face at left is the (001) face.
See figure 2 for a diagram of this type of borax crystal.

For electron micrographs, the number is in the lower right corner on the front.

 # 192   Enstatite var. Hypersthene and Ilmenite on Plagioclase   (x40)
Summit Rock, Klamath Co., Oregon
The crystal on the left with the complex termination is the hypersthene. The two sides are
different, following the two disgrams in the text. The crystal on the right is ilmenite.

 # 199   Hypersthene, Ilmenite and fluorapatite on Plagioclase   (x50)
Summit Rock, Klamath Co., Oregon
The same crystal as that shown in micrograph #192, except looking directly down on the
termination. The crystal at upper right is a different ilmenite. The slender hexagonal rods
are fluorapatite.

 # 196   Ilmenite and Hypersthene on Plagioclase   (x36)
Summit Rock, Klamath Co., Oregon
This ilmenite crystal shows the alternating flat and beveled faces as shown in the diagram
in the text. The crystal at right is the hypersthene, seen laying down.

 # 194   Pyrite on Phillipsite   (x80)
Rock Island Dam, Chelan Co., Washington
Several crystals showing a habit with nearly equally developed (100) faces (square) and
(111) faces (triangular). See the diagram on the previous page. The vug also contained
small calcite crystals totally coated with phillipsite.

.036kx   30kv 196

.050kx   20kv 199

.040kx   30kv 192

.080kx   30kv 194