

**Northwest
Micro Mineral
Study Group**



MICRO PROBE

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SPRING MEETINGVANCOUVER, WASHINGTON

May 4, 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. 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. In this issue, Bill Wise gives a very complete summary of Vanadium minerals. How many do you have? Bring some of your more unusual ones for others to look at. That way we can see what they really look like.

Morning:

Bob Smith will talk and show slides of collecting in the Black Hills.

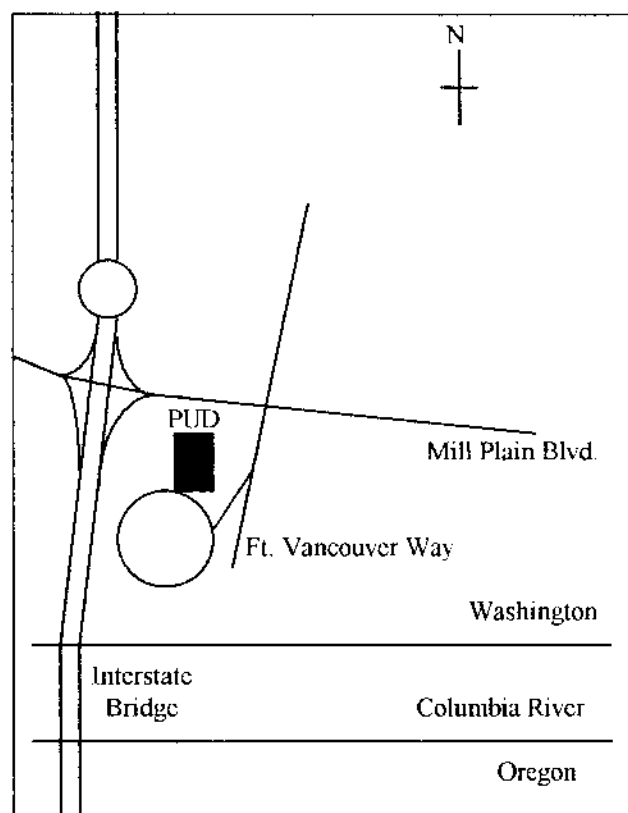
Afternoon:

We will have a short business meeting and our usual review of the collecting status of locations in the Northwest.

Anyone who has slides to share with the group should bring them along to show at this time.

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 noon.

Restaurants are available in the local area. Some of us will plan to eat dinner together, so please plan to join us if at all possible.



Erionite Crystals and Associated Minerals from Alder Creek,
Wheeler County, Oregon

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I have been interested in minerals and mineral collecting for several years, but I did not start collecting my own minerals until the summer of 1996. It was spring of that year I contacted Rudy Tschernich concerning buying some minerals and made arrangements to visit him in Snohomish. I asked him about possible collecting localities and he generously provided maps and directions to several locations, including several in Wheeler and Grant Counties, Oregon. All the famous locations were included on his list, but many relatively unknown sites were also present. In three days, I made a whirl-wind trip from Rudy's house to 11 locations, nine in east-central Oregon. Of course, I did not have time nor "gross vehicle weight" to collect all the Oregon locations.

In 1998, my wife and I returned to Oregon to collect more sites on Rudy's list. One I particularly wanted to visit was the location on Alder Creek. Alder Creek flows into the John Day River two miles east of Service Creek. As we drove north along Alder Creek, we were greeted by a flagman and what looked like road construction. Not wanting to get tied up for an indefinite time, we opted to stop and turn around. At this point, I said I would just check the road cut and we would be on our way. I use the term "road cut" loosely. It is really a dirt bank five to six feet high with a few rocks sticking out of it. The rock at the northern end was highly viscicular with many small cavities that I could see were lined with crystals. The rock toward the middle and southern part of the cut was darker, more dense and contained only a few cavities, all very small, mainly filled with some noncrystalline white material. I grabbed a few samples of both types of rocks to check later.

During the winter, I began looking at the material collected during the summer. The rock forming the northern end produced small but nice crystals of a variety of zeolites and associated minerals. The rock from the middle/southern end produced only phillipsite, apophyllite, and a very few prismatic hexagonal crystals of erionite. I sent a sample to Rudy and he confirmed my identification.

The location is apparently a new one, being much closer to Oregon State Highway 19/207 than the location Rudy identified. Rudy's locality is 1.5 to 2 miles north of the highway and the new one, I found, is a bit over .5 miles north. I have been referring to it as "lower Alder Creek."

The easiest way to find the location is travel north along Alder Creek to a small quarry, located on the road; this is a little over one half mile. Turn around and backtrack about 50 to 75 yards and begin looking at the "road cuts." The correct one is on the west side, is low (five to six feet), has a few rocks sticking out, and has the fence set back away from the road.

All the mineral specimens recovered from this location are very small. Cavities in the rock are generally less than 10 mm in diameter. Weathered, broken fragments of larger cavities are present along the slope, but none were found in an intact or unweathered state.

Analcime was found in a single cavity from the northern section of the road cut. The cavity (less than 3.0 mm across) is completely lined with very small colorless trapezohedra. No other minerals were present in the cavity.

Apophyllite is the second most common mineral after phillipsite at this site. It is particularly common in the southern section of the road cut. The crystals are basic cubes with minor development of the pyramid. These small crystals, 0.1 to 0.3 mm in length, are slightly cloudy to milky white.

Calcite is common as small white, light yellow, or light brown scalenohedral crystals. Calcite occurs directly on phillipsite and occasionally completely fills cavities.

Chabazite is not common at this location. Colorless to white rhombohedra of chabazite up to 4.0 mm across are present on phillipsite in some cavities. The phacolite variety of chabazite was seen from a weathered fragment of a larger cavity.

Erionite crystals, found at the location, are colorless, hexagonal prismatic crystals with striations along the long axis. The prisms are 0.1 to 0.3 mm long and occur in cavities lined with a hard white material. This material completely fills many cavities overgrowing the erionite. Only a few open cavities were found and these are very small (one to five mm in diameter). Erionite crystals are associated with chabazite (one cavity) and phillipsite (three cavities).

Gyrolite occurs in a few cavities. Small (0.1 to 0.4 mm) compact mounds composed of thin white blades are present on phillipsite. All gyrolite samples were recovered from the northern end of the road cut.

Phillipsite is the most common mineral at this location, where it lines nearly all the cavities. Two distinct forms are present. The first is colorless to white morvenite twins that form a druse lining cavities. Individual crystals of this type range up to .2 mm in size. A few cruciform twinned crystals are visible in some of the larger cavities. The second habit is a tightly packed mound of radiating colorless crystals. These mounds are up to 0.3 mm across. The mound habit is present in the darker rocks that contain the erionite crystals.

Stilbite was present in a single cavity. The specimen consisted of a single 1mm flat-topped crystal resting on phillipsite.

Thanks to Mary Ellen, my wife, for all her work proof reading and correcting my writing. Special thanks to Rudy Tschernich for "pointing me in the right direction" and looking at any material I send to him.

Reference:

Tschernich, R. W, *Zeolites of the World*, (Geoscience Press, Phoenix, AZ, 1992).

Pegmatites of the Black Hills

1. Tin Mountain and Tip Top Mines

Robert Smith

In the southwest part of South Dakota, along the Wyoming border is the mountainous uplift called the Black Hills. They seem to have escaped from the Rocky Mountains, since Harney Peak (at 7242 feet) is the highest point between the Rockies and the Atlantic Ocean. And to the geologically minded, they are a paradise of formations and mineral areas. Some of the fascinating systems include numerous sediments, such as ancient limestones, sandstones, and shales, as well as igneous inclusions of all sorts. Perhaps the most important mineralogical formations are the granitic intrusions associated with the Precambrian igneous invasion. These are the many pegmatites that are common in the Black Hills.

There are said to be at least 20,000 pegmatites in the Hills, but this is just a guess. They range in size from a few inches to mountainous. It is these pegmatites that I want to look at in a series of papers. The igneous intrusions were implaced into pre-existing sediments and metamorphic sediments during Precambrian times. The common pre-existing rocks were the schists. Some fascinating mineralogy occurs in these schist contacts as well, and we will look at those in a future paper.

Near the end of the Mesozoic Era, about 80 million years ago (give or take a week), the slow uplift of the area began. This uplift was probably tectonic in origin, though much of its history is still unclear. In any event, this uplift continued for the next 50 million years and led to the slow erosion of the entire Black Hills area. This activity exposed many of the pegmatites as well as many other great geologic features.

Some of the pegmatites are disseminated within the major pluton itself. However, numerous other pegmatites are intruded into the schist throughout the Hills. Pegmatites can be found in almost any part of the Black Hills, but there are two areas (or swarms) that are most interesting to the mineralogist. These are near the towns of Custer and Keystone in the central Black Hills. I would like to start with two major mines near the town of Custer in Custer county. These are the Tin Mountain Mine and the Tip Top Mine.

The Tin Mountain Mine

The Tin Mountain Pegmatite is found about 6 miles southwest of Custer. The outcrop is the top of a knoll about 20 feet above the valley floor. The outcrop is an L-shaped irregular pipe plunging in a northwest direction. Basically, it seems to be a four-zoned pegmatite intruding into schist and is quite large for the area. The zones include massive quartz with large spodumene logs and beryl. Areas of perthite and tourmaline-rich quartz also exist.

The most common minerals mined here were beryl, amblygonite, spodumene, and pollucite. In spite of the name given the prospect, very little cassiterite was ever recovered from the pegmatite. However, a large number of very interesting minerals have been collected from the mine and the dumps. These include the following:

Albite	Columbite/tantalite	Montebrasite
Almandine	Covellite	Montmorillonite
Amblygonite	Ferrisickelerite	Muscovite
Aurichalcite	Fluorapatite	Pollucite
Autunite	Fourmarierite	Pyrolusite
Azurite	Goethite	Quartz
Beryl	Hemimorphite	Smithsonite
Biotite	Lepidolite	Sphalerite
Bismuth	Loellingite	Spodumene
Bismuthenite	Malachite	Triphylite
Bornite	Meta-autunite	Uraninite
Calcite	Microcline	Uranophane
Cassiterite	Microlite	Vandendreisscheite
Chalcopyrite		Zircon

The mine has extensive underground workings. However, most of the underground cuts have been flooded for years. In fact, very little activity has taken place at the pegmatite since the 1930s. Small amounts of prospect work is done every now and then, but little major activity (except for the removal of road material) has occurred for years. The head frame and loading bins have become decrepit over the years. Those that remain are dangerous and should be avoided.

One of the most interesting specimen minerals found in the mine is the excellent zircon. Crystals up to 3 inches have been collected. These are some of the best in the Hills. I have also found good amblygonite crystals on the dumps. Phosphates are collectable but not particularly common.

Another notable find from the Tin Mountain area is the cesium- and rubidium-rich muscovite. This seems to occur in reasonable amounts and may be important as a source of these uncommon elements in the future.

All in all, the Tin Mountain Pegmatite is a fascinating mine in a beautiful part of the Black Hills and a good place to visit.

The Tip Top Mine

This pegmatite is a lens-shaped body that occurs about 5 miles southwest of Custer. The dike is primarily a quartz-perthite pegmatite that was originally a prospect for tin. Again, very little of the cassiterite ore was ever mined.

The major economic minerals from the mine were potash feldspar and sheet mica as well as amblygonite and beryl. The mining took place in a pit that is now mostly flooded. However, some recent work has been done near the glory hole with a number of important finds being uncovered. So far, over 80 minerals have been recovered from the pegmatite.

The most important minerals (as far as collectors are concerned) are the set of phosphate minerals found at the Tip Top. This is one of the major phosphate locales in the world. Over 50 phosphate minerals have been found here, and at least 8 of them are new minerals for which this is the type locale. These include:

Ehrieite	Jahnsite	Tinsleyite
Fransoletite	Robertsite	Tiptopite
	Segelerite	

Some of the minerals from the mine are world-class examples. These include the red Montgomeryite, Robertsite, and Beryl. Along with the Palermo #1 mine in New Hampshire and the Hagendorf pegmatites in Germany, the Tip Top is the major phosphate locale in mineralogy. The best reference for the Tip Top is the great article by Cambell and Roberts in the July/August Mineralogical Record (V, 17, #4).

Lately both the Tin Mountain and the Tip Top have been examined for the potential of reuse. Study has been made to see if there is sufficient stockpile of minerals for new economic recovery. Some potential has been found; however, I think that the recovery of specimen material may be the most important use of these mines in the future.

We have looked at only two of the more than 20,000 pegmatites in the Black Hills, so we have only 19,998 to go. Of course, we may not get to them all, but in future papers I will try to cover some of the remaining important mines. Next, I intend to look at some of the mines in the Keystone area. Till then, keep on digging!

Reference:

Cambell & Roberts, *Phosphate Minerals from the Tip Top Mine, South Dakota*, **Min. Rec. 17**, #4, pg 237.

Dunn *et. al.*, *Red Montgomeryite from the Tip Top Mine*, **Min. Rec. 14**, #3, pg195.

Feldman & Heimlich, *The Black Hills*. (Kendel Hunt, 1980).

Page *et. al.*, *Pegmatite Investigation of the Black Hills*, **USGS PP 247**, (1953).

Roberts & Rapp, *Mineralogy of the Black Hills*, **SDSMT Bul. 18**, (1965).

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On Filiforms, Nanowires and Whiskers

Don Howard

I think we have all wondered from time to time while looking at a particularly intricate or odd-shaped crystal, how did that ever grow that way. The myriad of faces on some crystals are amazing. In this article I would like to examine some of the main considerations behind the way crystals grow. In particular, I would like to focus on filamentary crystals – needles and sprays and fine wires – that we usually class as filiform.

Crystals are composed of repeating layers – the so-called unit cell – stacking regularly over and over to form a visible sample out of very tiny building blocks. The limiting step in this process is almost always the formation of a new layer on one of the crystal's faces. To see why this is so, consider the schematic representation in the diagram below. Each little block represents one unit of the material. Suppose for the purposes of this discussion that the forces that hold a unit in place act just between neighboring units, so that the strength of the attractive force depends on how many neighbors in a unit are touching. This force is opposed, of course, by thermal energy that tries to randomize things, thus breaking the regular structure apart and causing units to 'dissolve', that is, to return to the surrounding medium, whether solution or vapor, from which the crystal has begun to grow. At any time, these two competing processes are both going on, so that some units arrive at the surface and stick while others come loose and leave. Whether the crystal grows or shrinks depends on which of the two processes is happening most rapidly. When the two rates exactly match, the process is described as a *dynamic equilibrium*.

Several different sites are identified on the diagram. A unit such as (a), embedded in a surface, sees 5 units surrounding it, and is therefore more tightly held than one such as (b) located along a step that only has 4 neighbors. A free unit sitting on a face, such as (c), has only one neighbor, and is therefore bound very loosely indeed; so much so that thermal agitation is much more likely to knock it off than either unit (a) or (b). If another unit came along, the notch labeled (d) would have the most neighbors – three – and therefore be the site most likely to stick. A unit reaching site (e) would only see two neighbors, and would be more loosely held than (d), but more tightly held than if it tried to attach at (f) where there would be only one neighbor.

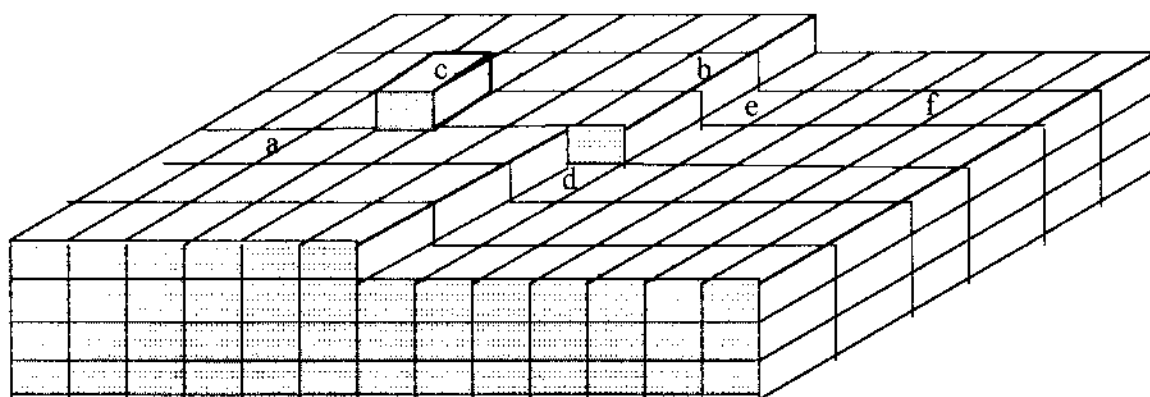


Fig. 1 A block representation of a crystal surface, with various sites identified so they can be discussed in the text above. The crystal is intended to have orthorhombic symmetry.

In general, we would see that sites with numerous neighbors would fill and stay longer than sites with few neighbors. In figure 1, the site marked (d) would be most likely to add a unit. Once it did, another identical site would be created awaiting an add-on unit, and so forth until the step was straight all the way across. Then to continue to grow, a unit would have to be added at (e), thus creating another line that, once complete, would move the step one unit to the right. Adding a unit on a completed step, such as (c), would not be very easy, and so would go slowly. In fact, while a unit sat at (c), other units would need to be added beside it in order to stabilize it before thermal energy caused it to leave. It is easy to see, using this model, how a flat face would form by adding units to a step until it had been grown out, and a new layer would take a while to form. Starting a new layer by getting a cluster to form on it is a process called *nucleation*, and it is the step that limits the growth of the crystal.

All faces in a crystal do not grow at the same rate.

To see this, consider a (111) face in our block representation of a crystal, as shown in fig. 2.

Here, a unit to be added sees three neighbors at each site. Thus, in this model, units added onto the (111) face would have three times the binding of those added onto a (001) face, as in fig. 1. We would expect the problem of nucleating new planes to be much easier for the (111) face, and that it would grow much more quickly, so that soon only (100), (010), and (001) faces would bound our "crystal". The rule here would be: *the faster growing faces disappear until only the slowest growing faces are left*. A natural crystal would therefore be expected to be bounded by the slowest growing faces, where nucleating a new face is most difficult.

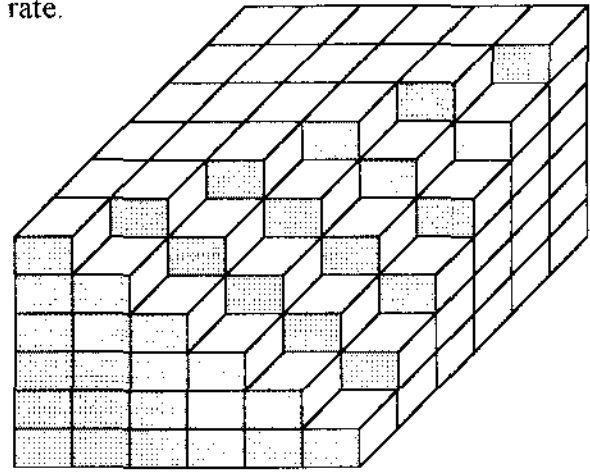


Fig. 2 A (111) face in the same block representation as fig. 1.

Now it is easy to see why some crystals almost always grow in the form of needles. In a mineral like natrolite, which is orthorhombic, the (100) and (010) faces are slow to nucleate new layers, but the (001) direction is much faster. The crystals are therefore normally elongated along the c-axis. Similarly, for a mineral like millerite, which is trigonal, fast growth is along the c-axis and the crystals are generally in the form of fine wires with trigonal cross-sections, as shown in Micrographs #337 and 342. So in this way we can explain the filamentary nature of many minerals.

Aha! But what about cubic minerals such as native copper and pyrite? Clearly this argument does not apply there. All three directions are crystallographically identical, so should be expected to grow at roughly the same rate. Cubic minerals would be expected to be approximately equant, with the shape determined by whichever class of faces are slowest to grow. And in fact, most cubic minerals *are* equant: cubes or pyritohedra of pyrite, dodecahedra of analcime, garnet, and paulingite, octahedra of faujasite, etc. So something else must be responsible for filiform growth in cubic crystals.

In fact, the direct mechanism for nucleating a new face described above runs into a difficulty. Based on the relative energies involved, the rate-limiting step of nucleation would cause crystal growth to be so slow that in general it would take eons to make a decent sized crystal. And

yet we know that crystals of water-soluble salts can form overnight, or at most in a few days. So we need to re-examine just how most crystals really *do* grow. We have assumed that the order in crystals is perfect, and yet we know that nature in fact hates perfect order – the concept in physics is called *entropy* and it says that, at any temperature above absolute zero, a certain amount of disorder is required.

The particular kind of disorder thought to be responsible for rapid growth in natural crystals is called a *screw dislocation*. This is depicted in fig. 3. The easiest

way to visualize this is to imagine a knife cutting into the crystal from the left in to the middle, and then shifting the back portion behind the cut up one unit with respect to the front portion. This results in a step that only extends half the way across the upper face. The dislocation itself is a line that runs perpendicular to the face. Considerable

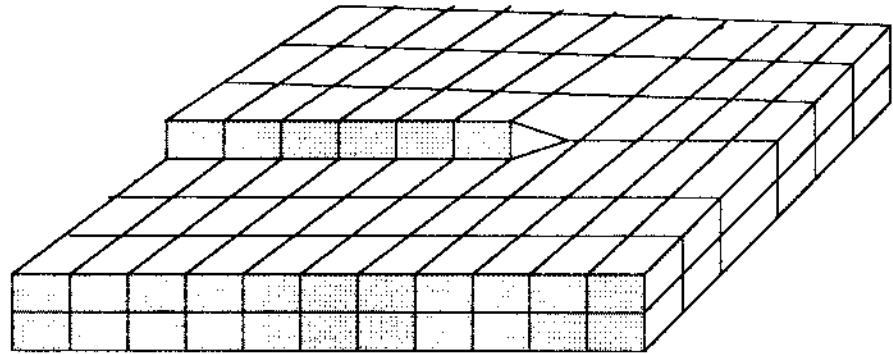


Fig. 3 Emergence of a screw dislocation onto the face of a crystal. The dislocation itself is a vertical line perpendicular to the face at its center. A step results that extends only part way across the face. Adding units cannot make the step vanish.

distortion to the shape of the component units results in the immediate vicinity of the dislocation line, and that results in increased energy for the crystal, but the gain through entropy (disorder) makes up for that small amount of extra energy.

Suppose now we supply new units to cause the crystal to grow. The step is present, so it will try to grow out. But adding units does not make it disappear. It is pinned in the center, so the offset step just spirals around and around the pin point, much like a spiral staircase (hence the name *screw* dislocation). No new layer need nucleate. Growth goes on permanently at the rate governed by adding to a step rather than requiring a new step to form.

How does such a dislocation form in the first place? There are several possibilities. Physical damage to a crystal will introduce dislocations. The grain boundary between two separate crystals when they touch is a possible source of dislocations. Even a single crystal, forced to grow around a foreign grain or a protrusion of the substrate can be misaligned when it meets on the other side and a screw dislocation results. But one of the easiest ways is for dislocations to already exist – by any one of these mechanisms – in the substrate the crystal begins to grow on. However introduced, once one or more dislocations are present in the crystal, the growth rate is greatly speeded up *in a particular direction*. And often it is easier to introduce a dislocation in one direction than it is in another, which also favors asymmetric growth.

The presence of dislocations in a substrate is believed to be the cause of a phenomenon in metals called *whisker growth*. If a piece of certain metals is heated in vacuum (to prevent surface chemical reactions) sufficiently to cause considerable mobility of atoms along the surface, fine hairs grow out from the surface. Presumably, atoms freed thermally to move encounter the step

generated by the dislocation and bond there, causing the step to circle round and round and form a fine pillar of the metal up from the original surface.

Dislocation-based growth is the one usually used to explain filiform formation in an otherwise cubic material, such as native copper or pyrite. But it is hard to see how this will lead to anything but linear growth. **Then how do right-angle bends happen?** Somehow the dislocation would have to change directions. But a screw dislocation is a straight line through the crystal lattice. One possibility is that the growing needle encounters foreign material in such a way that a new dislocation is created whose direction is perpendicular to that of the original dislocation. But the original is still there, and should continue to grow once the impediment has been removed. And since the screw dislocation is a line defect, it extends to *both* sides of the crystal and the new growth should be in *two* opposite directions and not in just one. Of course, the foreign object could still be there, but examination of the bend regions in pyrite (see Micrograph #143) never reveals such an object, but rather a smoothly finish end. The bend generally occurs in the middle of a cavity far from any wall, so that kind of contact is not involved. Moreover, some materials, like copper, exhibit numerous bends in the same crystal. (See for example Micrograph #886 in Vol VIII, #9 of the *Microprobe* of the native copper crystal from the Beaver Valley Quarry, Shine, Jefferson Co., Washington, and Micrograph #145 of this issue for a crystal of pyrite from the Clackamas River, Oregon.) The explanation is thus far from satisfying.

What other ways could a preferred direction happen? One way is for an electric field to exist. The forces between atoms are, after all, electrical in nature, and the presence of a conducting material, such as copper or pyrite, would alter a field to cause much stronger forces at the tip of a needle. But how would the needle get started in the first place? What would generate such an electric field over a protracted length of time? And we still have the problem that bends would not be favored in this geometry.

A new process has been discovered and explored in the last few years in the field of semiconductors. The procedure generates what have become known as *nanowires*. It is a *catalyzed* growth under very particular conditions. A typical experiment would go something like this: On a smooth surface of silicon, small particle of gold are deposited – only a few nanometers (a nanometer is 10^{-9} m or 0.000001 mm) in diameter. The sample is heated up in an atmosphere of vaporized indium phosphide. This semiconductor vapor dissolves in the tiny gold beads. When a critical concentration is reached, the indium phosphide precipitates out *under* the bead onto the silicon substrate, lifting the gold in the process. Over a period of time, the bead climbs up, leaving a wire of semiconductor behind whose cross-section is the same as the area of the bead. By varying the composition of the vapor, scientists have even managed to grow diodes on this tiny size scale.

Various materials in addition to gold are known to act as catalysts in this process. Some of them are iron compounds. Could a process like this occur in nature, with catalyzed crystallization creating filiform growth? And if at some point the capping catalyst particle slips aside, the crystal might shift and grow in another direction, causing the bends that we see. In this case, the perfect end on the pyrite crystal in Micrograph #143 would be the natural result of completing the layers that had been begun. Nature is not in near as much of a hurry as lab scientists, so the process could take months or years rather than a few hours. This is a *promising new* approach in the growing of semiconductor devices. As the breadth of materials that can act as a catalyst becomes known over time, perhaps we will come to recognize another of Mother Nature's tricks to form the bent filiforms that have intrigued and amazed us under our microscopes.

Twisted Millerite

Don Howard

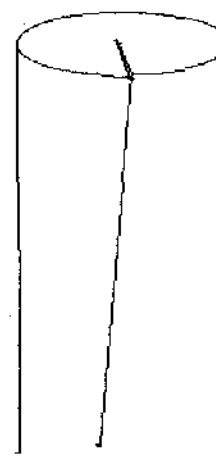
It was with regrets that I read recently that the collecting spot at Hall's Gap, Kentucky was being permanently closed to collectors. This was a truly excellent location for beautiful specimens of millerite, a nickel sulfide. The mineral is trigonal and always forms as fine golden metallic hairs. At Hall's Gap, these criss-cross small cavities lined with a drusy of white to pale tan colored quartz. The specimens are fun to look at under the microscope, especially when you come to recognize that a few of the needles are twisted like a corkscrew! The golden needles are shiny and reflect the light beautifully. The twisted ones look like dashed lines instead of solid ones.

So, why would a filamentary crystal end up twisted?

In the previous article, I explain how a screw dislocation can speed up the growth process of a crystal by eliminating the necessity to nucleate new layers. But the dislocation puts a strain on the crystal that can be partially relieved by allowing it to twist slightly. If you want to see how this works, take a cardboard tube, such as one of the ones that comes in the center of a roll of paper towels, and slit it straight down one side. Now try to push one side of the slit up with respect to the other. You find that the only way to do this is to *twist* the cardboard tube. The more you try to offset one side with respect to the other, the more the twist that must be introduced. A little geometry reasoning will yield that the pitch of the twist is determined by the ratio of offset to tube circumference.

Crystals with screw dislocations running down their center appear to work the same way. By estimating the distance for a complete twist and comparing it to the diameter of the crystal, we can estimate the necessary offset created by the dislocation.

In millerite, the *c* dimension of the unit cell is 0.315 nm. The crystals shown in Micrograph # 337 and 342 are of the order of 0.01 mm, or 10,000 nm. If we assume that the dislocation is offset one *c*-unit, then by taking simple ratios we would find that the distance for a complete twist would be of the order of 10 cm.



Examination of the crystals in the micrographs, and several others like them, indicate that the distance for a complete twist is 1 mm or less. Thus the step height of the dislocation would have to be 100 or more units. What is a minor strain at one step would generate a huge disturbance at 100. In fact, the crystals would have to have a hollow core of at least a dozen or two unit cell spacings to accommodate such a huge dislocation.

Examination of the ends of some of these crystals has been inconclusive. Some do show holes and some do not. In addition, some untwisted crystals show holes in their centers. Whether the dislocation explanation is correct or not, therefore, is still open to interpretation.

Whether or not we can explain *how* the crystals have become twisted, they are certainly another of those fabulous unusual things that Mother Nature has managed to do and that we can view in our microscopes. It is a shame that Hall's Gap will not longer be providing examples of these fascinating specimens.

List and Classification of Vanadium Minerals

Compiled by Wm. S. Wise
(from the *International Micromounter's Journal*)

This list of vanadium minerals includes those through 2001 and early 2002. The classification is basically that proposed by Evans & White (1987, *Min. Record*, **18**, 333-340), but with a few changes to accommodate some new minerals and newly discovered structures.

The formulae used here express the composition of each mineral from a structural sense. For example, the formula for simplotite, given as $\text{Ca V}^{+4}_2 \text{O}_9 \cdot 5 \text{H}_2\text{O}$ in Fleischer's Glossary of Minerals, 1999, expresses only the chemical content, while the formula used here, $\text{Ca (V}^{+4}\text{O)}_2 (\text{V}^{+5}\text{O}_4)_2 (\text{H}_2\text{O})_5$, shows that vanadium occurs in two different sites and valence states in the structure. The number of water molecules is given with a subscript, like all other components, a style used by chemists and increasingly by some mineralogists. The valence state of the vanadium, +3, +4, or +5 is given for those minerals in which it has been determined.

A. Sulfides

1. Patronite	$\text{V (S}_2)_2$	black
2. Sulvanite	$\text{Cu}_3 \text{V S}_4$	reddish bronze
3. Colusite	$\text{Cu}_{13} \text{V (As,Sn,Sb)}_3 \text{S}_{16}$	reddish bronze
4. Germanocolusite	$\text{Cu}_{13} \text{V (Ge,As)}_3 \text{S}_{16}$	yellow
5. Stibicolusite	$\text{Cu}_{13} \text{V (Sb,Sn,As)}_3 \text{S}_{16}$	dark gray
6. Nekrasovite	$\text{Cu}_{13} \text{V (Sn,As,Sb)}_3 \text{S}_{16}$	pale brown
7. Yushkinite	$\text{V S [(Mg,Al)(OH)}_2]$	pinkish violet bronze

B. Species with isolated tetrahedra, $(\text{VO}_4)^{3-}$ or $(\text{V}_2\text{O}_7)^{4-}$

1. Vanadinite	$\text{Pb}_5 (\text{V}^{+5} \text{O}_4)_3 \text{Cl}$	red to brown
2. Descloizite	$\text{Zn Pb (V}^{+5} \text{O}_4)(\text{OH})$	brown
3. Cechite	$(\text{Fe,Mn}) \text{Pb (V}^{+5} \text{O}_4)(\text{OH})$	brown
4. Mottramite	$\text{Cu Pb (V}^{+5} \text{O}_4)(\text{OH})$	olive green
5. Pyrobelonite	$\text{Mn Pb (V}^{+5} \text{O}_4)(\text{OH})$	red to black
6. Tangeite	$\text{Ca Cu (V}^{+5} \text{O}_4)(\text{OH})_2 (\text{H}_2\text{O})_2$	olive green
7. Volborthite	$\text{Cu}_3 (\text{V}^{+5}_2 \text{O}_7)(\text{OH})$	yellow green
8. Turanite	$\text{Cu}_5 (\text{V}^{+5} \text{O}_4)_2 (\text{OH})_4$	green
9. Leningradite	$\text{Pb Cu}_3 (\text{V}^{+5} \text{O}_4)_2 \text{Cl}_2$	bright red
10. Vesignieite	$\text{Ba Cu}_3 (\text{V}^{+5} \text{O}_4)_2 (\text{OH})_2$	olive green
11. Dumahelite	$\text{Cu}_4 \text{Pb}_2 \text{Bi (V}^{+5} \text{O}_4)_4 (\text{OH})_3 (\text{H}_2\text{O})_8$	yellow green
12. Pucherite	$\text{Bi (V}^{+5} \text{O}_4)$	brownish red
13. Dreyerite	$\text{Bi (V}^{+5} \text{O}_4)$	orange yellow
14. Clinobisvanite	$\text{Bi (V}^{+5} \text{O}_4)$	yellow
15. Schumacherite	$\text{Bi}_3 [(\text{V,As,P})\text{O}_4]_2 \text{O (OH)}$	yellow
16. Hechtsbergite	$\text{Bi}_2 \text{O (V}^{+5} \text{O}_4)(\text{OH})$	brown
17. Pottsite	$\text{Pb Bi H (V}^{+5} \text{O}_4)_2 (\text{H}_2\text{O})_2$	yellow
18. Wakefieldite-(Y)	$\text{Y (V}^{+5} \text{O}_4)$	brownish gray
19. Wakefieldite-(Ce)	$(\text{Ce,Pb}) (\text{V}^{+5} \text{O}_4)$	black
20. Mouanaite	$\text{Fe}_2 \text{Pb (V}^{+5} \text{O}_4)_2 (\text{OH})_2$	brownish red

21. Krettnichite	$\text{Mn}_2 \text{Pb} (\text{V}^{+5} \text{O}_4)_2 (\text{OH})_2$	reddish brown
22. Brackebuschite	$\text{Pb}_2 (\text{Mn,Fe}) (\text{V}^{+5} \text{O}_4)_2 (\text{H}_2\text{O})$	dark brown
23. Gamagarite	$\text{Ba}_2 (\text{Fe,Mn}) (\text{V}^{+5} \text{O}_4)_2 (\text{H}_2\text{O})$	deep red
24. Chervetite	$\text{Pb}_2 (\text{V}^{+5}_2 \text{O}_7)$	colorless
25. Schubnelite	$\text{Fe} (\text{V}^{+5} \text{O}_4) (\text{H}_2\text{O})$	green
26. Gottlobite	$\text{Ca Mg} (\text{V}^{+5} \text{O}_4, \text{AsO}_4) (\text{OH})$	orange
27. Nabiasite	$\text{Ba Mn}_9 [(\text{V}^{+5}, \text{As})\text{O}_4]_6 (\text{OH})_2$	dark red
28. Palenzonaite	$\text{Na Ca}_2 \text{Mn}_2 (\text{V}^{+5} \text{O}_4)_3$	wine red
29. Reppiaite	$\text{Mn}_5 (\text{V}^{+5} \text{O}_4)_2 (\text{OH})_4$	red orange
30. Fianelite	$\text{Mn}_2 (\text{V,As})_2 \text{O}_7 (\text{H}_2\text{O})_2$	red orange
31. Cassedanneite	$\text{Pb}_5 (\text{V}^{+5} \text{O}_4)_2 (\text{CrO}_4)_2 (\text{H}_2\text{O})$	red orange
32. Averievite	$\text{Cu}_5 \text{O}_2 (\text{V}^{+5} \text{O}_4)_2 (\text{Cu Cl}_2) (\text{Cs,K,Rb}) \text{Cl}$	black
33. Stoiberite	$\text{Cu}_5 \text{O}_2 (\text{V}^{+5} \text{O}_4)_2$	black
34. Fingerite	$\text{Cu}_{11} \text{O}_2 (\text{V}^{+5} \text{O}_4)_6$	black
35. Mcbirneyite	$\text{Cu}_3 (\text{V}^{+5} \text{O}_4)_2$	black
36. Lyonsite	$\text{Cu}_3 \text{Fe}_4 (\text{V}^{+5} \text{O}_4)_6$	black
37. Howardevansite	$\text{Na Cu Fe}_2 (\text{V}^{+5} \text{O}_4)_3$	black
38. Ziesite	$\text{Cu}_2 (\text{V}^{+5}_2 \text{O}_7)$	black
39. Blossite	$\text{Cu}_2 (\text{V}^{+5}_2 \text{O}_7)$	black
40. Schaferite	$\text{Na Ca}_2 \text{Mg}_2 (\text{V}^{+5} \text{O}_4)_3$	orange red
41. Cheremnykhite	$\text{Pb}_3 \text{Zn}_3 \text{TeO}_6 (\text{V}^{+5} \text{O}_4)_2$	greenish yellow
C. Vanadium in silicate and phosphate minerals		
1. Roscoelite	$\text{K}_2 \text{V}^{+3}_2 (\text{Al}_2 \text{Si}_6 \text{O}_{20}) (\text{OH,F})_4$	olive green
2. Chernykhite	$(\text{Ba,K})_{0.4} (\text{V}^{+3}, \text{Al})_{2.3} \text{Si}_4 \text{O}_{10} (\text{OH})_2$	dark green
3. Goldmanite	$\text{Ca}_3 (\text{V}^{+3}, \text{Fe}^{+3}, \text{Al})_2 \text{Si}_3 \text{O}_{12}$	deep or brownish green
4. Cavansite	$\text{Ca} (\text{V}^{+4} \text{O}) (\text{Si}_4 \text{O}_{10}) (\text{H}_2\text{O})_4$	blue
5. Pentagonite	$\text{Ca} (\text{V}^{+4} \text{O}) (\text{Si}_4 \text{O}_{10}) (\text{H}_2\text{O})_4$	blue
6. Haradaite	$\text{Sr} (\text{V}^{+4} \text{O}) (\text{Si O}_3)_2$	bright green
7. Suzukiite	$\text{Sr} (\text{V}^{+4} \text{O}) (\text{Si O}_3)_2$	bright green
8. Almbosite	$\text{Fe}_9 \text{V}_4 \text{Si}_3 \text{O}_{27}$	blue
9. Kurumsakite	$(\text{Zn,Ni,Cu})_8 \text{Al}_8 \text{V}_2 \text{Si}_5 \text{O}_{35} (\text{H}_2\text{O})_{27}$	yellow
10. Nagashimalite	$\text{Ba}_4 (\text{V,Ti})_4 \text{Si}_8 \text{B}_2 \text{O}_{27} \text{Cl} (\text{O,OH})_2$	greenish black
11. Natalyite	$\text{Na} (\text{V,Cr}) (\text{SiO}_3)$	dark green
12. Medaite	$(\text{Mn,Ca})_6 (\text{V,As}) \text{Si}_5 \text{O}_{18} (\text{OH})$	brown
13. Saneroite	$\text{Na}_{2.3} \text{Mn}_{10} (\text{V,Si}) (\text{Si}_{10} \text{O}_{34}) (\text{OH})_4$	deep orange
14. Franciscanite	$\text{Mn}_6 \text{V}_{2-x} \text{Si}_2 (\text{O,OH})_{14}$	cherry red
15. Vanadomalayaite	$\text{Ca} (\text{V}^{+4} \text{O}) \text{Si O}_4$	deep red
16. Mukhinite	$\text{Ca}_2 \text{Al}_2 \text{V}^{+3} (\text{SiO}_4) (\text{Si}_2 \text{O}_7) \text{O} (\text{OH})$	reddish brown
17. Springcreekite	$\text{Ba}_2 \text{V}^{+3}_2 (\text{PO}_4)_2 (\text{OH,H}_2\text{O})_6$	black
D. Isolated divanadate chains $(\text{V}^{+5}_2 \text{O}_6)^{-2}$		
1. Rossite	$\text{Ca} (\text{V}^{+5}_2 \text{O}_6) (\text{H}_2\text{O})_4$	pale yellow
2. Metarossite	$\text{Ca} (\text{V}^{+5}_2 \text{O}_6) (\text{H}_2\text{O})_2$	colorless
3. Munirite	$\text{Na} (\text{V}^{+5} \text{O}_3) (\text{H}_2\text{O})_2$	pearly yellow
4. Metamunirite	$\text{Na} (\text{V}^{+5} \text{O}_3)$	colorless
5. Dickthomssenite	$\text{Mg} (\text{V}^{+5}_2 \text{O}_6) (\text{H}_2\text{O})_7$	light brown

6. Delrioite	$\text{Ca Sr (V}^{+5}_2 \text{O}_6) (\text{OH})_2 (\text{H}_2\text{O})_2$	pale yellow green
7. Metadelrioite	$\text{Ca Sr (V}^{+5}_2 \text{O}_6) (\text{OH})_2 (\text{H}_2\text{O})$	yellow
8. Alvanite	$(\text{Zn,Ni}) \text{Al}_4 (\text{V}^{+5}_2 \text{O}_6) (\text{OH})_{12} (\text{H}_2\text{O})_2$	light bluish green
9. Ronneburgite	$\text{K}_2 \text{Mn (V}^{+5} \text{O}_3)_4$	reddish brown
E. Square pyramid (VO)⁺² species (excluding silicates)		
1. Minasragite	$(\text{V}^{+4}\text{O}) (\text{SO}_4) (\text{H}_2\text{O})_5$	deep blue
2. Orthominasragite	$(\text{V}^{+4}\text{O}) (\text{SO}_4) (\text{H}_2\text{O})_5$	deep blue
3. Stanleyite	$(\text{V}^{+4}\text{O}) (\text{SO}_4) (\text{H}_2\text{O})_6$	deep blue
4. Sincosite	$\text{Ca (V}^{+4}\text{O})_2 (\text{PO}_4)_2 (\text{H}_2\text{O})_5$	green
5. Barriosincosite	$\text{Ba (V}^{+4}\text{O})_2 (\text{PO}_4)_2 (\text{H}_2\text{O})_5$	green
6. Simplotite	$\text{Ca (V}^{+4}\text{O})_2 (\text{V}^{+5}\text{O}_4)_2 (\text{H}_2\text{O})_5$	dark green
F. Uranyl-divanadate (V₂O₈)⁻⁶ layer complexes		
1. Carnotite	$\text{K}_2 (\text{UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_3$	yellow
2. Tyuyamunite	$\text{Ca (UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_9$	yellow
3. Metatyuyamunite	$\text{Ca (UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_3$	yellow
4. Strelkinitite	$\text{Na}_2 (\text{UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_6$	golden yellow
5. Margaritasite	$(\text{Cs,K,H}_3\text{O})_2 (\text{UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})$	yellow
6. Fritzscheite	$\text{Mn (UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_{10}$	yellow
7. Sengierite	$\text{Cu (UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_6$	green
8. Curienite	$\text{Pb (UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_5$	yellow
9. Francevillite	$(\text{Ba,Pb}) (\text{UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_5$	yellow
10. Vanuralite	$\text{Al (OH) (UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_{11}$	lemon yellow
11. Metavanuralite	$\text{Al (OH) (UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_8$	yellow
12. Vanuranylite	$(\text{H,Ba,Ca,K})_{1.6} (\text{UO}_2)_2 (\text{V}^{+5}_2 \text{O}_8) (\text{H}_2\text{O})_4$	yellow
G. Iso- and heteropoly molecular complexes		
1. Pascoite	$\text{Ca}_3 (\text{V}^{+5}_{10} \text{O}_{28}) (\text{H}_2\text{O})_{17}$	orange
2. Hummerite	$\text{K}_2 \text{Mg (V}^{+5}_{10} \text{O}_{28}) (\text{H}_2\text{O})_{16}$	orange
3. Huemulite	$\text{Na}_4 \text{Mg (V}^{+5}_{10} \text{O}_{28}) (\text{H}_2\text{O})_{24}$	yellow orange
4. Sherwoodite	$\text{Ca (Al V}^{+4}_2 \text{V}^{+5}_{12} \text{O}_{40}) (\text{H}_2\text{O})_{40}$	bluish black
5. Phosphovanadylite	$(\text{Ba,Cs,K,Na})_x (\text{V}^{+5},\text{Al}) \text{P (O,OH) (H}_2\text{O})_{16}$	greenish blue
H. Octahedral low-valence oxides, hydroxides		
1. Montroseite	$\text{V}^{+3} \text{O (OH)}$	black
2. Paramontroseite	$\text{V}^{+4} \text{O}_2$	black
3. Haggite	$\text{V}^{+4} \text{V}^{+3} \text{O}_2 (\text{OH})_3$	black
4. Duttonite	$\text{V}^{+4} \text{O (OH)}_2$	pale brown
5. Doloresite	$\text{V}^{+4}_3 \text{O}_4 (\text{OH})_4$	brown
6. Lenoblite	$\text{V}^{+4}_2 \text{O}_4 (\text{H}_2\text{O})_2$	blue
7. Mannardite	$\text{Ba (H}_2\text{O) V}^{+3}_2 \text{Ti}_6 \text{O}_{16}$	black
I. Anhydrous oxides		
1. Schreyerite	$\text{V}_2 \text{Ti}_3 \text{O}_9$	reddish brown
2. Kyzylkumite	$\text{V}_2 \text{Ti}_3 \text{O}_9$	black
3. Berdesinskiite	$\text{V}_2 \text{TiO}_5$	black
4. Tivanite	$\text{V TiO}_3 (\text{OH})$	black

5. Coulsonite	$\text{Fe V}_2 \text{O}_4$	black
6. Magnesiocoulsonite	$\text{Mg V}_2 \text{O}_4$	black
7. Vuorelainenite	$\text{Mn,Fe} (\text{V,Cr})_2 \text{O}_4$	black
8. Nolanite	$(\text{Fe,V})_4 \text{V}_6 \text{O}_{16}$	black
9. Karelianite	$\text{V}_2 \text{O}_3$	black
10. Stibivanite	$\text{Sb}_2 \text{V O}_5$	yellow green

J. Vanadium bronzes

1. Hewettite	$\text{Ca} (\text{V}^{+5}_6 \text{O}_{16}) (\text{H}_2\text{O})_6$	red
2. Metahewettite	$\text{Ca} (\text{V}^{+5}_6 \text{O}_{16}) (\text{H}_2\text{O})_3$	brownish red
3. Barnesite	$\text{Na}_2 (\text{V}^{+5}_6 \text{O}_{16}) (\text{H}_2\text{O})_3$	red
4. Hendersonite	$\text{Ca}_{1.3} (\text{V}^{+5}_6 \text{O}_{16}) (\text{H}_2\text{O})_6$	greenish black
5. Grantsite	$\text{Na}_2 \text{Ca}_{0.4} (\text{V}^{+5}_6 \text{O}_{16}) (\text{H}_2\text{O})_4$	dark olive green
6. Straczekite	$(\text{Ca,K,Ba}) (\text{V}_8 \text{O}_{20}) (\text{H}_2\text{O})_3$	greenish black
7. Corvusite	$(\text{Na,Ca,K})_x [(\text{V}^{+4}, \text{V}^{+5})_8 \text{O}_{20}] (\text{H}_2\text{O})_4$	purplish black
8. Fernandinite	$(\text{Ca,Na,K})_x [(\text{V}^{+4}, \text{V}^{+5})_8 \text{O}_{20}] (\text{H}_2\text{O})_4$	dark green
9. Bokite	$\text{K} (\text{Al,Fe})_9 (\text{V}_{26} \text{O}_{76}) (\text{H}_2\text{O})_{30}$	brownish black
10. Bariandite	$\text{Al}_{0.6} [(\text{V}^{+4}, \text{V}^{+5})_8 \text{O}_{20}] (\text{H}_2\text{O})_9$	black
11. Navajoite	$(\text{V}^{+5}_2 \text{O}_5) (\text{H}_2\text{O})_3$	black
12. Bannermanite	$\text{Na} (\text{V}^{+5}_6 \text{O}_{15})$	black
13. Melanovanadite	$\text{Ca} (\text{V}^{+4}_2, \text{V}^{+5}_2 \text{O}_{10}) (\text{H}_2\text{O})_5$	black
14. Namibite	$\text{Cu Bi}_2 \text{O}_3 (\text{V}^{+5} \text{O}_3)$	dark green
15. Shcherbinaite	$(\text{V}^{+5}_2 \text{O}_5)$	yellow green
16. Kazakhstanite	$\text{Fe}_5 \text{V}^{+4}_3 \text{V}^{+5}_{12} \text{O}_{39} (\text{OH})_9 (\text{H}_2\text{O})_9$	brownish black

K. Aluminous layer vanadates

1. Alvanite	$\text{Al}_6 (\text{VO}_4)_2 (\text{OH})_{12} (\text{H}_2\text{O})_5$	bluish green
2. Rusakovite	$(\text{Fe,Al})_5 [(\text{V,P})\text{O}_4]_2 (\text{OH})_9 (\text{H}_2\text{O})_3$	yellow
3. Satpaeite	$\text{Al}_6 (\text{VO}_4)_4 (\text{OH})_3 (\text{H}_2\text{O})_{24}$	greenish yellow
4. Steigerite	$\text{Al} (\text{VO}_4) (\text{H}_2\text{O})_3$	yellow
5. Schroderite	$\text{Al}_2 (\text{PO}_4) (\text{VO}_4) (\text{H}_2\text{O})_8$	orange yellow
6. Metaschroderite	$\text{Al}_2 (\text{PO}_4) (\text{VO}_4) (\text{H}_2\text{O})_6$	orange yellow
7. Vanalite	$\text{Na Al}_8 \text{V}_{10} \text{O}_{38} (\text{H}_2\text{O})_{30}$	bright yellow

L. Vanadium minerals of uncertain structure

1. Pintadoite	$\text{Ca}_2 (\text{V}_2 \text{O}_7) (\text{H}_2\text{O})_9$	green
2. Rauvite	$\text{Ca} (\text{UO}_2)_2 (\text{V}_{12} \text{O}_{32}) (\text{H}_2\text{O})_{16}$	dark purplish red
3. Fervanite	$\text{Fe}_4 \text{V}_4 \text{O}_{16} (\text{H}_2\text{O})_5$	light brown
4. Santafeite	$(\text{Ca,Sr,Na,Mn})_5 \text{Mn}_2 \text{V}_4 \text{O}_{14} (\text{OH})_{10}$	black
5. Rankachite	$\text{Ca Fe V}_4 \text{W}_8 \text{O}_{36} (\text{H}_2\text{O})_6$	dark brown
6. Tomichite	$(\text{V,Fe})_4 \text{Ti}_3 \text{As O}_{13} (\text{OH})$	black
7. Uvanite	$\text{U}_2 \text{V}_6 \text{O}_{21} (\text{H}_2\text{O})_{15}$	brown, yellow
8. Vanoxide	$\text{V}_6 \text{O}_{13} (\text{H}_2\text{O})_8$	black
9. Kolovranite	hydrous Ni, Zn vanadate	yellow

FIGURE CAPTIONS

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

- # 145 Pyrite on Heulandite (x80)**
Clackamas River, Clackamas Co., Oregon
 One of the filiform crystals that form in the cavities of the basalt. The only attachment to the matrix is at lower right. Numerous bends and parallel growths are observed.
- # 143 Pyrite on Heulandite (x500)**
Clackamas River, Clackamas Co., Oregon
 A close-up view of the right-angle bend shown at top center in micrograph #145. Notice that the end is finished off smoothly and there is no evidence of any foreign material clogging the joint. The back of the continuation (extending horizontally right) is complete.
- # 158 Erionite (x100)**
Alder Creek, Wheeler County, Oregon
 Tiny clear hexagonal prisms with striated faces. The angular crystals in the background are chabazite. The cavities are often filled with an overlayer of soft, white clay.
- # 159 Erionite (x350)**
Alder Creek, Wheeler County, Oregon
 Another crystal from the same cavity, showing a close-up of the detail of the striations.
- # 337 Millerite on Quartz (x400)**
Hall's Gap, Kentucky
 Two crystals, the upper untwisted while the lower has a left-handed twist. The crystals are triangular in cross-section.
- # 142 Millerite on Quartz (x161)**
Hall's Gap, Kentucky
 Numerous wire-like crystals. The one in the foreground has a right-handed twist. Most of the others are untwisted, though some have been bent, presumably from physical damage during collecting.

CREDITS:	All micrographs	Don Howard
	Specimens:	
	#143 & 145	Charles Sweany
	#158 & 159	Larry French
	#337 & 342	William Henderson

