Growth Hillock

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Figure 1. **Specular reflection of light from a rhombohedral quartz crystal face.**

There is a fascinating world of textures and shapes on crystal surfaces that most people overlook or are unaware of. Even the flattest crystal faces have topography (more appropriately microtopography or nanotopography) with vertical dimensions of microns or even nanometers (1 nanometer = 0.000000001 meter). It is simple to observe larger aspects of the topography of crystal faces. The next time you are holding a well-formed crystal orient it so that light reflects directly off a face (fig. 1). In other words, observe the face in specular reflection. Once you have found the correct orientation you may need to rotate it slightly in different directions so that the reflection becomes a little diffuse. By following these steps, subtle features on the crystal surface will become apparent. You will see the small differences in the height or orientation of different segments of the crystal face. The surface topography may include features such as steps (or *striations*), pits, flat areas (or *terraces*), spirals, and little mounds (or *hillocks*). Although some of these features may be visible to the naked eye, many more are apparent when viewing the crystal face in specular reflection under a microscope.

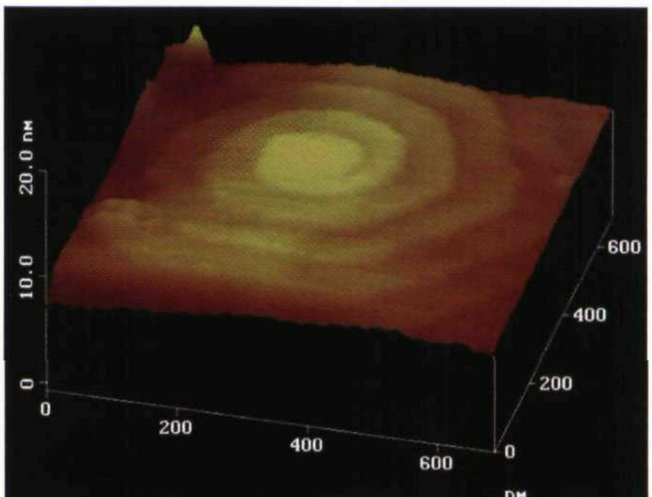

Figure 2. **Atomic force microscopy image of a growth spiral on the pinacoid (001) crystal face of a graphite from near Wlotzkas Baken, western Namibia. Two layers of carbon atoms make up the dominant steps in the image, which measure 0.66 nanometer in height. From Rakovan and Jaszczak (2002).**

The microtopography of crystal surfaces can vary greatly and can be influenced by the conditions under which the crystal formed, the mechanism of crystal growth, the degree and mechanism of dissolution, and the degree and type of physical abrasion, cleavage, or fracture. The scale of microtopographic features on crystal surfaces ranges from those with atomic dimensions (fig. 2) to dimensions of the entire crystal face (fig. 3). Surface microtopographic features are

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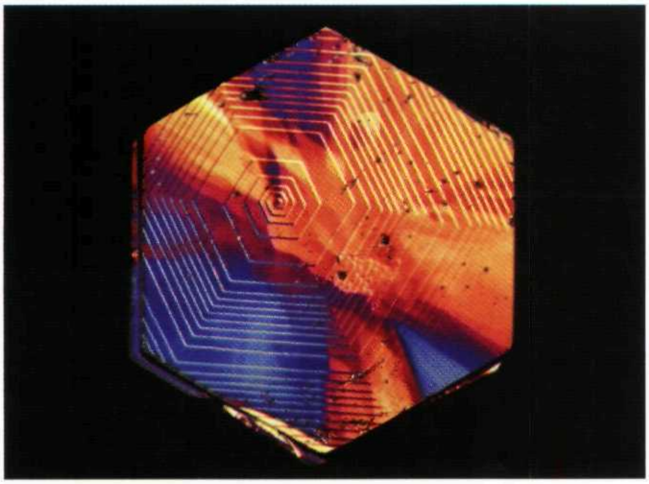

Figure 3. **Differential interference contrast microscopy image of a much larger growth spiral than in figure 2. This one is also on the (001) face of a graphite and is from Gouverneur Talc Company No. 4 quarry, Harrisville, New York. Here the steps are several microns in height, and the spiral covers the entire crystal face, which measures 3 mm across. The colors are not inherent in the sample but are an artifact of the imaging technique. John Jaszczak photo and specimen.**

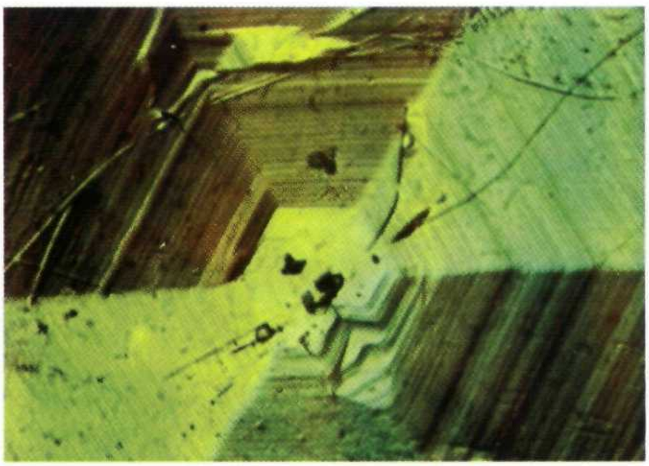

Figure 4. **Differential interference contrast microscopy image of a growth hillock with six vicinal faces on the (001) crystal face of an apatite from the Siglo XX mine, Llallagua, Bolivia. The colors are not inherent in the sample but are an artifact of the imaging technique. From Rakovan and Reeder (1994).**

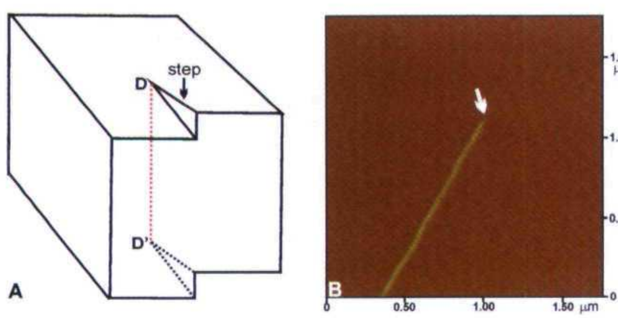

Figure 5. **(A) Schematic of a screw dislocation, D–D', creating a step where it intersects the upper crystal face. (B) Atomic force microscopy image of a dislocation step on a (001) surface of an orthoclase crystal. The arrow points to the emergence of a screw dislocation at the surface. Modified from Teng et al. (2001).**

often important clues to the conditions in which, and mechanisms by which, crystals have formed, as well as to post-growth reactions with the environment (Sunagawa 1987). Thus, surface microtopography can be a powerful tool for interpreting the growth and weathering history of minerals, as well as being aesthetically pleasing and interesting.

One common surface microtopographic feature is a *growth hillock*, a small mound on a crystal face. These can be rounded in morphology, but more frequently they exhibit a geometrical shape (fig. 4) composed of small, shallow sloping faces (called *vicinal faces* or simply *vicinals*). Vicinal faces are typically only hundredths of one degree in inclination from the main crystal face on which they form. As the name implies, growth hillocks arise during growth of a crystal. To understand exactly what they are and how they arise, we must look at some of the details of how crystals grow.

For crystals to form flat faces, atoms must be added to them during growth in a layer-by-layer fashion. This is analogous to building a brick wall. If the bricks are neatly stacked row-by-row, the result is a nice flat wall. In the growth of crystals, particularly from water or other fluids, one of the most common layer growth mechanisms is spiral growth. The potential for spiral growth occurs when a screw dislocation (the topic for another column) in the crystal intersects a crystal face. The displacement of the structure around the dislocation creates a step on the face where the dislocation emerges (fig. 5). For energetic reasons (Burton, Cabrera, and Frank 1951; Sunagawa 1984), attachment of atoms or growth units on the crystal face during growth takes place preferentially along the step. As material is added at the step, it grows out laterally. Because the step terminates at the dislocation, when it propagates laterally a new step orientation is created that itself can advance laterally as atoms are added to it. As this process continues during growth, more and more new step segments are created, resulting in a spiral microtopography (fig. 2), hence the name *spiral growth*. A good animation of spiral growth, created by Don Woodraska and John Jaszczak, can be found at http://www.phy.mtu.edu/~jaszczak/si%20seminar/screwgrow.html. As the spiral continues to grow, step segments of parallel orientation become more numerous, and the lateral dimensions of the spiral increase. Consequently, small growth hillocks present the appearance of a distinct spiral, whereas larger hillocks on the same face appear to be pyramids, and the spiral mechanism of their growth may not be obvious (fig. 6). Thus, a growth hillock is most often (see below) a growth spiral that appears to be a pyramid because of its size and the close spacing between parallel step segments. The symmetry and shape of a growth hillock is dependent on the structure of the crystal face that it forms on; hillocks with three, four, and six vicinal faces are most commonly observed.

The feature article in this issue is about fluorites from the North Pennines of England. Two characteristic features of these fluorites are the abundance of penetration twins on the [111] axis and the common and pronounced occurrence of four-sided growth hillocks on the cube {100} faces of these twinned crystals (figs. 1, 8). These hillocks are interesting in regard to their relationship to the twinning. It appears that the apex of every such hillock corresponds to the intersection of the edge of one twin component (TC1 in fig. 7) with the face of the second crystal in the twin (TC2 in fig. 7). Because of the protrusion of TC1 through the face of TC2 in figure 7, it would have been impossible for the hillock to have formed by the simple spiral growth mechanism, as TC1 would block step migration around the spiral. Instead, these hillocks are composed of discrete layers that decrease in lateral size toward the apex of the hillock.

Thus, not all growth hillocks are growth spirals, however; such hillocks are much less common. Another example of well-formed growth hillocks that could not have formed by simple spiral growth is shown in Rakovan and Jaszczak (2002) for graphite crystals from Namibia. Hillocks on the {100} faces of fluorites from the North Pennines may have developed by a mechanism similar to the "twist-tilt boundary mechanism" proposed by Frank (1949) and suggested by Double and Hellawell (1975) and Kvasnita, Yatsenko, and Jaszczak (1999) to occur in graphite. These latter studies delve into complex ideas of how some crystals grow. For a good review of the basics of crystal growth, including the spiral mechanism, see Nassau (1971a,b,c).

ACKNOWLEDGMENTS

I would like to thank John Jaszczak and Pete Richards for their reviews of this column and helpful suggestions.

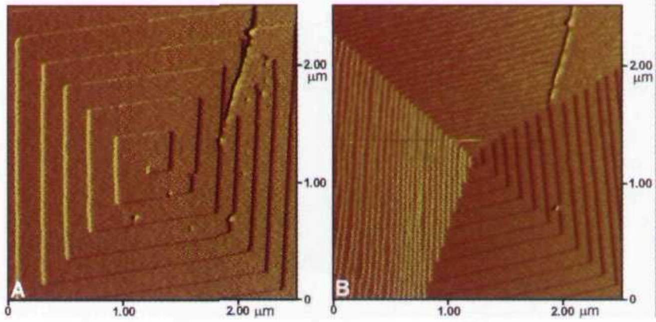

Figure 6. **Left: Atomic force microscopy image of a growth spiral on the (104) crystal face of a synthetic calcite. The image was collected in situ during growth of the crystal. Right: The same spiral after a period of continuous growth. Note that on first observation you see a four-sided pyramid or growth hillock. From Teng, Dove, and De Yoreo (2000).**

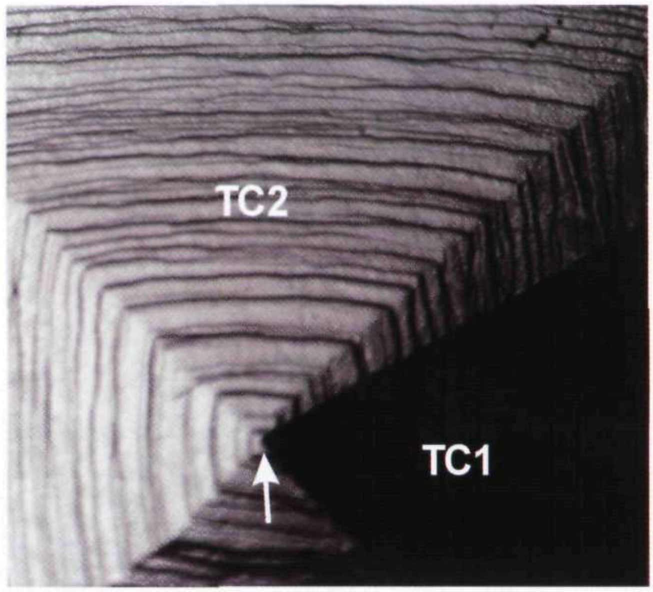

Figure 7. **A reflected light image of the cube (100) face of a "spinel"-twinned fluorite from the Rogerley mine, Weardale mining district, England. Note the four-sided growth hillock on the crystal face in specular reflection. The apex of the hillock, indicated by the arrow, lies at the point where one twin component (TC1) intersects the face of the second twin component (TC2). Also see figure 8 (left), a fluorite crystal from the Rogerley mine showing growth hillocks (fig. 1, p. 399); photo by Jesse Fisher.**

Figure 8.

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