

## How do dendrites form?

Anyone who has seen "moss agate" is familiar with the delicate branching structures that look like fossil plants. These features, called dendrites aren't plants, and the processes that form them are essentially inorganic. Dendrites are fairly common. They often form on bedding plane and joint surfaces in limestone, shale, granite and other rocks. They frequently develop during the industrial processes of making various alloys. They control the shape of some snowflakes. Most annoyingly, they form as frost on your car windshields on wintry mornings.

Dendrite refers to any mineral that grows in a delicate branching pattern. The habit is similar to arborescent, although I use tend to use the term arborescent when the branches are relatively stout, rather than moss-like. Many minerals can take on dendritic forms. These include various iron and manganese hydroxides, copper, gold and silver. How do these structures form if they aren't plants?

Dendrites are thought to form when crystallization is rapid and there is a limited amount of what chemical is formed available. These are conditions associated with disequilibrium. Frost on your windshield is a good example. The little frost flowers grow fast, but if there is too much moisture they intergrow to make a solid sheet of ice without the delicate form showing. Black dendrites on a limestone bedding plane are another example. These make what people often "pyrolusite dendrites", although recent analyses have shown them not to be pyrolusite, but instead other manganese hydroxides such as romanechite, birnessite, coronadite, and cryptomelane. At any rate, a fluid bearing manganese in solution is seeping along a bedding plane surface as little tendrils of liquid. The liquid dries out, becomes supersaturated in manganese compounds and the dendrites form fast. However since there isn't a lot of manganese in the tendrils to start with, the manganese hydroxide doesn't form a solid sheet, preserving the fractal patterns of the fast mineral growth.

Dendrite formation can be modeled artificially and studied quantitatively. This is done because understanding dendrite growth is an essential part of material science, especially alloy formation. It turns out that the shape and amount of dendrite growth affects all sorts of properties of materials - such as their flexibility, springiness, stretchiness, electrical conductivity and so forth. NASA did a crystallization experiment on a Space Shuttle mission to study the nature of alloy growth under weightless conditions. A video of growing copper dendrites can be found at <http://nepp.nasa.gov/whisker/dendrite/index.html> . Dendrites can be modeled exactly by simple computer programs in which the computer constructs what happens when sticky particles encounter another at random. The way they stick together beautifully generates dendrites. So this random relationship over time turns out to form an elegant pattern. A lot of nature works this way.

In minerals dendrite growth isn't quite random. The little atoms (particles in the above experiment) don't stick at random, but do so according to the crystalline structure of whatever mineral they are forming. Thus in ice and snow the branching often takes a hexagonal form and in copper, a lot of branching is at right angles, consistent with copper's cubic crystal structure.

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