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Cracking the problem of ice nucleation

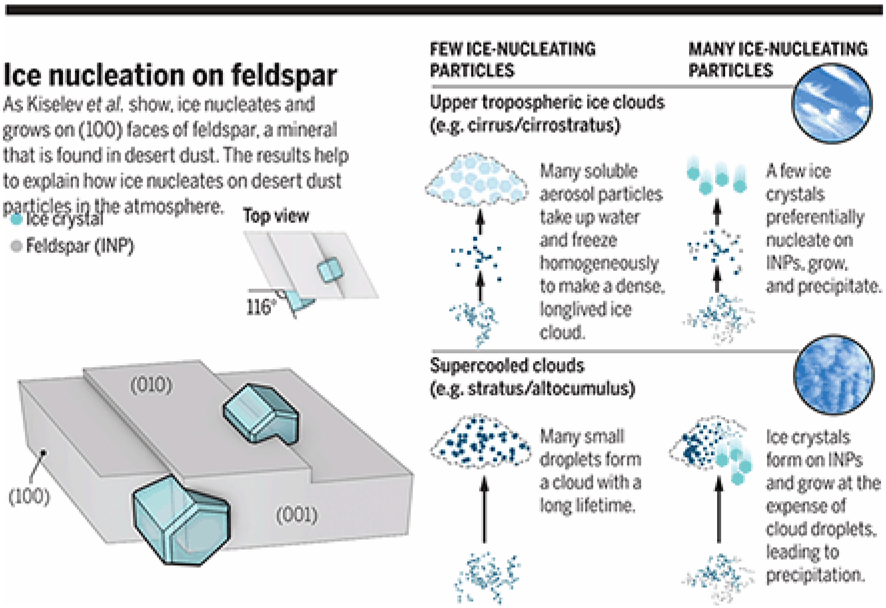
Ice-nucleating particles in Earth's atmosphere have a profound impact on cloud properties. Among the plethora of particle types in the atmosphere, certain feldspars associated with desert dust have been identified as very important ice-nucleating particles (1). As Kiselev et al. (2) show on page 367 of this issue, specific crystallographic features, which only appear in small patches in cracks or other imperfections, may be responsible for feldspar's capacity to nucleate ice (see the image). These results not only help us to understand why certain feldspars are so good at nucleating ice, but may help pave the way to a more general understanding of how ice crystals nucleate.

Ice nucleation is important for clouds throughout the atmosphere. In the upper troposphere, around the cruising altitude of a passenger jet, ice clouds form through two routes: In the absence of ice-nucleating particles, many soluble aerosol particles spontaneously freeze to form a dense cloud of small ice crystals, whereas in the presence of ice-nucleating particles, only a few ice crystals form, producing a cloud with a shorter lifetime (3) (see the figure). At lower altitudes, clouds can exist in a supercooled state, where liquid water persists in a metastable state even at temperatures below -33°C (4). In the absence of ice nucleation, clouds of small supercooled water droplets can exist for many days. But nucleation of just a few ice crystals and their rapid growth can result in the dissipation of a supercooled cloud (5, 6) (see the figure).

A whole host of different particle types in the atmosphere can serve as ice-nucleating particles (7). However, one of the most important aerosol types for ice nucleation throughout the atmosphere is mineral dust from the world's deserts, which inject thousands of teragrams (10^{12} g) of dust into the atmosphere every year.

Scientists long assumed that clay minerals were the ice-nucleating component of desert dust. However, recent studies have shown that the alkali feldspar component of desert dust is exceptionally efficient at nucleating ice (1, 8–10). This discovery has helped to better model the global distribution of desert-dust ice-nucleating particles (11). But it has remained unclear why certain feldspars are so good at nucleating ice.

Kiselev et al. now report a crucial step toward addressing this question. Using an electron microscope, they recorded movies of ice crystals growing on feldspar surfaces. They made the striking observation that most ice crystals grew with the same crystallographic orientation (see the image). This observation implies that the feldspar surface properties direct the nucleation and growth of the crystals.



Ice nucleation on feldspar

As Kiselev et al. show, ice nucleates and grows on (100) faces of feldspar, a mineral that is found in desert dust. The results help to explain how ice nucleates on desert dust particles in the atmosphere.

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Using a combination of computer simulations and analysis of the directional growth of crystals on feldspar surfaces, the authors conclude that nucleation occurs on a particular crystallographic face of feldspar, denoted as the (100) plane. The (100) face is not typically present on feldspar crystals because it is unstable. However, Kiselev et al. suggest that it may be exposed at steps, cracks, and cavities.

Although the work is a substantial step forward, open questions remain. For example, the study is directly relevant for clouds where ice nucleates from water vapor (e.g., cirrus), but not for those in which dust is immersed in supercooled water droplets (e.g., stratus). It remains to be shown whether the same sites that are responsible for nucleation from liquid water are also responsible for nucleation from the vapor phase.

Kiselev et al.'s study also advances the field of heterogeneous nucleation in general. There are very few systems where we can understand and rationalize why a material is good or bad at nucleating another material. Feldspars are a family of minerals that have similar crystal structures and compositions, but that nucleate ice with very different efficiencies (10, 12). They thus provide a means of systematically varying material properties and examining the impact of these changes on ice nucleation. This offers the possibility of deepening our understanding of why certain feldspars are so good at nucleating ice. It may also enable the identification of other materials that nucleate ice effectively. This opens the door to the design and manufacture of ice-nucleating materials for a range of applications, including artificial cloud seeding and cryopreservation.

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