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DAYBREAK HEALTH & SCIENCE

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GIFT OF LIFE
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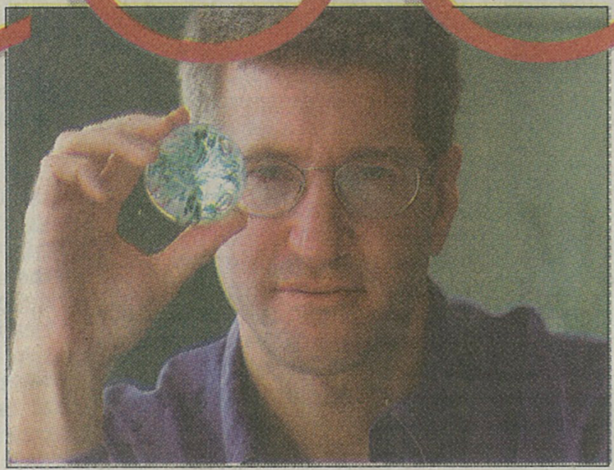
COOL MATH



Leah Hogsten/The Salt Lake Tribune
University of Utah math professor Ken Golden.

Utahn explains a key step in how sea ice maintains Earth's climate and ocean life

BY LEE SIEGEL
THE SALT LAKE TRIBUNE

A Utah mathematician used a theory of how one substance percolates through another material to explain how slush forms on the surface of Antarctic sea ice. The study provides the first theoretical explanation of a process that is crucial for maintaining Earth's climate and life in polar oceans.

"You can call me the slush king," joked Ken Golden, a University of Utah math professor and main author of the study in the current issue of the journal *Science*.

Golden's study shows certain mathematical formulas describing percolation accurately predict the abrupt transformation of solid sea ice into a permeable layer that allows saltwater and nutrients to flow upward and flood the surface.

The flooding nourishes algae, which grow in the ice and live at the bottom of the polar food chain. The flooding also forms slush that later freezes, adding new ice to the floating ice pack covering the sea around Antarctica.

"Understanding what maintains that thin ice cover — it's often only 20 inches thick — is really important for understanding the climate," said oceanographer Miles McPhee of the University of Washington's Polar Science Center. "Any knowledge that adds to our understanding of how sea-ice behavior can be described mathematically is quite valuable. That is the importance of what Ken is doing."

The Utah study "is definitely very interesting and important," said geophysicist Hajo Eicken of the University of Alaska, Fairbanks. "It is a big step forward in predicting a very difficult-to-predict phenomenon. . . . It shows you can apply the same set of mathematical formulas and make predictions about materials as different as sea ice and a conducting surface on a microchip."

The layer of ice covering Earth's polar oceans often is a solid barrier separating the sea below from the sky above. But every few days, a storm blows in, warming the top of the ice and dumping snow on it.

That triggers a sudden change: Tiny pockets of air and briny saltwater in the ice grow larger and connect with each other. The entire ice pack becomes permeable. Sea water percolates up through the ice and floods the snowy surface, creating a vast expanse of slush.

Then, as air temperatures drop again, the slush freezes, creating new ice. That maintains the polar ice pack, preventing much of the heat in ocean water from reaching the colder atmosphere and overheating Earth's

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Ken Golden collected ice data and got idea for a study on 1994 Antarctic trip.

Cool Math: Utah Professor Studies Sea Ice

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climate.

And as the slush freezes, brine — or concentrated saltwater — percolates downward and drains into the sea below. Less salty sea water flows upward, carrying nutrients that feed algae living in the ice. When the ice melts in the spring, the algae serve as the base of a food chain that nourishes all creatures in the polar seas, McPhee said.

Polar sea ice is a mixture of pure-water ice, air and brine. Scientists have been mystified for years about the sudden formation of slush atop polar ice.

They have observed that solid, impermeable sea ice becomes permeable and its surface floods and becomes slushy when it warms to 23 degrees Fahrenheit — several degrees below freezing — and when liquid brine exceeds 5 percent of the ice volume.

Yet conventional theories of how liquids and gases percolate through solids indicate the ice should contain at least 25 percent liquid brine before the salty water can percolate through the ice. And no one knew why percolation started at a below-freezing temperature of 23 degrees.

Golden's key insight was that he recognized percolation of brine through ice resembles the behavior of "compressed powders," which are not powders in the common sense, but are "composite" mixtures of large solid particles and much smaller solid particles.

Engineers trying to develop flexible materials capable of conducting electricity made such mixtures in the 1960s by combining large plasticlike polymer particles with small metal particles. One percolation theory describes how the small metal particles connect together when the mixture is compressed, allowing electricity to flow through the mixture.

Golden used the same theory — which is a set of mathematical formulas — to describe how small pockets of brine in impermeable sea ice connect with each other to make the ice permeable and allow the brine to percolate.

He found the theory perfectly predicted what scientists had long observed: Brine begins to percolate through sea ice when brine makes up 5 percent of the volume of the ice, not the 25 percent predicted by other percolation theories.

The same percolation formulas describe how electricity flows through certain semiconductors and how stealth aircraft coatings evade radar detection, Golden said.

Eicken said because sea water is warmer than polar air, the ice pack tends to melt from below. Regular flooding and formation of slush on the ice surface allow the ice pack to maintain itself, he added.

Without the ice, tremendous amounts of heat would pour from the polar oceans into the atmosphere, likely making Earth's temperature warmer than it is and probably changing weather patterns, Golden and McPhee said.

Understanding how brine flows through sea ice also is important for accurate satellite measurements of how global climate change affects the extent and thickness of polar ice. When the satellites bounce microwaves off the ice, slush can be mistaken for open water, so understanding slush formation can reduce such mistakes, Golden said. The military also wants accurate measurements of polar ice to help ships and submarines navigate, he added.

McPhee said Golden's study not only explains slush formation, but also reveals why fresh water from melting ice enters the sea as a flood each spring. The fresh melt water pools on the ice surface, then abruptly floods into the sea below when the ice reaches 23 degrees Fahrenheit and becomes permeable.

Golden conducted the new study with geophysicists Stephen Ackley of the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, N.H., and Victoria Lytle of the Australian Antarctic Division at the University of Tasmania.

The Utah mathematician performed much of the study using a handheld calculator, but the data were collected during his 1994 expedition to Antarctica aboard a U.S. research ship and during Lytle's 1995 trip on an Australian vessel. Golden witnessed brine flooding the ice surface during his 1994 trip — prompting him to conduct the new study.

Golden, who first visited Antarctica in 1980, tried to make a third trip last July. But it was aborted when fire crippled the main engine of an Australian research vessel, which drifted in the ice for three days before repairs allowed it to hobble back to its Tasmanian port.

"I was scared," Golden said, noting wind chills hit 76 degrees below zero during the day the ship was without power. "You realize how much your life depends on the functioning of this ship."