PHYSICAL CHEMISTRY

Ice niceties


GETTY

The molecules in ice crystals normally form a hexagonal lattice, which is why all snowflakes are six-sided (pictured). But on page 218, Lupi *et al.* report that the tiniest ice crystals prefer a different arrangement — a finding that has implications for climate models (L. Lupi *et al. Nature* **551**, 218–222; 2017).

The authors used computational simulations to investigate how nanoscale ice crystals form from water. They found that a molecular arrangement consisting of randomly ordered layers of hexagonal and cubic arrays is the most thermodynamically stable arrangement in crystallites of up to 100,000 molecules.

The findings disagree with the classical theory of crystallite formation, which is used to predict the rates at which ice crystallites form in the atmosphere — a variable that influences cloud formation. The authors conclude that the classical theory must be corrected to improve climate and weather forecasts. **Andrew Mitchinson**

OCEANOGRAPHY

Mixed up at the sea floor

Circulation of the ocean's densest waters modulates millennial-scale shifts in climate. Contrary to conventional wisdom, a study finds that the shape of the sea floor constrains where these waters rise towards the surface. SEE ARTICLE P.181

ANDREW L. STEWART

A network of ocean currents known as the global overturning circulation has a central role in Earth's climate[1,2]. The deepest branch of this circulation consists of cold, dense waters that originate from near Antarctica and spread northward, eventually rising towards the surface through turbulent mixing with overlying waters[3]. Over periods of hundreds to thousands of years, variations in the deep branch modulate oxygen supply and carbon dioxide storage in the deep ocean[4,5]. Yet the pathways of the circulation remain uncertain because of a paucity of measurements in the deepest parts of the ocean[3,6]. On page 181, de Lavergne *et al.*[7] report that the shape of the sea floor, combined with intensification of turbulent mixing close to the ocean bed, requires these waters to return southward at a much greater depth than was previously estimated[3,6].

The upper branch of the global overturning circulation has received particular attention because of its prominent role in heat transfer between the Southern and Northern hemispheres, and is the subject of an international monitoring effort[1]. By contrast, there have been few direct measurements of the deep branch. Oceanographers rely instead on global inverse models, which use sparse measurements of the ocean's temperature, salinity and dissolved gases to estimate the deep branch's structure[3,6].

Partly because of these observational limitations, our conception of the deep branch has changed little since 1966, when oceanographer Walter Munk proposed that these waters sink at high latitudes and rise throughout the ocean interior[8]. As they rise, the waters become less dense through turbulent mixing with lighter waters — a mechanism known as water-mass transformation. This mechanism is integral to theories of the deep branch's structure, comprehensive climate models and global inverse models[6,9].

However, the turbulent flows that facilitate mixing result from tides and other deep currents interacting with the rough sea floor, and tend to be most intense close to the bottom of the ocean[10]. Bottom-intensified mixing, combined with geothermal heating through the ocean bed, implies that water-mass transformation should be concentrated close to the sea floor[11]. In turn, this suggests a pattern of circulation that involves deep waters rising near the sea floor, in contrast to Munk's model of waters rising throughout the ocean interior[10,12] (Fig. 1).

De Lavergne and colleagues have investigated the implications of bottom-intensified turbulent mixing for the structure of the overturning circulation's deep branch. Globally, the shape of the sea floor varies gradually at depths greater than 2.5 kilometres (see Fig. 2 in the paper[7]). This allows waters that have a relatively small range of densities to access a disproportionately large fraction of the sea floor, and thereby undergo faster water-mass transformation than would otherwise occur. Using calculations that take into account bottom-intensified mixing, the authors show that the shape of the sea floor strongly favours water-mass transformation at a depth of about 4 km. Their results imply that the sea floor's

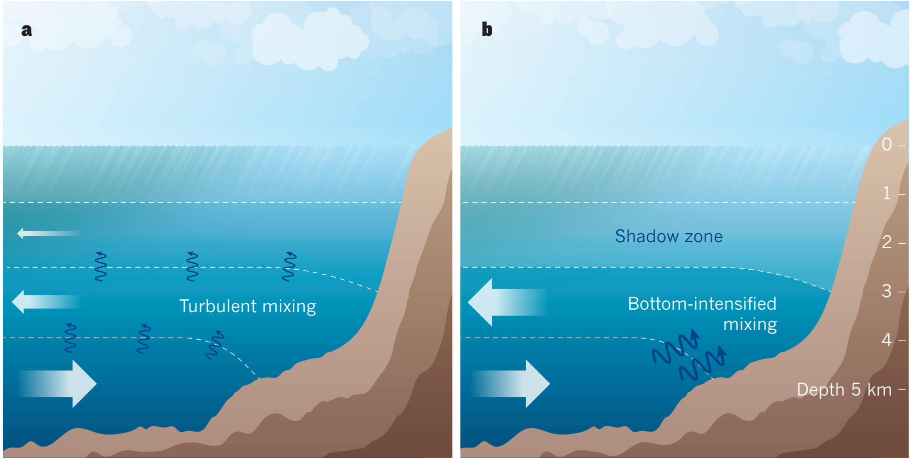

Figure 1 | A revised view of circulation in the ocean's densest waters. **a**, Historically, the ocean's densest, Antarctic-sourced waters were thought to rise towards the surface throughout the ocean interior, becoming less dense through turbulent mixing with overlying waters[6,8,9]. The dashed lines join points of constant density, the arrows indicate the flow of water and the size of the white arrows represents the volume of transported water. **b**, De Lavergne *et al.*[7] account for intensification of turbulent mixing near the ocean bottom, which implies that the densest waters rise close to the sea floor. They show that the sea floor's shape strongly favours waters undergoing changes in density at a depth of about 4 kilometres. This result suggests that the sea floor controls the separation between northward- and southward-flowing waters, and implies that there is weak circulation in a 'shadow zone' at depths of 1–2.5 km in the Indian and Pacific oceans.

shape makes the leading contribution to setting the boundary between northward- and southward-flowing waters.

The authors further argue that because the rate of water-mass transformation drops off sharply at depths shallower than 4 km, the southward-flowing component of the deep branch must be confined to depths greater than 2.5 km. This conclusion is supported by observed distributions of radiocarbon (carbon-14) and silicic acid ($Si(OH)_4$) in the ocean. For example, de Lavergne and colleagues report the presence of a 'shadow zone' of old, radiocarbon-depleted water in the northern Indian and Pacific oceans at depths of 1–2.5 km (see Fig. 3 and Extended Data Fig. 3 in the paper[7]). The deep branch is therefore much more compressed against the bottom of the ocean than has previously been estimated[3,6].

De Lavergne *et al.* make a compelling case that access to the sea floor is of paramount importance in determining how and where deep waters rise towards the ocean surface. Although direct measurements of near-bottom turbulence on a global scale are not available, the authors take a thorough approach to computing their water-mass-transformation rates. They test a wide range of parameterizations of turbulent mixing, including several that impose pronounced and realistic geographic heterogeneity, and consistently find a sharp peak in the transformation rate at a depth of about 4 km. The shape of the sea floor therefore provides a strong constraint on the overturning circulation's deep branch that is applicable to both present and past climates.

The authors' finding that deep waters change density most rapidly at a depth of 4 km is approximately consistent with studies that use global inverse models[6]. However, the proposed confinement of the deep branch below a depth of 2.5 km has mixed support from the scientific literature. In particular, the shadow zone that the authors identify in the Pacific Ocean is traversed by the overturning circulation in previous studies[3,6], but not in that of the authors. It is difficult to reconcile these views of the deep branch because the authors provide only a qualitative comparison between their revised circulation structure and distributions of radiocarbon and silicic acid. Their work therefore highlights the need for improved models of the global overturning circulation that can represent deep waters rising close to the sea floor. ■

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NEUROBIOLOGY

A genetic cause of age-related decline

Genetic variation in a neuropeptide signalling pathway regulates age-related declines in health in nematode worms. This discovery points to a mechanism that influences individual differences in ageing. **SEE ARTICLE P.198**

PATRICK T. MCGRATH

The human genome was published[1,2] in 2001, but the DNA sequence of any individual does not exactly match this reference sequence. Each individual genome contains millions of polymorphisms — variable sites that differ from the reference. Much research is dedicated to understanding how polymorphisms influence biological traits, but this remains a formidable challenge, because the underlying genetic basis of traits is typically complex. On page 198, Yin *et al.*[3] add to our understanding of the genetic basis of ageing.

The authors report that, in the nematode worm *Caenorhabditis elegans*, naturally occurring genetic variation in two genes modifies age-related declines in mating and feeding traits. They further show that this variation acts to modulate a signalling pathway that controls neuronal activity.

In classic genetics, genes that regulate traits of interest are identified by screening numerous animals that have been subject to mutation such that each harbours a different genetic change. This approach has long been used in model organisms to identify single, damaging changes that cause inactivation of a gene,