TINY WATER MOTIONS LEAD TO BIG IMPACTS

Unlocking the secrets behind salt giants in hypersaline lakes

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OUR TEAM has been conducting field observations and numerical studies in the Dead Sea to gain insight into the formation of kilometer-thick so-called *salt giants* that have been identified in the sedimentary sequences of Earth's crust. At present, the Dead Sea is the only deep hypersaline lake on Earth that allows us to study the coupled heat and salt transport processes that create such large salt deposits. As a terminal lake, its surface level has been declining at a rate of one meter annually due to the diversion of freshwater inflow from the Jordan River and evaporation from industrial ponds. This has led to a dramatic increase of the Dead Sea's salinity—now about 10 times that of the ocean—and as a result has led to the formation of salt crystals that settle onto the lake floor where they have formed a salt deposit of about four meters thick since around 1980.



Smooth salt deposit formed during winter.







The formation of these salt deposits is governed by so-called *instabilities* of the water column, which allow tiny disturbances to grow into large-scale flows. Particularly important in the Dead Sea, the *double-diffusive instability* occurs when warm and salty surface water exists above cooler and less salty water below. This situation exists during summers, when intense sunshine heats up the surface water and causes it to warm and evaporate leaving the salt behind so that it becomes warmer and more concentrated. When the lake surface is disturbed by waves or other motion, tiny parcels of warm water enter the cooler water below. Since heat diffuses more rapidly than salt, this warm water parcel cools rapidly. Colder water can hold less dissolved salt, and hence some of this parcel's salt precipitates out and forms crystals that sink to the bottom. This instability amplifies centimeter-scale disturbances and causes them to grow into meter-size *salt fingers* of warm and salty brine that descend to the cooler lower layers of the lake, where they lose heat, become supersaturated, and precipitate salt crystals that "snow" onto the lakebed. As these salt fingers grow larger and stronger, they develop yet another instability, which can lead to the emergence of *thermohaline staircases*, across which the temperature and salinity of the water jumps by a large amount over a very short distance. During winter, on the other hand, the entire water column is well mixed. Hence salt fingers do not form, but since the water is still supersaturated, it now produces fine salt crystals at all depths that form a smooth deposit (see photo on previous page). *Salt chimneys* (pictured, top right) form around discharges of underwater springs; the mixing of spring water with Dead Sea brine results in mineralization of aragonite and gypsum that form vertical chimneys, which are coated externally by halite through contact with the supersaturated Dead Sea brine.

At present, the Dead Sea is the only water body on Earth that is salty and deep enough to produce the salt fingers that generate this salt snow. Consequently, it represents a unique opportunity for researchers to study the mechanisms that create and shape thick salt deposits, such as the one that formed below the Mediterranean Sea about five million years ago when the Strait of Gibraltar closed off, cutting off the supply of water from the Atlantic Ocean, thereby creating an inland sea similar to the Dead Sea today.

The rapid lake level decline of about one meter annually also exposes vast areas of newly formed beach every year (pictured above right, bottom image) and provides lessons regarding the stability, erosion, and protection of arid coastlines under sea level change. It offers opportunities to study the natural formation of beach berms and the transport and sorting of gravel that enters the Dead Sea via seasonal streams that discharge flash floods. These transient streams display strong meandering behavior as they incise deeply into the newly exposed beach areas, and they form knickpoints as a result of the sea level fall. The setting of the Dead Sea allows us to determine the migration velocity of such knickpoints, and to test measures for protecting coastal infrastructure from their impact.

Interested readers can find additional information in an upcoming review in *Annual Review of Fluid Mechanics.*

Left: Layers of salt (halite) and sediment (mud) deposited in the past four decades. Annual layers are of ~0.1 meter thick.
Top right: Salt chimneys up to 20 meters in size. Top right, bottom image: Coastline showing annual steps of about one meter due to lake level fall.