Thermohaline Currents – Tutorial Script

Ocean currents are moving rivers of water. In this highly generalized bathtub cross-section of the ocean, the equator is in the center, the south pole to the right, and the north pole to the left; we also see three basic ocean layers: the surface layer, the deep layer, and the boundary between the two called the **pycnoline**. As discussed in an earlier video tutorial, the pycnocline is the boundary between two water layers of different density.

Surface currents are primarily caused by winds blowing across the surface of the oceans. They, therefore, happen in the surface layer. **Thermohaline currents** are caused by density differences, which are themselves caused by differences in the salinity or temperature of the water, hence the name *thermohaline*. Thermohaline currents are found in the deep layer. They move vertically due to density and then spread out horizontally to minimize pressure differences. For example, cold water at the polar ocean surface is denser than the water around it. When that water sinks, it spreads out laterally across the bottoms of all the world's oceans and becomes the deep water layer. At the poles therefore, the surface water and deep water are basically the same – same density; same temperature. They are not separated by a pycnocline. The depth profiles of these waters are therefore called **isothermal** and **isopycnal**. If they also have the same salinity, we'd call them **isohaline**. Do they? Depends on the seasons. In the polar winters, ice formation increases, leaving the surface water more saline. In the polar summers, ice melting increases, leaving the surface waters fresher. So salinity might change slightly with depth at the poles.

What about at the equator and tropics? You can see from this image that in these zones, the pycnocline is well developed. Surface waters are heated up by the strong direct sunlight in these and become quite warm. Even though the surface waters at subtropical highs have higher-than-average salinity due to high evaporation rates (as discussed in previous video tutorials), these waters are still so warm that they end up being less dense than the deep polar water that sits under them. So in the subtropics and equator, the depth profiles show that with depth, density increases, temperature decreases, and salinity decreases either a little or a lot, depending whether you're descending at the equator (only a little saltier than polar water) or the subtropics (a lot saltier than polar water).

What about at the midlatitudes? In these zones, the pyncocline comes and goes with the seasons. During the summers, the surface waters are heated up enough to separate from the deep water and stop mixing. In the winter, however, the pycnoclines disappear as the surface waters cool. The surface and deep waters mix, and the depth profiles are more isopycnal.

Why does the separation of surface and deep waters matter so much? It's a major barrier to mixing in the world's oceans, including mixing and resupply of nutrients necessary for biological productivity. When photosynthesizing autotrophs living at the ocean's surface (otherwise known as phytoplankton) die, their remains rain down to the bottom of the seafloor, where they decompose. The nutrients in their bodies are released into the water. Where pycnoclines exist, these nutrients are trapped at depth. Phytoplankton will eventually use up all available nutrients at the surface, and their populations diminish until nutrients can be added back to the area through increased river runoff or through the disappearance of the pycnocline.

In this graph, water depth is increasing as we move down the Y axis. The dashed lines represent the boundaries between water masses. Within each layer of water characteristics like temperature, salinity, and density are pretty uniform, but as each layer may have different characteristics than the one above or below it, travel across the pycnocline not only means changes in density, but it also means changes in temperature and/or salinity. In this example there are three water masses sitting atop each other, the one on top the least dense; the one at the bottom the most dense. Three layers means two boundaries or two pycnoclines. What causes the density differences? Between the top layer and the middle layer, salinity increases. The same is true between the middle and the lower water layer. Because salinity changes at each of these boundaries, these pycnoclines are also called haloclines. When we look at temperature, we see it's decreasing between the top and the middle layer and there's no change between the middle and bottom layer. Because temperature changes at the first boundary, that pycnocline and halocline is also a thermocline. However, the middle and bottom layers are isothermal, so there's no thermocline between them.

Pause now.

This picture shows cross-sections through the three major oceans and their major thermohaline currents. Each of these cross sections shows a surface layer atop a number of different deep water currents. AAIW means Antarctic Intermediate Water. It originates in the oceans north of Antarctica at about 55°S latitude and descends down below the surface waters of the Atlantic, Pacific, and Indian Oceans. It sits atop all the other thermohaline currents, which means it must be the least dense.

This birds-eye view of the surface waters around Antarctica show the origination points of the Antarctic Intermediate Water. In these zones two surface currents are converging and pushing water toward each other, making surface water pile up. Some of that water pile pushes downward (otherwise known as **downwelling**), where it can descend below the pycnocline and slide equatorward at depth. Although the Antarctic Intermediate Water is cold, it is not as cold as the water underneath it. It is also a bit fresher due to the high precipitation rates at this latitude where low pressure systems dominate.

The deepest densest water in all the world's oceans is the Antarctic Bottom Water. It is densest because it is the coldest. Its salinity and proximity to freezing temperatures allow it to cool below the freezing point of freshwater and average -1 to 1°C. The Antarctic Circumpolar Current is a surface current that isolates Antarctica from surrounding weather and current systems and allows it to get colder than almost anywhere else on the planet. That cold water then feeds the deep and intermediate waters of all the world's oceans.

Arctic Ocean waters are also isolated, but because they are trapped under sea ice most of the year and surrounded by shallow continental shelves on all sides, they are not able to enter all the world's oceans. Their primary exit is through a narrow shallow passageway between Greenland and Svalbard in the North Atlantic. After exiting, these waters sink to the bottom of the North Atlantic and spread southward until they meet the Antarctic Bottom Water, which they then ride over. Eventually these waters travel atop the Antarctic Bottom Water all the way down toward Antarctica at which point they rise up to the surface. Why? Surface currents in that region are being pulled away creating an area of surface water depletion that allows deep water to well up (otherwise known as **upwelling**). The North Atlantic Deep Water then mixes at the surface and can become part of both the Antarctic Bottom Water and the Antarctic Intermediate Water. Watch the Ocean Mixing & Pollution video tutorial to learn more about how these currents help spread and mix pollutants worldwide.

The Mediterranean Sea, south of Europe and north of Africa, contributes its own intermediate water or thermohaline current to the Atlantic Ocean. High evaporation rates in the area make that water super warm, but also super salty. That means increased density which makes it sink. A shallow sill at the opening of the sea isolates the sunken dense water and keeps the majority of it from mixing with the nearby Atlantic Ocean. When enough of it piles up to reach above the sill, it exits its basin and due to its density sinks down to about 1,000 meters depth and spreads out across the Atlantic Ocean just under the pycnocline. It sits in the Atlantic Ocean bathtub at about 40°N as a small lens of water. Imagine being a whale or submarine traveling through this area – you'd go from cold North Atlantic Deep Water, derived from the Arctic, and about 3°C, to 10 to 12°C very salty water.

The same thing happens in the Red Sea, where evaporation rates are even higher. This sea feeds an intermediate current found in the Indian Ocean, called the Red Sea Intermediate Water, which can be as warm as 23°C and much more salty. It sits as a lens of super warm super salty water within the coldest water of the world's oceans.

Let's compare the temperatures, salinities, and densities of all these thermohaline currents. In this chart, the y-axis shows temperature in °C increasing as we move upwards. The x-axis shows salinity in parts per thousand getting higher as we go to the right. Each curved line represents a specific density; the lines in the lower right are the densest; upper left, the least dense. The least dense water in this plot is the North Atlantic Central Surface Water, with salinities greater than the 35 ppt average for seawater, but temperatures warmer than most of those shown on this plot. The warm temperature is what makes it least dense, and hence surface water. Antarctic Intermediate Water is the next lowest in density. It is much colder than the surface water, but also fresher. The densest water in this picture is the Antarctic Bottom Water, followed closely by North Atlantic Deep Water. The Antarctic Bottom Water is slightly fresher than the North Atlantic Deep Water, but also much colder. Mediterranean Intermediate Water sits in the middle density position – both warmer and saltier than any of the other thermohaline currents shown in this image. But where is the Red Sea Intermediate Water? It is SO warm and SO salty that it doesn't even show up on this graph. In fact, we have to shrink the graph to see it.

Pause now.

For more information and more detail, continue on to the next video in the series.

[End credits]

<u>Ocean Circulation Series:</u>
Part 1: Thermohaline Currents
Part 2: Surface Currents
Part 3: Ocean Mixing and Pollution
Part 4: ENSO

Thermohaline Currents
Geoscience Video Tutorial
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