Without hot rock, much of North America would be underwater

A University of Utah study shows how various regions of North America are kept afloat by heat within Earth's rocky crust, and how much of the continent would sink beneath sea level if not for heat that makes rock buoyant.

Of coastal cities, New York City would sit 1,427 feet under the Atlantic, Boston would be 1,823 feet deep, Miami would reside 2,410 feet undersea, New Orleans would be 2,416 underwater and Los Angeles would rest 3,756 feet beneath the Pacific.

Mile-high Denver's elevation would be 727 feet below sea level and Salt Lake City, now about 4,220 feet, would sit beneath 1,293 feet of water. But high-elevation areas of the Rocky Mountains between Salt Lake and Denver would remain dry land.

"If you subtracted the heat that keeps North American elevations high, most of the continent would be below sea level, except the high Rocky Mountains, the Sierra Nevada and the Pacific Northwest west of the Cascade Range," says study co-author Derrick Hasterok, a University of Utah doctoral student in geology and geophysics.

"We have shown for the first time that temperature differences within the Earth's crust and upper mantle explain about half of the elevation of any given place in North America," with most of the rest due to differences in what the rocks are made of, says the other co-author, David Chapman, a professor of geology and geophysics, and dean of the University of Utah Graduate School.

People usually think of elevations being determined by movements of "tectonic plates" of Earth's crust, resulting in volcanism, mountain-building collisions of crustal plates, stretching apart and sinking of inland basins, and sinking or "subduction" of old seafloor. But Hasterok and Chapman say those tectonic forces act through the composition and temperature of rock they move. So as crustal plates collide to form mountains like the Himalayas, the mountains rise because the collision makes less dense crustal rock get thicker and warmer, thus more buoyant.

The study – published online in the June issue of *Journal of Geophysical Research-Solid Earth* – is more than just an entertaining illustration of how continents and mountains like the Rockies are kept afloat partly by heat from Earth's deep interior and heat from radioactive decay of uranium, thorium and potassium in Earth's crust.

Scientists usually attribute the buoyancy and elevation of various continental areas to variations in the thickness and mineral composition (and thus density) of crustal rocks. But Chapman says researchers have failed to appreciate how heat makes rock in the continental crust and upper mantle expand to become less dense and more buoyant.

"We found a good explanation for the elevation of continents," Hasterok says. "We now know why some areas are higher or lower than others. It's not just what the rocks are made of; it's also how hot they are."

Chapman says it will take billions of years for North American rock to cool to the point it becomes denser, sinks and puts much of the continent underwater. Coastal cities face flooding much sooner as sea levels rise due to global warming, he adds.

Why it is Important to Know How Heat Affects Elevation

The new study's scientific significance is that by accounting for composition, thickness and, now, temperature of crustal rock in North America, scientists can more easily determine how much elevation is explained by forces such as upwelling plumes of molten rock like the "hotspot" beneath Yellowstone, and places where vast areas of mantle rock "dripped" down, letting mountains like the Sierras rise higher.

The new method also will make it easier to identify areas where crustal rocks are unusually hot due to higher-than-average concentrations of radioactive isotopes.

Chapman says temperatures in Earth's crust and upper mantle often are inferred from measurements in boreholes drilled near the surface, while elevation reflects average rock temperatures down to 125 miles beneath Earth's surface. Inconsistencies in both measurements can be used to reveal the extent to which borehole temperatures are affected by global warming or changes in groundwater flow.

Elevation increases in a given area could provide notice – tens of millions of years in advance – of volcanic processes beginning to awake deep in the lithosphere, he adds.

Most Regions Would Sink, but Seattle would Soar

Some locations – sitting atop rock that is colder than average – actually would rise without the temperature effect, which in their case means without refrigeration.

Instead of its current perch along saltwater Puget Sound, Seattle would soar to an elevation of 5,949 feet. Seattle sits above a plate of Earth's crust that is diving or "subducting" eastward at an angle. That slab of cold, former seafloor rock insulates the area west of the Cascades from heat deeper beneath the slab. Removing that effect would warm the Earth's crust under Seattle, so it would expand and become more buoyant.

To calculate how elevations of different regions would change if temperature effects were removed, the researchers did not remove all heat, but imagined that region's rock was as cold as some of North America's coldest crustal rock, which still is 750 degrees Fahrenheit at the base of the crust in Canada. Here are other locations, their elevations and how they would sink if their crust had the same temperature:

-- Atlanta, 1,000 feet above sea level, 1,416 feet below sea level.

-- Dallas, 430 feet above sea level, 1,986 feet below sea level.

-- Chicago, 586 feet above sea level, 2,229 feet below sea level.

-- St. Louis, 465 feet above sea level, 1,499 feet below sea level.

-- Las Vegas, 2,001 feet above sea level, 3,512 feet below sea level.

-- Phoenix, 1,086 feet above sea level, 4,345 feet below sea level.

-- Albuquerque, 5,312 feet above sea level, 48 feet above sea level.

-- Mount Whitney, Calif., tallest point in the lower 48 states, 14,496 feet above sea level, 11,877 feet above sea level.

A Lesson from the Abyssal Ocean Depths

Chapman says it may seem paradoxical, but "the answer to questions about the elevation of Earth's continental areas starts in the oceans."

The Earth's crust averages 4 miles thick beneath the oceans and 24 miles thick under continents. The crust and underlying layer, the upper mantle, together are known as the lithosphere, which has a maximum thickness of 155 miles. The lithosphere is broken up into “tectonic plates” that slowly drift, changing the shapes, locations and configurations of continents over the eons.

Ice floats on water because when water freezes it expands and becomes less dense. Rock and most other materials expand and become less dense when heated. Hasterok says it has been well known for years that “elevations of different regions of the continents sit higher or lower relative to each other as a result of their density and thickness. Most elevation that we can observe at the surface is a result of the buoyancy of the crust and upper mantle.”

He adds that elevation changes also can stem from heating and expansion of rocks that makes them more buoyant – a phenomenon named “thermal isostasy” that explains “why the hot mid-ocean ridges are much higher relative to the cold abyssal plains.”

New ocean floor crust is produced by volcanic eruptions at undersea mountain ranges known as mid-ocean ridges. Molten and hot rock emerges to form new seafloor, which spreads away from a ridge like two conveyor belts moving opposite directions. As new seafloor crust becomes older and cooler over millions of years, it becomes denser and loses elevation. Chapman and Hasterok say there is a 10,000-foot elevation difference between the peaks of the mid-ocean ridges and older seafloor.

Given that, Chapman says he has been puzzled that differences in rock temperature never have been used to explain elevations on continents.

“Our goal was to show that temperature variations add a significant contribution, not only to the ocean floor, but also to continental elevation,” Hasterok says. “For example, the Colorado Plateau sits 6,000 feet above sea level, while the Great Plains – made of the same rocks [at depth] – are much lower at 1,000 feet. We propose this is because, at the base of the crust, the Colorado Plateau is significantly warmer [1,200 degrees Fahrenheit] than the Great Plains [930 degrees Fahrenheit].”

When You’re Hot You’re High in North America

Chapman says that in the study, he and Hasterok “removed the effects of composition of crustal rocks and the thickness of the crust to isolate how much a given area’s elevation is related to the temperature of the underlying rock.”

First, they analyzed results of previous experiments in which scientists measured seismic waves moving through Earth’s crust due to intentional explosions. The waves travel faster through colder, denser rock, and slower through hotter, less dense rock. Then they used published data in which various kinds of rocks were measured in the laboratory to determine both their density and how fast seismic waves travel through them.

The data allowed researchers to calculate how rock density varies with depth in the crust, and thus how much of any area’s elevation is due to the thickness and composition of its rock, and how much is due to heating and expansion of the rock.

Seafloor crust has the same composition and thickness most places away from the tall mid-ocean ridges, so it is easy for scientists to observe how elevations vary with ocean crust temperature. But to determine the temperature effect on continents, “we wave this wand and create a transformed continental crust that is everywhere the same thickness [24 miles] and composition [2.85 times the density of water],” Chapman says. “Once we’ve done that, we can see the thermal effect.”

That, in turn, made it possible to calculate how much heat flow contributes to elevation in each of 36 tectonic provinces – sort of “mini-plates” – of North America.

For example, the New England (Central) Appalachians Province has an average elevation of 897 feet, but if its rocky crust were cooled to that of old, colder continental crust like the Canadian Shield, the province would sit 563 feet below sea level, a drop of 1,460 feet. New York City, within that province, has an elevation listed as 33 feet. Subtract 1,460 feet and the Big Apple gets dunked 1,427 feet below sea level.

Source: University of Utah