What are the mysterious continent-sized lumps deep inside Earth?

For decades, planetary scientists have been trying to understand the origins of two colossal geological anomalies inside our planet. New insights suggest they could be leftovers from a cosmic collision

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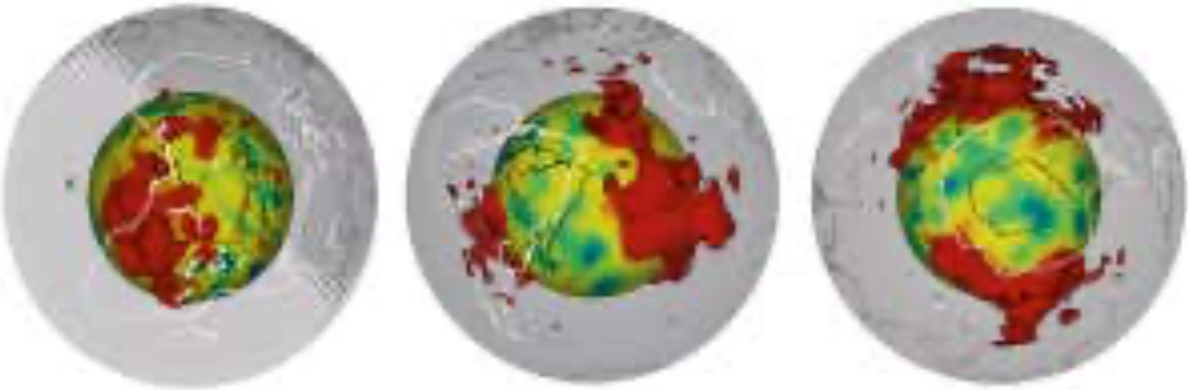
OUR planet is like a bad cake in a cosmic baking contest. On inspection of the first slice, the judges might say its layering is quite neat. The crunchy crust sits on a solid-but-squidgy mantle, which wraps around a gooey outer core. But cut another slice and they will soon see that something has gone awry. Looming inside the neat layers are two giant, messy lumps.

These two blobs are colossal. They are the size of continents, covering almost a third of the boundary between the core and the mantle. We also know that they are hotter than their surroundings. But everything else about these blobs is mysterious, from what they are made of and where they came from to how they affect our planet today.

The quest to understand them has so far verged on the quixotic. Geologists and planetary scientists are pursuing it with vigour, however, because the blobs are likely to be guarding some serious secrets. We are scrambling to get a better picture of these shadowy underworld titans, not least how ancient they are.

That is important because if they turn out to be geologically youthful, it would suggest we are living through a special epoch. There must be something particularly strange going on down there, to produce such giant oddities. Whereas "if these things are truly ancient", says Sujoy Mukhopadhyay at the University of California, Davis, "it tells us something about how our planet formed". And they might even surprise us with an answer to a bigger question, one that goes beyond parochial concerns about our own planet.

Since the late 19th century, geologists have used vibrations called seismic waves, normally generated by earthquakes, to map the interior of our planet. These waves move slowly in less dense and rigid rock, but faster through more tightly packed matter. After studying their speed in countless rock types, geoscientists sent seismic waves through Earth to see the composition of its internal structure: a solid inner core, surrounded by a liquid outer core, which sloshes molten iron and nickel around to generate its magnetic field. On top of this is the mostly solid mantle, the bulk of Earth's interior. Capping all this is the crust, an amalgam of rocks that have been erupted, broken up, squashed together and pulled apart. This is what you learned about at school.



Dr. Hiroki Ichikawa (http://dagik.org/misc/gst/index.html)

But what you may not know is that, in the 1980s, seismic waves hit on something odd: two giant clumps inside the planet's mantle, making up about 8 per cent of the mantle's volume. These lumps sit on top of the liquid core, one below the Pacific, one beneath Africa. As wide as ocean basins, they also seem to rise almost 1000 kilometres vertically, into the mantle. They are uneven and misshapen, like the waxy blobs of a lava lamp. But right from the get-go, the questions of what they are doing there, and how they got there, have confounded Earth scientists.

It is even hard to know what to call them. When seismic waves hit the blobs, they slow down. This earned them the name "large low-shear-velocity provinces", a clumsy collection of words. "It's not an acronym you can easily say," says Paul Byrne, a planetary scientist at Washington University in St Louis, Missouri. Some call them superplumes. Byrne insists "blob is fine".

Most of what we know about these blobs is through seismology, but seismology has its flaws. Temperature changes the density and rigidity of a rock, but so does its composition. "It's really hard to tell the difference between the two," says Harriet Lau, a geophysicist at the University of California, Berkeley. Most agree that the blobs are probably hotter than the surrounding mantle, but it is hard to tell if they are made of the same stuff, with lots of iron in them, or if they are packed with other minerals.

Rise and fall

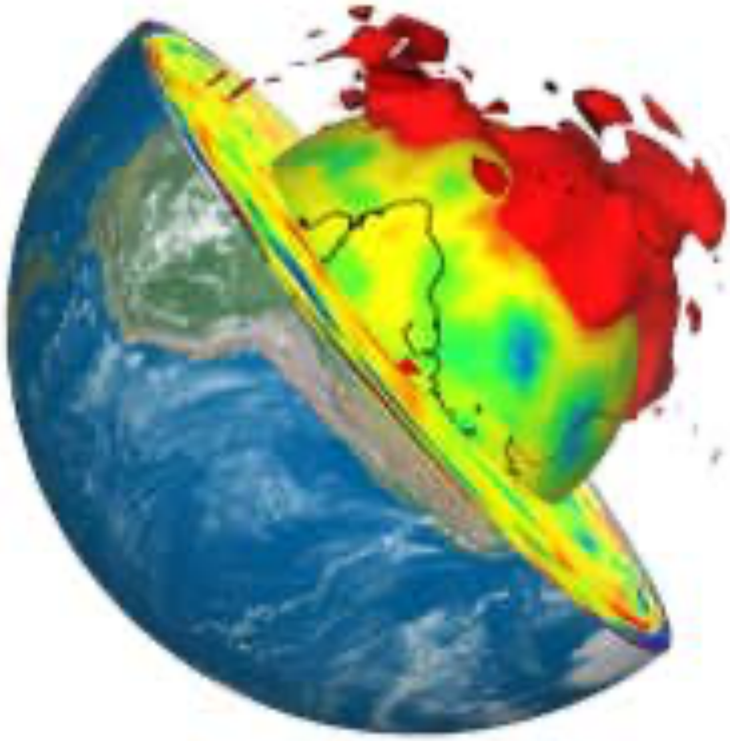
The simplest explanation is that they are made of the same material as the mantle, and are just hotter. If so, their presence may be a result of the disintegration of Pangaea, Earth's most recent supercontinent, which formed around 330 million years ago and started breaking up around 200 million years ago. Continents are part of the planet's outer shell, made of crust and some upper material in the mantle. As Pangaea broke into tectonic jigsaw pieces, prominent subduction zones – deep wounds that allow one tectonic plate to descend beneath another – opened up. For the past 250 million years, defunct chunks of tectonic plates, called slabs, have been descending into the lower mantle. Since the insides of our planet are hotter, the blobs might simply be the warm spots on the core-mantle boundary that aren't receiving any of this cooler falling material.

Then again, the simplest explanation isn't always the correct one. There is also a chance these blobs aren't just hotter, but are also made of different stuff to the rest of the mantle. If so, where they came from is a mystery. And the key to solving the mystery lies in their density, which determines what rises and falls, and gives clues about temperature and chemical composition. "Density is kind of the holy grail in this debate," says Paula Koelemeijer, a seismologist at Royal Holloway, University of London.

Working separately, Lau and Koelemeijer have both been trying to figure how dense these blobs are. In 2017, using GPS sensors to measure tidal changes to the shape of the crust caused by the blobs, Lau and her colleagues estimated the blobs to be fairly dense. But that same year, Koelemeijer and her colleagues used a type of seismic wave sensitive to deep mantle structures, to study where the blobs sit in relation to the core. They were always elevated above the rest of the core, hinting that they were less dense than the surroundings.

The two approaches "were showing us conflicting results", says Koelemeijer. To crack the case, the researchers decided to team up. Early results from their new work indicating that the blobs may be mostly light – perhaps bundles of hot, buoyant mantle plumes – but with dense plant-like roots. But until the results are published, they don't want to speculate about what this could mean for the blobs' origins.

Another important conundrum is the age of these blobs. Scientists examined lava spewed by oceanic volcanoes powered by the blobs (see "Shaping Earth"), finding odd chemistry. Some of this volcanic material seems like it "hasn't ever erupted at the surface of the planet", says Lau. This includes radioactive elements dating back to the first 50 to 100 million years of Earth's life, stuff you won't find in younger rocks. "That's a very strong argument to say there's something really ancient down there," says Mukhopadhyay.



Strangely shaped entities inside Earth rise out of the crust and into the mantle
Dr. Hiroki Ichikawa (http://dagik.org/misc/gst/index.html)

If so, that would go against the idea that plate tectonics caused the blobs. Plate tectonics began at least 3 billion years ago, but we don't know exactly when it started. If the blob matter is truly primordial, even older than the advent of plate tectonics, then where else could it have come from? One option is that this material crystallised deep within the molten soup that was the very young Earth, remaining there since.

A more intriguing suggestion, which has been gaining interest in recent years, is that the blobs come from elsewhere in the solar system.

Around 4.5 billion years ago, when Earth was just an infant, an object the size of Mars, known as Theia, is thought to have slammed into the planet. This giant impact sent molten matter screaming into orbit around our magma-covered world, material that coalesced to form the moon. This idea of how the moon formed has been around since the 1970s, and remains the leading hypothesis. In recent years, however, some have taken it further, wondering if Theia may also be the origin of the blobs. Segments of Theia's corpse could have been preserved on the fringes of Earth's core for the past 4.5 billion years.

If that's right, it would solve the origins of the Earth blobs and settle the debate over how the moon formed in one fell swoop. Except that is a tricky thing to prove. For one, Theia has been destroyed, so we can't take samples to compare with the lava created by the blobs’ mantle plumes. Another issue arises when trying to virtually reproduce the giant, primordial impact. Chemical analyses of lunar material scooped up during the Apollo era suggest that the moon is mostly made of Earth material, but simulations of the giant primordial impact create a moon mostly made from Theia. A recent study suggested you get something geologically closer to the real moon if Theia hit a magma-ocean-covered Earth, but it still isn’t a perfect replication of reality.

There are various ways we could yet get a better understanding. If Earth blobs truly are primordial, then ancient radioactive elements would give off a unique neutrino signature that, hypothetically, could be detected at the planet’s surface. But that would need the right sort of detectors placed at the perfect spots, and we aren’t there yet.

Most scientists hope to do more with the tools they already have – seismology, chief among them. Most seismometers, the devices that detect seismic waves, are on land, which makes up less than a third of Earth’s surface area. The oceans, on the other hand, are “one massive blind spot that global seismology is yet to really improve upon”, says Lau. Floating seismometers, or vast arrays of sea-floor seismometers that can peer into the planet in considerable detail, are starting to fix that. This sort of research is showing our pair of mystery objects “not as two massive blobs, necessarily”, says Koelemeijer, “but much patchier with more details.”

The plot thickened last year when Qian Yuan, a doctoral student at Arizona State University, presented intriguing new results at the Lunar and Planetary Science Conference, held online. According to a combination of his colleagues’ prior work and Yuan’s computer simulations, after Theia’s collision with our planet 4.5 billion years ago, much of the upper segment of Earth was liquefied, and Theia was largely obliterated. About 20 per cent of Theia’s mantle punched through to Earth’s lower mantle, a solid layer that for the most part didn’t join in with the sloshing molten world above. Yuan’s argument is that there, below that shield, Theia’s mantle shards remain, surviving to this very day.

That may sound far-fetched, but it would tally with the hints of primordial matter in some of the lava driven onto the planet’s surface by the blobs’ plumes. And there might be ways to test Yuan’s hypothesis.

According to Yuan, samples of the moon’s crust offer additional clues. A team of his colleagues has studied the chemistry of these rocks, and found that they suggest the lunar mantle – a stand-in for Theia’s mantle – has a preponderance of dense iron oxide. That suggests the blobs are denser than Earth’s mantle.

If so, that may explain why they still exist today: instead of being swept up by the mantle’s currents and blended into it, their high density let them sink to the base of the mantle and become stubbornly stuck there, to this day. Subducting plates may be influencing the location and composition of the blobs today, but perhaps Theia gave birth to them. That would have been a sight to behold, says Yuan. “It’s beyond my imagination.”