The *next* supercontinent

The formation of a new mega land mass is just a matter of geological time. But what will it look like, asks **Stephen Battersby**

ASIA is torn in two. The Atlantic and Pacific oceans are swallowed. Where once there were beaches, great mountain ranges judder into the skies, fusing together a scatter of separate land masses into one mighty new supercontinent. Call it… Aurica.

That's what João Duarte calls it, anyway. A geoscientist at the University of Lisbon, Portugal, he has his own distinct vision of how Earth may look 250 million years from now. He joins a band of fortune tellers gazing into the distant future, all with different ideas about how and where the next supercontinent will form, and what cataclysms might strike along the way.

The answer will determine Earth's future climate and prospects for sustaining life. But getting it right requires grappling with a machine whose workings we still understand only imperfectly: that of plate tectonics.

Earth's surface is clad in rigid rock plates – together called the lithosphere – formed of surface crustal rock laminated on to hard cold mantle rocks. Given their rigidity, it is surprising that these plates don't simply lock together, unmoving. And indeed, until about 50 years ago geologists thought that Earth's land masses were fixed, despite German geophysicist Alfred Wegener having proposed the idea of continental drift in 1915.

The creation and destruction of ocean basins makes plate motion possible. Plates move apart at mid-ocean ridges, where molten rock rises and cools to form hard, dense basalt. They move together at subduction zones, where old ocean lithosphere plunges under a neighbouring plate. As it penetrates the warmer, softer mantle beneath, it causes earthquakes and feeds volcanoes.

BRETT RYDER

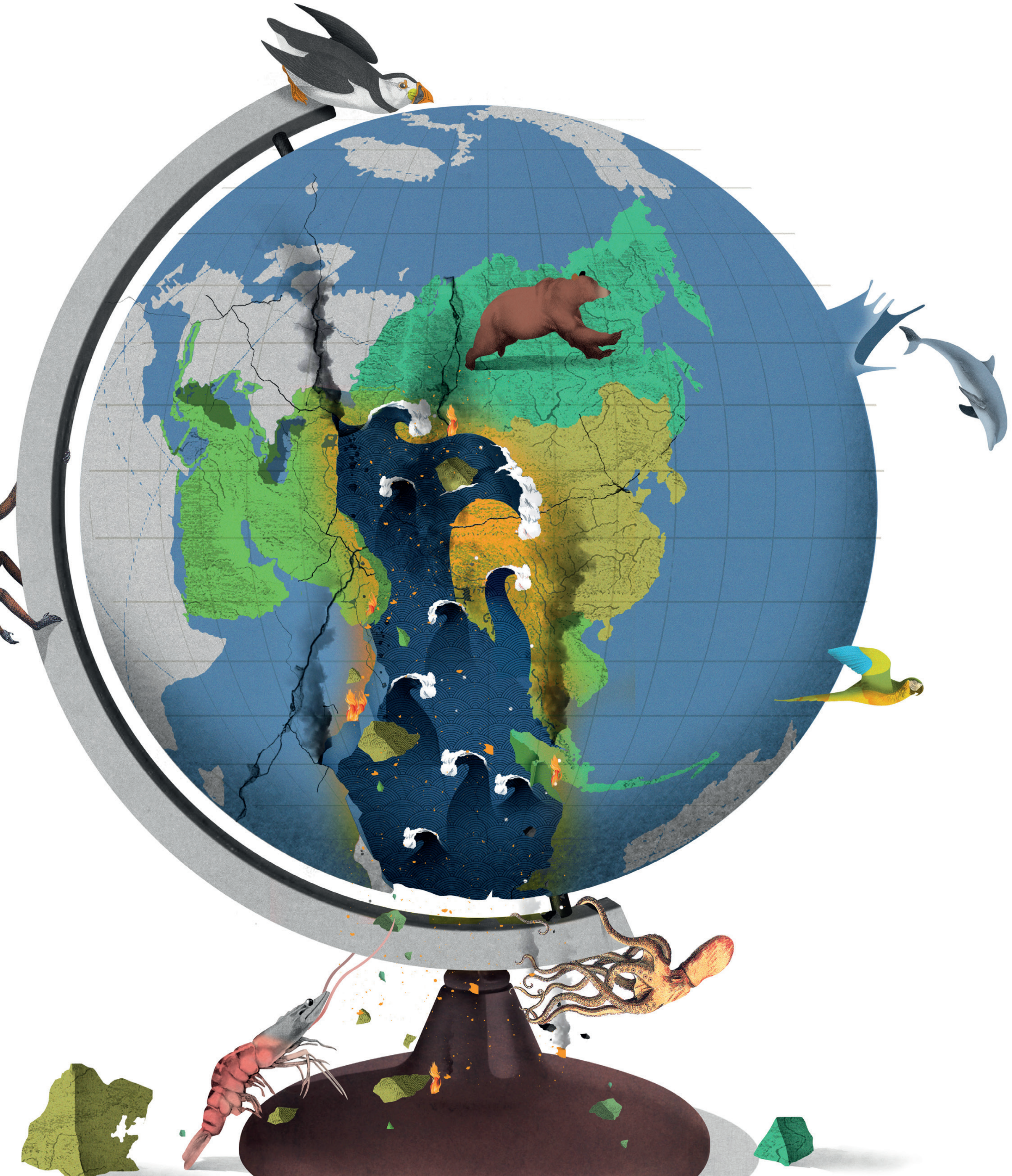
Magnetic signals recorded in sea-floor rocks, and chemical traces from the roots of ancient mountain ranges, tell us how continental drift has changed the face of Earth. They point clearly to a time 180 million years ago when all today's continents were stuck together in one vast land mass centred roughly where present-day Africa is: the supercontinent Pangaea, from the Ancient Greek for "all of Earth".

Cycling continents

We know that Pangaea came together about 330 million years ago. Before that, some consider a relatively short-lived gathering of continents near the South Pole to be another supercontinent, named Pannotia or Greater Gondwana. Another supercontinent, Rodinia, probably dominated the planet between about 1.2 billion and 700 million years ago. And about 2 billion years back it is thought there was another, known as Nuna or Columbia.

What has been will be. "For more than 20 years we have recognised that Pangaea was just the latest in a series of supercontinents," says Brendan Murphy at St Francis Xavier University in Antigonish, Canada. "That implies there will be another one in the future."

What's unclear is how that vast land mass will form. One model simply projects what's happening today into the future. The great split that broke Pangaea apart is still growing, and the two biggest land masses on Earth, Africa-Eurasia on the one hand and the Americas on the other, are on the move. The Atlantic is spreading as new rock wells up at its mid-ocean ridge, while the Pacific is shrinking, consumed by the subduction zones that surround it, the famous ring of fire.



"If you simply run plate tectonics forward in time, you would see the Pacific close and the Atlantic open," says Mark Behn at Woods Hole Oceanographic Institution in Massachusetts. In about 250 million years a new supercontinent, Novopangaea, would form on the opposite side of Earth from the original Pangaea, as the Americas and Asia crunch in around northbound Australia.

"We're still struggling to understand the rules of plate tectonics"

But it may not be that simple. "You can get to 50 million years by projecting present-day motions," says Christopher Scotese at Northwestern University in Evanston, Illinois. "To go any further, you have to understand why plates are moving, what are the driving forces, what are the rules of plate tectonics." That's something we are still struggling to do.

Since 1982, Scotese has been making maps of past and future Earth using various rules of thumb. The most important rule is widely accepted: plate tectonics is driven mainly by the pull of sinking slabs at subduction zones, with a smaller push from new rock forming at mid-ocean ridges. Work out the layout of subduction zones and ridges at any time, and you can begin to see how the continents should be tugged and nudged around.

But three kinds of cataclysmic event can change the course of this smooth voyage. A subduction zone can swallow a spreading ocean ridge, as is happening today off North America's west coast, where the Juan de Fuca ridge is slowly being consumed. Or a pair of unsinkable continents can collide, snuffing out subduction in between and forcing a great mountain range, as India and Eurasia have done to build the Himalayas.

The third possible cataclysm is much harder to fathom or predict. "The fundamental question is how you start new subduction zones," says Behn.

This has to happen somehow, or all existing subduction zones would eventually be killed by continental collisions, and place tectonics would cease altogether. In 2008, Behn and his colleague Paul Silver suggested that if a supercontinent forms simply by closing the Pacific, destroying all the main subduction zones around it, plate tectonics could shut › down for a long time. They suggest something similar may have happened in the past.

But even if that is true, evidence that plate tectonics has gone on for almost all of Earth's history, with many cycles of supercontinent formation and destruction, indicates that new subduction must start eventually, somewhere.

The most likely spot is at passive margins, for example on the Atlantic coasts of Europe, Africa and the Americas. These are places where old oceanic lithosphere, spreading out from mid-ocean ridges, meets continental crust. The oceanic lithosphere has had time to cool since formation and become denser than the rock beneath, so it wants to sink.

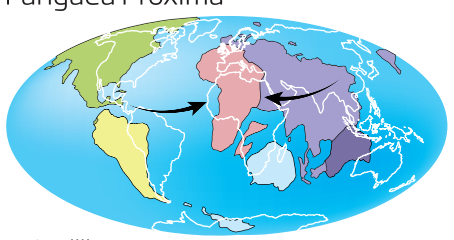
But it can't. Old, cold lithosphere rocks are hard to crack. Even the weight of kilometres-deep river sediments washed on to the passive margin from the continents isn't enough on its own. The weakening effect of water seeping into the rocks may help, but probably not enough to crack those passive margins.

Four futures of Earth

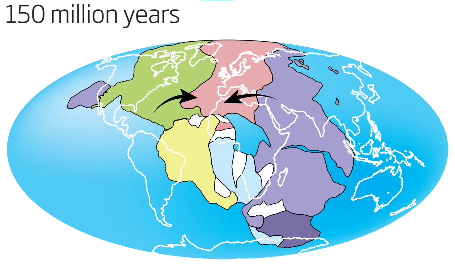
Depending on how plate tectonics plays out, four very different supercontinents could form

Africa · North America · Australia · South America · Antarctic · Eurasia · New land

Pangaea Proxima



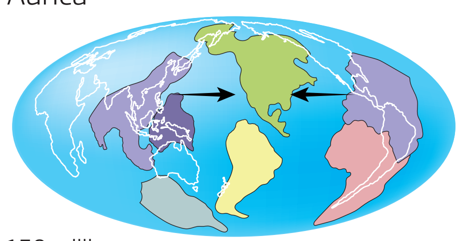
150 million years



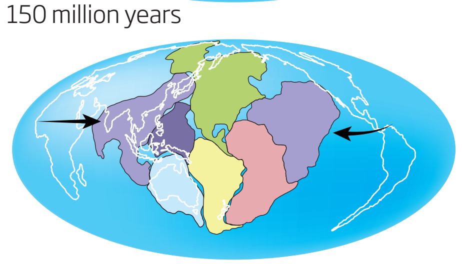
300 million years

In around 100 million years, subduction spreading along the western side of the Atlantic causes it to start closing. North America ends up fused with the west coast of Africa, with South America swinging round to end up at the south of a new supercontinent centred on the present-day Atlantic

Aurica



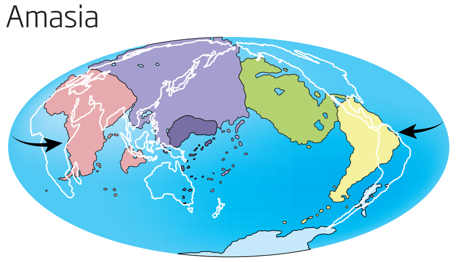
150 million years



300 million years

Subduction starts on both sides of the Atlantic, and both Atlantic and Pacific close. Eurasia splits, its western half moving westwards with Africa, and its eastern half migrating eastwards. It scoops up Australia to form a new supercontinent, centred where the Pacific is now

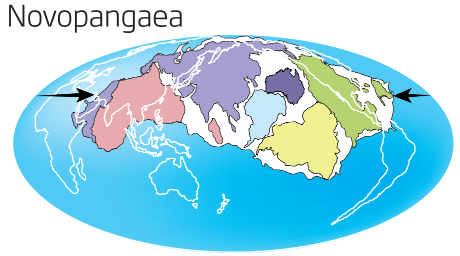
Amasia



250 million years

The Atlantic continues to open but widens more at the south. Africa moves west and Australia moves north; meanwhile South America pivots and ends up with its west coast fused to North America's east coast. Antarctica remains aloof from this straggly new supercontinent

Novopangaea



250 million years

Current tectonic movements continue, with the Atlantic widening and the Pacific consumed by subduction. South America swings westwards and northwards, scooping up Antartica and Australia; Africa rotates anticlockwise, taking western Europe with it, its current south ending up fused with Arabia

In the 1980s, Scotese suggested that subduction is catching. While it is difficult to break old ocean lithosphere from scratch, "a nick will localise stresses and tear more easily", he says.

There are already two small subduction zones in the western Atlantic: the Lesser Antilles volcanic arc near the Caribbean, and the Scotia arc in the far south off Tierra del Fuego. These both look as though they have sneaked in from old subduction zones in the Pacific ocean. Scotese suggests that eventually they will spread south and north, joining up to form a long subduction zone up the east coast of the Americas. In his projection, this will eat the Atlantic's mid-ocean ridge about 100 million years from now, and the Atlantic will start to close again. After 250 million years, the Americas will have collided with an already merged Africa and Eurasia – as will Australia and most of Antarctica – to form what Scotese calls Pangaea Proxima.

Others have come to a similar conclusion by looking at the geological record, which shows that oceans periodically open and close in something known as the Wilson cycle. In the 1980s, Thomas Worsley and Damian Nance at Ohio University suggested that the next supercontinent might form more or less in the way it split up, by closing the Atlantic.

Old and crusty

In 2012, Ross Mitchell, then at Yale University, and his group mapped out a third route. The shifting of mass associated with the formation of a supercontinent affects Earth's rotation, changing its spin axis relative to the solid body of the planet. By looking at the orientation of magnetic crystals in rocks that cooled around the time that different supercontinents existed, the team showed that Rodinia formed about 90 degrees in latitude away from the position of Nuna, and Pangaea about 90 degrees from Rodinia. Mitchell and his colleagues predict that the same thing will happen again, meaning the next supercontinent should form somewhere near the North Pole, as Asia and North America crunch together. They call the result Amasia.

Some support for this view came in 2016, when Masaki Yoshida at the Japan Agency for Marine-Earth Science and Technology in Yokosuka published a numerical simulation of mantle motion. It shows continents converging near the North Pole, guided there partly by plumes of hot, rising mantle rocks that help to keep the Pacific open in the south while it closes in the north. This makes

LINDSAY LOU/GETTY

New rock welling up at ocean ridges helps to drive plate tectonics

Amasia relatively straggly, with the Americas forming a huge promontory and Antarctica remaining aloof, unlike the compact form of the original Pangaea and the other imagined supercontinents of the future.

Duarte thinks all these models have problems. Amasia and Novopangaea would both be surrounded by large areas of ocean crust that is more than 400 million years old, which he finds implausible. In 2008, Dwight Bradley at the US Geological Survey in Anchorage, Alaska, looked at rocks around ancient passive margins and found the oldest were about 180 million years old on average, and much less than that in recent ages. Hardly any lasted 400 million years. Duarte thinks this is no coincidence. "Somehow plates in Atlantic-type oceans may have to start subducting after about 200 million years," he says.

Scotese's Pangaea Proxima does not have the old-crust problem: the Pacific could in theory stay open for many hundreds of millions of years with new crust constantly being generated and destroyed. But Duarte considers this improbable too, because ridges such as the Juan de Fuca are already being subducted. "It may not be very likely that new ones form in the middle of the oceanic plates where they are cold and strong," he says.

Duarte agrees with Scotese that subduction may spread like a virus, a process he calls invasion. He has found evidence that subduction is beginning to invade the Atlantic's eastern margin, off the coast of Portugal, where forces generated by the remnants of an ancient subduction in the Mediterranean are helping to create new faults in the ocean floor.

In Duarte's model of Earth's future, published last year, subduction will spread along both sides of the Atlantic within a few tens of millions of years, and the ocean will begin to close. But the Pacific will keep on closing, too, meaning something else has to give. That something is Asia. A rift cuts across the continent, from the Indian ocean up to the Arctic, as the Himalayan Plateau

> "Our distant cousins will be shaped by a strangely shaped world"

collapses under its own weight. A new ocean opens up, and the eventual outcome is a new supercontinent with the two halves of Asia on the outside and American and Australia at its core – hence Aurica.

Nice try, says Scotese. "Trying to close the Atlantic and Pacific – I think that's original." But suggesting a subduction zone on the eastern as well as the western side of the Atlantic actually makes things more difficult, he says, because that could preserve the mid-Atlantic ridge. "To close the ocean you have to subduct the ridge – but if you have subduction all around the ocean, the ridge can stay in the middle and supply crust to both sides."

The proponents of each idea are keen to stress that the future is uncertain, and that their own model is just one option (although of course the most likely one). Whoever is right, our distant cousins will have to adapt to a strangely shaped world, and will in turn be shaped by it. "The whole Earth system is ultimately controlled by plate tectonics," says Scotese. As continents move through different climate zones, they cause new problems for existing life forms and create opportunities for others. Extreme volcanism can also cause or at least contribute to mass extinctions, as in the vast outpouring of lava that formed the Deccan Traps in India about 65 million years ago. This changed the global climate and may have put the dinosaurs under serious stress, before a meteorite provided the knockout.

Driving forces

Climate may differ wildly between different supercontinent scenarios, affecting Earth's habitability. Amasia, near the North Pole, might gather a massive ice cap. Novopangaea could be similar to original Pangaea, which may have seen extremes of weather, with a vast interior desert and a seasonal "mega-monsoon". Or if plate tectonics were to shut down for a while, that would radically affect the atmosphere. Volcanoes would cease to pump out carbon dioxide, and the planet might enter a severe ice age. We could model the climate on each hypothetical supercontinent – "but that is building a house of cards then building balconies on your house of cards," says Scotese.

Earth's future depends on what forces really drive the motion of the continents, and that remains the real unknown. The only way we can cut through the profusion of possibilities is to make plate tectonics more quantitative, says Duarte. "To make substantial progress we need more observations of the Earth's interior," he says. "For example, there are barely any permanent seismometers on the bottom of the oceans." We could also use neutrinos from the sun to probe the planet's interior, he suggests. Certainly more powerful models that can capture geochemical processes on scales large and small are needed.

So trying to gaze into Earth's distant future may help us to understand the inner workings of our complex and opaque world today. But important though that is, it's not the real motivation for sketching out the next supercontinent, 10 million generations removed. "It's for fun," says Duarte. ■

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