IT COULD HAPPEN ONE NIGHT

CATASTROPHES FROM THE PAST WILL STRIKE AGAIN — WE JUST DO NOT KNOW WHEN.

BY NICOLA JONES

One hundred thousand years ago, a massive chunk of the Mauna Loa volcano cracked away from Hawaii and slid into the sea, launching a wave that rose as high as the Eiffel tower up the slopes of a nearby island. That mega-tsunami was not an isolated incident: the past 40,000 years have seen at least ten gigantic landslides of more than 100 cubic kilometres in the North Atlantic ocean alone, each capable of producing waves tens to hundreds of metres high. Another is bound to happen sometime — although whether it will strike tomorrow or 10,000 years from now is anyone's guess.

This week, the World Economic Forum published its 2013 global risks report, which includes a section, produced in collaboration with *Nature*, on X factors: low-probability, high-impact risks resulting mainly from human activity (see go.nature.com/outhzr). But the natural world holds unpredictable threats as well. The geologic record is peppered with evidence of rare, monstrous disasters, ranging from asteroid impacts to supervolcanoes to γ-ray bursts. *Nature* looks into some of the life-shattering events that Earth and the broader Universe could throw our way.

DEATH BY VOLCANO

Earth is now in the middle of a flare-up of supervolcanic activity[1]. Over the past 13.5 million years, no fewer than 19 giant eruptions have each spewed more than 1,000 cubic kilometres of rock — enough to coat an entire continent in a few centimetres of ash and push the planet into 'nuclear winter'. One of the most recent such eruptions, of Toba in Indonesia 74,000 years ago, was such a catastrophic event that some scientists have blamed it for starting the last ice age and slashing the human population to about 10,000 people. One estimate[1] suggests that there is a 1% chance of a super-eruption in the next 460–7,200 years.

The four youngest, most active supervolcanic systems in the world are Toba, Campi Flegrei in Italy, Yellowstone in the northwestern United States and Taupo in New Zealand. All four systems are being monitored for groundswell and seismic swarms — clusters of small earthquakes that can signal moving magma — and all occasionally show these warning signs. But no one knows whether the result of each flare-up will be a small squirt of steam or — much more hazardous — a mega-eruption of lava. "If something were brewing, we would get warning hours, days and months ahead," says Shan de Silva, a volcanologist at Oregon State University in Corvallis. "But how big it's going to be, we don't have a handle on."

To help answer these questions, scientists are now drilling into the heart of one of the top contenders for the next blow-up: the Campi Flegrei caldera, a crater that is 13 kilometres wide and includes the city of Naples. Since 1969, the ground at Campi Flegrei has bulged upwards by as much as 3.5 metres, and researchers are eager to find out whether the culprit is underground steam or a pool of magma. Previous bouts of volcanic activity in the caldera came after the ground surface had swelled up by several metres or more[2], and researchers think that major activity could occur within the next few decades or centuries. To investigate the risk, scientists at Campi Flegrei plan to drill more than 3 kilometres into the crater, despite concerns from some researchers that the drilling could trigger earthquakes or an explosion.

One goal is to look at the magma pool beneath the crater: the shallower and more molten it is, the greater the chances of a super-eruption. Characterizing such pools through seismic studies is hard, and the range of error is huge. "We really are groping in the dark," says de Silva. Scientists estimate that 10–30% of the magma under Yellowstone, for example, is liquid — shy of the 50% thought to be needed for super-eruption. But pockets of molten magma in the chamber could still cause eruptions several-fold larger than the 1980 blast from Mount St Helens in Washington state, warns Jacob Lowenstern, head of the Yellowstone Volcano Observatory for the US Geological Survey in Menlo Park, California.

The effort to drill into Campi Flegrei and measure features such as temperature and rock permeability should help researchers to interpret seismic-imaging studies of magma pools, says Lowenstern. "If we want to be able to successfully image Earth, we occasionally need to make a few strategic incisions into the patient," he says. As for the dangers of drilling, Lowenstern is convinced that the project will have minimal impact. "It's like a pinprick on an elephant," he says. The Campi Flegrei team finished an initial 500-metre test well in December 2012 without incident. And seismologists safely drilled a hole of similar size into the Long Valley caldera in California — a supervolcano site that erupted 760,000 years ago and holds the same killer potential as Yellowstone.

Until more is learned about these systems, societies must accept that the threat of a super-eruption is real, yet remote. Lowenstern says that although the chances of one happening this year are tiny, "it is theoretically possible".

DEATH BY FUNGUS

Although viruses and bacteria grab more attention, fungi are the planet's biggest killers. Of all the pathogens being tracked, fungi have caused more than 70% of the recorded global and regional extinctions[3], and now threaten amphibians, bats and bees. The Irish potato famine in the 1840s showed just how devastating such pathogens can be. *Phytophthora infestans* (an organism similar to, and often grouped with, fungi) wiped out as much as three-quarters of the potato crop in Ireland and led to the death of one million people.

Potato blight is still a threat: 13_A2, a highly aggressive strain of *P. infestans*, is now rampant in Europe and North Africa. Across the globe, *Phytophthora* causes some US$6.7 billion in annual damages, according to a 2009 estimate[4]. Sarah Gurr, a plant pathologist at the University of Oxford, UK, estimates that the worst theoretical potato infestation would deprive 1.3 billion people of food each year. Other major staple crops face similar threats, such as rice blast (*Magnaporthe oryzae*), corn smut (*Ustilago maydis*), soya bean rust (*Phakopsora pachyrhizi*) and wheat stem rust (*Puccinia graminis*). The stem-rust superstrain Ug99 has in recent years slashed yields in parts of Africa by as much as 80%.

If all five crop staples were hit with fungal outbreaks at the same time, more than 60% of the world's population could go hungry, says Gurr. "That's apocalyptic", but unlikely, she says — "more of a James Bond movie". David Hughes, a zoologist at Pennsylvania State University in University Park, adds that terrorists could use fungi to wreak havoc by targeting economically important crops. In the 1980s, for example, a possibly deliberate infection wiped out cacao crops in northern Brazil, changing the country's demographics and ecology as people moved from

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unproductive farms to the cities and cleared more rainforest. "If you wanted to destabilize the world, you could easily introduce rubber blight into southeast Asia," he says, which would trigger a chain reaction of economic and political effects.

Modern agriculture has exacerbated societies' vulnerability by encouraging farmers to plant the same strains of high-yield crops, limiting the variety of resistance genes among the plants, says Gurr. "We've skewed the arms race in favour of the pathogen," she says. "That's why we're on the brink of disaster."

Researchers estimate that there are 1.5 million to 5 million species of fungi in the world, but only 100,000 have been identified. Reports of new types of fungal infection in plants and animals have risen nearly tenfold since 1995 (ref. 3). Gurr suggests that climate change might be a culprit.

Humans have cause for concern as well. In the past decade, a tropical fungus called *Cryptococcus gattii* has adapted to thrive in cooler climes and invaded the forests of North America's Pacific Northwest. By 2010, it had infected some 280 people, dozens of whom died. Although fungi are not spread as easily from person to person as viruses, for example, and anti-fungal agents can effectively tackle most infections, there are still reasons to worry. Fungi continue to evolve, and once they are established in an ecosystem, they can be almost impossible to wipe out.

Given these trends, experts say that fungi have not received enough attention from researchers and governments. "I'd be very surprised if an abrupt fungal infection killed a large swathe of people. But it's not impossible," says Matthew Fisher, an emerging-disease researcher at Imperial College London. "Complacency is not a recommended course of action."

A GIANT SOLAR FLARE COULD KILL HUNDREDS OF MILLIONS AND SET US BACK 150 YEARS.

DEATH FROM ABOVE

The heavens hold plenty of threats. The Sun occasionally launches outsize solar flares, which fry electricity grids by generating intense currents in wires. The most recent solar megastorm, in 1859, sparked fires in telegraph offices; today, a similarly sized storm would knock out satellites and shut down power grids for months or longer. That could cause trillions of dollars in economic damage.

A solar flare some 20 times larger than that may have hit Earth in 774, according to Adrian Melott, a cosmologist at the University of Kansas in Lawrence, and Brian Thomas, an astrophysicist at Washburn University in Topeka, Kansas. "That's not an extinction event," says Melott, "but for a technological civilization, it could kill hundreds of millions of people and set us back 150 years." Fortunately, there are ways to mitigate this worst-case scenario should it occur: engineers can protect the grid with fail-safes or by turning off the power in the face of an incoming blast.

Next up the scale of disaster magnitude is a large comet or asteroid strike. Sixty-five million years ago, an asteroid 10 kilometres wide hit Earth and triggered the end-Cretaceous mass extinction; 2-kilometre rocks, thought to be capable of causing extinctions on a smaller scale, smack the planet once or twice every million years. Astronomers are hard at work tallying and tracking asteroids in Earth's vicinity, and scientists are investigating ways to divert any real threats that might materialize.

A far rarer danger — and one that could not be avoided — is the blast of radiation from a nearby γ-ray burst. Perhaps the most frightening of these celestial explosions is the 'short-hard' γ-ray burst, caused by the violent merger of two black holes, two neutron stars or a combination. If one such blast were directed at Earth from within 200 parsecs away (less than 1% of the distance across the Milky Way), it would zap the globe with enough high-energy photons to wipe out 30% of the atmosphere's protective ozone layer for nearly a decade[5]. That sort of event — expected once every 300 million years or so — would double the amount of ultraviolet (UV) light reaching the ground and scorch phytoplankton, which make up the base of the ocean's food web.

Astronomers have no way of knowing whether such a rare event is imminent. Neutron stars are small and dark, so there is no catalogue of those within striking distance. "We wouldn't see it coming," says Thomas. In as-yet-unpublished work, he estimates that such an event could cause a 60% increase in UV damage to crops, with up to 60% reduction in crop yields.

From a distance of about 2,000 parsecs, 'long-soft' γ-ray bursts — which result from the collapse of massive stars — could also cause extinctions. But these events are rarer than short-hard bursts, and easier to spot in advance because they come from larger, brighter stars. The two-star system WR 104 is some 2,500 parsecs away from Earth, and is far enough along in its life cycle that it is expected to explode some time in the next few hundred thousand years — although the beam from the burst is unlikely to hit Earth.

It is possible that a γ-ray blast has hit the planet before. Melott, Thomas and their colleagues have suggested that the mass extinction at the end of the Ordovician period, 440 million years ago, could have been triggered by a γ-ray blast that wiped out some species through UV exposure and killed off others by creating a sunlight-blocking haze of nitrogen dioxide[6]. This would explain why some species went extinct before the globe cooled during that period, and it fits the extinction pattern, which shows that among marine organisms, the greatest toll was on plankton and other life in the upper part of the ocean.

Thomas says that none of these potential disasters is keeping him up at night. He does, however, "have some canned food in the basement" — a prudent backup in the event of any disaster.

DEATH BY WATER

Eight thousand years ago, sediments covering an underwater area the size of Scotland slipped from their moorings off the west coast of Norway and raced along the sea floor. The Storegga slide triggered a tsunami that ran at least 20 metres up the nearby Shetland Islands, and probably wiped out some coastal tribes as it clobbered shores around northern Europe. The scar it left on the ocean floor stretches nearly 300 kilometres. "It's absolutely enormous, and I'm not using the word 'enormous' lightly," says Peter Talling, a sedimentologist at the University of Southampton, UK, who is leading a project to assess the country's risk of similar slides.

The United Kingdom is not the only country concerned about giant submarine landslides. "There are definitely areas that have potential," says Uri ten Brink, a geophysicist at the US Geological Survey in Woods Hole, Massachusetts, who conducted a 2008 study of possible sources of tsunamis on the US east coast, where some nuclear power plants are within striking distance of such waves. "There are far larger piles of sediment around today than Storegga ever was," ten Brink says, including deposits along the coast of southern Alaska and off the Amazon, Niger and Nile river deltas. Smaller slides are more probable and can still have a huge local impact — and they often strike without warning. In 1998, a relatively small (magnitude-7) earthquake triggered an underwater slide that launched a 15-metre-high tsunami into Papua New Guinea, killing 2,200 people.

Researchers say that it is hard to quantify the threat of marine slides, particularly the giant ones. "There is so little information about events that happen so rarely," says ten Brink. "We just have to learn as much as we can." ■ SEE EDITORIAL P. 134

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