impact of their work."

How the Mauna Kea stand-off plays out could affect astronomical research in other locations and other fields of science around the world, she says.

Astronomers confronted this new reality this month, when thousands of them attended a meeting of the American Astronomical Society in Honolulu. The conference featured many sessions on Hawaiian culture and astronomy and saw anti- and pro-TMT demonstrations. "It's an industry that is congruent with our culture as explorers," said Malia Martin, a Native Hawaiian who supports the TMT, as she waved a Hawaiian flag outside the convention centre.

Changing course

The fight over the TMT has become a symbol of historical inequities in Hawaii, notably the seizure of lands from Native Hawaiians before and after the United States annexed the islands in 1898. "This is a political issue rooted in historical injustice," says Greg Chun, executive director of Mauna Kea stewardship for the University of Hawaii, which manages the mountaintop land on which the observatories sit. Homes and vehicles across the islands often fly the Hawaiian flag upside down as a symbol of protest against the US government.

TMT officials have tried to address some of these long-standing issues, in part by establishing educational and workforce-training programmes for local residents. But the project, which is expected to cost its partners in the United States, India, China, Japan and Canada more than US$1.4 billion, has not been able to proceed with construction. Both times it tried – first in 2015, and then again in July 2019 – the *kia'i* blocked the road to Mauna Kea's summit.

The 13 existing telescopes atop the mountain face an uncertain future. The University of Hawaii has committed to removing five as a condition of the permit to build the TMT. The three chosen so far are among the oldest telescopes on Mauna Kea.

The future of the rest – which include some of the world's most scientifically productive observatories, such as the Keck and Canada-France-Hawaii telescopes – is assured only until 2033. Astronomy will end on Mauna Kea after that if the state government does not renew the university's master lease on the mountaintop, which governs all the telescopes' operations.

From her spot at the base of the mountain, Wong-Wilson says she is open to the possibility of the lease being renewed. "There is space for discussion about improving the way astronomy remains upon our mountain," she says. "But attitudes have to change. Astronomers look at us like we're the bad guys, like we're intruding on their space. It's quite the opposite: they're in our space."

Cutting-edge astronomy should continue within the footprint of the existing observatories, says Rosie Alegado, an oceanographer at the University of Hawaii at Manoa. She helps lead a group of Native Hawaiian scientists who this month called for an immediate halt to the TMT project while organizers seek "informed consent" for the telescope to move forward (S. Kahanamoku *et al.* Preprint at https://arxiv.org/abs/2001.00970; 2020). They also called for Indigenous people to have more overall input into decisions involving the mountain. "I feel like astronomy on Mauna Kea could represent an example of when science got off course, but we course-corrected and came back stronger than ever," she says.

> **"Gone are the days of the scientific conceit of being separate from the community."**

Momentous decision

How that might happen remains to be seen. If the TMT moves to the Canary Islands, it will take with it money it would otherwise spend to help maintain the infrastructure for astronomy on Mauna Kea, such as the road to the summit. The move could also shift the focus of TMT partners, a few of whom operate some of the existing telescopes, away from Hawaii.

State and local governments have brokered a detente between TMT officials and the *kia'i* until the end of February. Representatives of various groups are meeting to try to hammer out some sort of agreement for whether and how the TMT might proceed on Mauna Kea.

But the clock is ticking. The telescope needs funding from the US National Science Foundation to keep moving forward. To get it, the project would need to be ranked highly in the next 'decadal' survey of priorities for US astronomy, which scientists are compiling. Results are expected in early 2021. The TMT might not get a high ranking if it can't show a clear path to construction – which means that the issues with Mauna Kea need to be sorted out, or it needs to move to the Canaries.

For Dempsey, the debate has pushed long-simmering disagreements over science and land rights to the fore. "I'm kind of glad in some ways that we've been forced into this conversation," she says. "We didn't do enough creative things in our local community in Hawaii until we were forced to – by people saying that this is not okay."

SUPERCOMPUTER SCOURS FOSSIL RECORD FOR HIDDEN EXTINCTIONS

Palaeontologists have charted 300 million years of Earth's history in breathtaking detail.

By Ewen Callaway

Palaeontologists have a fuzzy view of Earth's history. An incomplete fossil record and imprecise dating techniques make it hard to pinpoint events that happened within geological eras spanning millions of years. Now, a period that saw a boom in animal complexity and one of Earth's greatest mass extinctions is coming into sharp focus.

Using the world's fourth most powerful supercomputer, Tianhe II, a team of scientists based mostly in China mined a fossil database of more than 11,000 species that lived during the period from around 540 million to 250 million years ago. The result is a history of life during this period, the early Palaeozoic era, that can pinpoint the rise and fall of species during diversifications and mass extinctions to within about 26,000 years (J.-x. Fan *et al.* *Science* **367**, 272–277; 2020).

"It is kind of amazing," says Peter Wagner, a palaeontologist and evolutionary biologist at the University of Nebraska–Lincoln, who was not involved in the work. Being able to look at species diversity on this scale is like going from a system where "people who lived in the same century are considered to be contemporaries, to one in which only people who lived during the same 6-month period are deemed to be contemporaries", he wrote in an essay accompanying the study (P. Wagner *Science* **367**, 249; 2020).

Such a view, Wagner adds, will help scientists to identify the causes of mass extinctions – such as the event at the end of the Permian period, some 252 million years ago, that wiped out more than 95% of marine species – as well as understand less dramatic species die-offs

SHUTTERSTOCK

Trilobites disappeared from the fossil record during a mass extinction 252 million years ago.

and rebounds that have been hard to uncover because of gaps in the fossil record. An understanding of these processes could reveal parallels to the planet's current loss of biodiversity.

Patchy record

Most organisms in Earth's history didn't leave fossils, and scientists have identified only a tiny fraction of those that did. As a result, it can be hard to tell whether changes in the fossil record mark real shifts, such as mass extinctions, or are simply caused by a lack of fossil finds.

In the 1960s, palaeontologists began analysing the fossil record systematically, revealing multiple mass extinctions and periods during which life flourished. But these and later efforts could usually pinpoint biodiversity changes to within only about ten million years, because fossils were lumped into relatively long geological periods and analysed en masse.

To improve on this, a team led by palaeontologist Jun-xuan Fan at Nanjing University in China created and analysed a database of fossil marine invertebrates that were found in more than 3,000 layers of rock, mostly from China but representing geology around the planet during the early Palaeozoic. The group then used software to measure when individual species had emerged and gone extinct.

The program took advantage of the fact that species were usually found in multiple rock formations — each spanning hundreds of thousands to millions of years — and used this information to place upper and lower limits on the period in which the species actually existed. The effort revealed for how long, and in what order, all 11,000 species had existed. It took the supercomputer around seven million processor hours.

Using this approach, the team was able to learn extra details about events such as the end-Permian extinction, and the Cambrian explosion around 540 million years ago. The analysis showed, for instance, that species diversity declined in the 80,000 years leading up to the end-Permian mass extinction, which itself occurred over about 60,000 years.

The findings also cast doubt on the existence of a smaller-scale die-off known as the end-Guadalupian extinction, which is thought to have wiped out many marine species around 260 million years ago. That was the biggest surprise, says Mike Benton, a palaeontologist at the University of Bristol, UK, who has documented changes in vertebrate diversity during that period. The study, he adds, "represents a pretty amazing big-data endeavour".

Benton hopes to see the effort extended to later periods — particularly the past 100 million years. Palaeontologists disagree over whether an apparent increase in animal diversity in this period is the result of sampling bias.

Norman MacLeod, a palaeontologist at the University of Nanjing and a co-author of the study, says the team's work might help to reveal the underlying causes of changes in biodiversity, by charting ups and downs on a timescale that can be matched with environmental and climatic shifts.

Wagner adds that the team's approach will be most valuable in uncovering — and explaining — smaller-scale extinctions, not dissimilar to those occurring today. Such extinctions could turn out to be "a bad 100,000 years, or a bad week" for some groups of organisms but not others, he says. "When you get this resolution, it starts opening the doors to actually testing what the smaller-turnover events might be like."

STUDIES OF EMBRYO-LIKE STRUCTURES STRUGGLE TO WIN US GRANTS

Biologists say they need clearer guidelines on funding rules for this nascent field.

By Nidhi Subbaraman

Scientists can now create clumps of cells that resemble human embryos, raising hopes that they could study the elusive first stages of human development while avoiding the ethical concerns that make it difficult to study actual human embryos. But as these embryo models — in which human stem cells are transformed into embryo-like structures whose growth mirrors stages of embryonic development — grow in popularity, US researchers say that they are finding it increasingly difficult to obtain federal funding for such work.

The US National Institutes of Health (NIH) in Bethesda, Maryland, has funded and still does fund work on embryo-like structures. A spokesperson told *Nature* that the agency considers grant applications involving models that "could be considered an organism" on a "case-by-case basis", and cited a provision of federal law known as the Dickey–Wicker Amendment, which bars the government from funding research that creates or destroys human embryos.

But the ban, which dates back to 1996, was put in place before the advent of techniques that produce embryo-like structures from stem cells. Scientists working on such research say that they need clearer guidance on what is eligible for federal funding. "The writing on the wall is that synthetic embryos are out of bounds with the NIH. The next step in the science is not allowed," says Eric Siggia, a physicist who studies developmental systems