OCEANOGRAPHY'S BILLION-

A mammoth undersea US project will soon start streaming data to researchers. But some wonder whether the system is worth its high price.

BY ALEXANDRA WITZE

On a sunny day in July, it takes 90 minutes for the R/V *Thomas G. Thompson* to traverse the locks connecting Seattle's inland waters to Puget Sound. On deck, John Delaney looks impatiently out to sea. As an oceanographer at the University of Washington in Seattle, he has made this trip many times to explore beneath the Pacific's waves. But Delaney hopes that this seven-week expedition will be the beginning of the end for these time-consuming journeys. "We don't want to be ship-bound," he sighs. Instead, he is spending money — a lot of money — to open a permanent window onto the sea floor.

Delaney is the architect behind a 925-kilometre network of fibre-optic cable and instruments being installed on the seabed off the coast of Washington and Oregon. If all goes according to plan, these will stream real-time data back to shore by 2015, delivering some of the first live video footage of an underwater volcano erupting, hydrothermal vents growing and clouds of microbes billowing from the sea floor. The cabled network is a key part of the massive US Ocean Observatories Initiative (OOI), which aims to create a flood of continuous information from select sites.

Oceanographers have long relied on brief glimpses of data from single research cruises or isolated buoys or moorings. The OOI, and Delaney, aim to exchange those flashes of insight for a constant spotlight. "The goal is to launch an era of scientific discovery," Delaney says, thumping his fist on the ship's deck rail. "This is a game-changer."

Many US oceanographers have not yet considered just how the OOI's broad scope and potential might affect their research. But some who have been watching its development closely warn that the project is an expensive gamble. Construction costs will run to US$386 million, and the programme will then consume about $55 million per year for operations and maintenance. By the end of its planned 25-year lifetime, the OOI will have cost nearly $1.8 billion — an unprecedented price tag in oceanography.

The running costs will eat up about one-sixth of the annual budget for ocean sciences at the US National Science Foundation (NSF), and that proportion could increase. "That money is being pulled right out of what could otherwise be allocated for peer-reviewed science," says Charles Eriksen, an oceanographer at the University of Washington who is not involved with the project. Critics also complain that the OOI sites cover only a fraction of a per cent of the world's oceans.

Such objections hold little water with Delaney. "People say cables are expensive," he says. "Well, ships are expensive too." The hour and a half it takes to traverse Seattle's locks costs the University of Washington roughly $4,000.

TELECOM SPIN-OFF

The OOI sprouted from a germ of an idea planted by Delaney and Alan Chave, an ocean scientist now at the Woods Hole Oceanographic Institution (WHOI) in Massachusetts. It was the early 1990s, and Delaney was frustrated with getting only enough ship time to visit the sea floor for a day or two every couple of years. Chave had been working for the US telecommunications giant AT&T, and he suggested hooking a piece of old telephone cable up to instruments on the seabed. The fibre-optic cable would provide electricity and stream data back to shore. "This is transformational," Delaney thought.

The idea of a permanent oceanographic observatory slowly gathered steam at the NSF, and by 2007 the agency had decided to invest some $330 million in the concept. The problem was working out exactly what to build. To qualify as a national facility and justify the cost, the observatory needed to expand beyond sea-floor cables to include instruments that could plumb the full depth of the water column. OOI proponents initially dreamed up an observatory on steroids: multiple cabled arrays along with more than a dozen coastal and deep-water sites. Not surprisingly, the final project design cut back on most areas. "You have to build what you can afford," says Deborah Kelley, a marine geologist at the University of Washington and an OOI project scientist.

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After input from hundreds of researchers, the project team settled on three main components (see 'A mega-ocean observatory'). The first, and most ambitious, is the fibre-optic network southwest of Seattle, most of which has now been laid. This will connect dozens of sea-floor instruments across the Juan de Fuca tectonic plate, which slides under North America and drives seismic activity along the west coast from northern California to Vancouver Island in Canada. The instruments will focus on an active underwater volcano called Axial Seamount, and a formation called Hydrate Ridge, where methane vented from the sea floor feeds a unique ecosystem.

The second component involves laying an array of moorings to support instrumentation off the east and west coasts of the United States. In each array, automated profilers will shuttle up and down cables measuring chlorophyll, oxygen and other factors from the sea floor to the surface. Six gliders will rove between moorings to make similar measurements. The third part of the project will use moorings and gliders to monitor four deep-water sites in the far north and south. These six sites will be run by WHOI, the Scripps Institution of Oceanography in La Jolla, California, and Oregon State University in Corvallis.

Together, these stations will marshal the forces of about 760 sensors, of 47 different designs, to collect data on variables ranging from water temperature, salinity and density to acidity, carbon dioxide and oxygen levels. "One of the most transformational things is how interdisciplinary it will be," says Kelley.

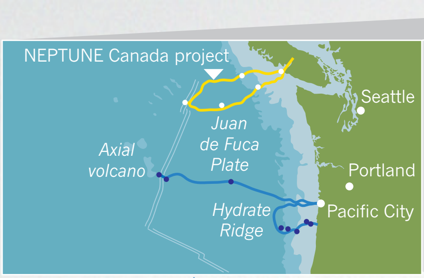
Elsewhere, similarly ambitious oceanographic observatories are already in use. Japan has two dense sea-floor observatories — DONET and DONET2 — with a focus on earthquake and tsunami studies. And many nations operate networks of buoys: the international Argo project has an array of more than 3,000 floats. The OOI will collect a broader selection of data than those efforts. In Canada, a cousin to the OOI has been up and running since late 2009. That project, called NEPTUNE Canada, involves 800 kilometres of fibre-optic cable laid on the northern part of the Juan de Fuca plate. The Canadian government has spent Can$200 million (US$194 million) on sea-floor observatories. The OOI's cabled observatory will be very similar, but because it is

PHOTO: ALLISON FUNDIS, UNIV. WASHINGTON; GRAPHIC: NIK SPENCER/NATURE

DOLLAR BABY

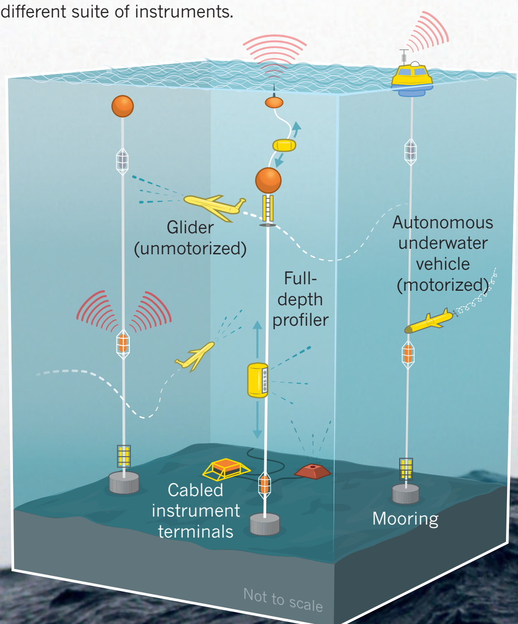
A MEGA-OCEAN OBSERVATORY

The US Ocean Observatories Initiative includes one sea-floor cable observatory (called Regional Scale Nodes), four deep-sea sites, and two coastal arrays of instruments; but together, this covers only a fraction of a per cent of the world's oceans.



MARINE TOOLBOX

The project's many instruments, including those shown here, incorporate a total of about 760 sensors. Each research site includes a different suite of instruments.



getting a later start, it will have newer designs of sensors and moorings, says Kate Moran, president of Ocean Networks Canada, which oversees NEPTUNE Canada.

It is these sensors that Delaney is dreaming of as the R/V *Thompson* reaches the Axial volcano in July. When the captain pulls the ship to a halt above the underwater mountain, engineers manoeuvre a boxy yellow submersible called ROPOS down into the water. From 1,500 metres below the ocean surface, it sends back a murky video feed of an eight-metre-high mineral chimney, its sides festooned with microbial growth, its top spouting shimmering hot water.

SNAPSHOT SCIENCE

Visiting Axial like this costs almost $70,000 a day and provides only a snapshot of the volcano's behaviour. Oceanographers have, in the past, dropped off seismometers and hydrophones at Axial and retrieved them later, allowing them to study an eruption after the fact. And, in 2011, an expedition led by the US National Oceanic and Atmospheric Administration happened to arrive just months after the volcano erupted, providing scientists with a fortuitous opportunity to study fresh lava flows. But sightings of underwater eruptions are rare, even though this is the most common type of volcanism on Earth.

Axial is expected to erupt again within a decade and OOI researchers plan to catch it in the act. A bottom-pressure tiltmeter will measure gradual changes that could indicate that the volcano is inflating, and a cutting-edge mass spectrometer will sniff the water for hints of magma rising from below. When an eruption seems imminent, a fleet of gliders could be deployed to study chemicals in the water column. A high-definition video camera, installed this summer, will watch a hydrothermal vent on Axial's flanks. All this should yield details about how magma reaches the volcano's summit, how that relates to seismic activity, and how organisms living in this extreme environment deal with an eruption. "There are so many questions we don't have answers to," says Kelley.

Delaney says that the $126-million cabled observatory is the only way to spy on Axial properly. The OOI's investment in other parts of the ocean will also gather data that cannot be obtained using existing equipment, says Tim Cowles, programme director at the Consortium for Ocean Leadership, the organization in Washington DC that is overseeing the OOI.

The four high-latitude deep-sea moorings, for example, will help to study the exchange between air and water where powerful winds whip the sea surface into a froth. Weather forecasters and climate modellers need better information on how energy and gas move between the deep ocean, the sea surface and the atmosphere. But because oceanographic equipment tends to take a beating in fierce weather, measurements are few and far between at high latitudes. A team led by Uwe Send at Scripps deployed 57 instruments at a site in the Gulf of Alaska in July, making it the first deep-sea OOI site to be completed.

The coastal arrays, meanwhile, should be useful for studies of algal blooms. Gradual changes in near-surface temperatures can drastically affect how phytoplankton blooms form in the spring, but catching such changes in the act is tricky, says Kendra Daly, a biological oceanographer and OOI project scientist at the University of South Florida in St Petersburg. "We have no ability to predict exactly when that will happen, so it's hard to get ship time to be out there right when the bloom starts and ends," she says. Measuring nutrient concentrations and primary productivity on the spot will allow researchers to better quantify how much carbon dioxide is absorbed by blooms, which has implications for understanding how biological systems interact with climate, Daly says.

To even start to tackle these science questions, the OOI team will need to get its instruments into the water before a tight deadline of February 2015. After that, the money available to complete the job will dry up. "All those things that have to happen in the last six months of the project do make all of us nervous," says Cowles. The project's schedule has been frantic since 2009, when the OOI received an initial input of almost $106 million from the government stimulus bill enacted in the wake of the economic recession. That infusion of funds was welcome, but it left the team scrambling to get everything in place. "It kicked us out of the gate ahead of schedule, and we've been trying to catch up ever since," says Cowles.

At least one hurdle stands in the way of a timely completion. For now, the team led by the University of Washington can't connect the instruments it has deployed to the backbone power-and-data cables leading to the shore. The NSF requires that the company that made the cables, L-3 MariPro of Goleta, California, ensure that they are in proper working order before handing them over, and L-3 MariPro is running behind. Delaney's team had to shorten this summer's field season and bank some of its ship days for 2014, intending to connect the instruments then.

And there are other, bigger worries. One is the daunting cost of maintenance. OOI sites are slated to be serviced every one, three or five years — depending on the equipment — which will run up a hefty ship-time bill. And unforeseen glitches are bound to strike. NEPTUNE Canada has run into major technical issues, including the failure of kilometres-long segments of cable and instruments that stopped working after just a year on the sea floor.

BY THE END OF ITS 25-YEAR LIFETIME, THIS OBSERVATORY WILL HAVE COST NEARLY $1.8 BILLION.

Ensuring data quality is also a concern. "That's the big worry in my mind," says Douglas Luther, an oceanographer at the University of Hawaii at Manoa and an OOI project scientist. The OOI's cyberinfrastructure team is developing automated algorithms to flag up any obvious problems — such as sensors that record temperatures hundreds of degrees above those of neighbouring devices — but there is currently no money to fund a big quality-control team.

Another question is how much demand there will be for the data. Not everyone will be able to abandon field trips in favour of using the OOI's instruments. Microbial oceanographer Julie Huber of the Marine Biological Laboratory in Woods Hole studies microbes living on and in Axial volcano. The OOI's cabled network isn't much use to her — so far there is no instrument she could plug in for her microbial monitoring. "It doesn't replace me having to go out there," she says.

OCEAN OUTREACH

The OOI's leaders could follow the example of their northern colleagues. Canada's undersea cabled networks, which cost Can$16 million annually to run, have nearly 8,000 active data users per year, which is right around the level their funders wanted to see. In large part, that is because Ocean Networks Canada employs six staff scientists to reach out to researchers and educators with suggested ways to use the data. "Users just don't come — you have to work at it," says Moran. So far, the OOI has no formal outreach plan.

There are also fears that NSF programme managers will feel under pressure to fund projects that use OOI data, in order to validate its cost. "Mostly, we'll be paying a lot of money trying to make this hardware a success," says Russ Davis, an oceanographer retired from Scripps who helped to develop key floats for the Argo array. "If it isn't awfully wonderful, it's going to look bad for the NSF and be bad for science."

For Delaney, the OOI's potential outweighs such concerns. As the *Thompson* makes its way across the Pacific, leaving the underwater volcano behind, he muses about the interconnectedness of the oceans. "A single ship can only be in one place at one time," he says. "We need to be present in multiple places in multiple times."

That omnipresent capability is what the OOI is all about. And if it costs a lot of money, Delaney wants the research community to keep the sums involved in perspective: NASA, for comparison, spends billions each year. "Our investment in the ocean is way below our investment in outer space," he says. "But the return is much greater." ■ SEE EDITORIAL P.461

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