

colleagues made their measurements.

Measuring the composition of the slugs is not easy. Because collecting a gas sample in the midst of a volcanic eruption is hazardous, a remote sensor is necessary. The gas from a slug dissipates quickly, mixing with the surrounding air and quiescent emissions, so that getting an accurate measurement requires adequate time resolution. And determining the gas ratios requires measuring many different molecular species simultaneously.

Burton and colleagues met all those requirements with a technique called open-path Fourier-transform IR spectroscopy, which quantifies the composition of the slugs based on the characteristic molecular vibrations of the component gases. With a spectrometer 240 m away from the volcano's vent, they sampled the IR radiation emitted from the hot surfaces inside the crater. That radiation was passed through a Michelson interferometer and Fourier transformed to give the frequency spectrum. The resulting absorption lines correspond to the vibrational transitions of the gas molecules between the magma and the detector. The composition of the slug gas could then be inferred from the relative strengths of the absorptions. Measurements of H<sub>2</sub>O and CO<sub>2</sub> had to be corrected to account for the presence of those gases in the intervening air, so those measurements had higher uncertainties (20–25% and 10%, respectively) than the measurements of other gases (4–6%).

A representative set of measure-

ments, with a spectrum taken every 4 s, is shown in figure 2. The baseline gas composition is that of the quiescent emissions, and the periodic spikes correspond to the slugs. The data show that the slugs have less H<sub>2</sub>O, more CO<sub>2</sub>, and a greater CO<sub>2</sub>/SO<sub>2</sub> ratio than the quiescent emissions, all of which suggest a greater source pressure. "The enormous variation in the CO<sub>2</sub>/SO<sub>2</sub> ratio, to 22 or 23 for the most intense explosions from a background level of 8, was a very pleasant surprise," says Burton. "No one really had any idea what type of variation there would be, if any." Smaller explosions gave off gases richer in H<sub>2</sub>O than the larger slugs, and with a slightly smaller CO<sub>2</sub>/SO<sub>2</sub> ratio.

To convert the gas compositions into a pressure or depth of origin, the researchers needed to know how much gas was dissolved in the magma to begin with, so they looked at the analyses of the products of Stromboli's most severe eruptions.<sup>2</sup> Some 10 km beneath the surface, pockets of basaltic magma become trapped in chunks of olivine (a mineral that solidifies at a much higher temperature than basalt), which are then propelled from the volcano in violent explosions. Starting from the volatile content of the basalt, Burton and colleagues ran a computer simulation of how the magma would degas as it rose through the volcano's plumbing. They found that the typical slug's composition corresponded to a depth of origin of about 3 km—right around the level of the sea floor.

That the slugs originate so far below

the surface is a clue that they probably form from a foam that builds up at a structural discontinuity rather than from small bubbles that rise steadily through the conduits at different speeds. Although the smaller slugs had a different composition, indicative of a shallower origin of about 0.8 km, the researchers speculate that they might actually form at the same depth as the larger slugs. But because the smaller slugs rise through the magma more slowly, they could become contaminated by the bubbles in the shallow magma they pass through.

Burton and colleagues are currently working on setting up a permanent automatic system to monitor the Strombolian gases. Previously, they had to transport their spectrometer to the peak every time they wanted to take a measurement. That meant obtaining only snapshots of activity and taking no measurements during the larger explosions. The researchers also hope that their measurements will eventually lead to the discovery of a warning signal for the largest, most dangerous eruptions. "The slugs don't just bring gas from that depth," says Burton. "They also bring information, and that's extremely precious."

Johanna Miller

## References

1. M. Burton, P. Allard, F. Muré, A. La Spina, *Science* **317**, 227 (2007).
2. A. Bertagnini, N. Métrich, P. Landi, M. Rosi, *J. Geophys. Res. [Solid Earth]* **108**, 2336 (2003).

# Sonar mapping suggests that the English Channel was created by two megafloods

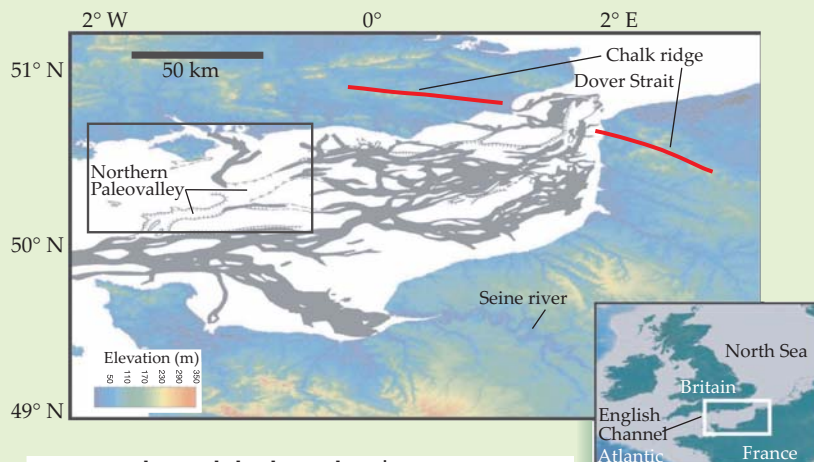
Until about 450 thousand years ago, Britain and France were connected by a land bridge, even at times of high sea level.

Catastrophic geological events that suddenly change the cartographic face of Earth are as rare as they are spectacular. When the isthmus that joined Iberia to North Africa was breached some 6 million years ago, the resulting superflood created the Strait of Gibraltar and refilled the long-dessicated Mediterranean basin in just a few decades. Some geologists argue that the Bosphorus strait at Istanbul is the result of a similar breach eight thousand years ago: Mediterranean waters spilling into the lower-lying, previously landlocked Black Sea, they speculate, suddenly raised its level, sweeping away human communities around its littoral and giving rise to the flood myths of Gilgamesh and Noah.

In 1985 Alec Smith at Royal Holloway College London invoked a fragmentary seismic survey of the English Channel's floor to conjecture that the Dover Strait, which links the Channel to the North Sea, was created a few hundred thousand years ago by a sudden, catastrophic breach of the chalk ridge that had connected Britain to north-eastern France (see figure 1). But the Channel-floor data available in 1985, and indeed for the next two decades, could not convincingly distinguish between Smith's bold hypothesis and more gradualist explanations for the opening of the Dover Strait: glacial erosion, tidal scouring, or ordinary fluvial erosion in glacial episodes of minimum

sea level when the Channel basin was just a complex of river valleys.

But now a team led by Sanjeev Gupta and Jenny Collier at Imperial College London has reported that newly available high-resolution sonar mapping of several thousand square kilometers of the English Channel's floor (the black rectangle in figure 1) brings to light strong evidence of the catastrophic flooding that Smith had proposed.<sup>1</sup> The bathymetric data, mostly from unpublished shipborne sonar mapping over 24 years by the UK government's Hydrographic Office, chart the Channel floor with horizontal and vertical accuracies of 20 meters and 10 centimeters, respectively.



**Figure 1. The English Channel** and its environs as they appear today. The color scale shows elevations on land in Britain and France. On the sea floor, which has been repeatedly exposed in glacial periods of low sea level, the valleys of ancient rivers are indicated. Paleovalleys shown gray are now filled with sediment, and those shown white and outlined by dashed lines are unfilled bedrock. A high-resolution bathymetric survey of the channel floor within the black rectangle is the basis of reference 1. That area's principal feature is the Northern Paleovalley. Before the Dover Strait was opened a few hundred thousand years ago, the elevated chalk ridges (red) of southeast Britain and northeast France were joined together in a continuous land bridge even in interglacial periods of high sea level. In the inset, the gray marine area indicates the shallow waters of the continental shelf. (Adapted from ref. 1.)

Unaware of that laboriously accumulated treasure trove, Collier, a marine geophysicist, and Gupta, a geologist specializing in sedimentary rock formations on land, had begun their own sonar survey of a smaller area of the Channel floor four years ago. They were using an innovative "swath sonar" instrument with a fanned array of ultrasound beams, pulsed at 10 Hz, that could continuously and rapidly map a 300-meter-wide strip of sea floor as the ship moved forward. "It's rather like mowing a lawn," says Collier. "And we have a sophisticated gyroscopic sensor that corrects for the ship's pitch and roll."

"But soon after we started," recalls Gupta, "Graeme Potter at the Hydrological Office showed us some of their charts, saying 'you might find this interesting.' It was like seeing the surface of a distant planet up close for the first time. So we quickly recruited Potter as a coauthor."

It had been known that the shallow Channel floor in the area of the Hydrographic Office survey was traversed by a long submarine valley called the Northern Paleovalley. The new revelation was that, in high resolution, the valley showed deep channels and scours sharply incised into bedrock, streamlined islands, braidlike branching patterns, cataracts, and "hanging

tributaries" that, taken together, are hard to explain in the absence of tor-  
rential megafloods.

"Particularly striking was the resemblance of these sea-floor shapes to what one finds on the ground in the Channeled Scablands of eastern Washington State," says Gupta. That strange landscape was carved out some 15 thousand years ago, toward the end of the most recent glacial episode, by a megaflood after the sudden collapse of the high glacial dam that penned up the enormous Paleolake Missoula in western Montana. When the dam broke, water escaping westward at  $10^7$  tons per second incised and scoured the landscape for about a week as it made its way to the valley of the Columbia River.

### Glacial advance and retreat

Global warming notwithstanding, we're still in what geologists call an ice age. For the past two million years, large-scale ice sheets have advanced and retreated over the northern reaches of Eurasia and North America at intervals on the order of a hundred thousand years. For most of the previous hundred million years, by contrast, even the poles did not have year-round ice caps.

The farthest advance of European glaciation in the present ice age was

# VACUUM PUMPS



**\$1,075.**

**7 CFM, 12 m<sup>3</sup>/h  
After Discount**

**Ask About Discounts for  
Distributors and Universities**

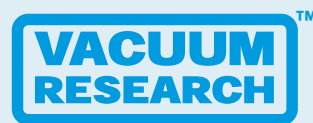
**5 sizes from 3 to 28 CFM,  
6 to 48 m<sup>3</sup>/h, 100 to 800 l/min**

**Ultimate vacuum better than  
5 X 10<sup>-4</sup>Torr, .006 Pa**

**Full 2 Year Warranty on  
All Parts and Labor**

**To Order or Questions  
Please Call (412) 261-7630**

**Complete Specifications at  
[www.vacuumresearch.com](http://www.vacuumresearch.com)**



**Vacuum Research Ltd.  
2419 Smallman St.  
Pittsburgh, PA 15222 USA**

See [www.pt.ims.ca/12310-14](http://www.pt.ims.ca/12310-14)  
AVS Show—Booth #503

about 450 thousand years ago. At that time a continuous ice sheet covering all of Scandinavia and most of Britain north of the Thames blocked the North Sea's northern outlet to the Atlantic. With the chalk ridge at Dover damming the alternative exit to the south, the North Sea became a high, freshwater lake fed by glacial meltwater and rivers like the Thames and the Rhine.

On the other side of the chalk dam, the view was quite different. At times of maximum glaciation, so much water is sequestered as nonfloating ice that the worldwide sea level is about 100 m lower than it is during interglacial episodes like the present. So the shallow Channel basin, a part of the European continental shelf, would have been exposed dry land tilted gently westward.

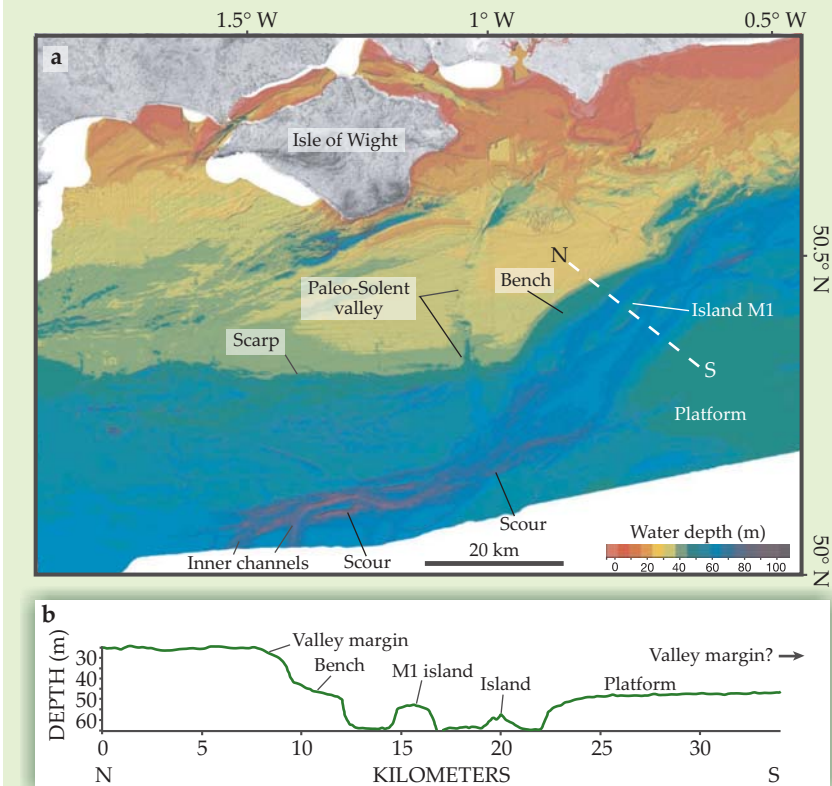
It was probably at that geological juncture, Gupta and company conclude, that the chalk dam gave way. Rising at least 30 meters above today's sea level, the dam's chalk was an upfolded formation of sedimentary limestone (calcium carbonate), a material much stronger than blackboard chalk—which is, in fact, calcium sulfate. But as the pent-up North Sea kept rising, it eventually overtopped or ruptured the dam, thus setting in motion the dam's rapid collapse.

As the liberated North Sea water raced westward, its maximum flow rate along the Northern Paleovalley, Gupta and company estimate, was  $10^6$  tons per second. The estimate is based on the cross section of the incised pathway, its slope, and a hydrological roughness parameter that describes the dependence of flow velocity on a channel's surface attributes.

## A second megaflood

Detailed examination of the bathymetric data indicates a second megaflood of comparable violence, most likely when the channel basin was once again exposed at another glacial maximum 200 thousand years later. Figure 2a is the overall bathymetric depth chart created by the Imperial College team from its own sonar measurements and those of the UK Hydrographic Office. The profile (figure 2b) of the Northern Paleovalley at the sea-floor island labeled M1 shows sharply incised channels cut into a limestone bench.

The close-up view of the streamlined island and its surroundings shown in figure 3 offers striking evidence of the two separate megafloods. The scarp marking the outer margin of the bench would have been incised into the side of



**Figure 2. High-resolution sonar bathymetry** of the region of English Channel floor within the black rectangle in figure 1. (a) Colors indicate depth below present sea level. British coastal features above water are shown gray. The deepest area, marking the floor of the Northern Paleovalley, shows long scours and sharply incised channels whose braidlike branching outlines streamlined islands. Higher up, a streamlined scarp separates a flattened bench from the valley's north wall. The submerged valley of the paleo-Solent river passes east of the Isle of Wight and then forms one of several hanging tributaries as it joins the Northern Paleovalley. (b) A depth profile along the dashed line N-S in panel a cuts across the sea-floor island M1. (Adapted from ref. 1.)

the valley by the first deluge. The rivulets traversing the bench, now some 50 m under water and stopping abruptly at the edge of the deeper channel, appear to be ordinary fluvial erosion by small tributary streams during an interlude after the first megaflood when the bench was once again dry land. The apparent continuation of some of these rivulets on M1 and other such islands implies that the channels that outline them were cut into the bedrock bench by a later megaflood.

Further evidence of two megafloods comes from the offshore course of the valley of the paleo-Solent, an ancient river whose estuary formed the Isle of Wight at the end of the most recent glaciation (see figure 2a). Where the paleo-Solent joins the Northern Paleovalley, more or less at right angles, the bathymetry shows two abrupt "knick-point" drops 4 km apart. They suggest that the tributary was left hanging on each of the two occasions when the

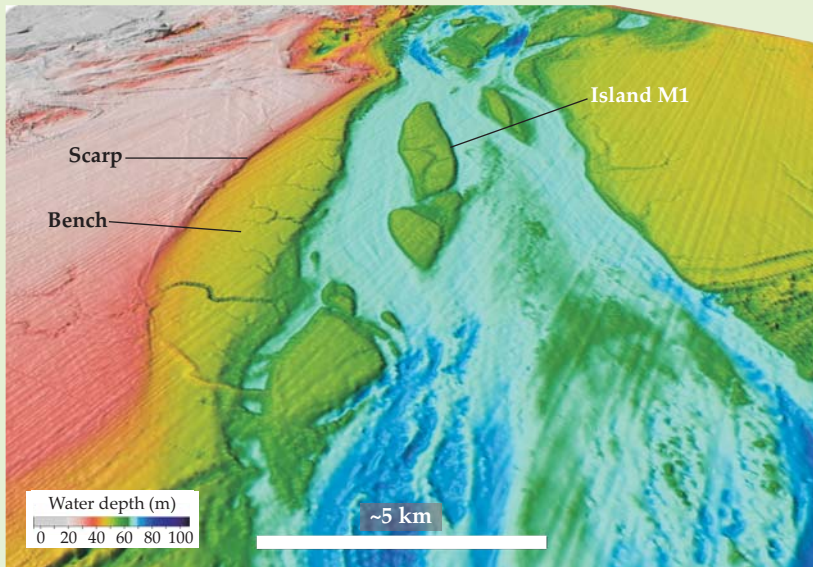
Northern Paleovalley was scoured by a megaflood.

Phillip Gibbard, a specialist on ice-age Europe at Cambridge University, argues that the second megaflood resulted from the collapse of a new southern barrier somewhat north of the already open Dover Strait during the glacial maximum 200 thousand years later. The North Sea's northern access to the Atlantic was once again blocked by an extensive ice sheet.<sup>2</sup> This time, he conjectures, the southern dam was either a bedrock outcropping or a moraine of boulders deposited by the previous glaciation.

## "This fortress"

The second megaflood would have completed the separation of Britain from the European continent. It not only widened the Dover Strait, Gibbard contends, but also greatly expanded the principal river that flows westward through the Channel basin when it's ex-





**Figure 3. Close-up of submerged island M1 and vicinity in perspective view looking east—that is, upstream when a mighty river flowed along the exposed English Channel floor during recent glacial periods. Rivulets on the bench are evidence of ordinary fluvial erosion when the bench was exposed after its presumed formation by a megaflood about 450 thousand years ago. The continuation of some rivulets onto adjacent sea-floor islands suggests that the intervening deeper channels were incised and scoured by a second megaflood some 200 thousand years later. The fine striation throughout the figure is an artifact of the sonar sampling pattern. (Adapted from ref. 1.)**

posed during periods of low sea level. Henceforth at such times, it would be fed by the diverted Thames, Rhine, and other great rivers that previously flowed into the North Sea. It would, in fact, be much wider than any river in Europe today. And at interglacial intervals of high sea level, Britain finally became the island Shakespeare called “this fortress built by Nature for herself.”<sup>3</sup>

The swollen river system left by the second megaflood may have proved a formidable barrier to migration by human and equine species. *Homo heidelbergensis*, a presumed ancestor of the Neanderthals, had inhabited Britain in rather large numbers from about 700 thousand years ago. But, to the puzzlement of anthropologists, humans—and horses—largely disappeared from Britain, though not from nearby France, about 180 thousand years ago until the Neanderthals arrived 120 thousand years later. The chalk land bridge was long gone when Heidelberg Man vanished from Britain. Gupta and Collier speculate that even when the Channel basin was exposed during periods of low sea level, the river, bloated by the second megaflood, had become just too much of an obstacle for the limited capabilities of *H. heidelbergensis*.

But not all prospective immigrants would have been equally intimidated. Under Trafalgar Square, paleontologists have found fossil hippopotamus bones from an unusually warm interglacial interlude 120 thousand years ago.

Bertram Schwarzschild

## References

1. S. Gupta, J. S. Collier, A. Palmer-Felgate, G. Potter, *Nature* **448**, 342 (2007).
2. P. Gibbard, *Nature* **448**, 259 (2007).
3. W. Shakespeare, *Richard II*, act II, scene 1.

## Rights & Permissions

You may make single copies of articles or departments for private use or for research. Authorization does not extend to systematic or multiple reproduction, to copying for promotional purposes, to electronic storage or distribution (including on the Web), or to republication in any form. In all such cases, you must obtain specific, written permission from the American Institute of Physics.

Contact the

**AIP Rights and Permissions Office,  
Suite 1N01,  
2 Huntington Quadrangle,  
Melville, NY 11747-4502  
Fax: 516-575-2450  
Telephone: 516-576-2268  
E-mail: rights@aip.org**

## Hey!

You need a low-noise amplifier? Go to [www.femto.de](http://www.femto.de) and find handy high performance signal recovery tools, like ...

### ... Variable-Gain Low-Noise Current Amplifier – DLPCA-200



- Variable Gain over 9 Decades for Measuring sub-pA to mA
- Max. Bandwidth 500 kHz
- Low Input Noise down to 4 fA/√Hz
- Ideal for Photodiodes and STMs

### ... Wideband Voltage Amplifier – Series HVA



- Bandwidth DC up to 500 MHz
- Switchable Gain up to 60 dB (x 1,000)
- For Pulse Measurements and as Pre-amplifier for Oscilloscopes

### ... Lock-In Amplifier Module – Series LIA-MV-150



- Manual and Remote Control
- Ultra Compact Package
- Low Cost
- For Spectroscopy, Surface Analysis and Laser Stabilization

**F E M T O**®

Sophisticated Tools for Signal Recovery

FEMTO® Messtechnik GmbH  
Paul-Lincke-Ufer 34  
D-10999 Berlin/Germany  
Tel.: +49-30-4 46 93 86  
Fax: +49-30-4 46 93 88  
e-mail: info@femto.de  
[www.femto.de](http://www.femto.de)