A year after the event, the shocking images of destruction broadcast from the Indian Ocean tsunami are still fresh in our minds. **Dave Tappin** describes the ongoing research into its origins and reviews what we have found out so far.

# Learning from the tsunami

On 26 December 2004, just before one in the morning Greenwich Mean Time, a massive earthquake of magnitude 9.0 to 9.3 struck the eastern margin of the Indian Ocean. It ruptured over 1300 miles of the Earth's crust stretching from northern Sumatra to Burma. It was the largest earthquake since Chile in 1960 and the largest ever recorded by modern instruments. Because of the scale of the rupture, together with its location under the sea, it generated a tsunami wave that, after travelling at speeds of up to 600 km per hour across the ocean, struck the surrounding coastlines with devastating effect. Although almost undetectable at sea, upon approaching the nearby coast of Sumatra the wave built up to heights of over 30 m. Farther afield in Thailand, Sri Lanka and India wave heights were not as high although waves of up to 10 metres were experienced. More than 200 000 people died in the tsunami wave, with over half the casualties in Sumatra. Many hundreds of thousands more were made homeless. In most places the wave struck with little or no warning. The tsunami is the most destructive in recorded history.

Although the destruction was mainly confined to the Indian Ocean, the impact of the catastrophe was of global extent. The wave travelled around the world, being measured as far away as Britain. It was tracked by satellite and measured on yachts anchored offshore the devastated areas.

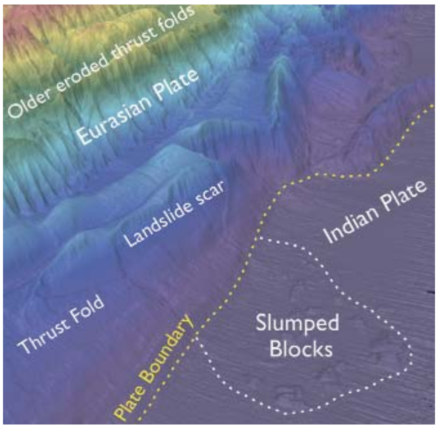
Although the majority of the casualties were local inhabitants, the presence of large numbers of tourists resulted in the event being captured extensively on video and still cameras. It has become the most visualised tsunami ever. Study of earthquake mechanism has led to re-evaluations of how ruptures of this magnitude take place and the hazard that they pose.

The causes of tsunamis are well known. A vertical movement of the sea bed displaces the overlying water column so that gravitational collapse at the sea surface results in a wave that travels outward from the source. The magnitude of the sea surface movement is proportional to that at the sea bed and the size of the tsunami wave that strikes the coast. In the instance of the Indian Ocean event, the maximum vertical sea bed movement was 15 m.

Tsunami are most commonly caused by earthquakes, but other causes are:

- submarine landslides, such as that off Papua New Guinea in 1998 when over 2000 died
- volcanic eruptions, such as Krakatoa in 1883, when over 60 000 died
- the collapse of volcanoes, such as the Canary Islands or Hawaii
- subaerial landslides such as on Flores Island in 1992 when 2000 died
- the impact of extraterrestrial objects.

Early assessments of the Indian Ocean tsunami indicated that, although the impact far from the earthquake on the coasts of India and Sri Lanka could be explained solely by this mechanism, the massive waves experienced on the nearby coasts of Sumatra might be due to an additional cause such as a submarine landslide triggered by the earthquake shaking. To determine whether this was true the British government despatched the HMS *Scott*



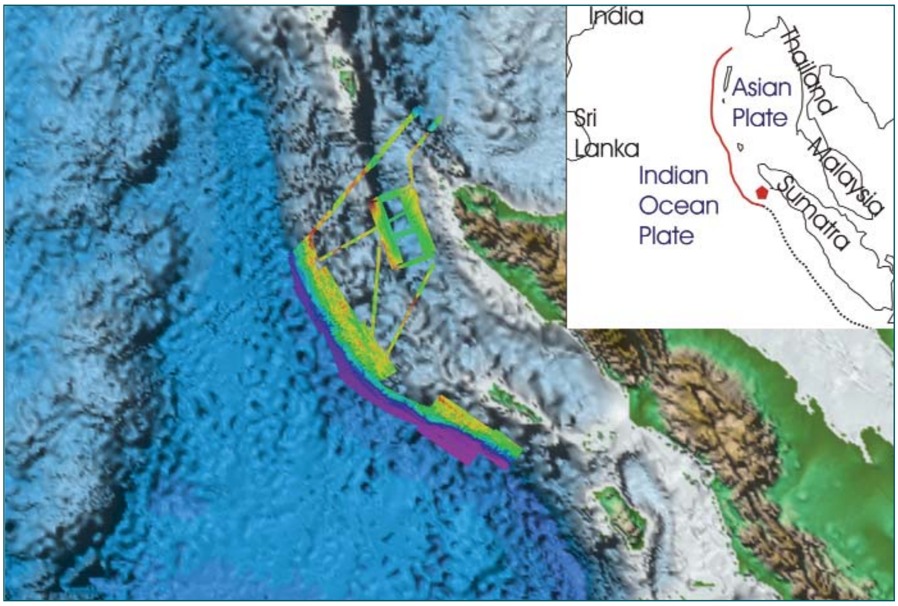

*Submarine landslide on the Sumatra plate margin. The displaced blocks on the right originated from the scar on the accretionary thrust fold in the centre of the image. They have travelled up to 13 km from their source. Largest blocks are 100 m high by 2 km wide. The landslide is recent, but probably not caused by the earthquake of 26 December.*

to investigate the sea bed over the earthquake rupture zone. The *Scott* has the capability to rapidly survey large sea-bed areas using a unique deep-water geophysical mapping system. In addition to identifying submarine landslides, a second objective was to see if there was any evidence of recent sea-bed movements such as those hypothesised by earthquake models.

Vertical sea-bed movements of 10 to 15 m could be imaged by the *Scott*'s mapping system. The detailed images acquired by the *Scott* were the first ever from the area. They mapped the area where two of the great mobile plates that form the Earth's crust meet and interact. In these regions, where one plate slips rapidly beneath the other, rupture of the crust can lead to destructive earthquakes and tsunami. The images reveal complex sea-bed morphology formed over millions of years as the two plates have collided. Submarine landslides were identified but were judged too small to have contributed to the tsunami. Vertical sea-bed movements of up to 15 m were located, confirming the mathematical models of the earthquake rupture.

The results from the study of the Indian Ocean tsunami are still being appraised and published, but an immediate impact is that awareness of the hazard from tsunami has been raised. Every country in the world has now assessed or is assessing its own risk from the hazard. In Britain a recent review has concluded that the risk is small.

There is some small danger though. In 1755 the city of Lisbon was destroyed by a massive earthquake the source of which was in the western Atlantic. Sea-bed movement created a tsunami that inundated the west African and Iberian coastlines. The earthquake and tsunami killed over 60 000 people. The tsunami wave travelled as far as the English Channel and was felt along the southern British coast. There is some evidence to suggest that in 1607 a tsunami struck the shore of the Bristol Channel. Over 8000 years ago a massive submarine landslide off Norway caused a tsunami that inundated the adjacent coastline and then travelled outward to strike the coast of eastern Britain, the Shetland Islands and the Faroe Islands. The most controversial threat from a tsunami may be due to the collapse of the volcanoes of the Canary Islands. Modelling of catastrophic failure indicates that the wave would be felt along the south coast of Britain.




*Location of the HMS* Scott *bathymetry. Inset map shows the location of the 26 December 2004 earthquake (red dot) and the rupture zone (red line).*

## An ancient megatsunami

A thin bed of fossil-rich sand and gravel on the flanks of the extinct Kohala volcano, Hawaii has been dated as 120 000 years old. Fossil foraminifera are found abundantly in this deposit and indicate that the grains originated in coral reefs and lagoons. The deposit is now 61 m above sea level but, taking into account the rate at which Hawaii has subsided, it would originally have been at a palaeoaltitude of 400 m. The broken and abraded fossils (molluscs, coral, bryozoa and foraminifera) indicate a high-energy depositional environment. This and the geological setting suggest that a megatsunami, caused by the collapse of the Alika Slide, carried the foraminiferal sands high above sea level.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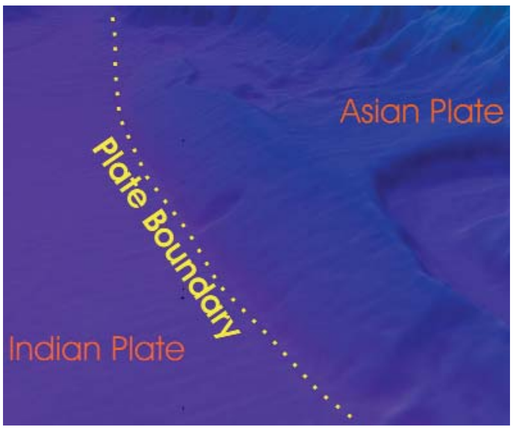
***A BBC/Discovery Channel special entitled 'The Unstoppable Wave' was broadcast in January 2006 featuring Dave's work on HMS* Scott.**




*The 'ditch', a 15-kilometre long, 15-metre deep feature (yellow dotted line) that is interpreted as due to vertical sea-bed displacement taking place during the earthquake of 26 December 2004.*