FIRST SEAFLOOR SURVEY BY ROYAL NAVYÂ€™S HMS <I>SCOTT</I>

The Eastern Indian Ocean Earthquake and Tsunami

The earthquake offshore Sumatra, Indonesia and the Nicobar-Andaman Islands, India on 26th December 2004 (Figure 1) was the second largest earthquake ever recorded (in 50-60 years recording history) with a moment magnitude of 9.3. The resulting tsunami wave propagated across the Indian Ocean causing devastation in coastal south-east Asia, Sri Lanka, India and East Africa and the loss of an estimated 300,000 lives. First post-disaster seafloor survey of the area was recently completed.

The earthquake resulted from a tectonic-plate process known as subduction. A subduction zone occurs where two tectonic plates advance towards one another, resulting in one sliding beneath the other. In this case, the oceanic Indian plate is moving towards and subducting beneath the continental Eurasian plate (Figure 2). As the two plates converge, strain builds up on the fault between the two plates (plate boundary) and is periodically released as earthquakes. Because these earthquakes occur beneath the sea, the seafloor movement they generate can often produce a tsunami. Subduction zones produce the largest earthquakes in the world due to the large potential fault area (see below). The collision process produces forces of compression that in turn produce folded ridges and compression-fault motion. As the plates collide sediments are scraped off one plate and transferred to the other. These folded and faulted sediments form the accretionary wedge (Figure 2), the region where most recent deformation caused by plate collision occurs.

Surveying the Consequences
The 2004 earthquake was initiated offshore Sumatra at a depth of ~30-40km below the seafloor, on the plate boundary fault (Figure 2). It then propagated along the fault zone, mostly to the north along the subduction zone and to the west to the position where the fault between the plates comes closest to the seafloor (plate boundary or deformation front, Figure 2). The earthquake ruptured a total fault length of about 1,200km, extending from offshore Sumatra to the Andaman Islands and with a rupture width of ~ 150km. Maximum slip on the fault was 10-20m. It is the rupture area and fault-slip that together dictate the magnitude of the earthquake. The slip on the fault caused the entire overlying seafloor to move and initiated the tsunami wave, although the exact nature of this movement is complex and currently poorly understood.
The Royal Navyâ€™s HMS *Scott*, a hydrographic survey vessel, conducted the first seafloor survey of the southern and initial area of the earthquake rupture zone. The expedition represented the first time the HMS *Scott* had worked with scientists on a research project. Multi-beam bathymetric data of the seafloor was collected using 12kHz, 361 beam hull-mounted Sass IV sonar. An area of ~40,000 square km of seafloor was surveyed during the three-week expedition. The region lacks any publicly available multi-beam data from before the earthquake and very little recent geophysical data in general.

Revealing Results
Initial results reveal the geomorphology of the seafloor and clues to the tectonic and sedimentary processes controlling this morphology. The morphology revealed has been created over thousands and millions of years as the two plates have converged. The gradient of the seafloor from the plate boundary (deformation front) where the two plates collide, across the accretionary-wedge folds is very steep, rising ~4,000m over a distance of about 20km in places. These steep slopes and continuing uplift due to collision, augmented by earthquake shaking, leads to extensive slope failure and submarine landslide. The seafloor of the accretionary-wedge folded ridges is therefore heavily eroded in places (see Figures 3 and 4). At the deformation front, coherent landslides produce angular blocks that have slid onto the non-deformed Indian plate. The youngest of these features has angular coherent blocks and a steep landslide headwall scarp, and may be recent. Sediment from these landslides and slumps is transported into neighbouring basins by short canyon and channel systems. No evidence was found of recent landslides large enough to contribute significantly to the tsunami generated in 2004.
The individual fold ridges of the accretionary wedge can be identified in the multi-beam images. The youngest of these fold ridges at the deformation front where the plates meet are relatively uneroded and only a few hundred metres high (Figure 3); they will have formed over thousands of years. The quality of the data allows us to
investigate a range of more subtle features, some perhaps formed by tectonic movement during large earthquakes. Some show a detailed history of erosion over long and short periods of time and some will help in more general studies of the physical and chemical changes that occur within accretionary wedge sediments.
Post-expeditionary analysis and interpretation of the data continues and initial results will be presented at forthcoming international scientific meetings and published in peer-reviewed journals. The data and results will also be used to plan the next phase of study, including higher resolution study of selected targets, some of which may have formed during the 2004 earthquake. Geophysical data imaging of the sub-surface will also be essential to gain an understanding of the structure of the subduction system, the nature of the plate boundary fault which generated the fault system and how slip was transferred from this major fault to the seafloor. These results will give scientists better insight into how the earthquake was generated, what controlled its magnitude and how these factors contributed to the

initiation of the tsunami. This information will be used to assess future earthquake and tsunami hazards in the Indian Ocean and other subduction zones around the world.

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