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On geological time scales, the floor of the ocean is young compared to the continents, as it is continuously recycled by internal convective forces. Oceanic lithosphere forms by ascending magma at mid-ocean ridges and is consequently transported towards the continents. At convergent margins it is subducted beneath them and ultimately transferred back into the Earth's interior.

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Surveying Deep-water Seeps at Convergent Continental Margins

During their lifetime the oceanic lithosphere becomes cooler and heavier, and increasingly more sediments are deposited on top of them. During subduction, the oceanic crust with its overlying sediments is brought to great depths and exposed to high pressure and temperature. As a result fluids and volatiles from both the crust and the sediments are expelled and try to ascend to the surface. In a subduction zone both the oceanic crust and the overriding continental crust are heavily fractured and multiple fluid pathways are present. Part of the fluids eventually reach the seafloor and seep into the overlying water. In addition, these fluids play a major role in many of the natural disasters associated with subduction zones such as earthquakes, volcanic eruptions, submarine landslides and tsunamis. To understand this role, and to understand their influence on the geochemical evolution of the hydrosphere, clear identification of the fluids and a quantification of the fluid and volatile budget during the subduction process is of major importance.

However, manifestations of fluid seepage at the ocean floor are not easy to detect. In many cases the fluids lead to large quantities of liquefied sediments (muddy sediments in particular) and their movement and expulsion leads to the formation of mud volcanoes, mud domes, or mud diapirs. These features have dimensions of several tens to hundreds of metres and can be detected by ship-borne echo sounders or multibeam bathymetry systems. At other sites, however, the fluids and volatiles do not entrain solid material with them and just seep through the seabed. These seepage sites vary in size, but can be relatively small and quite often do not show any morphological form. The interaction of the fluid with seawater and processes such as microbially-mediated oxidation of methane (an abundant component of the fluids), can lead to the precipitation of carbonates and the occurrence of chemo-

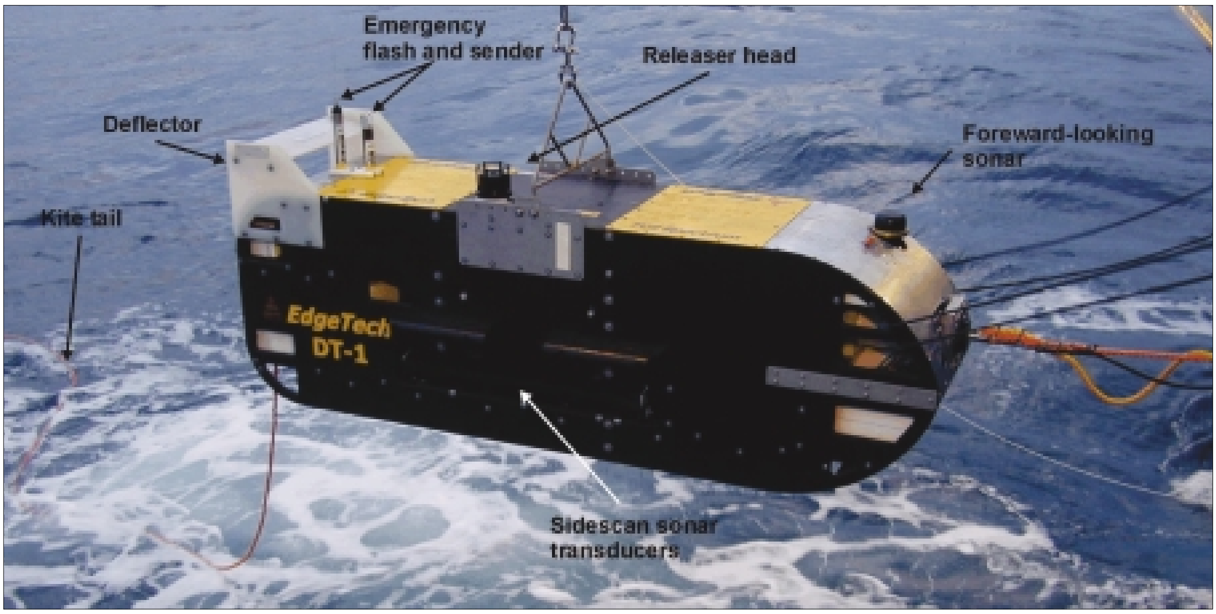

Figure 1: The DTS-1 side-scan sonar towfish during deployment.

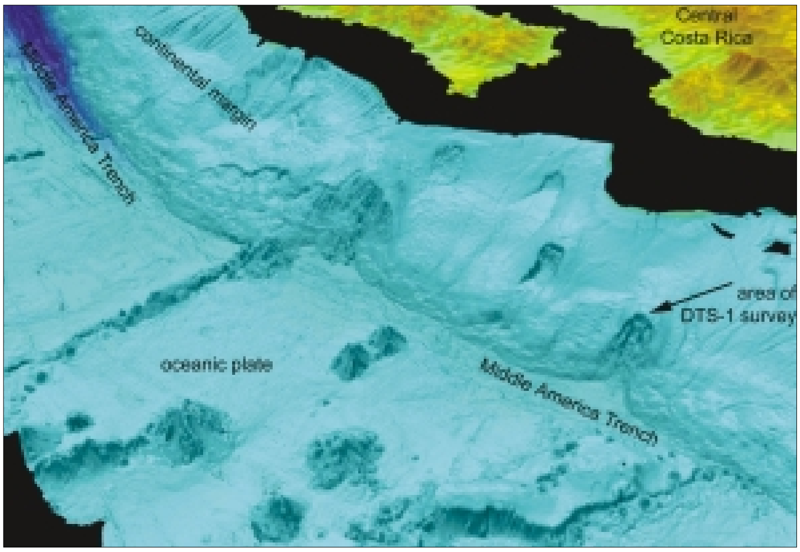

Figure 2: Perspective view of the bathymetry of the Pacific continental margin off central Costa Rica, showing the subduction of the oceanic plate beneath the continental margin along the Middle America Trench. Domal uplifts and deep scars document the trails of earlier subducted seamounts. The figure covers an area of approximately 250km x 150km. The water depth of the Middle America Trench increases from 2,800m (lower right) to about 4,600 m (upper left corner of the figure).

synthetic communities. These carbonates can be detected as backscatter anomalies in side-scan sonar images.

To explore sites of fluid seepage in deep water IFM-GEOMAR has set up the deep-towed side-scan sonar system DTS-1.

Technical Description of the DTS-1

The DTS-1 side-scan sonar (Figure 1) is a slightly modified EdgeTech Full-Spectrum dual-frequency, chirp side-scan sonar working with 75 and 410kHz centre frequencies. The 410kHz side-scan sonar has an across-track resolution of 1.8cm over a 300m wide swath and the 75kHz side-scan sonar provides a maximum across-track resolution of 5.6cm and a 1,500m wide swath. In addition to the side-scan sonar sensors, the DTS-1 contains a 2-16kHz, chirp sub-bottom penetrator giving a nominal vertical resolution of slightly less than 10cm and up to 50 metres penetration. An attitude sensor provides information on heading, roll and pitch. Data are stored in the underwater unit and transferred to the ship. The sonar electronics and the telemetry are housed in two titanium pressure vessels that are mounted on a towfish of 2.8m x 0.8m x 0.9m in dimension. A releaser with separate receiver head and an emergency flash and sender are included in the towfish. Positioning of the towfish is accomplished by a Posidonia USBL-system. An optional sonar covering the area ahead can be mounted on the towfish. Whereas the system is designed to operate in water depths down to 6,000m, the actual working depth is limited by the length of available deep-sea-cables on German research vessels (8,000m maximum) to about 3,500m water depth.

The main operations of the DTS-1 side-scan sonar are essentially run using an adapted version of Hydrostar Online software by Elac Nautik GmbH. The data processed with Caraibes and Prism, software packages developed by Ifremer and Southampton Oceanography Centre, respectively.

Surveying Seeps Offshore Costa Rica

Offshore Central America the oceanic Cocos and Pacific plates are subducted beneath the continental Caribbean plate at a speed of about 9 cm per year. This segment of the Central America Margin was chosen by the special research programme SFB-574 at Kiel University for a comprehensive, multi-disciplinary approach to study the role of volatiles and fluids in the subduction process. Initially, extensive side-scan sonar surveys were carried out with the DTS-1 in order to map possible fluid-venting structures, to quantify the extent of carbonates at the seafloor, and to identify possible targets for detailed investigations.

The area off central Costa Rica is particularly interesting, because about forty percent of the oceanic plate is covered by large seamounts (i.e. extinct volcanoes) that move with the oceanic plate towards the trench (Figure 2). As the oceanic plate is subducted, these seamounts plough into the lower continental slope, uplifting the overlying layers and forming local domes. Normal faults and fractures are generated on the crest of the domes due to the uplift, which also deforms and destabilises the slope sediments. In the wake of the seamount large portions of the continental slope sediments failed, leaving a pronounced slump scar behind. Fractures and faults constitute pathways for upward moving fluids and active fluid seepage is expected at this site. During a cruise with the German *RV Sonne* in 2002 this area was mapped extensively with DTS-1.

DTS-1 75kHz side-scan sonar data were collected along 5 NW-SE stretching profiles that are 0.7nm apart (Figure 3). One additional profile was run further to the Northeast using the 410kHz side-scan sonar sensor. The 75 and 410kHz side-scan sonar data have been processed with 1.0 and 0.25m pixel size, respectively.

DTS-1 side-scan sonar data perfectly show the network of faults that have been developed by seamount

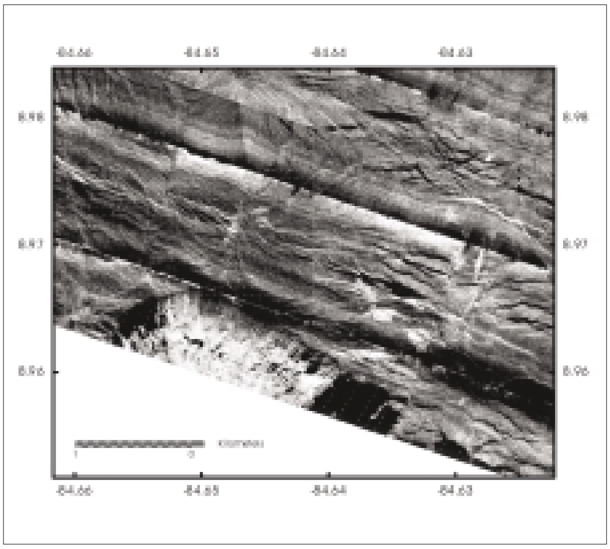

Figure 3: 75kHz side-scan sonar mosaic of the central domal uplift and slump scar of Parrita scar (offshore Costa Rica). High backscatter intensity is shown in light tones.

subduction. Most of the faults are parallel to the slope and even faults with small vertical displacement are well imaged. Most patterns of the side-scan sonar mosaic are related to the regional slope and seabed morphology, but some locations show high backscatter anomalies that morphology cannot explain. These locations possibly represent sites of fluid seepage and the high backscatter anomalies may represent carbonate pavements on the seafloor (Figure 3). A different manifestation of fluid seeps in the area around Parrita scar is shown in Figure 4. Here, a circular, crater-like structure of about 300m in diameter shows two patches of very high backscatter intensity in its northern half. This structure either represents an example of ascending fluids having entrained some solid material (i.e. it is a mud dome) or corresponds to the site of a more violent outbreak of fluid and now forms a pockmark. In either case the process of formation of the structure has been followed by the precipitation of carbonates that appear as high backscatter anomalies on the side-scan sonar image. Finally, the 410kHz side-scan sonar data show yet another structure related to cold seeps (Figure 5) in the form of several ridges of carbonate structures on the seafloor. The irregular surface of these carbonate structures is clearly shown on the side-scan sonar data.

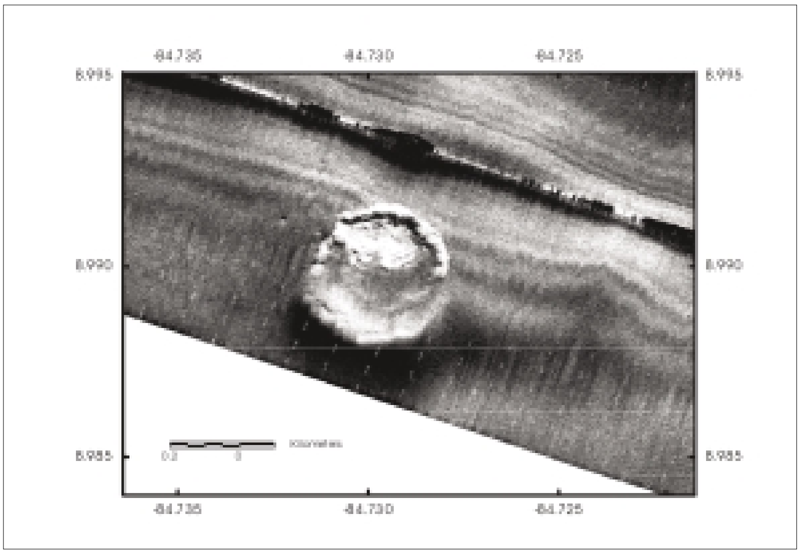

Figure 4: Part of 75kHz side-scan sonar profile from offshore Costa Rica showing a circular structure related to cold fluid seeps. Patches of high backscatter intensity (light tones) inside the crater are probably due to carbonate precipitation at the seafloor.

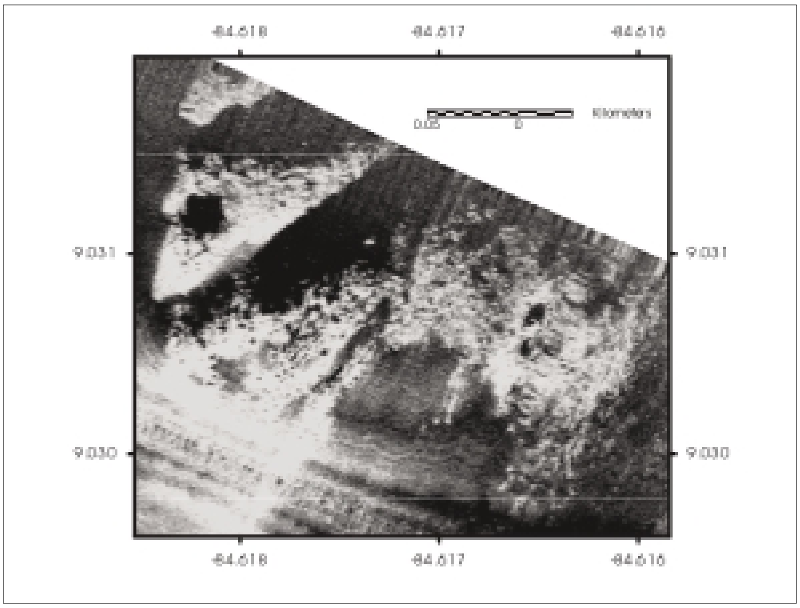

Figure 5: Part of 410kHz side-scan sonar profile over a carbonate mound offshore Costa Rica. High backscatter intensity (light tones) shows the distribution of carbonate pavements resulting from fluid seepage on the seafloor.

Conclusions

The dehydration of the subducting oceanic plate is of major concern, as the expelled fluids are variously connected to the generation of natural disasters. Part of the fluids move upward and eventually seep out at the ocean floor, where the oxidation of methane contained in many of these fluids leads to carbonate precipitation. Carbonates, therefore, indicate areas of fluid seepage at the seafloor and show higher backscatter in side-scan sonar images than surrounding fine-grained, muddy sediments. Side-scan sonar such as the DTS-1 consequently allows to identify and map areas of seeping fluids on the seafloor. Such fluid seeps are abundant on the continental margin of Pacific Costa Rica. Many seeps are connected to deep-reaching faults or fractures, as these structures constitute perfect pathways for uprising fluids. Such faults are particularly abundant in areas, where seamounts have been subducted.

Acknowledgements

The work offshore Costa Rica was funded through the special research program SFB-574 by the German Research Foundation (DFG). The cruise with *RV Sonne* was funded by the Federal Ministry of Education and Research (BMBF), Germany. The DTS-1 was funded through the program 'Geotechnologien' by the Federal Ministry of Education and Research (BMBF), Germany.

Biographies

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