

BATHYMETRY IN UNDERSTANDING OCEANIC & CONTINENTAL EVOLUTION

Multibeam Mapping of Continental Margin Morphology

A jigsaw puzzle of lithospheric plates comprises the outer shell of the earth. Oceanic plates, formed by ascending magma at mid-ocean ridges and transported towards the continents by internal convective forces, collide with continental plates at convergent margins and are subducted beneath them. This is accompanied by violent geological processes such as earthquakes, volcanic eruptions, submarine landslides and tsunamis.

The speed of drift of the plates is in the order of several centimetres per year, too slow to be observed directly. Still, these processes shape the surface of the ocean bottom and submarine morphology records these forces acting on the seafloor. Imaging the morphology helps both in recognising and understanding the action of these geological processes and in visualising the dynamic history of the ocean floor.

Continental margins show great variations in water depth, ranging from shallow shelf areas of less than 100m down to great abyssal plains more than 5,000m deep. Convergent margins are, in particular, among the steepest regions of the earth's surface. Imaging their morphology requires extensive bathymetric mapping and considerable efforts in acquisition, processing and visualisation of the data.

Data Acquisition

Due to the great range in water-depth of continental margins, "deep-water" multibeam systems have to be used. GEOMAR, the research centre for Marine Geosciences of Kiel University, has carried out extensive swath-mapping of large areas along active continental margins around the Pacific Ocean. These surveys were carried out with the large German research vessels Sonne and Meteor. The multibeam systems on these ships are STN-Atlas Hydrosweep DS I (RV Sonne before June 2001), STN-Atlas Hydrosweep DS II (RV Meteor) and Simrad EM-120 (RV Sonne since June 2001). In addition, data from other cruises with different ships from other institutions are also included in the final datasets.

These surveys are generally run as part of a multipurpose, multidisciplinary scientific cruise not set up as a dedicated mapping cruise. This means that track layout and profile planning has had to follow operational requirements rather than optimal survey layout plans. As a consequence, much data was gathered "in between" other experiments, frequently resulting in strongly varying data density and even in an incomplete coverage of the entire area of interest.

The "deep-water" survey systems with rather low frequencies of 12kHz (EM-120) or 15.5kHz (Hydrosweep) and beam angles of $2^\circ \times 2^\circ$ (EM-120) and $2.3^\circ \times 2.3^\circ$ (Hydrosweep) limit the resolution of bathymetric measurements to several tens of metres to hundred of metres horizontally and several metres vertically. To image the morphology, however, resolution and accuracy of the depth measurements are not as important as is compatibility of resulting data in the interests of seamless merging.

Data Processing

Routine processing of bathymetric data from continental margins comprises checking and processing of navigational and ancillary data (roll, pitch, heave, heading), calculating ray bending of beams through water layers, cleaning data and removal of artifacts, and calculation of a Digital Terrain Model (DTM). Considerable care has to be taken in calculating the DTM because of the disproportionate data distribution due to randomly spaced acquisition profiles.

Multibeam surveys in deep water generally yield less data per square unit than do shallow water surveys. This means that a statistical approach to data cleaning and outlier removal, as it is commonly applied to shallow water data, would result in disregarding of a large number of data points and hence to low resolution of the DTM. In order to extract as much information as possible, a thorough visual examination of all beams and manual data cleaning is performed, resulting in validation of any single sample. This admittedly time-consuming procedure allows gridding of the data with the highest possible resolution. The compilation and merging of data from several cruises also requires special attention. Interpolation and gridding of datasets of extremely varying quality is accomplished by allotting different weights to each dataset. In addition, a function weighting the outermost beams less than the more reliable inner beams is applied for interpolation in areas with overlapping tracks. In general, the processing of deep water data does not follow a routine scheme but has to be adapted to any particular dataset.

Data Visualisation

For the eye of the interpreter, submarine morphology can be best understood if represented as an image. Therefore we prefer to present the final results in shaded relief Figures rather than in isocontour maps. In order to enhance even fine details and make them visible, artificial illumination is applied to the data. The illumination effect is calculated from the gradient of the surface of the DTM in a distinct direction, thus enhancing features perpendicular to the illumination direction and suppressing structures parallel to it. By calculating the same DTM with different illuminations, many more detailed features can be detected.

Continental Margin Morphology off Costa Rica and Nicaragua

Off Pacific Central America the oceanic Cocos Plate converges with the continental margin at a speed of about 9cm per year. The Middle America Trench marks the deformation front at which the oceanic plate subducts beneath the continental margin. This segment of the Central American Margin provides, along a relatively short distance, a spectrum of quite different subduction styles and scenarios. These show up well in the submarine morphology. The compiled and merged bathymetry of this area is presented in Figure 1. The complete dataset covers a region of more than 600km in length and, on average, 100km width. It is evident from Figure 1 that the morphology of the oceanic plate varies remarkably along the trench. It is also quite obvious that the structure of the incoming, down-going plate influences the style of the morphology of the overriding continental margin.

Steep Subduction off Nicaragua

The ocean crust off Nicaragua in the north-west (Figure 2) is intensively cut by normal faults parallel to the trench. The distinct "Horst-and-Graben"-structure indicates a steep bending and descending of the subducting plate, clearly demonstrated in the perspective view (Figure 2). The down-going slab also tends to bend and over-steepen the continental slope, documented by the normal faults in the middle slope and by the large embayments caused by giant submarine landslides. The down-transported material is accumulated in trench-parallel ridges at the foot of the margin.

The Seamount Covered Segment off Central Costa Rica

Off central Costa Rica about forty per cent of the ocean plate is covered by large seamounts, extinct volcanoes, moving with the ocean plate towards the trench (Figure 3). As the ocean plate is subducted, these seamounts plough into the lower continental slope, uplifting the overlying layers and forming a local domal high. When the uplift becomes too steep the trailing flank fails, causing large submarine landslides and steep scarps. Such slides may cause local tsunamis. In Figure 3 may be traced several already subducted seamounts at different stages. Figure 4 presents an enlarged view of one of the most prominent seamount traces. The normal faults on top of the domal uplift, indicating extension, are clearly visible.

Subduction of the Cocos Ridge

Just a bit farther to the south-east, the style of subduction changes remarkably. Off the Osa Peninsula the Cocos Ridge, a broad swell of volcanic origin with a height of about 1.5km, enters the subduction zone with almost no observable bending (Figure 5). The ridge is formed by tilted blocks, trending parallel to the ridge axis. These blocks tilt away from the crest of the ridge and form a crestral graben filled with sediments. The sediments are partly accreted at the base of the slope. In contrast to the image of the steeply dipping slab off Nicaragua, the morphology of this segment of the continental margin documents a very shallow subduction of the oceanic plate.

Conclusions

The examples of the Central American continental margin demonstrate that information on the geologic and tectonic history preserved by ocean floor morphology can be revealed by bathymetric measurements. Compressional, extensional, shear movements of the subsurface, as well as uplift or subsidence, shape the ocean floor in a specific way. Seafloor soundings allow us to derive information on the geological history of the oceans. Bathymetric measurements in continental margin areas with strongly varying water depths require considerable attention in data acquisition and processing. However, the information they yield represent an important contribution to our understanding of global geodynamics.