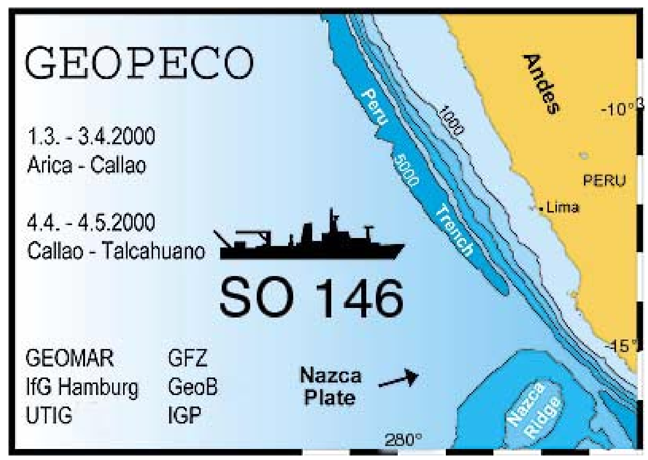
Peruvian cruise provides fresh insights into gas hydrates

Edited report from co-chief scientists Jörg Bialas of GEOMAR, Kiel and Nina Kukowski, GFZ, Potsdam on a geophysical acquisition campaign offshore Peru on board the RV Sonne to investigate the Peruvian convergent margin, its structure, geodynamics and gas hydrate systems.

Continental margin/plate tectonics

Off Peru, the oceanic Nazca plate is subducting beneath the South American plate making the Peruvian margin part of the circumpacific 'ring of fire', along which the most frequent and disastrous earthquakes and volcanic eruptions occur. Peru frequently suffers from strong earthquakes. No less than five large events with numerous victims and substantial physical destruction have taken place in the past 100 years. A most important role in the dynamics of this subduction zone is played by the Nazca Ridge, an elongated submarine basement high which subducts beneath southern Peru. Two large earthquakes have occurred along this part of the plate boundary and ruptured a 400 km stretch of the coastal area.



Gas hydrates

In large parts of the Peruvian margin, gas hydrates occur in the marine sediments, as has been inferred from seismic data and verified by Ocean Programme drilling. Gas hydrates – the 'burning snowball' – are solid, ice-like structures of water molecules forming a lattice of cages which contain low-molecular-weight gases such as methane as guest molecules. Gas hydrates are only stable at high pressures and low temperatures, conditions which are present in marine sediments at water depths of more than several hundred meters.

Often, free gas is present beneath the hydrate-bearing sediments. This causes the so-called bottom simulating reflector, a strong reflector with negative polarity. The great interest in gas hydrates results from their potential as a possible energy source as well as their potential role in climate change. Furthermore, gas hydrates influence slope stability on a local scale, which means they could also play a important role with regard to submarine avalanches or tsumani generation.

Open questions

- The internal structure of aseismic ridges and their role in subduction zone dynamics as not been well understood. It was commonly thought that they subduct aseismically, i.e. with a near absence of earthquakes. However, the Nazca ridge shows that this assumption may not be valid along some continental margins. Furthermore, the geometry of the subducting Nazca plate in the submarine part of the margin is not well known.
- Only little is known about the physical properties of hydrate bearing sediments, and the quantities of the hydrate in sediment are far from being established. The distribution of gas hydrates in marine sediments of the Peruvian margin varies in a complex way which is still poorly understood.

These open questions directly and indirectly impact the European economic system and make investigations into a better understanding of the character and evolution of such margins a long-term economic goal and not only a matter of pure research.

Results of the cruise

Structure of the continental margin and seismicity

During the GEOPECO cruise, an extensive geophysical data set was acquired which will enable us to make significant contributions to the problems described above. For the first time

the structure of the continental margin and the Nazca ridge was well imaged with six wide-angle seismic profiles. With three airguns, acoustic waves were generated which could travel through the earth's crust down to depths of more than 20 km beneath sea floor and are reflected and refracted through the intervening rock layers. The echoes of these waves were recorded with ocean bottom hydrophones or seismometers, deployed in water to a depth of about 6000 m. The remarkably steep dip in the Nazca plate close to the trench and the very steep continental slope indicate a high friction interface, which is in accordance with the observed high seismicity of the area.

Preliminary on-board seismic modelling showed that the downgoing Nazca ridge has an asymmetric crustal root and that here the dip of the downgoing plate is steeper than elsewhere. On the exposed part of the ridge, numerous submarine volcanic structures up to several hundreds of meters high, some of them with calderas, others in ridge-shaped masses with a rough surface, were observed with swath bathymetry. These details of the Nazca ridge morphology were previously unknown and indicate a complex and locally very variable magmatic activity during multiple episodes, which probably continued after the formation of the ridge itself.

As imaged in wide-angle seismic profiles across the continental margin at 13.5°S, 11.5°S, and 8°S, the Nazca plate thickness and structure varies. Its thickness varies between 7 km and 10 km, becoming thinner towards the north in the direction of decreasing age. At the latitude of the northernmost wide-angle profile, the oceanic plate has a very rough topography up to 80 km west of the trench with a relief of up to 800 m locally. Sediments were only found in pockets separating the highs.

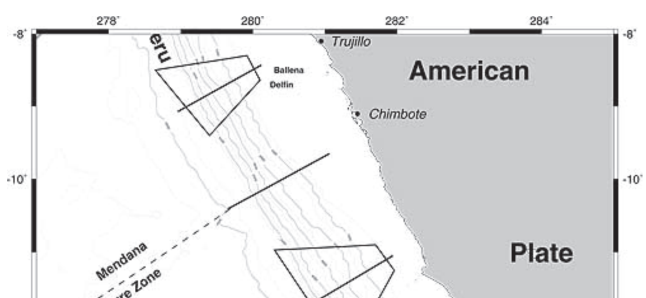
The structure's trend SSW–NNE in the northern part of the area surveyed with swath-mapping, while in the southern part and close to the trench, linear structures striking almost N-S were observed. This mapping of new structure will help scientists to better understand the mechanical processes where one plate is thrust underneath another and therefore the margin seismicity. In addition to the large earthquakes, small seismic events occur almost daily showing the dynamics of this continental margin. To observe natural seismicity, a small array consisting of several ocean bottom instruments was deployed for nearly 2 weeks. In this period, several earthquakes of various magnitudes were detected and relocated.

Sedimentary basins and gas hydrates

Several forearc basins on the upper slope play a key role in the gas hydrate systems of the Peruvian margin. These basins have developed since about 2 to 6 Ma in connection with the oblique subduction of the Nazca ridge from north to south. During the GEOPECO cruise, in the Yaquina and Lima basin, detailed investigations including seismic, bathymetric, gravimetric and magnetic data were acquired, supplemented by heatflow measurements, video-observations of the seafloor and sampling at some of these locations.

In the Yaquina basin, a detailed observation of the sea floor with the TV-sled OFOS and several series of densely spaced heat-flow measurements were carried out along a seismic line, in which a strong bottom-simulating reflector (BSR) indicating the base of the gas hydrate stability zone was identified. At several locations, authigenic carbonates were observed forming plateaus up to 15 m high and 500 m wide.

Living specimens of Calyptogena indicate the presence of H_2S, and methane-bearing fluid venting were also seen. These chemoautotrophic clams and tube worms (Vestimentifera) have specialized to live on H_2S. Very high resolution sediment–echo sounding data showed that populations of these species are often found where dipping sediment layers crop



out at the sea floor. These locations were sampled with the TV grab. The heat flow measurements showed significant local maxima at locations where fault zones cut the sea floor.

Similar Chemoherms have been reported from Northern Peru and at other margins, e.g. Alaska or Oregon. However, for the first time direct evidence for the presence of gas hydrate systems was found and the role of fault zones in gas hydrate transport was shown by three independent data sets (reflection seismics, seafloor mapping, and heat flow data) acquired simultaneously in one location.

In the Lima basin and adjacent lower slope, high resolution seismic experiments with small airguns (GI-guns) were performed along numerous closely spaced lines to map the complex BSR pattern in detail and to investigate the stratigraphy to systematically show a tectonically forced BSR-suppression in sediment with a very high organic carbon content.

During GEOPECO, an ocean bottom seismic source was deployed to study gas hydrate systems for the first time. These implosive sources generate a very clear seismic signal that allows sediment physical properties to be investigated at a high resolution. From these data, the depth of the BSR will be known in three dimensions. Such data is new and is expected to provide fresh insights.

The GEOPECO scientific team which undertook the project between March and May this year involved the collaboration of several German research institutions – GEOMAR, Kiel, GFZ, Potsdam, the Universities of Hamburg and Bremen – as well as international institutes – University of Texas, Austin; University of Utah, Salt Lake City; and the Peruvian Institute for Geophysics, Lima.