# R/V *Sonne* Off Peru

## *Along "Ring of Fire," New Geophysical Data for Investigating Gas Hydrates, Convergent Margin Structure, Seismicity*

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R/V Sonne is a 98-meter-long multipurpose research vessel, operated by RF Reedereigemeinschaft Forschungsschiffahrt (Bremen, Germany).

The Peruvian convergent margin—its structure, geodynamics and gas hydrate systems—was the goal of a two-month geophysical acquisition campaign of R/V *Sonne* from March 1 to May 4, 2000. The GEOPECO scientific team that undertook this project involved collaboration of several German research institutions: GEOMAR (Kiel), GFZ (Potsdam), universities of Hamburg and Bremen, and international institutes including U.S. universities of Texas (Austin) and Utah (Salt Lake City) and the Peruvian Institute for Geophysics (Lima).

### Continental Margin/Plate Tectonics

Off Peru, the oceanic Nazca plate is subducting beneath the South American plate making the Peruvian margin part of the circum-Pacific "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 large destructions took place in the last 100 years. The Nazca Ridge, an elongated submarine basement high, which subducts beneath Southern Peru, played a most important role in the dynamics of this subduction zone. No less than two of the large earthquakes mentioned occurred along this part of the plate boundary and ruptured a 400-kilometer stretch of the coastal area.

### Gas Hydrates

In large parts of the Peruvian margin, gas hydrates occur in the marine sediments as inferred from seismic data and verified from ODP (Ocean Drilling Program) drilling. Gas hydrates—the "burning snowballs"—are solid ice-like structures of water molecules forming a lattice of cages which contains low-molecular-weight gases like methane as guest molecules. Gas hydrates are only stable at high pressures and at the same time low temperatures—conditions that are present in marine sediments at water depths of more than several hundred meters. Often, free gas is present beneath the hydrate bearing sediments, which 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 locally influence slope stability, therefore, they also could play an important role in regard to submarine avalanches or tsunami generation.

### Open questions

Up to now, the internal structure of basement ridges and their role in subduction-zone dynamics is not 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 understood.

Up to now, only little is known about the physical properties of hydrate-bearing sediments, and also the quantity of the hydrate in sediment is 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.

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These open questions directly and indirectly impact the European economic system. As gas hydrate bearing sediments are also known from European marine exploration areas the gained knowledge will be of importance for the development and positioning of e.g. platforms. Understanding the formation and dissolution of gas hydrates is of great importance by means of global climate change and resources as well as in case of hazard occurrence. This makes investigations for a better understanding of the character and evolution of such margins a long-term economic advantage and not only a matter of pure research.

**Margin Structure, Seismicity**

During the GEOPECO cruise, an extensive geophysical data set was acquired which will enable us to make significant contributions to the problems described. 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 32-1 airguns, acoustic waves were generated which traveled through the Earth's crust down to depths of more than 20 kilometers beneath seafloor and were reflected and refracted through the intervening rock layers. The "echos" of these waves were recorded with seafloor hydrophones or seismometers, deployed in water depths down to about 6,000 meters. The remarkably steep dip of the Nazca plate close to the trench and the also very steep continental slope indicate a high friction interface, which is in accordance with the observed high seismicity.

Preliminary seismic modelling accomplished onboard shows that the downgoing Nazca ridge has an asymmetric crustal root and that in this area 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 where 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 seven and 10 kilometers, becoming thinner towards

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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 kilometers west of the trench with a relief of up to 800 meters localy. Sediments were only found in pockets separating the highs. The structures trend southsouthwest-northnortheast (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 north-south (N-S) were observed. This mapping of new structure will help scientists 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 two weeks. In this period, several events of various magnitude were detected and relocated.

**Sedimentary Basins, Gas Hydrates**

Several fore-arc basins on the upper slope play a key-role in the gas hydrate systems of the Peruvian margin. These basins have developed since about two to six million years in connection with the oblique subduction of 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 also supplemented by heat-flow measurements, video observations of the seafloor and sampling at some of these locations.

In Yaquina basin, a detailed observation of the seafloor with the TV-sled OFOS and several series of densely spaced heat-flow measurements were done 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 meters high and 500 meters wide. Living specimens of Calyptogena indicate hydrogensulfide ($H_2S$); also, methane-bearing fluid venting were seen. These chemoautotrophic clams and tube worms (Vestimentifera) have evolved to live on $H_2S$. Very high-resolution sediment-echosounding data showed that populations of these species often are found where dipping sediment layers crop out at the seafloor. These locations were sampled with the TV grab. The heat-flow measurements show significant local maxima at locations where fault zones cut the seafloor.

Similar Chemoherms were reported from Northern Peru and at other margins, e.g. Alaska or Oregon, however, here for the first time, direct evidence of 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

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flow data) acquired simultaneously in one location.

In the Lima basin and the adjacent lower slope, high-resolution seismic experiments with small airguns (GI-guns) were operated along numerous closely spaced lines to map the complex BSR pattern in detail and investigate stratigraphy to show systematically 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 in high resolution.


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For additonal information, visit website http://www.geomar.de/projekte/geopeco/index.html. /st/


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