GEOPHYSICAL INVESTIGATIONS ALONG THE PERUVIAN CONVERGENT MARGIN

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RÉSUMÉ

La marge continentale de Perou représent un sujet important des études géophysiques chez GEOMAR. Les résultats des interprétations des profiles sismiques réflexion sont présentés en combinaison avec la détermination du flux de chaleur apart de la profondeur du BSR (Bottom Simulating Reflection), des modélisations avec la méthode des éléments finites (FE) pour le flux des fluides et du chaleur, ainsi que des modèles réduits analogiques pour tester les interprétations kinematiques.

KEY WORDS: Peruvian Continental Margin, Reflection Seismics, Heat Flow, Fluid Transport, Finite Element Modelling, Sandbox Experiment

INTRODUCTION

The Peruvian continental margin is the subject of an integrated geophysical investigation at GEOMAR. Results from an interpretation of reflection seismic profiles are presented along with determinations of heat flow from the depth of the Bottom Simulating Reflection (BSR). These results can be used in finite element (FE) modelling of fluid and heat flow. Sandbox modelling is used to test kinematic interpretations.

SEISMIC STUDIES

From 13 reflection seismic profiles in three locations offshore Peru we present results from the southernmost profiles, lines 1017 and 1018, which are located at about 12° S (Fig. 1). These two profiles were acquired by SHELL in 1973 and have been re-processed at GEOMAR. In addition to conventional processing with a post stack time migrated section as output we have applied state of the art pre stack depth migration. The MIGPACK software package which we use for this purpose provides both a depth section and a velocity model. Two major advantages of this technique, which has been described by Diet et al. (1990), are the reduction of smearing effects compared to conventional post stack migration and the possibility to accomodate in the migration small scale lateral velocity variations. This leads to significant improvements for the imaging of structures in tectonically complex regions.

Fig. 2 presents a tectonic interpretation of line 1017. On the seaward side of this line, the subducted oceanic plate and its cover of sediments can be clearly identified. These sediments are underthrusted and can be followed some 20 km down the subduction zone. Duplex structures are interpreted in the accretionary wedge. A strong BSR marks the lower boundary of the stability zone for methane hydrates. The BSR shows a sharp negative seismic impedance contrast and is most probably caused by free gas beneath the hydrate zone. A major structural element further towards the continent is intensive normal faulting. Stratigraphic correlation of seismic horizons based on borehole information from ODP leg 112 allows a tectonic reconstruction of the Peruvian continental margin at this latitude. An unconformity which can be seen about 60 to 75 km landward from the trench represents a hiatus between late Miocene/early Pliocene during which there was an uplift of the continental plate, presumably caused by the subduction of the Nazca Ridge.

ASSESSMENT OF HEAT FLOW

A temperature gradient can be determined from seismic reflection lines in which a BSR is identified. This method, which has first been presented by Shipley et al. (1979) and Yamano et al. (1982), is based on the assumption that the BSR is located at the lower boundary of the methane hydrate stability zone. Thus, it represents a pressure/temperature point in the phase diagram for methane hydrates. Pre stack depth migration yields both a relatively accurate depth and good velocity information for the sediments above the BSR. Pressure at the BSR can be derived using a velocity/density correlation which is determined from core or logging data. Oceanographic data give access to temperatures at the seafloor. Information about thermal conductivity, which is available from ODP leg 112, then allows an estimation of heat flow values. The major advantage of this indirect method is that heat flow can be determined continuously along the BSR. Therefore, small scale lateral variations, which could indicate fluid venting, can be identified. A general increase in heat flow values towards the continent can be observed in the lower slope portions of both lines 1017 and 1018.

NUMERICAL MODELLING

Fluid and heat transport within the subducition zone off Peru is quantified using 2D coupled finite element modelling. These investigations assume a porous model with Darcian flow. Based on the interpretation of the seismic data, tectonic units have been discretized using unregularly spaced meshes. The physical parameters, which we have systematically varied, are permeability, porosity, thermal conductivity, heat production, and matrix compressibility. Our model calculations show the strong control of the tectonic structure on the fluid flow regime. Convective heat transport dominates only, if permeability exceeds 10^{-14} m^2.

SANDBOX EXPERIMNENT

Sandbox experiments have been conducted at the Laboratory for Structural Geology in Montpellier in April and December 1992 to test the concept of tectonic deformation at this convergent margin. They are based on the assumption that sediments in accretionary margins act as Coulomb material. It was possible with these experiments to model major structural elements and geometrical features at convergent margins and observe, how underplating elevated the front of the "backstop" off Peru. A period of tectonic erosion followed, which is assumed to have caused the subsidence observed in sediment from ODP cores.

DISCUSSION AND OUTLOOK

Different geophysical methods have been applied to achieve a better understanding of the complex processes which control the tectonic mechanisms in the subduction zone along the Peruvian continental margin. Improved images of tectonic structures clearly show the accretionary prism, the buttress of crystalline rock, against which accreted sediment was stacked, the normal faults from flexing of the continental crust during erosion, and the seismic stratigraphy resulting from uplift and subsidence.

Heat flow derived from the depth of the BSR generally increases towards the contintent, probably due to heat production in the continental crystalline. Friction at the subducted plate, however, could also play a role as another possible heat source. This should be investigated using modelling techniques.

Numerical modelling yields constraints on the thermal state and fluid flow pattern, whereas dynamic evolution and deformation behaviour is tested with sandbox experiments. Interpretations are constrained and greatly improved by integrating these techniques.

Future seismic work will focus on the Chimbote region further north, at about 9° S. We have a relatively dense set of seismic profiles from this area, which provides a three dimensional map of the main tectonic features. Heat flow in 3D will be estimated using the method described above.

It is planned to develop a FE model concept which allows for fluid transport in discrete fractures and for non-linear flow laws. We plan to work on the Chimbote data set for future investigations to get a basis for 3D modelling. We will try to include mechanical deformation in the numerical modelling.

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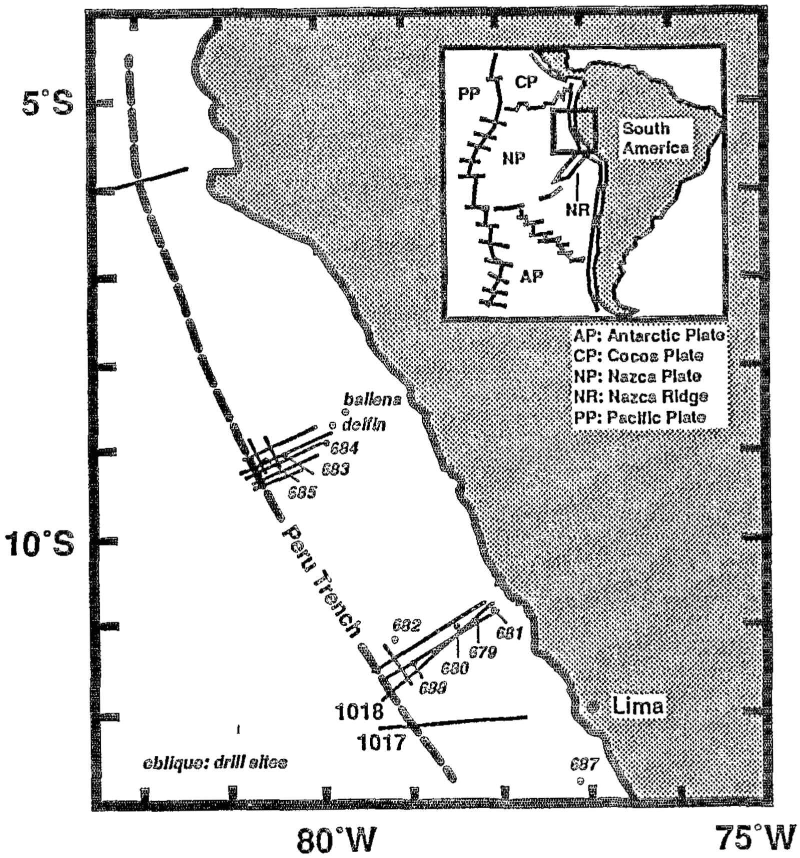

Fig. 1: Seismic lines from offshore Peru which are available at GEOMAR

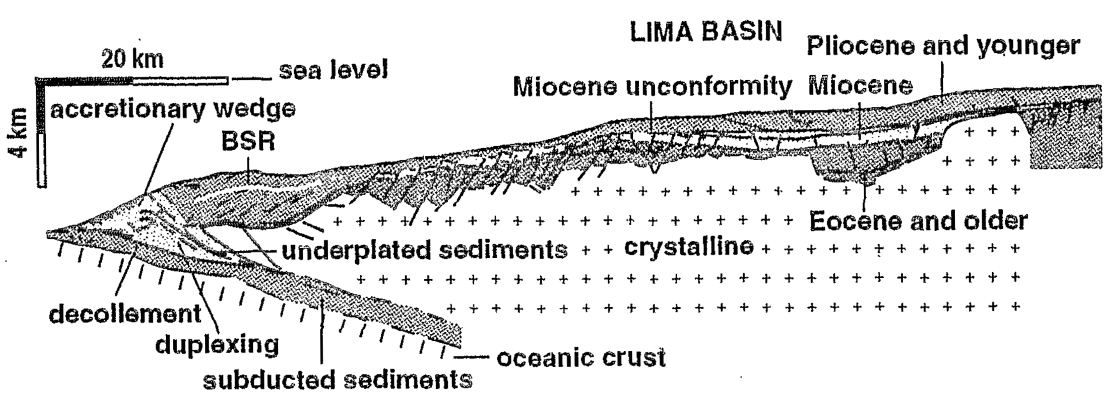

Fig. 2: Tectonic interpretation of line 1017.