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THE NATURE OF INTERMEDIATE-DEPTH SEISMICITY
IN THE CENTRAL ANDES

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INTRODUCTION

Intermediatedepth seismicity is a very hpical feature along subduction zones. The detailed shape of this seismic zone may differ from region to region, but there exists some common characteristics. In this contribution the nature of the intermediate depth seismicity is discussed comparing the situation along the converging zones of the Andean belt and in the Japan and the Kuril-Kamchatka arc system. In both regions the intermediatedepth seismicity is localised in the oceanic crust and in the uppermost mantle as well. Therefore the seismicity must be related to two different metastable phase transformations that are associated with the emission of seismic energy. The different shape of the seismic active zone is mainly dictated by the different converging rates, about 1 cda along the Japan and the Kuril-Kamchatka arc system and 10 cmla for the Andean arc.

THERMAL STRUCTURE OF THE DOWNGOING SLAB

For the study of the metastable phase transformations that are going on in the descending slab, the knowledge of the temperature field in the doungoing slab is of importance. The main parameters con-trolling the temperature distribution are: the rate of subduction; the age, thickness and dip of the de-scending slab, frictional heating along the shear plane between the upper and lower plate, the conduc-tion of heat into the slab from the deeper lithosphere and asthenosphere, and the heating of the top of the slab caused by the induced convecting corner flow in the upper plate.

A simple method for an approximate steady-state temperature calculation has been proposed by MOLNAR and ENGLAND (1990) and PEACOCK (1993).Here the method proposed by PEACOCK (1993) has been applied and exqended for a depth depending shear stress and variable dip angle. In ad-dition heating of the top of the slab by the induced corner flow has been taken into consideration.
For the follouing considerations hvo temperature gradient zones are of importance. In the upper zone, mainly situated in the oc-c crust immediately beneath the shear plane between the upper and lower plate, the temperature decreases

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METASSTABLE PROCESSES IN THE DOWNGOMG SLAB

The upper 8-10 km of the downgoing slab is composed of basaltic and gabbroic rocks forming the oce-anic crust. The underlying oceanic mantle is made up by peridotitic rocks uith olivine and pyroxene as main components. Therefore two different metastable processes must be considered for the explanation of intermediatedepth seismicity,

The metamorphic evolution of the subducted oceanic crust can be described by calculated P-T-paths and a model of metabasalt phase transformation (PEACOCK 1993). Fig. 1 presents the corresponding phase diagram. In steady-state subduction zones uith moderate to low rates of frictional heating and a dip of 2O0-30' most of the subducted oceanic crust moves along the low-T and high* path from the blueschist into eclogite field in the depth interval 70-120 km.. This path is associated with the release of a relative large amount of fluids (up 5.9 wt %), which cause hydraulic fracturing of the overlying rocks. The asso-ciation between the injection fluids and hydraulic fracturing of rocks and the emission of seismic energy is evidenced experimentally. In contradiction in flat subduction the cooling of the do\\ngoing slab is only moderate and the transformation runs along the high-T and low-P path which enters the eclogite field through the epidote-blueschist and amphibolite facies fields with small release of fluids.

An other process must be considered for the generation of seismicity in the uppermost mantle. KAO and LW (1995) have studied the double seismic zone along the Japan and Kuril-Kamchatka arc. Here the upper and lower seismic zone are separated more than 30 km. Thus the lower zone is situated in the up-permost mantle and a process must exist, which refers to mantle composition. They propose as the most likely candidate for such a process decomposing of Al-rich enstatite to Al-poor enstatite plus garnet. Like the transformation process oli\ine to spine1 that is associated uith the emission of seismic energy, the same is assumed for the enstatite process. Fig. 2 shows the corresponding phase diagram, derived by KAO and LW (1995) from petrologic, geothed and seismological data. It should be noted, that the critical phase boundary is situated along a low-P and high-T path below 80-100 km depth in the tem-perature range 40O0-500°C. This is just the same temperature interval of the upper gradient zone in the downgoing slab (Fig. 1).

Fig. 1: P-T-diagram of metamorphic facies Fig. 2: P-T-diagram of the emstatite system (based based on experimental and theoretical phase on KAO and LIU 1995). The grey zone as seismi-
diagrams compiled by PEACOCK (1993). cally active phase is derived from the seismological
At, Bt, Ct :P-T-path of the top of the oceanic and geothed situation along the Japan and Kuril-
crust, model A, B, C Kamchatka arc system. It is assumed that this
Ab, Bb, Cb :P-T-path of the base of the ace- diagram can be applied to other subducting systems
anic crust, model A, B, C as well.

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PISCO 94

Aiming to study the detailed structure of the intermediatedepth seismicity a network of about 25 mobile seismic stations were installed in the Precordillera and the Western Cordillera of the Central Andes op-erating between February and May 1994. The network operated in a continuous mode within an area of 200 km (W-E) X 250 km (N-S). About 50-100 events per day could be recorded in the magnitude range -0.5 to 4 (local magnitude scale). The accuracy of localising is i2 km. Most of the events could be lo-cated in the depth range 75 to 120 km. Fig. 2A, B shows two sections derived from the high resolution PISCO 94 experiment, showing different pattern of seismicity.
-75' -70' -65' 4 Seismicity between 21.75' - 22.25' S
E

E

Fig. 3: Seismicity pattern in the Central Andes, Fig. 4qB: Two sections through the Central based on the PDE catalogue. Andes showing the varying shape of the inter-mediatedepth seismicity

P-T PATHS AND SEISMICITY IN THE CENTRAL ANDEAN CONVERGING SYSTEM.

Aiming to match the observed seismicity with the metastable phase diagrams described above three thermal models with varying subduction parameters were calculated. Following parameters were used:

Table 1
model A model B model C

convergence rate 10 10 10 cmla
dip of the subduction plane 17' 2O0/4O0/6O km 15"/8"/40 km
thermal cond. crustlmantle 2.5.12.0 2.5.12.0 2.5.12.0 W1m.K

msity 1 1 1 lad m-2
mantle heat flux 0.050 0.050 0.080 W/m2
frictional heating ('I 60 150 40 150 40 150 kmlMPa
corner flow heating(') 400°/70-200 400°/70-200 0 "Cflun
(1) frictional heating increases linearly with depth, given max. depth (km)and max. stress (MPa)
(2) heating of the top of the slab by the induced corner flow, given the temperature increase('C) and in the corresponding depth interval (km).

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The transitional phase boundaries depicted from the phase diagrams are plotted in Fig. 5A, B, C. These transitional zones may have a nidth of at least 50'-100' C and 0.1-0.2 MPa (3-6 km). In addition the subducted slab may show deviations from the plane structure thus an actual thickness for the transitional phase zones of at least 10 km may result.
Fig 5A should be compared with Fig 4A. The seismicity is concentrated in the depth interval behveen 80 and 120 km. In Fig 4B, lower section, the seismicity is strechted between 80 and 200 km depth. The corresponding model in Fig. 5B shows that the transitional phase boundaries are situated behveen 80 and 160 km. In the third case (Fig. 5C), the flat subduction, there a strongly reduced or even no seismicity in the intermediatedepth level because in both phase diagrams the descending slab moves along the high-T-low-P path associated nith only small release of fluids.

Fig. 5A,B,C The geothermal structure in the donngoing slab (parameters see table 1)
model A: dip 17'; model B: dip 20°/400; model C: dip: 15O/8O

CONCLUSIONS

The nature of intermediatedepth seismicity is caused by metamorphic processes going on in the upper and lower temperature gradient zone in the downgoing slab. Considering seismological data, geothermal calculations, and petrologic considerations the intermediatedepth seismicity in the Central Andes is explained by hvo Merent metastable phase transformations, which occur in the oceanic crust resp. in the uppermost mantle. Both processes are associated nith the emission of seismic energy. The Merent shape of the seismically active zone in the Central Andes can be modelled by variations of the parame-ters controlling the temperature field in the downgoing slab. The same processes take place along the Japan and Kuril-Kamtchatka arc system. A clearly recognisable separation of both zones depends on the thermal structure in the donngoing slab, which is dictated by the converging rate.
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