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Swiss National Committee for the International Geodynamics Project
Working Group 3: Explosion Seismology

The Structure of the Earth's Crust and Upper Mantle from Controlled Source Observations

Report by *J. Ansorge**) and *St. Mueller**)

The Swiss activities in explosion seismology pertinent to the International Geodynamics Project can be subdivided into the following topics:

(1) The structure of the crust and upper mantle in Switzerland with special emphasis on the Alps
(2) The comparative investigation of the crustal structure beneath the various orogenic systems surrounding the Western Mediterranean, i.e. the Alps, the Pyrenees and the Betic Cordilleras in Southern Spain
(3) The continuing comparison of the earth's crust beneath the old Hercynian mountain system of the Black Forest and Vosges Mountains, the Rhenish Massif, the Armorican Massif and the southwestern part of the Iberian Meseta
(4) The determination of the fine structure of the upper mantle in Europe from long-range seismic observations
(5) The ultimate aim of these investigations is to contribute to a better understanding of crustal evolution.

The above-listed subjects of main effort and areas of interest are clearly visible in the schematic compilation of explosion seismic profiles in Fig. 1. All these experiments have been organized and carried out in close cooperation between many European geophysical institutes which were grouped together for individual areas by the common scientific interest. Fig. 1 shows those areas of investigation in Europe where Switzerland had a substantial scientific interest. Only the main contributions of Switzerland to the Geodynamics Project in the field of explosion seismology will be mentioned in this brief report.

The Rhinegraben, the Swiss and French Folded Jura Mountains southwest of the Rhinegraben and the Alps have been the areas of prime interest. All three

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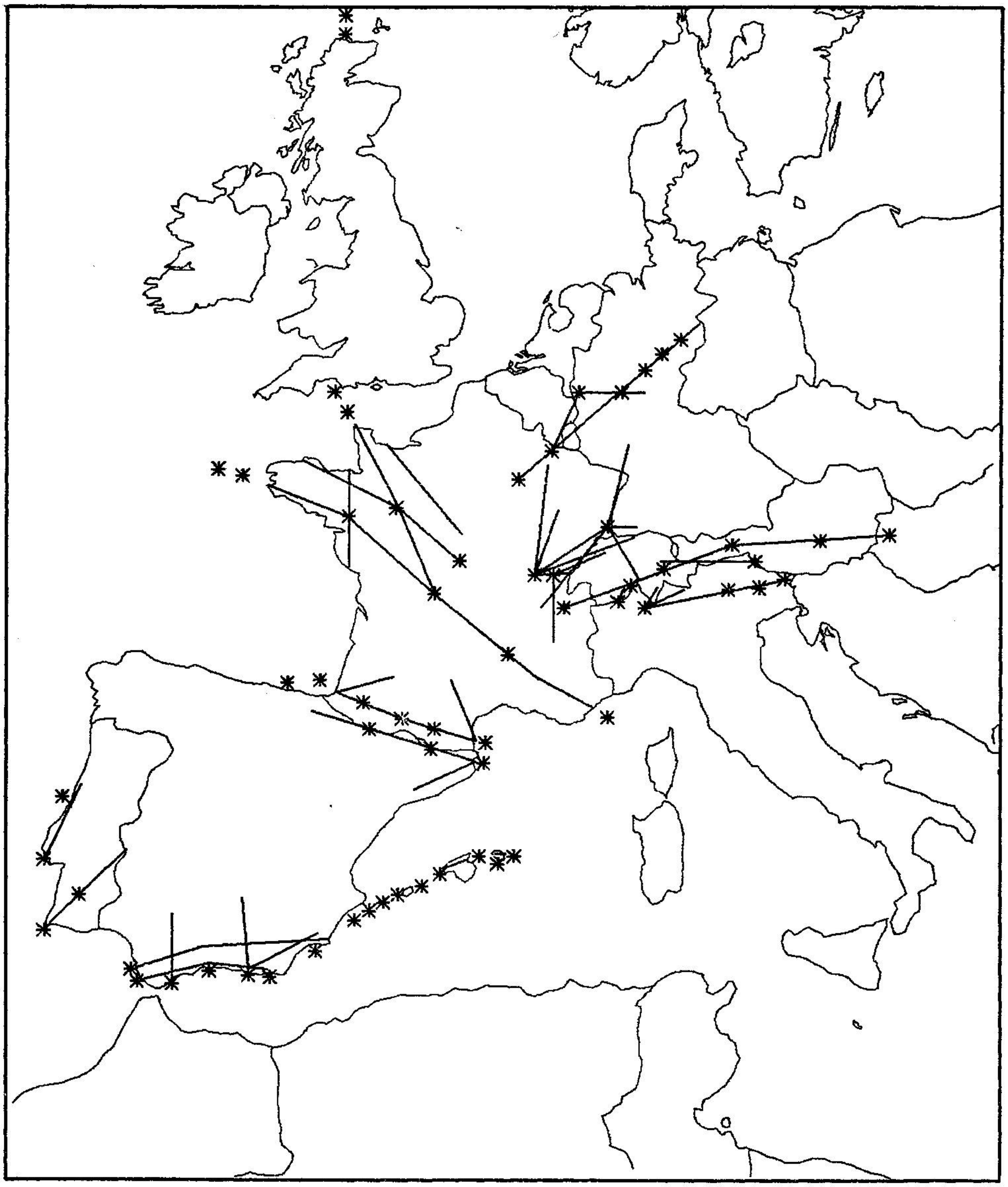

Fig. 1 Location of lithospheric seismic profiles and shotpoints in Europe. The map shows only those projects in which there has been a major Swiss participation and contribution between 1971 and mid 1979.

regions are connected by the Swiss geotraverse extending from the southern Rhinegraben across the Alps to the Po valley in northern Italy.

The area next to the Rhinegraben, i.e. the folded Jura, is characterized by the influence of a pronounced mantle upwarp to a depth of less than 30 km which is only slightly more than under the Rhinegraben itself. The crustal structure in this area continues southwestward to the Bresse depression and Massif Central in France (MUELLER et al., 1973b; EGLOFF and ANSORGE, 1976; PRODEHL et al., 1976).

In order to achieve a better understanding of the Alpine structure and evolution which is the main goal of the Swiss geotraverse a series of detailed crustal seismic experiments has been performed in the central and southern Alps in recent years. The most outstanding undertaking was the lithospheric seismic profile along the axis of the Alps in 1975 over a distance of 850 km from France to Hungary (ALP 75) (ALPINE EXPLOSION SEISMOLOGY GROUP, 1979; MUELLER et al., 1976). This was supplemented on a minor scale south of the Periadriatic line in the Southern Alps by another profile parallel to the tectonic strike extending over a distance of 380 km (ANSORGE et al., 1979). Fig. 2 shows four velocity depth distributions along the main line of ALP 75 from west to east

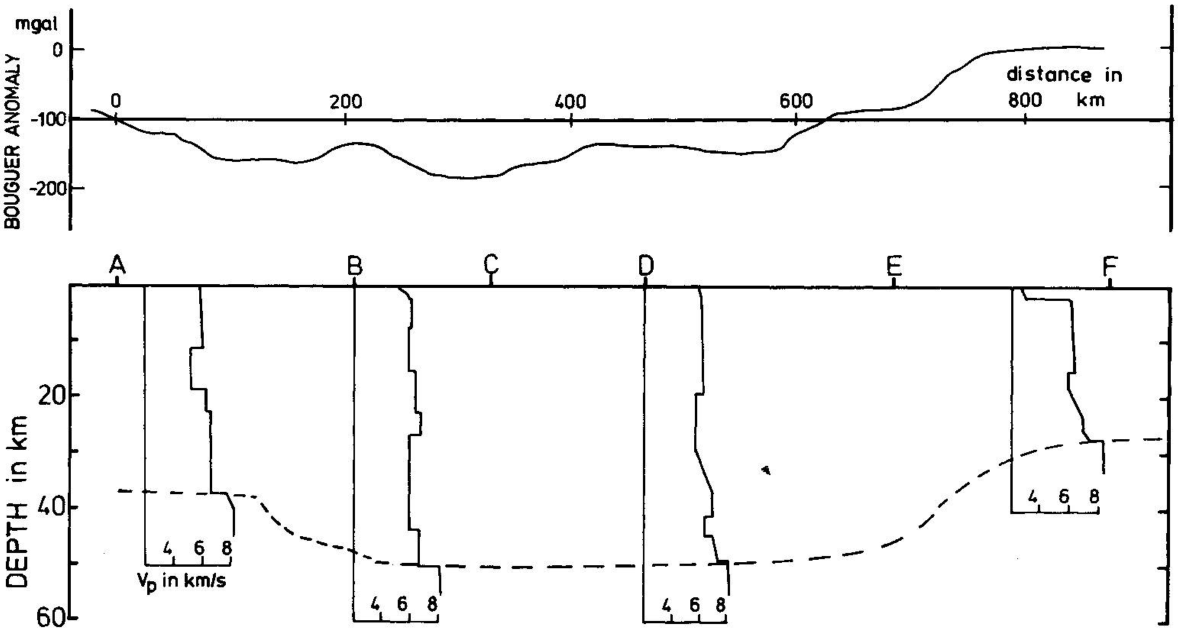

Fig. 2 Crustal structure along the main line of the Alpine Longitudinal Profile 1975 illustrated by selected velocity-depth functions. The dashed line represents the crust-mantle boundary. Vertical exaggeration is five times (after MILLER et al., 1978).

with A through F indicating the position of shotpoints (MILLER et al., 1978). The velocity-depth models near the endpoints A and F pertain to the crustal transition across the margins of the Alps where horizontal velocity variations have to be assumed. But even in the center of the Alps pronounced lateral differences of the crustal structure between the Western and Eastern Alps seem to exist as one can see from the models near points B and D in Fig. 2. Whereas the velocity-depth distribution for shotpoint D is characterized in its upper part by a uniform velocity gradient, the distribution for shotpoint B shows a multilayered upper crust including a low-velocity zone. Both velocity-depth distributions have in common a rather marked low-velocity zone which lies at depths between 19 and 33 km in the east and between 26 and 43 km in the Western Alps. The dashed line in Fig. 2 gives the Moho topography with the same mean depth of 50 km for the crust-mantle boundary in the central part of the Alps.

It has been tried to combine the interpretation of all available explosion seismic data between the Rhinegraben and the Po valley together with the current knowledge of the tectonic regime along the Swiss geotraverse in order to come to a conclusive picture of the tectonic evolution. This implies - among other findings - the interpretation of the Aar Massif as a flake of the upper crust which has been sheared off at the level of a zone of velocity inversion in the upper crust and then has been bent upward. Two crustal slabs are superimposed in the adjacent central Alpine (Penninic) block. The Ivrea Zone in the Southern Alps is characterized also by a flake-type structure where the whole crust has been sheared off above the crust-mantle boundary and then has been pushed upward (MUELLER et al., 1976).

Two other areas with special interest are the Betic Cordilleras in Southern Spain and the Pyrenees which are both parts of the Alpine belt in the Western Mediterranean area (Fig. 1). A fairly conclusive picture of the crustal structure in the eastern part of the Betic Cordilleras and under the Balearic Islands has been obtained by a sufficient number of experiments. Strong lateral variations of the Moho depth from 23 km under the east coast to 29 km and 38 km under the south coast and the center of the Cordilleras, respectively, characterize this region. Similar pronounced variations in the internal structure of the crust have been found. The P_n velocity varies from 8.1 km/s under the Betic Cordilleras to 7.6 km/s under the Balearic Islands (WORKING GROUP FOR DEEP SEISMIC SOUNDING IN SPAIN 1974–1975, 1977). No crustal details can as yet be given for the Pyrenees. The data are still being processed.

The investigations along the continental margin of Portugal (MUELLER et al., 1973a; MOREIRA et al., 1977) have been extended to the Canary Islands where several crustal seismic experiments have been performed in close cooperation with Spanish institutions.

The continuing interest in continental rift structures has led to a promising investigation of the lithospheric structure of the Yellowstone-Snake River Plain in North America as the trace of an intraplate hotspot. This work which will be continued has been carried out in cooperation with the University of Utah and Purdue University.

Special attention has been paid to the fine structure of the uppermost mantle under Europe. Based on the interpretation of older European data ANSORGE and MUELLER (1971 and 1973) have already suggested that the lower lithosphere possesses a fine structure in the velocity-depth distribution. The first long-range profile with dense station spacing was observed in 1971 from a shotpoint off the coast of the Bretagne in France (Fig. 1) (GROUPE GRANDS PROFILS SISMIQUES AND GERMAN RESEARCH GROUP FOR EXPLOSION SEISMOLOGY, 1972). These data

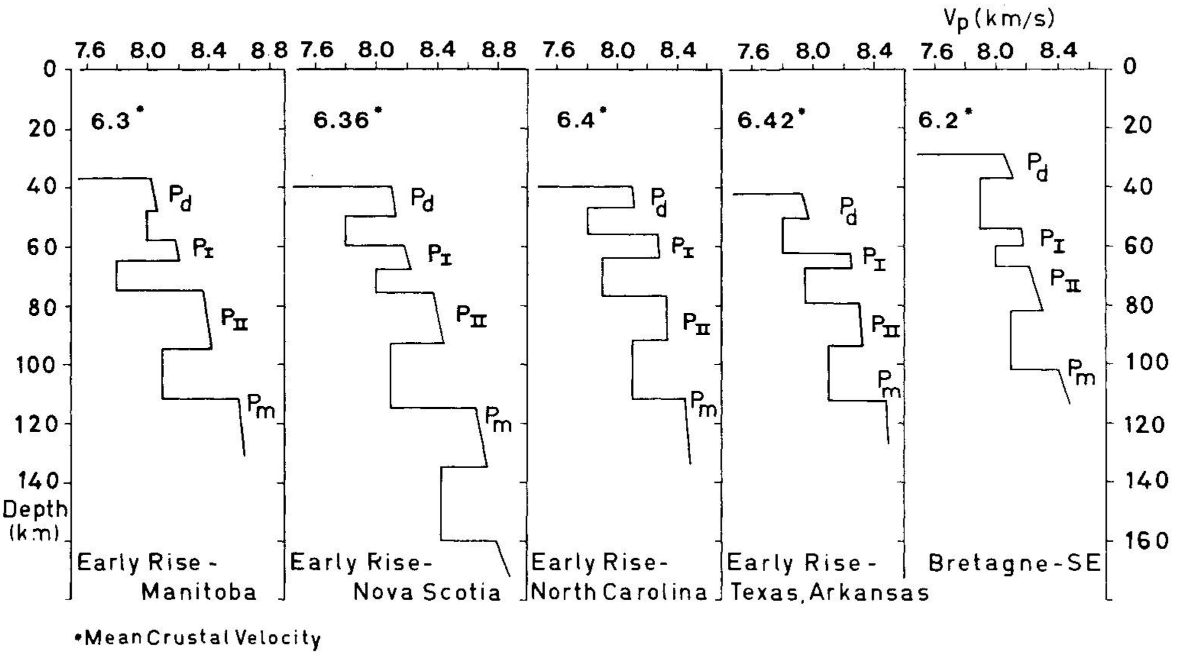

Fig. 3 Depth distributions of P-wave velocity in the uppermost mantle unter North America and western France (after ANSORGE, 1975).

have been interpreted by several authors all of whom came to the conclusion that there are strong variations of the P-wave velocity with depths which also include clear velocity reversals within a depth range of 100 km (HIRN et al., 1973; KIND, 1974; ANSORGE, 1975). Fig. 3 shows a comparison of the model derived from the Bretagne data with models obtained from observations during Project Early Rise (1966) in North America (ANSORGE, 1975; MUELLER and ANSORGE, 1975). Two facts are quite obvious: The average crust under North America is about 10 km thicker as compared to the crust under Europe. There seems to exist the same general structure of alternate layers with high and low velocities both under western Europe and stable North America. The average velocity under North America is by about 0.1 km/s higher than under western Europe.The deduced structures for the lithosphere under western Europe and the tectonically stable area of North America clearly show that the concept of a rigid lithospheric plate is a rather crude description of the actual situation.

The existence of a complex internal structure throughout the entire depth range between the M-discontinuity and the asthenosphere has also been demonstrated in the comparatively small region of the South German Triangle between the Rhinegraben in the west, the Bohemian massif in the east and the Alpine orogen in the south (ANSORGE et al., 1979). Unusually high average P-wave velocities of 8.5–8.6 km/s have been found in this area at depths between 40 and 50 km. These velocities are considerably higher than the average velocities of 8.2 km/s under other areas of western and central Europe.

With the availability of more and better explosion seismic data combined with more reliable information from petrology and the properties of rocks,

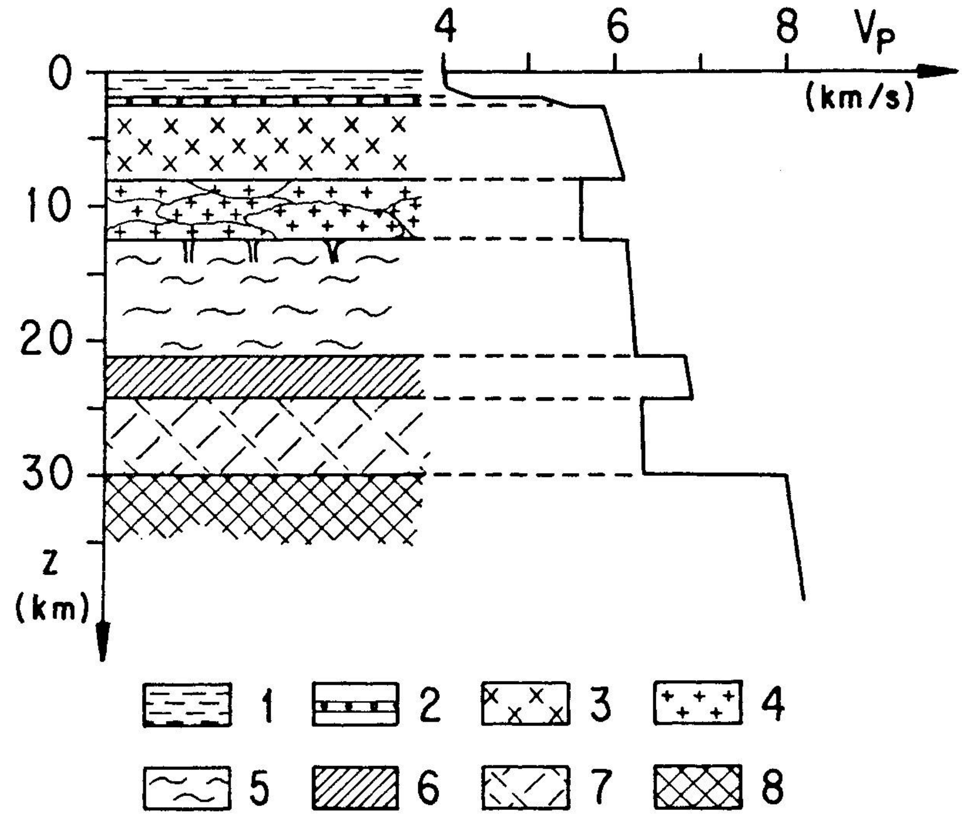

Fig. 4 Schematic new model of the continental crust:
1, Cenozoic sediments (near-surface low-velocity layer); 2, Mesozoic (and Paleozoic) sediments; 3, upper crystalline basement consisting of metamorphic rocks, such as gneisses and schists (zone of positive velocity gradient); 4, laccolithic zone of granitic intrusions (sialic low-velocity zone); 5, migmatites (middle crustal layer); 6, amphibolites (high-velocity tooth); 7, granulites (lower crustal layer); and 8, ultramafics (uppermost mantle) (after MUELLER, 1977a).

MUELLER (1977a) has proposed a new model of the continental crust (Fig. 4). The significant features of the new velocity-depth function are: The velocity gradient in the top part of the crystalline basement is governed by the increasing pore pressure with depth. The sialic low-velocity zone in the upper crust (LANDISMAN et al., 1971) has been associated with granitic intrusions and is again influenced by the water content and pore pressure. The middle and lower crust is characterized by a low average velocity which may be interrupted by thin high-velocity laminas. The crust-mantle transition must be relatively sharp in order to explain the observed multiply reflected wide-angle reflections from the M-discontinuity. In a subsequent step a first attempt has been made to outline a scheme of crustal evolution (MUELLER, 1977b).

Only a very small part of the described projects which were carried out by the Swiss Working Group for Explosion Seismology would have been possible without the encouragement of the Swiss National Committee for the International Geodynamics Project and especially the continuous support by the "Fonds National Suisse de la Recherche Scientifique", which is gratefully acknowledged.

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