Seismoactive fault systems in the basement and sedimentary cover of the Swiss Plateau and the Jura Mountains

Meanwhile, abrupt changes across faults have turned into useful information, welcomed as clues to interpret the tectonic history of the area: Post-Mesozoic block movements along strike-slip faults are the most likely explanation for abrupt changes of facies and thickness across faults below the Molasse Basin.

The amount of lateral movement along strike-slip faults must be considerable to become expressed in terms of thickness and facies of seismostratigraphic units, although giving any figures is still a matter of speculation.

The view of significant post-Mesozoic lateral block movements is strengthened by the observation of additional phenomena, regarded as typical expressions of wrench faulting, such as positive and negative flower structures, interpreted from seismic. The evidence of extensive fault and fracture zones in a well drilled by Nagra into the basement below a flower structure at Schafisheim, is a strong indication for the significance of fault systems below the Molasse Basin of northeastern and central Switzerland, interpreted as being related to lateral block movements.

Wrench faults underneath the northeastern Swiss Molasse Basin seem to have been strongly influenced by the tectonic heritage of the area. There are indications that movements went on repeatedly, some of them originating in the Paleozoic and rejuvenated episodically up to geologically recent times.

Seismoactive fault systems in the basement and sedimentary cover of the Swiss Plateau and the Jura Mountains

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Introduction

Detailed investigations of local and regional seismic activity have been performed during the last decade in northern Switzerland. These studies were made possible by the completion of the network of permanent seismic stations of the Swiss Seismological Service (SSS) and the installation of local temporary seismic networks (s. SSS, Montly Seismic Bulletins, Annual Reports). The increased density of seismic station distribution allowed an improved location of local small events and the construction of a large number of well-constrained fault-plane solutions and station diagrams.

Precise relative location of earthquakes

A characteristic feature of the seismicity of Switzerland is the occurrence of many earthquakes in clusters or swarms. The individual events of a particular swarm exhibit almost identical signal forms, and evidently correspond to repeated slip on the same fault. It is generally not possible to identify the actual rupture plane from a single fault-plane solution alone. The application of a very precise relative location technique to the earthquakes of a particular cluster, combined with the well-constrained fault-plane solution of the master event, enables the mapping of the active fault. Such detailed analysis has been performed for clusters of earthquakes in the eastern part of the Swiss Molasse Basin, in the Jura Mountains, and in the western part of the Swiss Plateau (Deichmann 1987b, 1990), as well as in the Helvetic zone of the eastern Swiss Alps (Roth 1990).

Focal depths in the northern foreland of the Swiss Alps

A major result of these investigations concerns the depth distribution of hypocenters: In the northern foreland of the Alps (Swiss Plateau, Jura Mountains) the foci of earthquakes are distributed throughout the entire depth range of the crust, down to 30 km (Jimenez & Pavoni 1984; Pavoni 1984; Mayer-Rosa & Garcia 1986; Deichmann 1987a, 1987b, 1990; Deichmann & Baer 1990).

Seismic energy release

Present tectonic activity, as documented by the distribution of earthquakes, is widely distributed in the crust of the foreland. A rough estimate based on the depth distribution of hypocenters of well located earthquakes shows that in the basement the seismic energy release per unit volume is at least as large as in the sedimentary cover. It seems that, at present, tectonic deformation of the sedimentary cover is intimately related with the tectonic activity in the basement underlying the Molasse basin and the Jura Mountains.

Focal mechanisms, fault systems and crustal stresses

The focal mechanisms are predominatly of strike-slip or normal fault type, or a combination of both types. Reverse faulting is indicated by the mechanisms of the earthquakes near Langenthal in 1974 and near Sarnen 1964. A systematic dependence of the mechanisms on focal depth is not observed. Based on well-constrained focal mechanisms and very precise relative locations it can be shown that the predominant north-south sinistral and the complementary east-west dextral strike-slip fault systems observed in the sedimentary cover of the northern and central Jura Mountains cut through the whole crust.

The orientations of P-axes display a regular counterclockwise rotation from NNW-SSE in the eastern Swiss Plateau to NW-SE and WNW-ESE in the Jura Mountains and western Switzerland, indicating a regular, fan-like pattern of maximum horizontal compressive stresses in the crust, roughly perpendicular to the axis of the Molasse Basin and the strike of the arc of the Jura Mountain chain (Pavoni 1977, 1980, 1984, 1987; Roth 1986). The orientation of P-axes corresponds well with the orientation of maximum horizontal crustal shortening as derived from a kinematic analysis of Neogene structural features. Maximum horizontal crustal extension, as indicated by the orientation of T-axes, is oriented parallel to the axis of the Swiss Molasse Basin and the fold axes of the Jura Mountains. Evidently the stress field which causes the present seismicity is very similar in its orientation to the stress field of the last 5 to 10 million years which produced the neotectonic deformation.

Criteria to define a seismoactive fault or fault zone

A fault, fault zone or fault system is considered to be seismoactive if one or several of the following criteria are satisfied:

(1) Direct observation of faulting in connection with an earthquake.
(2) Occurence of well-located earthquakes or micro-earthquake activity close to a known fault. In addition, a well-constrained fault-plane solution with one nodal plane showing the same orientation and sense of displacement as the fault is requested.
(3) Close correspondency of orientation of nodal planes and senses of displacement of well-constrained fault-plane solutions with the type and orientation of young fault zones observed in the epicentral region.
(4) Mapping of hypocenters by high-precision relative location of individual events of a local cluster of earthquakes displaying almost identical signal forms. Control by well constrained fault-plane solution(s).

Seismoactive faults

In the northern foreland of the Swiss Alps seismoactive faults and fault systems have been located in the western and eastern part of the Swiss Molasse Basin, and in the Jura Mountains. The Vuache fault in the southwestern part of the Geneva Basin is a well defined seismoactive fault (Sambeth 1984; Sambeth & Pavoni 1988).

The Fribourg fault zone, a north-south trending fault system with sinistral lateral displacement (Pavoni 1977; Pavoni & Mayer-Rosa 1978), represents a major seismoactive fault zone cutting transversely through the Molasse Basin and the underlying crust. The zone is outlined by the distribution of hypocenters of earthquakes 1972–1992 and well constrained fault-plane solutions (SSS, Annual reports; Pavoni 1977, 1984, 1987; Jimenez & Pavoni 1984; Fröhlich 1991). Seismoactive faults defined by high-precision relative location of hypocenters have been located near Günsberg, Läufelfingen and Zeglingen in the Jura Mountains (Deichmann 1990).

Conclusions

In the northern foreland of the Alps active faulting involves both the sedimentary cover and the crystalline basement throughout the entire depth range of the crust. The fact, that at present the crystalline basement is undergoing tectonic deformation is of importance for the understanding of the mechanism of folding of the sedimentary cover. The close relation of present active deformation in the basement with the observed Pliocene deformation of the sedimentary cover, as documented by the occurence of seismoactive faults, argues for an active role of fault movements in the basement with regard to the deformation of the overlying sedimentary series of the Swiss Molasse Basin and the Jura Mountains. It is reasonable to assume that the basement also underwent deformation during the folding of the Jura Mountains and the Chaînes Subalpines in the Pliocene.

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Present state of stress in the Swiss Molasse Basin

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Stress measurements in the Swiss Basin are carried out with different techniques but their number is very limited. Data exists from fault plane solutions of earthquakes, overcoring measurements and breakout studies in deep boreholes. Results from hydraulic fracturing experiments do not exist for the Swiss Molasse Basin but a number