MIOCENE TO PRESENT-DAY TECTONICS OF THE VIENNA BASIN TRANSFORM FAULT: LINKS BETWEEN THE ALPS AND THE CARPATHIANS

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Introduction

Extending from the central Eastern Alps through the Mur-Mürz-valley, the Vienna Basin and Moravia into the outer Carpathians of Polish Galicia, the 450 km long Vienna Basin transform system is one of the most conspicuous crustal structures between the Eastern Alps and the Carpathians. The fault developed during Miocene east-directed movement of Alpine crustal blocks into the Carpathian-Pannonian region (Fig. 1) which is referred to as eastward lateral extrusion (Ratschbacher et al., 1991; Decker and Peresson, 1996; Linzer et al., 1997). During lateral extrusion, parts of the central Eastern Alps moved eastwards between pairs of (E)NE-striking sinistral and (E)SE-striking dextral faults. Such pairs of faults are the sinistral Salzach-Ennstal-Mariazell-Puchberg fault and the dextral Periadriatic fault which were active during the Oligocene and the Early Miocene, and the sinistral Vienna Basin transform system and the dextral Lavanttal fault which moved mainly from the Early to the Late Miocene.

Earthquakes of low to moderate intensities along both the Vienna Basin transform and the Lavanttal fault show that kinematics of these faults is comparable to that of the Middle Miocene. It is evident that even moderate seismicity along the Vienna Basin transform which passes through densely populated and partially highly industrialized areas hosting numerous high-risk facilities causes high social and economical risks due to potential earthquakes. We therefore try to assess recent kinematics of the Vienna Basin fault system by drawing analogies to its Miocene history and by integrating microtectonic, geomorphological, seismological and 3D-seismic data provided by OMV. We show that this integrated approach provides information about the geometry and orientation of active faults, about the possible depth range of earthquake hypocenters, and about the average slip rate of the Vienna Basin fault through the Quaternary.

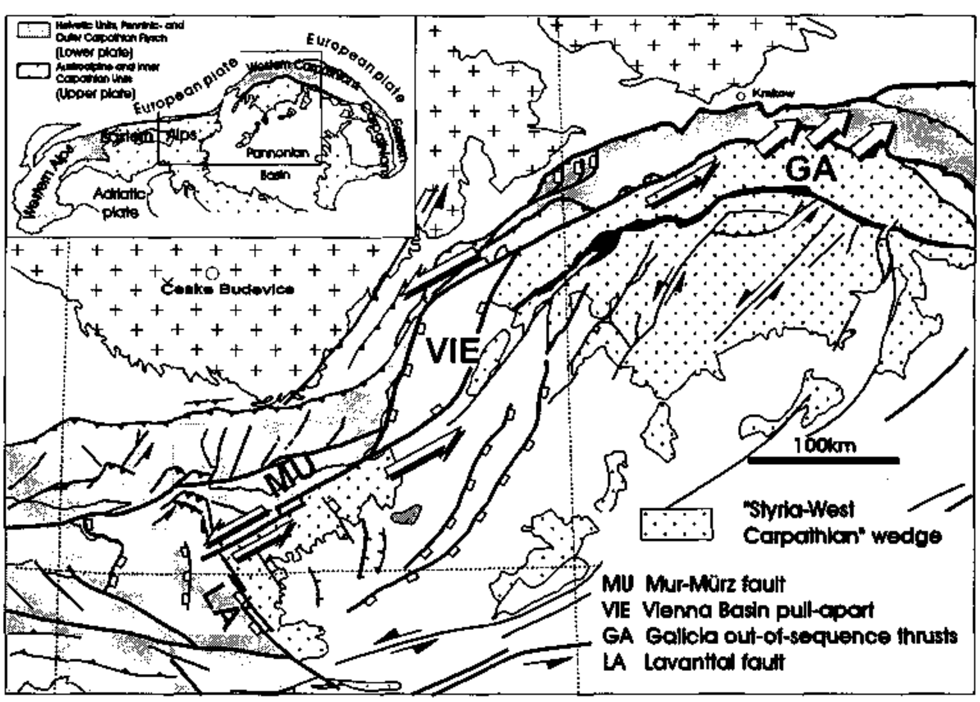

Fig. 1. Tectonic sketch map of the Vienna Basin transform fault extending over 450 km from the Mur-Mürz valley in the Eastern Alps to the Vienna pull-apart basin and to the Outer Carpathians of Moravia and Galicia.

Miocene tectonics

Sinistral movement along the Vienna Basin transform system started during the late Early Miocene (Ottnangian/Karpatian, c. 18-17 Ma) as indicated by initial subsidence of a series of small sedimentary basins along the Mur-Mürz-fault and by incipient pull-apart subsidence of the Vienna Basin. NE of the Vienna Basin, the sinistral fault crosses the flysch nappes of the outer Western Carpathians where NE-striking thrusts were reactivated as sinistral wrench faults. These faults link up with NE-directed out-of-sequence thrusts in Galicia. Together with the dextral Lavanttal fault, the Vienna Basin transform system deliminates a crustal wedge which moves towards NE and which is characterized by trailing-edge extension leading to subsidence of the Styrian Basin and to the tectonic exhumation of the Rechnitz metamorphic core, and by thin-skinned thrusting on its leading edge. Due to the kinematical linkage of strike-slip faults to thin-skinned thrusts we argue that deformation along the transform in the Vienna Basin and the continuation to the NE was restricted to the upper crust above the Alpine-Carpathian floor thrust. Miocene offset along the fault system in the Mur-Mürz-Vienna Basin area has been estimated with about 40±5 km. Since sinistral wrenching along the Vienna Basin transform continued up to the Late Miocene (c. 9-8 Ma; Peresson and Decker, 1997), this is equal to an average Miocene slip rate between 3.9 and 5.5 mm/year.

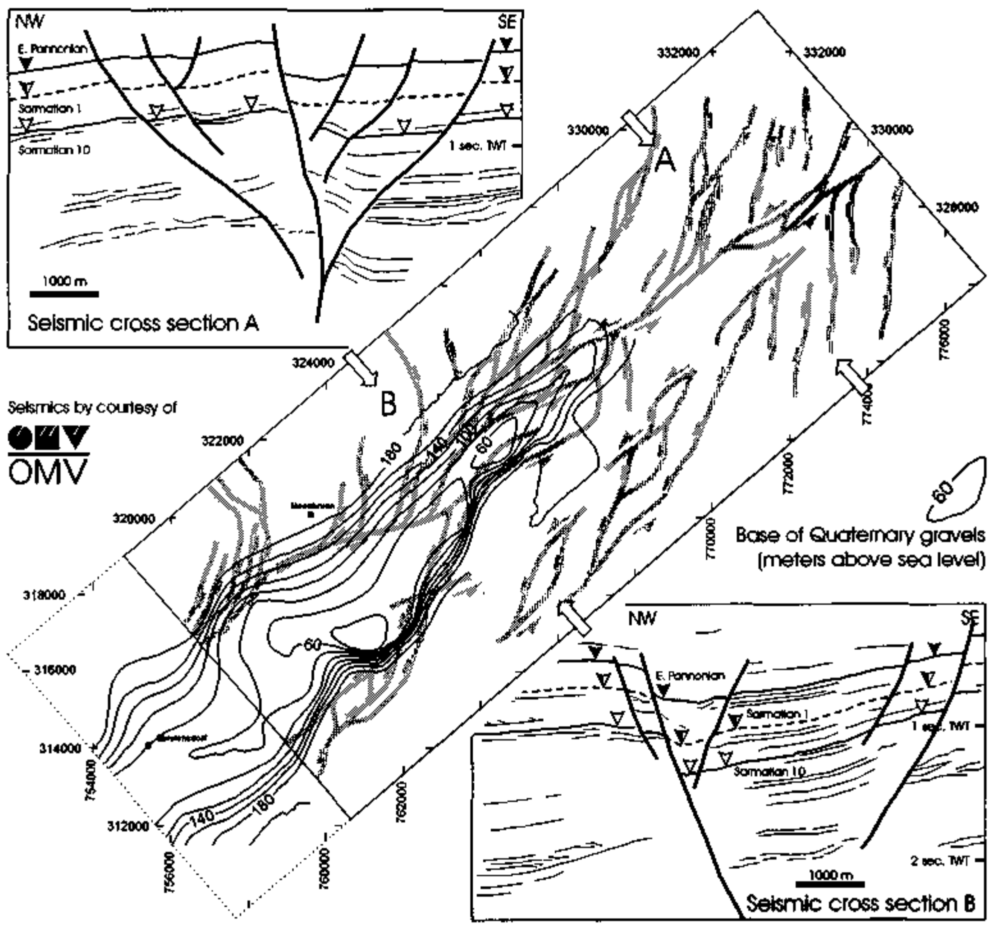

Fig. 2. Seismic cross sections and faults mapped from seismic data (OMV Moosbrunn 3D-seismic cube, southern Vienna Basin). Note the rhomb-shaped duplexes depicted by the offset of a mapped Sarmatian horizon and the negative flower structures shown in cross sections. The recent activation of the Miocene faults is indicated by thick Quaternary gravels incorporated in the flower structure.

In the Vienna Basin area, faults depict NNE-oriented extensional duplexes which are delimited by NE-striking sinistral faults and by N(NE)-striking normal faults. The latter are arranged in left-stepping en-echelon patterns. This surface fault architecture perfectly matches rhomb-shaped fault polygons mapped on Sarmatian and Pannonian horizons in 3D-seismic cubes in the Vienna Basin. In seismic cross sections, the N(NE)-striking normal faults define negative flower structures and merge into a subvertical principle displacement zone at depth (Fig. 2). Duplexing associated with substantial horizontal extension and normal faulting on NNE-striking faults is the main mechanism for the rapid subsidence of the Middle Miocene Vienna pull-apart basin. Growth strata show that normal faulting occurred from the Karpatian to the Pannonian (17-8 Ma). In 9 Ma, rift-type basement subsidence reached up to 5.8 km. Tectonic data, subsidence history and the thermal evolution of the Vienna pull-apart basin which is characterized by low paleo-heatflow throughout its evolution indicate that Miocene deformation was restricted to the uppermost 10-12 km of the crust above the Alpine floor thrust.

Active tectonics

The recent activity of the Vienna Basin fault system is indicated by moderate seismic activity recorded in the Mur-Mürz valley, in the Vienna Basin, the Little Carpathians and the Váh valley (Gutdeutsch and Aric, 1988). The epicenters line up to a NE-striking seismically active zone which extends to the High Tatra Mountains and which seems to terminate in the area of the Quaternary Orawa Basin N of the Tatra. Focal plane solutions and recent stress measurements indicate sinistral strike-slip motion along this fault (Gangl, 1975; Lenhardt, pers. comm.). Hypocenter depths mostly well above 12 km may indicate thin-skinned deformation which is restricted to the overthrust Alpine-Carpathian units. By analogy to the Miocene kinematics we speculate that the sinistral fault terminates in southern Poland where horizontal offset is transferred to thin-skinned thrust-type deformation. This model is generally supported by recent stress measurements from the outer Western Carpathians which indicate vertical stress partitioning and stress reorientation across the Carpathian floor thrust (Jarosinski, in press).

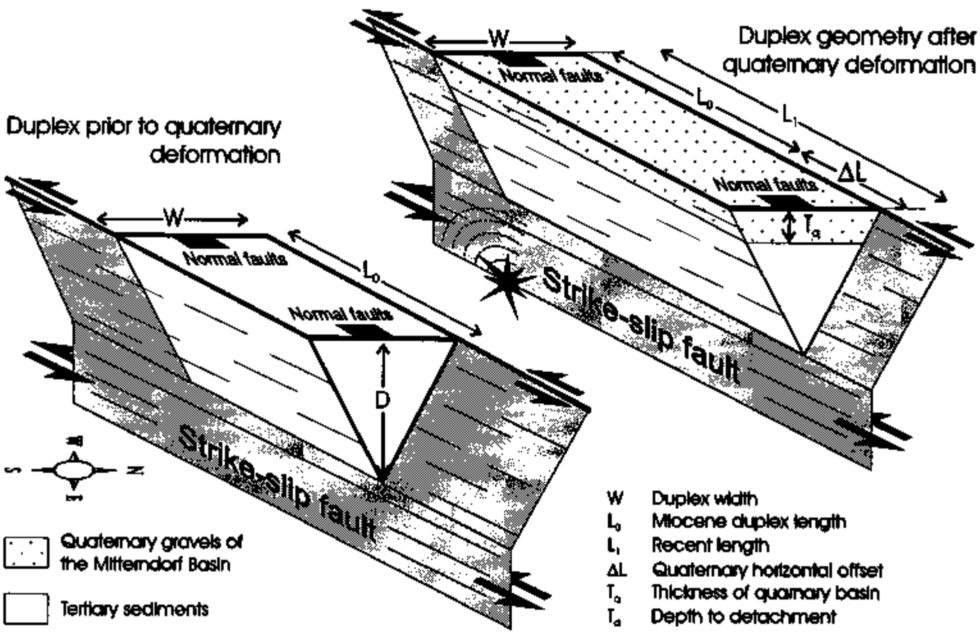

Fig. 3. Schematic drawing illustrating the duplex geometry which was used to quantify Quaternary horizontal displacement along the active faults of the Mitterndorf basin.

The active fault segment in the Austrian part of the Vienna Basin was mapped using analyses of microtectonic field data from Pliocene and Quaternary deposits, earthquake data, 3D-seismic cubes, thickness maps of Quaternary sediments, and geomorphological features like offset Quaternary terraces of the Danube seen in digital elevation data. Mapping of active faults shows patterns with N- and NE-striking faults which closely resemble the Miocene strike-slip duplexes. Sinistral movement along both, N- and NE-striking faults is proved by focal plane solutions from the Vienna Basin and the Mur-Mürz-Semmering region. Some of the faults delimit basins with up to 140 m thick Quaternary sediments. Comparison with seismic data of the 3D-seismic cube Moosbrunn shows that active tectonics use the pre-existing Miocene faults. The principle displacement zone imaged in seismic parallels a linear morphologic scarp of some 40 m height mapped in digital elevation data. The NE-trending scarp is traced over 15 km separating the elevated western block with Pannonian sediments at the surface from the eastern, downthrown block with up to 140 m thick Quaternary deposits. Short, pronounced valleys incise the fault scarp perpendicular to strike suggesting high syntectonic erosion partially compensating the vertical component of displacement. Wetlands and peats overlying thick Quaternary gravels of the downthrown block are interpreted as sag ponds along the fault zone. The distribution of Quaternary depocenters along the fault coincides with the fault patterns in Pannonian and Sarmatian horizons (Fig. 2). The amount of Quaternary sinistral lateral displacement along the fault zone crossing the southern Vienna Basin and the Moosbrunn seismic cube can be estimated by adopting a simple geometrical model which is able to quantify subsidence in divergent strike-slip duplexes. Fig. 3 shows that subsidence is achieved by lengthening the structure. By assuming constant volume of Miocene sediments inside the duplex prior to and after Quaternary deformation, it is possible to compute the lengthening of the duplex necessary for the observed subsidence (ΔL) which equals the Quaternary horizontal offset. Geometrical parameters appropriate for the Quaternary Mitterndorf Basin measured from seismic data and from Quaternary thickness maps indicate 1.5 to 2 km sinistral slip along the duplex during the Quaternary, corresponding to slip rates of 0.8 to 1.5 mm/year. These numbers are significantly higher than the slip rate of the Mur-Mürz fault which was estimated with 0.3 mm/year by seismic moment tensor summation (Aric, 1981).

Conclusions

We speculate that some aspects of Miocene tectonics along the Vienna Basin transform fault can serve as models for active tectonics in the Alpine-Carpathian transition area. Active faults seem to follow Miocene structures as shown by examples from the Vienna Basin. Other similarities between Miocene and recent tectonics are the thin-skinned nature of deformation and, eventually, the kinematical linkage of transform faulting and thrust-type shortening in the Carpathians of Galicia. Quaternary displacement along the transform fault in the southern Vienna Basin has been estimated with 1.5-2 km corresponding to a slip rate which seems to be significantly higher than the rate of seismic slip which was estimated from the energy released by earthquakes along the Mur-Mürz fault during this century.

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