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A short review of Environmental Tectonics of the Vienna Basin and the Rhine Graben area

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Abstract

ENTEC [Environmental Tectonics] was a European Community funded FP5 research network of nine European research institutes, coordinated by the VU Amsterdam in the years 2001-2004. The network aimed for a quantitative understanding of processes related to active tectonics in the Upper and Lower Rhine Graben and the Vienna Basin. These areas are associated with a much higher level of recent tectonic activity than hitherto realized, bearing major implications for the assessment of seismic hazards, which are generally solely based on historical catalogues. This paper reviews very briefly the results from the Rhine area and focuses on results for the Vienna Basin area.

Results for the Lower and Upper Rhine Graben areas show a strong influence of inherited structures on the rift behavior. The Lower Rhine Graben area is recently seismic active within a system of orthogonal extension. For the Upper Rhine Graben seismotectonic studies and geomorphological investigations demonstrate the activity of the present system, while field studies and several modeling approaches from regional to local scale helped to understand the Paleogene to recent evolution with oblique rifting and local stress perturbations.

For the Vienna Basin deformation rates of the main active fault system have been estimated by balancing (1.6-2.5 mm/yr) and seismic slip calculations (0.1-0.3 mm/yr). In comparison with GPS velocities from the literature a seismic slip deficit is indicated. Active faults have been mapped by integrating 3-D seismic data, subsurface horizons and Quaternary thickness maps, as well as geomorphological interpretations. The results show a complex fault system: A SW-NE trending negative flower structure is present in the southern and eastern Vienna Basin, with subsiding Quaternary basins on top. In the central Vienna Basin reactivated Miocene normal faults are present, as demonstrated by tilted terraces. Results have been compiled in a classified map of active faults and within a 3-D structural model. These are thought to be used in upcoming research on the kinematics and seismogenic behavior of the Vienna Basin area, thus providing important data for future seismic hazard assessments.

The ENTEC Network has shown, that integrated geoscientific approaches can lead to a significant better understanding of active tectonic processes in regions, which are difficult to investigate due to its quick surface reworking by fast erosion and human overprint as well as due to low deformation rates.

Das Projekt ENTEC [Environmental Tectonics] bildete ein Forschungsnetzwerk im fünften Rahmenprogram der Europäische Kommission in den Jahren 2001-2004. Es bestand aus neun Instituten aus Zentraleuropa und wurde an der VU Amsterdam koordiniert. Hauptziel der Forschung war es die Prozesse, welche in Zusammenhang mit aktiver Tektonik im Oberen und Unteren Rheingraben und im Wiener Becken stehen, quantitativ zu erfassen. Diese Gegenden zeichnen sich durch eine höhere tektonische Aktivität aus, als weitläufig angenommen. Dieses hat Konsequenzen für die Gefährdung durch Erdbeben, welche in der Regel nur auf der statistische Auswertung von historischen Beobachtungen beruhen. Die vorliegende Arbeit stellt kurz Ergebnisse aus dem Rheingebiet vor, und konzentriert sich anschließend auf eine Zusammenfassung der Ergebnisse aus dem Gebiet des Wiener Beckens.

Die Untersuchungen im Unteren Rheingraben zeigen den starken Einfluss von prä-existierenden Strukturen auf die Extensionsgeschichte des Grabens. Rezent dehnt sich der seismisch aktive Graben orthogonal zu den Hauptstörungen. Ein starker Einfluss ererbter Strukturen zeigt sich auch für die Öffnung des Oberrheingrabens. Seismotektonik und Geomorphologie belegen die Aktivität des südlichen Rheingrabens, während Felduntersuchungen und Modellierungen die komplexe paläogene bis rezente Entwicklung des Systems nachzeichnen und die zugrunde liegenden Prozesse beleuchten.

Horizontale Deformationsgeschwindigkeiten im Raum des Wiener Beckens konnten durch Bilanzierungstechniken (1.6-2.5 mm/a) und aus der Berechnung von kumulativen seismischen Momenten (0.1-0.3 mm/a) gewonnen werden. Vergleicht man diese Werte mit GPS Geschwindigkeiten aus der Literatur, zeigt sich ein seismisches Bewegungsdefizit. Aktive Störungen konnten durch die Integration von 3-D seismischen Daten und Untergrundkarten (kartierte Horizonte und Quartärmächtigkeiten) sowie geomorphologischer Interpretationen kartiert werden. Die Ergebnisse zeigen ein komplexes Störungssystem. Im südlichen Wiener Becken und am östlichen Rand zeigt sich eine negative Blumenstruktur, dessen Aktivität durch sich absenkende quartäre Becken belegt wird. Im zentralen Wiener Becken zeigen sich reaktivierte miozäne Abschiebungen, die quartäre Terrassen verkippen und vertikal versetzen. Die Ergebnisse wurden in einer klassifizierten Karte aktive Störungen im Wiener Becken festgehalten und dreidimensional in einem Strukturmodell integriert. Karte und Strukturmodell können als Grundlagen für nachfolgende Forschung zur Kinematik und zum seismogenen Verhalten des Störungssystems im Wiener Becken dienen und somit auch Einfluss auf zukünftige Überlegungen zur Erdbebengefährdung nehmen.

Das ENTEC Netzwerk in Europa hat gezeigt, dass integrierte erdwissenschaftliche Forschung wesentliche Beiträge zu aktiven tektonischen Prozessen in Regionen liefert, die sich bislang aufgrund ihre rasch verändernden Oberflächengestalt (durch Erosion und menschliche Überprägung) und geringen Deformationsraten einer genaueren Untersuchung entzogen haben.

1. Introduction

The Alpine orogen as well as the basins and rifts of the Alpine foreland are associated with a much higher level of recent tectonic activity than hitherto realized, bearing major implications for the assessment of seismic hazards (Cloetingh et al., 2003, Cloetingh and Cornu, 2005). Current seismic hazard estimates for intraplate areas are commonly based on probabilistic analyses of historical and instrumental earthquake data. The accuracy of these hazard estimates is limited by the nature of the data (e.g., ambiguous historical sources), and by the restriction of available earthquake catalogues to time scales of only a few hundred years. Both of these are geologically insignificant and unsuitable for describing tectonic processes causing earthquakes. In regions with low geological deformation rates, strong earthquakes may have longer recurrence times (thousands to ten thousands of years) than covered by the catalogues in use (Santanach and Masana, 2001; Cloetingh et al., 2003). Recent findings in paleoseismological studies in Central Europe prove, that large earthquakes occur in areas where in historic times only moderate events have been recorded (Camelbeeck and Meghraoui, 1996; Vanneste et al., 1999; Meghraoui et al., 2001). Until now, research on neotectonics and related seismicity has mainly focused on active plate boundaries characterized by a generally high level of earthquake activity (Cloetingh and Cornu, 2005). Furthermore, studies of the seismogenic behaviour of faults are generally done in arid regions where surface effects of faulting are preserved over long time spans (e.g. Wallace, 1986; McCalpin, 1996).

In order to improve the understanding of the seismogenic faulting and related processes in low strain regions it is therefore essential to integrate research with a multidisciplinary approach to overcome the problems of suppressed surface effects of faulting and human overprint of the landscape. ENTEC [Environmental Tectonics] was a European Community funded FP5 Research Network of nine European research institutes, coordinated by the VU Amsterdam (ENTEC, 2004). It has been developed in the context of the EUCOR-URGENT network (http:/comp1.geol.unibas.ch/). The main objective of ENTEC was to realize a quantitative understanding of the interplay of active tectonics, surface and subsurface processes, and the evolution of intraplate continental lithosphere in the foreland of the Alpine orogen, in order to provide valuable background information for future seismic hazard analyses. The ENTEC research strategy has been based on an integration of geological, geophysical, geodetic, geomorphological and technological approaches. These included various combinations and sequences of surface mapping of landforms and Quaternary geology, remote investigations of topography, GPS and other geodetic measurements, 2-D and 3-D seismic interpretation and subsurface mapping, balancing and quantification of deformation and finally analogue and numerical modeling.

The Upper and Lower Rhine Graben and the Vienna Basin have been selected as ENTEC natural laboratories, as both areas are the sites of some of the highest concentrations of industrial activity and urban development in Europe, and both regions coincide with areas of some earthquake activity (Fig. 1). At the same time, as a result of intensive exploration and production of natural resources by petroleum and groundwater companies, a unique subsurface database exists for these areas to validate environmental tectonic models.

In the first part, this paper will shortly review the main results of the ENTEC project for the Upper and Lower Rhine Graben. In the second, main part, we will summarize the results achieved for the Vienna Basin area.

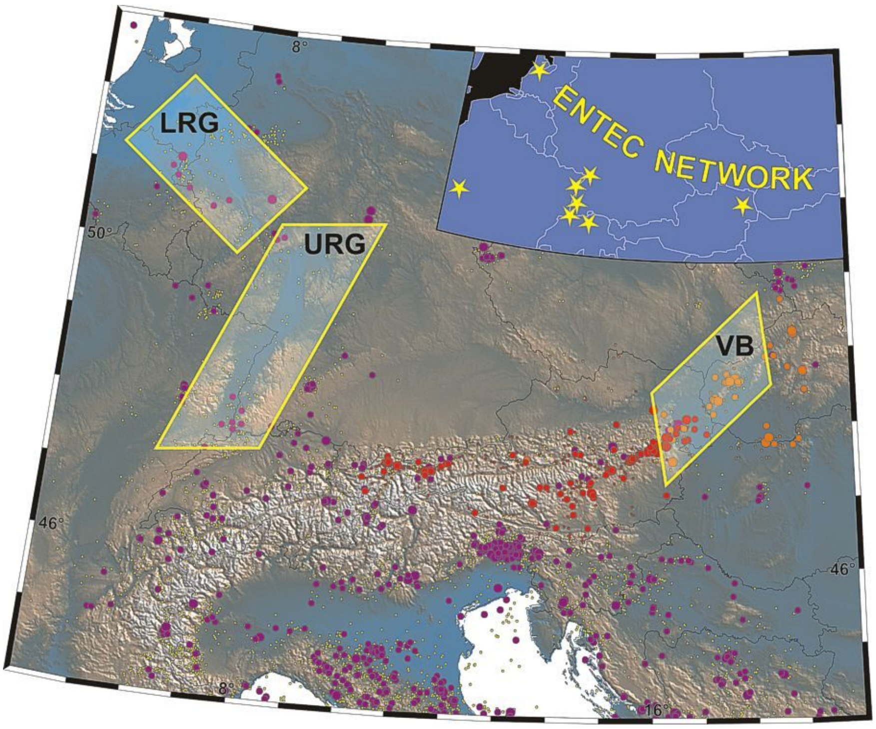

Figure 1: Sites of the ENTEC Natural Laboratory: Upper Rhine Graben (URG), Lower Rhine Graben (LRG), Vienna Basin (VB), and locations of the research centers forming the ENTEC network (inset). Dots represent epicenters of Earthquakes, colors indicate different Earthquake catalogues.

2. Environmental Tectonics in the Upper and Lower Rhine Graben

Research in the frame of Environmental Tectonics in the Rhine Graben aimed for understanding the dynamic system on local to lithospheric scale and therefore utilizes a wide range of methods (Cloetingh et al., 2003, ENTEC, 2004, Cloetingh and Cornu, 2005). We will shortly review the main results following the subdivision into Upper and Lower Rhine Graben.

2.1. Lower Rhine Graben

The Lower Rhine Graben, or more precisely the Roer Valley Rift System, located north of the Upper Rhine Graben, corresponds to the northern segment of the West European Rift. The main target was to understand and explain the Cenozoic to present-day evolution of the Roer Valley Rift System, and its implications for the high level of active neotectonics (ENTEC, 2004). To unravel this system, several different kinds of data and approaches where utilized (analogue modeling, interpretation of geophysical data, deep wells, high resolution digital elevation models).

Lithospheric analogue models show the development of two different modes of deformation, where either the crustal or the mantle shear zone predominantly control the regional thinning (Michon and Merle, 2003). These results might explain the different geometries visible in the European platform. Analogue models on a crustal scale revealed that observed deformation and deposition is controlled by structural inheritance and extension direction (ENTEC, 2004). Combined results from analyzing the subsidence, thickness distributions and the fault system allow the determination of the Cenozoic evolution and the quantification of subsidence (Michon et al., 2003). The results show, that the evolution of the Roer Valley Rift System is strongly controlled by inherited Variscan structures. During the Cenozoic, the system was affected by several successive phases of subsidence and inversion, inducing a large range of deformation. During the Late Oligocene WNW-ESE extension led to localized subsidence in the southeastern part of the graben, while, at the Oligocene-Miocene transition, subsidence increased strongly and migrated toward the northwestern part of the graben. For Miocene to Quaternary times, landforms affected by fault activity have been only vertically offset, indicating extension perpendicular to the graben (i.e., NE-SW; Michon and Van Balen, 2005).

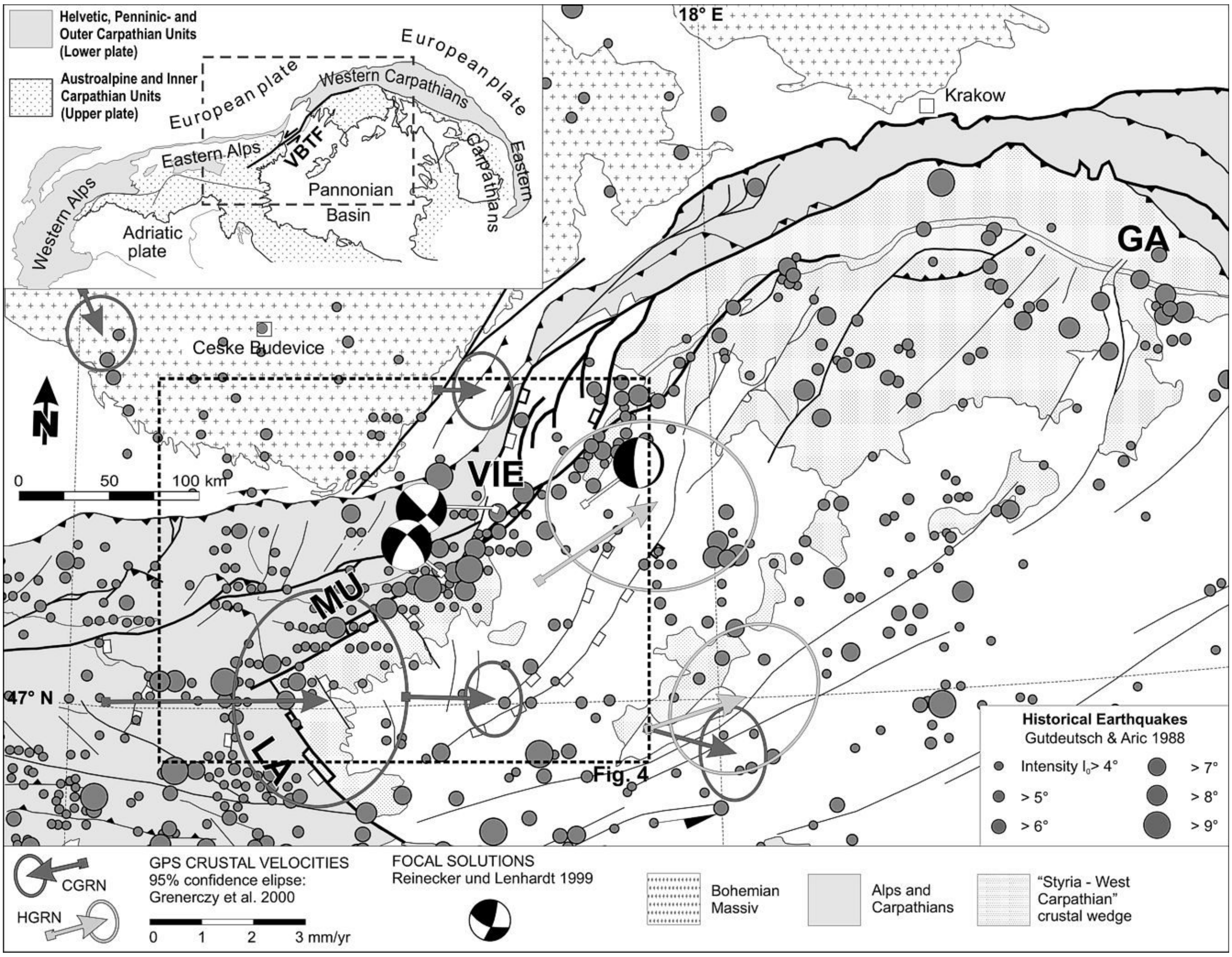

Figure 2: Tectonic sketch map of Vienna Basin Transfer Fault (VBTF) between Alps and Carpathians (inset). Structural sketch map show recent kinematics and seismicity along the fault zone. VIE = Vienna Basin pull-apart, MU = Mur-Mürz Fault, LA = Lavanttal Fault, GA = Galicia Thrust System (modified after Hinsch and Decker, 2003).

2.2. Upper Rhine Graben

The majority of the scientist of the ENTEC team worked in the Upper Rhine Graben and focused on geodetic measurements (GPS and leveling campaigns), utilized (structural geology and geomorphological analyses), seismological methods (paleoseismological, seismotectonic and tomographic inversion studies), and modeling techniques (balancing, analogue and mechanical modeling).

Geodetic research activities focused on monitoring the displacements in the Upper Rhine Graben area, where a GPS network has been established, and three measuring campaigns have been carried out since 1999. Results so far show, that displacement rates are not exceeding 1 mm/yr (Rozsa et al., 2005). Leveling campaigns indicate that faults in the Freiburg area are active with vertical displacement rates in the order of 0.45 mm/yr on the Main Border Fault and 0.35 mm/yr on the Weinstetten Fault (Rozsa et al., in press). Activity of faults at the eastern border of the Rhine Graben is also indicated by the seismotectonic studies. They reveal left lateral motion on the eastern boundary fault of the Upper Rhine Graben and its partly continuation underneath the Jura mountains. Active seismicity underneath the Jura Mountains is interpreted to be related to reactivated Permo-Carboniferous troughs (Lopes Cardozo and Granet, 2003). This is further elaborated and supported by imaging the structure of the southern Rhine Graben with local earthquake tomography and integration with near surface reflection seismic data, yielding the position of the crustal faults in the area (Lopes Cardozo and Granet, 2005; Lopes Cardozo et al., 2005).

Near surface investigations of these faults provided evidence for uplift and shortening in the area, post-dating the main phase of Jura folding. This deformation is attributed to thick-skinned reactivation of ENE-oriented basement faults (Giamboni et al., 2004). Paleostress analyses reveal that rifting in the southern Upper Rhine Graben began in Upper Eocene approximately perpendicular to the Graben axis. It was accompanied by transtension and sinistral movements along ENE-oriented basement faults, forming the Rhine Bresse Transfer Zone (Ustaszewski et al., in press). The Pliocene to recent uplift and shortening is documented by the deformation of Pliocene fluvial gravels as well as by progressive deflection and capture of rivers (Giamboni et al., 2004, Giamboni et al., 2005a,b). Scaled dynamic analogue models indicate, that the reactivation of the basement faults occurred under low displacement rates (<1 mm/a, Ustaszewski et al., 2005). Structural modeling (retro-deformation) of the rifting process revealed an early orthogonal rifting phase, with major fault activity on the border faults. Subsequently, deformation propagated into the inner parts of the graben with ongoing sinistral oblique rifting (Behrmann et al., 2003; Bertrand et al., 2005). Similar results are obtained by backward and forward numerical modeling (based on finite element and contact theories). Results indicate that opening of the Upper Rhine Graben was accompanied by some strike-slip motion, and that the central Rhine River Fault played a major role during the rifting history (Cornu and Bertrand, 2005, in press).

The mapped and structurally modeled faults are indeed seismically active, as indicated by investigations of Fracassi et al. (2005). Historical earthquake recordings, the structural pattern in the southern Upper Rhine Graben, and Quaternary basin fill data are combined to determine prospective seismogenic sources. For one of the major events in the southern Upper Rhine Graben, the 1356 Basel Earthquake, a paleoseismological study revealed an M 6.2 earthquake on an ENE-WSW trending fault (Lambert et al., 2005).

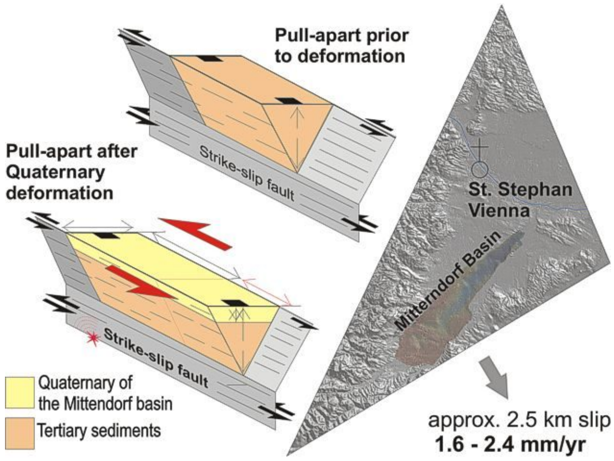

Figure 3: Schematic geometry of the shoebox model used for calculating Quaternary fault offset and average slip rates from the subsidence of the Mitterndorf basin, Southern Vienna Basin. Colored surface represents Quaternary gravel accumulations (modified after Decker et al., 2005).

3. Environmental Tectonics in the Vienna Basin area

3.1. Introduction

The project on Environmental Tectonics for the Vienna Basin focused on the understanding of the system of active faults in the vicinity of Vienna, in order to provide information on seismogenic processes and back-up future seismic hazard assessments for the most densely populated and economically important area of Austria. To address this issue, we subdivided our research approach into three parts: Quantifying the active kinematics (see section 3.3.), mapping the active faults in 2- and 3-D (section 3.4.) and building up a 3-D structural model of the subsurface (section 3.5.). In the following (section 3.2), we will shortly review the tectonic setting of the Vienna Basin and then summarize methods and results of the three main approaches.

3.2. Tectonic Setting

Eastern Austria is a prominent site of moderate seismicity with medium sized earthquakes (Magnitude: ML ~5.0 to 5.5), returning at periods of several decades (ZAMG, 2001; e.g. Schwadorf 1927 with $M_L = 5.2$). Most of the epicentres in Eastern Austria line up along the prominent Vienna Basin Transfer Fault System (VBTF). The 450 km long VBTF is one of the most conspicuous crustal structures between the Eastern Alps and the Carpathians, extending from the Central Alps through the Mur-Mürz Valley, the Vienna Basin and Moravia into the outer

Carpathians of Polish Galicia (Fig. 2). The fault system developed during Miocene northeast-directed movement of a major Alpine-Carpathian crustal block (Fig. 2), which is referred to as eastward lateral extrusion (Ratschbacher et al., 1991; Decker and Peresson, 1996; Linzer et al., 1997; 2002). Linked to the VBTF is the Vienna Basin, a thin-skinned Miocene pull-apart basin with a left stepping geometry (Fig. 2), which is considered to root on the basal detachment of the Alpine-Carpathian orogenic wedge at depths between 8 to 12 km (Royden, 1988; Royden et al., 1983).

The observed seismicity prove that the fault system is still active (Decker and Peresson, 1998; Gutdeutsch and Aric, 1988; Aric and Gutdeutsch, 1981). The seismicity pattern along the VBTF highlights a 400 km long and c. 30 km wide zone paralleling the Miocene fault system (Gutdeutsch and Aric, 1988). Recorded seismicity within the Vienna Basin area predominantly lines up at the south-eastern border of the basin in prolongation with the seismically active zones in the Eastern Alps and the Western Carpathians (Gutdeutsch and Aric, 1988; Fig. 2). Recent stress and focal mechanisms analyses from earthquakes along the VBTF indicate mainly sinistral strike-slip faulting along northeast striking subvertical faults (Reinecker, 2000; Reinecker and Lenhardt, 1999; Marsch et al., 1990; Gangl, 1975). These data are consistent with GPS observations, indicating approximately 2 mm/yr sinistral movement of the VBTF (Grenerczy et al., 2000). Evidences of Quaternary tectonic activity within the Vienna Basin has often been described in several papers and maps (e.g. Fink, 1955; Fink et al., 1958; Küpper, 1971; Fuchs and Grill, 1984), but not been assessed systematically. In order to map possible hydrocarbon pathways in the southern Vienna Basin

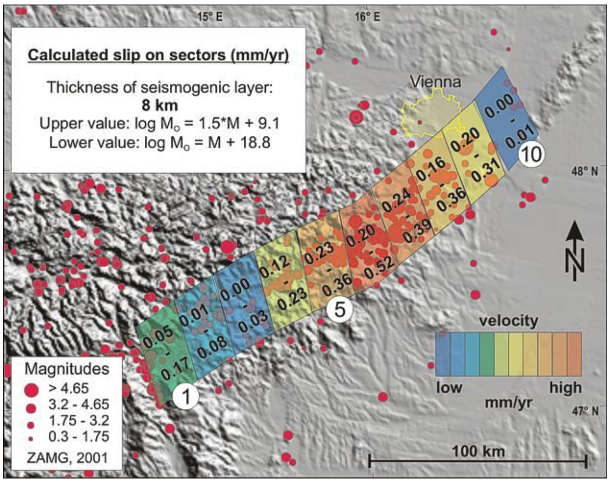

Figure 4: Calculated seismic slip rates from cumulative scalar seismic moments for arbitrarily selected fault sectors along the Austrian part of the Vienna Basin Transfer Fault (minimum thickness of the brittle crust: 8 km). The velocity range of individual sectors results from the use of two different empirical relationships for magnitude to moment conversion (upper by Hanks and Kanamori, 1979; lower by Purcaru and Berckhemer, 1978). All segments appear to be seismically active but show significant differences of calculated seismic slip (0 mm/yr - 0.52 mm/yr). Background image: shaded digital elevation model of the easternmost Eastern Alps and surroundings. Red dots are earthquake epicenters (modified from Hinsch and Decker, 2003).

Häusler et al. (2002) mapped possible active faults by integrating remote sensing and subsurface data, promoting the ENTEC project approach.

3.3 Quantifying the active kinematics

The first step for Environmental Tectonic analyses in the Vienna Basin was to quantify deformation rates for the fault system in the Vienna Basin using two different methods.

3.3.1. Geological balancing

In the southern Vienna basin, active faulting defines a small-scale pull-apart structure with an actively subsiding Quaternary basin. This basin is filled with up to 140 m fluvial gravel, sand and rare paleosoils. By adopting a geometrical model for thin-skinned extensional strike-slip duplexes, the amount of Quaternary sinistral displacement could be quantified (Fig. 3; Decker et al., 2005). 1.5 to 2 km sinistral slip accumulated during deposition of the basin fill in the last 400 ky, corresponding to a slip rate of 1.6 - 2.5 mm/yr.

3.3.2. Seismic slip calculations

For this approach we use the Austrian earthquake catalogue (courtesy of ZAMG, W. Lenhardt, ZAMG, 2001) to calculate deformation rates from seismic moment summations in order to check for possible seismic slip deficits. The energy released (more specific the seismic moment) from earthquakes along a fault system through time can be used to estimate the amount of seismic slip that occurred on the fault system (Brune, 1968). For crustal faults without special mechanical conditions, it is widely accepted, that movements on the fault system occur in general seismically (Scholz, 1998, 2002; Holt et al., 2000). In such a case the seismic slip should approximate the slip values calculated from other methods like geological balancing (see above) or GPS measurements. Details on the calculation steps are found in Hinsch and Decker (2003). The results show, that calculated rates for the generalized fault system vary from 0.1 - 0.3 mm/yr for brittle fault thicknesses between 6 and 10 km. Splitting the fault into segments reveals significant variations of the slip velocities along strike. Segments with less than 0.02 mm/yr seismic slip contrast from segments moving at 0.2 - 0.5 mm/yr (Fig. 4).

Comparing the found seismic slip values to geodetic velocities (ca. 2 mm/yr; Grenerczy et al., 2000), and geological determined strain rates (1.6- 2.4 mm/yr, see above; Decker et al., 2005), reveal a significant seismic slip deficit. Possible reasons for this seismic slip deficit are inadequate calculation parameters, changing mechanical conditions along strike of the fault system, and the usage of data covering an incomplete seismic cycle. The most likely possibility is that the seismic cycle exceeds the length of available seismological observation, thus larger earthquakes than those recorded cannot be excluded along the fault (c.f. discussion in Hinsch and Decker, 2003).

3.4. Mapping the active faults in 2-D and 3-D

This essential work is done on a multi-source basis: published and unpublished subsurface maps of the Quaternary and

Neogene levels, geological maps, satellite images, 2-D and 3-D seismic data, high resolution digital elevation models for geomorphological investigations of faults (scarps, hanging valleys etc.) and Quaternary terraces, field mapping and near surface geophysics.

Using these integrated data and methods, it was possible to constrain active faults and their kinematic relationship in the southern Vienna Basin (south of the river Danube) and for parts of the central Vienna Basin (Fig. 4). The results for the southern Vienna Basin are discussed in detail in Hinsch et al. (2005a) and are summarized here:

A negative flower structure with en echelon faults is responsible for a relatively linear scarp along the “Rauchenwarth Plateau” and the subsidence in the Mitterndorf basin, causing accumulations of up to 140 m of Quaternary gravels below the level of the drainage system (Hinsch et al. 2005a; Figs. 5, 6). A prominent normal fault branches from this flower structure system at a high angle (Figs. 5, 6). Activity of this fault, which continues into urban areas of Vienna, is indicated by river terraces significantly tilted against the general level of the Danube drainage. Terrace tilting can therefore be attributed to large-scale rollover due to active normal faults at the western margin of the basin.

Indications of active faulting in the central Vienna Basin are described in detail in Decker et al. (2005). They use geomorphological approaches, in combination with Quaternary sediment distribution, to allow mapping of active faults north of the Danube river. There, tilted and dissected terraces display a similar fault pattern like in the northern part of the southern Vienna Basin (Decker et al., 2005; Fig. 5). This indicates, that faults throughout the Vienna basin are still active, even, if no large scale pull-apart step-over of the seismic active principal displacement zone is observable.

The results from mapping active faults north and south of the river Danube are compiled in a classified map of active faults (Fig. 5; Hinsch et al., 2005a). The map also provides further information on the quality and source of the interpretation as well as different background datasets (digital terrain model, different geological maps etc.).

3.5. Building up a 3-D structural model of the subsurface

The results of mapping faults from Integrated datasets (described in the previous paragraph), especially from 3-D seismic data, is not only used for producing reliable maps of active faults, but also for 3-D structural modeling (e.g. Fig. 6). These models are constructed in order to bridge the local scale with geological interpretation from surface and subsurface data towards the basin scale by integrating results from different areas (Fig. 7). Main results of the 3-D modeling are presented in Hinsch et al. (2005b, this volume). The constructed fault geometries can now be used as input data for numerical models to assess the kinematics and mechanics of the Vienna Basin, as well as to assess fault surface areas within the seismogenic zones for the calculation of Maximum Credible Earthquakes (Hinsch and Decker, 2005).

3.6. Implications for the Vienna Basin

The results from the seismic slip calculations in comparison with geologically derived strain rates indicate that the seismic cycle exceeds the length of available seismological observation, and larger earthquakes than those historically recorded cannot be excluded along the fault. The integration of subcrop data, Quaternary thickness, earthquake data, geophysical data and geomorphology results in a detailed map of active faults (Fig. 5). The map depicts a major NE-striking fault system in the SE part

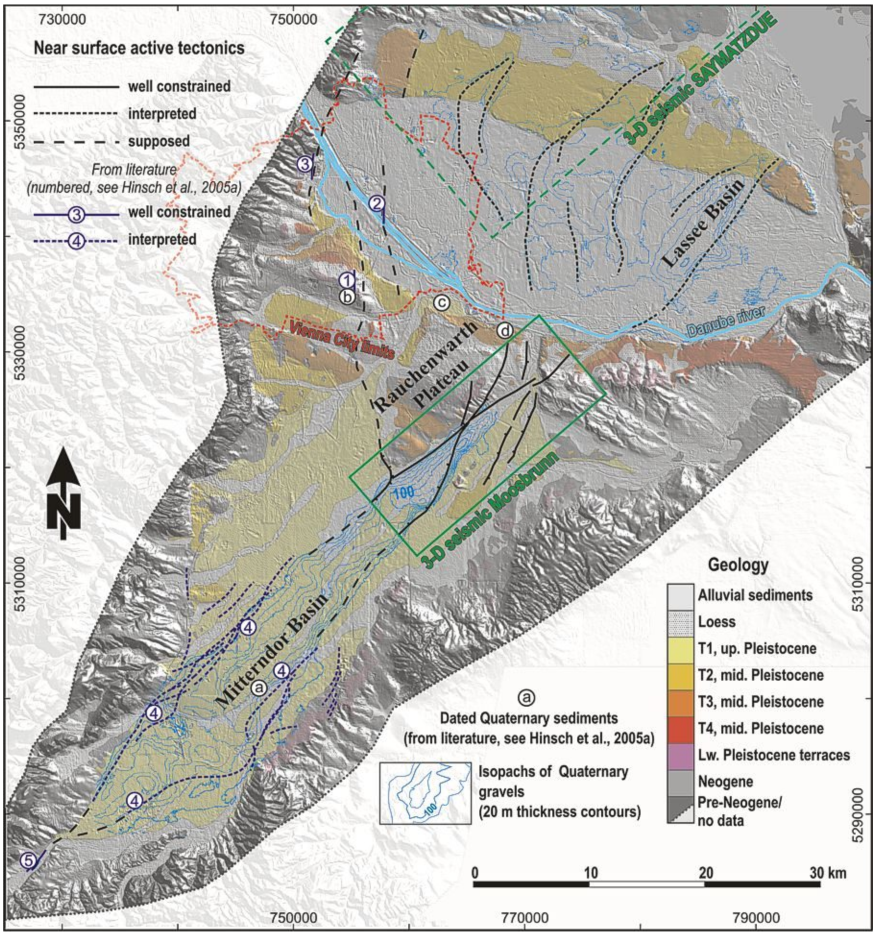

Figure 5: Compilation of active faults inferred from data described in Hinsch et al. (2005a) and published data referred herein. Background image: Geological map draped over shaded digital elevation model (25 m horizontal resolution) to illustrate the Quaternary sediment distribution and the geomorphology. Geological map simplified from Fuchs and Grill (1984).

of the Vienna Basin, following the seismically active zone, and numerous faults branching off from the main fault. Three of these branch faults, which have at least been active through the Pleistocene, pass through the urban center of Vienna. Most branch faults have not been the loci of recorded earthquakes. Accordingly, they are not reflected in seismic hazard maps, which are solely based on historical and instrumental earthquake data. First appraisals of the seismic potential of these faults reveal that they might produce earthquakes larger than historically observed (Hinsch and Decker, 2005). Given the economical relevance of the region (2.4 million Austrian inhabitants in the Vienna Basin, producing c. 45% of the Austrian GDP), it is grossly negligent to solely base seismic hazard estimates on analyses of incomplete data from a geologically irrelevant time span. Our study provokes to continue mapping of active faults throughout Austria in order to establish a fault catalogue, which can be integrated in future seismic hazard assessment, as it is common practice in other countries (e.g. CDMG/USGS, 1996). Further research should include paleoseismological investigations, to extend the knowledge on recurrence times of earthquakes with pre-historical events. Additional mechanical modeling could shed light onto the complex fault system and helps understanding coupling and stress distribution.

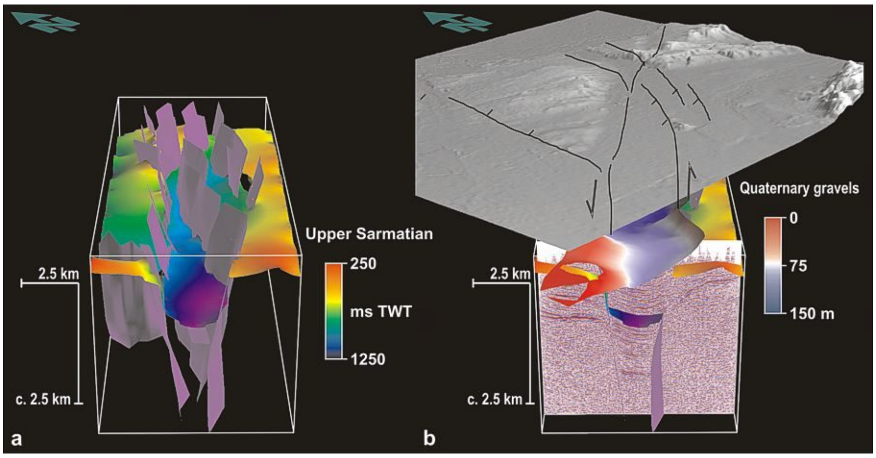

Figure 6: (a) simplified 3-D structural model form part of the southern Vienna Basin area; (b) Integration of different datasets for interpreting active faults. Seismic data with courtesy by OMV AG, Austria.

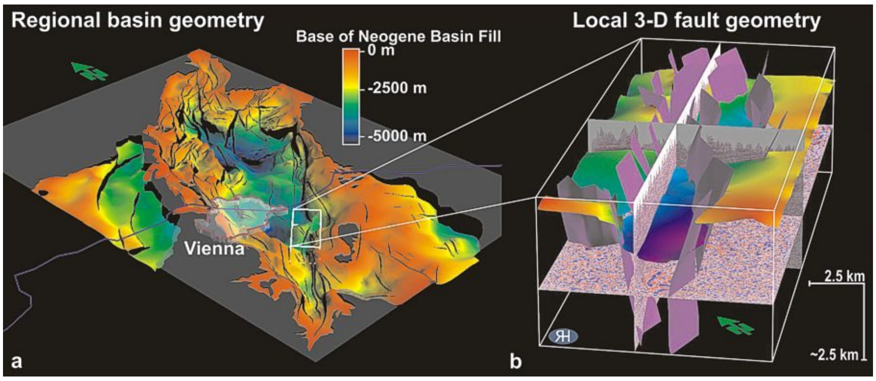

Figure 7: (a) 3-D structural model of the Vienna Basin and adjacent areas, based on data from subsurface exploration (Kröll and Wessely, 1993); (b) 3-D structural model form the southern Vienna Basin displaying the complex fault pattern at the southern tip of a pull-apart basin, comprising a negative flower structure and branching normal faults. The mapped faults are tectonically active (Hinsch et al., 2005a). Seismic data with courtesy by OMV, Austria.

4. Conclusions

Results obtained by the ENTEC studies have significantly enhanced our understanding of the tectonic processes in the Rhine Graben and Vienna Basin regions. These regions where previously hardly investigated in terms of active processes, because of the fast decay of surface expressions of tectonic movements by climate effects and human overprint. Like for other regions in Central Europe, integrated multidisciplinary geoscientific research is the key to understand the controlling factors of the geological processes active in the subsurface. Furthermore, new technologies like visualization and modeling techniques have been developed and integrated in the workflow. There is a significant number of ongoing and planned European research projects focusing on similar approaches. The papers presented in this volume of the Austrian Journal of Earth Sciences witness the need and the will to decipher active geological processes in our home environment.

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