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Combined geophysical, geomorphological and geological studies at the active Lassee Segment of the Vienna Basin Fault System

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Abstract: Integrated data from 2D seismic interpretation, geomorphologic mapping, GPR profiling and Quaternary basin analysis of the Lassee Segment of the sinistral Vienna Basin Fault System 30 km east of Vienna depicts an active sinistral wrench fault with a negative flower structure, which is partly filled with Pleistocene growth strata. The flower structure developed during the Middle and Upper Miocene and was reactivated during the Quaternary. The faults east of the flower structure offset a Pleistocene terrace of the Danube River. There, high resolution GPR depicts the existence of several surface breaking faults, controlling the morphology of a pronounced composite fault scarp.

Keywords: active tectonics, Vienna Basin, geophysics, geomorphology, seismic hazard

The NE-striking Vienna Basin Fault System extends from the Eastern Alps through the Vienna Basin into the West Carpathians (Decker *et al.*, 2005). It consists of several sinistral strike slip segments, which both differ in their kinematic and seismotectonic properties. Among these segments the so-called Lassee Segment attracted substantial interest as it appeared as a "locked" fault segment, which did not release significant earthquakes (Fig. 1) in the past seven centuries and hence shows a significant seismic slip deficit (Hinsch and Decker, 2003). The segment, however, is regarded to be the source of an intensity IX earthquake in the 4th Century (Decker *et al.*, 2006). These data and the location of the fault 30 km east of Vienna and 20 km west of Bratislava highlight its importance for regional seismic hazard assessment.

Methodology

Mapping of the Lassee Fault used an industrial 2D seismic grid (3 inlines, 11 crosslines) provided by OMV Austria. Seismic interpretation with *Landmark GeoGraphix* software integrates borehole data, reflection characteristics and seismic facies to map the 3D geometry of the fault at depth. These subcrop data are linked to near-surface and surface structures, which are mapped with tectonic geomorphology techniques and ground penetrating radar (GPR). GPR used two different antennas with center frequencies of 40 MHz and 500 MHz in order to obtain an adequate exploration depth as well as high-resolution images from the uppermost soil strata (Chwatal *et al.*, 2005). Detailed geomorphologic studies including precise leveling and differential GPS geodesy were carried out along the morphological scarps paralleling the fault in order to discriminate between active fault scarps and terrace risers.

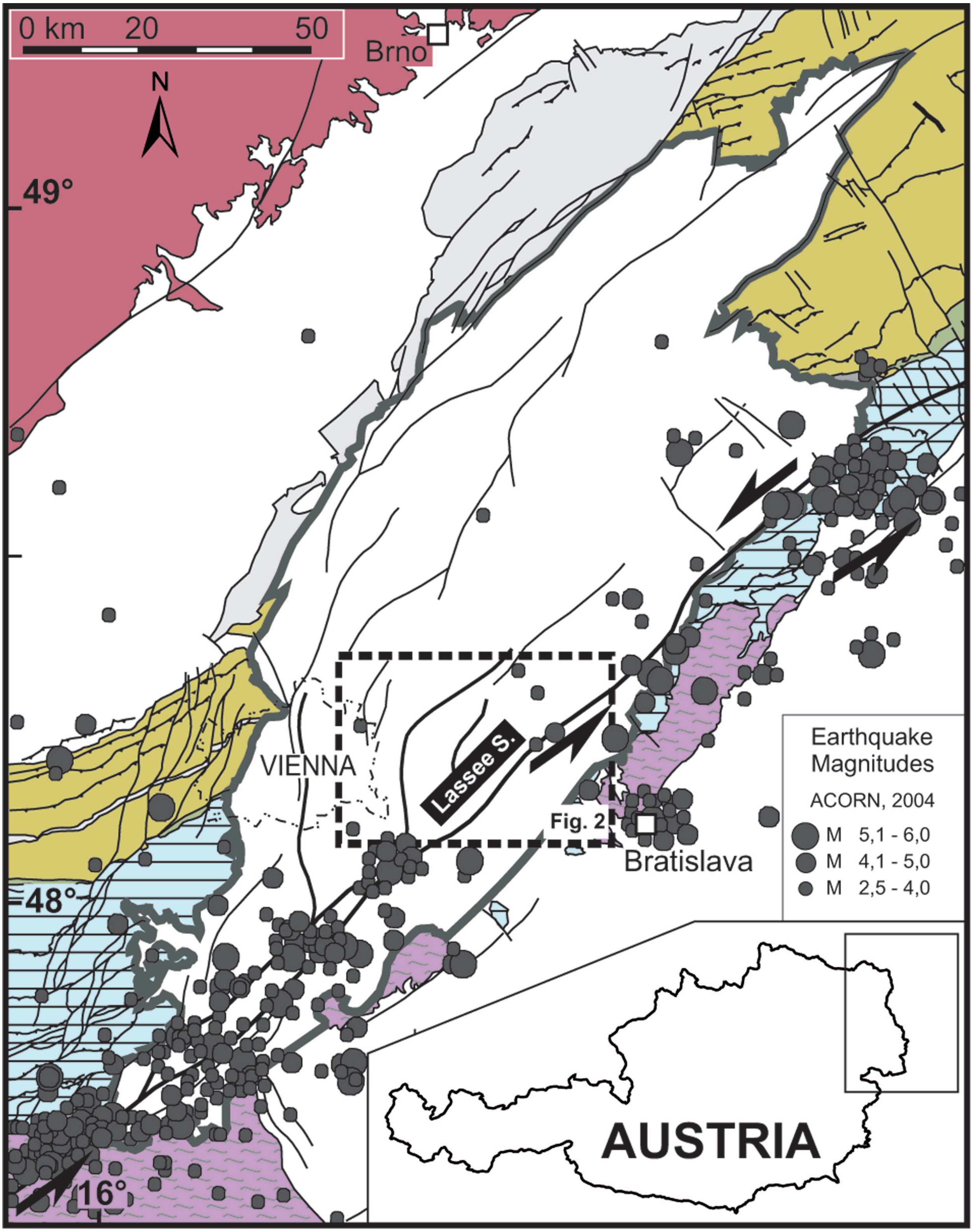

Figure 1. Tectonic sketch map of the Vienna Basin and the Vienna Basin Fault System highlighting seismotectonically active faults and Quaternary faults. Rectangle shows the location of figure 2.

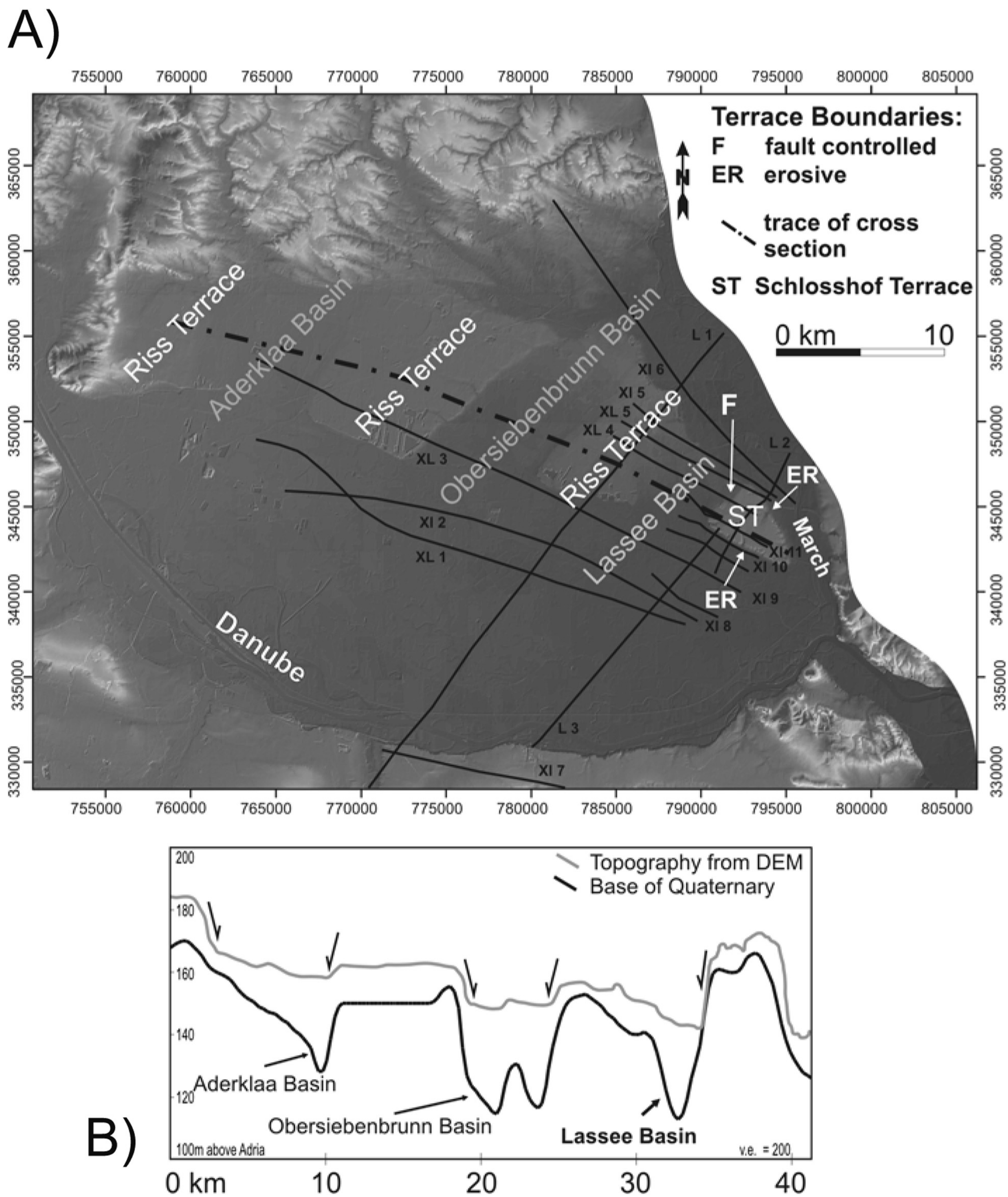

Figure 2. A) DEM of the eastern central Vienna Basin showing Pleistocene terraces (Riss, Fink, 1973) with fault-controlled NE-trending scarps and terrace risers facing towards the Holocene floodplains of the rivers March and Danube, B) cross section illustrating topography and thickness of Quaternary sediments (black dash-dot line in 2A). The Lassee basin includes about 40 m thick Quaternary sediments. Note that the SE basin margin coincides with a marked morphological scarp.

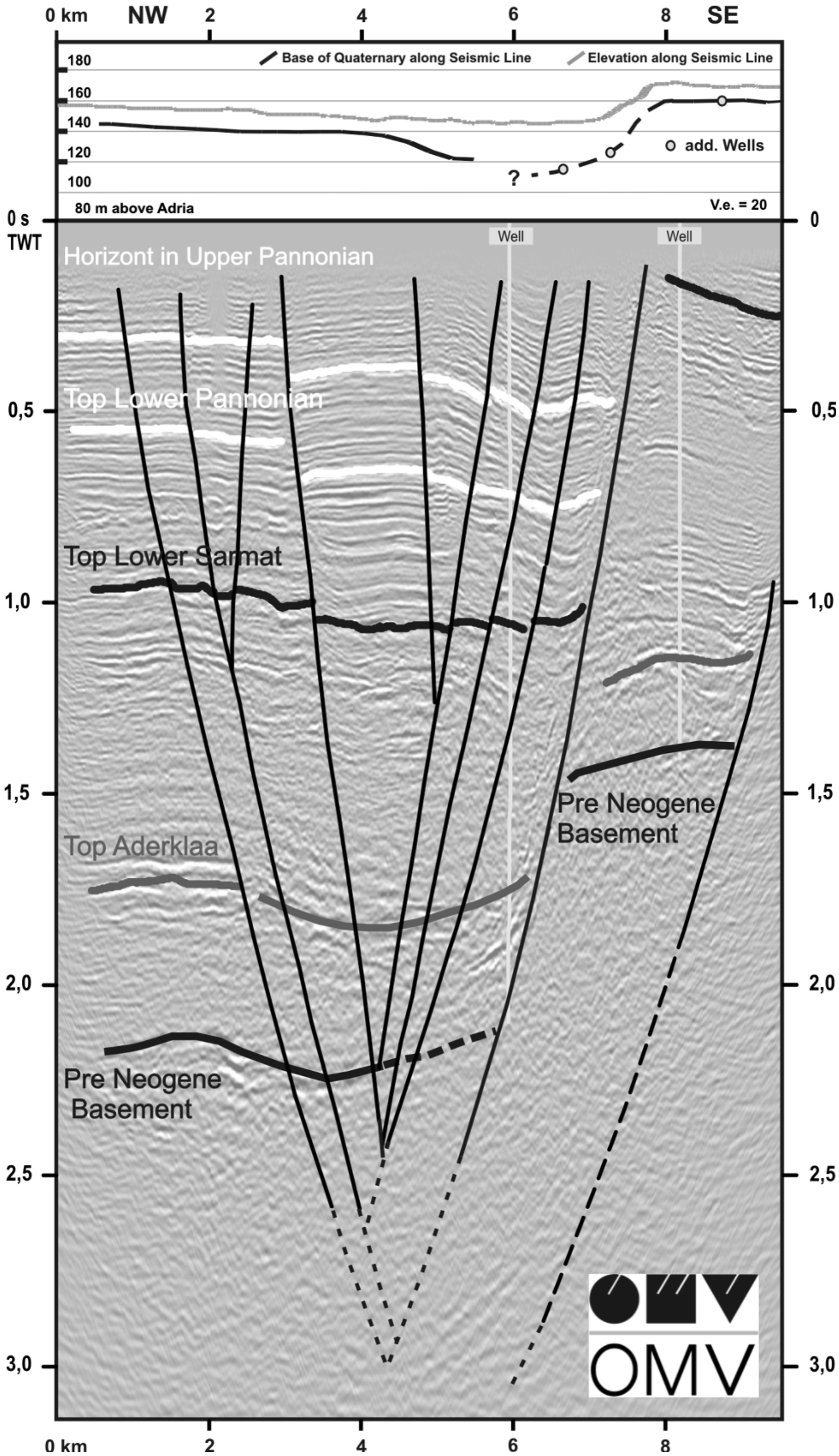

Figure 3. Seismic section XL4 (see figure 2a) depicting a negative flower structure with concave-up faults underlying the Quaternary Lassee basin. Maximum vertical throw occurs at the SE border fault causing an asymmetric shape of the flower, which is reflected by both the shape of the Quaternary basin and the SE dipping surface topography. The SE boundary fault coincides with the scarp of the Schlosshof terrace.

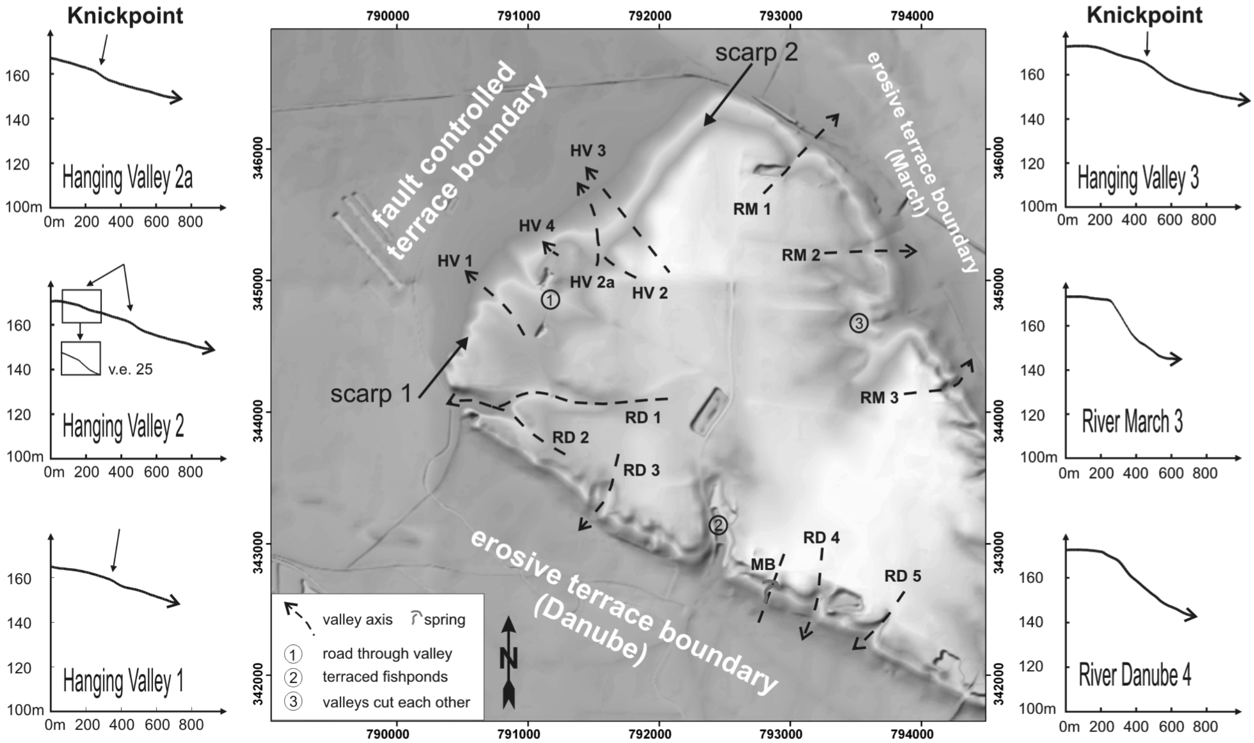

Figure 4. DEM of the Schlosshof terrace and topographic profiles (vertical exaggeration 12.5) along the axes of valleys, which cross the terrace boundaries. Note the characteristic steps (knickpoints) in the floors of the hanging valley crossing the NW scarp (HV1-HV3). The valleys significantly differ from valleys crossing the terrace risers towards the rivers March and Danube. Dashed grey line shows the trace of GPR section BR 4 in figure 5a.

Results and interpretations

Seismic crosslines (Fig. 2), which are covering the whole width of the Lassee Basin, consistently depict approximately 3000 m thick Neogene sediments overlying pre-Neogene basement. In all sections fault mapping depicts a negative flower structure with major branch lines situated at depths between 3500 and 5500 m, i.e. close to the interface between pre-Neogene basement and Neogene basin fill. We propose that the rheological difference between basement and basin fill pinpoints branch lines at this interface. The master fault is regarded to be thin-skinned rooting in the Alpine Carpathian floor thrust, which forms a major detachment at about 8 km depth (Royden *et al.*, 1983; Royden, 1988). Neogene growth strata inside the flower structure prove Miocene (Badenian to Pannonian) faulting with large variations of growth strata thicknesses along the fault zone. Maximum vertical displacement occurs on the SE border faults of the flower with a minimum of 500 to 850 m of Badenian to Lower Sarmatian (15.5-12 Ma) displacement. Post-Lower Sarmatian displacement cannot be quantified due to the erosion of Pannonian strata in the footwall block. Displacement during this time interval, however, must have been significant taking into account that the total displacement of the pre-Neogene basement is about 1500 m on average. The total displacement along the NW boundary is very small compared to the SE one and varies strongly along strike. The results of the 2D seismic mapping are summarized in figure 3.

The SE boundary faults of the flower structure coincide with a linear up to 25 m high morphological scarp forming the NW border of the Schlosshof terrace. A characteristic feature of this scarp is its division into two en-echelon right stepping segments, which is interpreted as due to the en-echelon arrangement of underlying splay faults and the presence of relay ramps. This composite scarp is incised by several hanging valleys indicative for a tectonic origin of the scarp. Topographic profiles through valley axes show characteristic steps resulting from the modification of valley floors by vertical tectonic displacement (Fig. 4, HV1-HV4). This is best illustrated by the 3D precession leveling of hanging valley HV 4 (Figs. 4 and 5) showing a very pronounced ca. 50 cm high linear scarp which cuts both the flanks and the floor of the valley. Such features are only observed in valleys crossing the SE

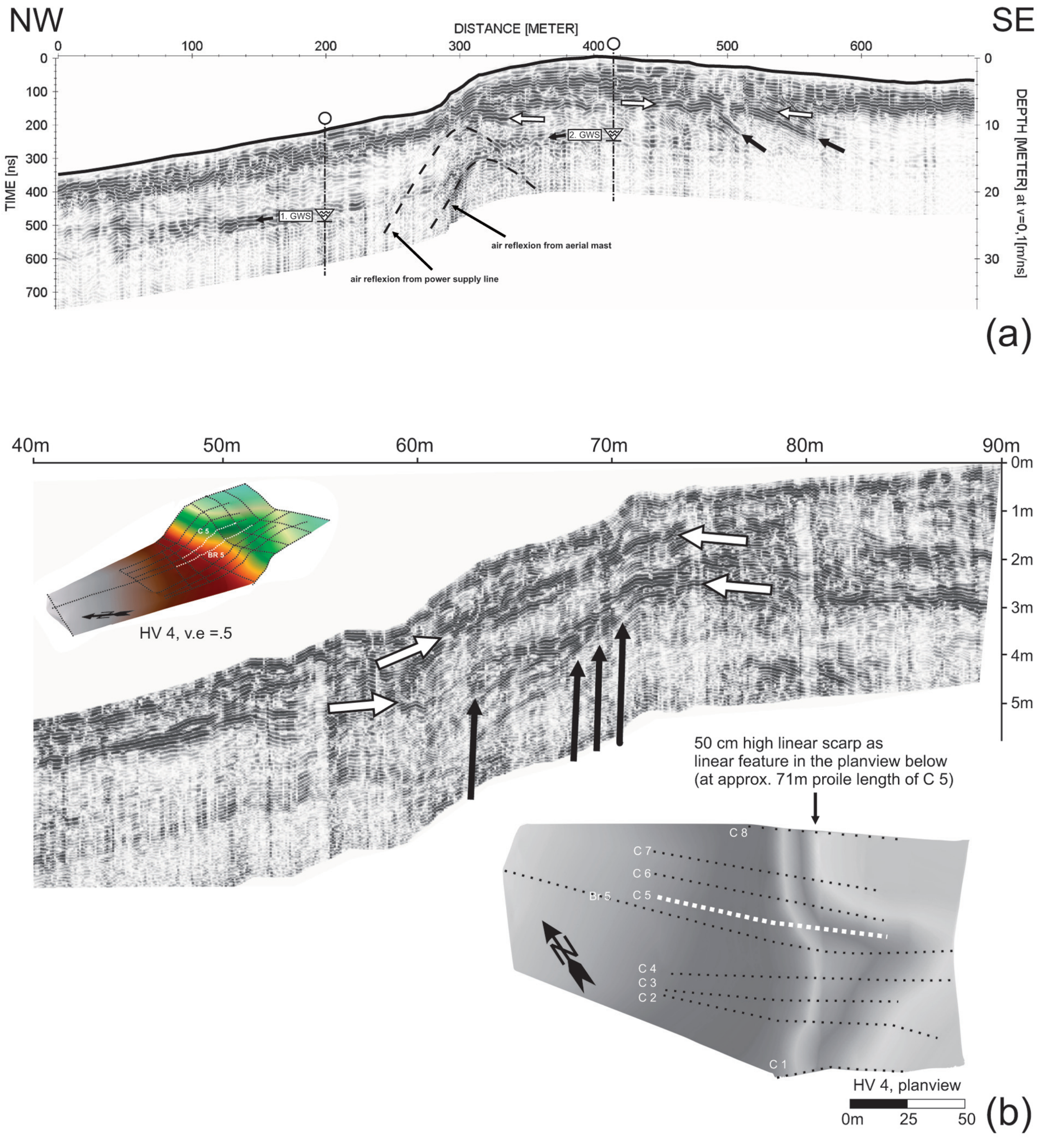

Figure 5. a) GPR section BR 4 (40 MHz, vertical exaggeration 5) crossing the scarp at about 300 m profile length. SE of the scarp Quaternary gravels (reflective upper unit) overly Neogene sediments (indicated by black arrows) with an angular unconformity. The base of Quaternary is also marked by a strong reflection (white arrows), which terminates below the scarp. NW of the scarp it appears to be situated below the GPR 40 MHz penetration depth. Two different groundwater levels are indicated through groundwater tubes, which are as well depicted as strong reflections in the GPR section, b) GPR section C5 (500 MHz, vertical exaggeration 2.5) crossing the fault scarp at the NW Schlosshof terrace boundary in the hanging valley HV4. Two sets of reflections (white arrows) are traced over the scarp. The lower band of reflections shows significant fault offsets at four positions (black arrows) with the right fault coinciding with a very pronounced linear surface scarp of some 50 cm height. The high-resolution DEM shows that this linear feature crosses both valley flanks and the valley floor. It is interpreted as a surface breaking fault.

boundary fault of the flower structure whereas valleys across erosional terrace boundaries display distinct valley floor topographies (Fig. 4, e.g. RM 3 and RD 4). The NW scarp is therefore interpreted as a fault controlled multiple event scarp (Yeats *et al.*, 1997).

For the reconstruction of the youngest fault history a GPR survey (40 MHz and 500 MHz) was done at the fault controlled scarp. The 40 MHz sections are very consistent in depicting the base of Quaternary strata at the elevated part of the terrace (i.e. the footwall of the fault) between 7 to 10 m depth, which correlates with borehole data. The base of Quaternary gravels is marked by a strong reflection, which is offset or terminates at the morphological scarp (section BR 4, Fig. 5a). Borehole data indicate the base of Quaternary sediments below the scarp (in the hangingwall of the flower) at some 30 m depth. 500 MHz GPR profiling revealed particularly interesting results from the hanging valley HV 4 (section C5, Fig. 5b) showing that the 50 cm high linear scarp crossing the valley is underlain by a fault offsetting the uppermost strata. The scarp is therefore related to a surface breaking fault slip event. In addition to this surface-breaking fault GPR section C5 shows at least three more faults, which are traced up to a minimum depth of about 2 m.

Conclusions

The Lassee Segment of the Vienna Basin Fault shows a Miocene negative flower structure, which was reactivated during the Pleistocene and Holocene. Geomorphologic data proves that the Pleistocene landscape evolution is significantly controlled by this fault. This is indicated by offset Pleistocene strata, multiple event fault scarps, hanging valleys and tilted Pleistocene terraces. High resolution GPR indicates at least 4 surface breaking faults at the segment. Earthquake recordings show that the Lassee Segment depicts virtually no active seismicity in the past seven centuries, while the segments to the NE and SW are characterized by abundant moderate earthquakes for this period of time (Fig. 1). The current study, however, proves significant faulting along the Lassee Segment during post Pleistocene times, which may be related to seismic activity. Nevertheless no such seismic activity is registered in recent earthquake catalogues. A possible reason for that may be that recurrence intervals along the segment are longer than the time span covered in historical earthquake catalogues (ACORN, 2004). However, trench studies are required in order to ensure weather the vertical offsets in 500 MHz GPR sections are caused by coseismic events or not. Such trench studies would also provide detailed information about magnitudes and timing of events in order to complete earthquake catalogues and consider them in future seismic hazard studies.

Acknowledgements

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