Contents

Abstract

This excursion leads to two sand pits in the vicinity of Eisenstadt, Burgenland, which illustrate the geodynamic evolution of the eastern margin of the Vienna Basin and the northern Eisenstadt Basin. Both sites impressively document deformation of unconsolidated sediments, which in addition to their regional significance provide remarkable insights into various processes of soft sediment deformation.

The first stop leads to the famous Steinbrunn sandpit (Fig. 1), a natural monument, which has been recently re-excavated. Here, the Pannonian sands and clays are folded by asymmetric, WSW verging antiforms with several meters amplitude; one of them is now again impressively exposed in three dimensions. Mechanic, geometric and regional geological criteria suggest that the structures were generated in the toe area of a gravitational slump.

The second outcrop of the excursion is located at St. Georgen am Leithagebirge (Fig. 1), where numerous conjugate deformation bands in barely cemented sands and gravels (Burgstall Formation) document an extensional deformation related to the nearby Eisenstadt Fault. The deformed unconsolidated sediments nicely illustrate the special properties and the mechanical differences between deformation bands and brittle fault in solid rock.

Stop 1: The Steinbrunn sand pit revisited: Tectonic or gravitational forcing of soft sediment folds?

ULRIKE EXNER, ERICH DRAGANITS & BERNHARD GRASEMANN

UTM Zone 33N, 606 900 E, 5 301 040 N, 250m NN

The Vienna Basin, located at the junction between the Eastern Alps and Western Carpathians, is one of the classic examples of pull-apart basins (e.g. ROYDEN 1985). During extensional lateral escape tectonics of the Eastern Alps, the basin was formed as part of the Pannonian Basin system (e.g. RATSCHBACHER et al. 1991) along a NE-SW trending system of normal and sinistral strike-slip faults (DECKER 1996). In the Miocene, syntectonic sedimentation accumulated up to 5500 m of marine and terrestrial deposits in the deepest parts of the basin (WESSELY 1983, STRAUSS et al. 2006). The deformation history of the basin has been described as multi-staged (DECKER 1996). An initial ESE-WNW-extensional phase in the Karpatian and Badenian (~17-13 Ma) was accommodated by NNE-SSW striking strike-slip faults and resulted in the initiation of the rhombic pull-apart basin (ROYDEN 1985). An intermediate stage of late-Miocene basin inversion with E-W compressional structures and simultaneous dextral reactivation of the strike-slip faults has been described (PERESSON & DECKER 1997). Pleistocene and present-day kinematics are again characterized by E-W extensional structures and the formation of local subbasins, e.g. the Mitterndorf basin in the SW part of the Vienna Basin (e.g. HINSCH et al. 2005).

Structural evidence of shortening like folds – or even more likely in unconsolidated sediments – deformation bands and thrust faults are basically absent in this part of the Vienna Basin. Based on this observation together with the fact that it is difficult to discriminate between tectonic and gravitational forces in deformed sediments with a low degree of lithification (ELLIOT & WILLIAMS 1988), we qualitatively investigated the structures in the re-excavated sand pit.

Outcrop description

In the Steinbrunn sand pit WNW of Eisenstadt, Burgenland, a spectacular example of deformed unconsolidated sediments has been described (MEYER 1974, SAUER et al. 1992). The site is accessible from the road connecting Müllendorf and Neufeld, from which a farm track turning south 100 m E of the bridge crossing the highway A3 leads to the sand pit (Fig. 1). The outcrop exposes a series of SW-verging, tight folds within virtually unconsolidated sand and silt layers (Fig. 2). Regional tectonic interpretations attributed this deformation to a late-Miocene, E-W compressional phase of basin inversion which followed the main E-W extensional phase in the early and middle Miocene (PERESSON & DECKER 1997). Since the declaration to a natural monument in 1980, the outcrop was increasingly covered by debris and vegetation and became effectively invisible. Recent re-excavation by the government of the province Burgenland now provides outstanding outcrop conditions which enable a re-evaluation of the remarkable structures in unconsolidated sediments.

In the studied outcrop, the sand layers are only partly cemented, while newly excavated layers in lower levels are virtually uncemented. Only some few sand layers show cementation and lithification, sometimes fading out laterally. Within the clay-rich layers isolated, up to several decimetres large concretions are abundant. The basal parts of the exposed stratigraphy contain more cohesive, cm to m thick silt and silty clay layers, which form conspicuous flame-shaped geometries in the fold cores indicative of the mechanics of soft sediment deformation (POTTER et al. 2005). Within the fold hinges, mud rich layers develop a pronounced cleavage, which may have been produced by either slump-straining or compaction (FARRELL & EATON 1988).

Conjugate sets of normal faults in parts of the NE-dipping fold limbs cut through sandy layers and terminate within

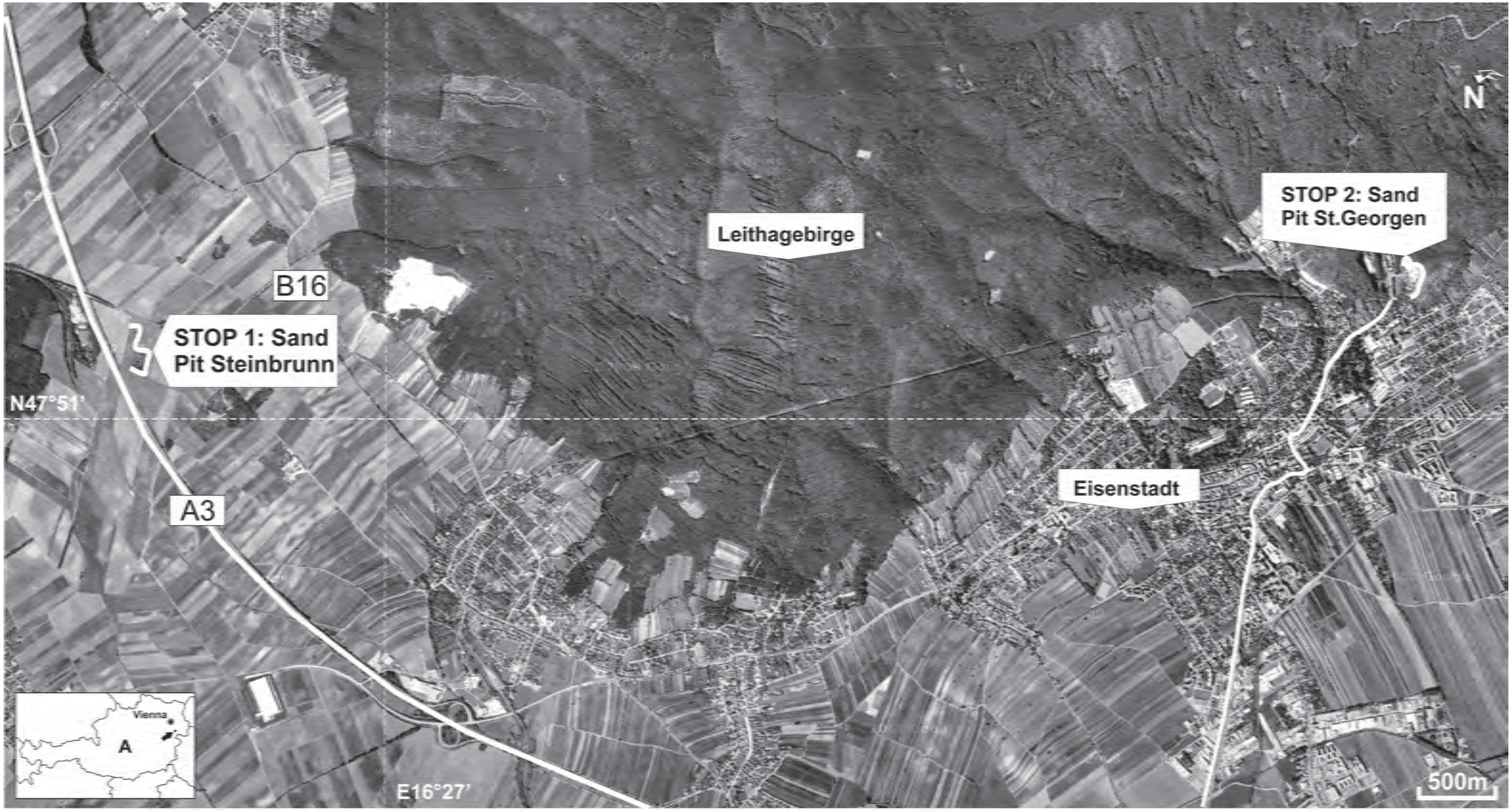

Fig. 1. Overview of the two excursion stops, the Steinbrunn and the St. Georgen sand pits, in the surrounding of Eisenstadt, Burgenland, Austria, (source: maps.google.com).

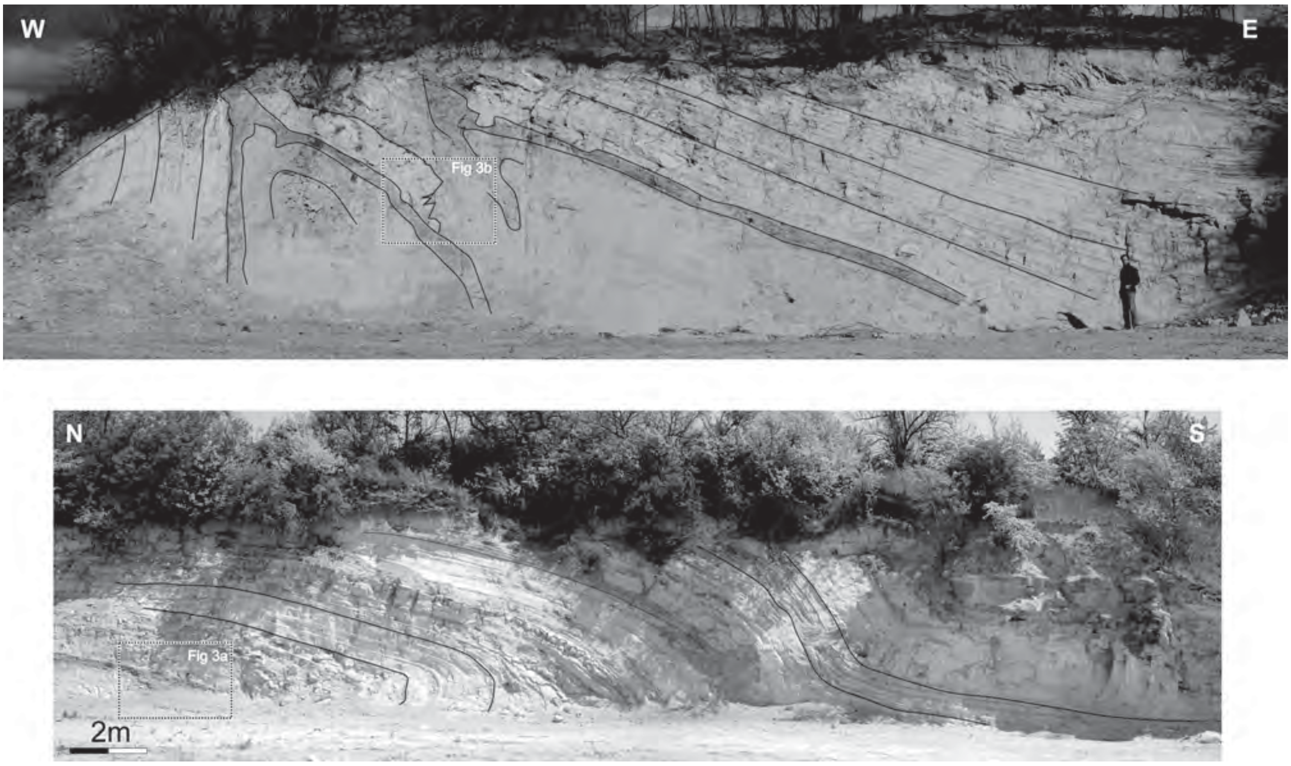

Fig. 2. Outcrop overview of the Steinbrunn sand pit. Two slightly SW-verging antiforms are exposed, the cores are composed of slits and clays, while the external layers comprise calcareous sands which are largely unconsolidated.

silt layers. Markers within the sand layers display only few cm of normal offset, but the fractures are filled with a max. 2 cm thick zone of clay fed from the overlying clay layer (Fig. 3). This feature suggests that the sediment was still even more unconsolidated during the formation of these structures.

Most of the observed folds have a tight fold geometry with straight fold limbs and amplitudes of several meters. In the westernmost part of the outcrop, some fold axial planes are refolded, forming type 3 (hooks-and-crescent) refold structures with high angles between the axial planes but almost parallel fold axes (Fig. 4). These fold shapes indicate either polyphase folding, which seems unrealistic for a short phase of basin inversion, or high strain during progressive folding and shearing. The latter has been frequently described in subaqueous slump structures (e.g. STRACHAN & ALSOP 2006).

In the immediate vicinity, outcrops within the same stratigraphic level do not display any comparable structures with E-W shortening kinematics. In contrast, exclusively E-W extensional structures (faults and deformation bands with normal offset) can be observed.

Line-length and area balancing give a rough estimate of the percent of shortening (~ 50%) and depth of an inferred detachment horizon (~ 2m below the current base of the outcrop, i.e. some 8 m below the topographic surface).

The new observations in the sand pit of Steinbrunn, enabled by the re-excavation of the outcrop, question the tectonic origin of the observed fold structures. We propose an alternative interpretation of the deformation features as the frontal zone of a gravitational slump, where shortening strain leads to the formation of tight folds (FARRELL 1984).

Acknowledgements

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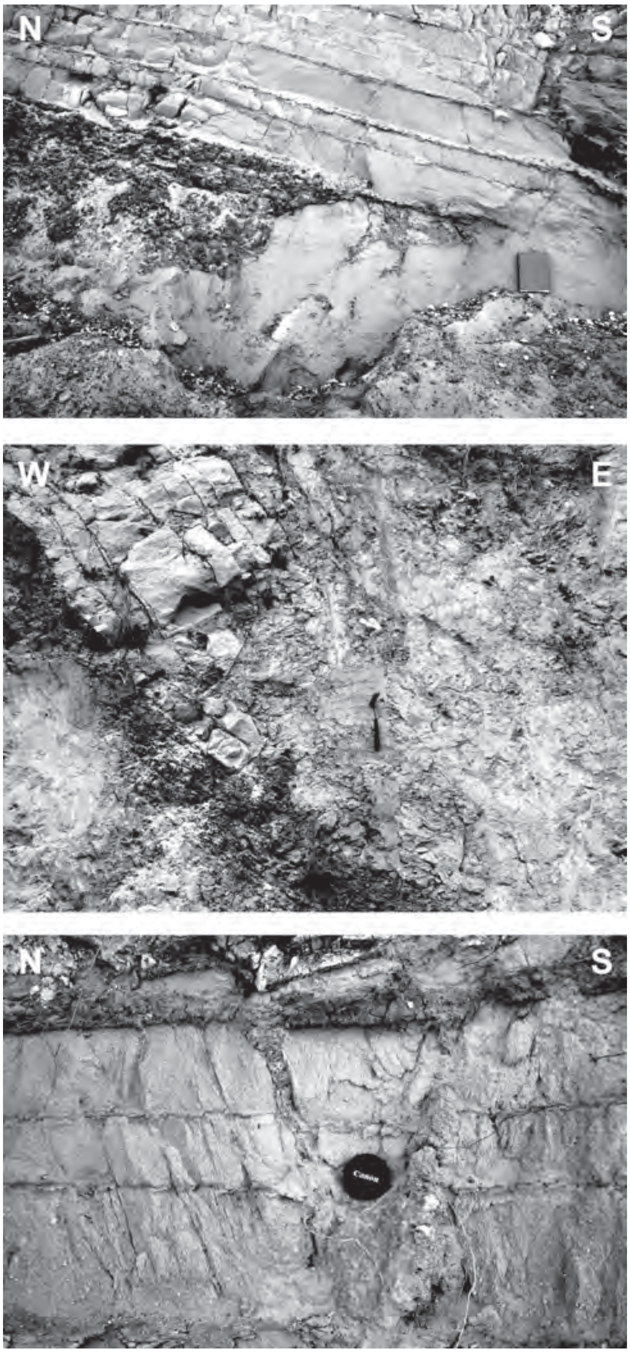

Fig. 3. Details of the exposed folds. (a) Clay injections in the southern exposed fold core. (b) Sand beds are disrupted in the upper limb of the northern antiform, showing clay intrusions into the fragmented beds. (c) Conjugate sets of normal faults with only 1-2 cm offset are filled with clay from the overlying layer.

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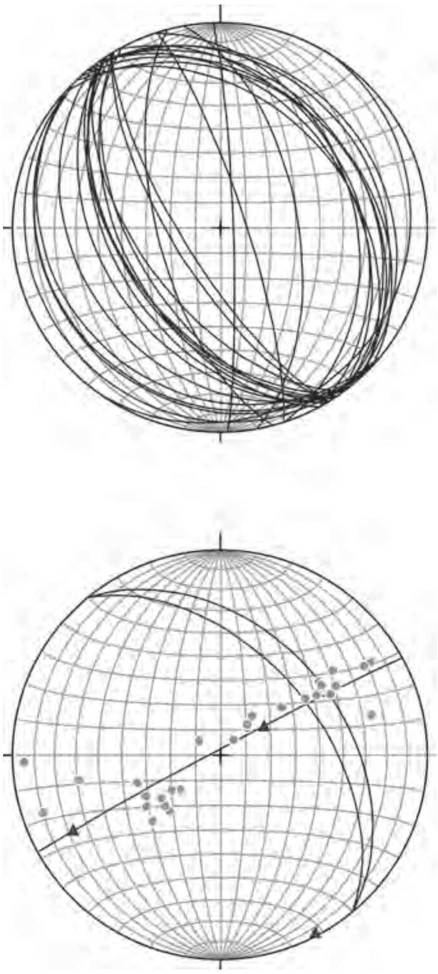

Fig. 4. Stereoplot, lower hemisphere. (a) Bedding planes with variable dips to NNE and SSW. (b) Constructed fold axis from the bedding poles, striking NNW-SSE. Axial planes are dipping moderately to the NE.

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Stop 2: Deformation Bands in unconsolidated sands and gravels of the sand pit St. Georgen, Burgenland

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UTM Zone 33N, 615 200 E, 5 301 720 N, 226m NN

Introduction

The sand pit St. Georgen, NE of the city of Eisenstadt, offers extraordinary examples of tectonic deformation structures in unconsolidated sands and gravels. The outcrop is now used as a storage place for building materials, permission to access needs to be requested at the entrance gate next to the fire brigade school along the road from Eisenstadt to Stotzing (Fig. 1).

Tollmann (1995) identified a normal fault in the southern part of the quarry, which juxtaposes calcareous sandstones and intercalated limestone beds in the hanging wall against the terrigeneous, carbonate-free sand and gravel (Burgstall Schotter) in the footwall. The dip slip displacement is documented by dip-parallel slickensides in the carbonatic hanging wall (see fig. 72 of Sauer et al. 1992), which have been eroded and are no longer exposed. This normal fault is oriented subparallel to the Eisenstadt fault, which represents a major fault bordering the Eisenstadt Basin.

The footwall of the fault comprises coarse clastic sediments, (Burgstall Schotter), deposited in a shallow marine environment with strong fluvial influence (Sauer et al. 1992, Zorn 2007). While a Badenian age is constrained for the calcareous rocks in the hanging wall by abundant microfossils (Zorn 2007), the lack of biogenic material in the underlying gravels and sands so far inhibited an exact age determination (Kroh et al. 2003). The exposed sediment is dominated by coarse sand with channels comprising gravel.

X-ray diffractometry analysis of the sands shows quartz, feldspar, muscovite and clay minerals, indicating a crystalline source of the material. Single gravel clasts up to 8cm in diameter can be identified as quartzites, micaschists and garnet-bearing gneisses. According to Tollmann (1955), the source of these metamorphic rocks is located in the south of the Eisenstadt Basin, not in the nearby Leitha Mountains. The lack of carbonate material can be documented at all grain sizes.

Deformation bands

The gravels and sands at the St. Georgen sand pit are cut by a multitude of conjugate deformation bands (Aydin 1978) with normal offset. Note, that due to the lack of cementation in these lithologies, the structures do not develop as faults with a localized slip surfaces typical for brittle deformation in solid rock (Fig. 1), but the form broader zones of continuous deformation (Fig. 5 and 6). Deformation bands develop in granular materials, such as porous rocks with weak or no cementation. Within these planar deformation zones strain is accommodated by translation, rotation and breaking of grains resulting usually in porosity reduction. Several types of deformation bands have been distinguished in the literature, depending on the amount of shear and amount of compaction or dilation within the deformation band (see Fossen et al. 2007 for a review). Additionally, different types of rock with different porosity, amount of compaction or cementation, composition (especially clay content) were found to develop specific types of deformation bands.

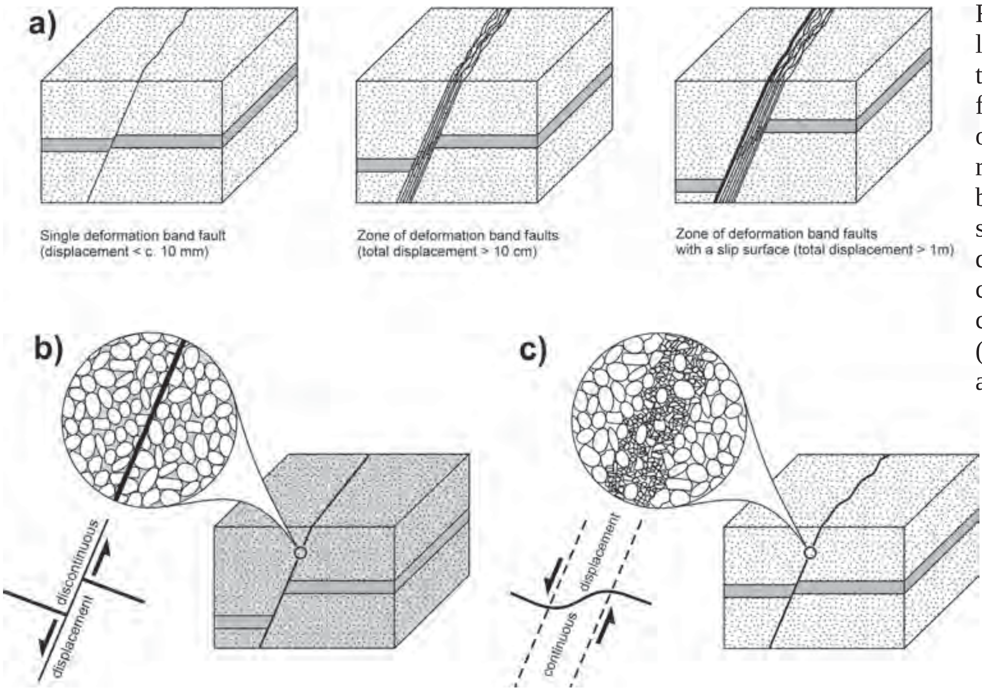

Fig. 5: (a) Progressive development of a single deformation band into a zone of deformation bands and a zone of deformation bands bordered on one side by a fault.
b) Fault with a localized slip surface and discontinuous displacement.
c) Deformation band with continuous displacement (modified after Draganits et al. 2005).

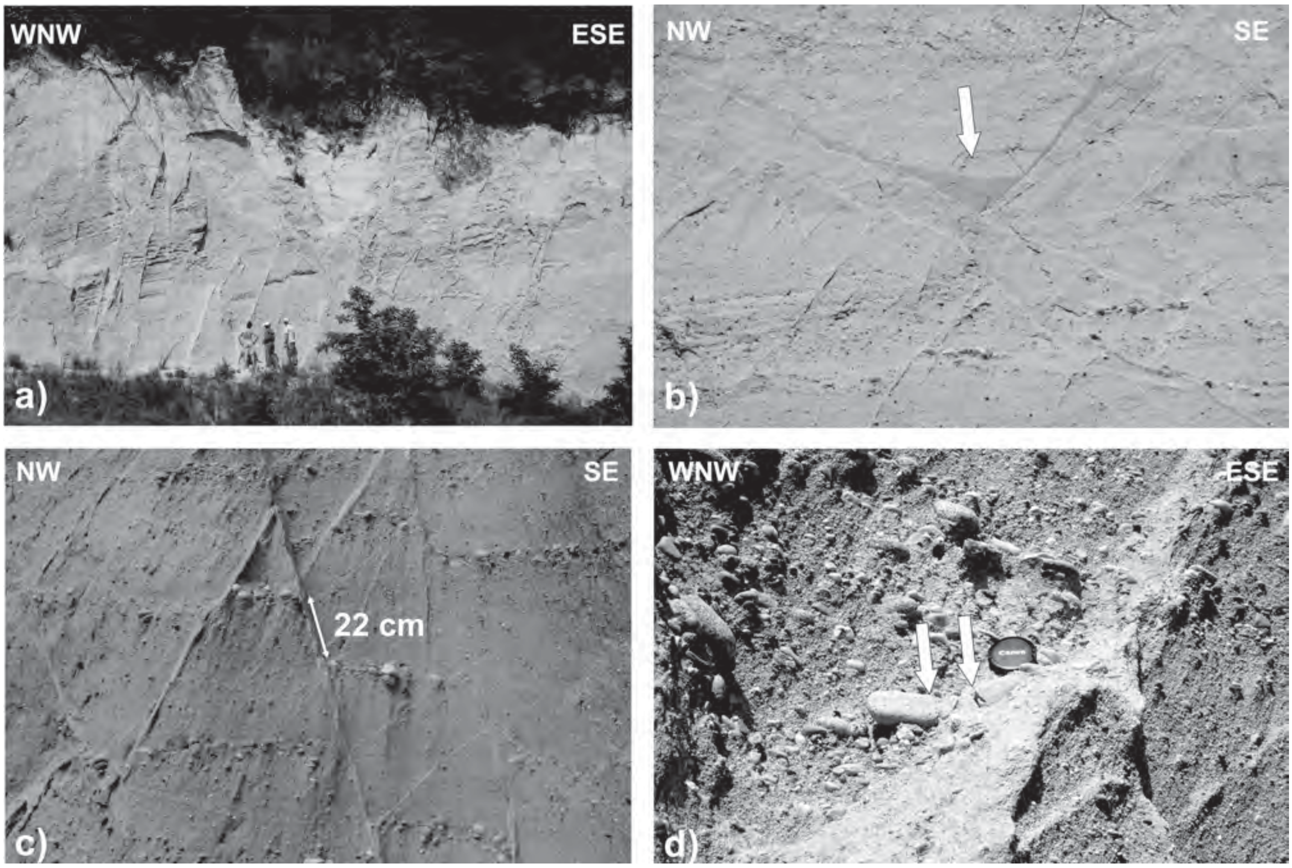

Fig. 6: (a) Set of conjugate deformation bands in the St. Georgen sand pit. (b) Red-brownish staining by infiltration of surface water in a bowl shaped compartment between a conjugate set of deformation bands highlighting the compartmentalisation of the sediments and the role of deformation bands as barriers and pathways for fluid flow. (c) Offset of gravel layers by conjugate sets of deformation bands. d) Broken pebble adjacent to a deformation band.

In this outcrop, the deformation bands occur as up to 15cm thick, planar zones protruding from the surrounding, undisturbed sediment. The bands record normal offset of the sedimentary beds between few cm and 1 m (Fig. 6). Comparison between thin sections from the deformation bands and the host rock revealed a pronounced porosity reduction, not only due to compaction, but especially due to preferential growth and possibly also precipitation of clay minerals within the deformation bands. Grain size distributions in the undisturbed sand and within a deformation band record an increased amount of coarse silt and fine-medium sand in the deformation band (Fig. 7).

The kinematics of the deformation bands can be described as follows (Fig. 8): Two sets of conjugate deformation bands are developed. One set is oriented parallel and conjugated, respectively, to the normal fault exposed in the southern part of the outcrop, striking NNE-SSW. Additionally, a second conjugate set can be observed, with one dominant orientation of long and continuous bands dipping steeply to the S, while the associated conjugate bands are not only much shorter and often thinner, but also show a more shallow dip to the N. Furthermore, due to their restriction to areas between closely spaced S-dipping bands, we conclude that the N-dipping, subordinate bands accommodate the strain between the more prominent S-dipping ones.

Migration of iron- or organic-rich fluids between the sets of deformation bands is documented by brownish staining, which highlight the compartmentalisation of the sediments and the role of deformation bands as barriers and pathways for fluid flow.

Notably, no deformation bands have been observed in the calcareous sediments of the hanging wall, where lower porosity and carbonatic cementation favoured the localisation of deformation in distinct slip surfaces.

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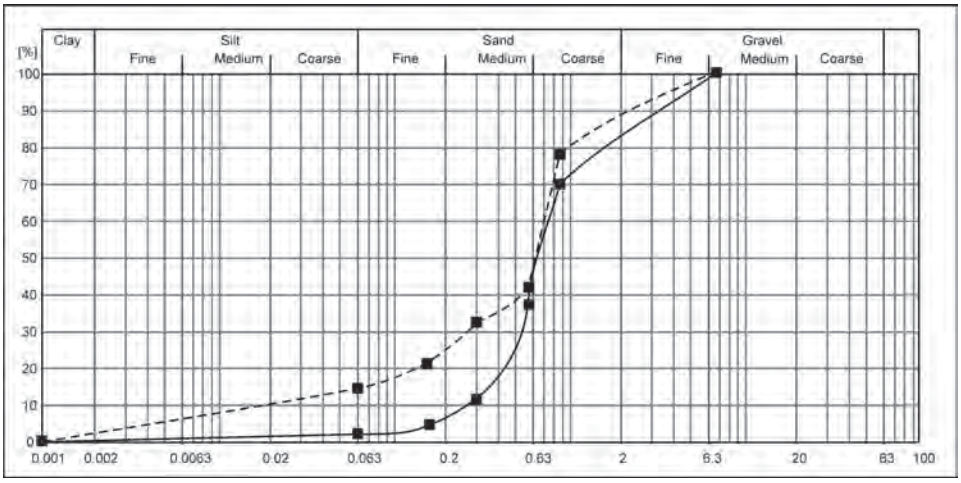

Fig. 7. Grain size distributions in the undisturbed sand (solid line) and with a deformation band (dashed line). Note the increased amount of coarse silt and fine-medium sand in the deformation band.

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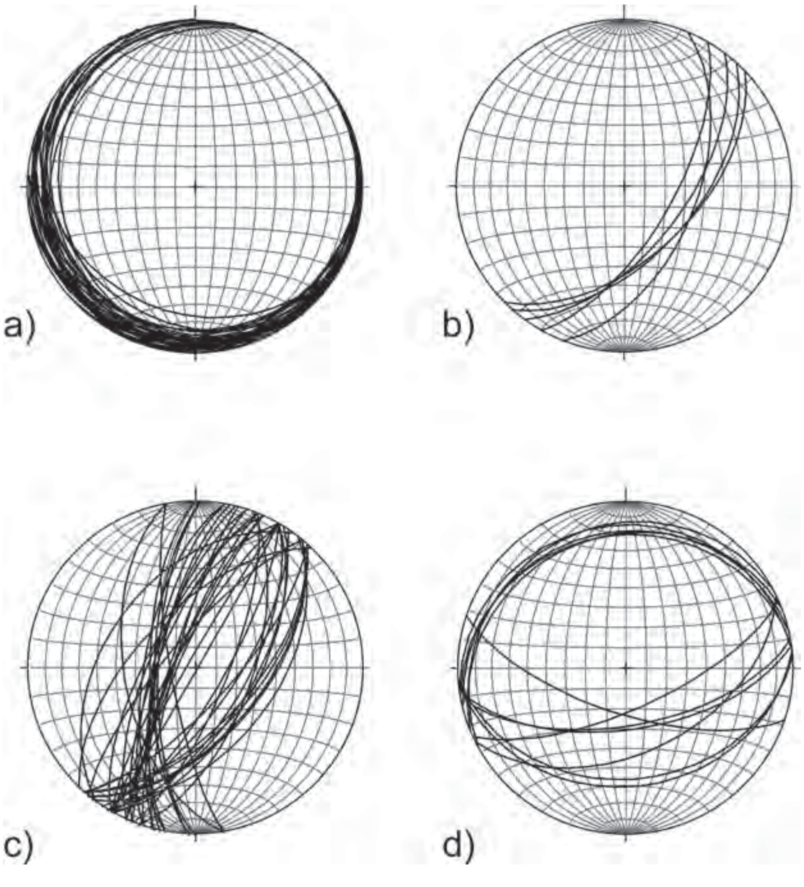

Fig. 8. Stereoplot, lower hemisphere:
(a) bedding,
(b) master fault
(c) conjugate set of deformation bands, subparallel and conjugate to masterfault,
(d) E-W trending, second set of conjugate deformation bands.