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Research paper

Dilatant shear band formation and diagenesis in calcareous, arkosic sandstones, Vienna Basin (Austria)

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A B S T R A C T

The present study examines deformation bands in calcareous arkosic sands. The investigated units can be considered equivalent to reservoir units in the Matzen field in the Vienna Basin (Austria), which is one of the most productive oil reservoirs in central Europe. The outcrop exposes carbonate-free and carbonatic sediments of Badenian age separated by a normal fault. Carbonatic sediments in the hanging wall of the normal fault develop single and multistrand dilation bands with minor shear displacements (<2 mm). In contrast, carbonate-free sediments in the footwall exhibit a more pervasive system of cataclastic shear bands, which are frequently accumulated in clusters with up to 70 cm displacement. The cataclastic shear bands show a permeability reduction up to 3 orders of magnitude and strong baffling effects in the vadose zone. Carbonatic dilation bands show a permeability reduction of 1–2 orders of magnitude and no baffling structures. We distinguished two types of deformation bands in the carbonatic units, which differ in deformation mechanisms, distribution and composition. Full-cemented bands form as cataclastic dilation bands with an intense syn-kinematic calcite cementation, whereas the younger loose-cemented bands are cataclastic dilatant shear bands cemented by patchy calcite and clay minerals. All analyzed bands are characterized by a two-staged petrophysical evolution: Porosity increase by dilation and grain fracturing is followed by a porosity and permeability reduction caused by authigenic cementation. The changed petrophysical properties and especially the porosity evolution are closely related to diagenetic processes driven by varying pore fluids in different diagenetic environments. The deformation band evolution and sealing capacity is controlled by the initial host rock composition.

1. Introduction

Deformation bands are tabular zones of localized strain in porous sedimentary rocks (Aydin, 1978; Antonellini et al., 1994). These features nucleate prior to faulting or in broad zones of distributed deformation, but due to their small thickness (mm to cm) and small offset (<1 m) generally are not recognized in seismic data. Deformation mechanisms such as grain reorganization, cataclasis, pore collapse or preferred cementation, which are dominant in the band, may lead to a significant loss of porosity and permeability relative to the host rock (Fisher and Knipe, 2001; Rawling et al., 2001; Fossen and Bale, 2007). As a result, deformation bands locally influence the migration of fluids into reservoir rocks or deteriorate reservoir quality by compartmentalization. Examples of these effects are well documented in literature (Eichhubl et al., 2004; Exner et al., 2013; Ballas et al., 2014), but their actual relevance for reservoir properties needs to be evaluated individually. Deformation bands are classified by their kinematic properties and dominant deformation mechanism. In terms of kinematic behavior, deformation bands are grouped into three end members: shear-, compaction- and dilation bands (Aydin et al., 2006). Based on the dominant deformation mechanisms band types are classified as disaggregation bands, cataclastic bands and dissolution/cementation bands (Fossen et al., 2007). Factors like composition, grain size, shape, sorting, initial porosity, cementation and stress level and configuration determine the deformation mechanisms and band type. Natural samples are frequently mixtures between different end members. Several studies investigated different band types which developed under natural (e.g., Rawling and Goodwin, 2003; Tondi et al., 2006; Balsamo and Storti, 2010; Soliva et al., 2013) and experimental conditions (e.g., Vajdova et al., 2004; Baud et al., 2009; Cilona et al., 2012) in different

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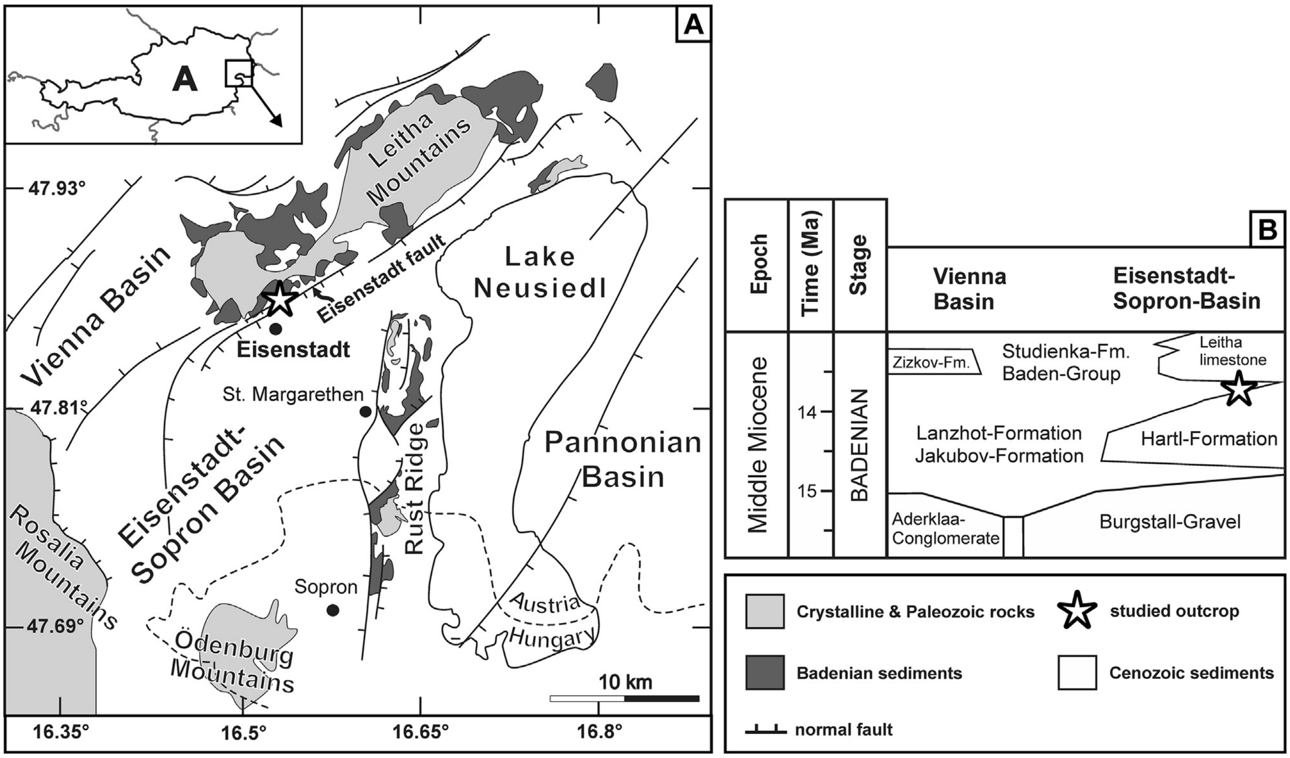

Figure 1. (A) Map of the outcrop location at the northern margin of the Eisenstadt-Sopron Basin (after Schmid et al., 2001). (B) Stratigraphic chart of the Badenian in Austria modified after Piller et al. (2004).

kinds of host rocks, or proposed constitutive models for their formation (e.g., Wong et al., 1997; Borja and Aydin, 2004; Nicol et al., 2013).

According to theoretical considerations, localization under low confining pressure leads to the formation of dilation bands (Aydin et al., 2006). Only very few examples of dilation bands have been reported in the literature (Du Bernard et al., 2002; Sample et al., 2006; Exner et al., 2013), some of them occurring in very specific geometrical relationships to more pervasive shear bands, i.e. the extensional quadrants close to the tips of shear bands (Du Bernard et al., 2002). None of the reported examples show any evidence of cataclasis in combination with dilation. In the present study, we propose an evolutionary scenario of deformation bands forming under low confining pressure, where an initial stage of dilation and minor shear associated with cataclasis is preserved by subsequent fluid infiltration and carbonate cementation. Importantly, the high content of detrital siliciclastic material plays an important role in the structural and diagenetic evolution of these deformation bands. In contrast, deformation bands in pure carbonates are reported to evolve as compaction bands even at low confining pressure (Tondi, 2007; Rath et al., 2011). However, similar localization structures developed in the underlying, carbonate-free units show a high degree of grain fracturing and subsequent clay mineral cementation. Our aim is to quantify the influence of initial composition and intensity of deformation on the structural and diagenetic evolution of deformation bands. Proposing an evolutionary model for porosity changes within the investigated bands and quantify their final effect on permeability and reservoir quality.

2. Outcrop description

The investigated outcrop is located at the northern margin of the Eisenstadt-Sopron Basin (Austria), which is a satellite basin of the Vienna Basin (Fodor, 1995). The abandoned sandpit exposes terrigeneous, carbonate-free sands and shallow marine, carbonatic sediments of Badenian age (Fig. 1B; Sauer et al., 1992). Both lithologies are crosscut by numerous deformation bands with identical orientation and kinematics, and were formed at shallow depths <150 m (Strauss et al., 2006). The region is dominated by an extensional deformation regime (ESE-WNW) in the vicinity of the Eisenstadt Fault (Fig. 1A), which shows about 80 m of dip-slip displacement down to the southeast of the basin and postdates the deposition of the investigated units (Fodor, 1995; Decker, 1996). The terrigenous and marine lithologies are divided by a normal fault with presumably several tens of meters of displacement into carbonate-free sediments in the footwall and a ca. 20 m thick carbonatic unit in the hanging wall (Fig. 2A). The main normal fault is composed of multiple, anastomosing fault planes marked by greenish marly cataclasites and slickensides indicating a dip-slip motion (Sauer et al., 1992). Following on previous studies in the terrigenous sands (Exner and Tschegg, 2012; Lommatzsch et al., in press), this paper is focused on the structures in the carbonatic sediments (Fig. 2). The investigated units comprise arkosic sands and gravels, which were reworked in a shallow marine environment (Sauer et al., 1992) and thus contain carbonate bioclasts. The beige carbonatic sands are intercalated with and gradually replaced by well cemented, massive limestone beds of several dm thickness towards the top of the outcrop, which are regarded as the base of the Badenian Leitha limestone due to their biogenic content (Fig. 1B). The planar bedding in the carbonatic host rocks dips gently to the southwest (5–7°) and is characterized by a faint, cm thick layering and a parallel alignment of mollusk shells or accumulations of red algae (Fig. 2B).

The quarry exposes two conjugated, intersecting sets of NNE-SSW trending deformation bands (Fig. 3). The main normal fault is parallel to the SE-dipping set of deformation bands and shows a