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ORIGINAL PAPER

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Fluid focusing and back-reactions in the uplifted shoulder of the Rhine rift system: a clay mineral study along the Schauenburg Fault zone (Heidelberg, Germany)

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Abstract A retrograde sequence of fluid-controlled, low-temperature mineral reactions has been preserved along an east-west striking, dextral-oblique-slip fault in the uplifted Rhine Graben shoulder. This fault (the Schauenburg Fault, near Heidelberg), juxtaposes Permian rhyolite against Carboniferous (Variscan) granite and shows syn- or post-rift displacement of the north–south trending, eastern boundary fault of the rift basin. Both mineral texture and rock fabric indicate that the fault forms a site of high rock permeability and fluid flow, and records the exhumation and fluid-rock history of the rift shoulder since the Mesozoic. The reaction sequence and mineral compositions of the clay minerals within the cataclasite, and adjacent granite and rhyolite lithologies, document progressively decreasing fluid temperatures, with back-reactions of pure $2M_1$ illite to $1M_d$ (R3) illite-smectite, and eventually smectite and kaolinite assemblages. Compositional variations are attributed to Tertiary to Recent fluid flushing of the fault zone associated with rift flank uplift, and with progressive dilution of the electrolyte-rich, acidic to neutral hydrothermal brines by down-flowing electrolyte-poor, meteoric waters.

Keywords Clay minerals · Rhine rift system · Faulting · Fluid-rock interaction · Exhumation

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Introduction

Uplifted rift shoulders play an important role in influencing the regional flow of fluids within intracontinental extensional basins (Person and Garven 1994; Stanislavsky and Gvirtzman 1999). The localized areas of higher topography create a hydro-dynamic gradient that drives waters downward into aquifers within the syn-rift sequence (Abebe 2000; Lampe et al. 2001; Clauser et al. 2002). Our understanding of the regional hydro-dynamic behavior of rift shoulders and their evolution through time has been advanced by modeling fluid flow, taking into account permeability, thermal gradients, topography, crustal stress and fluid chemistry (van Balen and Cloetingh 1993; Bartels et al. 2000; Pribnow and Clauser 2000). An important aspect of such studies is to predict the physical and chemical properties of faults in the uplifting graben shoulders, which have implications for understanding and exploiting water, thermal and mineral resources in sedimentary basins (Carlé 1958; Evans 1990; Sibson 1994; May et al. 1996; Lampe et al. 2001), as well in the safety assessment of underground waste repositories (Gautschi 2000).

The formation of clay minerals in faults have been shown to play a particularly important role in influencing the flow of fluids in sedimentary basins (Knipe 1993). Clay growth affects anisotropy, permeability and porosity as well as fault strength (Morrow et al. 1984; Wintsch et al. 1995; Wibberley 1999; Warr and Cox 2001; Solum et al. 2003). Clay minerals also provide important information concerning fluid composition, temperature and the degree of fluid–rock interaction (Velde 1985; Inoue et al. 2004). However, in contrast to the well studied continuous, prograde clay mineral reactions from smectite to illite–smectite to illite–muscovite within burial diagenetic, low temperature metamorphic and hydrothermal environments (Srodon and Eberl 1984; Hunziker et al. 1986; Dong et al. 1997), the nature of retrograde illitic and smectitic mineral reactions in fault rocks (Zhao et al. 1999; Abad et al.