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ORIGINAL PAPER

On the origin of mixed-layered clay minerals from the San Andreas Fault at 2.5–3 km vertical depth (SAFOD drillhole at Parkfield, California)

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Abstract A detailed mineralogical study is presented of the matrix of mudrocks sampled from spot coring at three key locations along the San Andreas Fault Observatory at depth (SAFOD) drill hole. The characteristics of authigenic illite–smectite (I–S) and chlorite–smectite (C–S) mixed-layer mineral clays indicate a deep diagenetic origin. A randomly ordered I–S mineral with ca. 20–25% smectite layers is one of the dominant authigenic clay species across the San Andreas Fault zone (sampled at 3,066 and 3,436 m measured depths/MD), whereas an authigenic illite with ca. 2–5% smectite layers is the dominant phase beneath the fault (sampled at 3,992 m MD). The most smectite-rich mixed-layered assemblage with the highest water content occurs in the actively deforming creep zone at ca. 3,300–3,353 m (true vertical depth of ca. 2.7 km), with I–S (70:30) and C–S (50:50). The matrix of all mudrock samples show extensive quartz and feldspar (both plagioclase and K-feldspar) dissolution associated with the crystallization of pore-filling clay minerals. However, the effect of rock deformation in the matrix appears only minor, with weak flattening fabrics defined largely by kinked and fractured mica grains. Adopting available kinetic models for the crystallization of I–S in burial sedimentary environments and the current borehole depths and thermal structure, the conditions and timing of I–S growth can be evaluated. Assuming a typical K^+ concentration of 100–200 ppm for sedimentary brines, a present-day geothermal gradient of 35°C/km and a borehole temperature of ca. 112°C for the sampled depths, most of the I–S minerals can be predicted to have formed over the last 4–11 Ma and are probably still in equilibrium with circulating fluids. The exception to this simple burial pattern is the occurrence of the mixed layered phases with higher smectite content than predicted by the burial model. These minerals, which characterize the actively creeping section of the fault and local thin film clay coating on polished brittle slip surfaces, can be explained by the influence of either cooler fluids circulating along this segment of the fault or the flow of K^+-depleted brines.

Keywords SAFOD · Illite–smectite · Mixed-layered clays · San Andreas Fault

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Introduction

The crystallization of clays in fault zones and their influence on fluid–rock interaction, rock deformation and shear strength has been suggested as a possible explanation for a weak fault behavior (Rutter et al. 1986; Vrolijk and van der Pluijm 1999; Rutter et al. 2001; Warr and Cox 2001). As often reported along exhumed segments of the San Andreas Fault in western California, the occurrence of such mineral phases as chlorite, illite, smectite, as well as kaolinite, serpentine and talc, are typically associated with strong fluid–rock interaction and brittle deformation under low-