New insights into the formation of diagenetic illite from TEM studies

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ABSTRACT

Diagenetic illite from the Proterozoic Chuanlinggou Formation, China, has been investigated using the techniques of transmission electron microscopy (TEM), selected-area electron diffraction (SAED), X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive spectrometer (EDS). Polytypes of 1Md and 1M illite coexist in the diagenetic illite. The 1Md polymorph is predominant in the <0.2 μm size fraction, which has high Al and low Mg contents and irregular crystal shapes. Lattice-fringe imaging and one-dimensional structural imaging show abundant structure defects. The 1Md illite has both layer and sheet terminations caused by edge dislocations and layer displacements along c* caused by screw dislocations. These observations indicate that the disordered 1Md structure of the diagenetic illite resulted from abundant dislocations. The dislocation serves as nucleation sites for the illite nano particles to spontaneously nucleate in the initial stage of illite formation. Such a nucleation process obeys the Ostwald ripening rule. The illite only shows a 1.0 nm thickness for each layer in high-resolution TEM images, which suggests that the illite crystals have no mixed smectite layer, and the 1Md illites are authigenic and not illitized from smectite or illite/smectite. Heterogeneous nucleation led to directly crystallization of the 1Md illite during the initial growth of illite in shales under a low-temperature and tectonic-stress-free environment. The results have implications for interpreting the distribution of 1Md illite in sedimentary rocks.

Keywords: Diagenetic illite, heterogeneous nucleation, 1Md polymorph, edge dislocation, screw dislocation

INTRODUCTION

Nucleation has been widely discussed in material science. It is relevant to the process of crystallization of nanometer-sized materials (Abraham 1974; Penn and Banfield 1998; Mendez-Villuendas and Bowles 2007). It is also a subject for scientific investigations in diagenesis, metamorphism, magmatism, and deformation of Earth’s materials (Porter and Easterling 2001). Some researchers suggested that nucleation is predominant in the early or initial stage of phyllosilicates’ growth (e.g., Baronnet 1992; Baronnet and Kang 1989; Warr and Nieto 1998).

Illite, a phyllosilicate, has a poor crystallinity, deficient interlayer cations, a size of less than 2 μm, and a crystal structure similar to muscovite with a pair of tetrahedral sheets (T sheets) linked by one octahedral sheet (O sheet) in the so-called 2:1 layered structure (Bailey 1984; Rieder et al. 1998). It is widespread in many geological settings of the Earth’s crust, such as diagenesis in mudrocks, very low grade metamorphism and hydrothermal systems, mostly in near-surface and relatively shallow geologic environments, and considered to provide a good record of natural process (Środoń and Eberl 1984; Chen and Wang 2007). A regular sequence of polytypic transition in illite, similar to the dioctahedral mica, from the 1Md through the 1M to the 2Mt polytype with increasing temperature is well known (e.g., Velde 1965; Grathoff and Moore 1996). Illite has commonly a 1Md structure in its original state of formation (Grubb et al. 1991). There are a lot of evidence suggesting the 1Md illite is a heterogeneous, disordered metastable phase crystallized at low-temperature and low-pressure conditions (Baronnet 1992; Chen and Wang 2007).

However, whether the 1Md illite originates as a result of direct crystallization or as a replacement of smectite is still controversial. It has been proposed that the authigenic illite formed from the illitization of smectite by a layer-by-layer replacement during burial diagenesis in Paleozoic pelite or shale with organic matter or fluid playing a role in the illitization processes (e.g., Gill and Yemane 1999; Bauluz et al. 2000; Grathoff et al. 2001; Elliott and Haynes 2002). Other models include formation from a dissolution/crystallization process obeying the Ostwald step rule (e.g., Grubb et al. 1991) and from early 3D-nucleation and 2D-layer growth (e.g., Pandey et al. 1982; Baronnet and Kang 1989).

Lattice imperfection and deformation created during crystal growth or recrystallization can reflect various stages of diagenesis and metamorphism, and a varying physicochemical environment (Ahn and Peacor 1986; Banfield et al. 1994; Jiang et al. 1997). The type and distribution of lattice imperfection are related to specific geological conditions for mineral formation and can help reconstruct the structural mechanism of a phase transformation (Drits 2003; Jiang et al. 1997). Therefore, the lattice imperfection or structure defect of illite is important for studying its formation mechanism.

Transmission electron microscopy (TEM) has become the best technique for investigating lattice imperfection in solid-state...