Characteristics of mixed-layer smectite/illite density separates during burial diagenesis

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ABSTRACT

We report a method to physically separate smectite from illite in natural shale samples. This method is based upon the large contrast in the density of mixed-layer clay minerals reported in the literature. Our objective was to investigate the behavior of separate density fractions of mixed-layer smectite and illite during burial diagenesis.

Samples were obtained from shale cuttings hand-picked from a well drilled offshore Louisiana. Each sample was separated into 5 fractions: “pure” end-member smectite (EMS), smectite-rich mixed-layer clays (SML), illite-rich mixed-layer clays (IML), “pure” end-member illite (EMI), and quartz (FGQ). The mineralogy of each clay-mineral separate as determined by XRD was reasonably consistent at all depths, although the abundance of the mixed-layer separates varied. The illite-rich mixed-layer fraction increased in abundance with depth at the expense of the smectite-rich mixed-layer fraction. The fine-grained quartz fraction showed an increase in abundance, a decrease in average grain size, a loss of K-feldspar, and a heavier isotopic signature with depth. We did not, however, find a correlation with depth in the amount of the end-member clay fractions. The isotopic signature of the end-member smectite shows evidence of equilibration with depth, but the end-member illite does not. We conclude that the discrete illite fraction is detrital in origin, and was not involved in the clay-mineral transformation at the depths sampled in our well. It reflects the sediment provenance.

The results of this study illustrate the efficacy of the newly developed density separation technique for physically isolating clay mineral species from one another.

INTRODUCTION

Lynch (2000) considers smectite to illite diagenesis the most important reaction in clastic sedimentary diagenesis. Since the pioneering work of Hower et al. (1976), there have been several excellent studies examining the smectite to illite transition. These works document the decrease in expandability of mixed-layer clays and the increase in illite crystallinity with increasing burial depth. Šrodoń (1980) developed a method using X-ray diffraction (XRD) peak positions to measure the smectite-illite ratio of the mixed-layer clay fraction. A number of studies have relied on this method or similar methods to verify the smectite to illite transition. Recent studies use the method of matching modeled XRD patterns of various calculated clay mixtures to patterns from actual samples (Reynolds 1989). The ability to physically separate individual clay minerals and X-ray them separately would permit a more-direct approach to the study of the smectite to illite reaction.

The physical separation of clay-mineral species (by differences in chemical, size, magnetic, dielectric, and density properties) has been burdened with difficulties (Towe 1974). Overlapping ranges of properties between different clay minerals are among the primary causes for the inability to separate them physically. Particularly troublesome impediments to separation by density are the extremely small grain size, the platy morphology of clays resulting in large surface areas that can “raft” mineral grains, adsorption of material from separating media, and electrostatic forces that can cause flocculation. In spite of these inherent difficulties, the tangible research benefits that would result from a successful clay-mineral separation method encouraged us to develop this technique.

Density differences of smectite-illite

There has been partial success involving the quantitative separation of clay minerals. Studies of the separation of clay minerals by settling and particle size (Kerns 1967), adsorption by organic heavy liquids (Nelson 1995), dielectric separation (Müller 1967), and magnetic separation (Russel et al. 1984; Schultz and Dixon 1979) have all documented that certain clay minerals can be concentrated given time, patience, and special equipment. However, quantitative clay-mineral separation has not yet been realized for two of the major clay-mineral constituents of non-metamorphosed shales, illite and smectite. It is not uncommon to find fine-grained sedimentary rocks dominated by mixtures of smectite and illite, with variable amounts of quartz, feldspars, kaolinite, chlorite, and heavy minerals in clastic basins world-wide. This mineralogy is particularly evident in the U.S. Gulf Coast section where discrete smectite, discrete illite, and mixed layer illite-smectite with variable proportions of illite interlayers have been reported (Aronson and Hower 1976). In addition, minor amounts of quartz and feldspar are usually present in Gulf Coast shales, particularly in the coarser grain sizes. The ability to physically separate smectite from illite will be of use to the many investigators of these rocks.