Cation exchange capacity and water content of opal in sedimentary basins: Example from the Monterey Formation, California

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ABSTRACT

Surface characteristics of sedimentary opal-A and -CT were investigated for a large collection of samples from the Monterey Formation, California, based on the bulk rock mineral and chemical analysis, cation exchange capacity (CEC), and water content. Two approaches were used: (1) modeling bulk CEC and adsorbed water content for the entire data set using the contents of opal and clay minerals measured by XRD, and (2) correcting the chemical composition and CEC of the most pure opal samples for the mineral impurities quantified by XRD.

Modeling indicates that the bulk rock data can be best explained by mixing an illite-smectite (CEC = 59 meq/100 g, 7–8% H2O), consistent with the XRD characteristics of the clay fraction, with opal-A (8 meq/100 g, 3.4% H2O), and opal-CT (13 meq/100 g, 3.7%H2O).

Correcting the chemical composition of the most pure opal samples leaves a large excess of cations (Al, Fe, Na, K, Ca, and Mg). Iron is suspect to form traces of separate (oxy-)hydroxide phases, not detected by XRD, while Al for Si substitution in the opal structure produced local negative charge, which was compensated by Na, K, Ca, and Mg exchange cations. A perfect balance of positive and negative charges is observed if the clay admixture in pure opals has the composition of montmorillonite. The concentration of heterogeneous impurities in silica network in opal leads to smectite formation on or within the diatom frustules. These dispersed smectite particles, perhaps monolayers, can be missed during the bulk rock mineral quantification.

The recalculated CEC of the opal, assuming the occurrence of dispersed smectite particles, varies from 3 to 11 meq/100 g, which is slightly less than that evaluated by modeling all the rock samples in the set, and corresponds to 10–50% of the total opal charge quantified by the degree of Al for Si substitution. The remaining charge of the opal structure represents non-exchangeable cations. As opposed to smectite, opal CEC may depend on the size of cation used for the CEC measurement.

For opals in the Monterey Formation the content of water removable at 200 °C can be modeled as a sum of a constant value and a variable value dependent on CEC; the latter component is similar to the H2O-CEC relationship that is typical for smectite. The combined system of a constant H2O + variable H2O in opal can potentially be applied for mineral modeling programs in wireline log formation evaluation in diatomaceous hydrocarbon reservoirs.

Keywords: Adsorbed water, cation exchange capacity, illite-smectite, Monterey Formation, opal, smectite

INTRODUCTION

Cation exchange capacity (CEC) is among the most important physicochemical properties of sedimentary rocks. In the oil and gas industry, the CEC value reflects the quantity of hydrated cations, allows calculation of the mineral surface-bound water, and is used for various corrections and calibrations in wireline log analysis where it is employed in calculating effective porosity and permeability in hydrocarbon reservoirs (Clavier et al. 1984; Fertl and Chilingar 1988; Brown and Ransom 1996; Matteson et al. 2000). CEC is also important to hydrocarbon production, where it relates to formation damage potential, affects drilling and completion strategies, and is needed to design effective reservoir stimulation techniques.

One of the most common paradigms in measuring and modeling the sedimentary rock surface properties is the assumption that the bulk rock CEC and the total specific surface area (TSSA) are interrelated and control the quantity of adsorbed water via the content of hydrated cations, while CEC and TSSA of zeolite-free rocks are controlled almost exclusively by the quantity and type of clay minerals in a rock (Fertl and Chilingar 1988; Kaufhold 2006; Środoń and McCarty 2008; Środoń 2009; Środoń et al. 2009; Kaufhold et al. 2010). Therefore, the total adsorbed water in a sedimentary rock is essentially that of the clay-bound water (CBW). Clay minerals, including smectite, mixed-layered illite-smectite (I-S), and other less-common expandable mixed-layered clays (i.e., chlorite-smectite and kaolinite-smectite), contribute to the bulk CEC and TSSA, proportionally to their content in the