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Research paper

Diagenesis of the palaeo-oil-water transition zone in a Lower Pennsylvanian carbonate reservoir: Constraints from cathodoluminescence microscopy, microthermometry, and isotope geochemistry

A.N. Kolchugin [a], A. Immenhauser [b, *], B.F. Walter [c], V.P. Morozov [a]

[a] Kazan Federal University, Institute of Geology and Petroleum Technologies, Russia
[b] Ruhr-University Bochum, Faculty for Geosciences, Institute of Geology, Mineralogy and Geophysics, Germany
[c] Eberhard Karls University Tübingen, Department of Geoscience, Germany

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ABSTRACT

Oil-water transition zones in carbonate reservoirs represent important but rarely studied diagenetic environments that are now increasingly re-evaluated because of their potentially large effects on reservoir economics. Here, data from cathodoluminescence and fluorescence microscopy, isotope geochemistry, microthermometry, and X-ray tomography are combined to decipher the diagenetic history of a 5-m-long core interval comprising the oil-water transition zone in a Lower Pennsylvanian carbonate reservoir. The aim is to document the cementation dynamics prior, during, and after oil emplacement in its context of changing fluid parameters. Intergrain porosity mean values of 7% are present in the upper two sub-zones of the oil-water transitions zone but values sharply increase to a mean of 14% in the lower sub-zone grading into the water-saturated portions of the reservoir and a very similar pattern is observed for permeability values. In the top of the water-filled zone, cavernous porosity with mean values of about 24% is found. Carbonate cements formed from the earliest marine to the late burial stage. Five calcite (Ca-1 through 5) and one dolomite (Dol) phase are recognized with phase Ca-4b recording the onset of hydrocarbon migration. Carbon and oxygen cross-plots clearly delineate different paragenetic phases with Ca-4 representing the most depleted $\delta^{13}C$ ratios with mean values of about −21‰. During the main phase of oil emplacement, arguably triggered by far-field Alpine tectonics, carbonate cementation was slowed down and eventually ceased in the presence of hydrocarbons and corrosive fluids with temperatures of 110–140 °C and a micro-hiatal surface formed in the paragenetic sequence. These observations support the "oil-inhibits-diagenesis" model. The presence an earlier corrosion surface between phase Ca-3 and 4 is best assigned to initial pulses of ascending corrosive fluids in advance of hydrocarbons. The short-lived nature of the oil migration event found here is rather uncommon when compared to other carbonate reservoirs. The study is relevant as it clearly documents the strengths of a combined petrographic and geochemical study in order to document the timing of oil migration in carbonate reservoirs and its related cementation dynamics.

1. Introduction

Reservoir oil-water transition zones (Christiansen et al., 2000; Heasley et al., 2000; Byrnes and Bhattacharya, 2006; Carnegie, 2006) are generally described as the intervals from which both oil and water are produced. Following the definition of Fanchi et al. (2002), the top of this interval is the elevation at which water-free oil is produced. The lower limit, although often gradual, is the shallowest depth at which oil-free water is present. In some reservoirs, the entire column is in a transition zone. In the past, oil-water transition zones, ranging in thickness from less than 1 to several 100 m, were considered non-economic and often not cored (Christiansen et al., 2000). More recently, however, oil-water transition zones in reservoir rocks worldwide have been

* Corresponding author.
E-mail address: adrian.immenhauser@rub.de (A. Immenhauser).

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