Multiphase Structural Diagenetic Controls on the Spatial Distribution of Reservoir Properties: A Case Study in an Upper Carboniferous Tight Gas Sandstone Reservoir Analog

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Abstract

Upper Carboniferous sandstones are one of the most important tight gas reservoirs in NW-Europe. We focus on the Upper Carboniferous of the Piesberg quarry on the southern rim of the Lower Saxony Basin of N-Germany, which exposes fluvial cyclic deposits, consisting of strongly cemented sandstones fining upwards into siltstones and shales with intercalated coal seams. We identified the quarry as promising outcrop analog with respect to 3D sedimentary body geometry, structural inventory and spatial distribution of reservoir qualities from seismic to subseismic scale. We digitized the entire quarry using LIDAR laser scanning, forming the basis of a high-resolution 3D reservoir analog model from km to mm scale that allows the characterization of the outcrop in terms of lithology, structural inventory and reservoir quality. We introduce an automated approach for quantitative measurement of bedding and fracture orientation based on the LIDAR dataset. The main porosity is secondary and resulted from carbonate dissolution and limited dissolution of feldspar. The spatial distribution of reservoir properties is both stratigraphically and structurally controlled. Around faults dissolution is higher and the porosity can increase to up to 25% and permeability up to 100 mD, whereas average porosity is around 6 % and average permeability in the range of 0.001 mD or smaller. The structural diagenetic characterization explains the reservoir property evolution and links it to the structural development during burial history. This includes the temperature impact during deep burial, telogenetic impact because of inversion tectonics and structural impact on present day reservoir properties. Despite the learnings from the quantitative data of the outcrop analog, this study also highlights critical aspects of outcrop analog studies. We demonstrate the importance to assess reservoir outcrop analogs with holistic, multi-disciplinary approaches, whereby the diagenetic characterization was found to be a linking element. We contribute to the crucial question to what extend an outcrop could act as a suitable subsurface reservoir analog and which data from outcrops may be directly compared and integrated with actual subsurface data. Our results may contribute to reduce uncertainties in Upper Carboniferous tight sands reservoir characterization and provide essential learnings for future outcrop analog studies in the region or elsewhere.