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Reservoir characteristics and diagenesis of the Buntsandstein sandstones in the Campine Basin (NE Belgium): supplementary data

Pieter Bertier

KU Leuven, Geology, Celestijnenlaan 200E, B-3001 Heverlee; current address: Qmineral BV, Gaston Geenslaan 1, 3001 Heverlee, Belgium; pbertier@qmineral.com.

Rudy Swennen

KU Leuven, Geology, Celestijnenlaan 200E, B-3001 Heverlee, Belgium; ***corresponding author****: Rudy.Swennen@Kuleuven.be.*

Raymond Kemps

Research Group for Materials Technology, VITO, Boeretang 200, B-2400 Mol, Belgium; Raymond.kemps@vito.be.

Ben Laenen

VITO NV, Boeretang 200, B-2400 Mol, Belgium; Ben.Laenen@vito.be.

Roland Dreesen

Geological Survey of Belgium, Royal Belgian Institute of Natural Sciences, Directorate Earth and History of Life, Jennerstraat 13, B-1000 Brussels, Belgium; Roland.dreesen@telenet.be.

ABSTRACT

The red beds of the Buntsandstein (Early Triassic) in the Campine Basin (NE Belgium) display porosities between 5.3–20.2% (average 13.7%) and permeabilities varying between 0.02–296.4 mD (average 38.7 mD). Knowledge of their reservoir controlling properties, which today are missing, is important in view of potential geological storage of CO_2 or natural gas and geothermal reservoir potential within these sandstones. Therefore the effects of diagenesis were assessed based on petrography, stable isotope analyses, fluid inclusion microthermometry, X-ray diffraction, electron microprobe and porosity-permeability core analyses.

These sandstones were deposited by a dryland river system, in a warm, mostly arid climate with episodic rainfall and high evaporation rates. During wetter periods especially feldspars were dissolved. Strong evaporation during dry periods led to reprecipitation of the dissolved species as K-feldspar and quartz overgrowths, smectite and calcite/dolomite. Sediment reworking resulted in framework grains becoming clay coated. The clay coats are better developed in finer than in coarser grained sediments. The original smectite composing the rims converted to illite during burial. The tangential orientation of the clay platelets in the rims led to illite-mica-induced dissolution of quartz during burial/compaction, which is manifested as bedding parallel dissolution seams that are filled with clays and micas, especially in the fine-grained sandstone/siltstone/claystone. These constitute important barriers to the vertical flow within the reservoir. The released silica did not really affect the red sandstones but was exported (often on mm to cm scale) to nearby bleached horizons, where nucleation inhibiting clay rims are less well developed. The red colour of the sandstones arises from the presence of small amounts of Fe-oxides in the inherited clay rims. Migration of fluids enriched in organic acids, expelled from underlying Carboniferous coal-bearing strata, resulted in local bleaching of coarser grained horizons. In the finer grained sediments, the red colour was mostly preserved, which suggests that the reductive capacity of the fluid was limited.

KEYWORDS

sedimentology,
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compaction

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Supplementary data

Geochemical evolution of the eogenetic environment

Figure S1 shows two activity diagrams for the K_2O-Na_2O-SiO_2-Al_2O_3-H_2O system at 30 °C and 1 atm. The scarcity of eogenetic kaolinite and the abundance of smectite in the Buntsandstein suggest a high activity of aqueous silica. The smectite, which before illitisation likely constituted a major part of the omnipresent clay rims, must have been at least partly authigenic, as smectite is a common eogenetic phase in arid continental environments (Morad et al., 2000; Worden & Morad, 2003; McKinley et al., 2003). Figure S1 illustrates that quartz is saturated in the smectite stability field, even at relatively low K^+/H^+ (and Na^+/H^+). Yet, the rims clearly predate the syntaxial quartz and K-feldspar. They are covered and often engulfed by the syntaxial overgrowths, but the overgrowths are clear and devoid of clay. The rims are, based on the fact that they are circumgranular and show other characteristics of inherited clay rims, presumed to have been formed in vadose zones of low-lying sabkha or inter-dune environments that were later reworked. The interstitial water in these environments was likely enriched in Al, Mg, Fe and Ca, which favour smectite saturation with respect to quartz saturation. The relatively high content of reworked carbonate fragments in the studied samples suggests that besides smectite also carbonates formed in the latter environments.

Petrographic observations suggest that the syntaxial quartz and K-feldspar overgrowths in the Buntsandstein formed partly simultaneously. Precipitation of syntaxial quartz overgrowths requires low degrees of quartz supersaturation. The diagrams show that these conditions can only be fulfilled if the K^+/Na^+ ratio in the fluid is relatively high. K-feldspar saturation in Na-rich fluid implies supersaturation of amorphous silica, and thus cannot take place concurrent with the precipitation of quartz overgrowths. The low Na activity in the system is also reflected in the absence of zeolites, which are common eogenetic phases in Na-rich arid continental environments (Morad et al., 2000). Evaporation combined with ongoing alteration of Al-silicates is suggested to have caused the aqueous geochemical evolution towards K-feldspar saturation. Increasing K^+ activity and pH by Al-silicate alteration initially resulted in K-feldspar authigenesis. Once K-feldspar saturation was reached, further geochemical evolution was driven by continued evaporation, as K-feldspar alteration was the main source of K^+ (and silica). The activity diagrams show that quartz is saturated in the lower, low K^+/H^+, part of the K-feldspar stability field, which clarifies the simultaneous quartz and K-feldspar authigenesis.

Quartz cementation continued after K-feldspar precipitation ceased as evidenced by K-feldspar overgrowths engulfed in quartz cement. Decreasing K^+ activity would lead to smectite or illite precipitation (although illite is not a common eogenetic phase), so K-feldspar precipitation was probably halted by depletion of Al in the fluid.

The inferred trend describing the evolution of the eogenetic aqueous geochemical environment (Fig. S1) corresponds to the meteoric weathering trend, as described by many authors (Morad et al., 2000; McKinley et al., 2003; Maraschin et al., 2004), but in the opposite direction. Progressive weathering stands for dilution by acidic meteoric water, while in the eogenetic environment of the Buntsandstein exactly the opposite situation, i.e. evaporative concentration and gradually rising pH, took place. This geochemical trend evidently does not describe a gradual evolution of the depositional environment over geological periods of time, which could never explain the occurrence of all the above-described eogenetic phases in a sediment column of several hundreds of metres, deposited over a time period of about 10 Ma. The trend reflects the short-term geochemical evolution of the vadose and phreatic water in the depositional environment due to strong evaporation following a period of increased rainfall. Such cycles of meteoric weathering and subsequent evaporation could repeat on short term, maybe even on seasonal or annual basis.

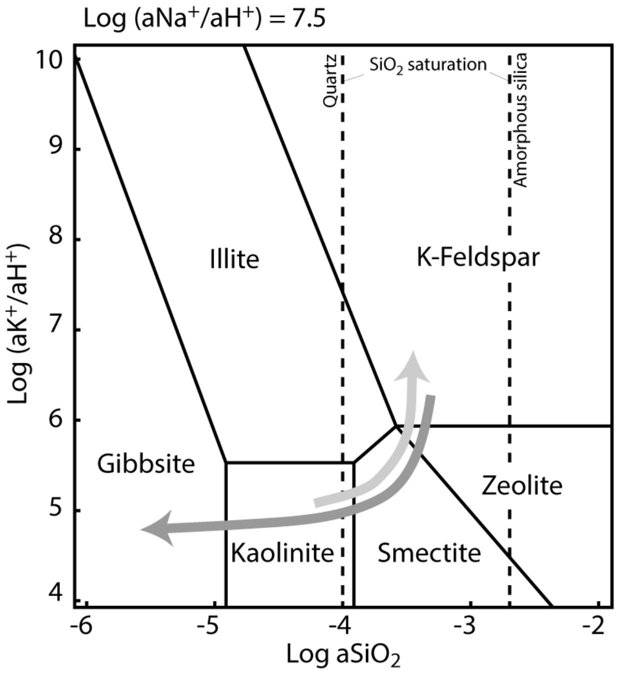

Figure S1. Activity diagrams for the K_2O-Na_2O-SiO_2-Al_2O_3-H_2O system at 30 °C and 1 atm. A trend describing the evolution of the eogenetic aqueous geochemical environment was inferred from petrography (light grey arrow). It corresponds to a meteoric weathering trend (darker grey arrow), but in the opposite direction. Progressive meteoric weathering stands for dilution by acidic meteoric water, while in the eogenetic environment of the Buntsandstein exactly the opposite situation, i.e., evaporative concentration and gradually rising pH, took place.

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