

Tackling TSR risk in deeply buried carbonate reservoirs: new insights from coupling fluid inclusion study with clumped isotopes δ_{47} /U-Pb thermochronology

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Thermochemical Sulphate Reduction (TSR) reactions in deep carbonate reservoirs represent a challenge for resource exploration, both in terms of operation costs and safety. A new workflow coupling recent analytical techniques has therefore been developed to identify and quantify TSR risk. Carbonate and sulfate rock samples from five sub-surface cores of the late Carboniferous (~315Ma) / early Permian (~275Ma) drilled in the Loppa High and the Finnmark Platform within the Norwegian Barents Sea were investigated to identify potential diagenetic phases formed as TSR by-products. A petrographyfluid inclusion study on carbonate cements was first performed to identify the phases which witnessed past presence of H₂S in the basinal fluids. Absolute Temperature-Time constraints on the precipitation of selected cements were then acquired by jointly applying clumped isotopes (δ_{47}) thermometry and *in-situ* U-Pb chronometry. The study shows that in samples from depths >4000m, traces of H₂S and CH₄ were found in fluid inclusions within calcites precipitated at 140 - 160°C, between 120-110 Ma ago. However, in wells where the same geological formations occur at shallower depths (>2100m), vein calcites seem to have formed at lower temperatures (50 - 60°C and 80 - 100°C). Fluid inclusions show little to no H₂S contents. Nevertheless, these veins are still associated with reduced sulphur. Framboidal pyrite occurs in veins cemented by calcites precipitated below 60°C, while millimetric euhedral pyrite occurs in veins filled by calcites precipitated in the upper temperature range (>100°C). These observations suggest that these sulphide phases may have formed through BSR and TSR reactions, even though they are not accompanied by H₂S. Different environmental conditions (temperature, Eh) may explain this absence, suggesting that the reservoirs have merely entered the TSR thermal window, and that a deeper burial is required to reduce the valency of sulfur (S⁺⁶ in sulfates) further than in pyrite (S⁻¹) and generate H₂S (S⁻²). By placing timing and temperature constraints on the formation of vein carbonates, this integrated study allows to make a regional assessment of the TSR risk during exploration.

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