Abstract

Fluid escape from reservoirs: implications from cold seeps, fractures and injected sands
Part II. The fluids involved

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Abstract

Petroleum fluids escape from hydrocarbon reservoirs through permeable networks of fractures, injected sands and by seepage through low permeability host rocks. Carbon stable isotope analysis of carbonate cement associated with such structures shows that the escaping petroleum fluid is intimately involved in precipitating carbonate cement. Within fractures and injected sands, oxidation of chained hydrocarbons supplies bicarbonate to the co-existing aqueous solution from which carbonate precipitates ($\delta^{13}C$ around $-20\%e$ V-PDB). $\delta^{13}C$ values within carbonate crusts associated with seeps are lower (as low as $-50\%e$ V-PDB) suggesting a component of carbon derived from methane within these structures. This suggests a separation within the escaping petroleum fluids, with chained hydrocarbons remaining trapped within sand injectites and fractures, whereas more buoyant fluids (methane) continue to escape through low permeability host rocks. The abundance of fluorescing (chained) hydrocarbon inclusions within cement associated with fractures and injected sands versus the scarce occurrence of fluorescing inclusions within carbonate crusts associated with seeps is in agreement with results from stable isotope analysis. Oxygen stable isotope ratios indicate that carbonate cement within fractures and sand injectites precipitates at temperatures between 30 and 50 °C in the subsurface, whereas carbonate cement associated with seeps at the seafloor precipitates at temperatures around 0 °C.

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Keywords: Injected sandstones; Cold seeps; Carbonate cement; C/O stable isotopes

1. Introduction

Hydrocarbon reservoirs in the North Sea exhibit a close association between fractures, sand injectites and seeps, the combined network of which has a significant impact on fluid escape from reservoirs and aquifers (Mazzini et al., 2003). A link between hydrocarbon reservoirs and seeps has in several instances been suggested. Examples of released reservoir gases include hydrocarbon seeps from the Gulf of Mexico (Roberts and Aharon, 1994), Southeastern Mediterranean (Coleman and Ballard, 2001), North Sea (e.g. UK block 15/25, Judd et al., 1994) and Southern and Eastern Skagerrak (Hovland, 1991). As with cold seeps, injected sandstones are observed above numerous hydrocarbon reservoirs (Jennsen et al., 1993; Dixon et al., 1995; Duranti et al., 2002). The
role of reservoir fluids in activating injections and subsequently using injected sands as fluid flow pathways has, to our knowledge, never been investigated. In outcrop, injected sands and cold seeps can be spatially related and a possible common origin of the two phenomena is inferred (Schwartz et al., 2001; Weberling et al., 2001). In the present study, we focus on escape of petroleum fluids through fluid escape systems as recorded in carbonate cements observed in the samples described in Part I (Mazzini et al., 2003).

2. Methods of study

Carbon and oxygen isotopic analysis was undertaken at the SUERC facility in East Kilbride using an AP2003 triple-collector mass spectrometer. The reproducibility of the system is $\pm 0.1$‰ for both $\delta^{13}C$ and $\delta^{18}O$ values. All data are reported as per mil deviation from the V-PDB international standard. Samples for fluid inclusion analysis of carbonate cements were prepared as doubly polished wafers and examined using a Linkam THM600 heating–freezing stage attached to a Nikon Optiphot2-POL microscope. Fluorescence of the fluid inclusions under ultraviolet light (illumination source 435 nm) was investigated using a Nikon Eclipse E600 microscope with a UV-2A filter block.

3. Results

3.1. Isotopes

Fig. 1 shows the results of the oxygen and carbon stable isotope analysis of carbonate cements associated with fractures, injected sandstones and seeps encountered within Tertiary to Recent sediments above North Sea hydrocarbon reservoirs. Isotopic results show three main groups of cold seeps. The first group includes the samples from modern cold seeps retrieved from the seafloor ($1\% < \delta^{18}O < 3\%$) and very low $\delta^{13}C$ values ($-50\% < \delta^{13}C < -39\%$); the second group are samples from modern seeps formed in the subsurface, with similar positive $\delta^{18}O$ values (mean value $2\%$) but less depleted $\delta^{13}C$ values (mean value $-20\%$). Samples from paleo-seeps (group 3) have $\delta^{18}O$ values varying from $-1.5\%$ to $-5-5\%$, and $\delta^{13}C$ values from $-8\%$ to $-35\%$. A clear trend can be detected, with less depleted $\delta^{13}C$ values corresponding with more depleted $\delta^{18}O$ values (Fig. 1). Injected sands have consistent negative $\delta^{18}O$ values ($-11\% < \delta^{18}O < -3\%$) and $\delta^{13}C$ values.

Fig. 1. C/O stable isotope values of carbonate cemented seeps, injected sandstones and fractures. See text for explanation.
around $-20\%$. The fractures analysed show two clusters: both groups have similar $\delta^{18}O$ values ($-10\%o < \delta^{18}O < -4\%o$ PDB), but reveal two distinct groups with negative and positive $\delta^{13}C$ values.

3.2. Fluid inclusions

Hydrocarbon inclusions can be detected using UV fluorescence. All samples analysed reveal the pres-
ence of fluorescing primary hydrocarbon inclusions within carbonate cement (Fig. 2). Cold seep samples reveal the presence of rare fluorescing inclusions at inter and intra-crystal sites. Raman spectroscopy confirms the presence of hydrocarbon chains, including propane, methane and ethane within fluid inclusions (Mazzini et al., 2002). Within cemented injected sandstones and fractures, hydrocarbon inclusions are often trapped abundantly with co-existing aqueous inclusions as two immiscible fluid phases. In samples retrieved from the same locations, the fluorescing colour of hydrocarbons within reservoir units, sand injectites and cold seeps is similar, suggesting that all structures together are responsible for fluid escape from the reservoir. In most cases, the fluid inclusions are monophase, all-liquid inclusions, suggesting trapping below 50 °C. Elevated temperatures within certain deeper buried sections are most likely due to continuous recrystallisation of carbonate upon burial.

4. Discussion and conclusion

The extreme $^{13}$C depletion observed within the cold seep samples indicates a strong contribution of carbon from hydrocarbon gases (methane). The depletion within injected sands and cemented fractures is less and can be explained by bicarbonate derived from oxidation of long-chained hydrocarbons. This is in agreement with the observation of numerous fluorescing inclusions (chained hydrocarbons) within injected sands, whereas they are relatively scarce within cold seeps. Fractures show both an extreme positive outlier (fermentation?) and a negative outlier (oxidation?). The lower $\delta^{18}$O values within fractures and injectites is most likely related to the slightly elevated temperatures of the subsurface fluids (30–50 °C) with respect to the temperatures recorded in cold seeps (close to 0 °C). The isotopic trend within the cold seep samples could be due to replacement of methane-derived aragonite at the surface by calcite derived from seawater (causing a shift to lower $\delta^{13}$C values and less negative $\delta^{18}$O values) upon burial.

References


