Abstract

Fluid escape from reservoirs: implications from cold seeps, fractures and injected sands
Part I. The fluid flow system

A. Mazzini*, R. Jonk, D. Duranti, J. Parnell, B. Cronin, A. Hurst

Department of Geology and Petroleum Geology, University of Aberdeen, Meston Building, Aberdeen AB24 3UE, UK

Abstract

Fluid escape from reservoirs can take place through (hydraulic) fracturing, sand injection and seepage. Above several Tertiary hydrocarbon reservoirs in the North Sea, substantial amounts of fractures, sand injectites and seeps occur. Petrographic observations of these features show that all have carbonate cement associated with them that contains fluorescing hydrocarbon inclusions. The petroleum fluids escaping were partially trapped during the cementation and analysis of the cements allows understanding of the fluid flow system and the fluids involved. Cathodoluminescence indicates that sand injectites and fractures have one phase of cement associated with them. Seeps, however, show zoned carbonate cement, suggesting precipitation in a varying geochemical environment. This suggests that fractures and sand injectites were short-lived fluid-conduits, whereas seeps can act as fluid escape pathways over prolonged periods of time.

© 2003 Elsevier Science B.V. All rights reserved.

Keywords: Cold seeps; Injected sands; Hydrocarbons; Cathodoluminescence

1. Introduction

Fluid escape from hydrocarbon reservoirs in the shallow crust is a common phenomenon, but the fluid flow pathways can be diverse and are presently not fully understood. Fluids follow different pathways and generate diverse geological structures and phenomena (Fig. 1). The occurrence of fluid seepage on the sea floor is manifested by the presence of hydrothermal vents (metal-rich deposits) and cold seeps (typically carbonate deposits). Cold seeps are associated with carbonate mounds, coral reefs, pockmarks, mud volcanoes and seamounts. It is at these sites that seeping gases sustain chemosymbiotic communities inducing the precipitation of authigenic carbonates (Hovland et al., 1987; Ritger et al., 1987; Paull et al., 1992). Seep deposits can assume different scales and shapes, such as exposed and buried mineralised chimneys (Jorgensen, 1989), cemented fluid conduits and veins, micro and macro slabs, and cemented sedimentary layers (Hovland and Judd, 1988). In the subsurface, rapid fluid escape can take place through networks of fractures and injected sands. Often, fluid overpressures generate the pathways for fluid escape through (hydraulic) fracturing and sand injection (Cosgrove, 2001), but more importantly, once created they remain fluid escape pathways. Fluids may be trapped where

* Corresponding author. Tel.: +44-1224-273435; fax: +44-1224-272785.
E-mail address: a.mazzini@abdn.ac.uk (A. Mazzini).

0375-6742/03/$ - see front matter © 2003 Elsevier Science B.V. All rights reserved.
do:10.1016/S0375-6742(03)00046-3
fractures or injected sandstones terminate or may continue to seep to the surface. It is important to know whether structures are truly trapping and sealing or whether fluid escape continues to take place, eventually manifesting itself as seeps on the sea floor. Carbonate is the most common cement associated with these features at shallow burial and the cements yield valuable information on the origin of the fluids and its various components. Our goal is to understand the linkage between reservoirs, fractures, injected sandstones and seeps via a study of carbonate cementation.

2. Methods of study

Polished slabs and thin sections were studied using standard petrographic and cathodoluminescence techniques in order to analyse and distinguish the cementation phases. Cathodoluminescence was conducted with a Citl Cold Cathode Luminescence 8200 mk3 linked with a Nikon M32 × microscope to evaluate the compositional variations during the crystal growth.

3. Study area

The North Sea is a major producing hydrocarbon province. Some of the earliest descriptions of fluid escape features on the sea floor (Hovland and Judd, 1988) and descriptions of injected sandstones (Jenssen et al., 1993; Dixon et al., 1995; Lonergan and Cartwright, 1999) associated with hydrocarbon reservoirs are from this province. In the present study, samples were retrieved from the sea floor and from cores associated with several Tertiary hydrocarbon reservoirs showing substantial degrees of carbonate cement associated with seeps, fractures and sand injectites (Duranti et al., 2002).
4. Results

Carbonate cements in seeps, fractures and sand injectites were analysed. Fluid inclusion and isotope data indicate an intimate association with hydrocarbons. (Jonk et al., 2003, this issue), Seep deposits (Fig. 2A) are cemented with blocky and fibrous calcite, which is often recrystallised aragonite. Cath-
Cathodoluminescence shows zones of dull and bright luminescent calcite. It also shows a continuous precipitation history of carbonate with no evidence of dissolution events (Fig. 2B). Cement in injected sandstones is poikilotopic calcite. Minus cement porosities around 50% suggest that cementation took place early in the burial history (Fig. 2C). Cathodoluminescence shows one phase of cement (Fig. 2D). Fractures are around 1 mm thick and are cemented with calcite. The calcite exhibits either a beefy or a blocky texture (Fig. 2E). Again, the cathodoluminescence shows one phase of cement (Fig. 2F).

5. Discussion and conclusion

Although all fluid escape features found above hydrocarbon reservoirs are characterised by carbonate cement, the cathodoluminescence shows a striking difference between seeps versus fractures and sand injectites. Seeps show zoned cement, suggesting varying geochemistry of the cementing fluid. The likely prolonged history of fluid seepage could be responsible for this. However, both sand injectites and cemented fractures show one phase of cement and thus one fluid phase responsible for cementation. This, together with the observed high minus cement porosities in sand injectites suggests rapid cementation following fracturing and sand injection. Cross-cutting relations between cemented fractures and sand injectites are often contradictory, suggesting coeval fracturing and sand injection. Fluid overpressure in the reservoir causes rapid fluid escape through hydraulic fracturing and sand injection. The newly created fluid flow pathways are quickly cemented. Once cemented, fluid escape can continue to take place through seepage at the top of the structures (Fig. 1). Seepage takes place more slowly over a prolonged time, recording the longer-term geochemical changes in the cementation environment. This study suggests that fluid escape from reservoirs can occur catastrophically over short time-spans through (hydraulic) fracturing and sand injection, but continued fluid escape can take place less catastrophically over a prolonged time through seepage. This conclusion is supported by fluid inclusion analysis. UV light observations on the described samples (Jonk et al., 2003, this issue) show that similar types of fluorescing hydrocarbon inclusions occur in injectites, fractures and cold seep features sampled from the same location. This suggests that fluid escape from reservoirs can only be fully understood if the spatial and temporal distributions of both components are analysed.

References