Methane-related fluid migration and processes of carbonate diagenesis – study of a paleo-seep system (Pobiti Kamani area, Varna, Bulgaria)

Миграция на метан-обогатени флуиди и процеси на карбонатна диагенеза – базово изследване на газово палеоизворна система от района на „Побитите камъни“ (Варна, България)

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Introduction

The sandstone structures of the Pobiti Kamani area (Lower Eocene Dikilitash Formation), located within the eastern Moesian Platform unit, ± 20 km west of Varna (NE Bulgaria), have attracted the attention of many scientists (e.g. Nachev et al., 1986; Iliev et al., 1998; Nachev, Nachev, 2001 and references herein), sparking off various theories for their origin. One of the later models, carefully suggested by Botz et al., 1993) and defended by L. Dimitrov, proposed the key-role of past upward migration of hydrocarbon-bearing fluids through the sediment column, similar to phenomena at active methane seeps along the Black Sea shelf (Dimitrov, 2002). This link between methane seepage and the formation of the carbonate-cemented sandstone structures was recently undeniably confirmed by the strongly depleted $\delta^{13}C$ signatures (as low as −44‰ VPDB) for the carbonate cements (De Boever et al., 2006).

Methane seeps draw the interest of the scientific community since they mark sites where geological, (micro)biological and hydrological processes closely interact. Distinct and long-lasting products of these seepage processes are authigenic carbonate deposits of different morphologies, which permit the increasing recognition of analogue seep systems in the geological record. The objectives of our ongoing research of the Eocene seep system exposed, in the Pobiti Kamani area are threefold. (1) The reconstruction of the formation and diagenesis of the diverse carbonate-cemented structures present, the controlling factors on their 3D-distribution. (2) The process of carbonate cementation in relation to the influx of methane-bearing fluids. (3) The impact of fault zone deformation structures on the migration of hydrocarbon-bearing fluids. In this contribution, some of the results related to first two topics will be presented.

Methane-related calcite cementation in tubular concretions

One of the most prominent structures exposed in the area are m-scale tubular-shaped, calcite-cemented sandstone concretions. To investigate the diagenesis and evolution of pore fluids during formation of a single tubular concretion (i) and (ii) the process of carbonate precipitation, an integrated approach was applied, including petrography, carbonate geochemistry ($\delta^{13}C$, $\delta^{18}O$, EPMA) and the analysis of lipid biomarkers (De Boever et al., submitted).

Microscopic observations reveal a (sub)arkosic sandstone, cemented by non-ferrous calcite cements. The fabric and sequence of diagenetic phases are similar throughout a single tube but also when comparing various tubes from different locations. Altered feldspar grains are locally surrounded by an authigenic K-feldspar overgrowth, which precedes the predominant dull luminescent mosaic calcite cement (MCa). Bulk stable isotope signatures of MCa-cemented tube samples indicate calcite cementation in equilibrium with Lower Eocene seawater at ambient seafloor temperatures ($\delta^{18}O$ = −0.5 to +0.5‰ VPDB). $\delta^{13}C$ values as low as −44.5‰ VPDB reveal that the carbon is predominantly methane-derived. Strong variations in $\delta^{13}C$ values (as high as −8‰ V-PDB) and $\delta^{18}O$ values (as low as −9‰ V-PDB) within a single concretion are presumably related to telogenetic recrystallization of MCa cements and additional cementation by equal cements.

The lipid biomarker study showed that pervasive methane-related calcite cementation was the consequence of a pore water alkalinity increase, resulting from sulphate-dependant anaerobic oxidation of methane. Abundant archaeol and hydroxyarchaeol components, enclosed within the calcite cement, reveal the presence of anaerobic methane-oxidizing archaea with $\delta^{13}C$ values of −111‰. Terminally-branched alcohols and dialkylglyceroldiethers (DAGEs) with $\delta^{13}C$ values ranging from −103 to −67‰ point to the former presence of sulphate-reducing bacteria, the syntrophic partners of methane-oxidizing archaea.

Controlling factors on the morphology and spatial distribution of the tubular concretions

"Tubular" concretions have been described from different ancient seep systems and are considered the focused, shallow subsurface plumbing system of past methane seepage In order to evaluate possible controlling factors on the distribution of these focused fluid paths in unconsolidated sandy sediments, the spatial distribution of the tubular concretions and the spatial variation in their morphological characteristics were investigated by detailed field mapping and geostatistical methods (De Boever et al., in revision). Tubular concretions were classified in three main field-based types and the position of each individual tube, together with its morphological characteristics were mapped over several 100 m^2 at two selected locations in the study area (the Central group and the Strashimirovo group).

It is suggested that the regular, cylindrical morphology of most tubular concretions is primarily the consequence of cementation around a buoyancy-driven, vertically upward directed fluid path through the rather homogeneous sandy host sediments. Their morphology likely was additionally influenced by differences in the depositional/diagenetic fabric of the host lithology, which affected the fluid path and thus the locations of cementation.

Geological mapping and mapping of the position of each individual tubular concretion by means of GPS in the 2 study locations strongly suggested that the locations of focused fluid migration were controlled by the structural framework, dominated in the region west of Varna by Paleogene NNW- to NNE-oriented normal and strike slip faults. Furthermore, the spatial pattern of the tube positions possibly mimics the spatial geometry of deformation structures typical of fault damage zones. A geostatistical data analysis of tube contour data (m) underlined this spatial structure. The computed directions of maximal spatial correlation of "tube contours" over distances >100 m are interpreted as an indication for the continuity of fluid flow characteristics over a certain distance and time along specific (structural) lineations.

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