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Research paper

A genetic model of hydrocarbon-derived carbonate chimneys in shelfal fine-grained sediments: The Enza River field, Northern Apennines (Italy)

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ABSTRACT

Methane Derived Authigenic Carbonate (MDAC) concretions have been recently exposed in the Pleistocene Argille Azzurre Fm. outcropping along the Enza riverbanks, Northern Apennines foothills, Italy. The relations between the sediment deposition, the coeval tectonic deformation and the MDAC concretions have been investigated to unravel the mechanism of methane migration through the sediments and the processes leading to MDAC occurrence. The biogenic methane responsible for the formation of MDAC chimneys and slabs has been generated in the organic-rich Pliocene sediments located in the Po Plain subsurface. The gas migrated up-dip towards the Northern Apennines foothills. The MDAC cements are mainly composed of dolomite, whose precipitation requires thousand years and the absence of SO_4 in the pore fluids. According with the sedimentation rates of the MDAC-hosting Pleistocene succession, the Sulphate Methane Transition Zone migrated upwards faster than time required for dolomite precipitation. Therefore, the connate water migrating together with the methane could have acted as second DIC source, allowing the MDAC formation also in the methane-rich zone.

1. Introduction

Natural fluid emissions occur in a wide range of geologic and geodynamic settings, with new seepage sites being discovered all around the world. Their study has been mainly addressed to the classification of the emission-related structures, often represented by mud volcanoes (e.g. Bonini, 2007; Mazzini et al., 2009), to their role in the degassing of deeply buried sediments (e.g. Dimitrov, 2002 and references therein) and to the emission of greenhouse gases in the atmosphere (e.g. Kvenvolden and Rogers, 2005). Several studies have been recently done on the relations between the evolution of local petroleum systems and the development of fluid emissions (e.g. Aslan et al., 2001; Bonini, 2007; Capozzi and Picotti, 2010; Sun et al., 2012; Oppo et al., 2013, 2014). Moreover, attention has been addressed to the microbiological communities associated with the cold seeps (e.g. Heller et al., 2012) and to their role in degrading the occurring hydrocarbons (e.g. Oppo et al., 2013). The role of the microbe consortia that promote the Anaerobic Oxidation of Methane (AOM), together with Sulphate Reduction (SR) (Boetius et al., 2000), has been also studied to understand the formation of the Methane-Derived Authigenic Carbonates (MDAC). These latter represent the main by-products of the AOM-SR process in marine environment (e.g. Reitner et al., 2005 and references therein).

The MDAC occurrence is reported in various present-day marine settings, such as passive and active continental margins, as well as in the geological record (e.g. Magalhães et al., 2012 and references therein). Their morphologies include crusts, mounds, conduits and irregular bodies. Various pipe-like and cylindrical concretions are described in the recent literature (e.g. Mazzini et al., 2003; Clari et al., 2004; Conti et al., 2004; Hovland et al., 2005; Nyman et al., 2010), with diameters typically ranging from centimetres to few decimetres. Exceptionally large structures are also documented, reaching more than 10 m in length and 4 m in diameter (Nyman et al., 2010). The pipe-like concretions, defined in this paper as MDAC chimneys, usually develop in pelitic marine sediments. There is a lack of knowledge about the processes leading to the chimneys precipitation in different time and

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geologic setting. The modern MDAC chimneys form within the sediment pile below the seafloor, thus limiting their direct observation. A single example of authigenic carbonate chimneys developing above the seafloor has been documented in the Black Sea, due to the persistent anoxic condition of the bottom water (Michaelis et al., 2002). Therefore, the onshore fossil records could provide new evidences to reconstruct the fluid migration, in space and time, in relation with the sedimentological and stratigraphic setting where they occur. Moreover, a detailed reconstruction of the processes of MDAC formation into the sedimentary pile could be achieved.

The objective of this work is the study of MDAC chimneys and slabs recently exposed in the Pleistocene deposits along the Enza riverbanks in the Northern Apennines foothills, Italy (Fig. 1). The nearby present-day activity of mud volcano fields, where hydrocarbons and saline waters are emitted on the surface, allowed defining the local Miocene petroleum system (Oppo et al., 2013). They could provide a first indication to understand the relation between the Enza MDAC field formation and the active petroleum system. Mineralogy and stable isotope analyses of the MDAC and of their hosting sediments (described in detail in Viola et al., in this volume) have been considered to reconstruct the Enza MDAC field evolution. The relations between the MDAC formation, the sediment deposition and the coeval tectonic deformation have been investigated to unravel how the methane diffuses in the pelitic sediments and control the formation of authigenic carbonates.

2. Materials and methods

The study of the Enza River chimney field is based on the detailed reconstruction of the local geologic evolution by means of seismic data interpretation and field surveys. The seismic interpretation has been calibrated by field data (e.g. Ponza, 2010; Ponza et al., 2010; Gunderson et al., 2014) and by the stratigraphic log of San Polo d'Enza 1 hydrocarbon exploration well (Fig. 1).

Four chimneys (En4, En5A, En5B and En1e) and one dark-grey carbonate concretion (Cr1) have been sampled during a preliminary survey in April 2010. The analysis of their mineralogy and stable isotopes in the carbonate cements has been conducted at the Georg-August-University of Göttingen, Germany. Further four samples of carbonate concretions, two chimneys (En5 and En10), one slab (Cr2) and one concretion (Cr3), together with 31 samples of the hosting sediment, have been collected in May 2013 for their mineralogical and geochemical characterization at the University of Bologna. These latter samples are the main subject of the Viola et al. (in this volume). The concretions have been divided in 29 subsamples to be analysed. The samples have been powdered, homogenized in agate mortar and analysed for mineralogy by X-ray diffractometry (XRD) using a Philips PW 1130 (Cu Kα radiation Ni filtered). Estimates of the relative minerals abundance were determined using MacDiff software packages and carbonate mineral compositional limits defined according to Goldsmith and Graf (1958) and Lumsden (1979). Major and trace elements have been

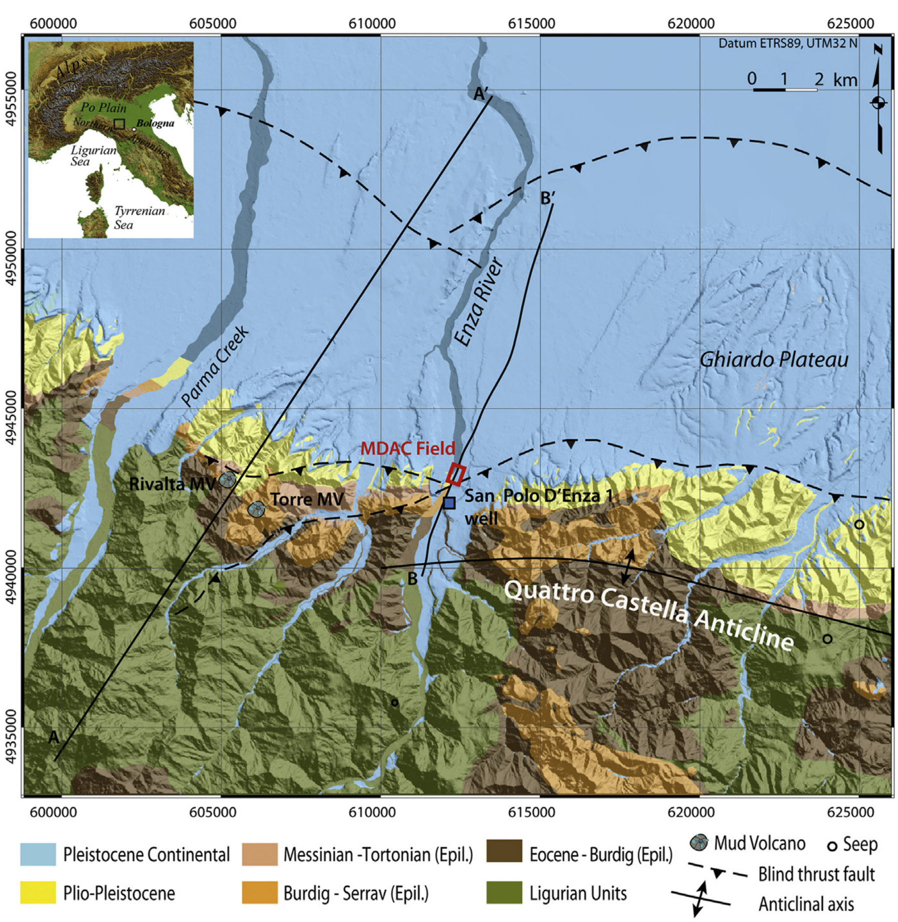

Figure 1. Geological map of the investigated area of the Northern Apennines with location of the Enza MDAC field and San Polo d'Enza deep well. The traces of cross section AA′ and seismic line BB′ of Figures 2 and 3 are indicated. The locations of spontaneous fluids seepage are from Oppo et al. (2013).