Marine and Petroleum Geology 48 (2013) 90–99

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Evidence of climatic control on hydrocarbon seepage in the Miocene of the northern Apennines: The case study of the Vicchio Marls

Daniela Fontana[a,*], Stefano Conti[a], Claudia Grillenzoni[a], Silvia Mecozzi[a], Fabrizia Petrucci[a], Elena Turco[b]

[a] Department of Chemical and Geological Sciences, University of Modena and Reggio Emilia, Italy
[b] Department of Physics and Earth Sciences "Macedonio Melloni", University of Parma, Italy

ARTICLE INFO

Article history:
Received 5 April 2013
Received in revised form
25 July 2013
Accepted 29 July 2013
Available online 14 August 2013

Keywords:
Hydrocarbon seepage
Authigenic carbonates
Miocene
Climatic change
Northern Apennines
Biostratigraphy

ABSTRACT

The Vicchio outcrop in the Tuscan Apennines contains excellent exposures of a Miocene methane-derived carbonate system, made up of more than 80 carbonate bodies enclosed in marly sediments. Facies analysis, composition and a detailed biostratigraphic study of the carbonates and enclosing Vicchio Marls allowed us to document the role of climatic changes and eustasy on seepage in these ancient deposits. Results of our study indicate that the stratigraphic horizon bearing seep-carbonates is constrained by two planktonic foraminiferal events, the Acme End (AE) of *Turborotalita* cf. *T. quinqueloba* (13.75 Ma) and the Acme$_1$ Beginning (A$_1$B) of *Paragloborotalia siakensis* (13.32 Ma), encompassing about 400,000 years. The AE of *T.* cf. *T. quinqueloba* approximates the mid-Miocene global cooling event (Mi3b), as defined by the $\delta^{18}O$ maxima (13.78 Ma). The glacio-eustatic sea level drop associated with this cooling event is estimated to be approximately 60 m. Assuming that the highest rates of glacio-eustatic sea level fall coincide with $\delta^{18}O$ maxima, the timing of the seepage onset (at about 13.75 Ma) is concomitant with the phase of sea level-lowering. The ascent and emission of methane-rich fluids may have been triggered by pressure drop due to the eustatic fall associated with the Mi3b event. The moderate intensity of fluid expulsion is suggested by the lack of brecciation, by the scarcity of detrital particles in the carbonates and by the pervasive occurrence of carbonate in the enclosing marls. This type of seepage differs from focused fault-confined fluid flows, typical of other tectonically controlled Apenninic seep-carbonates.

1. Introduction

Cold seep-carbonates documenting the expulsion of fluids enriched in methane have been identified worldwide throughout the Phanerozoic record, in a variety of basin margins and tectonic-sedimentary settings (see Peckmann et al., 2002, 2003; Campbell et al., 2002; Campbell, 2006 and references therein; Pierre et al., 2012). A number of geological factors influence methane seep activity (Anka et al., 2011), but primary are regional and local tectonics, especially at the deformation front of foredeeps and accretionary prisms. Tectonic structures constrain the plumbing system, with faults serving as conduits and channeling water and methane up to the seafloor (Wiedicke et al., 2002; Aiello, 2005; Conti et al., 2010a).

Nevertheless, recent studies suggest that their occurrence is also controlled by climatic changes (Teichert et al., 2003). The increasing accuracy in dating seep-carbonates during Pleistocene glacial–interglacial cycles has shown that they are not formed continuously through time, but their formation seems to correlate with cold periods and sea-level low-stand (Teichert et al., 2003; Watanabe et al., 2008; Tong et al., 2013). Recently, Pierre et al. (2012) discussed the precipitation of seep-carbonates during glacial times from active methane seeps offshore southwest Africa. Kiel (2009) suggests that this correlation also exists on longer geological time-scales from the late Jurassic to the Recent, and shows statistically relevant correlations between the frequency of seep-carbonates in the past 150 Ma and low deep-water temperatures and low sea-levels. These studies suggest the need for further research on the role of climatic variations on seep-carbonate formation, a role which is still underestimated and not sufficiently investigated.

In the Miocene of the northern Apennines, the abundance and extent of seep-carbonates in different tectonic-sedimentary settings, from foredeep to satellite basins (Clari et al., 1994; Terzi et al., 1994; Conti and Fontana, 1999; Taviani, 2001; Peckmann et al., 2004), provide a rare opportunity to study the evolution of the

* Corresponding author.
E-mail address: daniela.fontana@unimore.it (D. Fontana).

0264-8172/$ – see front matter
http://dx.doi.org/10.1016/j.marpetgeo.2013.07.014

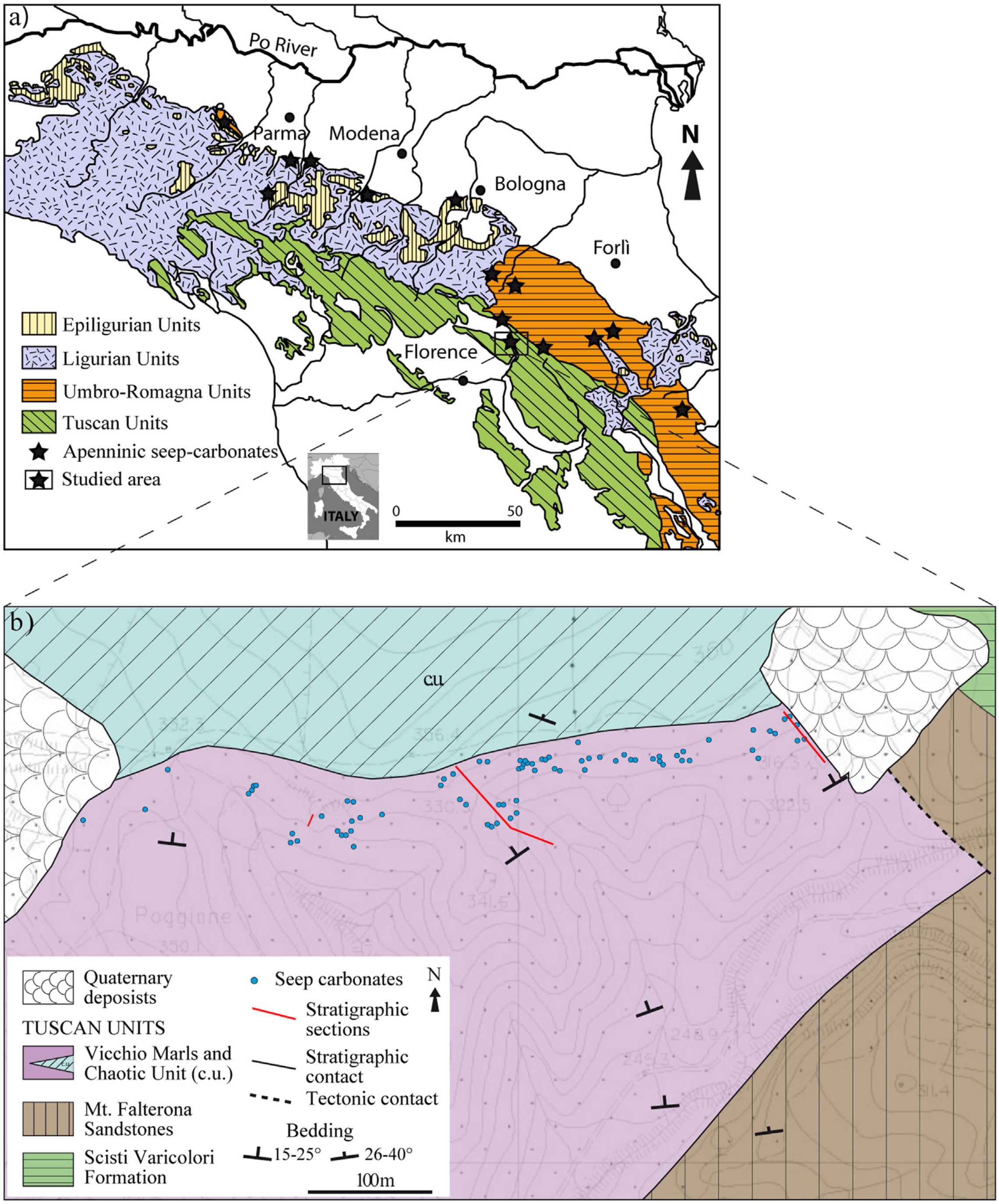

Figure 1. a) Simplified geology of the northern Apennines and b) detailed geological map of the Vicchio area. Note the distribution of seep-carbonate bodies (blue dots) along strike in the upper portion of the Vicchio Marls. Location of the measured stratigraphic sections is reported. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

seepage system, fluid migration paths, and in particular the tectonic and/or climatic controls on seepage. Part of these seep-carbonates, located atop intrabasinal highs and associated with sediment instability, commonly formed at the toe of the deformation front of the northern Apennine accretionary wedge. The parallelism between the areal distribution of these seep-carbonates and the Apennine structural trends suggests a close relationship between tectonics and gas/fluid emission (Conti et al., 2010a). In contrast, other seep-carbonates located in the Apenninic foredeep, such as those observed in the Vicchio Marls examined in this paper, seem not to be related to tectonic structures. The Vicchio Marls in the Tuscan Apennines contain excellent exposures of a Miocene seep-system (more than 80 carbonate bodies; Conti et al., 2010b) enclosed in marly sediments. A detailed stratigraphic and biostratigraphic study of these seep-carbonates and enclosing marls allows us to check the correlation between the onset of the seep-carbonate precipitation and the glacio-eustatic sea-level fall during the middle Miocene climate cooling. Since the major step in the Middle Miocene climate cooling is characterized by a global shift to heavier $\delta^{18}O$ values in carbonates (Abels et al., 2005), the $\delta^{18}O$ isotope record in the marls hosting the carbonates was examined. The study provides a significant opportunity to