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Fault development through fractured pelagic carbonates of the Cingoli anticline, Italy: Possible analog for subsurface fluid-conductive fractures

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ABSTRACT

The Cingoli anticline is a late Messinian thrust-related fold that developed along the northern Apennines front (Italy). This exposed anticline represents a potential analog of hydrocarbon reservoirs located in the nearby Po Plain and Adriatic Sea areas. The folded rock multilayer of the Cingoli anticline includes a heterogeneous, Mesozoic–Cenozoic, marine succession, consisting of massive platform carbonates below, and layered pelagic carbonates on top. This article reports the results of analyses conducted on pelagic micrites cropping out in two exposures located in the anticline backlimb. There, the late Cretaceous–Eocene *Scaglia Rossa* Fm., which is characterized by thin beds of pelagic limestones and marly limestones, is crosscut by pervasive, closely-spaced, stratabound fractures mostly consisting of pressure solution seams (PSSs) and sheared PSSs. The fractured strata are, in places, crosscut by small-offset fault zones. Field and laboratory structural data are used to define the nature and type of the different fracture sets as well as their temporal evolution and interaction. Seven main sets of stratabound PSSs and sheared PSSs are identified and interpreted as an early background fabric crosscut by or involved in later through-going fault zones. We propose a conceptual model of fault nucleation and growth that envisions the studied faults as late-stage structures, which formed by incorporating and connecting segments of bedding surfaces and early developed PSSs. We discuss our conceptual model in terms of fault and fracture permeability, highlighting the possible role exerted by the documented structures on subsurface fluid flow.

1. Introduction

Faults have a significant impact on fluid flow through rocks, as they may act as barriers, carriers, or combined barrier–carrier systems through the different fault zone compartments (Engelder and Scholz, 1981; Cooper, 1992; Antonellini and Aydin, 1994; Sibson, 1996; Caine et al., 1996, 2003; Odling et al., 1999; Salvini et al., 1999; Aydin, 2000; Billi, 2005; Micarelli et al., 2006; Agosta et al., 2007, 2009; Billi et al., 2008 among many others). These complex structures represent an important target in environmental, industrial, and economic studies and activities such as groundwater, hydrocarbon and geothermal exploitation, waste disposal, CO_2 storage, and assessment of pollutant dispersion in aquifers (e.g., Brusseau, 1994; Gudmundsson, 2000; Nelson, 2001; Caine and Tomusiak, 2003). In the hydrocarbon industry, fractured carbonate reservoir development is a very challenging task (e.g., properly deviating wells or determining the fractures that are open and those that are closed) due to the complexity of fracture patterns and their related permeability structure (e.g., Peacock and Sanderson, 1995; Willemse et al., 1997; Mollema and Antonellini, 1999; Antonellini and Mollema, 2000; Billi and Salvini, 2001; Graham Wall et al., 2003; Billi et al., 2003; Mazzoli and Di Bucci, 2003; Tondi et al., 2006; Antonellini et al., 2008; Agosta et al., 2010; Aydin et al., 2010; Guerriero et al., 2011). Recent works documented that fluid movements in fractured reservoirs are mainly controlled by a limited number of through-going conductive fractures (or fracture swarms), whereas the surrounding cloud of smaller fractures has a smaller influence on fluid flow (Lonergan et al., 2007; Ozkaya et al., 2007; Wennberg et al., 2007; Akbar and Montaron, 2008; Singh et al., 2008; Questiaux et al., 2010; Souque et al., 2011). The different contribution to fluid flow of the aforementioned structures is known from flowmeter data from producing wells (Ozkaya and Minton, 2007). What is less well known, in contrast, is the architecture and growth mechanisms of

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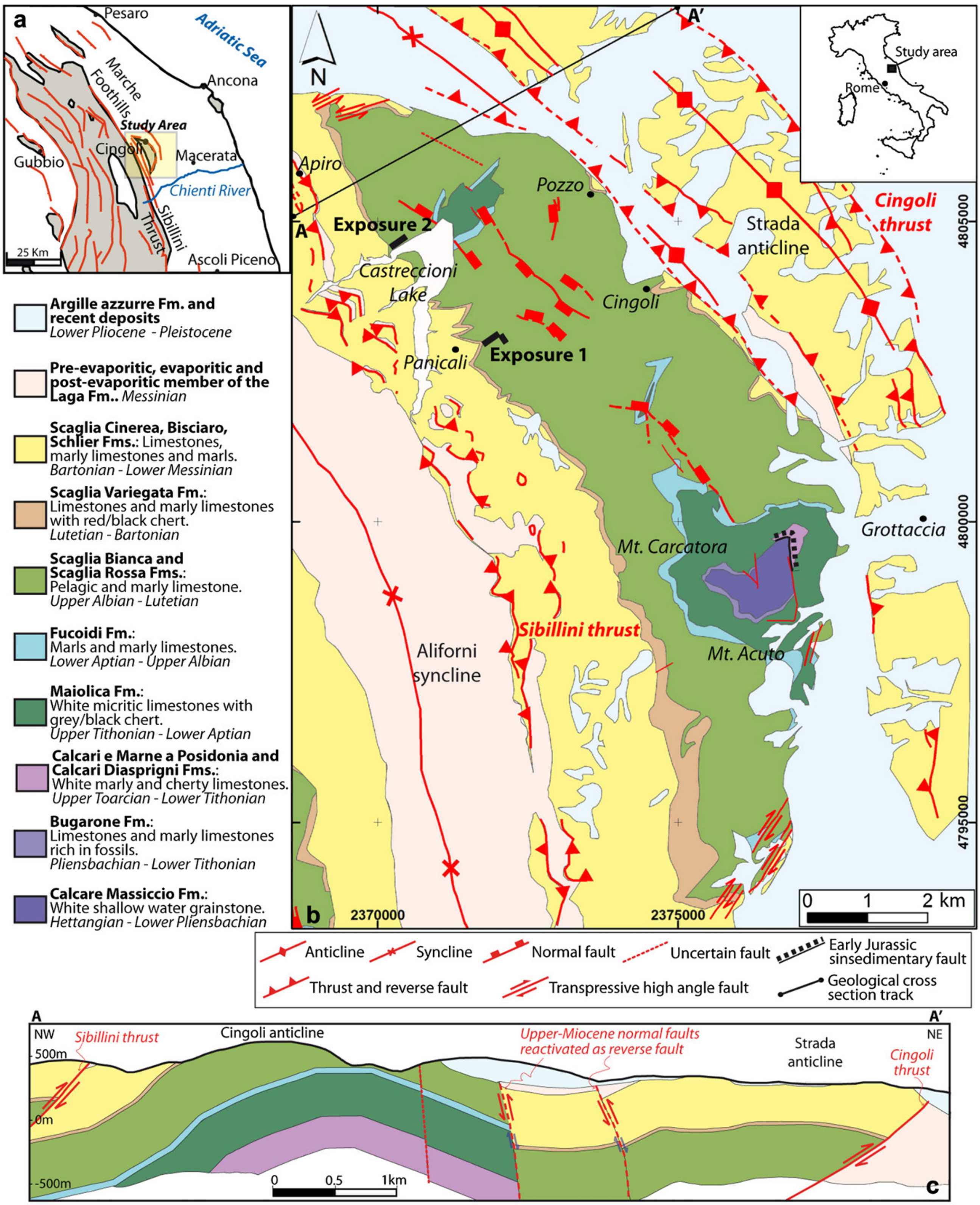

Fig. 1. (a) Location of the study area. The Cingoli anticline is in the foothills of the northern Apennines fold-and-thrust belt, Umbria-Marche area, Italy. (b) Simplified geo-structural map of the Cingoli anticline area (modified after Servizio Geologica d'Italia (2003) – Coordinate System: Gauss Boaga, Est – Roma 1940). The exposures studied in this paper are located in the northern sector of the anticline backlimb, within the *Scaglia Rossa* Fm. (c) Geological cross section through the northern sector of the Cingoli anticline, based on a seismic reflection profile and previous studies (Mazzoli et al., 2002; Deiana et al., 2002; Servizio Geologica d'Italia, 2003).