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Spacing and distribution of bed-perpendicular joints throughout layered, shallow-marine carbonates (Granada Basin, southern Spain)

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ABSTRACT

This contribution focuses on the controls exerted by sedimentological, petrographic and mechanical rock properties on the distribution of bed-perpendicular joints throughout layered carbonates. The study was conducted on Tortonian, shallow-marine skeletal grainstones and rudstones cropping out in the Granada Basin, southern Spain. The results of combined field and laboratory analyses are consistent with the rock grain size of the studied carbonates exerting a key control on distribution of the bed-perpendicular joints. A positive correlation between joint spacing and mechanical unit thickness is computed for the grainstones, whereas joints are almost absent in rudstones. The rock grain size affected the diagenetic processes, such as cementation and dissolution, and therefore the resulting porosity and uniaxial compressive strength (UCS) values. Quantitative data show that higher UCS values are commonly associated with greater calcite amounts, lower values of porosity and finer grain sizes and, hence, denser bed-perpendicular joint sets. In conclusion, this study documents that it is possible to infer the density of bed-perpendicular joints in layered carbonates based on the sedimentological, petrographic and mechanical parameters. Considering the impact that this type of joints has on subsurface fluid flow, the acquired knowledge can help the management of geofluids as well as the overall prediction of carbonate reservoir quality.

1. Introduction

Joints are opening-mode fractures widespread in the uppermost portion of the Earth's crust. These elements are often characterized in the field thanks to the peculiar morphology of their surfaces, which display plumose structures made up of hackles, arrest lines and fringes (Pollard and Aydin, 1988). Joints are commonly oriented roughly perpendicular to bedding and, often, arranged as systematic sets within competent layers (Bai et al., 2000; Fig. 1). The individual competent layers, which may be formed by one or more sedimentary beds having a homogeneous mechanical behavior, are named mechanical units (Gross et al., 1995; Gudmundsson et al., 2010; Fig. 1). Within individual mechanical units, joints commonly initiate at pre-existing flaws (i.e., isolated pores and fossils, mineral inclusions) characterized by different mechanical properties relative to the surrounding rock, and hence concentrating the remote stress (Pollard and Aydin, 1988). Thus, joints propagate in-plane across the rock terminating against the upper and lower mechanical unit boundaries, which mechanically represent traction free surfaces (Cooke et al., 2006; Gross et al., 1995; Gudmundsson, 2011; Gudmundsson and Brenner, 2004; Pollard and

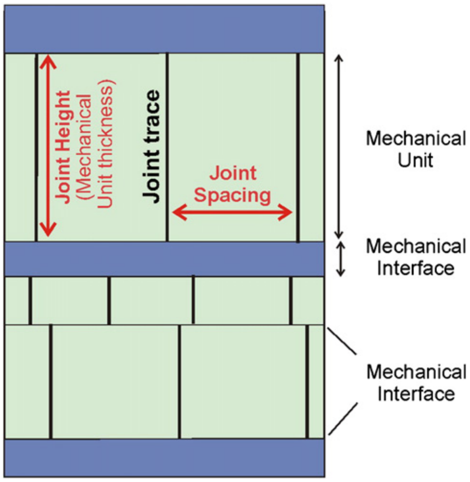

Fig. 1. Cross-section view of an ideal multilayer outcrop containing systematic, bed-perpendicular joints. Joints develop within mechanical units (competent layers) and terminate against mechanical interfaces, which may be represented by both stratigraphic contacts and weak rock layers that resist fracture propagation. Modified after Gross et al. (1995) and Underwood et al. (2003).

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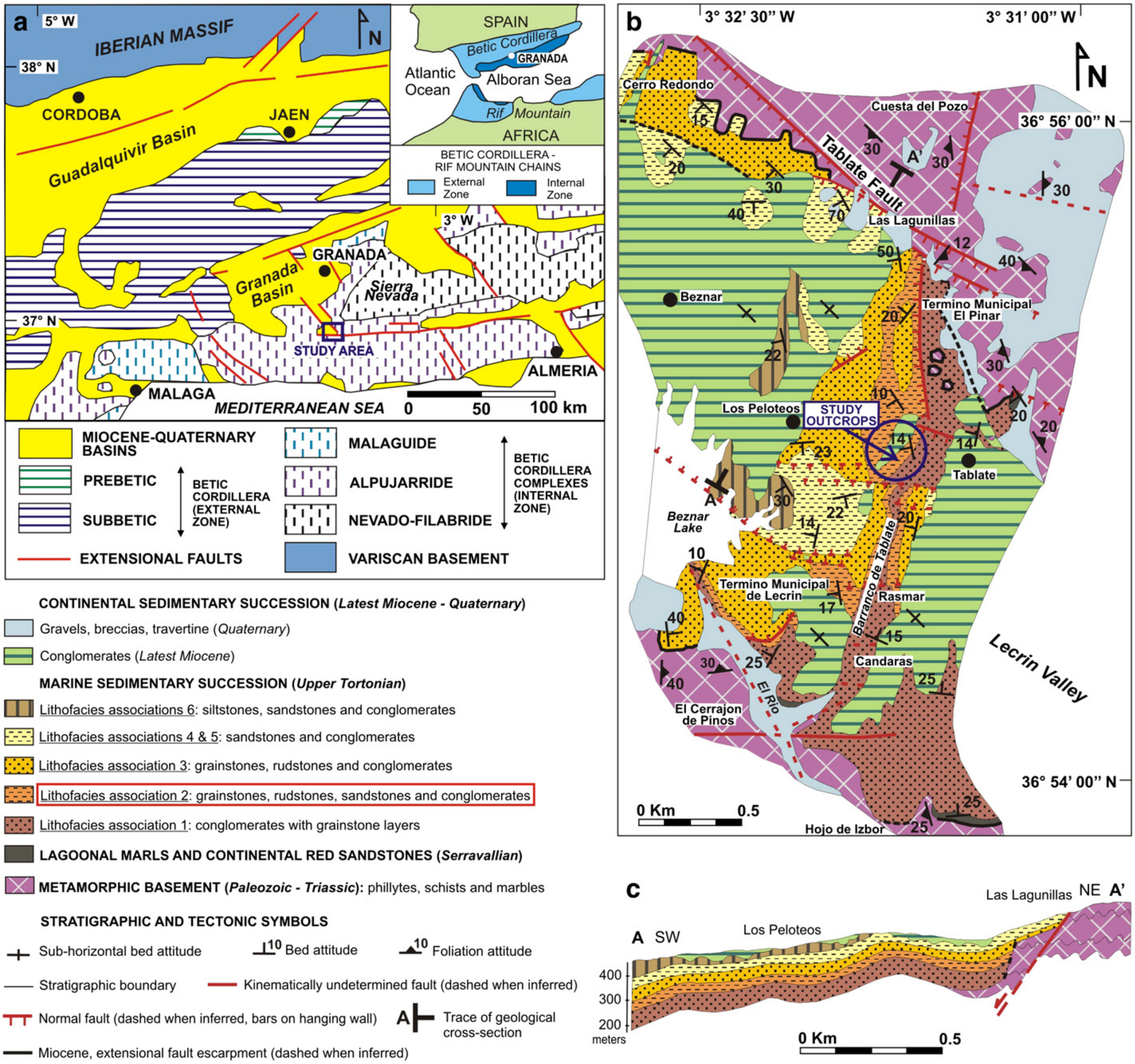

Fig. 2. (a) Geological sketch of the Granada Basin and the Betic Cordillera, southern Spain. (b) Geological map of the study area. The studied rocks are highlighted (within a rectangle) in the legend. The outcrop area (to the west of Tablate) in which the quantitative analyses were performed is shown in the map (within the circle). (c) Geological cross-section.
(a) is modified after Rodríguez-Fernández and Sanz de Galdeano (2006) and Sanz De Galdeano et al. (2003).

Aydin, 1988; Tavani et al., 2008). The result of this process consists of joints orthogonal to these mechanical interfaces (Fig. 1).

Both distribution and spacing of systematic bed-perpendicular joints depend on many factors, among which tectonic setting and evolution, tectonic and lithostatic stresses, mechanical unit thickness and lithological properties are the most important (Eyssautier-Chuine et al., 2002). In relatively undeformed sedimentary rocks (unfolded, away from fault zones), however, both distribution and spacing of bed-perpendicular joints, as well as other structural elements (i.e. bed parallel pressure solution seams and compaction bands), are typically controlled by stratigraphy (mechanical unit thickness and lithological/mechanical properties) rather than tectonics (Rustichelli et al., 2012; Underwood et al., 2003, and references therein). Almost tectonically undeformed outcrops may therefore represent excellent sites to study the controls exerted by mechanical unit thickness and lithological/mechanical properties on distribution and spacing of systematic bed-perpendicular joint. In particular, a wealth of field, theoretical and experimental studies documented that the spacing of bed-perpendicular joints is commonly proportional to the thickness of the individual mechanical units (Bai et al., 2000; Becker and Gross, 1996; Gross et al., 1995; Hanks et al., 1997; Huang and Angelier, 1989; Price, 1966; Underwood et al., 2003). Moreover, both theoretical and experimental studies on jointing within layered media pointed out Young's modulus and Poisson's ratio as principal mechanical rock properties controlling open fracture formation and spacing of bed-perpendicular joints (Bai and Pollard, 2000; Bai et al., 2002; Baud et al., 2000, 2009; Cilona et al., 2012; Gross, 1993; Gross et al., 1995; Hobbs, 1967; Nur, 1982; Wu and Pollard, 1995).

In carbonate rocks, some recent studies based on combined field and petrographic analyses also addressed the control exerted by the lithological properties (compositional, sedimentological, diagenetic and pore