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Three-dimensional reconstruction of diagenetic geobodies for geological carbon dioxide storage

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ABSTRACT

Geological storage of carbon dioxide (CO_2) may help in mitigating greenhouse gas emissions, the main cause of global warming. Deep saline aquifers form ideal storage sites for CO_2, but these are often complex due to differences in porosity and permeability, referring to heterogeneity, especially in carbonate reservoirs. Diagenetic heterogeneities, such as the presence of less reactive dolomite bodies in a more reactive limestone host rock, have huge impacts on CO_2 storage. As upscaling still poses a challenge, we bridge the gap between micrometre–centimetre lab experimental scale and reservoir scale by documenting heterogeneity at the inter-well, subseismic scale. We developed a method using satellite images, field pictures, GPS data and distance measurements to reconstruct diagenetic dolomite geobodies in three dimensions from outcrops (in Picos de Europa, northern Spain). The dolomite bodies studied have higher porosity than the limestone host rock, which is also observed in CO_2 reservoir targets. The geobodies are elongated in the direction of the main faults and their length/width ratio is about 2.5 in the Picos de Europa Formation. Geobodies hosted in different formations seem to vary in dimension. We suggest that large dolomite bodies are favoured in zones with large fluid input and flow rate slow enough to allow for extensive chemical reaction based on the disconnected dolomite body distribution and inferred fluid migration from the source. Understanding how these diagenetic bodies form helps with prediction of heterogeneity crucial in CO_2 storage reservoir modelling.

1. Introduction

In the transition stage towards clean energy, a proposed solution to mitigate anthropogenic emission of greenhouse gases, accepted as the main cause for global warming, is storage of carbon dioxide (CO_2) underground (Bachu, 2008). Carbon dioxide is recognized as the greenhouse gas of primary concern because of its large scale emissions linked to fossil fuel combustion for power generation and industrial processes. Of the potential repositories for CO_2 (including depleted oil and gas fields, coal beds or mines and the deep ocean), deep saline aquifers are considered as ideal candidates thanks to their wide occurrence, large storage capacity, low potential impact on groundwater resources and their isolation from biosphere (Bachu, 2000; Lemieux, 2011; Xu et al., 2006). The storage of CO_2 in geological beds is possible by a variety of physical and chemical trapping mechanisms and relate to the properties of CO_2 and the geological medium under subsurface reservoir temperature and pressure. Physical trapping occurs by (1) static trapping of mobile CO_2 by a structural trap involving a low-permeability barrier, and (2) residual gas or capillary trapping caused by multiphase flow processes (Andrew et al., 2013; Juanes et al., 2010; Suekane et al., 2008). These trapping mechanisms are short to medium term (tens to hundreds of years). There are three types of chemical trapping: (1) adsorption trapping when CO_2 adsorbs onto organic material in coal beds or shale, (2) solubility trapping through the dissolution of CO_2 in subsurface fluid, and (3) mineral trapping caused by the reaction of CO_2 with the host rock (Altman et al., 2014; Bachu, 2008; Mitchell et al., 2010).

The trapping mechanisms are inherently linked to the geological medium for CO_2 storage, and hence, a good characterization of the reservoir properties is required. Subsurface reservoirs show heterogeneity linked to variations in depositional facies, diagenetic products or structural elements (Morad et al., 2010; Moraes and Surdam, 1993; Shipton et al., 2002; Weber, 1982). Predicting this heterogeneity in subsurface aquifers is important during evaluation and planning before CO_2 injection can start. For example, the importance of understanding both the reservoir composition and heterogeneity of potential CO_2 storage systems was illustrated in the study by Higgs et al. (2015) on the Pretty Hill Formation of the

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Otway Basin (Australia), a natural analogue for CO_2 storage. Similarly, Civile et al. (2013) highlights marked spatial heterogeneities, inferred to result from primary depositional processes, diagenesis and fracturing due to tectonic events, in Italian carbonate reservoirs identified for CO_2 storage. The importance of heterogeneity linked to variations in permeability, porosity and amounts of more reactive calcite and less reactive dolomite has been demonstrated for CO_2 storage target reservoirs at the Weyburn-Midale field (Carroll et al., 2013). Differences in mineralogy in the reservoir impact on the type of processes resulting from CO_2 injection and may impact differently on potential leakage from CO_2 reservoirs (Romanak et al., 2012). As documented by Romanak et al. (2012), both dedolomitization (replacement of dolomite by calcite) and calcite dissolution processes can occur and are sensitive to CO_2. Moreover, upscaling from microns to centimetres up to reservoir scale simulations still poses issues, especially for carbonate reservoirs where the typical heterogeneous distribution of pores and reactive minerals and the uncertainty in the kinetics of carbonate minerals in CO_2-rich fluids contribute to the challenge (Carroll et al., 2013). Heterogeneity in geological reservoirs is present at various scales (Ambrose et al., 2008; Ringrose et al., 2008). As a result, effective parameters for large scale behaviour for CO_2

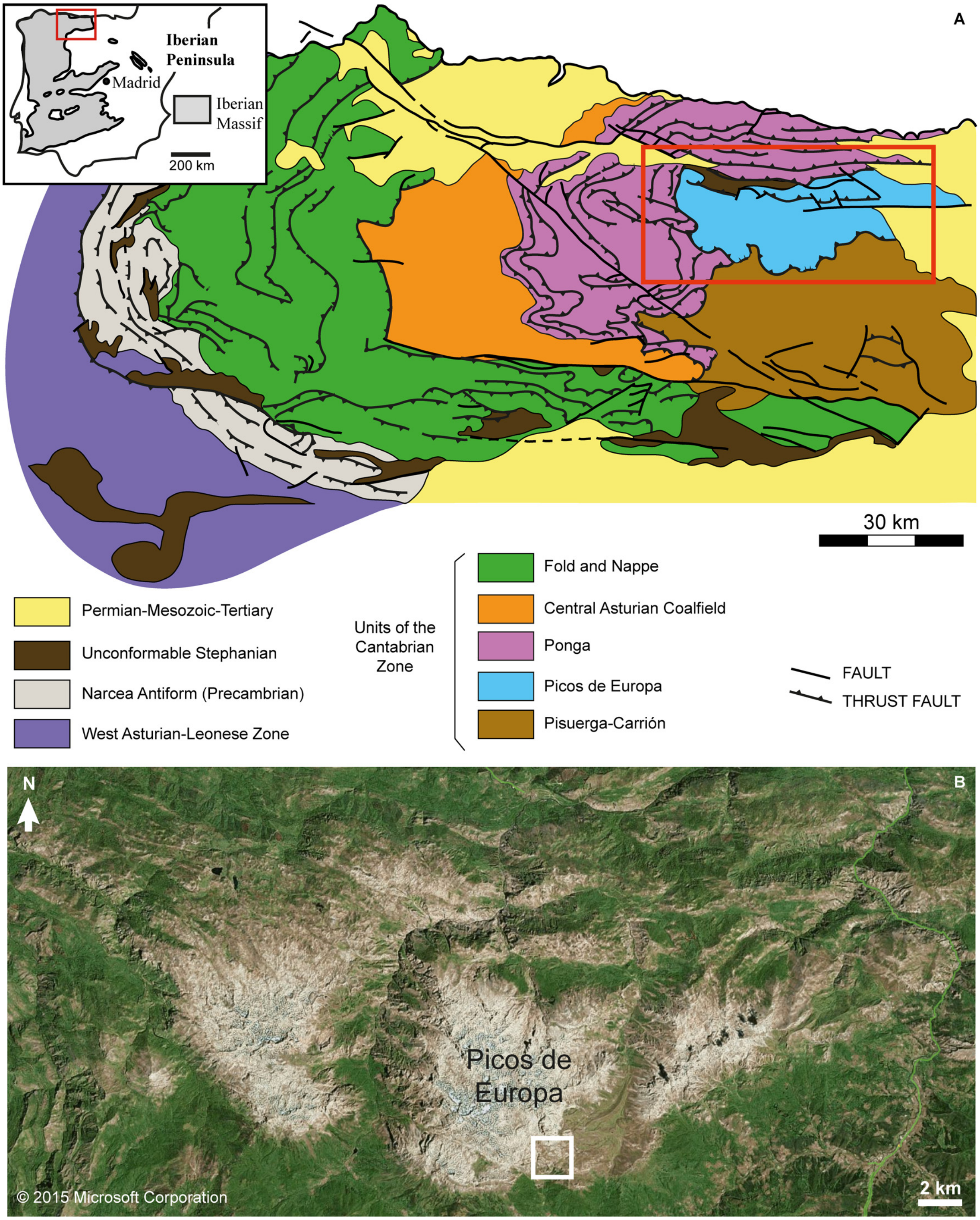

Fig. 1. (A) Geological map of the Cantabrian Zone in northern Spain (modified after Julivert (1971)). The Picos de Europa Province is indicated in blue. The red box delineates the area shown in B. (B) Bing maps satellite image of the Picos de Europa Province. The white box shows the area shown in Fig. 4. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)