Engineering Geology 166 (2013) 272–282

Contents lists available at ScienceDirect

Engineering Geology

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

Technical Note

Mercury porosimetry as a tool for improving quality of micro-CT images in low porosity carbonate rocks

Nicoletta Fusi [a,*], Javier Martinez-Martinez [b]

[a] Dipartimento di Scienze dell'Ambiente e del Territorio e di Scienze della Terra, Università degli Studi Milano-Bicocca, Piazza della Scienza 4, 20126 Milano, Italy
[b] Laboratorio de Petrología Aplicada, Departamento de Ciencias de la Tierra y del Medio Ambiente, Campus Sant Vicent del Raspeig, AP 99, 03080 Alicante, Spain

ARTICLE INFO

Article history:
Received 27 May 2013
Received in revised form 18 September 2013
Accepted 6 October 2013
Available online 14 October 2013

Keywords:
MicroCT
Mercury porosimetry
Porosity
Carbonate rock
Image analysis

ABSTRACT

The combined use of Hg-impregnation and microCT scanning is a powerful tool for detecting structural and textural features in low porosity massive carbonate rocks. Hg-impregnation of carbonate rocks can improve extremely the quality and resolution of microCT images, because of the high density contrast between Hg and the surrounding rock. The success of the combined used of these two techniques depends mainly on two different rock characters:1) Shape of the pores and characteristics of the porous system. Ink-bottle shape pores and tortuous complex porous systems prevent Hg from flowing out of the sample at the end of Hg-porosimetry test, producing reliable microCT images of the porous system itself. On the other side low tortuous cylindrical pores allow Hg flowing out, resulting in not completely true microCT images.2) Effective rock porosity. Hg-impregnation of carbonate rocks with very low porosity (<1%) and tortuous or ink-bottle pores improves significantly the analysis and quantification of their porous system. On the contrary, for carbonate rock with higher porosity (>4%), although with ink-bottle pores, microCT images are undetectable, as the relatively high quantity of Hg entrapped in the sample creates artefacts (metal effect) that completely obliterate the rock structure. Intermediate porosity (about 2%) can behave either as low porosity (<1%) or as higher porosity (>4%) depending on pore shape. A prevalence of tortuous ink-bottle pores results in undetectable microCT images, due to widespread metal effect. A small amount of cylindrical pores, reducing the quantity of entrapped Hg, results in a good quality of microCT images.
The resolution of the technique depends on the rock porous system. For low porosity (<1%) rock, due to high density contrast between Hg and rock, pores with radius one order of magnitude smaller than the voxel size are clearly imaged by microCT and pores with radius two order of magnitude smaller than the voxel size are still detectable. Hg-impregnated pores smaller than the voxel increase the voxel density, as a function of the relative volume of Hg and rock. As a consequence, pores smaller than the voxel size appear as large as the voxel itself and bigger pores appear larger than they really are (partial volume effect). Although Hg-impregnation improves 3D qualitative analysis of porous system and its relationships with rock texture, quantification of the porous system through segmentation of microCT images is strongly affected by intrinsic error in pore dimensions, caused by partial volume effect. Quantification error is a function of the shape of the porous system, being lower for rounded pores and higher for complex tortuous pore system.

1. Introduction

The movement of fluids through rocks is determined by the dimensions and structure of their porous system. The study of the pore network has numerous practical applications with economic relevance, such as storage capacity of hydrocarbons, contaminant transport, waste storage and rock durability.

Several different laboratory techniques have been developed to estimate porosity on rock specimens. Analysis of thin sections allows a 2D evaluation of porosity. Mercury and argon porosimetry tests determine the pore radius and their relative abundance in the sample, but cannot define the spatial arrangement of pore network within the sample. X-ray CT imaging provides, after proper image processing, 3D reconstructions of the pore system and pore dimensions; the advantage of X-ray CT with respect to the other methods is to show the 3D spatial arrangement of pore network and its relationship with rock textural features.

High-resolution X-ray computed tomography (CT) is a technology ideally suited to a wide range of geological investigations, as it is a nondestructive and relatively quick method to produce images that closely match serial sections through an object (Ketcham and Carlson, 2001). Stacks of images obtained with CT, processed by a suitable software, can be used to create three-dimensional representations of the main objects of interest.

* Corresponding author. Tel.: +39 0264482003; fax: +39 0264482073.
E-mail address: nicoletta.fusi@unimib.it (N. Fusi).

0013-7952/$ – see front matter
http://dx.doi.org/10.1016/j.enggeo.2013.10.002

The application of X-ray microtomography (microCT) to earth science problems is well known since two decades (Van Geet et al., 2001; Mees et al., 2003; Carlson, 2006; Cnudde et al., 2006; Cnudde and Boone, 2013;).

MicroCT scanning has been successfully applied to both heterogeneous and homogeneous.

Heterogeneous materials include rocks composed of different minerals characterized by different densities, such as: granites (Ikeda et al., 2000; Othani et al., 2000), sandstones (Pralle et al., 2001), pumice (Gualda and Rivers, 2006), schists (Ketcham, 2005) and metamorphic rocks in general (Denison et al., 1997a, 1997b), carbonate rocks with different carbonate minerals (Van Geet et al., 2000; Cnudde et al., 2009), evaporites (Remeysen and Swennen, 2008). Artificial heterogeneous materials, such as concrete, are well imaged in microCT (Cnudde et al., 2009). Internal structure of macrofossils, such as brachiopods, filled by sandy sediments, can also be successfully investigated by means of microCT (Angiolini et al., 2010; Pakhnevich, 2010).

Conversely, in homogeneous materials, characterized by high porosity or fractures, the density difference between air and water, filling the pores or fractures, and the material is clearly detected by microCT. These studies are carried out both on artificial materials, with medical and industrial application (Taud et al., 2005; Wonga and Chau, 2005; Tuan Hoa and Hutmacher, 2006; Lin-Gibson et al., 2007; Castellanza et al., 2009), and on natural materials, such as soils (Pierret et al., 2002), porous rocks (Nakashima et al., 2004) and fractured rocks (Viggiani et al., 2004; Raynaud et al., 2008; Crosta et al., 2010; Watanabe et al., 2011).

Homogeneous materials with low porosity are generally considered not suitable for microCT analysis, as usually dimensions of pores are micrometrics or sub-micrometrics. This pore size is in the range or below the maximum resolution of industrial microCT.

Intrusion of interconnected pores with heavy liquids, such as molten metals (Montemagno and Pyrak-Nolte, 1999) or mercury by means of Hg-porosimeter (Klobes et al., 1997; Cnudde et al. 2009), can provide a successful method to increase density differences between materials and pores. The combination of CT and Hg-porosimetry has been applied to Rapakivi granite (Klobes et al., 1997), which is characterized by a total porosity lower than 2%. On the basis of results obtained for this rock specimen, the authors suggest that the combination of the two techniques is suitable for rocks with a pronounced mercury intrusion–extrusion hysteresis, where the entrapped portion of mercury in the rock is used as a contrast agent in the porous system.

This study investigates how mercury intrusion can improve microCT images in low porosity carbonate rocks; in particular we aim to define, if present, a limit of porosity for which the combination of these two techniques is useful to investigate textural characters of rock and to compare Hg-porosimeter and image analysis results.

2. Materials

Nine well-known Spanish limestones and dolostones were analysed (Figure. 1). The lithotypes have been chosen for their homogeneous mineralogical composition (calcite or dolomite) and for their low porosity (<8%) (Martinez-Martinez, 2008). Each lithotype is characterized by different crystal sizes, different porosities and a particular textural feature.

Samples can be grouped into the following three main groups (acronym corresponds to the common commercial name of the stone):

2.1. Brecciated dolostones

Ambarino (A): a brecciated dolostone, composed by dolomite clasts surrounded by a fine-grained matrix. Clasts are small, most of them having maximum axis smaller than 2.5 mm. They present a microcrystalline texture with crystal size between 40 and 60 μm. The matrix is formed by a dense mixture of calcite and dolomite crystals. Proportions of both minerals in the matrix are very variable through the rock. The open porosity of the rock is about 4%.

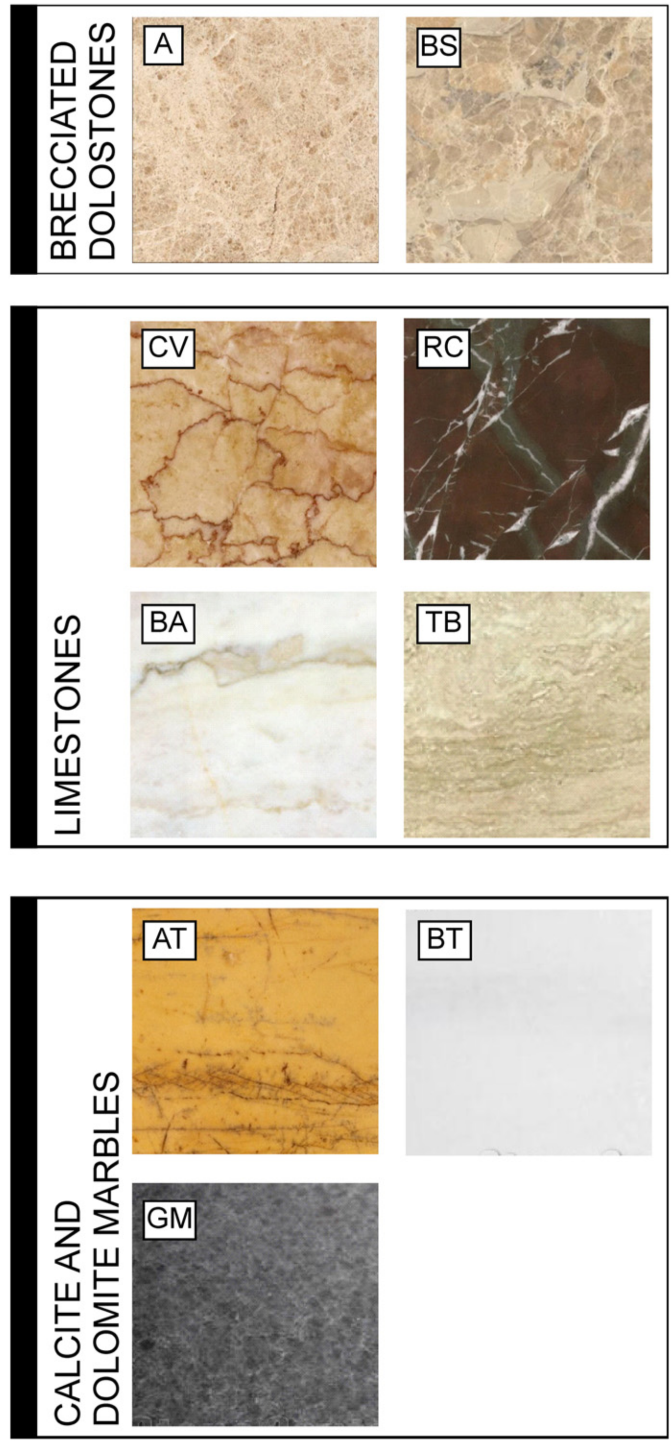

Fig. 1. Handspecimen of the nine studied carbonate lithologies.

Beige Serpiente (BS): a brecciated dolostone, similar to Ambarino. BS is composed by large microcrystalline dolomite clasts, with maximum axis up to 8 cm. These clasts are surrounded by a fine-grained matrix formed by a mixture of calcite (20%) and dolomite (80%) crystals. Clast porosity is about 1.6%, whereas matrix porosity is about 7%. Medium porosity of this rock is about 4%, but it can vary as a function of relative clast abundance.