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Three dimensional modelling of fractured and faulted reservoirs: Framework and implementation

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ABSTRACT

Modelling of coupled physical processes in fractured and faulted media is a major challenge for the geoscience community. Due to the complexity related to the geometry of real fracture networks and fault systems, modelling studies have been mainly restricted either to two dimensional cases or to simplified orthogonal fracture systems consisting of vertical and horizontal fractures. An approach to generate three dimensional meshes for realistic fault geometries is presented. The method enables representation of faults in an arbitrary incline as two dimensional planes within a three dimensional, stratified porous matrix of a generic geometry. Based on a structural geological model, the method creates three dimensional unstructured tetrahedral meshes. These meshes can be used for finite element and finite volume numerical simulations. A simulation of a coupled fluid flow and heat transport problem for a two layered porous medium cut by two crossing faults is presented to test the reliability of the method.

1. Introduction

The objective of this paper is to describe the influence of fractures and faults on fluid flow and transport properties in fractured and faulted reservoirs. In principle, faults may represent preferential pathways for fluids, or can act as a geological barrier. These two options depend essentially on the origin and orientation of the faults in relation to the recent and paleo stress field (Barton et al., 1995; Gudmundsson, 2001; Moeck et al., 2008; Scheck-Wenderoth et al., 2008; Magri et al., 2010).

In general, fractured reservoirs can be handled in two ways. The reliability of hydraulic properties of fractured reservoirs is connected to the size of a potential representative elementary volume (REV) (Bear, 1972; De Marsily, 1986). The representative elementary volume (REV) is the smallest volume over which a measurement can be made yielding a value representative of the whole. To completely represent fractures and faults in reservoirs a REV is not sufficient. Below the REV, the relevant parameter is not defined and the material must be treated as heterogeneous with a high variability of its properties. Above the REV the material can be considered as a statistically homogeneous and ergodic medium and can be modelled as an "equivalent homogeneous" medium. An overview concerning this problem, commonly referred to as "the scale effect," and the corresponding concepts to model the hydraulic flow is given by Guéguen et al. (1996). The description of fracture models and their characteristic parameters has been achieved with various theoretical approaches. Several methods have been developed to solve the sophisticated problem of transferring the complex structure of natural rocks to adequate, equivalent models. Such methods include the deterministic fracture networks (Kolditz, 1995a, b; David, 1993), fractal fracture networks (Kosakowski, 1996; Acuna and Yortsos, 1995) and stochastic fracture networks (Cacas et al., 1990a, b; Bruel et al., 1994; Wollrath, 1990; Zimmermann et al., 2000).

In all areas of geo-energy research (e.g. CO_2 sequestration and storage, shale gas and geothermal energy), the development of adequate reservoir and deposit models are of primary concern, while studying the dynamic behaviour during reservoir utilisation. Evaluating the response of geological deposits during CO_2 sequestration and storage (Ketzin site, e.g. Juhlin et al., 2007), shale gas extraction (Barnett shale, e.g. Gale et al., 2007) or geothermal heat recovery (Groß Schönebeck site, e.g. Blöcher et al., 2010) requires an understanding of the complex three dimensional geometry of the deposits. This geometry is difficult to

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assess, because the scale of numerical and experimental investigation alters the size of the measured parameters. Upscaling is an ongoing relevant issue (e.g. Lock et al., 2004; Zimmermann et al., 2003; McDermott et al., 2006). In case their size exceeds the correspondent REV, faults and fractures have to be treated as discrete objects in a reservoir model. Therefore, geometric modelling and mesh generation was the subject of several previous studies (Blessent et al., 2009; Kalbacher et al., 2007). We developed a 3D finite element model with unstructured tetrahedral meshes for matrix properties with embedded 2D discrete surfaces representing the faults and fractures.

The paper is organised as follows: After describing the general modelling techniques applying 3D geological structures and 2D planar surfaces to obtain a combined 3D mesh, we give an example of such a system with two geological layers and two dipping fault systems. This mesh is then used for a coupled thermal-hydraulic simulation. Finally, the results of this model are presented and discussed.

2. Description of model techniques and methods

Understanding and predicting physical processes occurring in complex fractured geological systems requires numerical models capable of simulating the coupling between the processes involved in their realistic three dimensional geological framework. The present paper describes a direct approach to generate unstructured tetrahedral meshes suitable for finite element or finite volume numerical simulations of coupled processes for complex faulted natural geological systems. The procedure is fully automated in a C++ source code written by the authors and provides 3D meshes that can be directly imported by existing numerical software. In the following, the different steps of the method are schematically illustrated for a relatively simple case geometry consisting of two geological layers cut by a system of two intersecting faults.

The first step is to integrate the geological structures defining the geometry of the unstructured model (Fig. 1). The input data

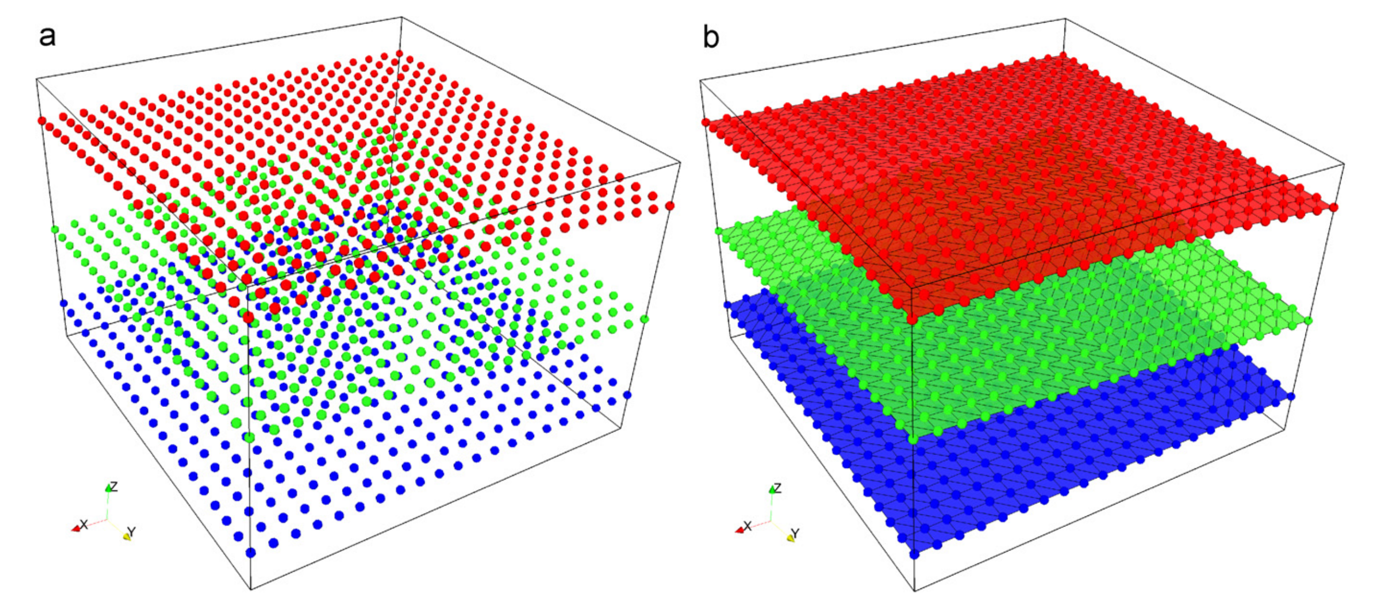

Fig. 1. Workflow of finite element mesh generation: scattered data points resulting from structural geological modelling (a) and triangulated interfaces of geological layers (b).

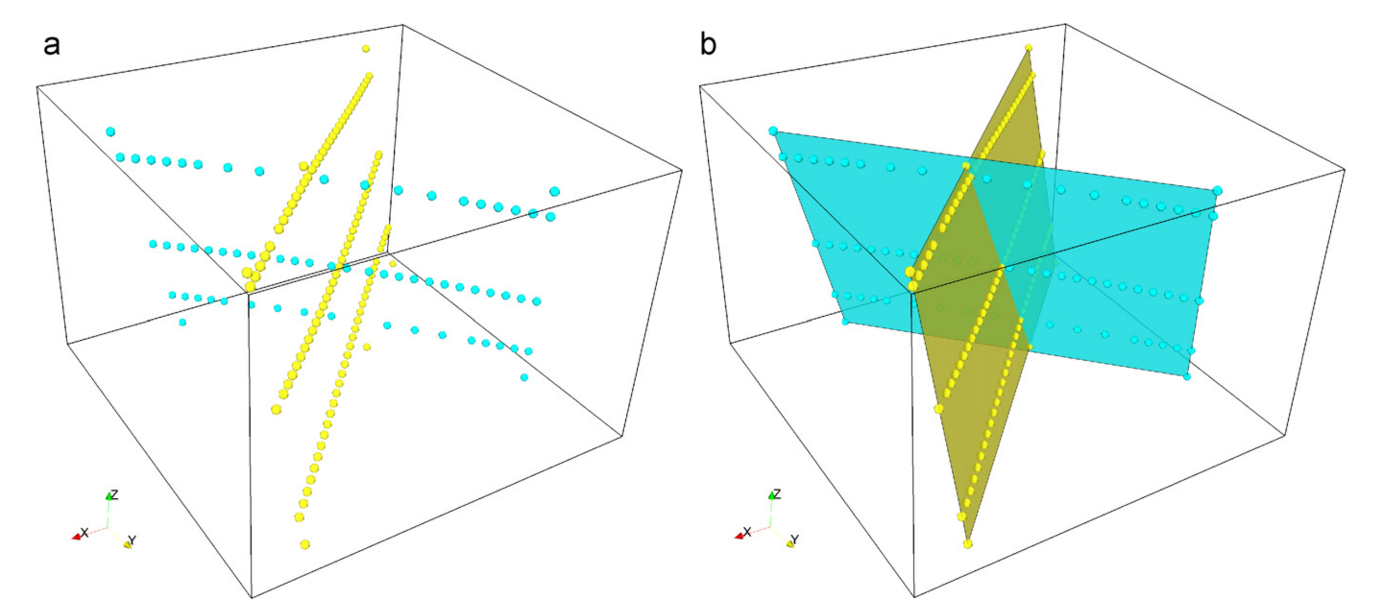

Fig. 2. Workflow of finite element mesh generation: scattered data points describing the faults geometry (a) and final convex hull of the outer fault polygons (b).