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Discrete element modeling of the faulting in the sedimentary cover above an active salt diapir

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ABSTRACT

Geological mapping, seismic analyses, and analogue experiments show that active salt diapirism results in significant faulting in the overburden strata. Faults associated with active diapirism generally develop over the crest of the dome and form a radial pattern. In this study, we have created a 3-D discrete element model and used this model to investigate the fault system over active diapirs. The model reproduces some common features observed in physical experiments and natural examples. The discrete element results show that most faults initiate near the model surface and have displacement decreasing downward. In addition, model results indicate that the earliest fault, working as the master fault, has a strong influence on the subsequent fault pattern. The footwall of the master fault is mainly deformed by arc-parallel stretching and develops a subradial fault pattern, whereas the hanging wall is deformed by both arc-parallel stretching and gliding along the master fault and top of salt, and hence develops both parallel and oblique faults. Model results replicate the fault pattern and deformation mechanism of the Reitbrook dome, Germany.

1. Introduction

An active diapir forcefully intrudes its overburden, driven by diapir pressure that overcomes the resistance of the overburden strength (Schultz-Ela et al., 1993). Active diapirs are generally circular or elliptical in map view. Most sedimentary rocks above active diapirs are heavily deformed by faulting and folding (Withjack and Scheiner, 1982; Schultz-Ela et al., 1993; Davison et al., 2000a, 2000b; Yin and Groshong, 2006, 2007). Although the geometries of faults associated with active salt diapirs are highly complex, they share several characteristic features. The faults associated with active salt doming are normal and commonly form a radial pattern in the map view.

Although investigations by geologists have illustrated the common features of faults associated with active salt diapirs, our understanding of the fault development is far from complete. The fault patterns in the brittle cover over active domes are typically complex because of the strongly 3-D nature of the deformation around the circular to elliptical structures. Surface exposures are rare, and our knowledge of active salt domes is obtained primarily from physical experiments, numerical modeling, and subsurface data. Most physical experiments are observed in cross section. While structural styles observed in the map view (e.g., Parker and McDowell, 1951; Withjack and Scheiner, 1982; Alsop, 1996; Yamada et al., 2005) or cross section (Cloos, 1955; Currie, 1956; Brewer and Groshong, 1993; Schultz-Ela et al., 1993) have significantly expanded our knowledge of the fault patterns of active salt domes, this 2-D technique has limitations when applied to define the 3-D fault patterns. In the absence of satisfactory understanding of 3-D fault patterns, interpretations based on well logs and seismic data are challenging because the strata are heavily faulted, making the correlation of fault very difficult. Numerical modeling is another approach to investigate active salt diapirism. Several investigators have used a finite element method to investigate active diapirism (e.g., Daudre and Cloetingh, 1994; Mazariegos et al., 1996). However, this continuum technique was mainly used to study the mechanism of active intrusion, and rarely to investigate the 3-D structural patterns of the faults over the intrusion.

To better understand the 3-D structural pattern and evolution of faults over active salt diapir, we have created a 3-D discrete element model. The discrete element technique (Cundall and Strack, 1979; Mora and Place, 1993, 1994; Place et al., 2002) is based on molecular dynamics, well established in the fields of physics and fluid dynamics. Unlike continuum techniques, this method permits large relative motion inside the model and simulates its evolution dynamically. It is a technique well suited to investigate heavily faulted structures. In recent years, investigators have used this technique to study a number of geological and

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geophysical problems, such as the reactivation of basement faults (Saltzer and Pollard, 1992), compressional folding and orogenic evolution (Morgan, 1997; Morgan and McGovern, 2005; Burbridge and Braun, 2002; Vietor, 2003; Strayer et al., 2004), fault propagation folding (Finch et al., 2003; Hardy and Finch, 2006, 2007), and graben formation (Seyferth and Henk, 2003). In this study, we use the discrete element technique to investigate the deformation over active diapirs, particularly the initiation and evolution of the faults.

2. 3-D discrete element model

2.1. Method

The discrete element model used here is developed from the lattice solid model (Mora and Place,1993, 1994; Place et al., 2002). The model elements consist of a series of soft spheres which obey Newton's equations of motion. The elements interact in pairs as if connected by breakable elastic springs and undergo motion relative to one another. The behavior of the elements assumes that the particles interact through a "repulsive–attractive" force (Mora and Place, 1993) in which the force Fs is given as:

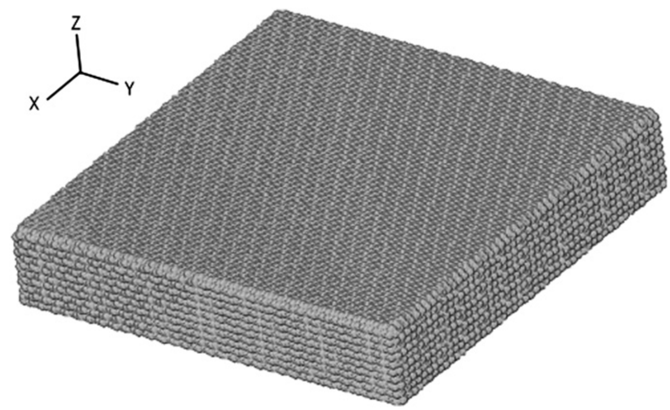

Fig. 1. Set-up of discrete element model. The discrete element model is composed of a regular hexagonal, homogenous lattice of 170,150 spheres with radius of one unit, represent the brittle sedimentary cover. The model is initially 170 units long, 170 units wide, and 30 units thick. Each unit represents 10 m.

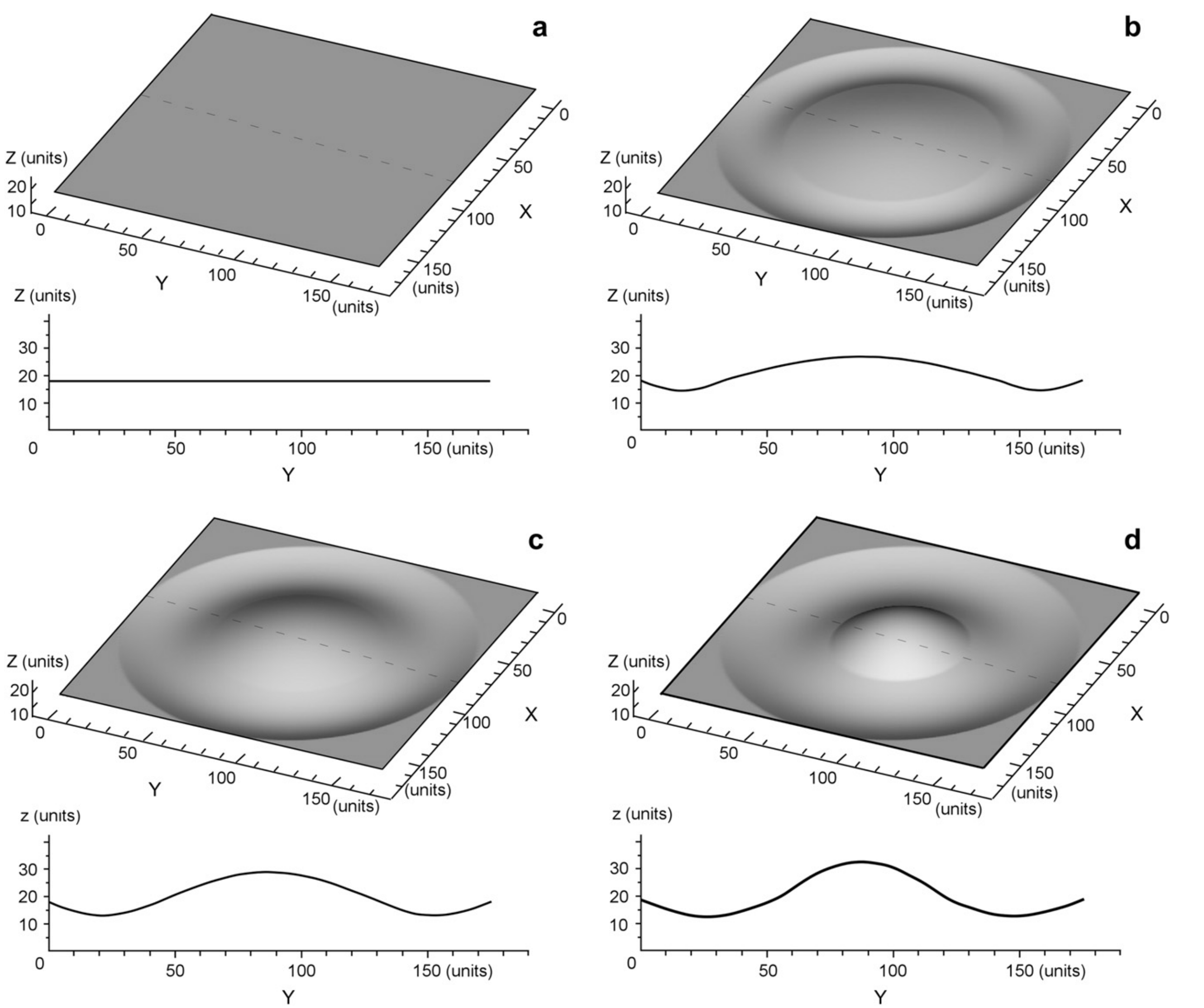

Fig. 2. The basal boundary of the model. (a) The horizontal basal boundary before deformation. (b) The basal boundary in the early stage of active doming. (c) The basal boundary in the middle stage of active doming. (d) The basal boundary in the late stage of active doming. The dashed line on the map shows the location of the cross section.