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Research paper

Experimental studies of the controls of the geometry and evolution of salt diapirs

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A R T I C L E   I N F O

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A B S T R A C T

Experimental models were conducted to study the controls of the evolution and geometry of salt diapirs, and the transition from passive to active diapirism. Both constant and variable sedimentation rate experiments were conducted. Constant sedimentation rate experiments show that the evolution of diapirs is strongly dependent on the rates of sand deposition and the thickness of the source layer. Low rates of sedimentation result in high ratios of salt flow to aggradation, leading to cylindrical diapirs which subsequently develop flared shapes with overhangs, whereas high sediment rates result in low ratios of salt flow to aggradation, resulting in tapered shapes and eventual eclipse and occlusion of the diapirs. Thick source layers result in higher salt flow rates than thin layers. Variable sedimentation rates result in changing shapes of diapirs over time. A small increase in sedimentation rates for flared or cylindrical diapirs result in an initial eclipse followed by tapering and a transition to active diapirism, enabling the diapir to pierce the overlying sediments. The narrower diapir continues to grow by passive diapirism. A large increase in rates results in a permanent eclipse, because the tapered diapir is unable to penetrate the greater thickness of the overburden. Finally, thicker source layers generally result in wider diapirs during both phases of deformation. Tapering and flaring are mechanisms of maintaining equilibrium between the rate of sedimentation and net salt flow rate. The resulting models are directly applicable to the analysis of poorly or partially imaged salt diapirs in natural subsurface examples.

1. Introduction

Salt diapirs form by three main mechanisms (Jackson et al., 1994; Hudec and Jackson, 2007), including (Fig. 1): (1) active diapirism, if the salt deforms, faults and eventually pierces the overlying sediments (Trusheim, 1960; Bishop, 1978; Nettleton, 1934; Schultz-Ela et al., 1993); (2) passive diapirsm, if the salt movement primarily conforms to the downbuilding of overlying sediments (Barton, 1933; Talbot, 1995), and (3) reactive diapirism, if the salt moves primarily in response to faulting induced by regional extension causing thinning and weakening of the overburden (Vendeville and Jackson, 1992a). Diapirs form by a combination of two or more of these mechanisms during different periods of their evolutionary history, with passive diapirism playing a major role in the evolution. The diapir evolution and geometry can also be influenced by ongoing extension and contraction.

Following studies by Seni and Jackson (1983) on the sedimentation and salt flow rates in the East Texas basin, Talbot (1995) examined the rates of sediment aggradation and salt rise on the shapes of passive diapirs. Koyi (1998) introduced the effects of regional extension into the model. Talbot (1995) proposed that the interface angle (α) between the sediments and the salt is dependent primarily on the rates of aggradation of sediments (Ra) and salt rise (Rs). On this basis, he classified the shapes of salt/sediment boundaries as tapering, cylindrical, and flaring (Fig. 2). The rate of aggradation (Ra) can be defined as the rate of increase in sediment thickness over unit time, incorporating the effects of sedimentation and erosion. The rate of salt movement (Rs) can be defined (see also Seni and Jackson, 1983) in two ways. The first is the net salt rise (Rsn), which can be defined as the vertical rise of the top of the salt over unit time. The second is the gross rate of salt rise (Rsg), which can be defined as the volume of salt moving through a unit area over time, or in the case of a cross section the area of salt moving through the unit length. The importance of this distinction will be apparent when we discuss the effects of tapering or flaring to attain an equilibrium in the net rates of salt rise and sedimentation.

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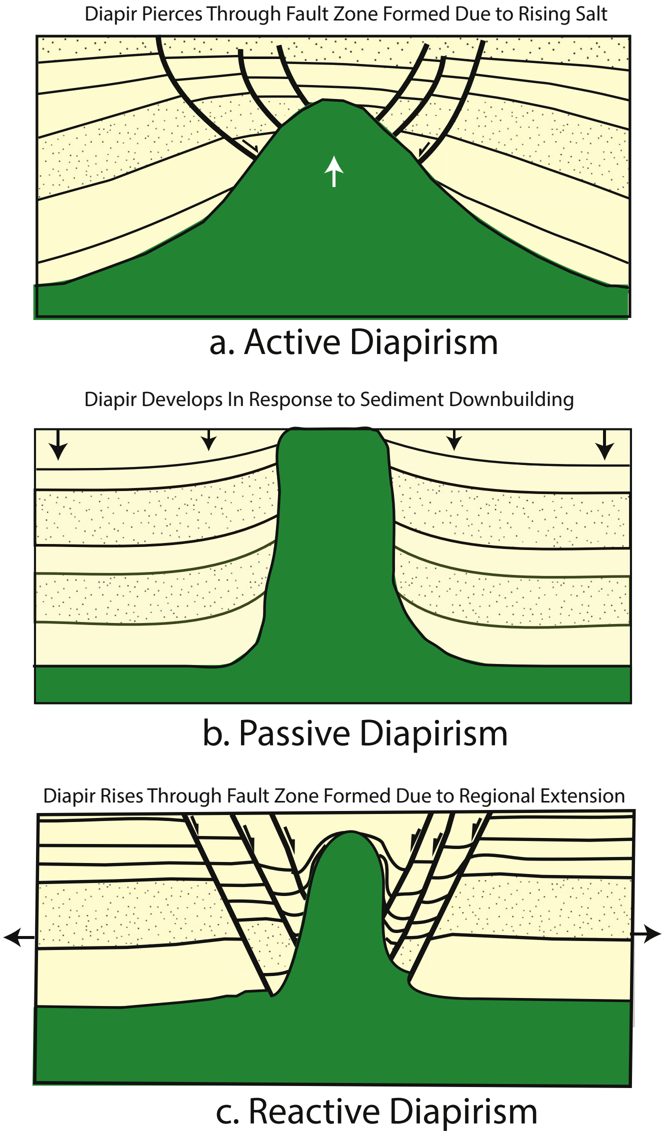

Fig. 1. Main mechanisms of diapir formation: (a) active diapirism, with the diapir piercing through faulted and fractured sediments above the rising salt; (b) passive diapirism, with the growth of the diapir due to sediment downbuilding (based on Barton, 1933); and (c) reactive diapirism, with the diapir rising through a fault zone formed by regional extension (modified from Vendeville and Jackson, 1992).

Although the average sedimentation rates can usually be determined in most basins, the rate of salt rise is dependent on the rate of aggradation (Ra) as well as some additional factors (Mitra and Karam, 2016), and is generally more difficult to estimate, especially when the net salt flow rate is not equal to the aggradation rate.

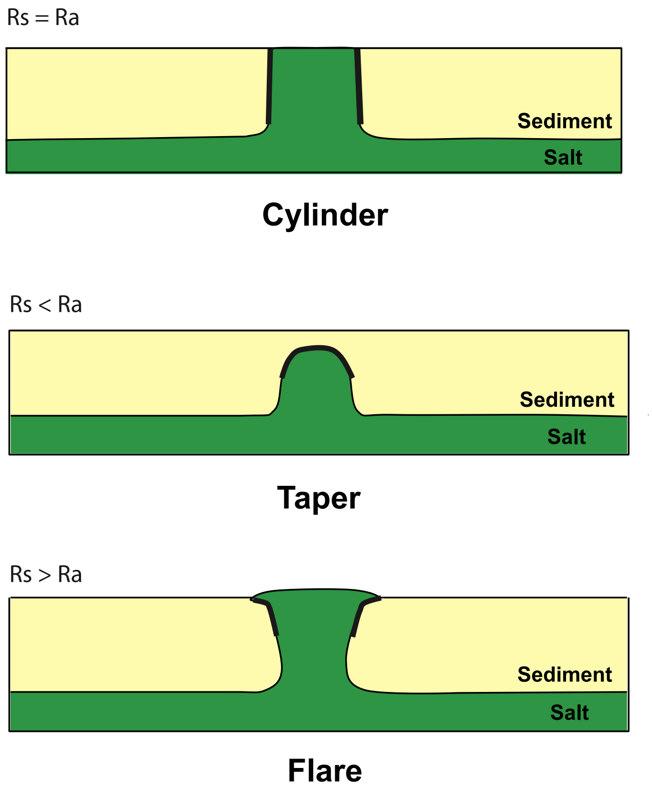

Fig. 2. Schematic figure showing the geometry of salt/sediment boundaries based on the relative rates of salt movement and sediment deposition (based on Talbot, 1995).

In this paper, we use a suite of physical models to study the controls of key parameters on the geometry and kinematics of diapirs formed by active and passive processes. We address the controls of the rate of salt rise by studying the effects of the following parameters: (1) thickness of sediment column, (2) sedimentation rate, (3) density of the sediments, and (4) thickness of the source layer. The experiments were conducted without any regional extension, so that they enable a study of the controlling factors that influence active and passive diapirism. Constant sedimentation rate experiments were used to study the influence of sedimentation rate, and column thickness and density on the two processes. Variable rates were used to study the transitions from active to passive diapirism and the resulting shapes of diapirs through different stages of their history.

2. Natural examples

Salt diapirs in all basins show a variety of shapes including simple tapers, cylinders and flares, as well as complex combinations of these main geometric types (Talbot, 1995). These variations reflect changes in the rates of gross salt flow, the most common cause for which may be variations in the rate of sedimentation. However, even within a single basin, where sedimentation rates are relatively constant, there can be significant changes in the diapir geometry.

As an example, we examine the diapirs in the East Texas salt basin, which has been a prolific producer of hydrocarbons from salt-related structural traps. The East Texas basin, which was connected to the Gulf of Mexico in the early stages of its evolution, contains a maximum thickness of about 500 feet of Jurassic Louann salt. Following the deposition of carbonates and evaporites in the Jurassic and Cretaceous, the basin was dominated by clastic deposition, which reached a thickness of about 20,000 feet in the center of the basin. The formation of the diapirs was driven primarily by gravitational (halokinetic), rather than tectonic processes (Seni and Jackson, 1983).

The shapes of the diapirs have been studied in detail based on seismic and well data (Wood and Giles, 1982; Jackson and Seni, 1984; Turner, 1993). The diapir shapes range from pillows (Hawkins and Van), to cylindrical walls (Grand Saline), to mushroom-shaped diapirs with cylindrical feeders and capped by flared domes with flat tops (Haynseville, Oakwood, and Bethel domes) or tapered tops (Butler, Palestine, and Steen domes).