

Extensional Tectonics and Salt Structures, Marib-Shabwa Basin, Yemen*

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Abstract

The purpose of this study was to decipher the combined effect of extensional tectonics and halokinesis on formation of structural features in the Marib-Shabwa basin of Yemen. Based on seismic interpretations, a close relationship has been found between the tectonic position in half-grabens and full-grabens and the developed salt structures in these subbasins. The hinge margin and hanging wall of half-grabens are characterized by *salt rollers* and *salt pillow* zones. Diapir zones, *tilted basinward* by uplift, dominate the footwall sides. Elongated diapirs formed in the axial zone of full-grabens that display *changing structural character along strike*: they are reverse fault-bounded at their middle portions in response to local contractional effects in the overburden; whereas toward their ends, the diapirs become normal fault-flanked indicating local extensional stresses. Accommodation zones among small-scale half-grabens are associated with normal-faulted *asymmetric* or non-faulted *symmetric diapirs*.

Regional Geology

The geological evolution of Yemen was driven by the plate motions that broke Pangea apart in the Mesozoic and formed the Gulf of Aden, Red Sea, and the Arabian Peninsula in the Cenozoic. The stratigraphy and regional geology of Yemen was established by detailed work of Beydoun (1964), Powers et al. (1966), Beydoun and Greenwood (1968), Hughes and Clarke (1988), Beydoun (1989), Haitham and Nani (1990), Paul (1990), Hughes and Beydoun (1992), Bott et al. (1992), Schlumberger (1992), and Beydoun et al. (1993). Hydrocarbon exploration activity became extensive after 1990 and provided considerable amount of subsurface data, which allowed revised synthesis of basin evolution in Yemen, such as the work of Redfern and Jones (1995), Ellis et al. (1996) and Beydoun et al. (1996). The petroleum geology was summarized in Csato et al. (2001).

Two major tectonic periods occurred that formed the tectonic evolution of Yemen. The first events took place in the Late Jurassic – Early Cretaceous, when three rift basins developed within Gondwana land: the Marib-Shabwa, the Sir-Sayun, and the Jeza-Qamar basin (Figure 1). The second major tectonic activity in the Cenozoic was related to the opening of the Gulf of Aden and the Red Sea and the collision of the Arabian Peninsula with Eurasia, respectively. The Mesozoic rifting and sedimentary basin evolution is well

constrained (e.g., Redfern and Jones, 1995; Beydoun et al., 1996), while the complex, polyphase tectonics in the Tertiary (Ellis et al., 1996) is much less understood.

At the end of the syn-rift phase, the Marib-Shabwa basin became isolated from the sea maintaining a periodically opened marine passage, which supplied saline water into the basin. The geographic separation and the warm climate gave rise to massive evaporation. The deposited salt (Sabatayn Formation) produced various halokinetic features during the Cretaceous and Cenozoic that has been the subject of this study.

Basin Tectonics

The study area is a sub-basin of the Marib-Shabwa rift in Yemen (Figure 1). The basin can be divided into two main segments: a southward sloping *Half-Graben* and a north-south-oriented *Full-Graben* segment (Figure 2). The full-graben is composed of smaller scale features: half-grabens 1, -2, and -3; tectonic accommodation zones between them; and a full-graben along the southern border fault.

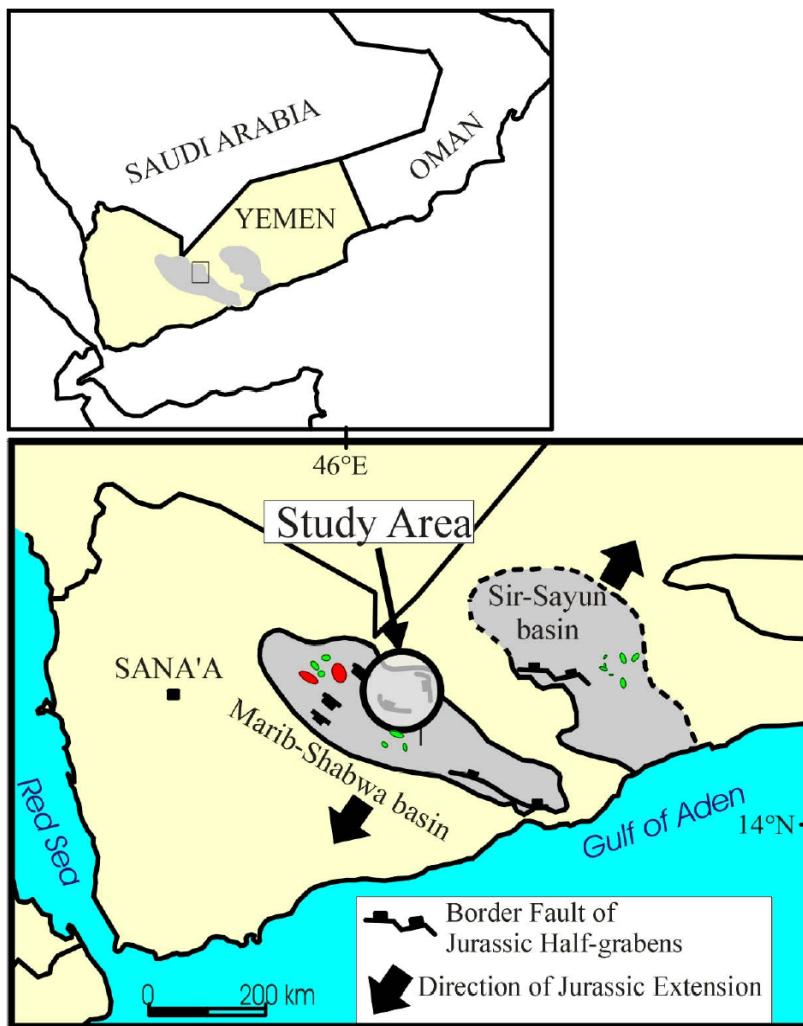


Figure 1. Location map of the study area.

The Paleogene brought about a major tectonic reactivation in association with the opening of the Gulf of Aden. Former Jurassic faults were rejuvenated, and eventually new tectonic elements formed. The extensional field slightly rotated anti-clockwise according to our observations, which is in correspondence with the orientation of half-grabens observed by Fantozzi (1996). Following the Paleogene events, intense volcanism occurred in the Miocene associated with renewed extensions of changing orientation in a clockwise direction (Huchon et al., 1991; Davison et al., 1994; Thouché et al., 1997). Later the entire area underwent a regional emergence with considerable erosion during the Neogene (Davison et al., 1994).

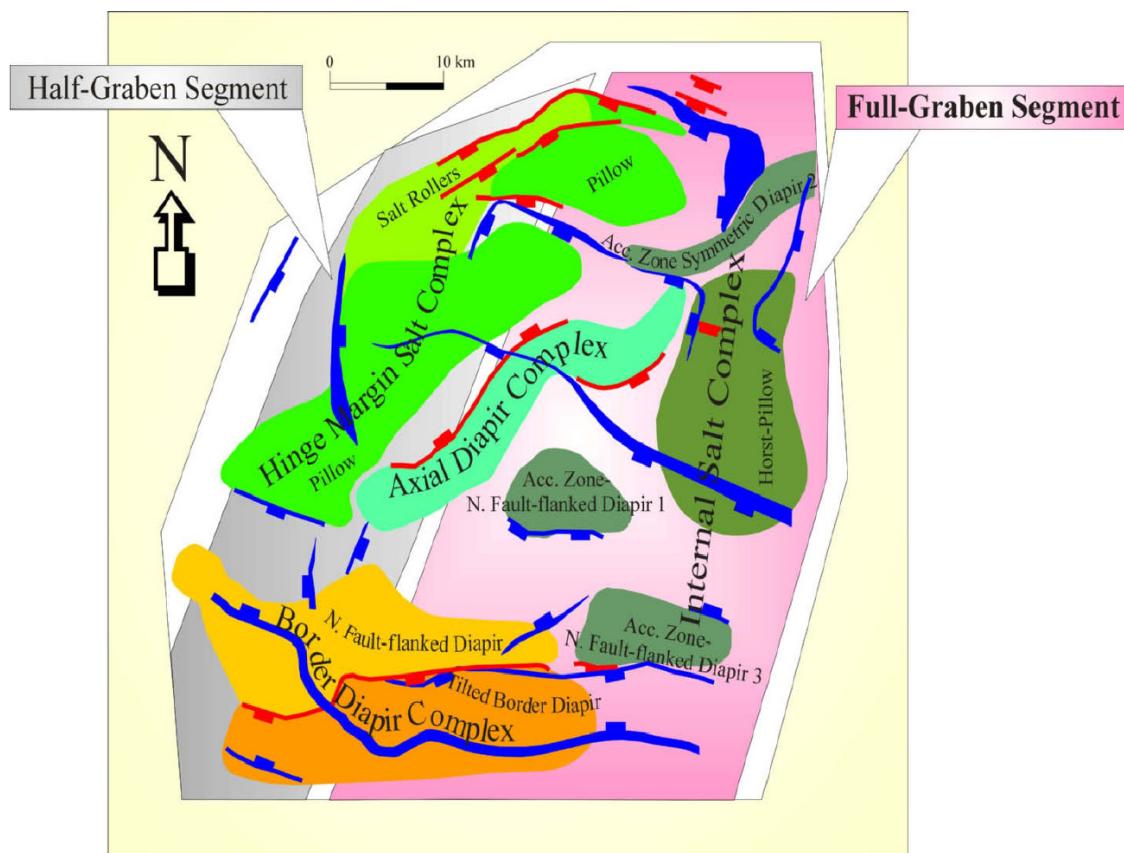


Figure 2. Salt structure map.

The Marib Basin was isolated from the sea in Tithonian time, and the continental rift became an evaporating environment. The salt precipitation occurred at the beginning of post-rift phase following Jurassic rifting. Differential loading of the overburden and some fault activity initiated salt mobilization and formation of initial pillows in the Early Cretaceous. Diapiric growth was maintained by passive *downbuilding* through the Cretaceous. Intense Paleogene faulting induced *reactive diapirism* that in places evolved into *active growth* (using the terminology of Vendeville and Jackson, 1992; Jackson and Vendeville, 1994 and Rowan, 1995).

Using subsurface data interpretations, this study has revealed a strong relationship between basin tectonics and salt dynamics. Special salt features are connected to tectonic positions in the Half-Graben and in the Full-Graben, respectively.

Salt Domains

Spatial zonation of salt structure domains is largely determined by basin tectonics. Mostly Tertiary tectonics induced salt diapirism; consequently, salt structures primarily evolved along Tertiary faults. Since the Paleogene tectonics developed by reactivation of Jurassic faults, the salt domains show close relationship with Jurassic basin structures as well.

The Half-Graben segment is divided into two main salt domains: the Hinge Margin Salt Complex and the Border Diapir Complex (Figures 2 and 3). The former domain covers the hinge margin and the hanging wall of the Half-Graben, while the Border Complex refers to connections with the southern border fault. *Salt Rollers Zone* associated with young growth faults and elongated *Salt Pillow Zone* on the hanging wall are distinguished; *Border Diapir Zone* tilted by footwall uplift and a *Normal Fault-Controlled Diapir Zone* surround the southern border fault.

The Border Diapir Complex is extended into the Full-Graben segment along a border-parallel, internal full-graben. The deepest portion of the main Full-Graben is occupied by an elongated diapir (Axial Diapir Complex), which shows varying structural characters along strike. In the middle, it is *Reverse-Fault-Bounded* in response to local contractional effects in the overburden. Southwestward and northeastward, the diapir becomes *Normal-Fault-Flanked*, indicating local extensional stresses. Similar change in diapir character was observed in the Border Complex. Tilted border diapirs transform into normal-fault-bounded diapirs along Tertiary border-subparallel faults. Accommodation or transfer zones among small-scale half-grabens are marked by normal or strike-slip faults and are associated with normal faulted *Asymmetric*, or non-faulted *Symmetric* diapirs. Internal horsts are covered by flat salt features: *Horst Pillows* (Figures 2 and 3).

Halokinetic History

The halokinetic history can be divided into two main stages: *Cretaceous passive growth and Paleogene reactive to active diapirism*. Seismic data provide evidence for early mobilization of salt after its deposition in the Early Cretaceous. Salt pillows formed first under the effect of differential loading and partly of local fault slip motion. During the rest of the Cretaceous, the pillows slowly grew in a passive way.

Diapiric growth was accelerated by the Paleogene tectonic activity. Faults weakened and broke the overburden, producing pathways for the moving salt. Additionally, fault tilting enhanced the differential loading. Once the overburden thinned by erosion due to diapiric arching, the salt broke its cover. Paleogene tectonics brought about characteristically reactive diapiric processes with subsequent active growth.

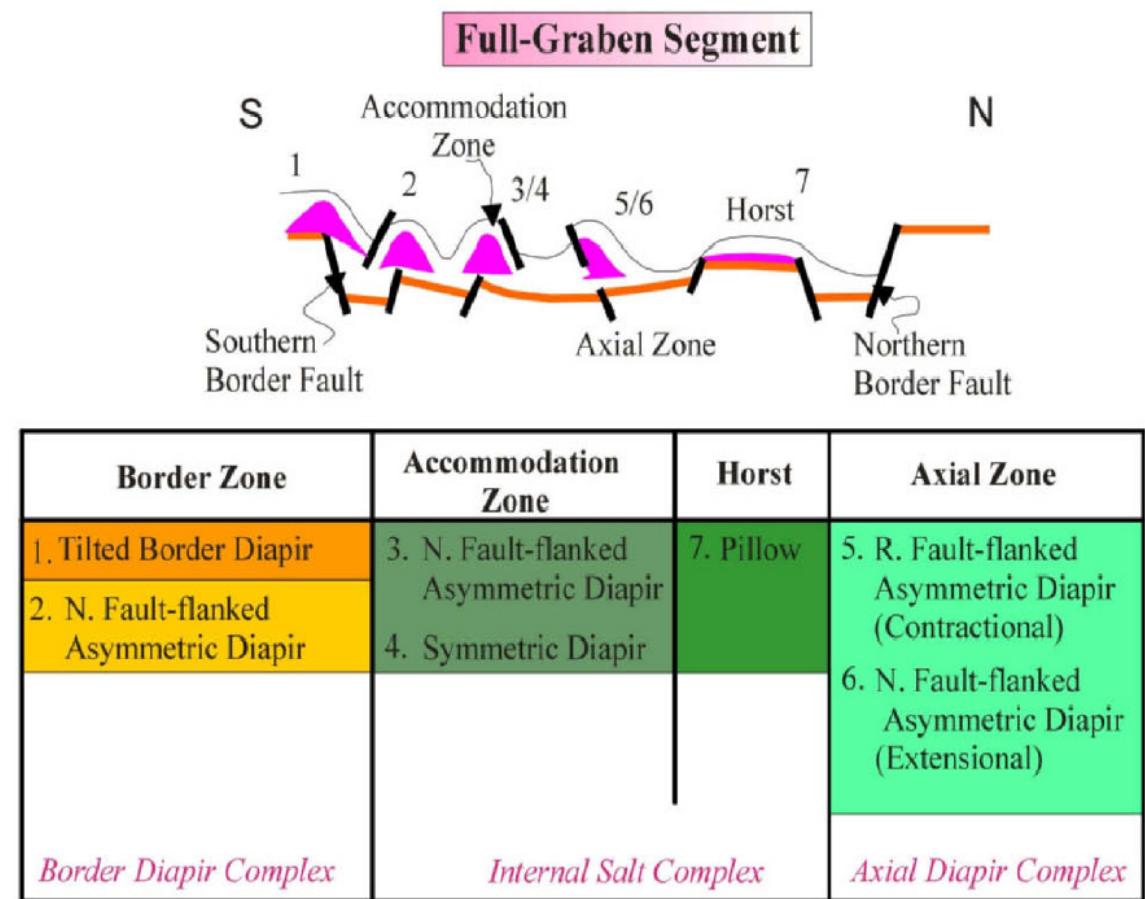
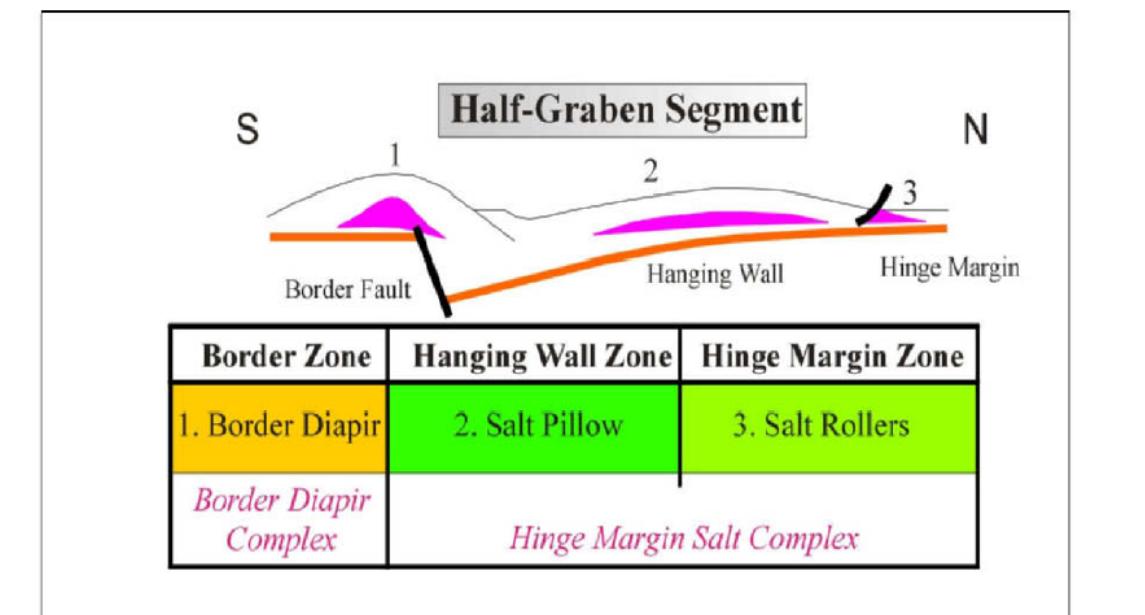


Figure 3. Tectonic positions of salt structures in the half-graben and full-graben.

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