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Structural, micro-structural and kinematic analyses of channel flow in the Karmostaj salt diapir in the Zagros foreland folded belt, Fars province, Iran

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ABSTRACT

One of the main characteristic of the Zagros foreland fold-and-thrust belt and the Zagros foreland folded belt are wide distributions of surface extrusion from the Hormuz salt diapirs. This study examines the structure and kinematic of channel flow in the Karmostaj salt diapir in the southwestern part of the Zagros foreland folded belt. This diapir has reached the surface as a result of the channel flow mechanism and has extruded in the southern limb of the Kuh-Gach anticline which is an asymmetric décollement fold with convergence to the south. Structural and microstructural studies and quantitative finite strain (R_s) and kinematic vorticity number (W_k) analyses were carried out within this salt diapir and its namakier. This was in order to investigate the structural evolution in the salt diapiric system, the characteristics and mechanism of the salt flow and the distribution of flow regimes within the salt diapir and interaction of regional tectonics and salt diaprism. The extruded salt has developed a flow foliation sub-parallel to the remnant bedding recorded by different colors, a variety of internal folds including symmetrical and asymmetrical folds and interference fold patterns, shear zones, and boudins. These structures were used to analyze mechanisms and history of diapiric flow and extrusion. The micro-structures, reveal various deformation mechanisms in various parts of salt diapir. The measurements of finite strain show that R_s values in the margin of salt diapir are higher than within its namakier which is consistent with the results of structural studies. Mean kinematic vorticity number (W_m) measured in steady state deformation of diapir and namakier is $W_m = 0.45–0.48 \pm 0.13$. The estimated mean finite deformation (W_m) values indicate that 67.8% pure shear and 32.2% simple shear deformation were involved; the implications of which are discussed. The vorticity of flow indicates that in the early stage of growth, Poiseuille flow was the dominate mechanism, especially in the core of diapir with higher pure shear component relative to simple shear component, whilst a Couette flow at the margins of diapir is the dominate mechanism with higher simple shear component relative to pure shear component. The obtained kinematic vorticity number reflects spatial partitioning of dominantly Poiseuille flow in core and Couette flow along edges of diapir. These two mechanisms reflect a persistent flow governed by a simultaneous combination of pure shear and simple shear in a hybrid Poiseuille-Coutte Flow.

1. Introduction

The Zagros foreland folded belt and the Zagros foreland fold-and-thrust belt are one of the world's largest salt province with well exposed salt diapirs and unknown numbers of salt structures that do not pierce the strata as salt diapirs and namakiers. This belt also includes almost two-thirds of the world's proven oil reserves and one-third of its gas reserves (Beydoun, 1991; Beydoun et al., 1992). These hydrocarbon reservoirs occur in various structural traps that are mostly related to the salt structures. The salt diapirs are sourced from a thick sequence of deeply buried Infra-Cambrian evaporates as known as the Hormuz series (Husseini and Husseini, 1990; Smith, 2012; Thomas et al., 2015).

Salt's flow rheology, mechanics and incompressibility, cause its inherent instability under a wide range of geologic conditions. Its rheology and mechanical properties makes it a very sensitive strain gauge and its tectonics which is usually related to the regional deformation in low temperature (Hudec and Jackson, 2007). When the salt begins to rise from its source layer, it takes different deformation paths and travels through various finite strain regimes until it reaches the surface where a diapiric dome spreads downslope as a namakier. The numerical modelling of two-dimensional finite deformation in composite rheology indicate that progressive strain in three different deformation regimes within the “salt” material shows: (I) a squeezed that-flow deformation regime and (II) a corner-flow deformation

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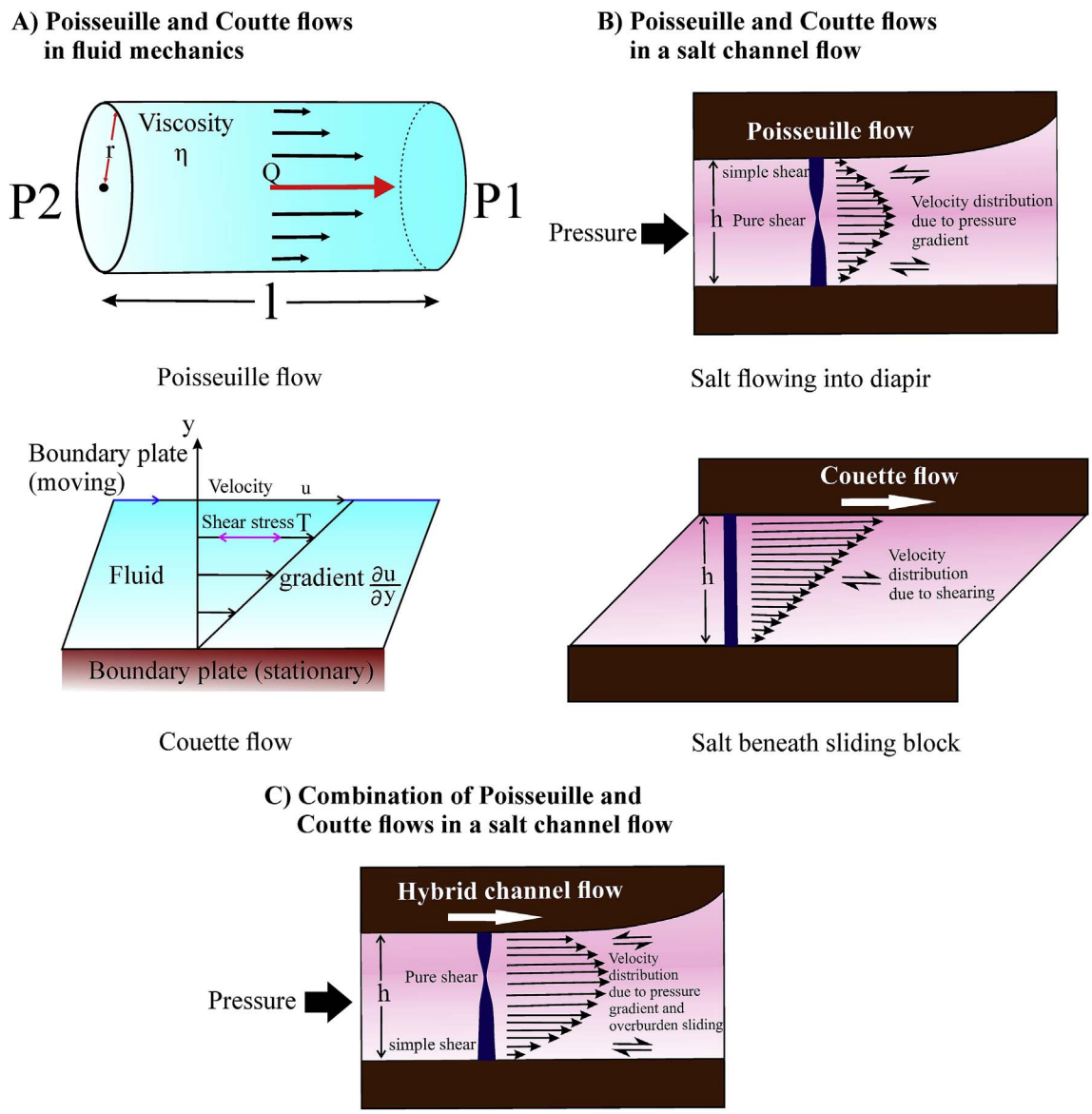

Fig. 1. A) The concept of two types of flow, Poiseuille (up) and Couette (down) flows, in fluid dynamics, Poiseuille law is a physical law that explains the pressure drop in an incompressible and Newtonian fluid in laminar flow flowing through a long cylindrical pipe of constant cross section. Couette flow is the flow of a viscous fluid in the space between two surfaces, one of which is moving tangentially relative to the other (Modified after Sutera and Skalak, 1993; Heller, 1960). B) Schematic diagram of end-members of flow in a salt channel flow of width h. Poiseuille flow with velocity profile caused by pressure gradient within the salt flowing into diapir (up), and Couette flow with velocity profile caused by shearing within the salt layer beneath sliding block (down). The width of the dark bar indicates schematically the vorticity values (Modified after Godin et al., 2006). C) Combination of Poiseuille flow and Couette flow.

regime within the source layer, and (III) a pure channel-flow deformation regime within the stem (Fuchs et al., 2015). Salt glaciers or namakiers (Talbot and Jarvis, 1984) are extrusive sheets of halite that have flowed downslope over the surface (Lees, 1927, 1931; Harrison, 1931; Gussow, 1968; O'Brien, 1957; Gera, 1972; Kent, 1958, 1970). In the many namakiers, bedrock obstruction causes the deformation zones including folds and slides (Talbot, 1979, 1981; Talbot and Jackson, 1987; Talbot and Pohjola, 2009).

InSAR analysis allows precise rates of current salt extrusion to be determined. Aftabi et al. (2010) on based on InSAR analysis suggested that the deformation of the Hormoz salt surface is non-steady, with rates of displacement varying between surficial uplifts of +1.4 mm day^{-1} and subsidence of −2.2 mm day^{-1}. They demonstrated that growth of the central dome occurs during short wet intervals to create a salt fountain morphology and then slowly decays during the long dry periods.

Some of the deformation mechanisms of salt include: i) Cataclastic flow which is important at low temperatures and confining pressures, involves micro fracturing and sliding of grain and grain fragments (Barr, 1977); ii) Crystal plastic process include kinking of the halite lattice and various combinations of slip rotation, glide or climb of dislocations through the grains which called dislocation creep and occurs at temperatures and pressures related to natural deformation at salt (Carter et al., 1982) and iii) Solution-transfer creep (Pressure solution) that is an important deformation mechanism in salt rock (Rutter, 1976; Ramsay, 1980) in which the mineral dissolves at grain contacts under high normal stress through a thin film of interstitial fluid because of the stress-induced chemical potential gradients and recrystallization at grain boundaries under low normal stress (Durney, 1972; McClay, 1977; Rutter, 1983; Urai et al., 1986) and iv) Recrystallization that is a reorganization of material with a change in grain size, shape and orientation within the same mineral (Poirier and Guillopé, 1979; Urai et al., 1986; Hirth and Tullis, 1992).

The internal structures of salt diapirs represent evidence of their