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Geodynamic evolution of the Salinas de Añana diapir in the Basque-Cantabrian Basin, Western Pyrenees

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ABSTRACT

The Salinas de Añana diapir is located in the Basque-Cantabrian basin part of the great evaporite basin, along with the Gulf of Mexico and the Central European basin, when the fragmentation of Pangea started. The evolution of these basins can only be achieved by understanding the control of salt in the sedimentary and tectonic evolution of these basins.

Sedimentation began with clastic Buntsandstein sediments and minor Muschelkalk limestones. Subsequent Keuper evaporites are the bottom of sedimentary cover constituted by Jurassic limestones and marls, a clastic Lower Cretaceous and an alternant limestone and marl Upper Cretaceous, whose deposition has been conditioned by salt tectonics. The emplacement of salt extends from the Aptian until now, favored by the duplication of the salt thickness associated with the thrust of Sierra Cantabria, so it is an excellent example to study changes in the regime of intrusion along the time. The geodynamic evolution of the Salinas de Añana diapir was determined through the interpretation of 45 reprocessed seismic lines, along with information from three wells. Migration of the salt in this diapir, conditioned by N120E and N30E pre-Alpine basement lineations, was determined using time isopach maps of the various rock layers. Vertical evolution of the diapir was determined through the reconstruction of a north-south section at various geologic times by flattening the respective seismic horizons. A minimum of salt flow into the diapir coincides with a minimum rate of sedimentation during the Turonian. Similarly, maximum flows of salt into the diapir occurred during the Coniacian and Lower Santonian and again from the end of the Lower Miocene to the present, coinciding with maximum rates of sedimentation during these times. In the Tertiary, probably during the Oligocene, the diapir was displaced to the south by the Sierra Cantabria thrust, maintaining the contact between the evaporites of diapir and the same evaporites of the lower block. Since the Oligocene, the salts of the lower block migrated towards and into the diapir, deforming the trace of the overthrust.

1. Introduction

Salt diapirs consist of evaporitic masses rising through their overburden (Mrazec, 1907). The rise of salt diapir is related to gravitational forces acting on the relatively dense host rock that sink into the evaporitic material (Ramberg, 1981). Three basic modes of diapirism are accepted: active, passive and reactive (Jackson et al., 1994). Reactive diapirism corresponds to salt rising in response to regional tectonics whether extensional or compressive (Jackson et al., 1994; Vendeville and Jackson, 1992; Hudec et al., 2009). Active diapir growth corresponds to intrusion of salt through the overburden (Jackson and Talbot, 1994) associated with doming and faulting of the diapir roof. Active diapir growth occurs only if the diapir roof is thin enough (Jackson et al., 1994). Passive diapirism (Jackson et al., 1994), also called downbuilding (Barton, 1933), occurs when diapir growth is conditioned by the sedimentation. The shape of the diapir and the growth velocity are partially controlled by the balance between the rates of sediment accumulation and diapir growth (Vendeville and Jackson, 1992). Passive growth commonly occurs for diapirs with thin and poorly consolidated roofs, with syn-sedimentary deformation as slumps and gravity-driven deposits (Davison et al., 1996). The balance between faulting and sedimentation may control diapir initiation. Low sedimentation rates, combined with extension,

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leads to progressive thinning of the diapir roof and can evolve towards active and then passive diapir growth (Ferrer et al., 2012; Poprawski et al., 2014). High sedimentation rates lead to diapir burial and normal fault growth (Vendeville and Jackson, 1992).

Diapirs could initiate early when the overburden is thin and unconsolidated and loading of sediments create an increased pressure that cause salt movement. Tectonics thinning the overburden could also trigger diapir growth (Jackson et al., 1994). Extension is the most effective process to trigger reactive diapirism (Jackson and Talbot, 1994), which leads then to a subsequently stage of active diapirism that allows the diapir to evolve to passive diapirism or downbuilding (Barton, 1933; Vendeville and Jackson, 1992). This involves the lateral propagation of salt into the growing diapir, pushed by overload sediments around it. The velocity of emplacement of the diapir is determined by the velocity of extension and the rates of the synkinematic sedimentation (Jackson et al., 1994). This causes the encasing material close to the diapir to sink to occupy the space left by the ascending salt, which can generate secondary diapirs (Warsitzka et al., 2012). The ascending process will depend on the availability of sufficient salt to maintain the growth of the diapir. If the rate of salt flow is superior to the sinking of the host rocks, the evaporites may be able to reach the surface and form salt glaciers (Talbot and Pohjola, 2009). On the other hand, if the diapir growth velocity is inferior to the sediments accumulation, the diapir shrinks (Giles and Lawton, 2002), arriving to the point where it can become buried below the covering sediments.

Several hypotheses have been made concerning the initiation of a diapiric process (Hudec and Jackson, 2007). Some authors call on instabilities due to buoyancy, tectonic forces, basal sliding or differential loading (Ge et al., 1997). Other authors deduct that, if there is enough salt thickness, with overburden thickness less than 1000 m, whatever perturbation can initiate salt movement (Warsitzka et al., 2012). In analog models, a gradient due to a change of slope or a difference in sediment cover is necessary (Hudec and Jackson, 2007).

The Basque-Cantabrian basin, in which the Salinas de Añana diapir is located, along with the Gulf of Mexico and the Central European basin (Mohr et al., 2005), were part of a major evaporite basin when the fragmentation of Pangea began to form the central protoatlantic, and salt behavior largely determined the sedimentary and tectonic evolution of these areas. In the Basque-Cantabrian basin, as in others related to rifting stages (Central European basin, Mohr et al., 2005; Gulf of Mexico or south Atlantic, Brun and Fort, 2011), sedimentation began with clastic Buntsandstein sediments and minor Muschelkalk limestones. Subsequent Keuper evaporites are overlain by, Jurassic limestones and marls, a Lower Cretaceous clastic section and an alternate marl and limestone Upper Cretaceous, whose deposition had been conditioned by the salt tectonics (Poprawski et al., 2014; Bodego and Aguirrezabala, 2014)

The Salinas de Añana diapir, formed by Triassic evaporites, is located in the Alava block, in the Basque-Cantabrian basin, western Pyrenees (Fig. 1). This diapir is ellipsoidal in shape, with its long axis striking E–W, is 5.5 km long and 3.5 km wide (Fig. 2). Its overburden consists of Tertiary continental deposits. At a regional scale, the Salinas de Añana diapir is aligned with the Murguía diapir along a N30E direction and with the Salinas de Rosio, Treviño (buried) and Peñacerrada diapirs, along a N120E direction. It has been studied by various authors over the past 60 years (Hempel, 1963; Pflug, 1967; Stackelberg, 1967; Olivé et al., 1979; Eguiluz and Llanos, 1988; EVE, 1989a, 1989b, 1989c, 1989d; Pinto et al., 2005; Frankovic, 2011). In the Basque Cantabrian basin, some diapirs have been related to the tectonic extension of the basin (Ferrer et al., 2008, 2012; Bodego and Aguirrezabala, 2014). Locally, halokinetic sequences have also been described in the overburden of the Bakio diapir. (Poprawski et al., 2014).

The aim of this paper is to establish the geometry of the Salinas de Añana diapir and to determine the source areas of the evaporites and their geodynamic evolution. Salt was available to the diapir during its entire history, first, starting in Albo-Aptian times, when the diapir started growing, and throughout the Cretaceous and early Paleogene, from the salt of the unit at its base and later, after the Pyrenean orogeny until the present, from the autochthonous salt below the Sierra Cantabria overthrust. The diapir has both a thin throat and ledges, in function of the different quantities of salt entering the diapir, which in turn is related to the local rate of sedimentation. Isopach maps were analyzed to determine, in part, the migration of salt. To complete the geodynamic evolution, vertical sections were restored via flattening of the interpreted seismic horizons.

2. Geological setting

The Basque Cantabrian basin is located at the western end of the Pyrenees (Fig. 1). The basin is bordered by the Landes high to the north, the Tertiary Ebro and Duero basins to the south, the Asturian massif to the west and the Pamplona Fault to the east. The geological succession is relatively simple (Robles, 2014). A Buntsandstein molasse was deposited, during a first rifting stage, over a Hercynian basement and behaves in unison with the basement. A thin section of Muschelkalk carbonates followed by red clays and gypsum evaporites of Keuper facies (Triassic) along with intrusive ophite masses completes the first stage. An inter-rift second stage corresponds to an extensive marine, mainly calcareous, Jurassic succession. The clastic Lower Cretaceous section consists of the Weald formation. The Aptian to Albian continental Utrillas and shallow-marine Valmaseda formations to the south and the shallow-water Urgonian limestones and marls to the north dominate this stage, coeval with the main extensional phase in the basin (Robles, 2014). An Upper Cretaceous marine limestones and marls sequence correspond to the last pre-orogenic stage (passive continental margin) (Robles, 2014). This sequence ends with a thin package of Paleocene limestone's (early compressional phase, Robles, 2014), over which Tertiary continental syn-orogenic rocks were deposited (Martínez-Torres, 1997).

Diapirism in the basin always involves the Triassic. Red clays and gypsum of Keuper facies crop out in several diapirs (Mena, Rosio, Orduña, Murguía, Salinas, Maestu, Estella, etc.). The greatest concentration of diapirs in the Basque-Cantabrian basin is in the Alava block and in the south border of the basin where it is thrust over the Tertiary Ebro basin by the Sierra Cantabria – Obarenes Mountains overthrust. This overthrust, which has emplaced the marine Meso-Cenozoic over the continental Tertiary deposits of the Ebro basin, accounts for a 15 km (minimum) shortening of the section (Martínez-Torres, 1993). Its roots constitute the subduction plane of Iberia below Eurasia plate (Martínez-Torres et al., 1994; Hernaiz and Solé, 2000; Pedreira et al., 2003). The entire Alava block, including the Salinas de Añana diapir, is affected by it. In the study area, the trace of the Sierra Cantabria overthrust is not directly detectable, as it is somewhere within, probably at the top of, the evaporites of the Keuper.

The diapirs in the Basque Cantabrian basin are located at the intersections of two families of lineations at N120E and N30E (Fig. 1), which correspond to pre-alpine Variscan basement fracture system (Rat, 1988) that have controlled the paleogeography (Wiedmann, 1979; García-Mondéjar et al., 1996; Robles, 2014). The diapirs of Villasana de Mena, Orduña, Murgia, Maestu and Estella to the north and the diapirs of Salinas de Rosio, Salinas de Añana, Treviño (buried) and Peñacerrada to the south are aligned along N120E faults. Several diapirs are also aligned along N30E striking