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Multi-phase inversion tectonics related to the Hendijan–Nowrooz–Khafji Fault activity, Zagros Mountains, SW Iran

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ABSTRACT

Distinctive characteristics of inverted structures make them important criteria for the identification of certain structural styles of folded belts. The interpretation of 3D seismic reflection and well data sheds new light on the structural evolution and age of inverted structures associated to the Hendijan–Nowrooz–Khafji Fault within the Persian Gulf Basin and northeastern margin of Afro-Arabian plate. Analysis of thickness variations of growth strata using "T-Z plot" (thickness versus throw plot) method revealed the kinematics of the fault. Obtained results show that the fault has experienced a multi-phase evolutionary history over six different extension and compression deformation events (i.e. positive and negative inversion) between 252.2 and 11.62 Ma. This cyclic activity of the growth fault was resulted from alteration of sedimentary processes during continuous fault slip. The structural development of the study area both during positive and negative inversion geometry styles was ultimately controlled by the relative motion between the Afro-Arabian and Central-Iranian plates.

1. Introduction

Inversion tectonics was introduced by several authors (e.g. Glennie and Boegner, 1981; Cooper and Williams, 1989) to describe changes of tectonic regime from extension to compression, and vice versa. After introducing different type of inverted structures (i.e. positive and negative types) by Williams et al. (1989), several examples of these structures were recognized and described worldwide (e.g. Biji, 2006 and references cited therein). Positive and negative inverted structures are created in response to change of tectonic regime following the contractional reactivation of inherited normal faults or extensional reactivation of inherited reverse faults, respectively (Fig. 1). Distinctive characteristics of inversion-related structural geometries consist of anomalous variations of fault-throw with depth, thicker strata on the hanging wall of thrusts faults and footwall shortcut thrusts (Cooper and Williams, 1989). The recognition of inverted structures is important in the oil industry because inversion can: a) modify the burial history of a sedimentary basin, b) uplift sediments above sea level generating secondary porosity, c) modify the attitude of the sedimentary package, allowing different directions of fluid migration with time, d)reactivate older faults, changing their sealing properties and e) form complex structures at depth and care needs to be taken to differentiate these from single event compressive thin-skinned thrust structures (Coward, 1994).

Constraining reactivation processes has practical implications for improving the evaluation of seismic hazards (Lisle and Srivastava, 2004) and assessing the impact of reactivation on fault seal quality and fluid migration (Holdsworth et al., 1997). The main gaol of this study is to describe and quantify the style of inversion tectonics adjacent to the Hendijan–Nowrooz–Khafji Fault from the Persian Gulf Basin and northeastern margin of the Afro-Arabian plate (Fig. 2). Due to the occurrence of large oil and gas resources of Iran and Saudi Arabia (Fig. 3) in the vicinity of this fault, it has tremendous geological and industrial importance. The Hendijan high and the Burgan–Azadegan high with NE–SW and N–S trends are the most prominent structural features in the Persian Gulf Basin. The Hendijan and Burgan–Azadegan high are structural trends were named based on elongated topographical feature in north part of Persian Gulf (the geological map of National Iranian Oil Company in SW Iran at scale 1:10,00,000). The Hendijan high in SW Iran hosts several Iranian and Saudi Arabian oil fields (Abdollahie

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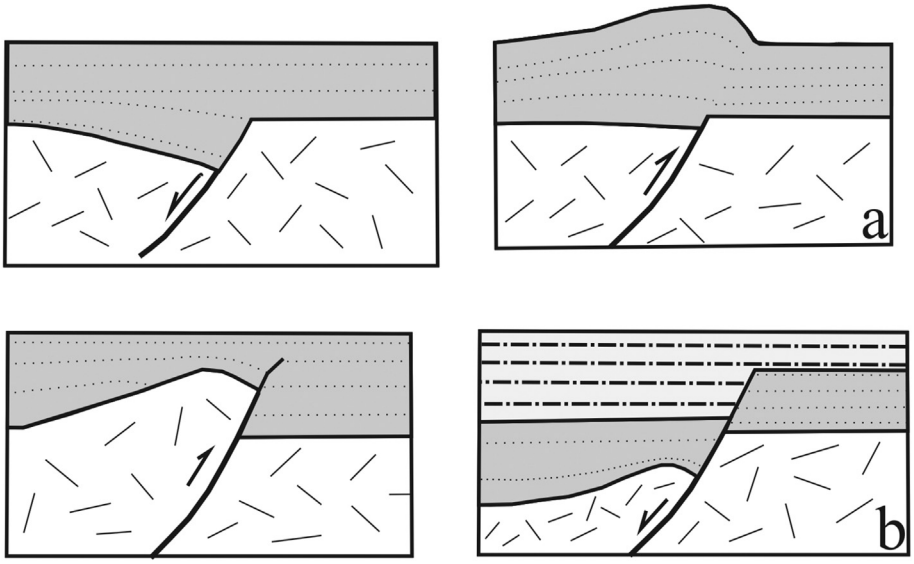

Fig. 1. Two Schematic diagrams of a classical inversion structure, interaction between pre-tectonic, syn-tectonic and post-tectonic is important. (a) The early normal fault is reactivated as reverse (positive inversion structure). (b) The early reverse fault is reactivated as normal (negative inversion structure).

Fard et al., 2006). The Hendijan Fault is one of the Important Lineaments that have Arabian tectonic trend and refer of a syncline structure in Arabian plate (Bahroudi and Talbot, 2003). These structures extend to the N within the Zagros Mountains (Fig. 2). Hence, we discuss the kinematic evolution of the Hendijan Fault based on the quantitative interpretation of 3D seismic reflection and well data. In this paper, we present new tectono-sedimentary data based on the geological interpretation of seismic sections to support the occurrence of a multi-phase inversion tectonics related to the Hendijan–Nowrooz––Khafji Fault activity within the Zagros Mountains, SW Iran. Based on the interpretation of growth strata and seismic stratigraphy, this paper describes the geometry styles of inverted structures and reliably approximates the age of the beginning of the positive and negative inversions in the Persian Gulf Basin.

2. Geological and tectonic settings

The Zagros Mountains is one of the most active collisional orogens within the Alpine–Himalayan orogenic belt. Closure of the Neotethys Ocean which resulted from oblique convergence between the Afro-Arabian plate and Central Iranian plate during the Cenozoic led to formation of this belt (Mouthereau et al., 2012 and references cited therein). Both the Zagros Range and its foreland belong to the northeastern part of the Afro-Arabian Plate. The Persian Gulf Basin, a rich region of hydrocarbon resources, is a part of this lithospheric plate. This basin is surrounded by the Arabian Shield in the west, Taurus range in the north and the Zagros range in the east and northeast. The regional geology of the Persian Gulf Basin has been described and analyzed in detail because of the high hydrocarbon potential of this region (e.g. Stern, 1985; Beydoun, 1991; Edgell, 1996; Alsharhan and Nairn, 1997; Bahroudi and Talbot, 2003). The Persian Gulf Basin was the site of ancient passive margin sedimentation on the margin of Gondwana during most of the Phanerozoic, which faced toward the Neotethys in the Mesozoic and toward the Paleotethys Ocean in the Paleozoic (Alavi, 1994; Bahroudi and Talbot, 2003; Abdollahie Fard et al., 2006). Main faults and folds in the northeast margin of Afro-Arabian plate have different trends such as N–S, NNW–SSE or NNE–SSW (Abdollahie Fard et al., 2006). North–south-trending faults within the Arabian basement have been repeatedly reactivated during the Permo-Triassic opening of the Neo-Tethys and have exerted a strong control over the structure, thickness and facies of the cover rocks (Zeigler, 2001). In the foreland part of the Zagros, north–south trends are attributed to the reactivation of Pan-African basement faults (Edgell, 1991, 1996) during the Permo-Triassic (Alsharhan and Nairn, 1997) till Late Cretaceous (Abdollahie Fard et al., 2006 and references cited therein). The ductile deep seated Precambrian Hormuz salt series, basement rocks movement and the late Tertiary Zagros orogeny, are main factors that have influenced the formation of the structural anomalies in the Persian Gulf (Saadatinejad et al., 2012). The study area is located in the Persian Gulf Basin along the northeastern margin of the Afro-Arabian plate adjacent to the Hendijan–Nowrooz–Khafji Fault. The names, lithologies and ages of the stratigraphic formations and groups used here (Fig. 4) are based on the classical stratigraphic chart for this region established by James and Wynd (1965), correspond to those employed by the National Iranian Oil Company in their regular exploration tasks synthesized in unpublished and confidential annual reports. The ages of the various stratigraphic units were established by determining foraminifera biozones and employing fossils such as sponge spicules, algae, echinoids, rudists, radiolarids, ostracods, gastropods, foraminifers, bryozoans, corals, stromatoporoids, crinoids, tintinnids, Favreina, annelids and palynomorphs collected in confidential exploration wells. The Hendijan–Nowrooz–Khafji Fault with few tens of kilometers is located in the southeastern-east part of Zagros range in Iran and the west of Persian Gulf (Fig. 1).

3. Methods

In active tectonic settings, growing structures often control the deposition process at different scales (Vergés et al., 2002). Growth fault activity led to change in the sediment thickness across the fault (i.e. synsedimentary fault). This event causes the differences in thickness of sediments both on the footwall and hanging wall during time of fault activity. Fault throws subsequent to the sedimentation of each horizon and the fault movement history can be determined using these thickness changes. Analysis of these thickness changes along a fault is now feasible using high quality