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An Investigation of Abnormal Fluid Pressure within an Evaporitic Cap Rock in the Gavbandi Area of Iran and its Impact on the Planning of Gas Exploration Wells

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Abstract

A synthesis of well logs was carried out and drilling mud weight data were analyzed to figure out anomalous high fluid pressure within the Triassic evaporitic cap rock (the Dashtak formation) and study its impact on the geometry of anticlinal traps in the gas rich Gavbandi province located in the southeast part of the Zagros Mountains. The results indicated that the location of anticlinal traps at the depth in which the Permian Dehram Group reservoir unit exists is horizontally displaced with respect to surficial crest of many anticlines within the Gavbandi area. This crestal shift may be induced by abnormally high fluid pressure in the "An evaporate "member of the Dashtak formation, detected in many exploration wells across the area. When fluid pressure increases due to compaction during shortening, the higher shaliness could probably cap more fluids and consequently increase the fluid pressure within the Dashtak formation. Anomalous high fluid pressure decreases internal friction and shear strength of rock units and facilitates fracturing and faulting within the Dashtak formation, which consequently causes crestal shift of anticlinal traps. This should be taken into account when planning a new exploration well in Gavbandi area in order to prevent trap drilling.

Keywords: Evaporitic Cap Rock, Fluid Pressure, Anticlinal Trap, Crestal Shift, Gas Exploration Well

1. Introduction

With more than 1500 Tcf of gas reserves discovered in more than 25 fields, the Gavbandi province of the Zagros contains about 15% of the world's proven gas reserves (Bordenave and Hegre, 2012; Motamedi et al., 2012) discovered in fractured Permian carbonates; it is sealed by the thick Triassic evaporates and originated from lower Silurian highly organic shales (Bordenave, 2002; Rahimpour et al., 2010). Anticlines located in the region are potentially prospective regarding burial and migration history as well as the source, reservoir, and cap rock characteristics; they are also suggested for drilling if structural conditions are provided.

Subsurface data sets acquired during the recent and successful hydrocarbon exploration in the Gavbandi area show that the Triassic Dashtak evaporites form an efficient tectonic detachment

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horizon, decoupling the post-Triassic succession from the Permo-Triassic rocks as reservoirs for gas (Sherkati et al., 2006; Sepehr et al., 2006; Motamedi et al., 2012). The variations of fold geometry and fold crest location across the detachment horizon have complicated the selection of the targets for gas at depth. Exploration wells drilled on the crest of several anticlines in the region indicated the rapid thickness variation of the Dashtak evaporites from one anticline to the next.

According to well completion reports from National Iranian Oil Company (NIOC), the Dashtak formation has shown abnormally high fluid pressure in several exploration wells drilled in the Gavbandi province. High fluid pressure enhances the capacity of detachment horizons within the sedimentary cover to slide during compression (Cosgrove, 1993; Teixell et al., 2000; Bilotti and Shaw, 2005), because it is an important parameter to decrease the internal friction and shear strength of rock units, which in turn facilitate their fracturing during deformation (Hubbert and Rubey, 1959).

The main objectives of this study are to evaluate fluid pressure within the Dashtak formation evaporites in the 14 exploration wells of the Gavbandi province and to figure out the association between these fluid pressures and the shift of trap location in the reservoir level with respect to surface anticlines due to tectonic over-thickening of the Dashtak evaporites. To achieve these objectives, well data (GR log and drilling mud weight) as well as depth converted seismic profiles were analyzed.

2. Results and discussion

2.1. Fluid over-pressure within the Dashtak formation

According to the stratigraphic isopach maps drawn from the well data (Szabo and Kheradpir, 1978; Setudehnia, 1978; Baghbani, 2003), the pre-folding thickness of the Dashtak formation varies from 550 to 850 m in the Gavbandi area. In the type section drilled in Kuh-e Siah anticline, its thickness is 814 meter. However, the observed tectonic thicknesses of the Dashtak formation highly increase to values between 1400 and 1900 m in the crestal area of some anticlines (Figure 1a). The Dashtak formation mostly consists of evaporites intercalated with dolomite or shale, and is divided into six members (Szabo and Kheradpir, 1978; Setudehnia, 1978). The basal member of this formation comprises 30 m shale and silty shale interbedded with dolomite and anhydrite called Aghar shale member. There are four (A-D) mostly evaporitic members of the Dashtak formation overlying this shale member. The Sefidar dolomite member comprises crystalline dolomite and chert separates the A to C evaporite members from the topmost evaporite D member. The evaporite “A member” with an average thickness of 300 m is the thickest unit in the Dashtak formation.

The thickness of the Dashtak formation varies significantly even in neighboring anticlines across the study area (Figure 1a). In addition, pore fluid pressure in the Dashtak formation is another parameter which changes across short distances, even in neighboring anticlines. According to well completion reports from NIOC, the “A member” of Dashtak formation has shown abnormally high fluid pressure in several exploration wells drilled in the Gavbandi area. These variations in the fluid pressure were also evaluated, based on normalized drilling mud weights, to examine the potential link between fluid pressure and tectonic over-thickening of the Dashtak formation.

To overcome the anomalous high fluid pressure encountered when drilling in the “An evaporite member” of the Dashtak formation, it is necessary to increase the pressure of the injected drilling mud. By knowing these injected mud pressures, it is then possible to estimate the pressure of pore fluid in the Dashtak formation. In this study, mud pressures were compiled to evaluate the fluid pressure distribution across the evaporite units of the formation after normalization with the lithostatic pressure corresponding to their specific overburden (NIOC drilled well reports). Fourteen exploration wells containing fluid pressure data were used to determine the good match between high fluid pressure and large tectonic thickness. Moreover, an isomap for the Dashtak formation fluid pressure was constructed by the interpolation of exploration well dataset (Figure 1b). The calculated values of fluid pressure for well points were imported into the GIS analyst software package. Using the algorithm of "nearest neighbor linear change", the interpolation of data points were performed in order to generate the isopressure map for the Dashtak formation across Gavbandi area (Figure 1b). There is a fairly good correlation between the domains in which anomalous fluid pressure is detected and the location of anticlines (e.g. Cham-e Noori and Day anticlines, in Figures 1a and 3b) in which significant crestal thickening of the Triassic cap rock is occurred (compare Figures 1a and d). However, the anticlines which do not show a crestal shift and over-thickening (e.g. Homa and Shanul anticlines in Figures 1a and 3a) are located in areas with a low fluid pressure (Figure 1b).

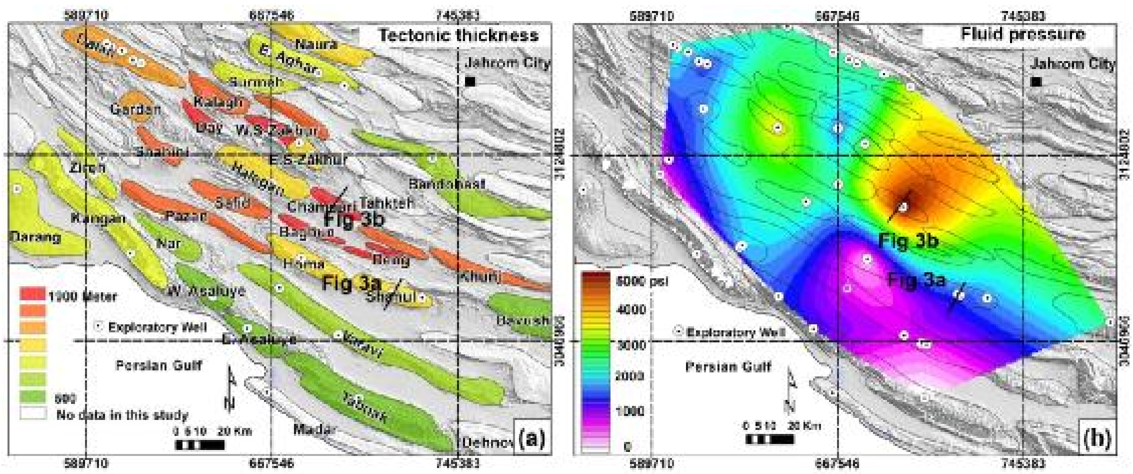

Figure 1
(a) Map showing the anticlines disposition in the studied area; the colors exhibits the Dashtak formation thickness in the crestal domain of the anticlines; (b) Isomap of fluid pressure in the "A member" of the Dashtak formation across Gavbandi area.

2.2. Cause of anomalous fluid pressure

The impermeable Aghar shale member (characterized by high gamma ray (GR) value), which is located at the base of the Dashtak formation, separates gas column pressure in the underlying reservoir carbonates (the Dehram Group) from the overlaying "An evaporite member", in which abnormally high fluid pressure is detected (Figure 2). This indicates no connection between the reservoir gas column pressure and high fluid pressure in the Dashtak formation as cap rock. In order to figure out the reason behind this anomalous high fluid pressure in the Dashtak formation "A member", the Cham-e Noori-1 and Day-1 wells showing the tectonic thickening as well as reported anomalous high fluid pressure were compared to the Homa-1 well in which the "A member" was not thickened and it had a normal fluid pressure. The comparison was made in terms of drilling mud properties, i.e. mud weight, and mud flow at the interval of the "A member" (Figure 2). Mud flow, which is an indication of anomalous high fluid pressure (Dyke and Baker, 1998; ASME shale Shaker Committee, 2005), was detected at the depths of 4297 and 4660 meters in the Day-1 and Cham-e Noori-1 wells respectively. However, no mud flow was detected in the "A member" of the Homa-1 well. The GR log, indicating shaliness (Rider, 1986) was also utilized to correlate with the mud weights in the wells (Figure 2). Furthermore, the comparison of the GR log with mud weights for these 3 wells provided data to propose that the “A member” interval in the Day-1 and Cham-e Noori-1 wells indicated higher shaliness with respect to the Homa-1 well (Figure 2). The higher fluid pressure in the Cham-e Noori and Day anticlines could probably be induced by more shale content in the Dashtak “A member”. The lack of permeability, because of the presence of the platy or flaky grains, gives shale rocks enough efficiency to cap the fluid (Al-Bazali et al., 2008). Therefore, when fluid pressure increases due to compaction during shortening, the higher shaliness could likely cap more fluids and thus could increase fluid pressure in the Dashtak formation.

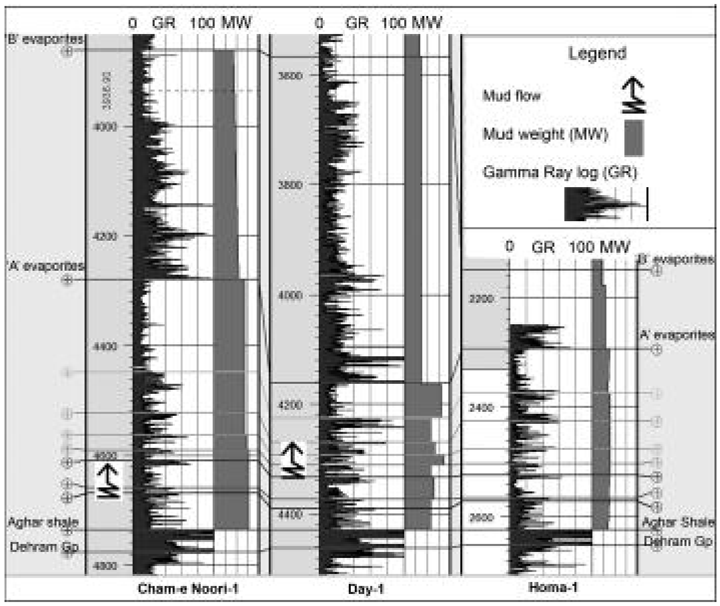

Figure 2

Well profiles indicating GR log correlation of Cham-e Noori-1, Day-1, and Homa-1 wells for “A and B members” of the Dashtak formation; the mud weight profile is calculated by normalizing the applied mud pressures; the location of mud flows are also indicated on the well profiles (the GR logging data were gathered from the NIOC data set).

2.3. Crestal shift of anticlinal traps

Regarding the thickness and the behavior of Dashtak formation detachment horizon, the interpretation of depth-converted seismic profiles indicated two different styles of anticlines developed across Gavbandi area. The first style of anticlines indicated a preserved pre-folding thickness of the Dashtak formation in their crest. In these anticlines, all structural levels were folded with a parallel geometry and no geometric decoupling and crestal shift were occurred. The best illusion of these folds was the Shanul anticline. Shanul anticline formed a symmetric and gentle fold with a nearly rounded and broad crestal domain. The parallel pattern of seismic reflectors indicated a parallel and harmonic folding geometry at different structural levels from surface to the depth of Paleozoic succession (Figure 3a). 776 m of the Dashtak formation was encountered in the Shanul-1 well, penetrated on the crest of the Shanul anticline.

On the contrary, the second style of anticlines indicated tectonic over-thickening of the Dashtak formation within their crestal domain. As a consequence, a crestal shift occurred in the location of the reservoir trap with respect to the surface closure. The best example of the second style is the Cham-e Noori anticline located in the central part of the Gavbandi area, where the Dashtak formation thickness increases from a normal thickness of 600 to 800 m to a thickness of about 1900 m in the core of the Cham-e Noori anticline (Figure 3b).

The anticline was decoupled above the Triassic Dashtak horizon, whereas the underlying Permo-Triassic and older sedimentary successions displayed a more regular and narrower anticline (Figure 3b). This decoupling across the Dashtak level was also constrained by its anomalous thickness of about 1900 m encountered in the Cham-e Noori-1 well. From Miocene carbonates at the ground surface down to the Triassic evaporates at the depth of 2786 m, well tops indicated a normal thickness of geological formations and dipmeter data showed the sub-horizontal attitude of layers. Then, 1900 meters of the Dashtak formation were encountered in the well. Below this doubly over-thickened evaporates, the top of the Permian reservoir carbonates was dipping 50 degrees to the north as measured by the well dipmeter. It showed that the crestal location of the Cham-e Noori anticline was shifted toward the southwest across the Dashtak formation with respect to the underlying Permian carbonates in the overlying post-Triassic succession (Figure 3b). In general, upon the integration of the isomaps of the Dashtak fluid pressure (Figure 1b) with seismic and well data (Figures 1a and 3), it can be proposed that the tectonic over-thickening of the Dashtak formation in the crestal domain of anticlines across the Gavbandi area should be constrained by the abnormally high fluid pressure within the formation.

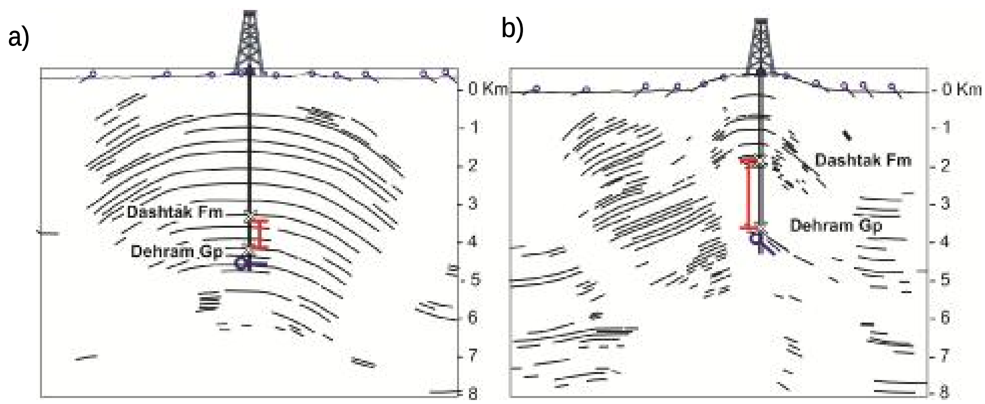

Figure 3

Depth converted seismic profiles tied to well data represent two different styles of anticlines in the Gavbandi area: (a) parallel pattern of seismic reflectors at the top and the base of the Dashtak formation exhibits no tectonic over-thickening in the Shanul anticline; and (b) diverging pattern of seismic reflectors indicates tectonic thickening at the crestal area of the Cham-e Noori anticline, which caused a shift in the location of anticlinal crest in Dehram Group reservoir level with respect to post-Triassic succession.

3. Conclusions

1. The location of anticlinal traps at the depth of Permian the Dehram carbonate reservoir is horizontally displaced with respect to shallow structures in many folds of Gavbandi area. This variation of structural geometry and fold crest location occurs along the Triassic evaporitic cap rock (the Dashtak formation). This geometrical decoupling complicates the selection of well locations targeting for anticlinal gas traps at depth, and therefore should be taken into account when planning a new exploration well in Gavbandi area in order to prevent trap drilling.
2. There is a strong association between the crestal shift of anticlines and the detected anomalous high fluid pressures in the “An evaporite member” of the Dashtak formation. High fluid pressure facilitates the development of fracturing and faulting within the formation by decreasing internal friction and shear strength of rocks. This faults cause tectonic thickening of the formation and

thereby the crestal shift of anticlinal traps. The higher fluid pressure may likely be induced by more shale content. When fluid pressure increases due to compaction during shortening, the higher shaliness may cap more fluids and therefore can increase fluid pressure within the Dashtak formation.

3. In general, upon the integration of the isomaps of the Dashtak fluid pressure (Figure 1b) with seismic and well data (Figures 1a and 3), it can be proposed that the tectonic over-thickening of the Dashtak formation in the crestal domain of anticlines across the Gavbandi area should be constrained by the abnormally high fluid pressure within the formation.

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Reference

Al-Bazali, T. M., Zhang, J., Chenevert, M. E., and Sharma, M. Factors Controlling the Compressive Strength and Acoustic Properties of Shales When Interacting with Water-based Fluids. International Journal of Rock Mechanics and Mining Sciences, Vol. 45, p. 729-738, 2008.

ASME Shale Shaker Committee, The Drilling Fluids Processing Handbook, Elsevier, 666 p, 2005.

Baghbani, D. Paleogeographic Evolution and Hydrocarbon Potential Estimation of the Dehram Group in Fars Area and Determination of 'Fars Paleo-high' Limits, National Iranian Oil Company, Exploration and Production, Tehran, Report 1946, 2003.

Bilotti, F. and Shaw, J.H. Deep-water Niger Delta Fold and Thrust Belt Modeled as a Critical-taper Wedge: The Influence of Elevated Basal Fluid Pressure on Structural Styles, AAPG Bulletin, Vol. 89, No. 11, p. 1475–1491, Doi: 10.1306/06130505002, 2005.

Bordenave, M.L., Gas Prospective Areas in the Zagros Domain of Iran and in the Gulf Iranian Waters, Presented at the AAPG Convention, Houston, 10–13 March 2002 (Extended Abstract). World Wide Web Address: www.aapg.org/datasystems/abstract/ 3annual_/extended/42471.pdf, 2002.

Bordenave, M.L. and Hegre, J.A. Current Distribution of Oil and Gas Fields in the Zagros Fold Belt of Iran and Contiguous Offshore as the Result of the Petroleum Systems, Geological Society, London, Special Publications, Vol. 330, p. 291–353, Doi: 10.1144/SP330.14, 2012.

Cosgrove, J. W., The Interplay between Fluids, Folds and Thrusts during the Deformation of a Sedimentary Succession, Journal of Structural Geology, Vol. 15, p. 491-500, Doi: 10.1016/0191-8141(93)90143-X, 1993.

Dyke.,V, K. and Baker, R. Drilling Fluids, Mud Pumps, and Conditioning Equipment, University of Texas at Austin, Petroleum Extension Service, Technology and Engineering, 252 p., 1998.

Hubbert, M. K. and Rubey, W. W., Role of Fluid Pressure in Mechanics of Overthrust Faulting, Geological Society of America Bulletin, Vol. 70, p. 115-166, 1959.

Motamedi, H., Sherkati, S., and Sepehr, M. Structural Style Variation and its Impact on Hydrocarbon Traps in Central Fars, Southern Zagros Folded Belt, Iran, Journal of Structural Geology, Vol.37, p.124-133, Doi:10.1016/j.jsg.2012.01.021, 2012.

Rahimpour-Bonab, H., Esrafili-Dizaji, B., and Tavakoli, V. Dolomitization and Anhydrite Precipitation in Permo-Triassic Carbonates at the South Pars Gas Field, Offshore Iran, Controls on Reservoir Quality, Journal of Petroleum Geology, Vol. 33, p. 43–66, 2010.

Rider, M. H. The Geochemical Interpretation of Well Logs. Blackie, Glasgow, p.106-118, 1958.

Setudehnia, A. The Mesozoic Sequence in South-west Iran and Adjacent Areas, Journal of Petroleum Geology, Vol. 1, p. 3–42, Doi:10.1111/j.1747-5457.1978.tb00599.x, 1978.

Sepehr, M., Cosgrove, J. W., and Moieni, M. The Impact of Cover Rock Rheology on the Style of Folding in the Zagros Fold-thrust Belt, Tectonophysics, Vol. 427, p. 265–281, Doi:10.1016/j.tecto.2006.05.021, 2006.

Sherkati, S., Letouzey, J., and Frizon de Lamotte, D. The Central Zagros Fold-thrust Belt (Iran), New Insights from Seismic Data, Field Observation and Sandbox Modelling, Tectonics, Vol.25, TC4007, Doi:10.1029/2004TC001766, 2006.

Szabo, F. and Kheradpir, A. Permian and Triassic Stratigraphy, Zagros Basin, South-west Iran, Journal of Petroleum Geology, Vol. 1, p. 57–82, 1978.

Teixell, A., Durney, D. W., and Arboleya, M. L. Stress and Fluid Control on Decollement within Competent Limestone, Journal of Structural Geology, Vol. 22, p. 349-371, Doi: 10.1016/S0191-8141(99)00159-5, 2000.