1D Mechanical Earth Model in a Carbonate Reservoir of the Abadan Plain, Southwestern Iran: Implications for Wellbore Stability*

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Abstract

Knowledge of the rock mechanical properties and stress tensor including orientation and magnitude of *in-situ* stresses has numerous implications in different aspects of petroleum exploration and production. In particular, these geomechanical parameters control fluid flow in naturally-fractured reservoirs, hydraulic fracture stimulation, wellbore stability, and reduce non-productive time in drilling operations. Knowledge of the *in-situ* stress state is particularly important in Iran, which has an extensive and mature petroleum exploration and production industry and is also prone to stress-related geohazards such as earthquakes. Yet, the 2016 release of the World Stress Map project contains very little *in-situ* stress information for Iran.

In this study, we present a comprehensive one-dimensional mechanical earth model in an appraisal well in a carbonate oil-bearing reservoir in southwestern Iran. Different rock mechanical tests including Brazilian, Uniaxial compressive strength, and tri-axial compressive tests are applied on the core samples to determine rock strength and elastic properties such as tensile strength, UCS, cohesion, friction angle, Young's modulus, and Poisson's ratio. These static rock mechanical properties then provide a reference to calibrate the well-log derived or dynamic rock mechanical properties. We use different sets of data such as pressure tests, leak off tests, borehole image log, and wireline data to estimate the continuous profile of vertical and horizontal stresses and pore pressure in different lithological layers of the studied well. Analysis of borehole breakouts and drilling induced tensile fractures suggest a NE-SW orientation for the maximum horizontal stress orientation which is consistent with deep earthquake focal mechanism solutions in the study area, derived from the World Stress Map database. The results also indicate normal (in some intervals strike-slip) tectonic stress regime which is different from deep earthquake focal mechanism solutions. The constructed 1-D MEM was calibrated by wellbore stability analysis of the current drilled well. The results indicated the unstable borehole in some intervals which was consistent with borehole image and caliper logs. Finally, we use the constructed 1D mechanical earth model in this study for sensitivity analysis of different wellbore trajectories and mud weight window for future well planning and safe drilling in this under-development oil field.

Geology and State of Stress in the Abadan Plain Basin

Abadan Plain Basin is located in the western Dezful Embayment, southwestern Iran. The basin is bounded by the Dezful Embayment in the north and the northeast; Persian Gulf–Mesopotamian foreland basin and Saudi Arabia in the southwest and south; and to Iraq in the west (Moallemi and Kermanshah, 2012). In comparison to the Dezful Embayment that mainly show NW–SE trend for anticlines and structural closure, the Abadan Plain contains N-S to NE-SW trend (i.e. Arabian trend based on Ahmadhadi et al. (2008).

To date, the World Stress Map-2016 database only contains three reliable stress orientations from petroleum wells in Iran (Heidbach et al., 2016; Rajabi et al., 2010), despite Iran has an extensive and mature petroleum exploration and production industry (Rajabi et al., 2014). Based on the information from two petroleum wells in the Abadan Plain, Rajabi et al. (2010) revealed that the orientation of maximum horizontal stress (S_{Hmax}) in this region is NE-SW (Figure 1). However, the other parameters of stress tensor, such as stress magnitudes and tectonic stress regime, are poorly understood in this region (Figure 1).

Methodology

Mechanical Earth Model is a quantitative representation of the *in-situ* stresses, pore pressure, rock strength properties, and rock elastic properties which usually constructed for a specific depth, well or field. It contains all required information for analysis of any geomechanics-related applications, such as wellbore stability, sand production prediction, hydraulic fracturing design, reservoir geomechanics modelling, CO_2 storage, compaction, and subsidence (Rajabi et al., 2017). In this study we constructed a one-dimensional Mechanical Earth Model (1-D MEM) based on various types of data in the study well. We first carried out Brazilian test, Tri-axial Compressive Strength Test, and Uniaxial Compressive Strength Test to measure the static rock mechanical properties. We then calculated log-derived or dynamic rock mechanical properties which then calibrated with static results (Figure 2). The calibrated elastic properties then have been used to calculate the magnitude of horizontal stresses based on poroelastic equations. We determined the overburden stress from the wireline log data by integrating formation bulk density. Finally, the analysis of borehole breakouts and drilling induced tensile fractures in image logs of the study well revealed the orientation of S_{Hmax}.

Results and Discussions

Interpretation of eight borehole breakouts and two possible drilling-induced tensile fractures in the studied wells revealed a trend of NE-SW for the S_{Hmax} orientation which is fully consistent with the previous studies in the region (Heidbach et al., 2016; Rajabi et al., 2010). Magnitudes of vertical and horizontal stresses show the presence of normal (strike-slip in some intervals) in the study area. The presence of normal tectonic stress regime in this region is somehow interesting as this area is located in the continental collision zone between the Arabian plate and Central Iran plate. Due to lack of leak-off test data we cannot calibrate the log-derived horizontal stress magnitude. However, a recent study by Haghi et al. (2018) shows the presence of normal tectonic stress regime in the Bangestan reservoir, northern Dezful Embayment in the Zagros Fault and Thrust Belt.

We applied a wellbore stability analysis based on the constructed 1-D MEM and the well trajectory. We calculated the stress concentration around the borehole base on previously developed analytical model (Zare-Reisabadi et al., 2012, Zare et al., 2010). The comparison between the principal stresses around the borehole and the rock failure criteria to determine whether the borehole wall has failed or not (Figure 3). The sensitivity analysis of borehole stability revealed that vertical (in the normal stress regions) or moderately deviated wells (in the strike-slip stress regions) are more stable wells.

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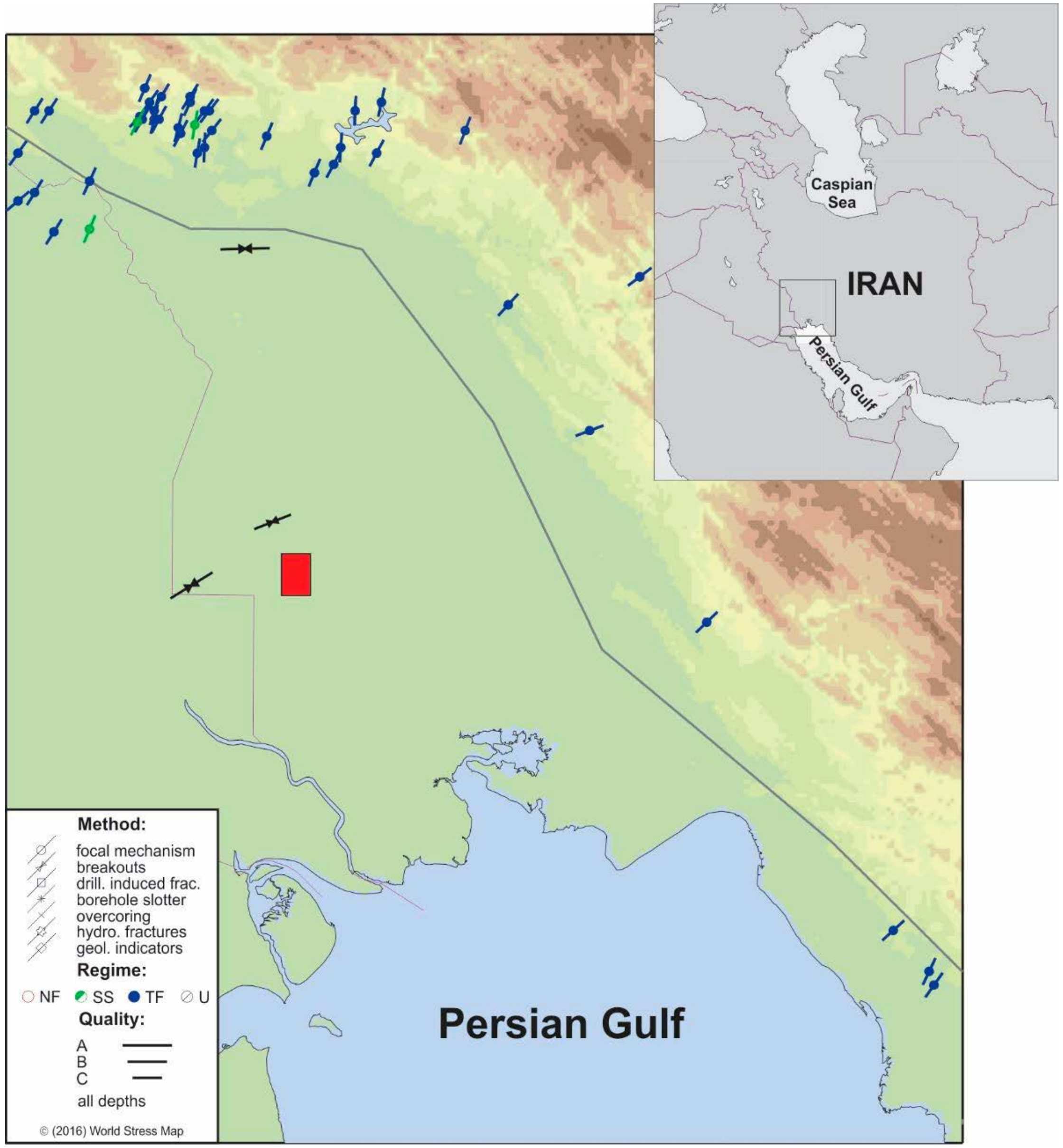

Figure 1. Maximum horizontal stress orientations in the study area from the World Stress Map database (Heidbach et al., 2016). Symbols and different colours indicate the method of measurement (circles are focal mechanism solutions, inward-facing arrows are breakouts) and the stress regime (SS=strike–slip faulting stress regime; TF=thrust faulting stress regime; black=undefined stress regime). Length of the lines indicates quality of data. The study well is located in the red rectangle.

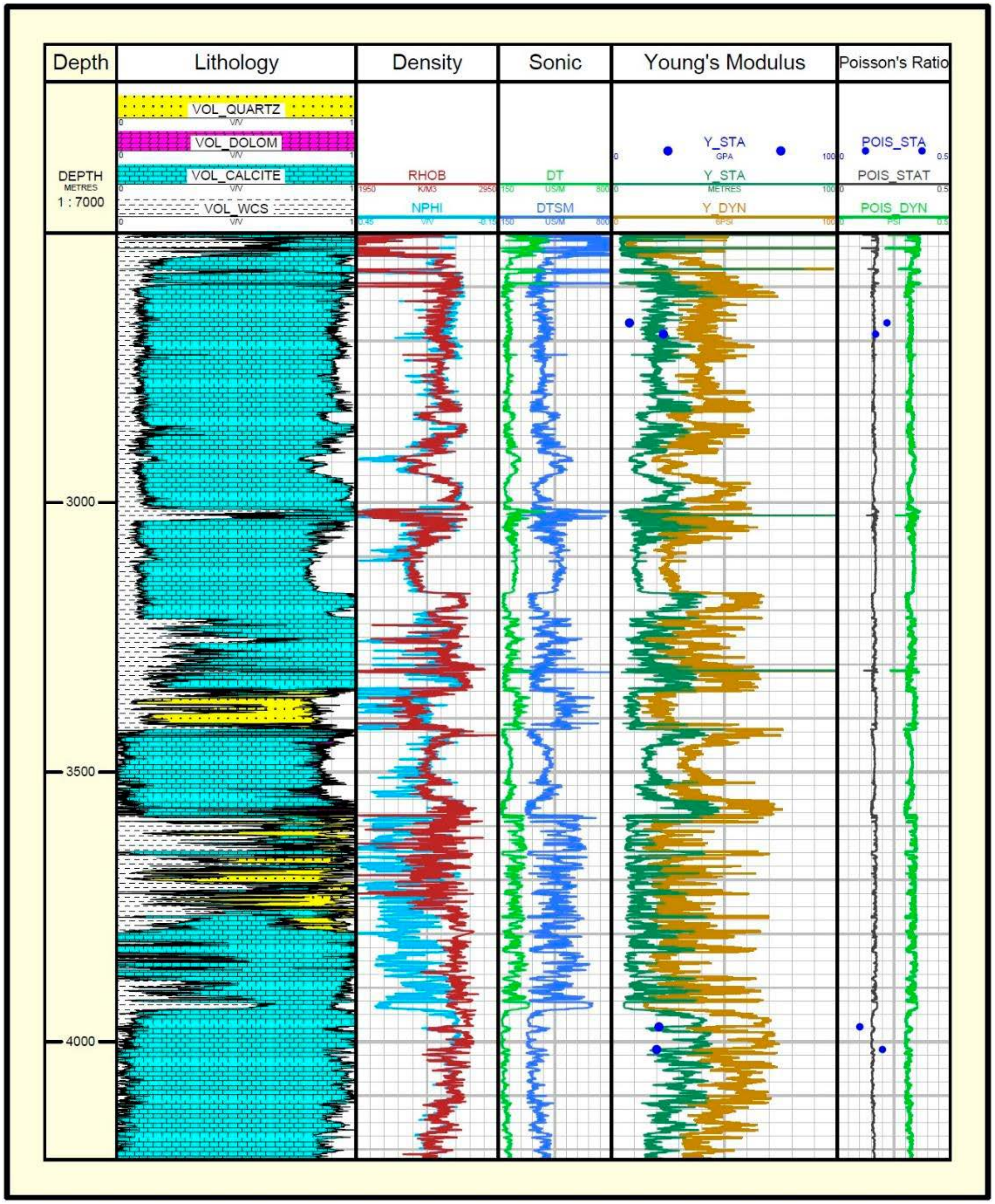

Figure 2. Dynamic and static elastic properties of studied well.

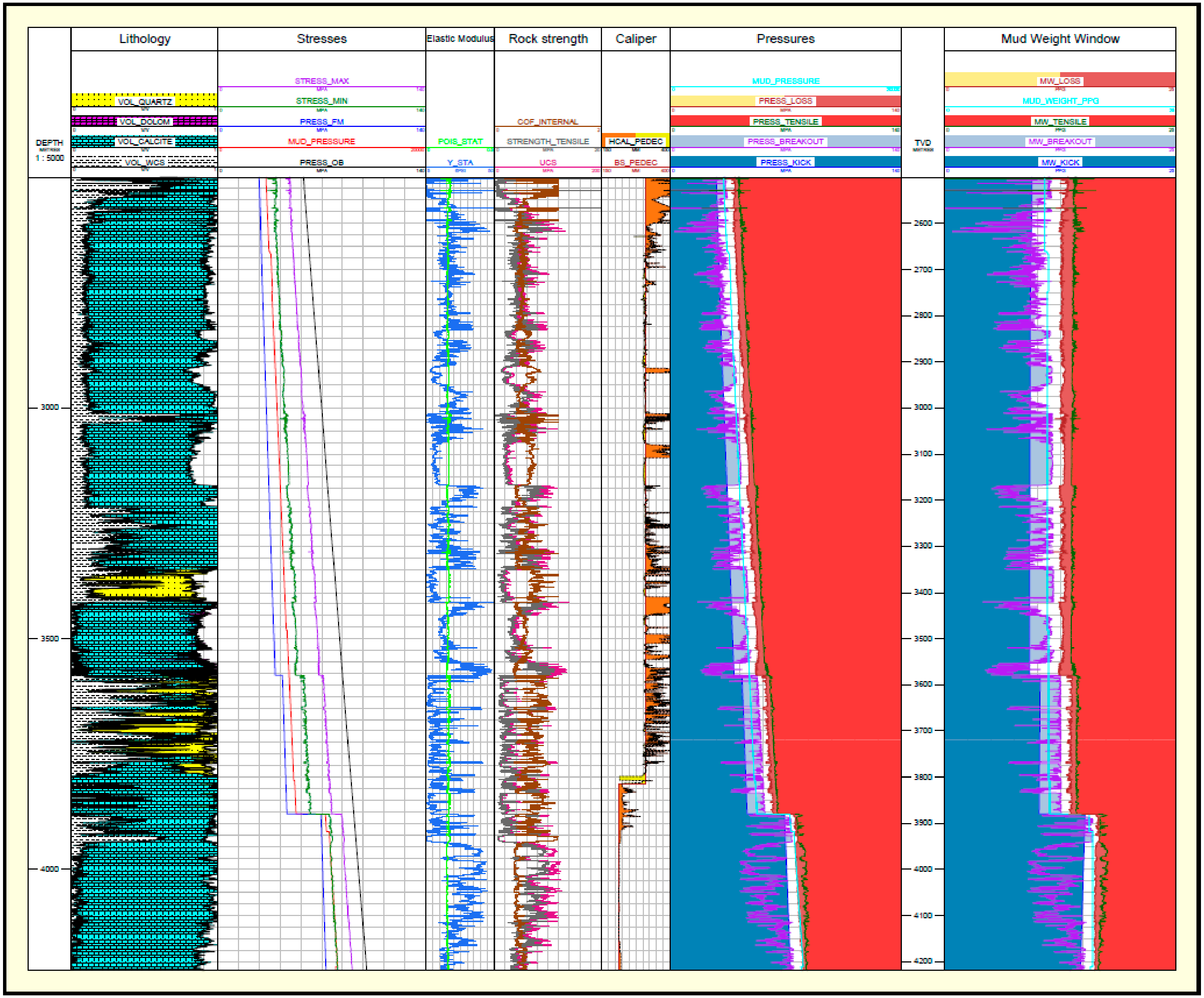

Figure 3. 1-D MEM and Wellbore stability analysis results.