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Quantitative prediction of fracture distribution in Upper Ordovician Lianglitage limestone formation, Hetianhe Gas Field, Tarim Basin, NW China

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Summary

This study aims to characterize fracture systems and analyze phases of fracture development in Upper Ordovician Lianglitage limestone, Hetianhe Gas Field, Tarim Basin. The Hetianhe Gas Field is located in a long and narrow NW-SE anticline. The anticline is about 100 km long, 1 km to 3.5 km wide, and it is bounded by two reverse NW-SE faults. The displacement along the faults is ~50 m to 500 m. The Lianglitage limestone is tight with low porosity and permeability and has thickness of 400 m. The burial depth of the limestone is varying from 1.5 km to 3.5 km (Wang et al., 2000). Fracture systems largely contribute to gas migration. Fracture permeability is a key parameter to gas production. Studying principal fracture sets in Upper Ordovician Lianglitage limestone will help to optimize well placement and improve hydrocarbon production.

Methods

Structural analysis of outcrops, core data, image well log and thin sections was used to identify and describe different fracture sets. Triaxial compressional and ultrasonic testing was conducted to analyze mechanical properties of the limestone. The Coulomb and Griffith rupture criterions and 3D finite element numerical simulation technique were applied to predict distribution of fracture sets. The magnitude of maximum principal paleo-stress was estimated on the basis of ultrasonic testing results by applying the equivalent paleo-stress method: the magnitude of paleo-stress is considered equal to the stress value that could generate the same fracture characteristics. We attempt to characterize fracture linear density, aperture and strain energy density. Geological model was built taking into account Upper Ordovician limestone formation thickness and geomorphology. Geomechanical model was discretized by methods of solid node 185, nodes and elements were defined with various mechanical parameters. The obtained simulation results of fracture parameters were validated by field production data.

Results

Three sets of fractures have been distinguished in Upper Ordovician limestone of the Hetianhe Gas Field according to intersection relationships between different sets of fractures, regional tectonic evolution analysis and results of inclusion testing. The set 1 includes calcite- or mud-filled fractures oriented N130-140° that are interpreted being formed during the Early Hercynian. The set 2 involves high-angle fractures, semi- to full-filled, oriented N90-100° and N150-170° that were formed in the Late Hercynian. The set 3 includes high-angle effective fractures with large aperture, open to semi-filled, oriented N10-40° and N60-80°, formed during the Himalayan. The strike of dominant fracture sets is NE-SW (N10-40°, N60-80°) and NW-SE (N150-170°). Fracture dip angle is variable with maximum density of fractures dipping at 45 to 90°. Fractures are more developed in the west of the studying area. Fractures are primarily concentrated in core of the anticline and damage zones of faults, mainly oriented oblique to the anticline fold axis. From the top to bottom of the formation, fracture density varies with a peak in

the middle of the formation. Linear fracture density is ranging from 3 to 9.5 fractures/m. Aperture of open fractures varies up to 0.6 mm. Fracture height is controlled by bedding and ranges from 0.05 to 0.5 m. Stress regime in the study area has been varying at different tectonic phases from thrust-fault in the Late Hercynian to thrust-fault and strike-slip fault in the Himalayan (Yang et. al, 2011; Zhang et. al, 2011; Yang et al., 2001; Ren et al., 2019). The analyzed fracture sets have been introduced in the geological model to simulate fluid migration in the limestone reservoir. The simulation results support that described fracture parameters are in good agreement with well production data. Two vertical wells Ma 5 and well Ma 4 are located at a distance of 18 km in the field. Well Ma 5 is characterized by lower fracture density but larger fracture aperture if compared to Well Ma 4. Formation pressure is 20.44 MPa in well Ma 5 and 18.5 MPa in well Ma 4. Gas production is 0.5-1.02e9 m^3/y in well Ma 5 and 1.25-2.76e^9 m^3/y in well Ma 4. The significant variation in formation pressure and hydrocarbon production in these two wells might be resulted from reservoir compartmentalization by fracture zones that prevent horizontal gas migration.

Conclusions

Fracture height in the Lianglitage limestone is controlled by bedding. Gas production in two analyzed wells of the Hetianhe Gas Field is in good agreement with estimated fracture height and density. In similar production horizon, long fractures with low density distribution represent channels for hydrocarbon migration; short fractures with low density distribution are associated with zones of higher production, while long fractures with high density distribution are typical for zones with lower gas production. The applied methods of fracture analysis have been validated by gas production data of the Hetianhe Field and can be used in the analysis of other fractured reservoirs.

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