Geostress Assisted Evolving Permeability Anisotropy and Its Possible Implication in Hydrocarbon Exploration and Exploitation

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Abstract

The present paper introduces concept of 'geostress assisted evolving permeability anisotropy' with use of stress induced acoustic emission and seismic wave (primary wave) response of rocks under variable stress conditions. The utilized concept may be helpful in identifying the hydrocarbon (petroleum) bearing strata and problems of petroleum migration, damage to petroleum wells caused by the variation in geostress conditions due to tectonic and technogenic activities. The study is based on the assessment of stress-induced evolution of permeability anisotropy with use of relative damage factor (RDF) in similar designed analogous experimental conditions. The sandstone specimens collected form different locations with respect to fault plane from vertical structural litho-succession of Upper Kaimur Group, Vindhyan Supergroup were used for the purpose due to their geomechanically isotropic nature (0.98). The prepared cubical and cylindrical samples of sandstones of dry and saturated with water, kerosene, petrol and diesel were deformed under cyclic stress conditions and incremental stress conditions on servo-controlled Material Testing System (MTS) to quantify the values of geostress and RDF by using acoustic emission analyzer system (MISTRAS-1100) and simple ultrasonic concrete tester.

The results of experimental investigations revel that the values of geostress is lower in locations near the fault planes (10.87 MPa-11.12 MPa). However, the value of geostress is higher away from fault plane (19.24MPa-21.42 MPa). Further, the sandstones located close to fault plane saturated with water, kerosene, petrol and diesel exhibits decreased geostress value such as 5.45MPa, 6.61MPa, 7.42 MPa and 9.01MPa respectively. However, the sandstones far away from fault plane under saturated conditions with water, kerosene, petrol and diesel imparts decreased values of geostress like 20.52MPa, 20.66MPa, 20.75MPa, 21.12MPa respectively. The decreased values of geostress due to saturation are maximum in low stress zones and minimum in high stress zone. The higher values of RDF in rocks of low geostress zone indicate the higher permeability of the in strata in natural condition. In saturated conditions the sandstone having low geostress values shows higher reduction and RDF values In particular the sandstones saturated with water shows higher RDF values in comparison to sandstone saturated with kerosene, petrol and diesel may be due to interaction of water with the matrix of rock resulting into the corrosion of matrix. Similarly the sandstones of lower geostress zone imparts highest RDF in parallel, intermediate in oblique and least in perpendicular direction to stress axis. In incremental stress condition the sandstone of low geostress zone exhibits initial decrease in RDF and reaches constant values. With progress in deformation the values of RDF pronouncedly increase parallel to stress axis in comparison to oblique and perpendicular to stress axis. In the last phase of deformation the values of RDF enhances more in oblique direction in compression to parallel and perpendicular direction to stress axis. The variation in value of RDF suggests the

rate of evolution of permeability varies with direction and magnitude of change in stress with geostress condition of basin. The sandstone of lower geostress values saturated with water and hydrocarbons shows further enhancement in evolution rates of permeability evidenced from increase RDF values. Thus both natural and saturated sandstones of different geostress zones deformed under incremental stress condition exhibits highest RDF parallel, higher oblique and least perpendicular to stress axis reveals strong permeability anisotropy. Thus, the evolution of permeability anisotropy is principally dependent on the geostress conditions. Thus, the evolution of permeability anisotropy is considered to be function of geostress. Therefore, the change in geostress condition of petroleum basins as result of natural disturbances and technogenic application may initiate the evolution of new stress-induced permeable conduits suitable for migration of petroleum from predicted sites and damage to oil and gas well. Hence, the study may prove to be forward step in locating petroleum bearing strata and migration of hydrocarbons and relevant to suggest degree of maintenance damaged well routs for improved recovery and enhanced economy of Petroleum Company.

Key words : Geostress, Petroleum basin, relative damage factor, stress, saturation

Introduction

Kerogene, a source of hydrocarbon involves deposition of biogenic components with geomaterial followed by their consolidation and progressive conversion. During syn- and post-depositional process the evolution of porosity and permeability during compaction and maturation are further modified by variation of pressures, temperatures and tectonic stresses in basin. Thus, the petroleum occurs in geological formations and strata under complex geostress conditions within several types of traps. Because of change in stress conditions the pores formed and filled with hydrocarbon exhibits modification and addition of new stress-induced porosity and permeability which leads to enhance density and alter the geometry of interconnected pores. The variation of density and shape of pores with direction cause permeability anisotropy. The secondary permeability provides suitable conduits and paths for flow of petroleum. The frequency of petroleum bearing conduits varies with magnitude and directions of geostress (in-situ stress). The evolution of additional stress induced permeability anisotropy may results several severe problems associated with migration of petroleum from predicted site, leads to insufficient recovery of petroleum and instability of oil and gas wells. In addition, the magnitude and direction of geostress also controls the reservoir pressure responsible for smooth exploitation process of petroleum. In summary the geostress including pore-stress existing or induced in reservoir or cap rock may cause (i) formation of stress induced discontinuities resulting in reservoir and cap rock fracturing, (ii) wellbore instability and related problems (iii) hampered recovery, and (iv) loss of gas and oil. Thus, a good understanding of geostress assisted-and stress-induced permeabilities may affect planning and design of hydrocarbon exploration and exploitation with reduced technical risks and enhanced economics.

In view of significant importance of above described aspects the present paper discuss the influence of geostress on evolving permeable conduits and application of RDF to quantify the permeability that may be useful to develop some new techniques for smooth and economic exploration and exploitation of petroleum.

For the purpose the sandstones blocks were collected from Upper Kaimur Group near Sukrut and Markundi localities, Sonbhadra, Uttar Pradesh due to geomechanicaly isotropic nature of rock (Dubey 2002 2006).

Methodology

The method used in the present investigation is principally based on application of acoustic emission analyzer and ultrasonic concrete tester. The prepared cylindrical drill cores and cubical samples from rock specimens collected from different levels of vertical structural litho-succession were deformed under cyclic and incremental stress conditions. The RDF values were determined during deformation of samples in incremental stress condition to quantify stress-induced permeability anisotropy. Further, the similar experimental exercises were repeated for the samples saturated with water, kerosene, petrol and diesel. The stress-strain behavior and level of acoustic emissions and response of primary wave were used to measure geostress and RDF for quantification of permeability anisotropy.

Experimental Works

The prepared cubical samples of size 5cmx5cmx5cm and cylindrical samples of length 6.28 cm and diameter 3.14 cm prepared (as per ISRM, 1981) form the sandstone in direction perpendicular to bedding by diamond cutter and core drilling system in water flushing medium were deformed under two cycles of cyclic stress and incremental stress condition on servo-controlled Material Testing System (MTS) with sensors of Acoustic emission analyzer and ultrasonic concrete tester. In addition the prepared dried sandstone samples submerged in water, kerosene, petrol and diesel were deformed under similar experimental stet up and stress conditions to understand the influence of saturation on geostress and RDF.

Results and Discussion

The results of experimental investigations revel that the geostress determined from sandstone of different locality imparts lower stress concentrations (10.87MPa to 11.12 MPa) near the fault planes. However, the sandstone located away from fault plane shows higher stress concentrations (19.20MPa- 21.42MPa) (Fig. 1)

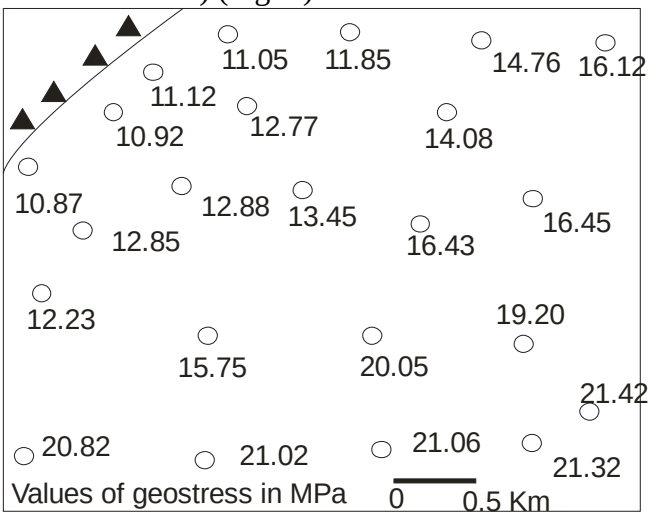

Fig.1 Distribution of geostress values in sandstone of Upper Kaimur Group.
The in samples having low geostress exhibit higher average value of RDF (0.556), while samples of higher geostress pertains low average value of RDF (0.0657) (Fig.2).

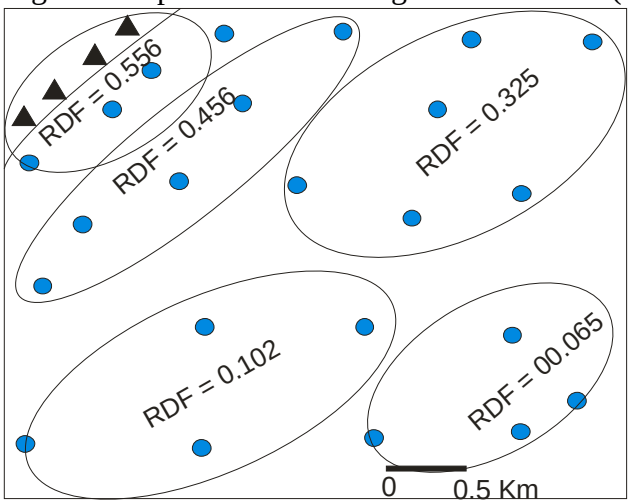

Fig.2. Distribution of average value of RDF in sandstones of Upper Kaimur Group.

The similar samples of low geostress zone saturated with water, kerosene, and petrol and diesel exhibit further reduction in stress values (5.45MPa, 6.61MPa, 7.42 MPa and 9.01MPa). However, the sandstones showing higher geostress values exhibits low reduction in geostress values due to saturation with water and fluid hydrocarbon (20.52MPa, 20.66MPa, 20.75MPa and 21.12MPa (Fig. 3).

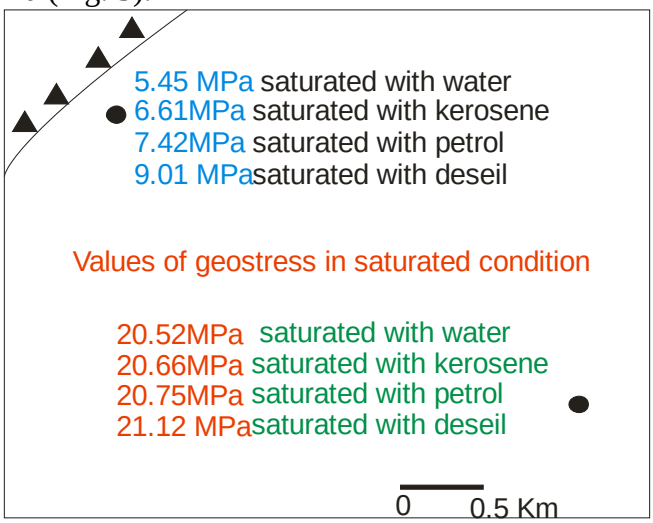

Fig.3. Influence of fluid saturation on geostress values for sandstone of Upper Kiamur Group.

In particular, the samples of low geostress zone saturated with water indicates pronounced reduction in stress concentration (49.67%) in comparison to stress concentrations in samples saturated with kerosene (39.19%), Petrol (31.74%) and diesel (17.11%) may be due to higher reactivity of water with ferruginous matrix of sandstones. However the reduction is lowminimum in samples of higher geostress zone saturated with water and fluid hydrocarbon exhibits lower reduction in stress values (4.21%-1.40%) The percentage reduction in value of geostress

decreases for samples saturated from water to petrol and diesel may suggest the reduction in geostress as function of dynamic viscosity of water and hydrocarbon fluids.

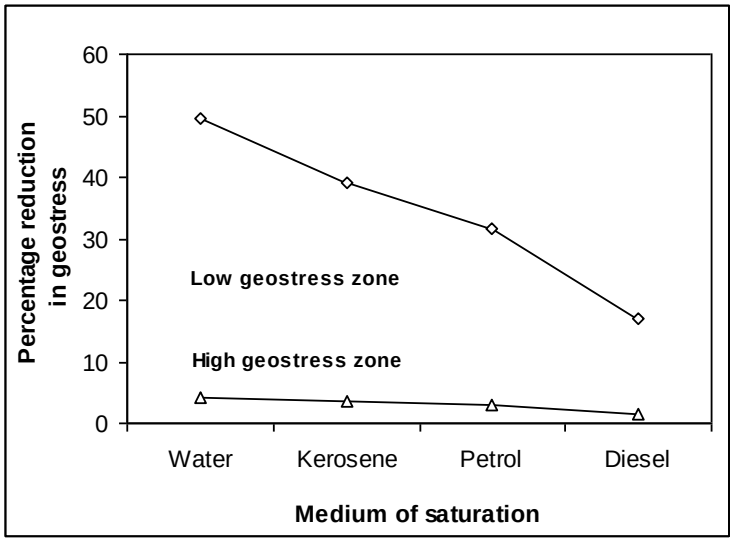

Fig. 3. Effect of fluid saturation on percentage reduction in geostress values

The value of RDF analyzed for samples saturated with water shows higher values may be due to pronounced dissolution and corrosion of matrix and development of pore pressure (0.758). The values of RDF in samples saturated with kerosene (0.652), petrol (0.487) and diesel (0.498).
In incremental stress condition the values of RDF initially decrease (0.652 to 0.052) in sandstone having lower geostress values and reaches a constant values for considerable time span which further enhances with progressive deformation, indicates evolution of permeable conduits. The same samples under increased stress increments exhibit higher RDF parallel to stress axis. Further, progress of deformation added the enhancement in RDF. Moreover, the values of RDF is higher in direction oblique to stress axis may be due to tilting of permeable conduits, while the value perpendicular stress axis suggest the least values of stress. The variation in stress magnitude results the change in value of RDF with respect to direction of stress axis. However, the samples saturated with fluids exhibits similar phases as observed in dry sandstone under incremental stresses. In saturated samples initially the values of RDF decrease with increment in stress but the decrease is resisted by presence of water in pores thus the decrease rate with lower rates. After decrease RDF phase the samples undergoes phase of constant DRF for shorter period and thereafter the samples shows initiation of RDF with higher rate may be due to enhanced pore pressure. The higher rate of evolving permeability may be due to change in geostress and pore stress caused by fluids saturation may result many exploration and exploitation related problems.

In particular the increase in RDF values in samples saturated with water is higher, kerosene (slightly lower) in petrol and least in diesel may be due to difference in their reactivity and dynamic viscosity

The both natural and saturated sandstones of different locations deformed under incremental stress condition exhibits highest RDF parallel, higher oblique and least perpendicular to stress axis reveals strong permeability anisotropy. The techniques may be applied (i) to check the

migration of oil, (ii) as a tool for exploration, and (iii) for solving geotechnical problems associated with recovery of petroleum.

Conclusion

The evolution of permeability anisotropy is a function of geostress condition of petroleum basins. The change in geostress (natural and technogenic) results redistributions of stresses pertinent to form new stress-induced permeability. The density and geometry of permeable conduits varies with change in stress conditions. The variation of relative damage factor (RDF) values in sandstones of low and high geostress zones in natural and saturated conditions with water and different types of liquid hydrocarbons suggests the evolution of permeable paths as function of geostress and basin condition. The sensitivity of RDF values with geostress condition and saturations may be useful for locating petroleum bearing strata and migration of hydrocarbons.

Thus the technique may be beneficial for techno-economic explorations and exploitation of hydrocarbon from petroleum basins. For high accuracy and field applicability more works may be required as it is an initial step.

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