Geothermal gradient anomalies of hydrocarbon entrapment of central Sirte Basin, Libya: a mature basin rejuvenation technique

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1. ABSTRACT

Compensated Geothermal Gradient (CGG-ESTI©) software[1] was used for bottom-hole temperatures (BHTs) database creation, raw BHTs correction, geothermal gradients plotting, geothermal cross-plot analysis and geothermal gradient contouring of 50 wells in the Hagfa (Marada) Trough of central Sirte Basin. The compensated geothermal gradient contours revealed higher geothermal gradients for most producing wells against a background of lower geothermal gradients for most dry-holes in the Hagfa Trough. In mature hydrocarbon producing Hagfa Trough of Sirte Basin, such anomalies reflects the presence of sealed permeable, heat-convicting subsurface traps, and can provide justifications for post-mortem analysis of dry-holes showing anomalous geothermal gradients, that may lead to re-entry to test missed, bypassed shallow traps, or deepen the "dry-hole" to test unreached hydrocarbon traps of such geothermally anomalous possible, probable and potential "un-discovery wells".
Two examples of successful discoveries are cited: the first for deep condensates discovery via deepening an old dry-hole in the Hagfa Trough, drilled when shallow reservoirs were the primary targets during early exploration years, and the second for shallow oil discovery by re-entry of a dry-hole, drilled when deeper targets became the primary exploration targets and shallow reservoirs got bypassed during later exploration days.

2. THE CONCEPT

Wells penetrating hydrocarbon traps exhibits anomalously higher geothermal gradients than adjacent dry-holes have been consistently published since early well logging days**. The high geothermal anomalies reflects thermally impeding parts of sedimentary basins in which hydrodynamic, stratigraphic and structural environments are actively converging deep HTP fluids into thermally convective shallower reservoirs. Such subsurface fluid migration process is responsible for entrapments of HTP components (H2O then HC) in sealed shallower LTP reservoirs. Unlike other well logging tools, the bottom hole temperature (BHT) recording device remained unchanged and uniformly calibrated since invention and introduction to the hydrocarbon drilling industry; which make the compensated geothermal gradient a valuable quick-look method in reviewing thousands of BHTs of old and new dry-holes logs and files in mature hydrocarbon producing basins.

3. THE SOFTWARE

An exclusive geothermal gradient modelling software **(CGG-ESTI©)** was used to:
3.1. Input and create Bottom Hole Temperatures (BHTs) databases, verifies and tests the reliability and corrects raw BHTs
3.2. Plot the corrected geothermal gradient of individual wells, and analyse the corrected BHT records of groups of wells to model the cluster limits of the thermally anomalous discovery, suspended or produced wells in the studied area/basin and
3.3. Use the modelled anomalous geothermal signature of discovery, suspended and producing wells to identify possible, probable or potential **"Un-discovery wells"** that are displaying similar geothermal gradient anomalies among hundreds of old low – normal geothermal gradients dry-holes[1].

4. THE ANALYSIS

Using the CGG-ESTI© Software to input and generate Bottom Hole Temperature (BHT) database, correct raw BHT readings, test the statistical significance of BHT measurements; then calculate and plot Compensated Geothermal Gradients (CGG) and Extrapolated Surface Temperature Intercepts (ESTI) of 50 exploration and development wells in the Hagfa (Marada) Trough of western Sirte Basin (Concessions 6, 13, 20, 47, NC130A, NC144 and NC149). Interactive cross-plot analysis was then applied on significant control wells to establish corrected geothermal cluster regimes of discovery versus dry holes. This was followed by discriminative computer contouring of the corrected data sets of control points to elucidate regional geothermal contours as well as local geothermal gradient anomalies [1].

5. THE RESULTS

As expected, the study found high compensated geothermal gradient anomalies to be associated with proven oil and gas fields in Hagfa (Marada) Trough area. Out of a database of 50 wells (31 dry holes and 19 producing or suspended wells) fourteen closed contours anomalies were identified. Some of these anomalies partly overlap with eighteen thermally anomalous wells identified via cross-plot analysis as hydrocarbon producing wells or at the flanks of hydrocarbon traps. The study identified and delineated

29 geothermal gradient anomalies ranked as 9 proven, 6 potential, 2 probable and 12 possible geothermal gradient anomalies of hydrocarbon entrapment [1].

6. CONCLUSIONS

The success rate of the CGG-ESTI© method in the Hagfa (Marada) area in identifying proven producing and suspended wells is 70% to 90% depending on the exclusion or inclusion of off-flank wells. The success rate of identifying wells that bypassed or stopped short of oil or gas traps using potential geothermal gradient anomalies in the Hagfa area should be similar to the success rate of identifying proven anomalies [1]. The CGG-ESTI© software is an additional tool for integrative prospects generation, dry-holes post-mortem and re-entry justification of possible, probable or potential missed and bypassed traps in "un-discovery wells" currently classified as dry holes. With hundreds of undeveloped single well discoveries, and many suspected "Undiscovery wells" in Sirte Basin the CGG-ESTI© method and software is a quick look tool for missed and bypassed prospects generation and exploration rejuvenation of Sirte and any other mature basin. Indeed "hydrocarbon explorers should update their subsurface geothermal maps the same way they update their subsurface structural and stratigraphic maps" (Meyer and McGee, 1985) [2].

7. APPLICATIONS

There is thousands of dormant BHT measurements in records of early suspended, P&A, wet, tight or dry boreholes in every hydrocarbon producing basin that can be similarly analysed and mapped in the method presented in this paper. In conjunction with other hydrocarbon exploration techniques, the discovery/dry-hole ratio can be improved by incorporating geothermal gradient maps in risk analysis. In view of such long-time recognition of geothermal anomalies association with hydrocarbon traps; then why not use identical geothermal anomalies to justify reviewing thermally anomalous dry holes/closures for bypassed or unreached hydrocarbon traps in oil producing provinces? Furthermore, there are many potential applications of the presented compensated geothermal gradient method and CGG-ESTI© software:

7.1. Rejuvenating mature basins: Quick look screening of old dry-holes and re-plotting their corrected geothermal gradient and geothermal gradient maps may delineate hydrocarbon kitchens, migration paths and entrapment fairways of studied concessions, countries, basins or provinces. The CGG-ESTI© software is a quick look software for inputting, correcting and screening thousands of BHT databases of hundreds of wells in mature hydrocarbon producing basins for "un-discovery wells" with promising geothermal anomalies among hundreds or thousands of dry holes, as some of these "dry" wells may be commercially producible under present logistics, technological, economical or geo-political environments.

7.2. Prospects generation: Trends of anomalous geothermal gradients can be an added factor in integrative prospects generation and exploratory fairways projection, and justify proposing new seismic surveys over:
7.2.1. Anomalous geothermal gradient model "signature" of proven discovery wells to identify nearby longstanding dry holes that may have missed, bypassed or/and stopped short of hydrocarbon traps.
7.2.2. Selecting new exploration acreages incorporating several "un-discovery wells" with anomalous geothermal gradients within, and around the studied area or basin.
7.2.3. CGG-ESTI analysis identifies key wells with reliable geothermal gradients for new petroleum systems analysis.

7.3. Justification of dry-hole post-mortem and further actions: Dry hole with anomalous geothermal gradient provides justification for systematic post-mortem, and may lead to re-entry and test, or deepening the dry-hole:
7.3.1. Re-examining the dry-hole file with due diligence and compare drilling proposals with results, as the well may have been suspended or declared "dry" under past logistics, exploration economics or geopolitical circumstances.
7.3.2. Re-analyse wire-line logs using up to date parameters and software.
7.3.3. Reviewing drilled dry prospects for alternative geological and seismic interpretation, or acquiring new, additional or infill seismic coverage as the dry hole may have missed bypassed or stopped short of a hydrocarbon reservoir.
7.3.4. The CGG-ESTI method/technique is an additional tool in exploring stratigraphic traps that display no seismic structural closure or expression of sealed porous and permeable reservoirs by diagenetic alterations, facies changes or regional tectonic tilts.

7.4. Interim drilling decisions: In multiple targets drilling, and shallow target(s) proved dry, and the well's interim geothermal gradient is anomalous then drilling the deeper targets is justifiable, and drilling can be terminated if interim geothermal gradient is passive.

8. REFERENCES

[1] Geothermal Gradient Anomalies of Hydrocarbon Entrapment, Hagfa (Marada) Trough, Sirte Basin, Libya, Target Exploration Consultants' Report (Tar-6), 90p.

[2] Meyers, H.J. and H.W. McGee, 1985. Oil and gas fields accompanied by geothermal anomalies in Rocky Mountain region. AAPG Bull., v. 69, p. 933-945.