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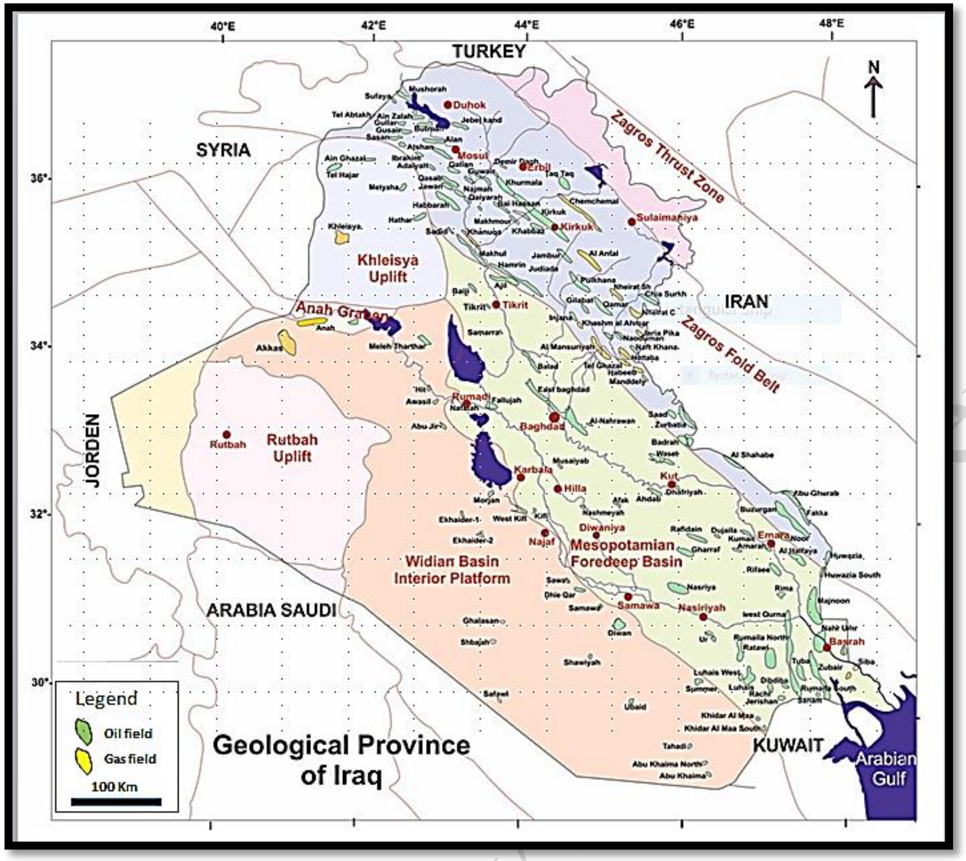
Target Exploration

Energy Geosciences Research & Development

Target



Geothermal Gradients and Geothermal Gradient Anomalies of Hydrocarbon Entrapments in

IRAQ and

Adjacent Territories in Iran, Jordan, Kuwait, Saudi Arabia and Syria

Target Exploration Report Tar5

Summary

Basically, this is a 360 page comprehensive geothermal gradients report with geothermal gradient maps of Iraq and adjacent parts of Iran, Jordan, Kuwait, Saudi Arabia and Syria in the area between Longitude 39° 00 00 E to 48° 00 00 E and Latitude 29° 00 00 N to 37° 00 00 N. It is also an indirect prospects generation report, which provides justifications to attempt "discovery by re-entry" of several thermally anomalous dry holes "**un-discovery wells**" to test potentially missed, bypassed or unreached probable hydrocarbon traps in the studied areas, especially where medium depth reservoirs were the primary targets for many P&A dry holes during early exploration years.

The Concept

Oil explorers realised since the early days of oil industry that wells penetrating hydrocarbon traps exhibits anomalous geothermal gradients. High geothermal anomalies characterise portions of thermally impeding sedimentary basins, in which hydrodynamic, stratigraphic and structural environments are actively focusing deep HTP fluids into shallower and thermally convective closed reservoirs. Such subsurface fluid migration process is responsible for lighter components (hydrocarbons) entrapment in the LTP shallow reservoirs if hydrocarbons are migrating along with the relatively higher density water. Dry holes and suspended wells (mainly because of low productivity and/or heavy oil contents) were found to cluster in a low CGG-high ESTI regimes, which characterize locations of low thermal impedance with ascending fluids and poor or breached seals.

Unlike other logging tools, bottom-hole temperature (BHT) recording devices (maximum recording mercury-in-glass thermometers) are one of the oldest un-evolved geophysical well logging tools. Early exploration BHT measurements are perfectly compatible and correlatable with present-day BHTs.

Today, thousands of BHT measurements lies dormant in records of early suspended, P&A, wet, tight or dry boreholes in every producing basin. Some of these "dry" wells may be commercially producible under present logistics, technological, economical or geo-political environments. 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?

The Software

Target Exploration developed and used exclusive geothermal gradient modelling software **(CGG-ESTI©)** to A. Input and creates Bottom Hole Temperature (BHT) databases, verifies and tests the reliability of the raw BHTs, and corrects them, B. Plot 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, C. Use the modelled anomalous geothermal signature of discovery, suspended and producing wells to identify old dry or "UN-DISCOVERY WELLS**"** that are displaying similar anomalies**.**

The Analyses

Target Exploration used the CGG-ESTI© software to input and generate Bottom Hole Temperature (BHT) database, correct the 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 In this study an exclusive computer program was used to create BHT database, correct, test the statistical significance of BHT measurements, calculate and plot Compensated Geothermal Gradients (CGG) and Extrapolated Surface Temperature Intercepts (ESTI) of 54 exploration and development wells in the study area (Long. 39° 00 00 E to 48° 00 00 E and Lat. 29° 00 00 N to 37° 00 00 N).

Discriminative computer contouring procedure was then applied on 54 statistically significant and less significant control wells with multi BHTs and 121 wells with single surface temperature (forced) geothermal gradients to generate regional as well as anomalous CGG-ESTI contours. 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.

The Report

The goals of this study project were: (1) mapping the geothermal gradients of North Arabia, (2) delineating geothermal gradient fairways and anomalies of oil and gas traps, then (3) locating and reviewing similar anomalies in the same area as they are indicators of potential, probable or possible, under-rated, bypassed or un-drilled hydrocarbon traps.

Using the CGG-ESTI data of 54 dry holes, producing and suspended wells, this study identified and delineated the regional geothermal fairways of gas and oil, and isolated areas of heavy oil and dry closures in North Arabia.

The study found an assortment of high geothermal gradient anomalies to be associated with proven oil and gas fields in various oil provinces of Iraq and Northern Arabia. The report delineated the regional geothermal migration and entrapment pattern of the studied area, identified 25 Proven geothermal gradient anomalies of hydrocarbon entrapment (i.e. associated with proven oil and gas fields), and used their model to identify and delineate 2 Potential, 3 Probable and 6 Possible geothermal gradient anomalies of hydrocarbon entrapment within the study area.

The Contents

Figures

5. Generalized stratigraphic correlation diagram across the northern part of the study area showing proven source, reservoir and seal rocks.
6. A conventional geothermal gradient map of the study area. The map was generated by manually contouring published and unpublished geothermal gradient values generated by forcing single ground surface temperatures on the BHT gradient.
7. A map showing fixed surface temperatures used by various authors to generate forced mean geothermal gradients in figure 6.
8. Diagrammatic illustration of a basin-type bottom-hole temperature profile showing the effect of annual surface temperature variations on the geothermal profile. Note that seasonal surface temperature variations are insignificant at the near surface equilibrium temperature (NSET).Mean geothermal gradient adopted in this study is a normal linear least square regression best fit of bottom-hole temperature readings against depths below ground surface. Linear Least square regression projects an extrapolated surface temperature intercept (ESTI) at zero depth which is intended to be an approximation of the NSET and may not be equivalent to the annual mean (average) ground surface, air or sea floor temperature.
9. A forced (fixed) or graphically calculated linear least square regression of bottom - hole temperatures against depth with a fixed average surface temperature for all control wells may differ from gradients derived through normal linear least square regression of the same well. The figure illustrates the difference in estimated depth of an isotherm using fixed AST geothermal gradient as compared with one derived from normal linear least square regression analysis.
10. A diagrammatic illustration of the importance of coupling the ESTIs with the calculated geothermal gradients of control wells; as identical mean geothermal gradients with different ESTIs may lead to differences in depths to an isotherm, (e.g. 1700 metres difference of isotherm between wells X and Y).
11. A statistically significant producing well in the study area. The large well-type symbol indicates relative statistical significance.
12. A statistically less significant well in the study area. Notice that the number of BHT reading are more than the well- spread BHTs of the statistically significant well in Figure 11, but the gradient is less representative of the whole drilled section because of BHT clustering in two points.

13. A graphical plot of a forced (fixed) single surface temperature geothermal gradient of a well in the study area. Note that the ESTIs, BHTs and TDs are synthetic and what has been researched and collected by Target E.C were only fixed surface temperature gradients.
14. CGG/ESTI cross-plot of all (undifferentiated statistically significant and less significant) multi BHTs wells used in the study. Notice that this figure is hard to interpret.
15. Compensated Geothermal Gradients/Extrapolated Surface Temperature Intercepts (CGG/ESTI) cross-plot of all producing multi BHT wells in the study area. The plot demonstrates clearly the clustering of most producing wells in a high CGG-low ESTI regime.
16. Compensated Geothermal Gradient/Extrapolated Surface Temperature Intercept (CGG/ESTI) cross-plot of all dry holes in the study area. The plot demonstrates the clustering of most dry holes in the low CGG-high ESTI zone.
17. CGG/ESTI cross-plot of statistically significant hydrocarbon producing wells among the studied wells.
18. CGG/ESTI cross-plot of statistically significant dry holes among the studied wells.
19. CGG/ESTI cross-plot of statistically significant suspended wells among the studied wells.
20. CGG/ESTI cross-plot of all significant dry holes and suspended wells in the study area.
21. Well location map illustrating proportional statistical significance of the BHT data and subsequent CGG and ESTI in control wells used in this study.
22. Compensated geothermal gradient contour map of the study area. Contour interval is 0.1° C /100 metres.
23. Extrapolated surface temperature intercept contours of the studied area, contour interval 5° Centigrade.

24. Geothermal gradient anomalies of hydrocarbon entrapment plotted against compensated geothermal gradient contours (black contours with contour interval = 5° Centigrade/100 metres) and extrapolated surface temperature intercept contours (blue contours of 0 and 35° Centigrade).
25. Well ---- of BPC, which was declared D&A in 19-- is, a good example of wells declared dry under past environments. As a result of this study we interpreted its geothermal signature as: probable trap-flank well in a source kitchen area. A review of the final well log revealed that it tested high-pressure gas and little water from the prolific Cretaceous Nahr Umr (Burgan) sandstone reservoir. In the final report of this well the BPC's concluded that there is a trap in the vicinity.
26. A map illustrating our interpretation of the regional exploration tracks of the CGG-ESTI map: The red tracts are with highest CGG-lowest ESTI trends indicative of locations of intense subsurface fluid migration and possible hydrocarbon entrapments. The tract do coincide with the regional structural elements of the area --------- etc.
The blue axes are trends with lowest CGG-lowest ESTI trends indicative of stratigraphic sections with low vertical fluid migration possibly due to the presence of deep and thick heat impeding source rock sections.
The broken green tracts are trends of possible meteoric water invasions of the Cretaceous reservoirs, which induced low CGGs and high ESTIs indicating poor sealing of heat convective reservoirs.
27. Regional 3rd order polynomial contours of all geothermal gradient values (CGGs and single surface temperature geothermal gradients) of the study. The map reveals the regional geothermal gradient background of the region.
28. A CGG-ESTI cross-plot of the Rut bah Platform.
29. A CGG-ESTI cross-plot of the wells influenced by the Euphrates Graben system.
30. A CGG-ESTI cross plot of statistically significant producing wells in the Basrah-Kuwait area.

31. A CGG-ESTI cross plot of statistically significant dry holes in the Basrah-Kuwait area.
32. A CGG-ESTI cross plot of suspended oil wells in the Basrah-Kuwait area.
33. Dendrogram of hierarchical clustering of 54 wells with multiple BHTs based on furthest neighbors analysis computed from the geothermal parameters (CGG, ESTI, SS, and Correlation Coefficient). The diagram illustrates the three groups of wells generated by the analysis, their status, statistical significance and location in the regional CGG/ESTI cross plot. Group 1 groups statistically significant wells that are producers.
Group 2 statistically significant wells grouped are: 3 suspended heavy oil well, 3 dry holes and 4 oil wells. The group corresponds to dry-suspended heavy oil wells and flank wells of the regional CGG/ESTI cross plot. Group 3 groups statistically significant gas well Risha-6 and dry hole Risha-30, both are in the producing wells domain in the regional CGG/ESTI cross plot, but are anomalously higher than the regional average for the producing wells.
34. A dendrogram of hierarchical clustering of 54 wells with multiple BHTs based on furthest neighbors analysis computed from the geothermal and geological parameters (CGG, ESTI, SS, correlation. coefficient, reservoir age, primary source rock age, reservoir's water salinity, TD. tectonic regime, API of the oil in the main reservoir). The diagram illustrates 7 groups of statistically significant wells generated by the analysis, their status, statistical significance and location in the regional CGG/ESTI cross plot.
35. Key to maps and figures used in this study.

Appendices

Appendix 1: Raw and corrected BH Temperature data and Geothermal Gradient plots of forced Geothermal Gradients with single surface temperature of 121 wells used in study.

Country	Iran	Iraq	Jordan	Kuwait	Saudi Arabia	Syria	Total Number of Used Wells
No. of Used Wells	30	57	7	5	0	23	121

Appendix 2: Raw and corrected BH Temperature data and Compensated geothermal gradient plots of 54 wells with multiple BHT data used in study.

Country	Iran	Iraq	Jordan	Kuwait	Saudi Arabia	Syria	Total Number of Used Wells
No. of Used Wells	0	38	3	8	2	2	53

Enclosures

Enclosure 1. Well location map of control wells used in study.
Enclosure 2. Manually contoured conventional geothermal gradient contours of the study area.
Enclosure 3. A map showing various surface temperatures used in generating fixed or forced geothermal gradients of Enclosure 2.
Enclosure 4. Well location map illustrating proportional statistical significance of the BHT data and subsequent CGG and ESTI of control wells used in this study.
Enclosure 5. Compensated geothermal gradient contour map of the study area. Contour interval is 0.1 °C/ 100 meters.
Enclosure 6. A contour map of the extrapolated surface temperature intercepts of the studied wells, contour interval 5° Centigrade.
Enclosure 7. Geothermal gradient anomalies of HC entrapment plotted against compensated geothermal gradient contours.

Success Rate

In our Target report on the geothermal gradient of Hagfa Trough, Libya (Tar-6) we found that out of the 31 dry holes and 19 producing or suspended wells used this study identified 14 closed geothermal gradient contour(s) anomalies. 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. 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.

Applications

The Report: This is a regional geothermal gradient report with raw BHT data and geothermal gradient map to be used by exploration geologists to identify depth and thickness of HC preservation window of exploration targets, and in selecting new exploration acreage within areas with variable geothermal gradients.

However, the report author identified geothermal gradient anomalies of hydrocarbon entrapment of 25 Proven geothermal gradient anomalies of hydrocarbon entrapment (i.e. associated with proven oil and gas fields), and used their model to identify and delineate 2 Potential, 3 Probable and 6 Possible geothermal gradient anomalies of hydrocarbon entrapment, encompassing several thermally anomalous dry holes of potential candidates for "discovery by re-entry".

Moreover, the report provides analogues for:

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.
2. Selecting new exploration acreages incorporating several "un-discovery wells" with anomalous geothermal gradients within and around Iraq.
3. Identifying key wells with reliable geothermal gradients for basin analysis.

A. **The Software:** The CGG-ESTI© software is a quick look software for screening large databases of wells in hydrocarbon producing basins for "un-discovery" dry holes with promising geothermal anomalies, as well as for justifying mid drilling decisions:

1. Quick look screening old wells and plotting their corrected geothermal gradient and geothermal gradient maps may delineate hydrocarbon kitchens, migration paths and entrapment fairways of the studied basin, province or country.

2. If the shallow drilling target proved dry, and the well's interim geothermal gradient is anomalous then drilling the deeper targets is justified. Otherwise, drilling can be terminated if the interim geothermal gradient is passive.

C. The Technique: A dry hole with anomalous geothermal gradient may provide justification for:

1. Re-examining the well file with due diligence as it may have been suspended or declared "dry" under past logistics, exploration economics or geopolitical circumstances.
2. Re-analysing the wire-line logs using up to date parameters and software.
3. Reviewing drilled dry prospects for alternative interpretation as the dry hole may have missed bypassed or stopped short of a significant hydrocarbon reservoir.
4. The technique can be an additional tool in exploring stratigraphic traps that display no seismic expression of sealed porous and permeable reservoirs by diagenetic or facies changes.

In conjunction with other hydrocarbon exploration methods, the discovery/dry-hole ratio can be improved by incorporating geothermal gradient maps in risk analysis. Indeed, "hydrocarbon explorers should update their subsurface geothermal maps the same way they update their subsurface structural and stratigraphic maps" (Meyer and McGee, *AAPG Bull, 1985*).

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