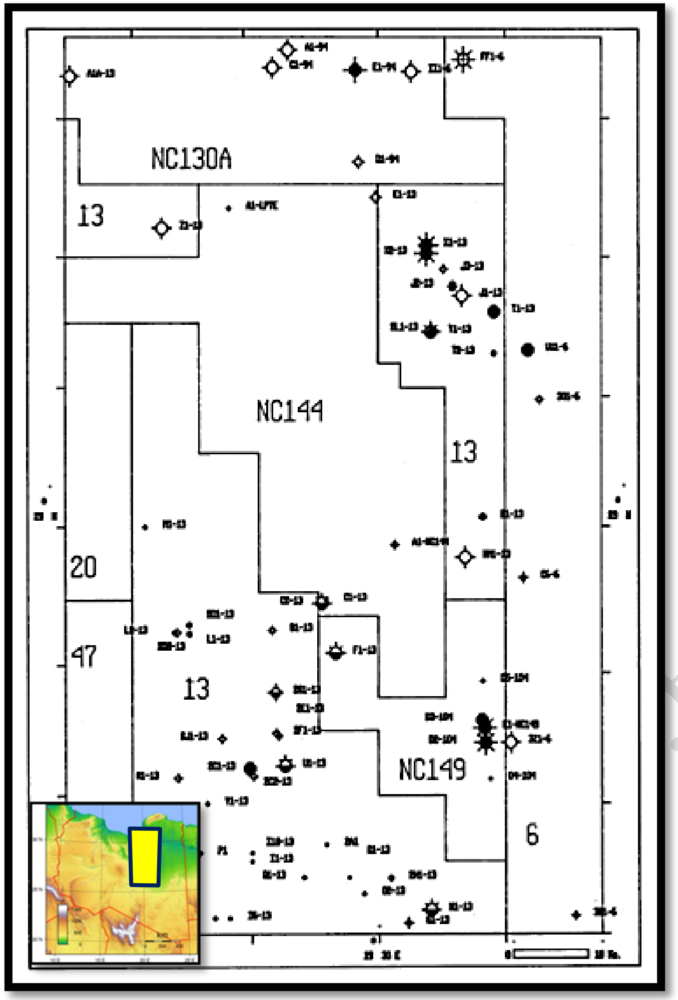
Target Exploration
Energy Geosciences Research & Development



Well locations map of the studied area

Geothermal Gradients and Geothermal Gradient Anomalies of Hydrocarbon Entrapment, Hagfa (Marada) Trough,

Sirte Basin, Libya

Target Exploration Report Tar6

Summary

Essentially, this is a geothermal gradients report with geothermal gradient maps of the Hagfa Trough in central Libya. However, in due course it is an auxiliary prospects generation report, which provides justifications for recommending re-entry of several thermally anomalous dry holes "un-discovery wells", to test potentially missed, bypassed or unreached probable hydrocarbon traps within the Hagfa Trough (i.e. discovery by re-entry).

The report cites examples of successful "discoveries by re-entry" of dry holes "un-discovery wells" in Sirte Basin, where medium depth reservoirs were the primary targets for hundreds of 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.

Unlike other logging tools, the early bottom hole temperature (BHT) recording device remained unchanged though the bulk of the HC exploration history. 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 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.

The study found high geothermal gradient anomalies to be associated with proven oil and gas fields in Hagfa (Marada) Trough area. **Out of the 31 dry holes and 19 producing or suspended wells used, fourteen closed contours anomalies were identified via our technique. 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 Report

This report is in 37 pages of text that reviews the theoretical background, discusses geothermal gradient mapping methods and explains the geothermal gradient correction, analyses and mapping methods used in the study. The report lists and discusses 29 identified and delineated geothermal anomalies of HC entrapment ranked as *9 PROVEN, 6 POTENTIAL, 2 PROBABLE and 12 POSSIBLE GEOTHERMAL GRADIENT ANOMALIES OF HYDROCARBON ENTRAPMENT.*

The report is well researched and illustrated, it includes:

1. Fifty A4 size geothermal gradient plots of control wells showing raw and corrected BHT data.
2. Twenty figures illustrating the research, the concept and the results of the study.

3. Five A2-size basin-wide geothermal gradients and geothermal gradient anomalies maps as enclosures showing: locations of more than 100 statistically ranked exploration and development wells, including key wells for basin analysis, surface temperature contours, geothermal gradient contours, geothermal gradient anomalies of proven, potential and probable hydrocarbon traps.
4. A Bibliography listing 70 publications on heat flow and geothermal gradients in relation to hydrocarbon exploration.

Figures

1. Location map showing oil and gas fields and major tectonic elements in the Hagfa (Marada) area. The shaded area between the Ora-Beda shelf to the WSW and the Zelten-Waha-Dor Marada high to the ENE delineates the location of the Hagfa (Marada) Trough.

2. East-West generalized stratigraphic correlation diagram across the Hagfa area showing proven source and reservoir rocks. The sections profiled to show relative thermal conductivities of the drilled rocks (rock conductivities estimated after Gretener, 1981).

3. Diagrammatic illustration of a basin-type bottom-hole temperature profile. It is showing the effect of annual surface temperature variations on the geothermal profile.

4. 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 my differ from that derived through normal linear least square regression. The figure illustrate the difference in estimating depth of an isotherm 130°C using fixed AST geothermal gradient as compared with one derived from normal linear least square regression analysis.

5. A diagrammatic illustration of identical mean geothermal gradients with different ESTIs may lead to a difference in estimating depth to an isotherm, e.g. 1700 meters difference of isotherm 100 °C between wells X and Y.

6. Typical statistically significant producing well in the study area.

7. Cross-plot of the significant producing and suspended wells in the study area. The plot demonstrates the clustering of producing and suspended wells within a high geothermal gradient zone.

8. Cross-plot of all studied wells in Hagfa Area.

9. Cross-plot of all statistically significant wells among the studied wells of Hagfa Area.

10. Cross-plot of statistically significant dry holes with no shows among the studied wells in the Hagfa Area.

11. Cross-plot of statistically significant dry holes with oil, gas and oil and gas shows among the studied wells in the Hagfa Area.

12. Cross-plot of all dry holes among the studied wells in the Hagfa Area. Wells that plot within the cluster zone of the producing and suspended wells display similar geothermal signature and may be considered as wells with potential, probable or possible anomalies.

13. Well K1-13 of Mobil oil Libya interpreted in this study as "probable flank well" was deepened after 25 years by Sirte Oil and encountered oil and gas at 300' below original TD. It has been renamed as producing well K1-NC149 (Figure 5) of the Wadi Oil Field.

14. Well location map of all control wells used in this study.

15. Well location map illustrating proportional statistical significance of the BHT data and corresponding geothermal gradients of control wells used in this study; in ascending order of well symbol sizes:

16. Compensated geothermal gradient contour map of the study area. Contour interval is 0.05 Degree Fahrenheit / 100 Feet.

17. Extrapolated surface temperature intercept contours of the studied area, contour interval 5 Degrees Fahrenheit.

18. Geothermal gradient anomalies of HC entrapment plotted against compensated geothermal gradient contours. Stippled areas on the geothermal gradient map are locations of the main proven, potential, probable and possible geothermal gradient anomalies of migration and entrapment.

19. Flow chart illustrating the procedure of discriminative computer contouring used to map the anomalies in this study.

20. Key to maps and figures used in the report.

Appendices

Raw and corrected BH Temperature data and Geothermal Gradient plots of 50 wells:

Well 3B1-6	Well C6-6	Well FF1-6	Well II1-6	Well M1-6
Well 3O1-6	Well UU1-6	Well 3Z1-6	Well A1a-13	Well B1-13
Well C2-13	Well 2C1-13	Well 2C2-13	Well 2C4-13	Well 2D1-13
Well 2D2-13	Well E1-13	Well 2E1-13	Well F1-13	Well 2F1-13
Well G1-13	Well 2G1-13	Well 2H1-13	Well J1-13	Well J2-13
Well J3-13	Well 2J1-13	Well K1-13	Well L1-13	Well 2L1-13
Well MM1-13	Well N1-13	Well R1-13	Well S1-13	Well T1-13
Well T2-13	Well U1-13	Well X1-13	Well X2-13	Well Y1-13
Well Z1-13	Well A1-94	Well B1-94	Well C1-94	Well D1-94
Well E1-94	Well D2-104	Well D3-104	Well A1-NC144	Well K1-NC149

Enclosures

Enclosure 1. Well location map of all control wells used in this study.

Enclosure 2. Well location map illustrating proportional statistical significance of the BHT data and subsequent CGG and ESTI of control wells used in this study; in ascending order of well symbol sizes.

Enclosure 3. Compensated geothermal gradient contour map of the study area. Contour interval is 0.05°F / 100 Feet.

Enclosure 4. Extrapolated surface temperature intercept contours of the studied area, contour interval 5°F.

Enclosure 5. Geothermal gradient anomalies of HC entrapment plotted against compensated geothermal gradient contours.

Success Rate

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.

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.

Applications

A. The Report: This is a geothermal gradients report which used geothermal gradient anomalies of hydrocarbon entrapment for prospects generation. The report delineates 6 potential, 2 probable and 12 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 the Hagfa Trough.
3. Identifying key wells with reliable geothermal gradients for basin analysis.

B. 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.

D. In conjunction with other hydrocarbon exploration techniques, 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***).

For an example of our publication of this geothermal exploration technique on Libya, see:

Ibrahim, MW and G. Reeh (2018 B) Geothermal gradient anomalies of hydrocarbon entrapment at central Sirte basin, Libya: a mature basin rejuvenation technique. Extended Abstract. Geo 2018 Conference and Exhibition, 5-8 March 2018, organised by AAPG ME Section, Manama, Bahrain, among our publications **on Libya and** other countries **in the publication list below.**

Publications

1. Ibrahim MW (1986) Compensated geothermal gradient: New Map of old data. AAPG Bull 70 (5) pp 603. Abstract.

2. Ibrahim MW (1988) Compensated Geothermal Gradient Anomalies in a mature hydrocarbon basin: Lake Pontchartrain, Lake Decade and Eugene Island, the Gulf Coast, Louisiana, USA. AAPG Bull 72 (2) pp 200. Abstract.

3. Ibrahim MW (1993) Geothermal Gradient Anomalies of hydrocarbon Entrapment, UKCS North Sea. (Abstract). In Proc. of 10th Iraqi Geological Congress, Union of Iraqi Geologist, Baghdad, 28-31 Feb. 1992.

4. Ibrahim MW (1994) Geothermal Gradient Anomalies of Hydrocarbon Entrapment, UKCS Quadrants 35-54, In Proceedings of European Petroleum Computer Conference, 15-17 March 1994, Aberdeen, SP Paper No. 27547, pp 85-96. (Ibrahim, 1994).

5. Ibrahim MW (1994) Geothermal Gradient Anomalies of Hydrocarbon Entrapment in the Middle East and North Africa, In Proceedings of GEO 94 the Middle East Geosciences Exhibition and Conference, 25-27 April 1994, Bahrain, Vol.2, pp 543-552.

6. Ibrahim MW (1996) Cretaceous Oil Plays in Mesopotamia, (Abstract). In PESGB Farm-in / Farm-out Seminar, 15 March 1996, London, 1p.

7. Ibrahim MW (1997) Geothermal gradient anomalies of hydrocarbon entrapment, Al-Hagfa Trough, Sirt Basin, Libya. In Geology of Sirt Basin, Salem m et al, Eds. Elsevier pub. Co., pp 419-433.

8. Ibrahim, MW (1999) Petroleum Geology and Hydrocarbon Provinces of Iraq. In Iraqi Petroleum Conference 1999, ENTRC-TARGET C. G., 9-10 September 1999, Imperial College, London. 17p.

9. Ibrahim, MW (2000) Missed, By-passed, and Under-estimated Hydrocarbon Traps: Examination of Basic Exploration Records Reveals Potential "Un-Discovery" Wells in Libya, (Abstract). Geo 2000, 4th. Middle East Geo-sciences Conference, 27-29 March, Bahrain. GeoArabia, V. 5, No. 1, p113.

10. Ibrahim, MW (2000) Missed, By-passed, and Under-estimated Hydrocarbon Traps: Examination of Basic Exploration Records Reveals Potential "Un-Discovery" Wells in Libya, (Abstract). AAPG Annual Convention, 16-19 April 2000, Louisiana, p. A-72.

11. Ibrahim, MW, (2002) Missed, Bypassed, and Underestimated Hydrocarbon Traps: Analysis of Basic Exploration Records Reveals "Un-Discovery Wells" in North Arabia, (Abstract). In AAPG Annual Convention, Houston, Texas, USA.

12. Ibrahim, MW (2007) Missed, Bypassed and Under-estimated Hydrocarbon Traps: Analysis of Exploration Records Reveals "Un-discovery Wells" in North Arabia, In MEOS, 15th Middle East Oil Show and Conference, 11-14 March 2007, SPE, Bahrain, Conference CD.

13. Ibrahim, MW. (2008). Missed, Bypassed and Under-Estimated Hydrocarbon Traps (Analysis of BHT Records Reveals "Undiscovery Wells" in Some OAPEC Countries). In Symposium on "Development in Petroleum Exploration & Production Technologies", Jointly Organized by OAPEC and the Oil and Gas National Authority in Kingdom of Bahrain, Manama-Kingdom of Bahrain; 10-12 November, 2008.Conf. Abstracts, P. 31-33. (IBRAHIM, 2008, ABSTRACT).

14. Ibrahim, MW. (2017B) Using geothermal gradient anomalies of hydrocarbon entrapment in rejuvenating mature basins and identifying missed and bypassed traps, 1P Abstract, Geothermal Cross Over Technology Workshop. Organised by AAPG Europe Section, Collingwood College; Durham University, UK. 25th - 27th April 2017. IBRAHM 2017

15. Ibrahim, MW. (2017C) Geothermal gradient anomalies of hydrocarbon entrapment of central Sirte Basin, Libya: a mature basin rejuvenation technique, Pp.152-153 extended abstract, Abstracts volume, 16th African conference, organised by the PESGB at Business Design Centre, London, UK. 31 August-1 September 2017. 172p.

16. Ibrahim, MW. (2017F) Application of compensated geothermal gradients (CGG-ESTI©) method in mature basins rejuvenation and prospects generation. Abstract and [ppp] in MENA 2017 Oil and Gas Conference (Energy Crossovers of MENA), the 11th Middle East and North Africa Oil and Gas Conference, 18-19 September 2017, organised by Target Exploration at the Imperial College, London, UK., 50P and one PDF CD. MENA 2017

17. Ibrahim, MW and B. Al-Kubaisi (2018A) Geothermal gradient anomalies of hydrocarbon entrapment at Southern North Sea basin, UKCS: a mature basin rejuvenation technique. Extended Abstract. Geo 2018 Conference and Exhibition, 5-8 March 2018, organised by AAPG ME Section, Manama, Bahrain. IBRAHIM 2018A.

18. Ibrahim, MW and G. Reeh (2018 B) Geothermal gradient anomalies of hydrocarbon entrapment at central Sirte basin, Libya: a mature basin rejuvenation technique. Extended Abstract. Geo 2018 Conference and Exhibition, 5-8 March 2018, organised by AAPG ME Section, Manama, Bahrain. IBRAHIM 2018B (PPTX)

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