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GEOTHERMAL GRADIENT ANOMALIES OF HYDROCARBON ENTRAPMENT AT SOUTHERN NORTH SEA BASIN, UKCS: A MATURE BASIN REJUVENATION TECHNIQUE

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ABSTRACT

Anomalous geothermal gradients of oil and gas fields are known since early well logging days; they are by-products of migration, entrapment and leakage of heat transporting fluids. This paper presents a computerised procedure (CGG-ESTI©) to correct Bottom-hole temperatures (BHTs), calculate and plot the geothermal gradients of individual wells, conduct interactive cross plot analysis geothermal gradient of 500 Exploration, production, suspended and dry-holes in the UKCS of the Southern North Sea Basin in order to define the limits of anomalously high geothermal gradients of known fields and discoveries, and use their anomalous geothermal cluster limits to identify missed and/or bypassed hydrocarbon traps in dry-holes showing similar geothermal anomalies among the 500 used wells. The study identified fifty proven, ten potential, eleven probable and twenty six possible CGG-ESTI anomalies of hydrocarbon entrapment, which amounts to 54% to 75% success ratio*. Geothermal anomalies of hydrocarbon entrapment is a quick look technique for integrative prospects generation, mature basin rejuvenation, dry-hole post-mortems and re-entry justification of possible, probable or potential "un-discovery wells" listed as dry holes in the North Sea and other mature basins.

EXTENDED ABSTRACT

The Objectives

Anomalous geothermal gradients of oil and gas fields are known since early logging days; they are by-products of migration, entrapment and leakage of heat conveying fluids. Bottom-hole temperatures (BHT) acquired by calibrated maximum recording thermometers permits mixing of old and new BHTs. This paper argues for a procedure to identify and map such geothermal gradient anomalies in order to find probable-potential undiscovered or bypassed hydrocarbon traps in or near dry-holes that are showing similar geothermal anomalies among a database of 500 exploration, production, suspended and dry wells in UKCS of the North Sea.

The Concept

Wells penetrating hydrocarbon traps exhibits anomalously higher geothermal gradients than adjacent dry-holes have been consistently published since early well logging days, (Ibrahim, 1994). 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 BHTs of old and new well logs at mature basins.

The Software

An exclusive geothermal gradient modelling software **(CGG-ESTI©)** was used to: **A**. Input and create Bottom Hole Temperatures (BHTs) databases, verifies and tests the reliability and corrects raw BHTs **B**. 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 **C.** 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, (Ibrahim, 1994)**.**

The Workflow

A. The CGG-ESTI© was used to input raw BHT readings below GL, correct, statistically test the BHT records and plot the corrected geothermal gradient and corresponding extrapolated surface temperatures of the wells, and use our incorporated "Statistical Sample Significance Test" to identify the wells with statistically significant BHT data. **B**. Cross plot the compensated geothermal gradients (CGG) against extrapolated surface temperature (ESTI) for all wells to identify the thermal regime of the area and/or basin. **C.** Cross plot significant CGGs vs. ESTIs to interactively define the secluding limits of dry holes cluster against producing and suspended wells cluster. **D.** Conduct discriminative contouring (Ibrahim, 1994) of the statistically significant CGGs and all CGGs and the statistically significant ESTIs and all ESTIs to generate compensated geothermal gradient contours (CGG), and extrapolated surface temperature intercepts contours (ESTI) of the studied quadrants. **E.** An overly of the two seclusion limits identified by CGG-ESTI cross-plot analysis should delineate the anomalous hydrocarbon entrapment fairways.

The Results

Average optimum regional anomalous CGG and ESTI secluding limits were established for producing wells in most of the Southern North Sea UKCS. This study delineated 50 proven, 10 potential, 11 probable and 26 possible CGG-ESTI anomalies of hydrocarbon entrapment were identified, which amounts to 54% to 75% success ratio, (Ibrahim, Tar-8).

Conclusions

1. Computerised graphical BHT correction of North America (Kehle,1972 and 1973) proved to be satisfactory, and CGG-ESTI cross-plot analysis revealed clustering of producers and suspended wells vs. dry holes and non-producer wells, which interactively explored to decide the optimum CGG and ESTI contours that delineate the geothermally anomalous spots and trends.
2. The CGG-ESTI mapping of geothermal gradient anomalies of hydrocarbon entrapment is a quick look tool for integrative prospects generation, mature basin reviews and re-entry justification of possible, probable or potential "un-discovery wells" listed as dry holes in the North Sea and other mature basins.
3. Citing several references they concluded that "hydrocarbon explorers should update their subsurface geothermal maps the same way they update their subsurface structural and stratigraphic maps" (Meyer and McGee, 1985).

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 addition to prospects generation there are other potential applications of the presented compensated geothermal gradient method and **CGG-ESTI**© software:

A. 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:
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 studied area or basin.
3. CGG-ESTI analysis identifies key wells with reliable geothermal gradients for new petroleum systems analysis.

B. 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:

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.
2. Re-analyse wire-line logs using up to date parameters and software.
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.
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 and facies changes..

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

D. 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.

E. Geothermal Energy Exploration and Prospects Generation: The CGG-ESTI and compensated geothermal gradient mapping method can be used for mapping the depth and thermal level of rock formations capable of generating steam, and in screening old shut-in or dry-holes for potential conversion to geothermal energy production. (Ibrahim, 2017).

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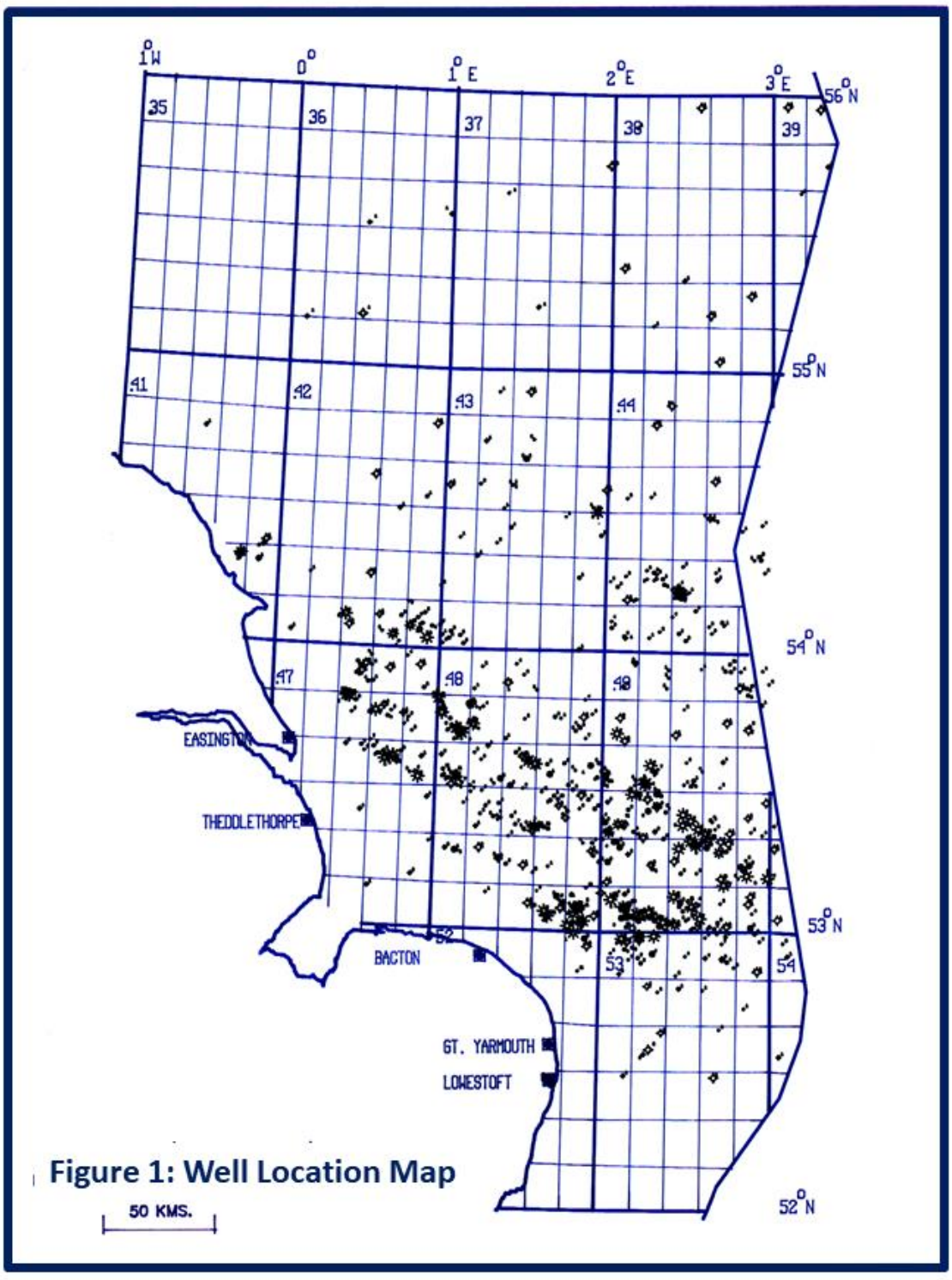

Figure 1: Well Location Map

Figure1. Well location map of the Southern North Sea Basin, UKCS. The size of well symbols corresponds to the statistical significance of geothermal gradients BHT data and corresponding extrapolated surface temperature intercepts of the well.