βαpp

Target Exploration

Energy Geosciences Research & Development

Target

GEOTHERMAL GRADIENT ANOMALIES OF HYDROCARBON ENTRAPMENT AT CENTRAL SIRTE BASIN, LIBYA: A MATURE BASIN REJUVENATION TECHNIQUE

Muhammad W Ibrahim

Target Exploration Consultants

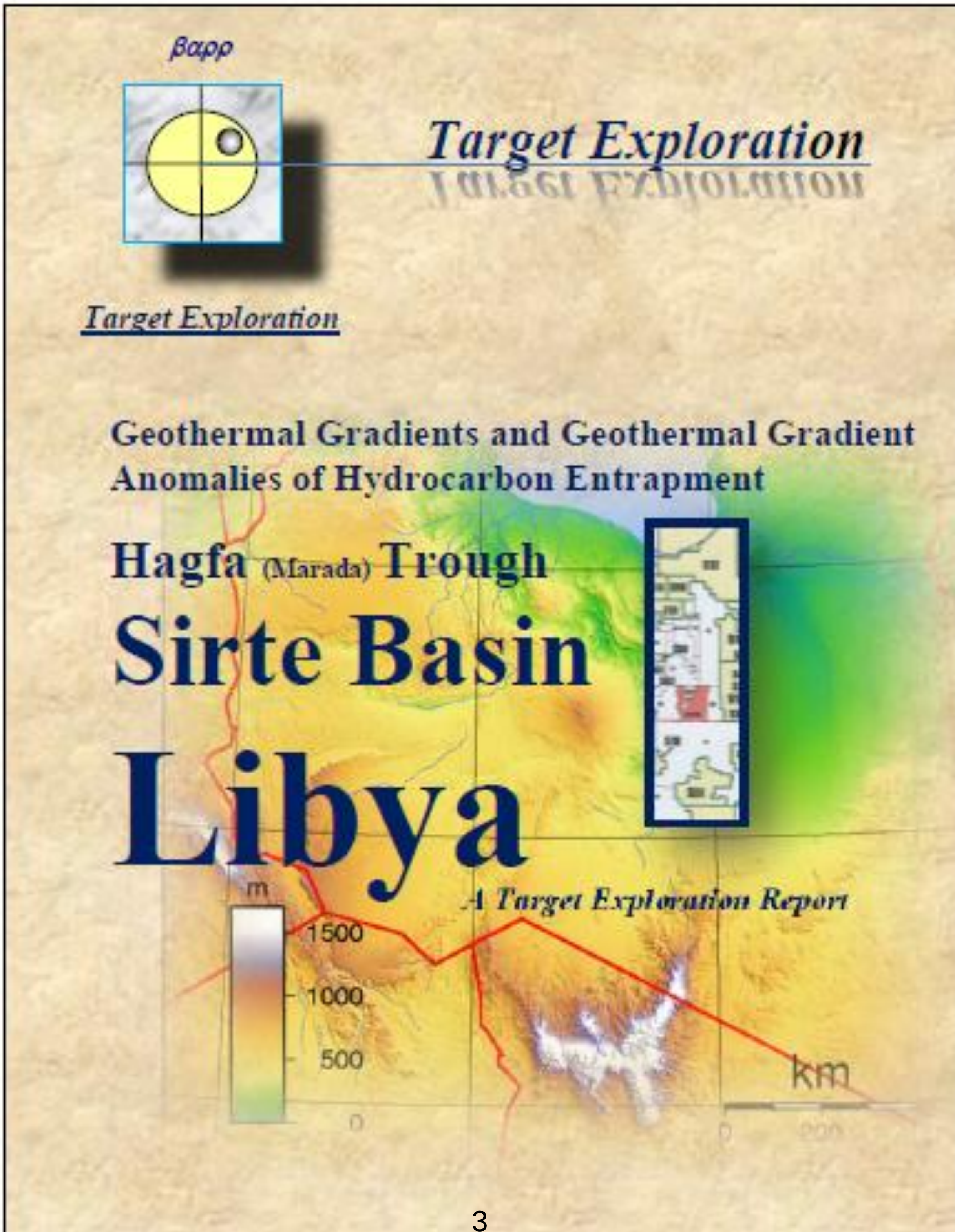
targetexploration.com

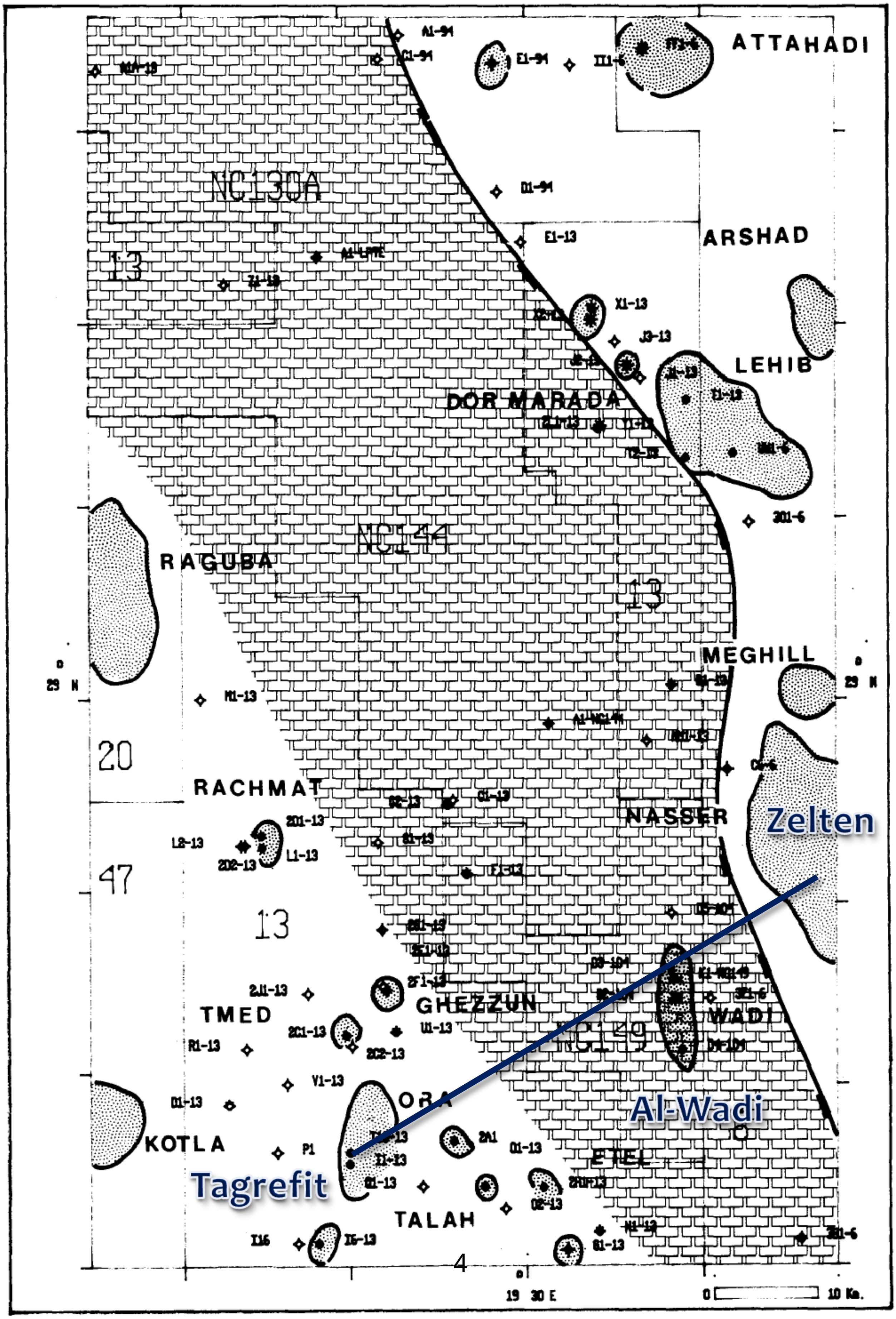
Geo 2018 Conference and Exhibition,

5-8 March 2018, Bahrain

1. **OBJECTIVES**
2. **LOGGING TOOL**
3. **CONCEPT**
4. **SOFTWARE**
5. **WORKFLOW**
6. **INTERPRETATION OF RESULTS**
7. **APPLICATIONS**
8. **CONCLUSIONS**
9. **REFERENCES**

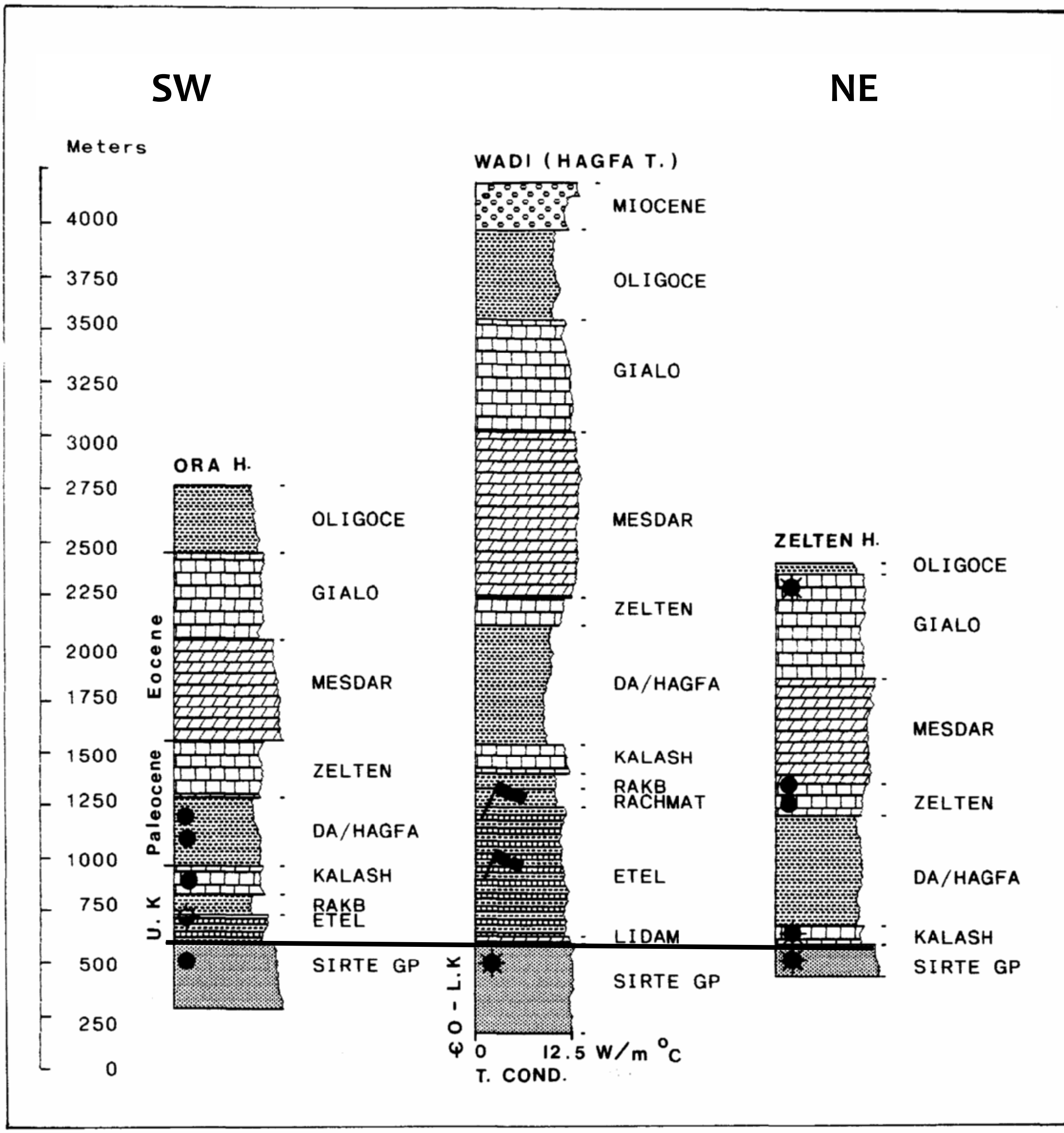
Hagfa Trough, Libya



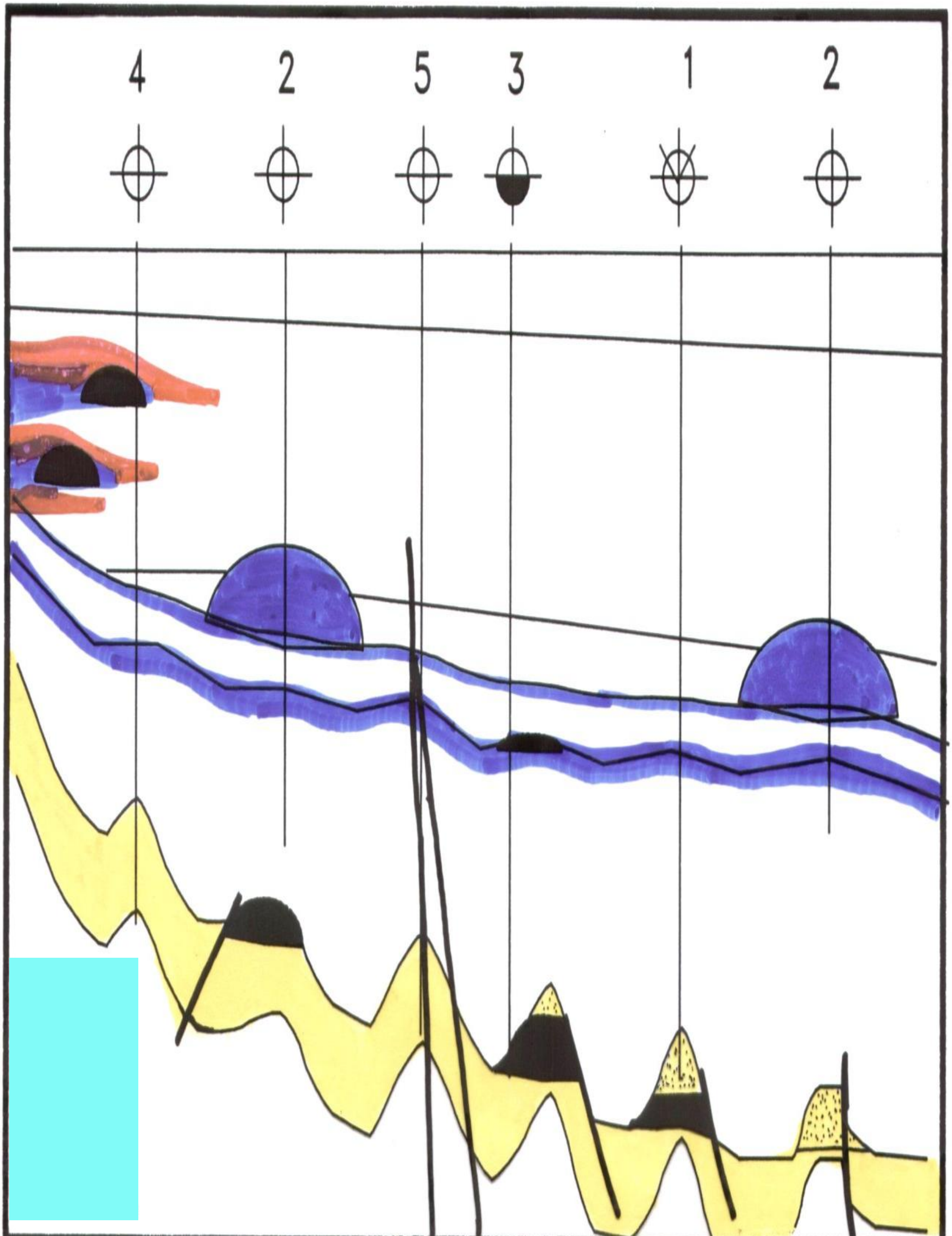

ATTAHADI
A1-94
C1-94
E1-94
NC130A
D1-94
E1-13
ARSHAD
13
X1-13
J3-13
LEHIB
DOR MARADA
3D1-6
NC144
RAGUBA
13
MEGHILL
29 N
M1-13
20
RACHMAT
NASSER
Zelten
2D1-13
L2-13
L1-13
2D2-13
47
13
2J1-13
TMED
GHEZZUN
WADI
2C1-13
U1-13
R1-13
2C2-13
NC149
V1-13
D1-13
ORA
Al-Wadi
KOTLA
P1
Tagrefit
2A1
ETEL
TALAH
I16
I6-13
19 30 E
0
10 Km.

1

Stratigraphy of Hagfa Trough, Central Sirte Basin



Examples of Missed & Bypassed HC Traps: Sirte Basin



1. THE OBJECTIVES

1. Collect and correct BHTs of 53 exploration, production, suspended and dry-holes at Hagfa Trough, Central Sirte Basin.

2. Use linear regression to calculate and plot the Compensated Geothermal Gradients (CGG) and Extrapolated Surface Temperature Intercepts (ESTI) of the control wells.

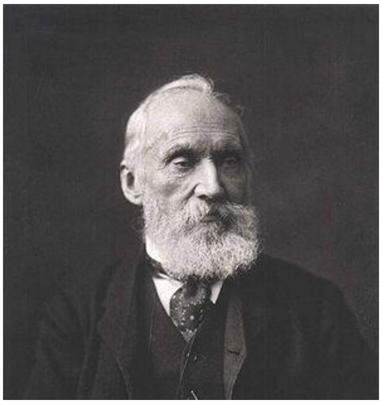
3. Cross-plot the CGGs vs ESTIs of studied wells to identify limit of anomalous CGGs and ESTIs associated with discovery and producing gas wells.

4. Contour map the CGGs and ESTI of all wells to identify and delineate the areal extend of geothermal gradient anomalies.

5. Use anomalous association of CGG-ESTI to delineate Proven Discoveries and Potential, Probable, and Possible Undiscovered or Bypassed Hydrocarbon Traps in/or near dry-holes showing Anomalous Geothermal Gradients.

2. THE LOGGING TOOL

Unlike other well logging tools, the bottom hole temperature (BHT) recording device remained unchanged and uniformly calibrated since invention and introduction to the well drilling industry; which make the geothermal gradient a valuable quick-look method in reviewing BHTs measurements of old and new well temperature logs at mature basins.



Well logging began when Lord Kelvin made measurements of temperature in water wells in England (1846)

The mercury-in-glass thermometer was invented by Physicist Daniel Gabriel Fahrenheit in Amsterdam (1714).

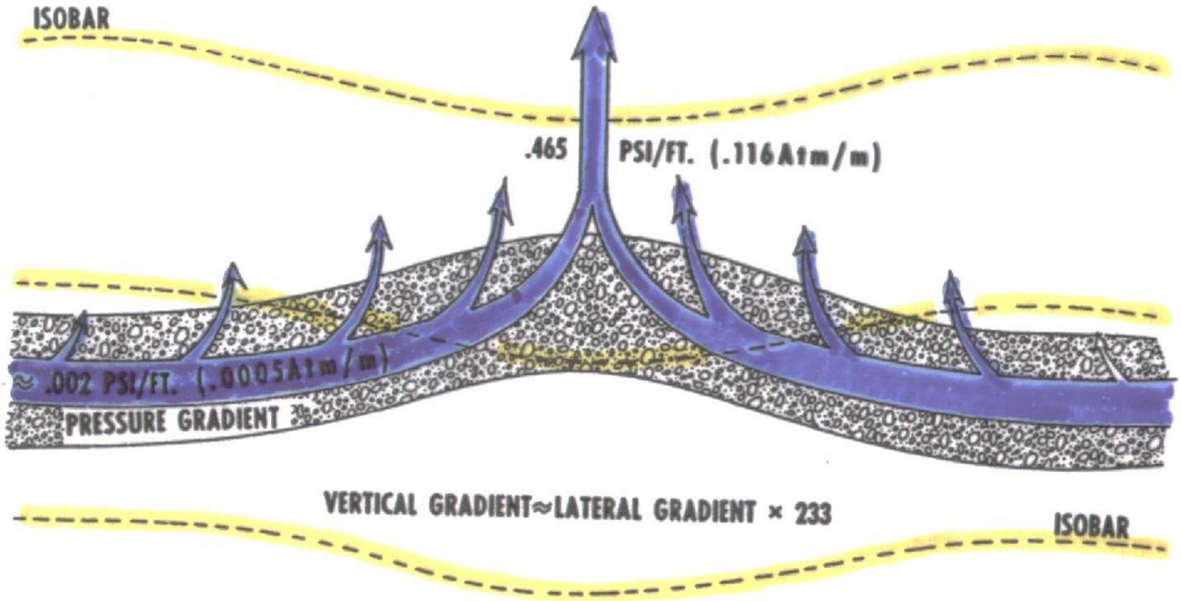
3. THE CONCEPT

A. Wells penetrating hydrocarbon traps exhibits anomalously higher geothermal gradients than adjacent dry-holes have been consistently published since early well logging days, (Meyer and McGee, 1985).

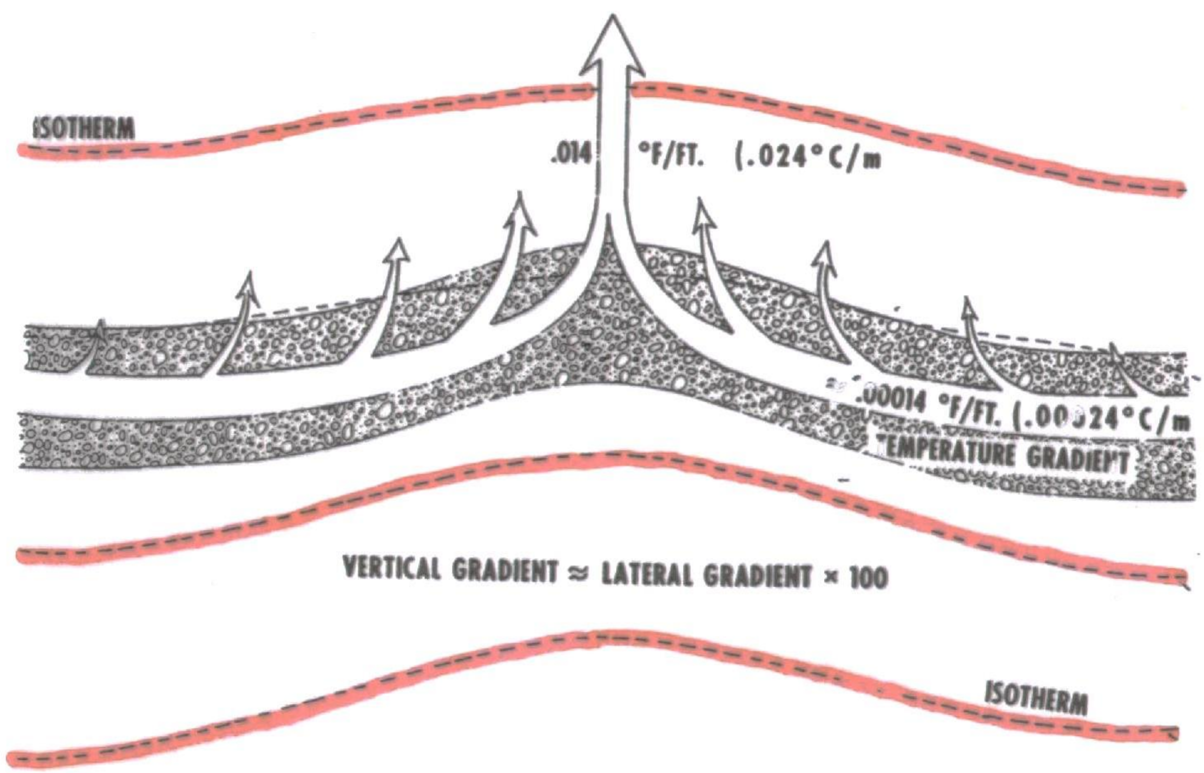
B. The high geothermal anomalies reflects thermally impeding parts of sedimentary basins in which hydrodynamic, stratigraphic and structural environments are actively converging deep HTP fluids into thermally convective shallower reservoirs.

C. Such subsurface fluid migration process is responsible for entrapments of HTP components (H2O then HC) in sealed shallower LTP reservoirs.

D. Bottom-hole temperatures (BHT) acquired by calibrated maximum recording thermometers permits mixing of old and new BHTs.

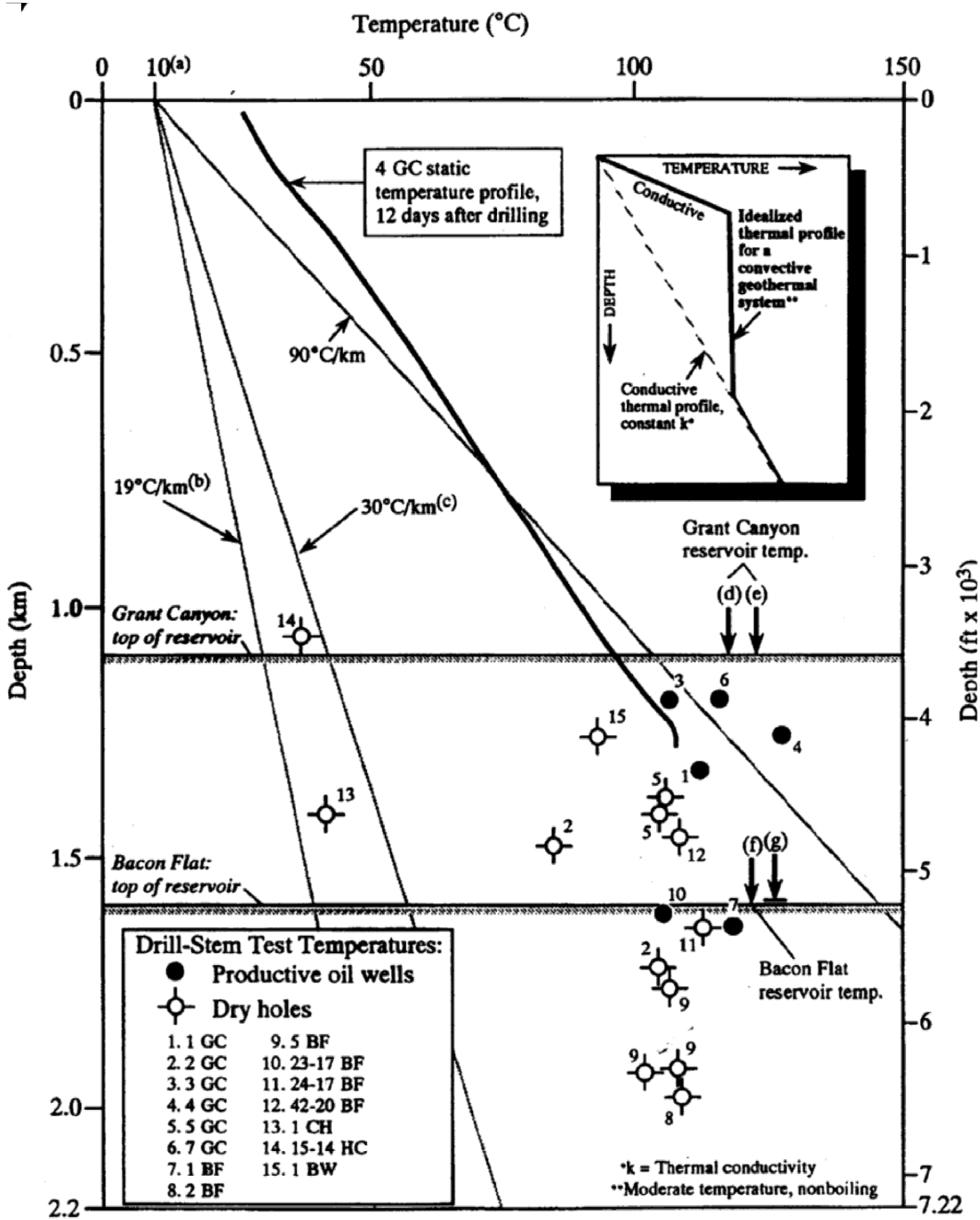


Pressure change imposed on convergent, upward-moving waters and their contents.



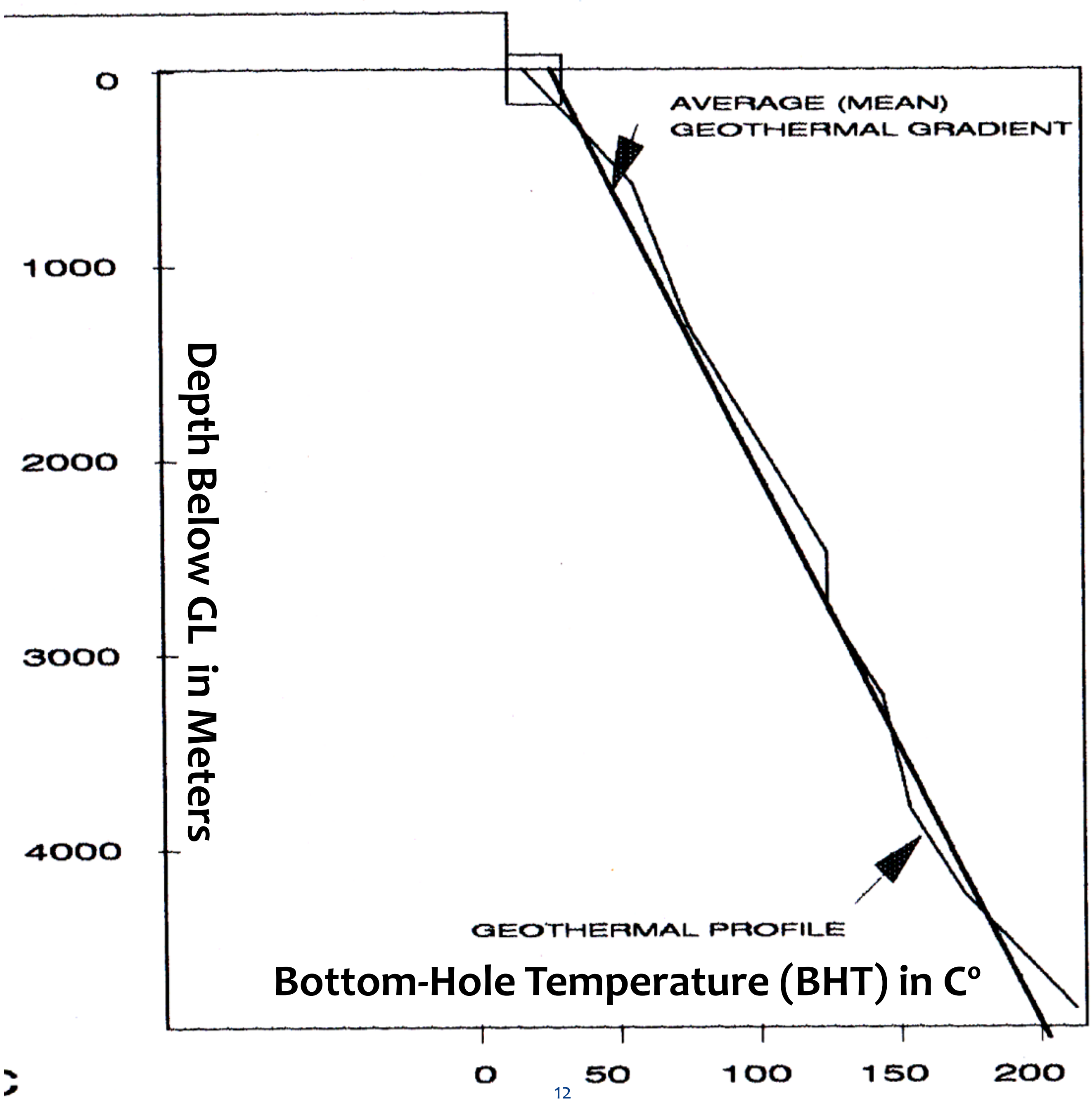
Temperature change imposed on convergent, upward-moving waters and their contents.

After Roberts, III, 1980

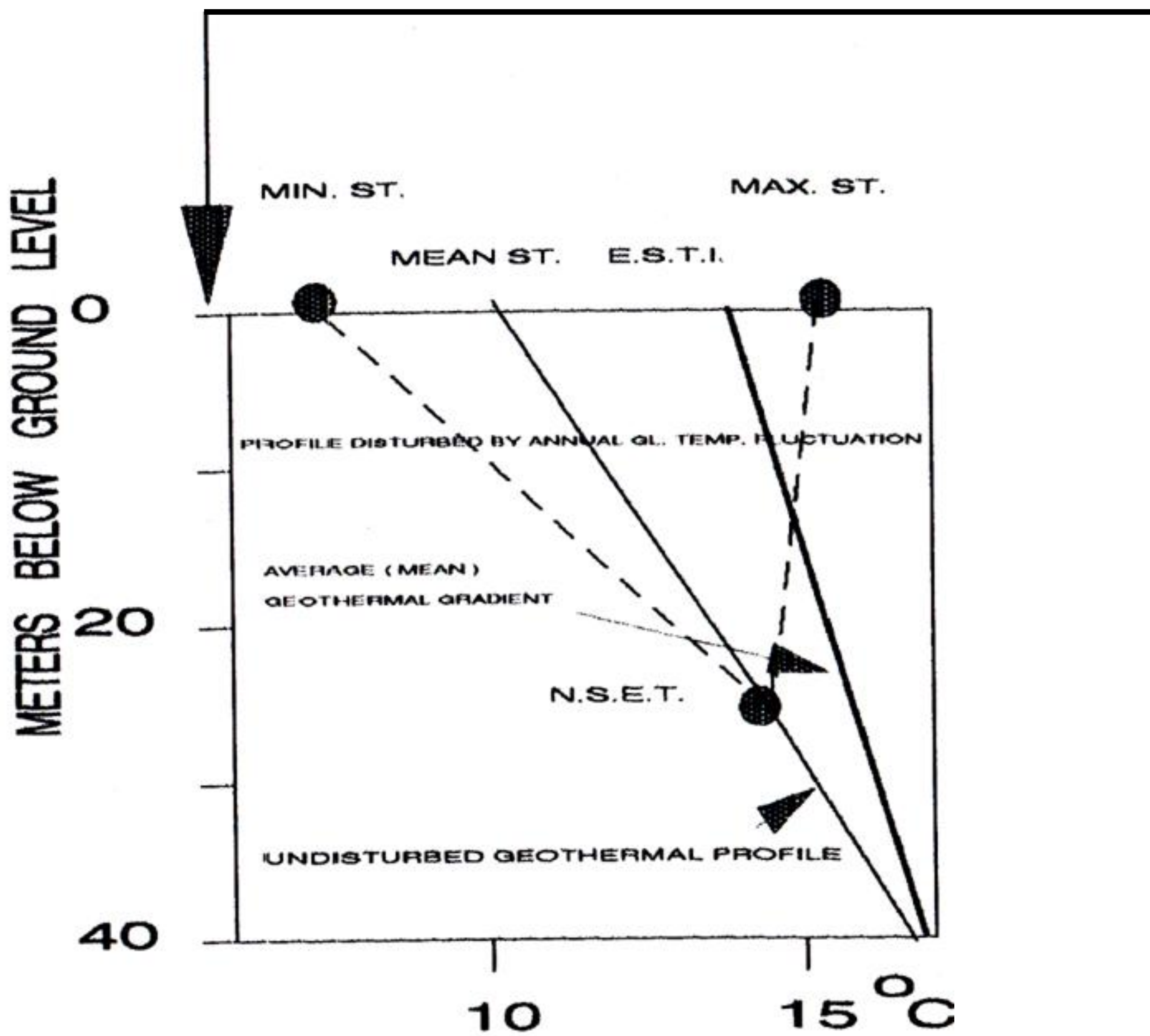


(After Meyer and McGee 1984)

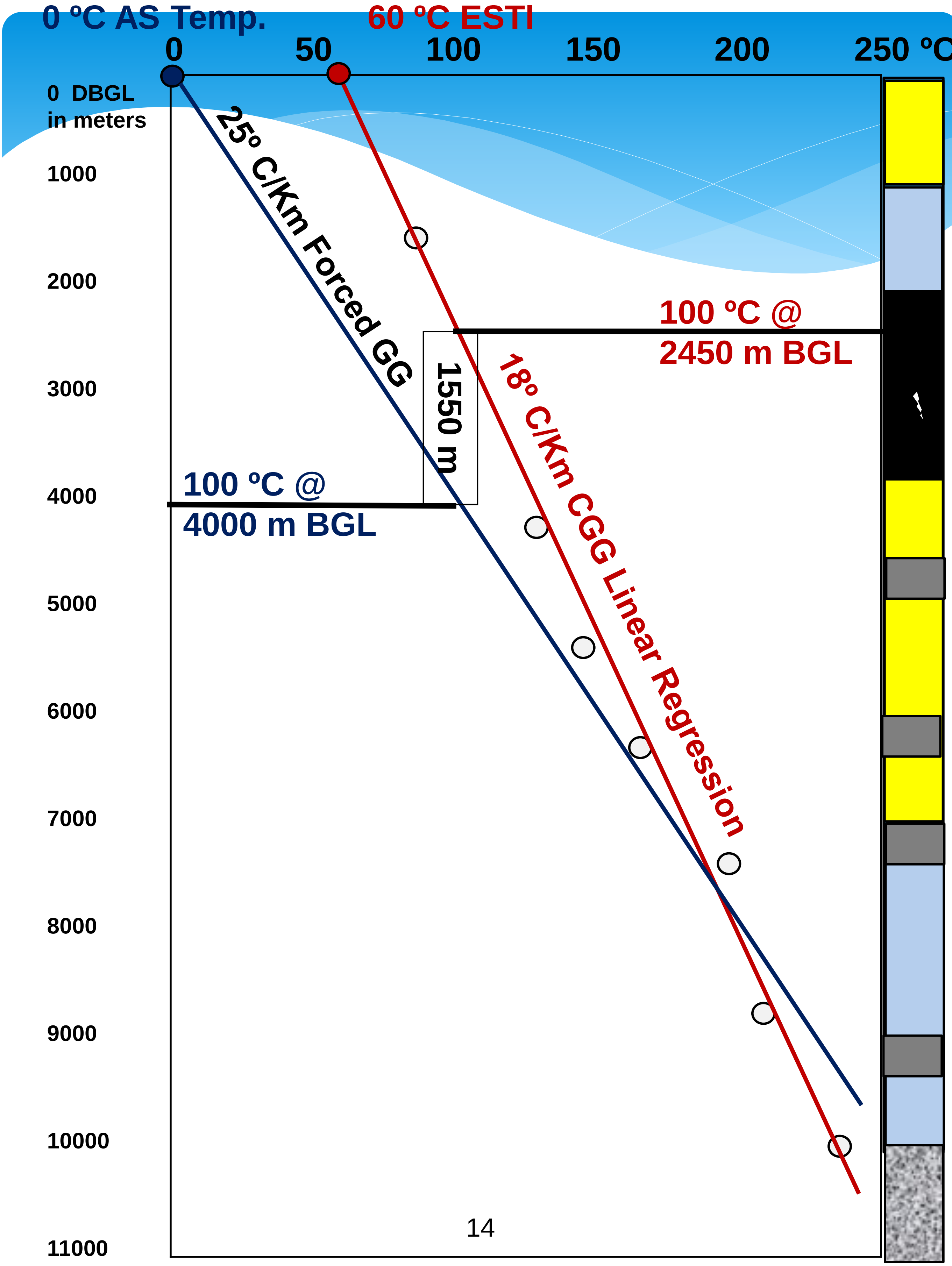
Geothermal Profile vs. Geothermal Gradient



Mean Surface Temperature vs. Near-Surface Equilibrium Temperature



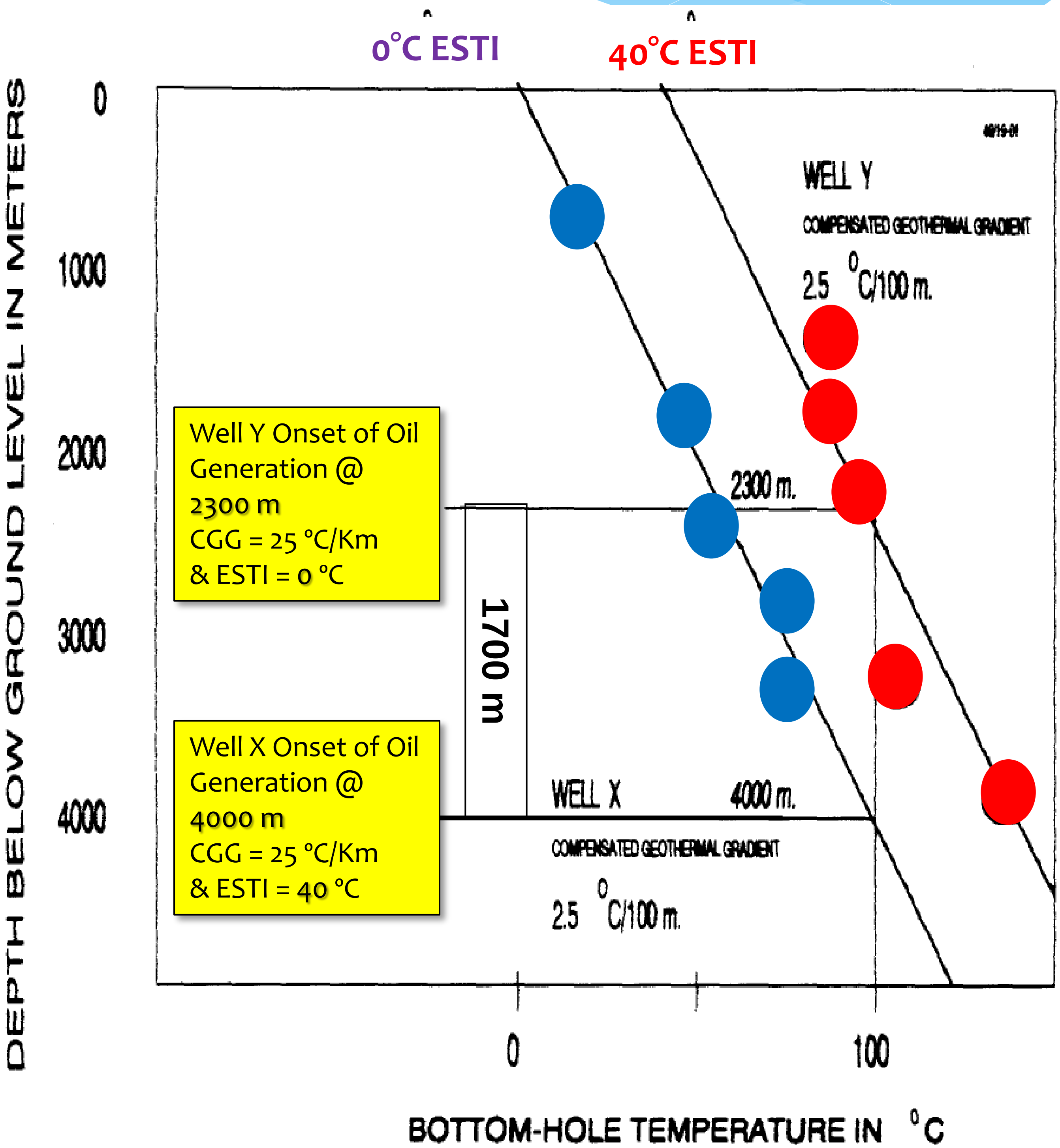
Bottom-Hole Temperature (BHT) in °C



0 ºC AS Temp.
60 ºC ESTI
0
50
100
150
200
250 ºC
0 DBGL
in meters
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
25º C/Km Forced GG
18º C/Km CGG Linear Regression
1550 m
100 ºC @
2450 m BGL
100 ºC @
4000 m BGL

1700 m Depth Difference to Temp. 100 C from Identical CGGs with different ESTIs

To map the Geothermal Gradients, statistical CGGs and ESTIs values of control wells must be used & contoured



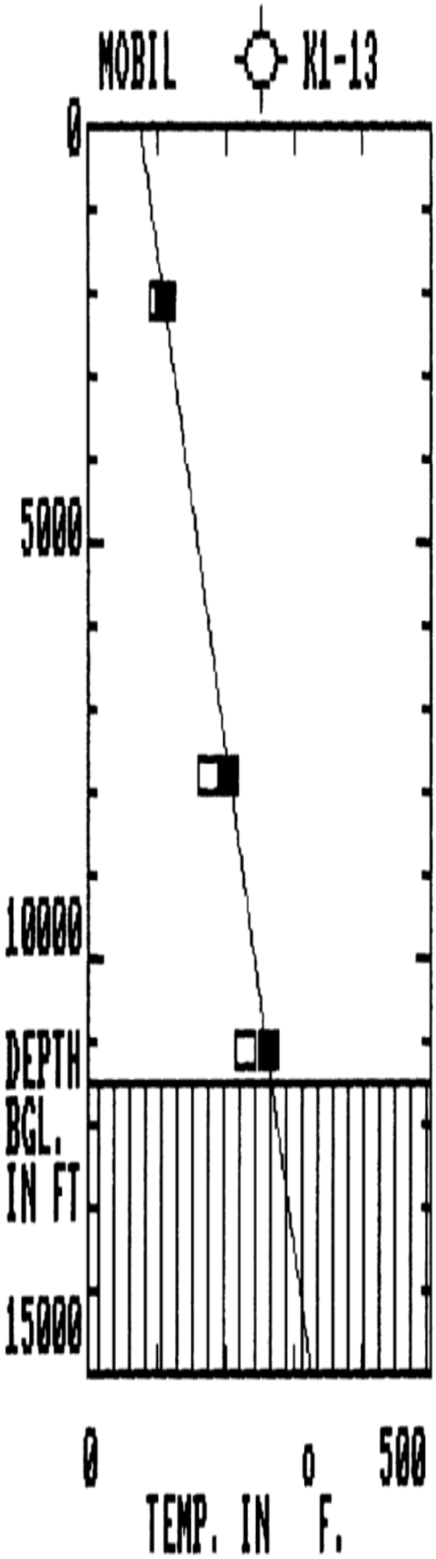
4. THE SOFTWARE

Compensated Geothermal Gradient – Extrapolated Surface Temperature Intercept (CGG-ESTI©) geothermal gradient modelling software 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 modelled anomalous geothermal CGG-ESTI signature of discovery, suspended and producing wells to identify possible, probable or potential "Un-discovery wells" displaying similar geothermal gradient anomalies from low – normal geothermal gradients dry-holes, (Ibrahim, 1994).



AREA : HAGFA
STATUS: 0
LAT. : 28.4510
LONG. : 19.3833

COMPLETED : 1963
KB. IN FT.: 617
GL. IN FT.: 602
TD. IN FT.: 11519

EXTRAP. SURFACE TEMP.INTERCEPT = 75.18454 °F

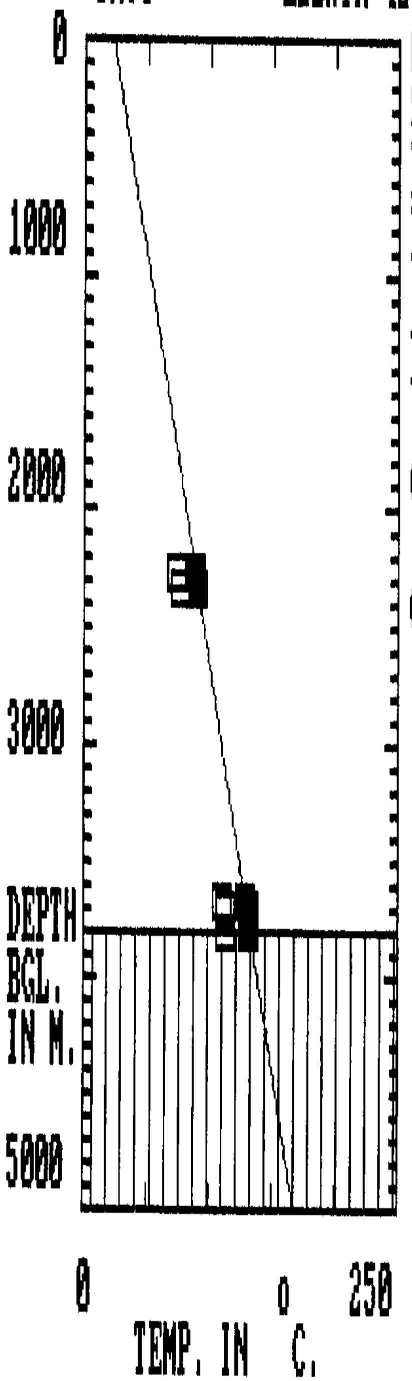
COMPENSATED GEOTHERMAL GRADIENT= 1.667244 °F/100 FT

COR. COEF. = .9992572   SS.TEST= .8102481

DBKB. FT.	DBGL. FT.	TEMP. °F.	CORR.TEMP. °F.
2161.0	2146.0	104.0	112.2
7794.0	7779.0	174.0	201.6
11084.0	11069.0	229.0	261.8

Statistically Significant CGG and ESTI Control Well Data

INOC ● ZUBAIR-42



AREA : ARABIA
STATUS: 1
LAT./Y-UTM : ND
LONG./X-UTM : ND

COMPLETED: ND
KB. IN M.: 0
GL. IN M.: 0
TD. IN M.: 3800

EXTRAP. SURFACE TEMP.INTERCEPT = 22.2494 °C

COMPENSATED GEOTHERMAL GRADIENT= 2.912111 °C/100 M.

COR. COEF. = .999451 SS.TEST= .1773286

DBKB. M.	DBGL. M.	TEMP. °C.	CORR.TEMP. °C.
2274.0	2274.0	73.3	88.2
2322.0	2322.0	75.0	90.1
3653.0	3653.0	110.6	129.0
3711.7	3711.7	112.8	131.2
3798.0	3798.0	113.3	131.7

Statistically Less Significant CGG and ESTI Control Well Data

5. WORKFLOW

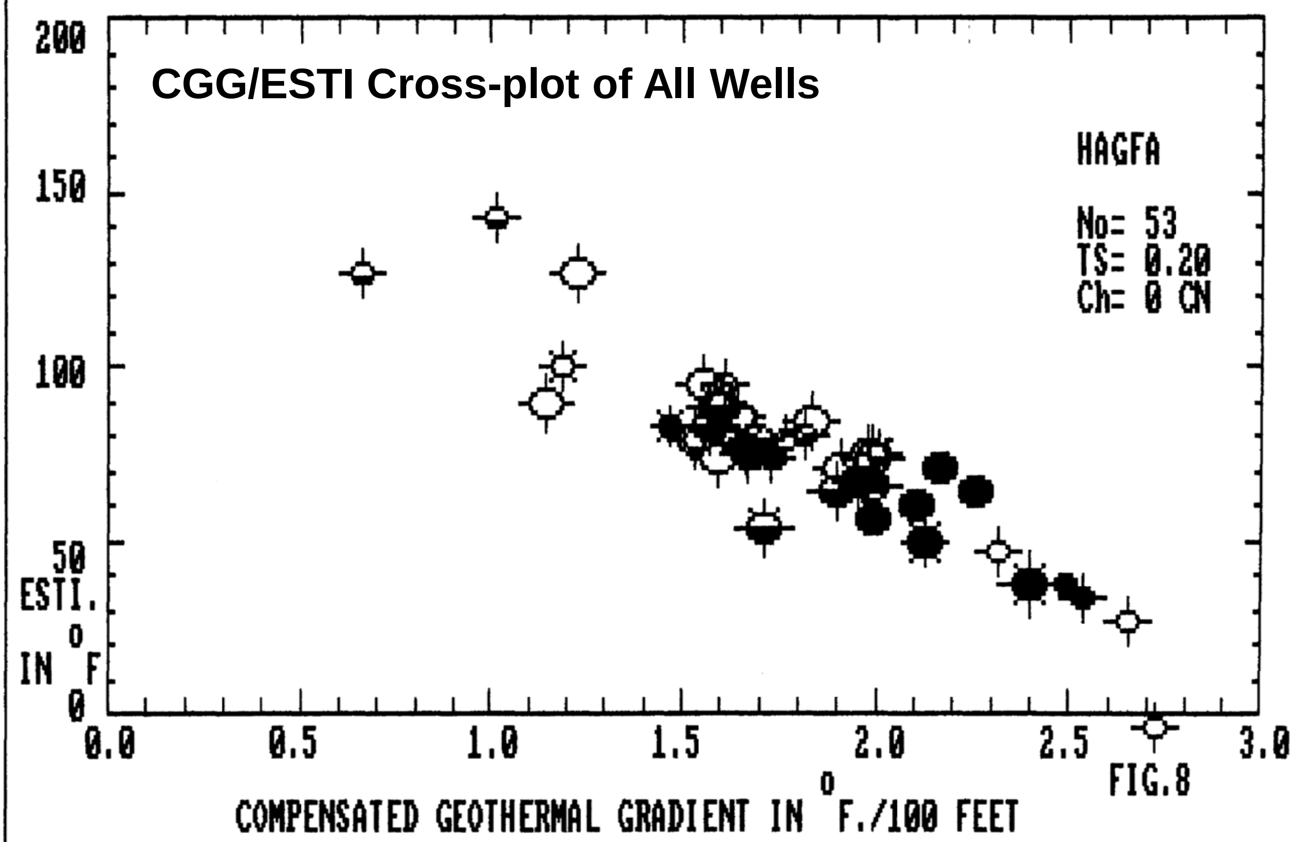
A. The CGG-ESTI© was used to input raw BHT readings below GL, correct, statistically test the BHT records and plot the corrected geothermal gradient and corresponding extrapolated surface temperatures of the wells, and use our incorporated “Statistical Sample Significance Test” to identify the wells with statistically significant BHT data.

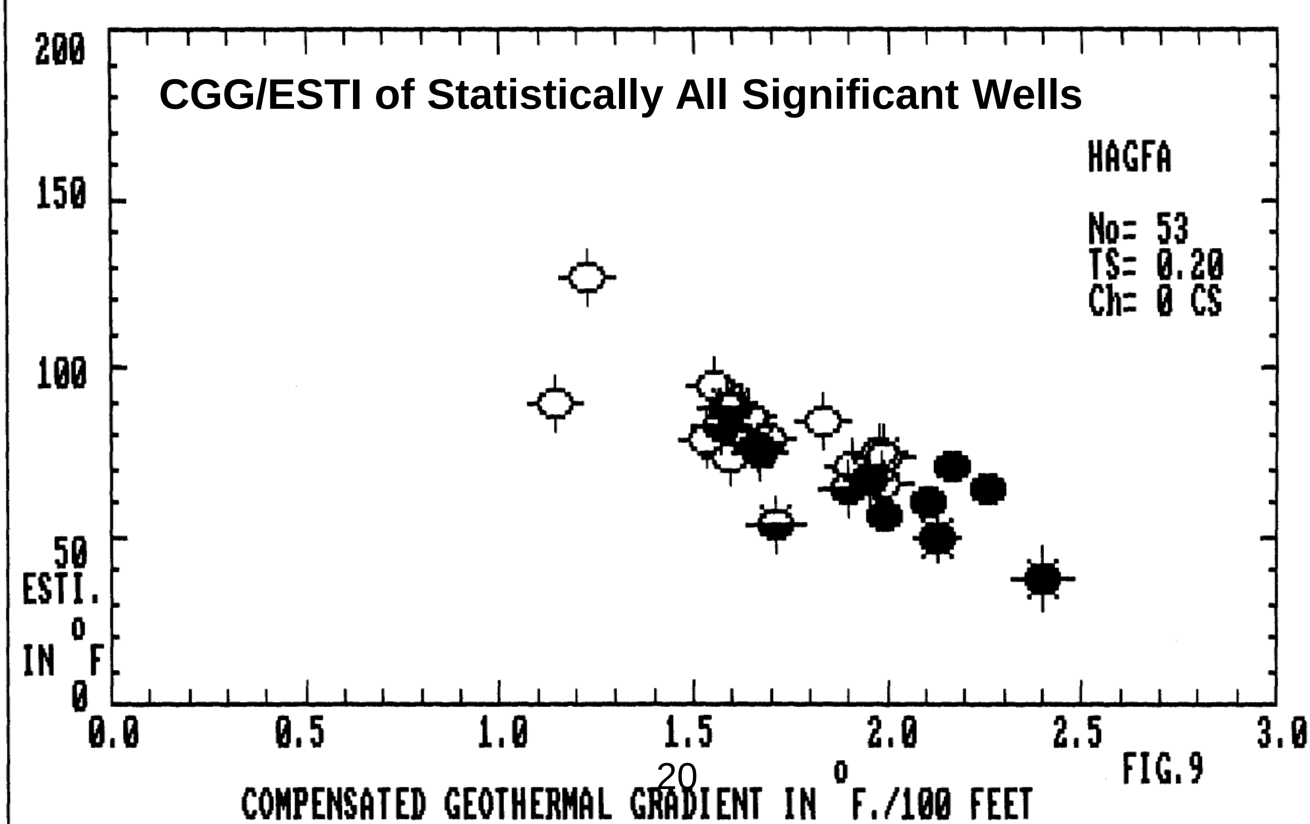
B. Cross plot the compensated geothermal gradients (CGG) against extrapolated surface temperature (ESTI) for all wells to identify the thermal regime of the area and/or basin.

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 CGG and ESTI seclusion limits identified by CGG-ESTI cross-plot analysis should delineate the anomalous hydrocarbon entrapment fairways.


CGG/ESTI Cross-plot of All Wells
HAGFA
No= 53
TS= 0.20
Ch= 0 CN
200
150
100
50
ESTI. o IN F
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
COMPENSATED GEOTHERMAL GRADIENT IN o F./100 FEET
FIG.8


CGG/ESTI of Statistically All Significant Wells
HAGFA
No= 53
TS= 0.20
Ch= 0 CS
200
150
100
50
ESTI. o IN F
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
COMPENSATED GEOTHERMAL GRADIENT IN o F./100 FEET
FIG.9

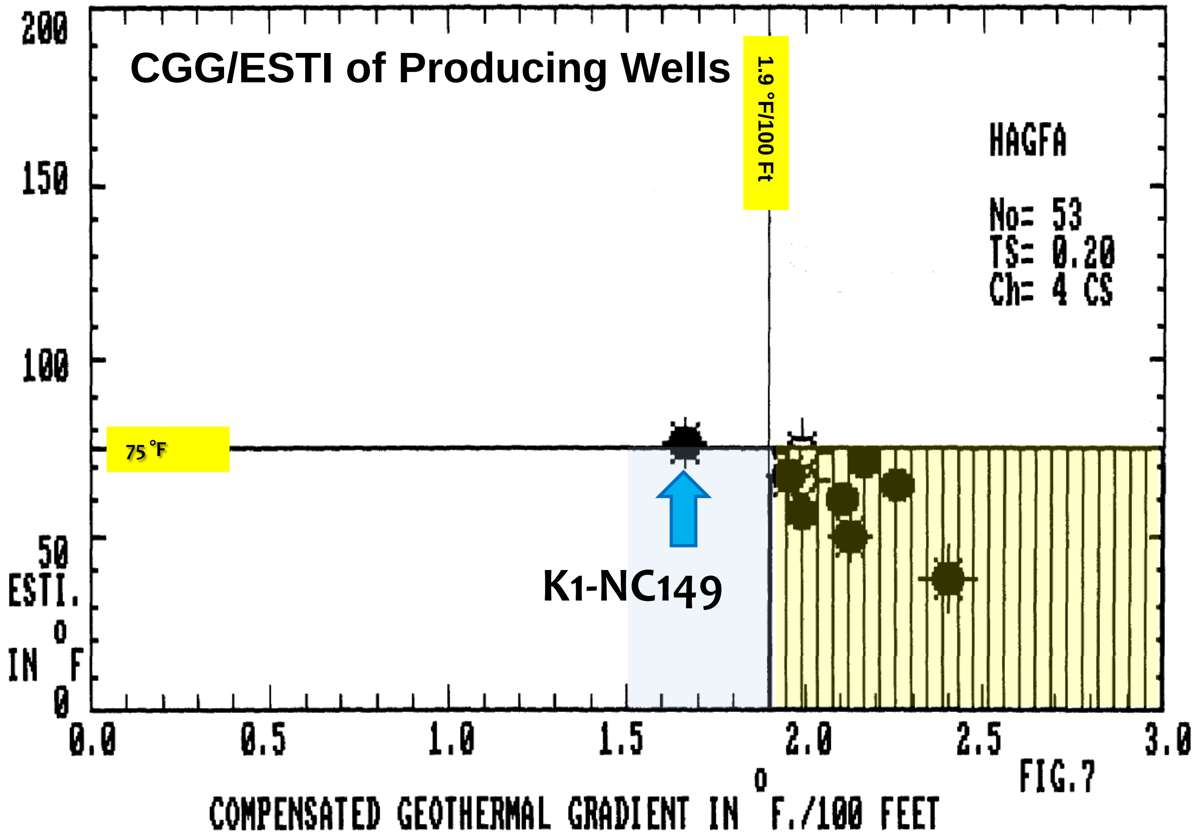

CGG/ESTI of Producing Wells
1.9 °F/100 Ft
HAGFA
No= 53
TS= 0.20
Ch= 4 CS
75 °F
K1-NC149
200
150
100
50
ESTI.
0
IN F
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
COMPENSATED GEOTHERMAL GRADIENT IN 0F./100 FEET

FIG.7

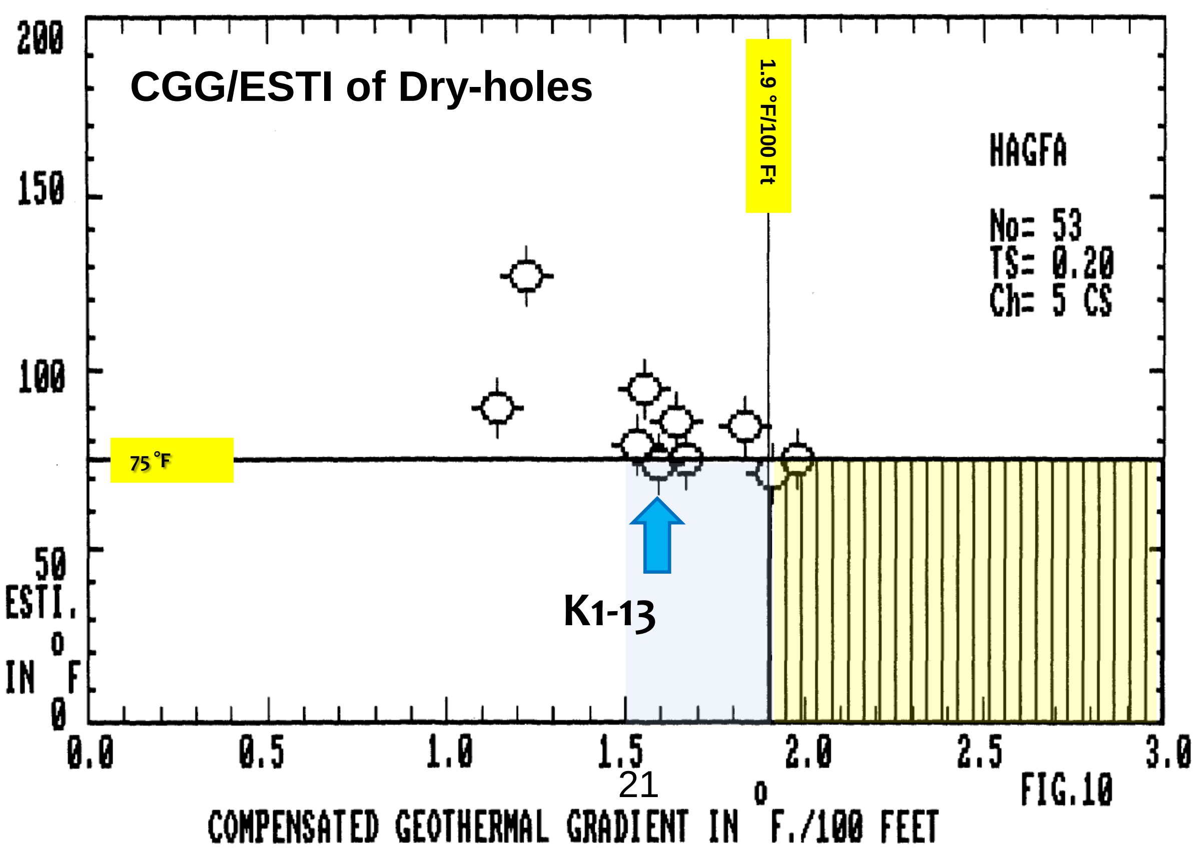

CGG/ESTI of Dry-holes
1.9 °F/100 Ft
HAGFA
No= 53
TS= 0.20
Ch= 5 CS
75 °F
K1-13
200
150
100
50
ESTI.
0
IN F
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
COMPENSATED GEOTHERMAL GRADIENT IN 0F./100 FEET

FIG.10

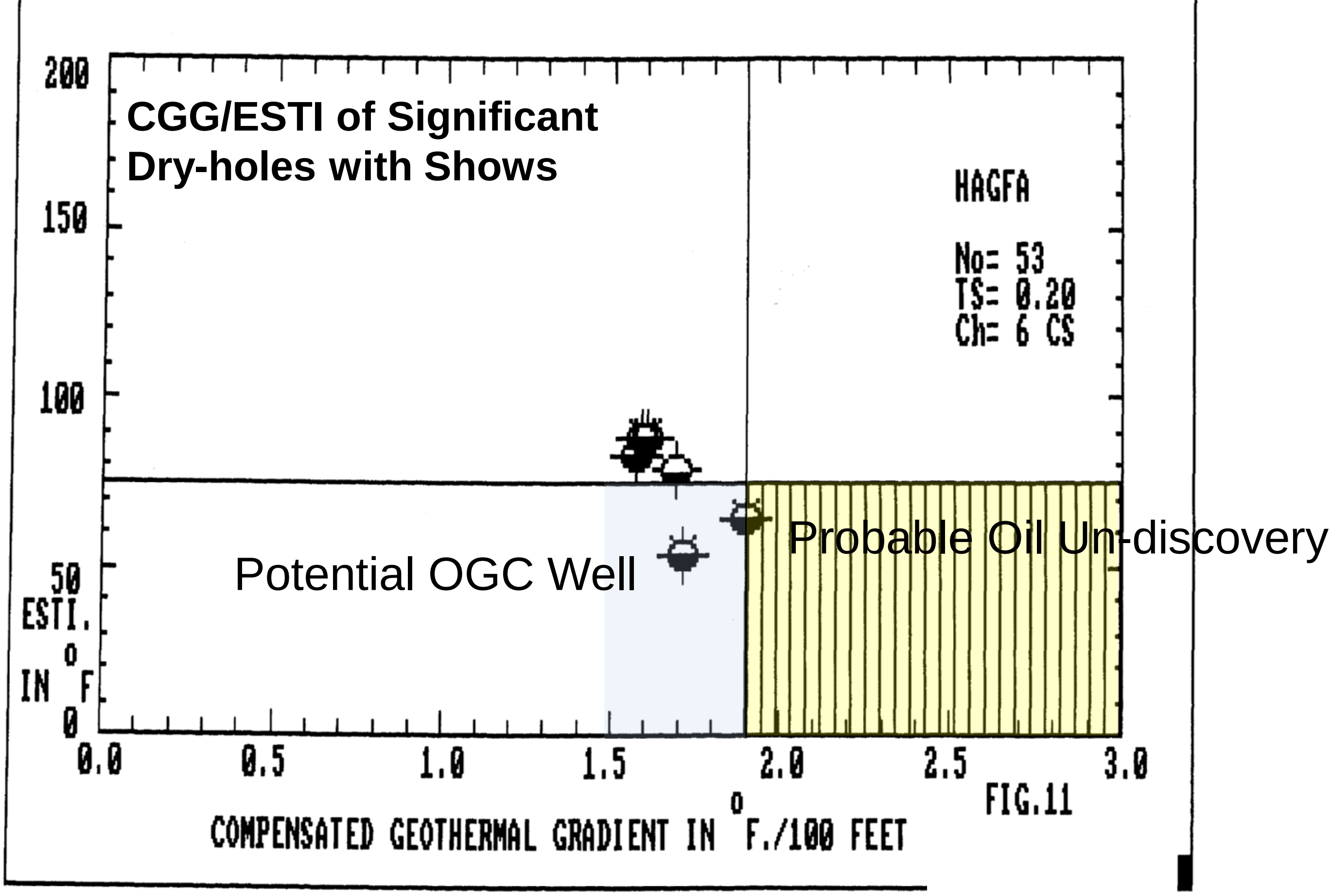

CGG/ESTI of Significant
Dry-holes with Shows
HAGFA
No= 53
TS= 0.20
Ch= 6 CS
Potential OGC Well
Probable Oil Un-discovery
200
150
100
50
ESTI.
0
IN F
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
COMPENSATED GEOTHERMAL GRADIENT IN 0 F./100 FEET

FIG.11

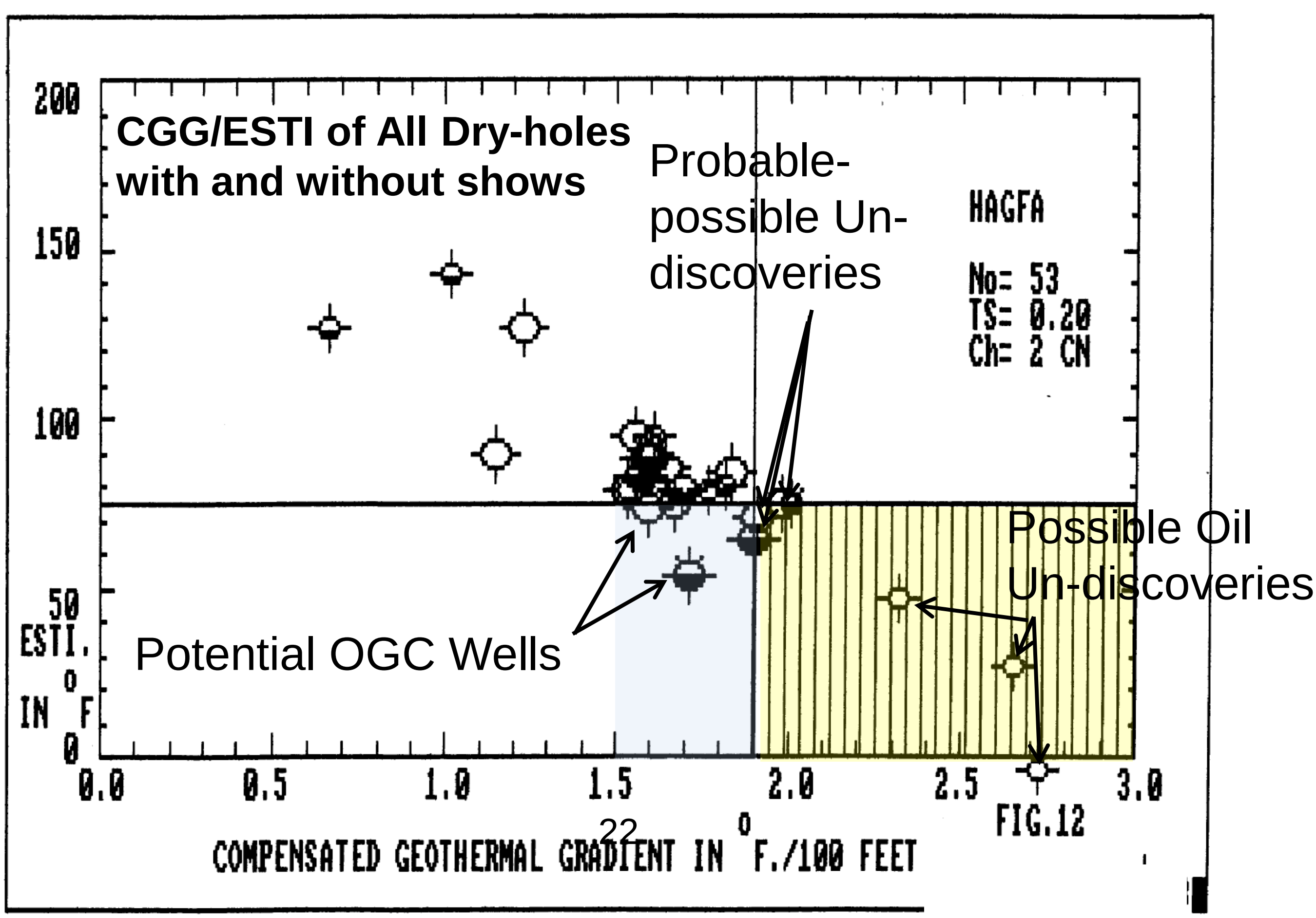
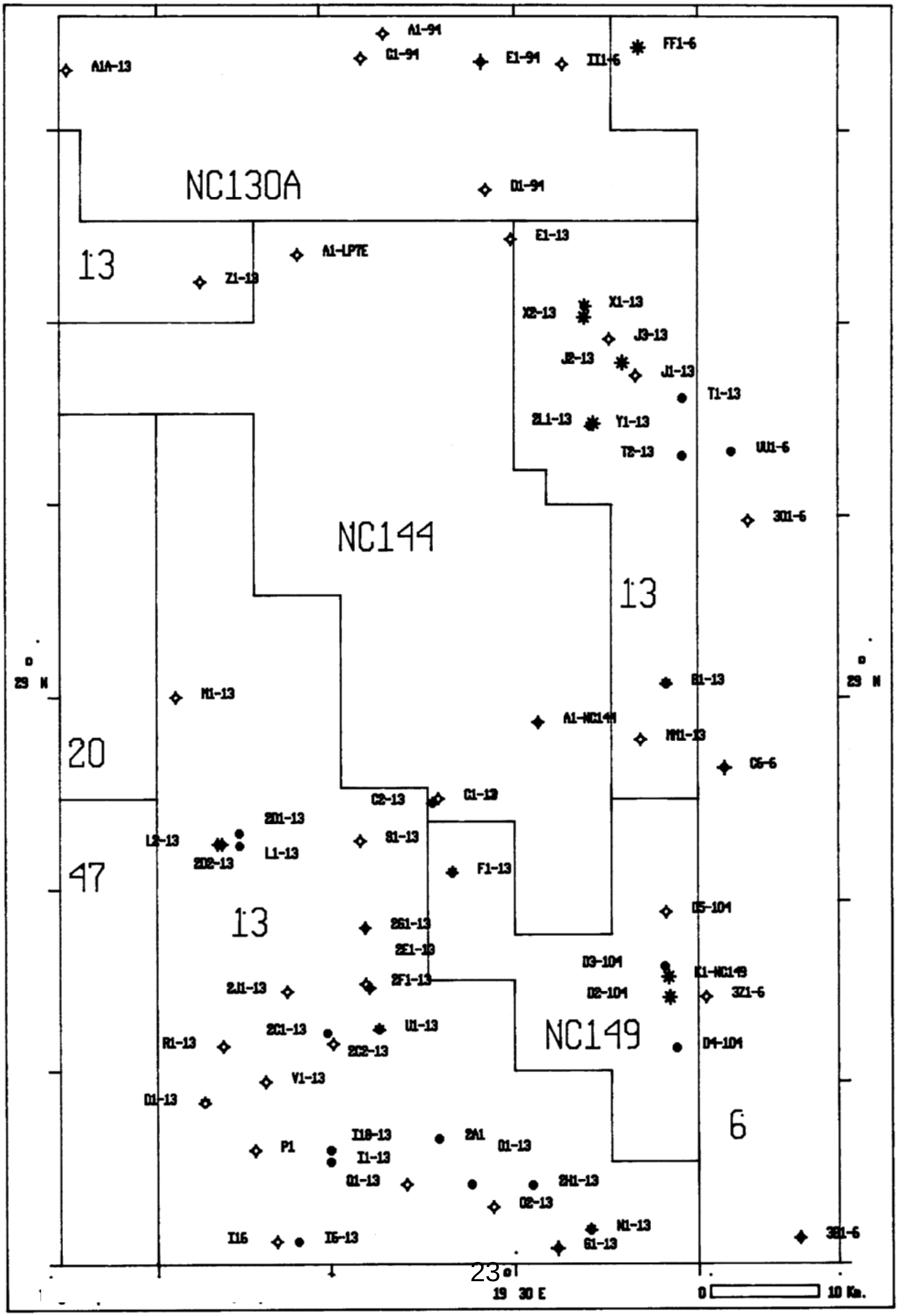
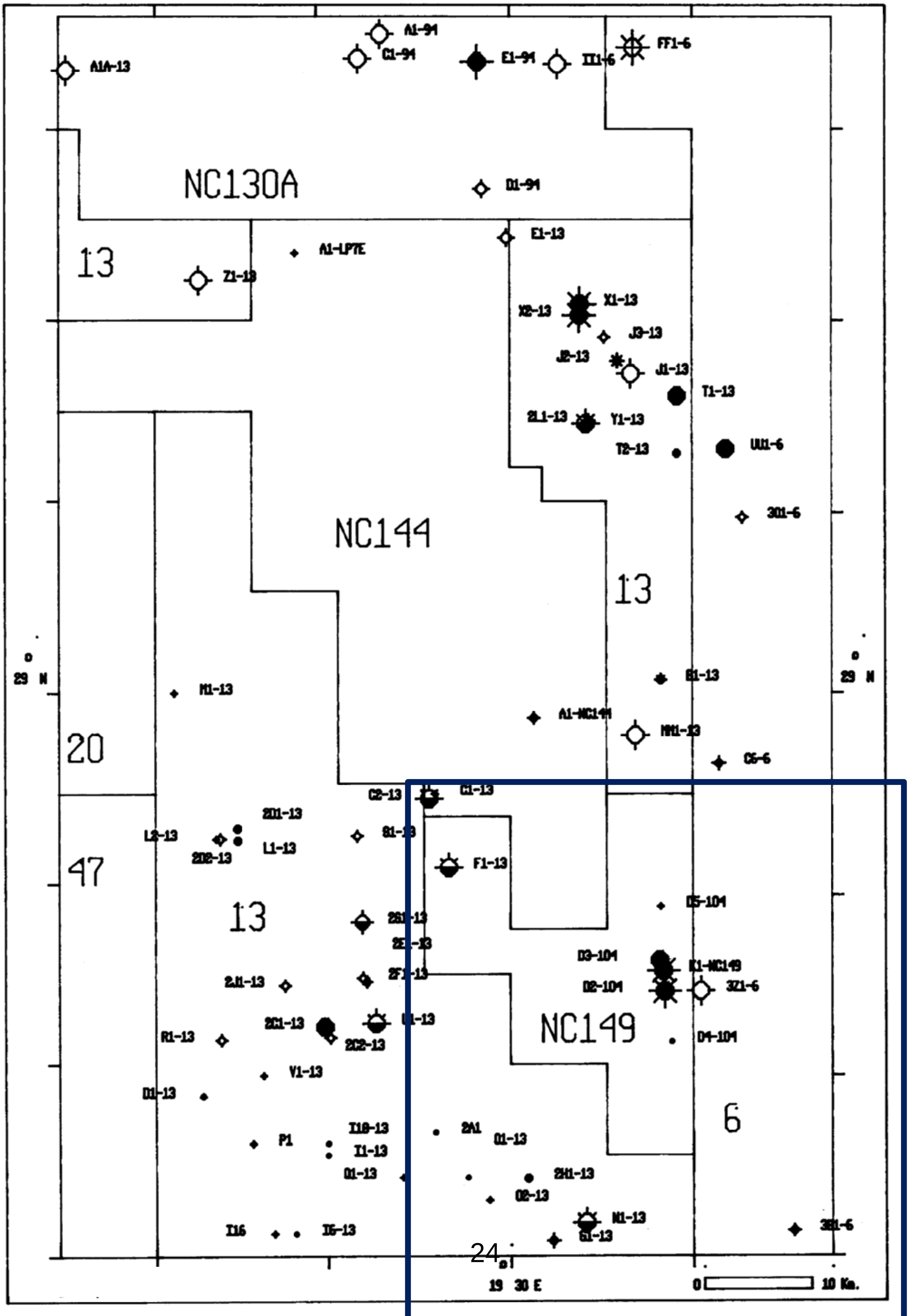

CGG/ESTI of All Dry-holes
with and without shows
Probable-
possible Un-
discoveries
HAGFA
No= 53
TS= 0.20
Ch= 2 CN
Possible Oil
Un-discoveries
Potential OGC Wells
200
150
100
50
ESTI.
0
IN F
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
COMPENSATED GEOTHERMAL GRADIENT IN 0 F./100 FEET

FIG.12

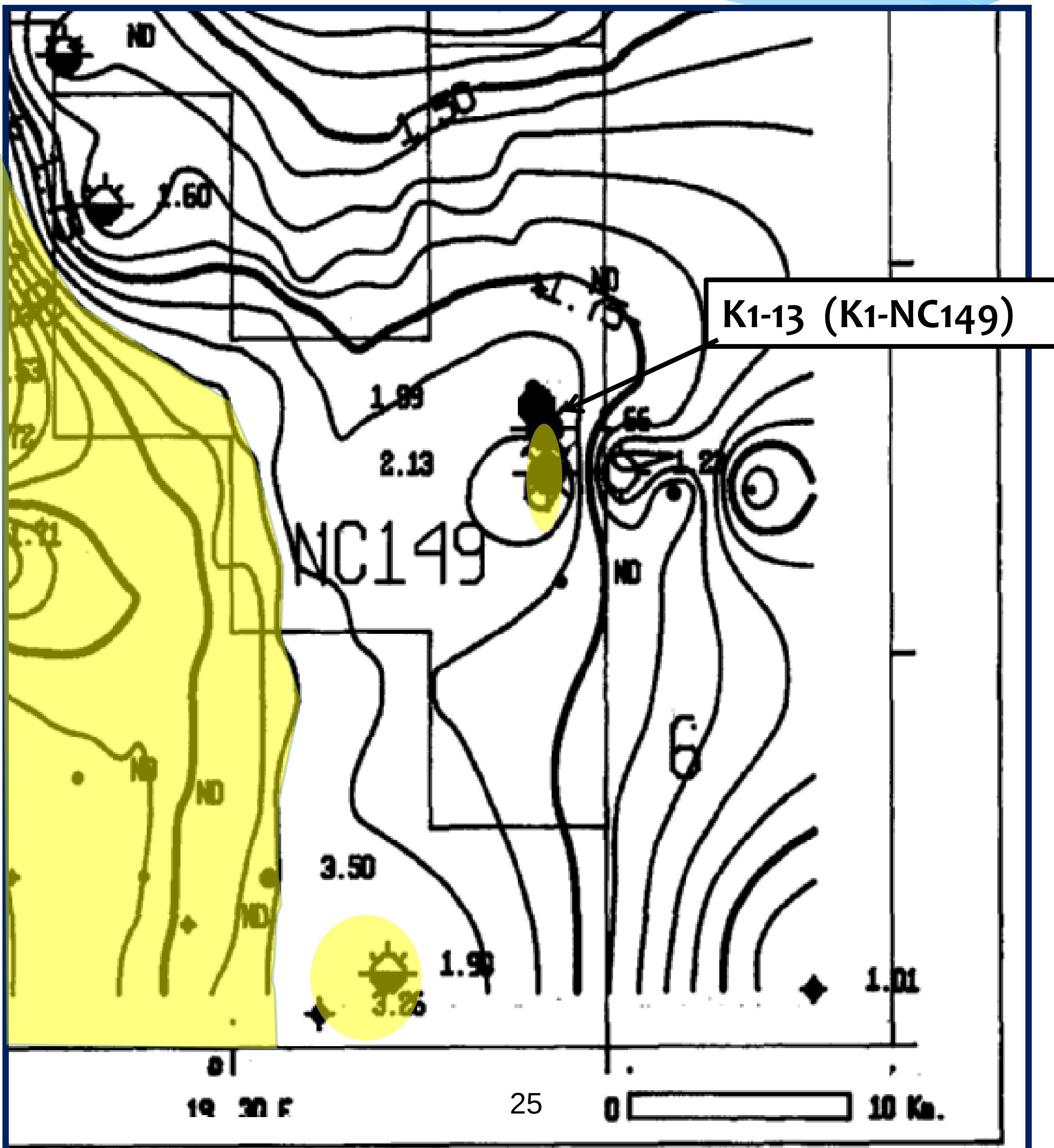
Well Location Map: Hagfa Trough, Sirte Basin



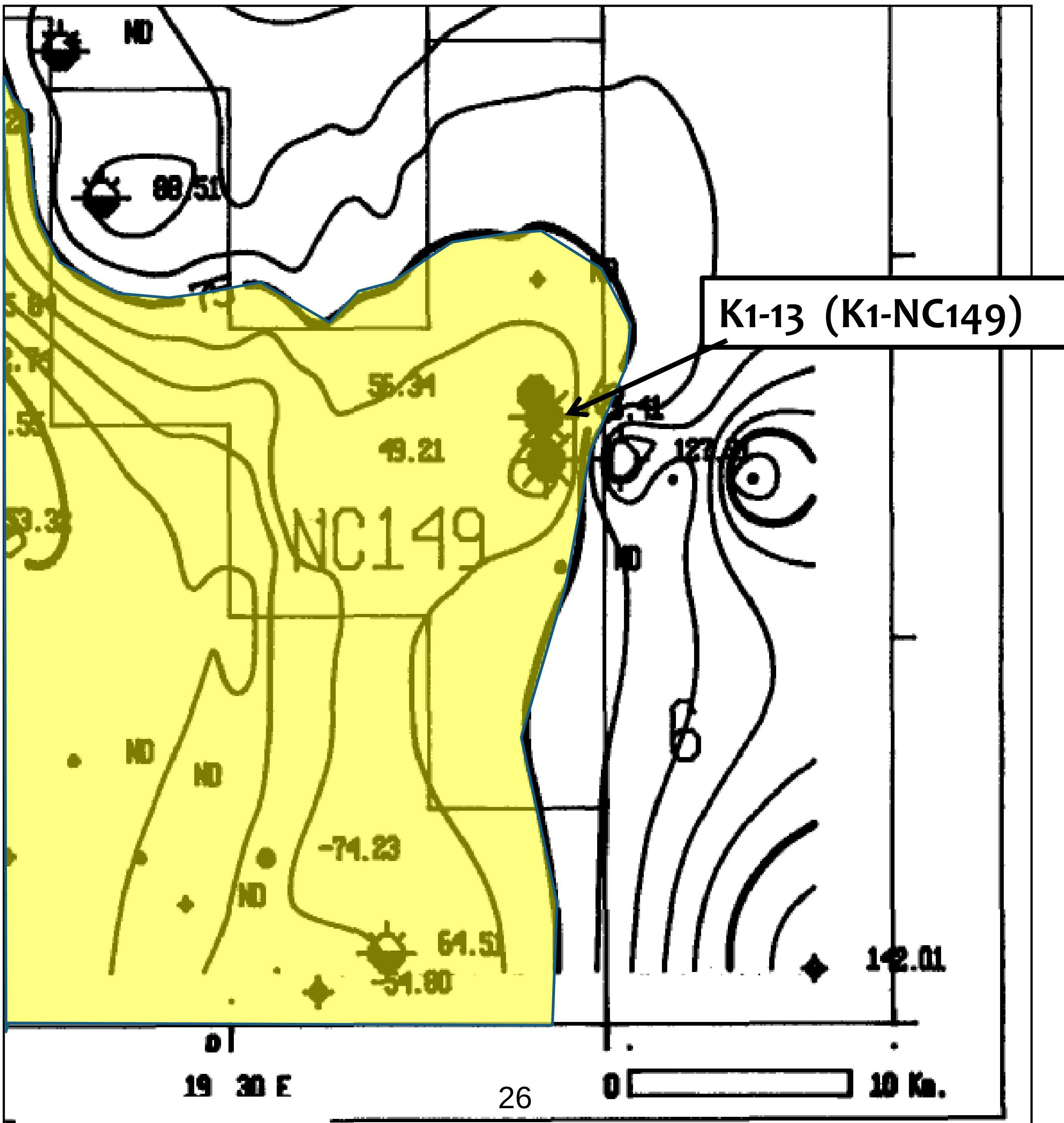
Proportional Well Location Map: Hagfa Trough



CGG Contours: C.I. 0.05 °F/100Ft



ESTI Contours: C.I. 5 °F



KEY TO MAPS AND FIGURES

LOCATION OR WELL   SIGNIFICANT WELL

UNCLASSIFIED WELL

P&A AS DRY HOLE

OIL WELL

GAS WELL

CONDENSATE WELL

OIL AND GAS WELL

SUSP.OR ABAND. OIL WELL

S OR A GAS WELL

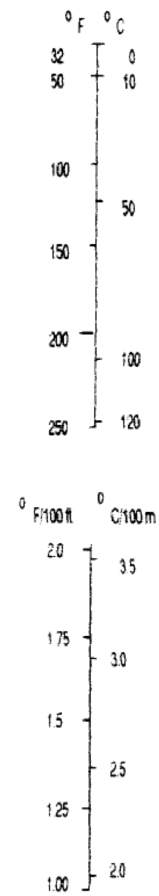
S OR A CONDENSATE WELL

S OR A OIL & GAS WELL

P&A WITH OIL SHOWS

P&A WITH GAS SHOWS

P&A WITH OIL & GAS SHOWS



COMPENSATED GEOTHERMAL GRADIENT CONTOUR IN DEG. F /100 FEET 1.50

EXTRAPOLATED SURFACE TEMPERATURE INTERCEPT CONTOURS IN DEG. F 75

SIGNIFICANT FAULT

LOW CGG-LOW ESTI ANOMALY

LOW CGG-High ESTI ANOMALY

UNCORRECTED B.H.T.

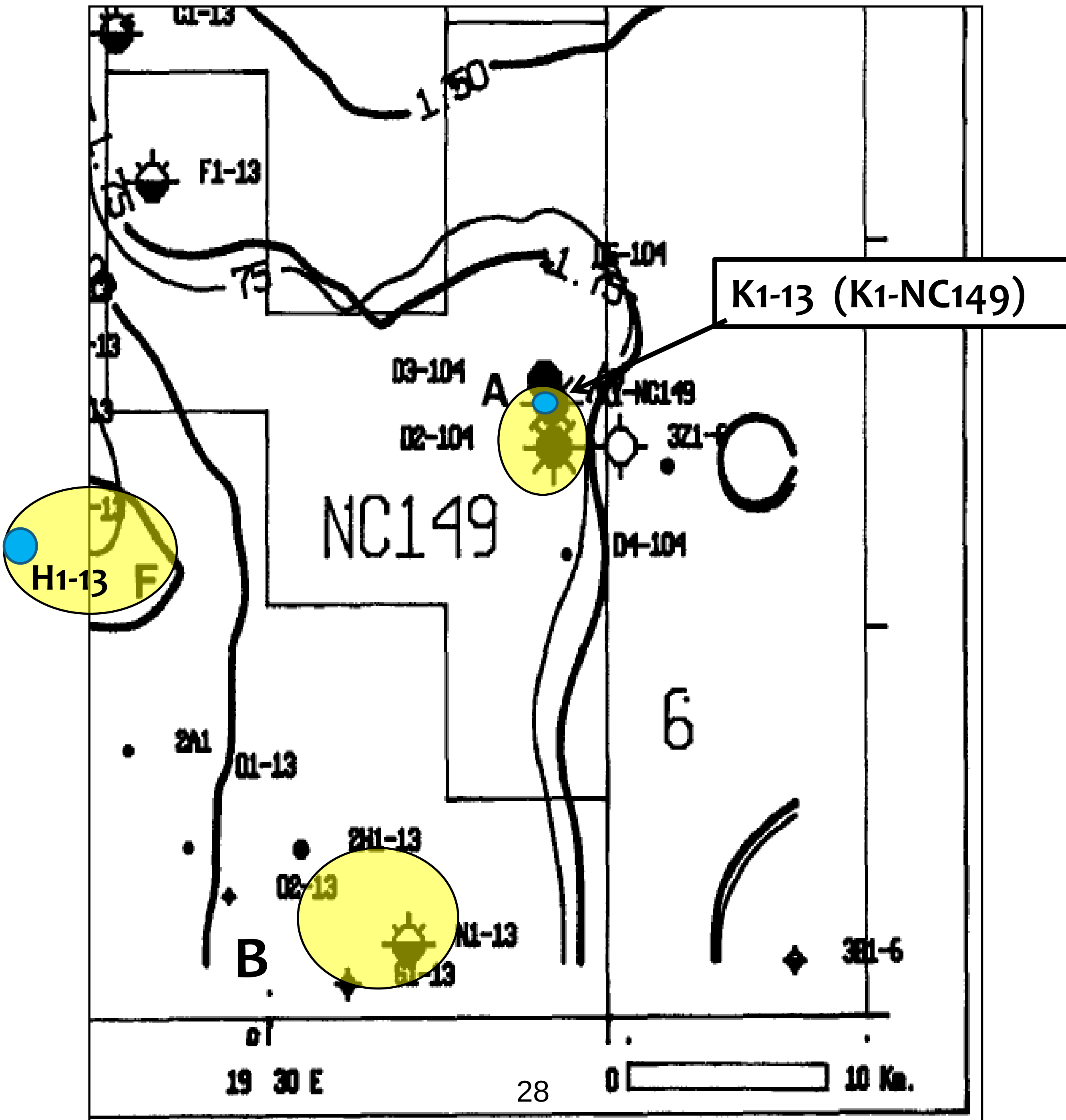
CORRECTED B.H.T.

No.= No. of wells studied

TS=SS Test= Test of significance of BHT record.(0.05 to 1.0)

Ch= Choice: 0-9, C= Corrected BHT; N= Plot all or S= Significant CGG-ESTI only

CGG-ESTI Anomalies of HC Entrapments



6. INTERPRETATION OF RESULTS

Total 53 Wells:

31 Dry Holes and

19 Producing or Suspended Wells

3 Unknown Wells

Confirm (Producing Fields) CGG-ESTI Anomalies:

14 Closed CGG and/or ESTI Anomalies overlapping with 19 HC Producing Wells.

Prospective CGG-ESTI Anomalies of HC Entrapment:

9 Proven CGG-ESTI Anomalies

6 Potential CGG-ESTI Anomalies

2 Probable CGG-ESTI Anomalies

12 Possible CGG-ESTI Anomalies

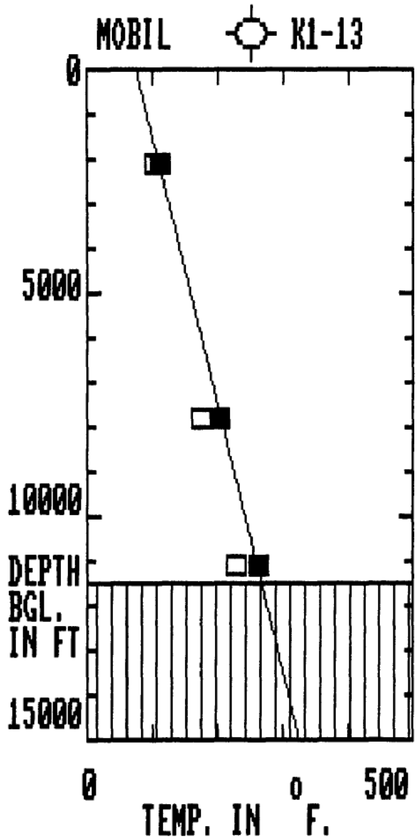
The success rate of the CGG-ESTI© method

The success rate 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 **(i.e. 70%-90%).**

7. APPLICATIONS

1. CGG-ESTI MAPS ARE PRIMARY INPUT to basin and petroleum system analyses and inherently delineates HC source kitchen(s) and traps fairways.
2. Anomalous geothermal gradient provides justification for dry hole post-mortem, and may lead to re-entry to test, or deepening the dry-hole.
3. CGG-ESTI MAPS are quick-look screening method of large number of dry-holes for missed, bypassed &/or unreached HC traps in MATURE BASIN REVIEWS.
4. Interim decisions in exploration drilling (terminate or continue drilling for the deeper target) and in appraisal drilling (Good Producers EXPRESS Good CGG-ESTI Anomalies).
5. Mapping the depth to steam generating thermal level of rock formations for geothermal energy projects.
6. Screening shut-in or dry-holes for conversion to geothermal energy injector/producers (Ibrahim, 2017).



AREA : HAGFA
STATUS: 0
LAT. : 28.4510
LONG. : 19.3833

COMPLETED : 1963
KB. IN FT.: 617
GL. IN FT.: 602
TD. IN FT.: 11519

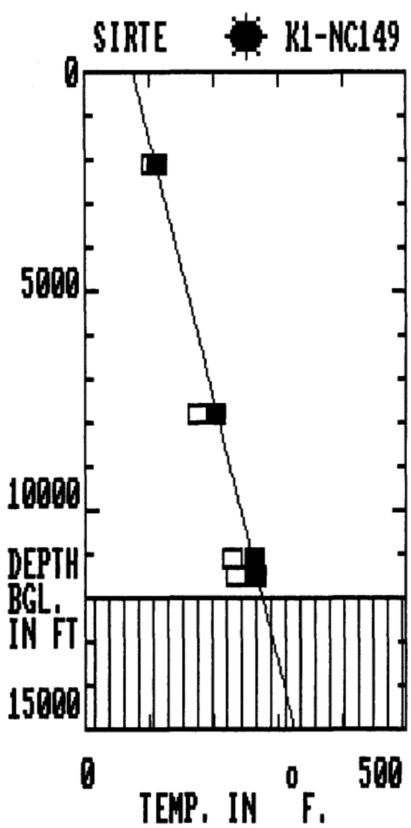
EXTRAP. SURFACE TEMP.INTERCEPT = 75.18454 °F

COMPENSATED GEOTHERMAL GRADIENT= 1.667244 °F/100 FT

COR. COEF. = .9992572 SS.TEST= .8102481

DBKB. FT.	DBGL. FT.	TEMP. °F.	CORR.TEMP. °F.
2161.0	2146.0	104.0	112.2
7794.0	7779.0	174.0	201.6
11084.0	11069.0	229.0	261.8

FIG. K1-13



AREA : HAGFA
STATUS: 3
LAT. : 28.4510
LONG. : 19.3833

COMPLETED : 1988
KB. IN FT.: 617
GL. IN FT.: 602
TD. IN FT.: 12000

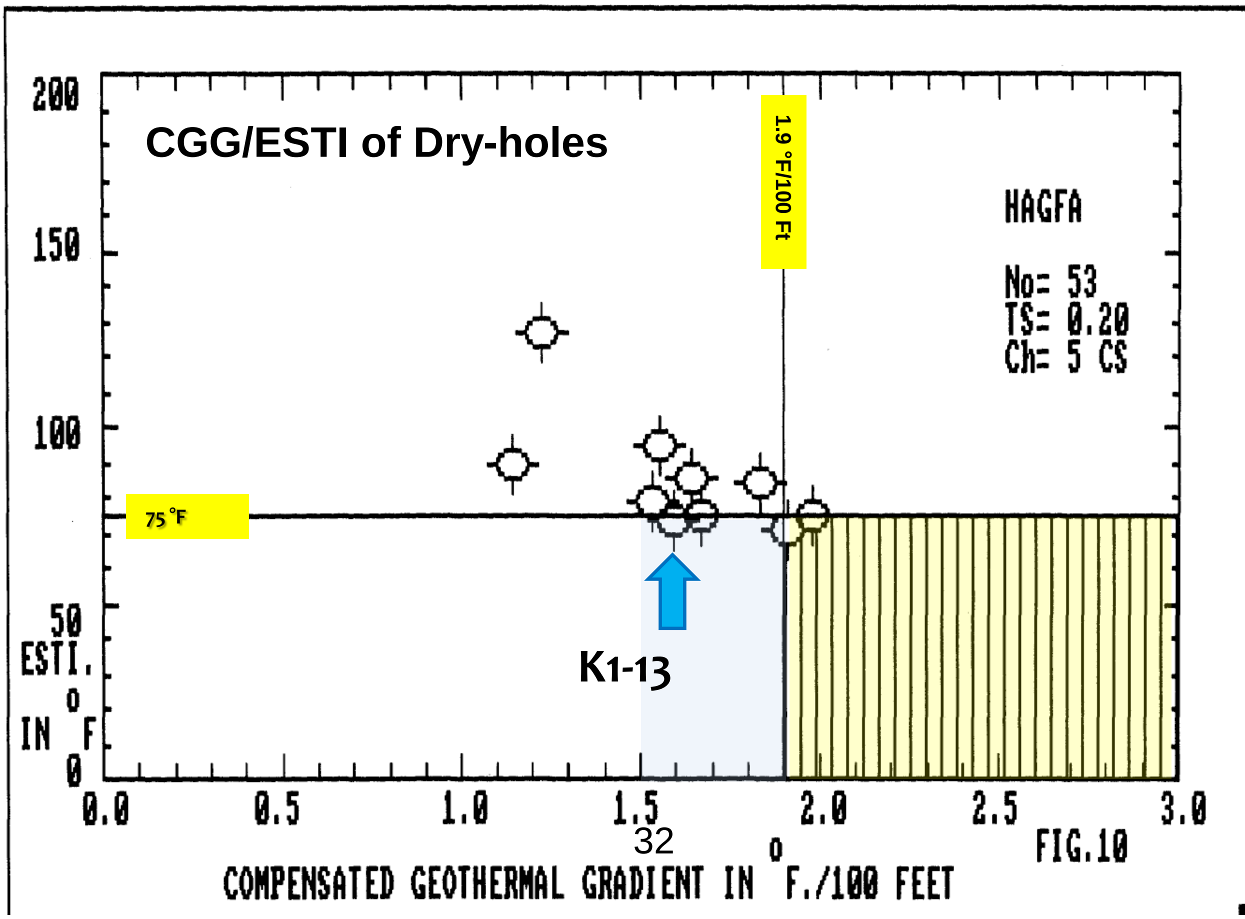
EXTRAP. SURFACE TEMP.INTERCEPT = 75.40563 °F

COMPENSATED GEOTHERMAL GRADIENT= 1.661695 °F/100 FT

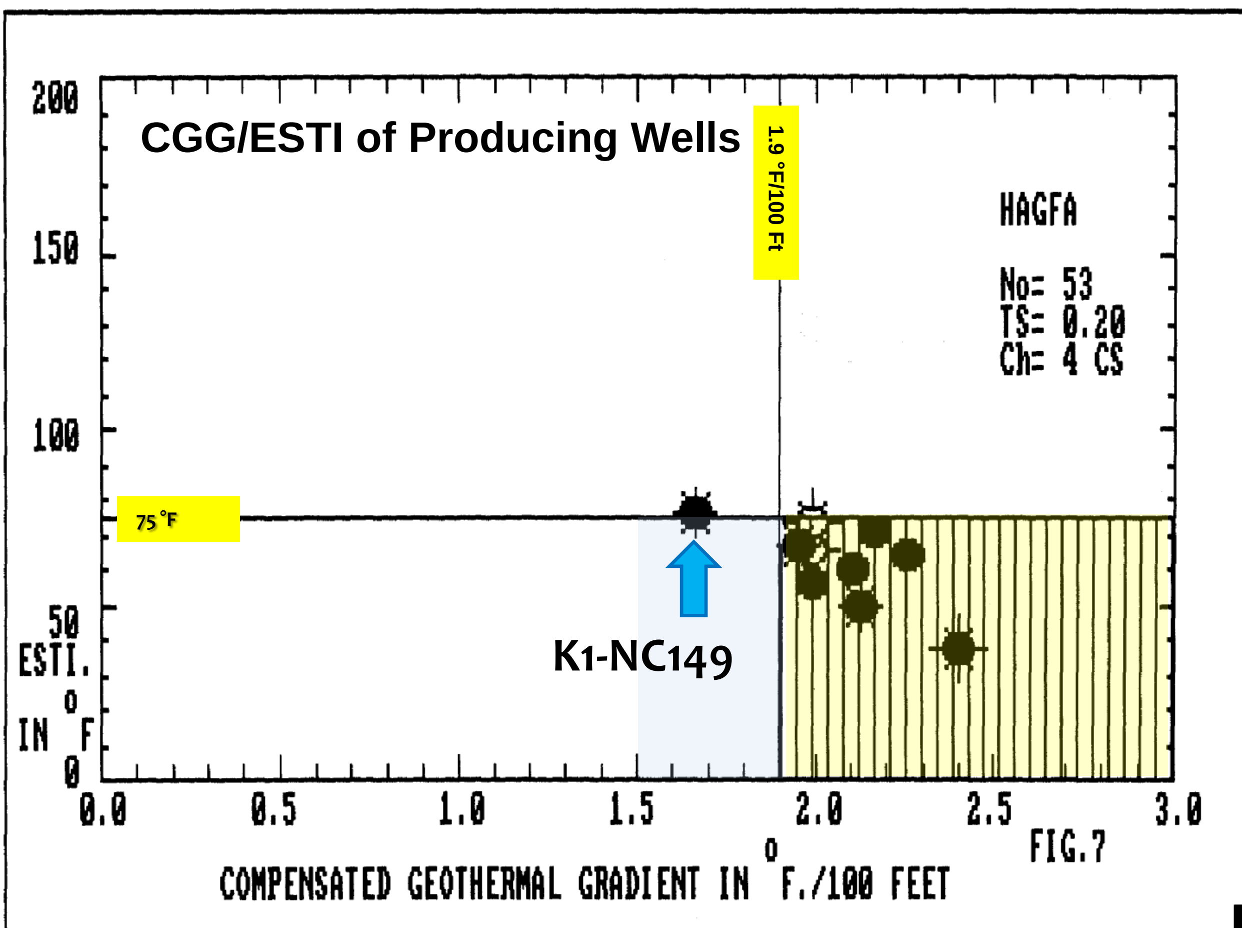
COR. COEF. = .9994408 SS.TEST= .7046818

DBKB. FT.	DBGL. FT.	TEMP. °F.	CORR.TEMP. °F.
2161.0	2146.0	104.0	112.2
7794.0	7779.0	174.0	201.6
11084.0	11069.0	229.0	261.8
11518.0	11503.0	233.0	266.0

FIG. K1-NC149

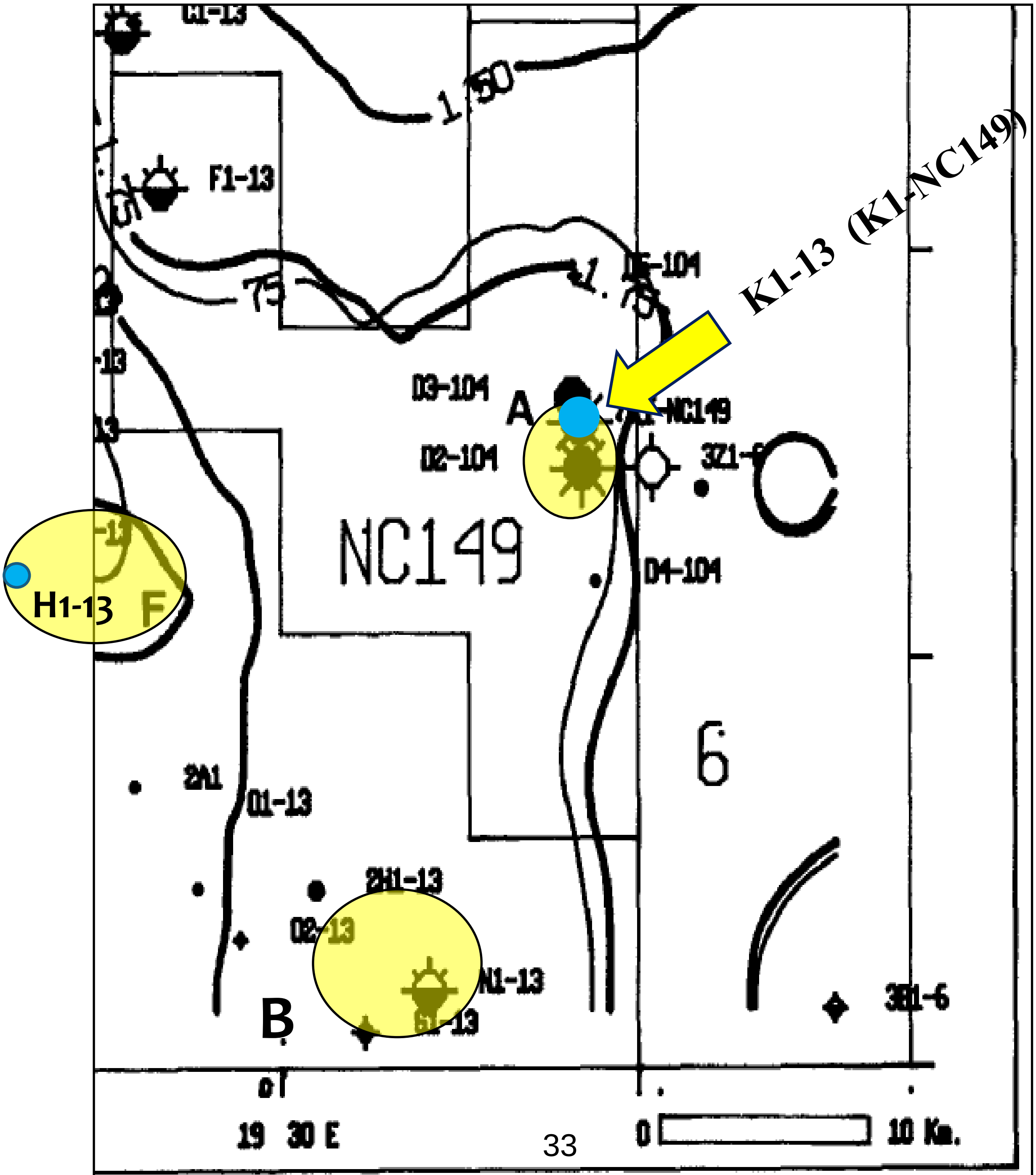


CGG/ESTI of Dry-holes
1.9 °F/100 Ft
HAGFA
No= 53
TS= 0.20
Ch= 5 CS
75 °F
K1-13
ESTI. IN °F
COMPENSATED GEOTHERMAL GRADIENT IN °F./100 FEET
FIG.10

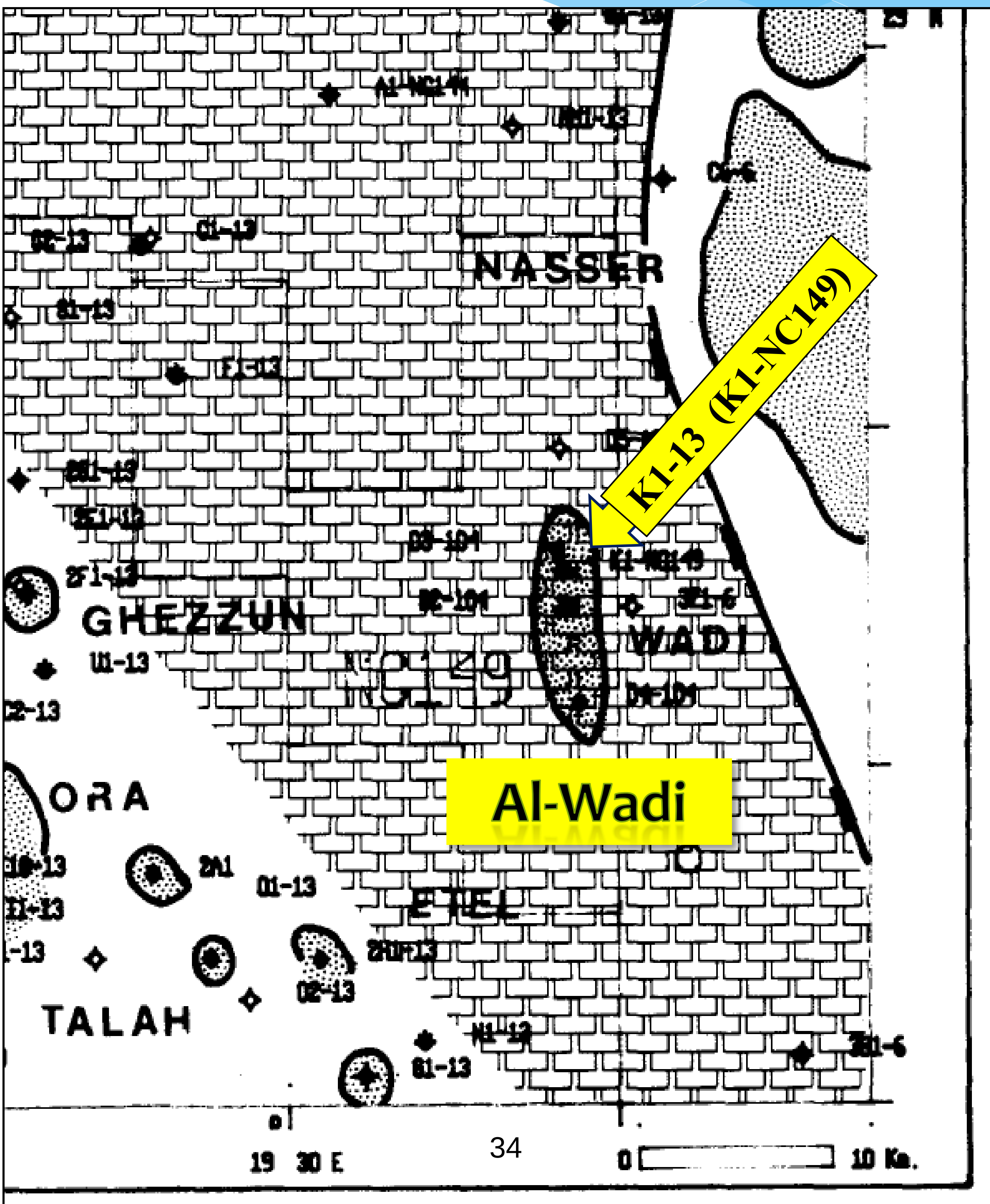


CGG/ESTI of Producing Wells
1.9 °F/100 Ft
HAGFA
No= 53
TS= 0.20
Ch= 4 CS
75 °F
K1-NC149
ESTI. IN °F
COMPENSATED GEOTHERMAL GRADIENT IN °F./100 FEET
FIG.7

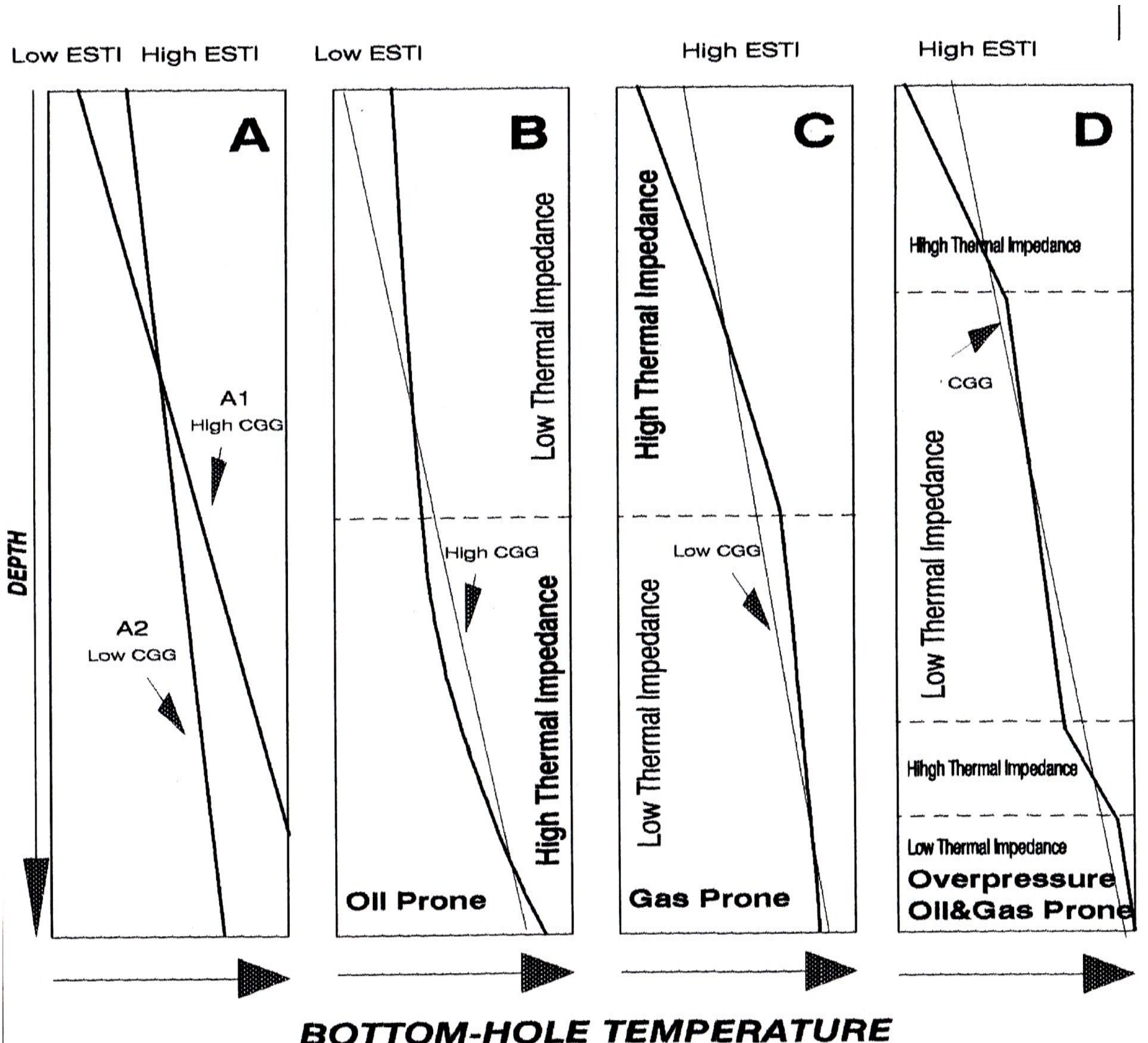
CGG-ESTI Anomalies of HC Entrapments



Location of Producing Well K1-NC149 (Former Dry-hole K1-13) in Al-Wadi Field



Oil, Gas and Over-pressured Oil & Gas Prone Geothermal Profiles and their CGGs and ESTIs



Modified After Roberts 1981

8. CONCLUSIONS

A. CGG-ESTI cross-plot reveals clustering of producers and suspended vs. dry holes and non-producer wells, and decide the optimum CGG-ESTI contours delineating geothermally anomalous trends.

B. The CGG-ESTI mapping of geothermal gradient anomalies of hydrocarbon entrapment is a quick look tool for integrative prospects generation, mature basin reviews, dry-hole post-mortem and re-entry justification of possible, probable or potential “un-discovery wells” listed as dry holes in the Hagfa Trough, Sirte Basin and other mature basins.

C. The CGG-ESTI method of compensated geothermal gradient mapping 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).

9. REFERENCES

Kehle, R.O. (Chairman), 1972, Geothermal Survey of North America, AAPG, 1971, Annual Progress Report, 29 p.

Kehle, R.O. (Chairman), 1973, Geothermal Survey of North America, AAPG, 1972, Annual Progress Report, 22 p.

Roberts III, W.H. 1980. Design and function of oil and gas traps. In W.H. Roberts III and R.J. Cordell (Eds.), Problems of Petroleum Migration, American Association of Petroleum Geologists, Studies in Geology, no. 10, p. 217-240.

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.

Ibrahim, M. W., 1986, Compensated Geothermal Gradient: New Map of Old Data, abstract, AAPG. Bull, V.70, No.5, P.603.

Ibrahim, M. W., 1988, Compensated Geothermal Gradient Anomalies in a Mature Hydrocarbon Basin: Lake Pontchartrain, Lake De Cade, and Eugene Island, Gulf Coast, Louisiana, abstract, AAPG. Bull., v.72, no. 2, p. 200.

Ibrahim M. W. 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, p 85-96.

Ibrahim, MW. Geothermal Gradients and Geothermal Gradient Anomalies of Hydrocarbon Entrapment, Hagfa (Marada) Trough, Sirte Basin, Libya, Target Exploration Report (Tar-6) 150 Pages.

Ibrahim, MW. (2017) 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 Sec., Collingwood College; Durham University, UK. 25-27 April 2017.

Target Exploration
Energy Geosciences Research & Development

βapp
Target

Thank you

Muhammad W Ibrahim

www.targetexploration.com