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Geothermal Gradients in Selected Wells by Using Borehole Temperatures

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Abstract

The temperature statistics from 48 oil and water boreholes are exploited to infer the geothermal inclination of Iraq. The recorded BHT of open hole logs is regularly lower than the accurate temperature. Consequently, the Horner scheme, was utilized in this study to correct BHT in which the reported temperature at a selected depth will be plotted versus rewarm time. The geothermal gradients (G.G.) vary noticeably horizontally (borehole to borehole) and vertically (depth). The inconsistencies in geothermal gradients throughout Iraq are a result of sediments' thermal conductivity variation, heat generation, distribution and geometry of faults, and groundwater effects. In Northern Iraq, the maximum, minimum, and mean geothermal gradients (G.G.) are 29°C/km in Butma-2, 15°C/km in Ziwe-1, and 21°C/km, respectively. In Western Desert, the lowermost gradient within the layers above Paleozoic units is 12°C/km in KH-9/7 water borehole within Rutbah Subzone and the maximum is 31°C/km for Akkas-1 oil borehole in the north western portion in the region within Jezira Subzone. However, the maximum G.G. (61°C/km) in the Silurian Akkas is verified within 2100-2350 meters' interval below the ground level. The average G.G. of 26°C/km in Western Iraq noticed in sections above the Paleozoic; however, G.G. value increases to 40°C/km in Paleozoic formations owing to presence of Akkas shale and rising heat from the basement unit. In Central Iraq, the average geothermal incline is about 20°C/km built on surrounding areas. In southern Iraq, the maximum G.G. (30°C/km) was reported in Nahr Umr-7 oil borehole in the Zubair Subzone. The lowest geothermal gradient (17°C/km) was detected in Luhays-12 oil borehole in the Zubair Subzone. The mean regional G.G. in southern Iraq is 22°C/km.

Keywords: geothermal gradients, borehole temperatures, carbonates formation, Iraq.

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التدرجات الحرارية الأرضية في العراق مستنتجة من درجات حرارة البئر

الخلاصة

يعد التدرج الحراري الجوفي أداة مهمة في التنقيب عن البترول وحاسمة للعديد من تقييمات المكامن. تم استخدام بيانات درجات الحرارة في ٤٨ بئراً لتحديد الاتجاه الحراري الأرضي في العراق.

تكون درجة الحرارة المسجلة لأباراقل من درجة الحرارة الحقيقية. وبالتالي، تم استخدام مخطط هورنر في هذه الدراسة لتصحيح درجات الحرارة الأبار حيث سيتم رسم درجة الحرارة المبلغ عنها عند عمق محدد مقابل وقت إعادة التدفئة.

تختلف التدرجات الحرارية الأرضية بشكل ملحوظ أفقيًا (من بئر إلى بئر) وعموديًا (العمق). يعتبر التناقض في التدرجات الحرارية الأرضية في جميع أنحاء المنطقة المدروسة هي نتيجة لتنوع التوصيل الحراري للرواسب واتجاه تدفق المياه الجوفية ونمط الصدوع وتوليد الحرارة.

وجد في شمال العراق أن أعلى انحدار جيوحراري هو ٢٩,٢ درجة مئوية/ كم في بئر بطمة -٢ في نطاق الطيات الواطئة. ولوحظ أن أدنى التدرجات الحرارية الأرضية هي ١٤,٩ درجة مئوية/ كم في بئر زيوي - ١ في منطقة نطاق الطيات العالية. ولوحظ أيضا أن متوسط التدرج الجيوحراري الإقليمي لكردستان العراق هو ٢١ درجة مئوية/ كم. في وسط العراق، يبلغ متوسط التدرج الحراري الأرضي حوالي ٢٠ درجة مئوية/ كم بناءً على المناطق المجاورة. في جنوب العراق، وجد أن أعلى انحدار جيوحراري هو ٢٩,٧درجة مئوية/ كم في بئر نهر عمر -٧ في منطقة نطاق الزبير. كما لوحظ بأن أدنى التدرجات الحرارية الأرضية هي ١٦,٧ درجة مئوية/ كم في بئر لوهيس-٢ في منطقة نطاق الزبير وأن متوسط التدرج الجيوحراري الإقليمي لجنوب العراق هو ٢٢,٢ درجة مئوية/ كم. أما في الصحراء الغربية فان أدنى انحدار ضمن الوحدات فوق الباليوزويك هو ١٢,٢ درجة مئوية/ كم في البئر KH-9/7 الكائن في الجزء الشرقي من المنطقة داخل منطقة نطاق الرطبة وأعلى قيمة كانت ٣١,٣ درجة مئوية/ كم في بئر عكاس-١ في الجزء الشمالي الغربي من المنطقة داخل نطاق الجزيرة. حيث تم تسجيل أعلى تدرج للطاقة الحرارية الأرضية وهو ٦١ درجة مئوية/ كم داخل وحدات الباليوزويك و داخل تكوين عكاس في عمق ٢١٠٠-٢٣٥٠ متر تحت السطح. وكان متوسط التدرج الحراري الأرضي في الصحراء الغربية هو ٢٦ درجة مئوية/ كم داخل الوحدات الأحدث من العصر الباليوزوي، ولكن هذا المتوسط يرتفع إلى ٤٠ درجة مئوية/ كم داخل وحدات عصر الباليوزويك بسبب وجود صخور الطفل السيلوري وتدفق الحرارة من ترسبات البروتيروزويك.

1. Introduction

Geothermal gradients (G.G.) are a useful parameter in an investigation of oil and essential to several oilfield operations. Similarly, temperature governing petroleum expulsion, hydrocarbon generation, hydrocarbon migration, sediment alteration, and fluid characterization inside sedimentary deposits [1]. Furthermore, G.G. is a relatively hygienic, renewable resources of producing electric power [2].

Bore hole temperature (BHT) in Basra is 95 ºC at 3000 meters’ depth, [3]. The G.G. in Ain Zalah Oilfield, northern Iraq is about 28 ºC/km [4] while a 25 ºC/km were reported for neighboring boreholes in the Kirkuk region [5] and are relatively below the average in the Folded-and-suture zones [6]. The G.G. contour map built on BHT in Iraq was proposed by Jassim and Al-Gailani [7]. The former assumptions concerning thermal conductivity and heat flow were accepted [8]. The BHT of numerous boreholes in northern and southern Iraq was utilized for adjustment in petroleum system modeling [9;10]. The mean G.G. in Kurdistan region is 21 ºC/km [11]. The

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average G.G. in Western Iraq reported to be 26 °C/km and 40 °C/km within the layers above and within Paleozoic units, respectively [12].

This study is based on borehole temperature in 48 boreholes throughout the country Figure (1) and nearby region to infer G.G. discrepancies in Iraq. These dissimilarities in G.G. were exploited to draw a G.G. map and to identify irregularities associated with hydrocarbon traps.

1.1 Geologic background

The continuing dynamic crash between the Arabian and the Iranian plates aids to the continuing progression of the Zagros Mountain [13]. The area challenged a chief compact occasion and widespread rupturing in the Late Miocene [14;15]. The Zagros Mountain includes giant structural traps, with cracking creating hydrocarbon reservoirs.

Western Desert is situated in Stable Shelf, Rutba-Jezira and Salman zones [16]. The Stable Shelf is a sturdy monocline rather exaggerated by Late Mesozoic and Cenozoic change in which the thickness of the sedimentary cover above the basement rocks are ranging from 5 to 13 km [17]. The most noticeable topographical characteristic in the region is the depressed Ga'ara [18]. According to existing proofs, the Hail Arch spreads from the Arabian Shield northward which has a chain of anticyclones (e.g., Rutba High where Ga'ara Uplift is the highest area) and Khleisia High detached by several depressions such as Anah Graben [18]. In Western Iraq, the visible rock types and their distribution have arranged by tectonic and structural conditions [19]. Horizontal facies variations are linked to the Rutba High which was the key factor of depositional settings morphology. Instead, Nukhaib Graben has facilitated the deposition of massive sizes of gravel sediments, Pliocene–Pleistocene Zahra Formation [19].

The Southern Iraq is located within the Mesopotamian Basin, of the Stable Shelf according to tectonic divisions of Iraq. The Mesopotamian Zone is a relatively flat land which has a gradient of no more than 10 cm per km that spreads from Baiji to the Persian Gulf. It is bounded by the folded ranges of Pesh-i- Kuh in the Northeast and Hemrin and Makhul in the North. The Southwest boundary is exaggerated by presence of faults [8]. The Stable Shelf is a monocline somewhat inflated by Late Cretaceous and Tertiary alteration. Possibly it was elevated during the Hercynian Orogeny; nevertheless, it dwindled between Late Permian until Late Tertiary [17]. The bearings of the structures in this area were biased by the geometry of the basement blocks, Paleozoic epeirogenic events and Mesozoic twisting [17]. In the Mesopotamian Zone, the fold structures commonly have NW-SE and N-S orientations in the eastern part and southern part,

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compatibly. Structures of this area frequently have positive enduring gravity anomaly excluding the structures of Zubair and Rumaila which associated with the negative residual gravity anomaly. The negative gravity anomalies within the structures are associated to halokinetic movement of Infracambrian evaporite [17]. Therefore, the structures of Rumaila, Zubair, and Nahr Umr are not related to the Alpine Orogeny, but are likely interrelated to passive diapirs movement of Infracambrian evaporite. There are three subzones within the Mesopotamian Zone: The Zubair Subzone in the South, the Euphrates Subzone in the West, and the Tigris Subzone in the Northeast. The Tigris Subzone is the widest part of the Mesopotamian Zone which comprises extensive synclines and narrow anticlines accompanying with normal faults [20]. In the Mesopotamian Zone, the sedimentary succession thickens to the east. It encompasses 1100 m, 500-700 m, 700-1400 m, 200-900 m, and 150-1500 m of Jurassic, Lower Cretaceous, Upper Cretaceous, Paleogene, and Neogene and Quaternary units, correspondingly [17].

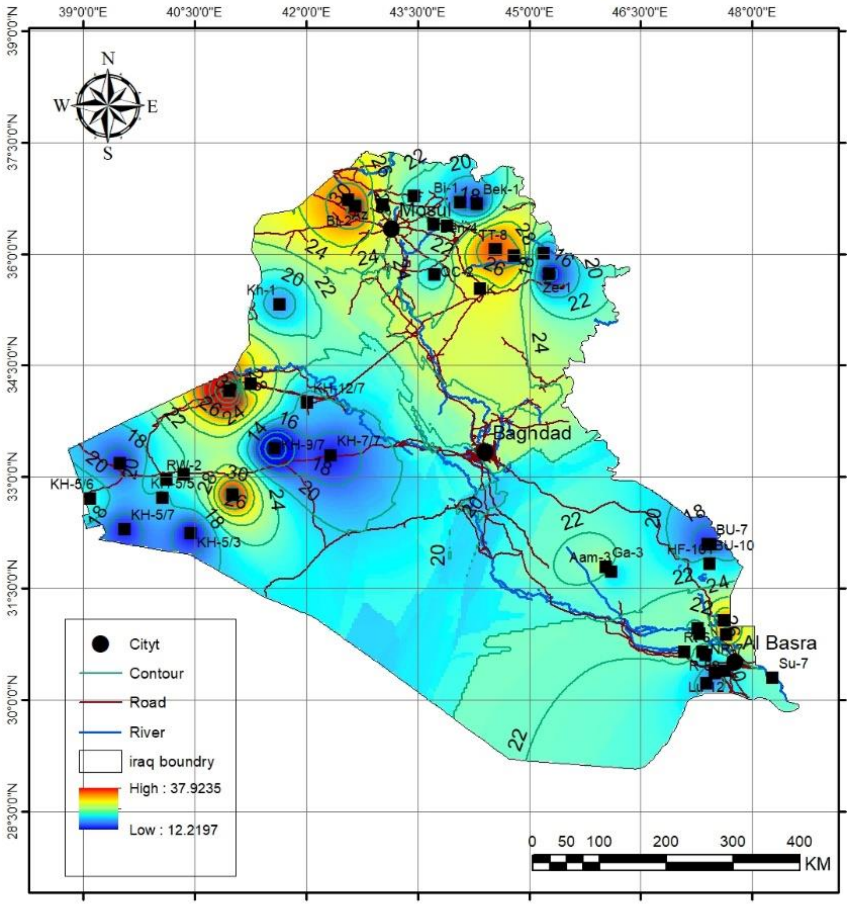

Fig. (1): Index map shows position of oil and water boreholes [11:12]

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2. Methodology

Due to unavailability of heat flow and thermal conductivity statistics, the bore hole and bottom-hole temperatures reported from discovery and production oil wells in Iraq were utilized for defining geothermal gradients. Forty-eight discovery and production oil wells in Iraq are selected for current research Figure (1). The boreholes have proper circumstances e.g., the time passed amid the recording temperature and ending the mud circulation. The sample locations were selected to replicate change of temperature laterally and vertically.

The recorded BHT of open hole logs is regularly lower than the accurate temperature [21]. Rotation of fluid in the open hole distributes an unsteadiness temperature at the time of recording it [21]. Consequently, the Horner scheme [22] was utilized in this study. An average temperature at a surface of 25 Celsius degrees, the correct BHT at the selected depth can be found from the linear function. The essential mathematical formula for determining geothermal gradient that was proposed by Forrest et al. [23] is utilized.

The G.G. in any underground position doesn't seem as straightforward. The rate of G.G. is related to the nature of rock (conductivity) which is naturally not similar through the entire well. Consequently, the amendment of borehole temperature derivative from broadly documented temperatures in an open hole based on Horner scheme isn't satisfactory to acquire dependable outcomes.

3. Results and Discussion

The wells are approximately scattered throughout Iraq Figure (1); thus, the geothermal gradient of each area will be presented disjointedly:

3.1. Northern Iraq

The BHT from 17 wells Table (1) were selected to determine geothermal gradient trend in Kurdistan region.

The surface temperature is assessed to be 21 ºC. Figure 2 displays the geothermal gradient contour map. For majority of wells, though, it is deceptive that the geothermal gradients are not similar through the whole depth Table (1). These incline anomalies naturally indicate the existence of seal rocks [24]. In Binary Sirwan-1, the unusual heat rise was observed at 1300 meters under the ground and this increase continues through deeper horizons. This interval specifies the boundary limit of the seal, Sehkaniyan Fm.

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The heat arises within the Butma Fm and revenues to a regular tendency through the Baluti Fm. Similarly, in Qara Jugh-2 & Sheikhan-2, the slopes rise above the Sarmord & Alan, correspondingly. Both units signify seals cover Qamchuqa & Adaiyah formations in Qara Jugh-2 & Sheikhan-2, consistently. In Jabal Qand-1, the oddly growth heat attained at almost 2100 meters below the surface signifies the boundary between Sargelu and Gotnia cap rock, and the upsurge of heat recorded in upper horizon. In Butma-2, the slope surges from 301 to 605 meters under the surface within Avanah / Jadalah and revenues to ordinary status through Aaliji and Shiranish. Figure (2) displays the low gradients in mountain area (Bekhma-1, Binary Sirwan-1, and Ziwa-1) in comparison to the Foothills Zone (Basttora-2B, Banenan-4, Qara Jugh-2, Jabal Qand-1, Butma-2, TT-8). These deviations perhaps related to variability in heat conductivity of sediments and water flow under the surface [25].

Table (1): Well names, well details, and G.G. rates in different localities

Locality	Surface Elevation (m)	Under Surface (m)	Recorded Temperature (ºC)	Geothermal Gradients (ºC/km)
Ziwe-1 (Ze-1)	1592.5	4200.0	80.0	14.5
Binary Sirwan-1 (BS-1)	1239.0	1309.0	52.0	17.8
Shiwashan-1 (She-1)	595.0	2089.5	81.0	29.3
(TT-08)	620.1	2045.0	84.7	31.1
(TT-10z)	610.2	2140.0	83.2	29.1
(TT-14)	612.3	2030.0	83.0	30.5
(TT-19)	621.9	2035.0	79.6	28.8
(Bek-1)	560.0	4068.0	85.8	15.6
(Bi-1)	515.6	3403.0	99.0	16.7
(Ba-2B)	378.0	2785.0	84.2	22.7
(QC-2)	799.0	1020.0	28.9	20.5
(Ben-4)	479.0	2494.0	82.0	21.9
(Sha-2)	658.4	3167.0	81.3	20.8
(JK-1)	398.4	2106.0	76.7	23.5
(Bt-2)	573.2	1310.6	61.7	32.7
(Az)	423.0	1882.0	73.7	28.0
(K)	400.0	780.0	40.5	25.0

These low gradients in mountain area are presumably connected to the highly heat conductive Mesozoic carbonate sediments. Additionally, the expansively splintered rocks in mountain region permit an extra powerful subsurface water movement. Probable exemptions in the mountain area are Ziwe-1 and Bekhma-1 whose recorded BHTs are slightly greater than that recorded in other boreholes in the mentioned region (15 and 16 ºC/km, respectively). This

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irregularity is perhaps linked to heat production from shales and existence of efficient cap rock. In Kurdistan region, dark colored shale beds in Ziwe-1 and Bekhma-1 from Jurassic units capable of generating more heat than Paleocene and Miocene claystones in Foothills Sector. However, a huge amount of shaly sediments should exist for considerable involvement [26]. Figure (2) displays the overall rise of the G.G. towards the Foothill area (in the direction of Basttora-2B, Banenan-4, Qara Jugh-2, Jabal Qand-1, and Butma-2). The maximum G.G. occur in the Shiwashok and Shiwashan-1 wells in Foothills Zone. The high G.G. in this zone is connected to the existence of weak heat conductive thick calystones beds that were deposited during late Paleogene.

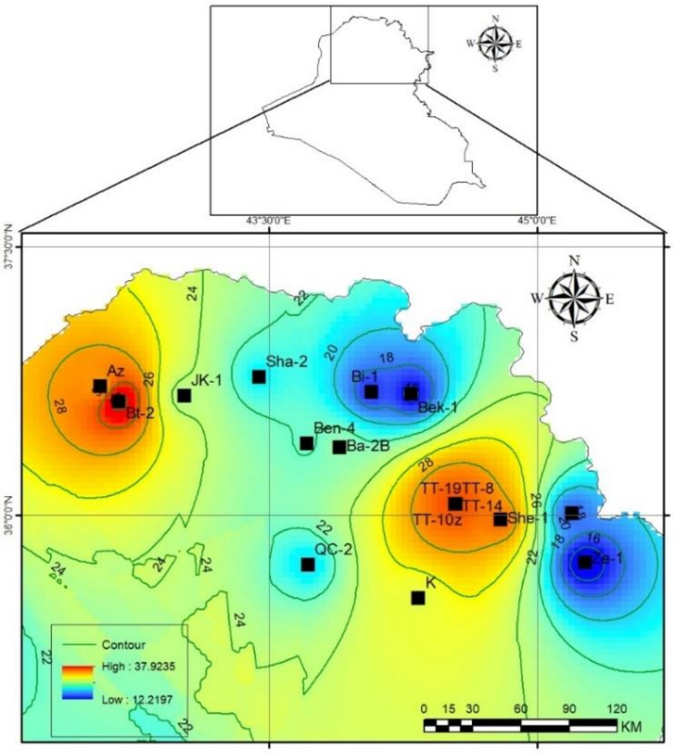

Fig. (2): Contour map displaying geothermal gradient in Kurdistan region

3.2. Western Iraq

Deliberating to climatic statistics, the yearly mean ground level temperature has been determined to be 21 degrees Celsius [27;28]. The temperature increases with depth Table (2). The relationship is fluctuating due to rock property inconsistency through the whole interval.

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Table (2): Borehole temperatures in Western Desert

Borehole Name	Ground Level Elevation (m)	Under Ground Level (m)	Recorded Temperature (ºC)	Geothermal Gradients (ºC/km)
KH-5/2	619.3	900.0	41.0	22.2
KH-5/3	730.6	1188.0	33.0	15.8
KH-5/4	559.0	600.0	39.8	31.3
KH-5/5	728.5	852.0	37.7	19.6
KH-5/6	807.2	1250.0	48.0	21.6
KH-5/7	856.1	750.0	33.3	16.4
KH-5/8	755.5	800.0	34.3	16.6
RW-2	649.8	242.0	26.2	21.5
KH-7/7	282.0	863.0	35.0	16.2
KH-9/7	404.8	581.0	28.1	12.2
KH-12/7	276.4	903.0	38.8	19.7
KH-17/7	283.3	708.0	38.7	25.0
(Ak-1)	352.0	1402.0	46.1	38.0
(Kh-1)	293.5	3791.0	93.3	19.1

The maximum geothermal gradient in Western Desert is 31ºC/km in sub-surface's upper horizons which is verified in KH-5/4 borehole in Al- Hazimi Valley. This temperature rate is related to envelopment of heat since this borehole is sited far from fault lines and movement of subsurface water Figures (3 and 4). The minimum G.G. (12ºC/km) is detected in KH-9/7 borehole. The low temperatures in this water borehole associated to its location which is adjacent to the main fault. Moreover, its location is situated in the route of subsurface water flow [21]. The low G.G. rates for upper units in the Khleisia-1 and Akkas-1 wells are related to their lineup with faults.

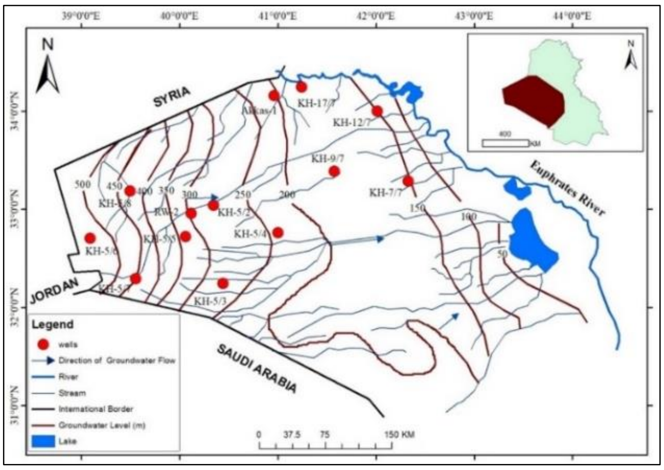

Fig. (3): Map of Western Iraq displays the position of water boreholes along the path of subsurface water movement [28]

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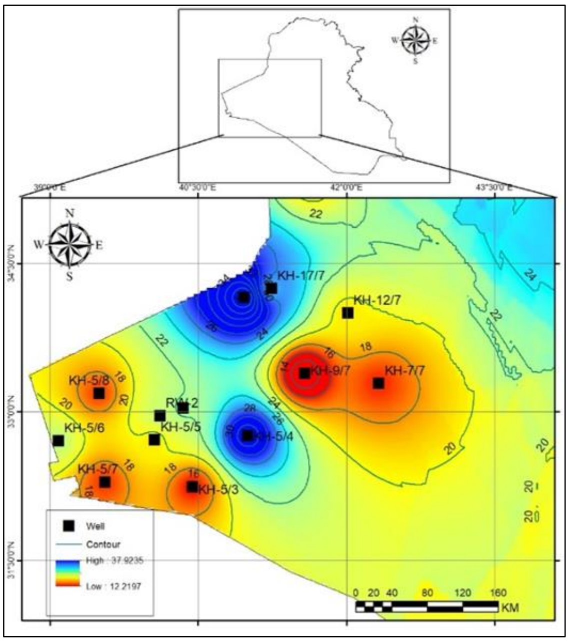

Fig. (4): Contour map showing geothermal gradient in Western Iraq

Both (Kh-1) and (Ak-1) boreholes are situated on the Hadhar-Bekhma and Anah-Qalat Dizeh faults, respectively [29]. Both boreholes are sited in the zone that known to have little radioactivity (1000-1100 counts per sec) [30]. The G.G. is considerably lower in the boreholes close to the faults Figure (4) because they act as a route for moving heat and aids subsurface water flow. The BHT in Khleisia borehole is lower in relative to Akkas-1 borehole for approximately the exact interval Figure (4). This higher heat in the Akkas-1 borehole is associated to occurrence of Paleogene low heat conductive clastic deposits compared to Cretaceous layers that comprise higher heat conductive (e.g., carbonate). Moreover, the thickness of shales of Akkas Fm, is lower in Khleisia-1 borehole-; subsequently, the quantity of produced heat is lower in Khleisia-1 borehole in comparison to Akkas-1 borehole. broadly cracked sediments in Khleisia-1 borehole enable an easier subsurface water movement too Figure (3). In Khleisia-1 borehole, the irregular heat rise was detected at 2135 meters beneath the ground level. The above-mentioned point is the upper boundary of the Akkas Fm (155 meters thick). The high heat is detected within the Paleozoic succession in Akkas-1 borehole as well (83 and 93 ºC in 2100 and 2350 meters, correspondingly). Accordingly, the G.G. is about 61ºC/km in this section. The rise in heat is resulted from possibly two dynamic parameters interrelated to features of the sediment debris and domination of the shaly sediments between 1463-2326 meters under the ground. These aspects are: the presence of unexpected element radiation (approximately 5.0

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micro-watt/m^3) of the stated sediments [31]; and weak heat conductive sediments which aids to gradual accumulation of heat. The G.G. is almost 40 and 49 ºC/km in the above and beneath the shale section, compatibly [32]. The excessive G.G. rate, 40 ºC/km is verified at Risha Oilfield in the eastern part of Jordan [32;33;34] owing to the presence of dark colored shales of the Batra Fm [35]. In western Iraq, dark colored shales in Akkas-1 and Khleisia-1 boreholes from Paleozoic stratigraphic units are more capable for heat producing than the younger stratigraphic units. Nevertheless, a huge amount of shale is vital for significant involvement to the total heat [26], and this circumstance exist since the Akkas Fm is approximately 150 meters thick in the area. Moreover, a heat rising from the basement (58 kwm) [36] has greater impact because the depth of basement rocks is 5 km in this region [17]. The high heat within upper horizons in the region probably related to the existence of dark colored shales and highly uranium content phosphorites, 4.6-65.0 Antipodal Vivaldi antenna (ava) 26 part per million in the upper Cretaceous and 2.9-50.9 ava 23 part per million in the Paleocene sequence [37;38;39]. The high G.G. in the Western Iraq declines toward Thirthar, and Tigris appearances in Central Iraq to turn out to be around 12-18 ºC/km [7]. To the south-eastern, the gradient is around 20 ºC/km [7]. The mean G.G. is also about the same amount in the western Iran adjacent to the Central Iraq [40;41]. This increase from west to east may be linked to existence of thick Lower Paleozoic mudstones which has low thermal conductivity. Contrary, the thick succession of Permian to lower Miocene carbonates and evaporites which have high thermal conductivities [8].

3.3. Southern Iraq

The borehole temperatures from 17 wells were applied to deduce geothermal gradient trends in southern Iraq. A good relationship exists between depth and temperature of all boreholes. The G.G. (depth vs. temperature) does not follow a straight line always Table (3). The surface temperature is assessed to be 25 ºC. Figure (5) displays the G.G. in which the lateral discrepancies throughout this region are shown. These G.G. variances naturally designate the seal layer and are perhaps linked to heat flow pathways and envelopment [24]. The maximum G.G. (≈30 °C/km) was observed in Nahr Umr-7 oil borehole. The lowermost G.G. (≈17 °C/km) was detected in Luhays-12 Well in the Zubair Subzone which is situated on Al Batin Fault. The mean provincial G.G. in southern Iraq is 22.2 °C/km. The area with lowest geothermal gradients is situated along the Falluja-Amara Fault in central part of southern Iraq and in the south east along the Tar Al Jir Fault.

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Table (3): Borehole temperatures and their G.G. in southern Iraq

Borehole Name	Ground Level Elevation (m)	Depth Below Ground Level (m)	Recorded Temperature (ºC)	Geothermal Gradients (ºC/km)
(Aam-3)	4.0	4100.0	104.0	19.3
(BU-7)	17.1	2816.8	82.2	18.2
(BU-10)	14.4	2170.0	72.2	15.3
(Zb-41)	0.9	2661.0	104.4	21.7
(Zb-47)	1.0	4510.0	121.0	21.3
(R-89)	2.1	4096.0	116.6	22.4
(R-158)	6.3	4414.0	110.0	19.3
(Ru-72)	17.4	4228.7	106.6	19.3
(Ga-3)	10.1	3451.0	78.3	24.3
(WQ-14)	0.8	3690.0	103.0	21.1
(WQ-15)	0.9	3529.0	104.4	22.5
(Lu-12)	17.9	3237.0	79.2	16.7
(Rt-6)	6.2	3600.0	91.7	23.0
(Su-7)	0.7	3416.0	100.0	21.9
(HF-161)	5.0	2837.0	91.0	21.7
(Mj-8)	4.9	1186.0	51.6	28.7
(NR-7)	5.2	2604.0	90.0	29.7

Figure (5) displays the overall growth of the G.G. towards the northeast and northwest of the area outside of Zubair Subzone. Within the Zubair Subzone, the faults divided the encroached salt diapers. This salt body, Jabal Sanam, comprises of a several rock types, dark colored dolomite, evaporite and transformed dolerite [42]. The anhydrite helped heat escaping because this type of rock is categorized as a strong heat conductive material (> $6Wm^{-1}K^{-1}$ at 20°C) in comparison to majority of upper and neighboring sediments, acting as a heat blanket outcome and a promising piece for low heat sources [43]. The maximum G.G. occur in the middle area of southern Iraq (NR-7 and Mj-8 oilfields). The higher geothermal gradients in Tigris Subzone can be linked to the occurrence of weak heat conductive Late Cretaceous claystone (Barremian Zubair and Aptian-Albian Nahr Umr formations).

The geothermal gradients in Majnoon and Nahr Umr oilfields, documented in previous studies [8;44], appear lower than that recorded recently in both wells. This inconsistency most likely related to the usage of uncorrected BHT in the previous studies. According to obtainable geophysical and stratigraphical evidence in northern Kuwait, the presence of superimposing "gas clouds" can be verified, related to the existence of "Conduits", which may be considered as source of heat. Immense water comportment clay horizons which might be able to store heat

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naturally have been noticed as well assisting the existence of irregular G.G. [45]. This situation may also be the reason for high geothermal gradient in Zubair Subzone.

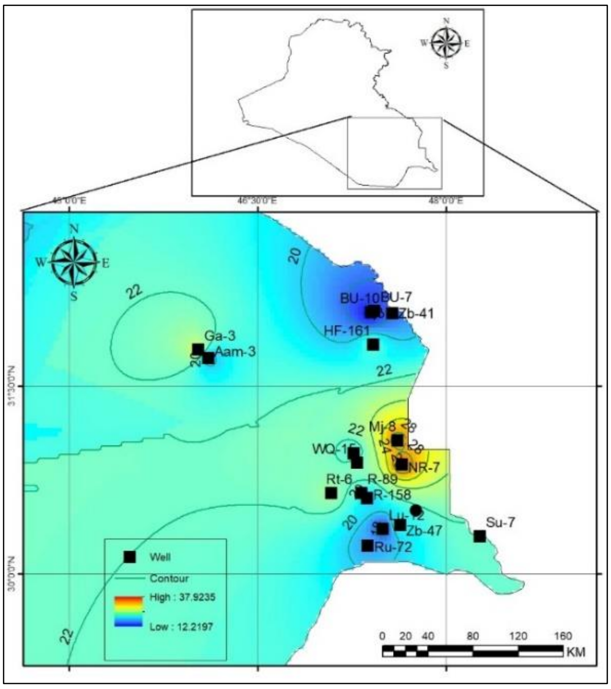

Fig. (5): Geothermal gradient trend in Southern Iraq

4. Conclusions

In northern Iraq, the G.G. vary noticeably horizontally (location to location) and vertically (depth). These differences are inferred to replicate variances in heat conductivity, heat production, and /or movement of ground water. The highest G.G. (29.2 ºC/km) is documented at the Foothill region. A minimum G.G. rate (14.9 ºC/km) is documented at the Mountain region. The mean G.G. in northern Iraq is 21 ºC/km.

In Iraqi Western Desert, geothermal gradients differ from location to another location. This inconsistency is inferred to imitate changes in heat conductivity of geological units, heat production, ground water movements, and heat transfer through faults. The maximum and minimum geothermal gradient values are 31.3 ºC/km at the KH-5/4 in the center portion of the region and 12.2 ºC/km at the KH-9/7 in the eastern part of the region, respectively. The mean geothermal gradient in Iraqi Western Desert is 26 ºC/km for shallow depths, but it increases to 40 ºC/km or even higher for Silurian intervals.

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In Southern Iraq, the uppermost G.G. (29.7 °C/km) is noticed in Nahr Umr-7 Well in the Zubair Subzone. The lowermost G.G. (16.7 °C/km) are observed in Luhays-12 Well in the Zubair Subzone, too. The mean regional G.G. in Southern Iraq is 22.2 °C/km.

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