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A Hypothesis on the Origin of Warm Groundwater 50KM NW of Benin City, Southern Nigeria.

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Abstract

The discovery of warm groundwater (about 52^{0}C) in Ofumwengbe community, near Benin City, Nigeria provides a strong impetus for this study, which seeks to provide a geological explanation of its origin. Eighty-Four (84) ditch cutting samples were obtained from three (03) groundwater wells drilled into aquifers within the Imo Formation, which underlies the study area. The methodology employed involves lithologic description, acid test to estimate calcite content as well as bulk geochemistry (25 samples analysed with CNS analyser) and elemental analysis (20 samples analysed with sodium peroxide fusion and ICP-OES and ICP-MS techniques). The results obtained show that the Imo Formation is dominated by light grey mudstones and subordinate sand units with varying degrees of effervescence. The average Uranium (U) and Thorium (Th) concentration in the samples are 4.37ppm and 9.4ppm respectively. The mean Total Carbon, Total Inorganic Carbon Total Organic Carbon (TOC) are 2.54 wt. %, 1.45 wt. % and 1.15 wt. % respectively. The observed lithological and geochemical characteristics suggest a proximal shallow marine paleoenvironment with oxic bottom waters, which agrees with data published by other researchers. Furthermore, the observed TOC, U, and Th data, the negative covariation between TOC vs. U, and Th indicate that the mudstones are not radioactive, and cannot by itself generate the heat observed in the warm groundwater. We hypothesize that a deeper heat source (perhaps the basement) transmitted heat through the fault systems of the Benin hinge line, which was subsequently trapped by the thick low thermal conductivity mudstones of the Imo Formation, ultimately warming up the water within the sand aquifer system of the Imo Formation.

1. Introduction

In this era wherein calls for the end of fossil fuel exploration have gained significant momentum, the search for sustainable clean energy sources is receiving heightened attention. Such energy sources include: Hydrogen, Hydroelectric power (HEP), solar energy, wind energy, geothermal energy, etc.

Nigeria's power source is contributed significantly by thermal (gas and coal fired) and HEP, both with a generation capacity of 10,396 MW at optimum functionality[1]. Sadly, this is about 25% of the targeted 40,000 MW required to attain energy sufficiency[1].There is tremendous potential for power generation from solar and wind sources in Northern Nigeria [2] and geothermal energy in some parts of Nigeria[3].

Geothermal energy refers to heat energy originating from the earth's interior, which can be due to heat dissipation from the metallic core or from radioactive decay of radioactive elements. Geothermal systems can be classified as high temperature (>250^{0}C) systems (fluids or brines pick up heat as it circulates through fractures of permeable zones above or in close proximity to hot igneous rocks), middle (125-225^{0}C) and low temperature (<125^{0}C) systems (fluids or brines pick up heat arising from the geothermal gradient in a sedimentary basin)[4].Nigeria's geothermal energy resources fall under the middle to low classification scheme[5]. These geothermal resources occur in areas underlain by basement rocks and sedimentary strata [6] with the more prominent occurrences in Lamurde, Awe, Akiri, Wikki, Ikogosi, Kanje, Igbonla, Keana, Azara, Ribi, Ruwan Zafi, Igbonla, etc.

A large proportion of scientific investigation on these geothermal resources have focused on harnessing it for power generation [5,6], whereas geological investigations into the origin of these warm springs/ warm groundwater have been sketchy. In the last two (2) years, there have been reports of warm groundwater occurrences from some boreholes around Ofumwengbe Community (close to Okada) by the Small Town and Rural Water Supply And Sanitation Agency (STRUWASSA), Edo state, Nigeria. The wells are artesian, penetrating great mudstone thicknesses ranging between 500ft to 1000ft. Bottom water temperatures up to 52^{0}C were recorded during well completion. The Significance of these warm groundwater occurrences for geothermal energy exploitation has provided the impetus for the geological investigation of the origin of the warm groundwater reported around Ofumwengbe Community, Edo State.

1.1 Geological Setting:

The Niger Delta Basin represents the last active phase of the Benue Trough, which was initiated in the early Jurassic to late Cretaceous. The modern Niger Delta Basin (Fig. 1) is a clastic wedge that covers an area of about 75,000 sq. km. It is bounded to the North by the Anambra Basin, the south by the Atlantic Ocean, the Benin hingeline and the Calabar hinge line to the east and west respectively.

The Niger-delta basin fill comprises of offlapping sequences with three (03) lithostratigraphic units, which are: the Benin Formation, the Agbada Formation and the Akata Formation in stratigraphic order [8-11]. The Akata Formation consists of predominantly mudstone with thickness up to 7Km in the shelf area, up to 2Km in the slope area, and up to 5Km in the deep basin area. The updip outcropping equivalent is the Imo Formation as well as the Ewekoro Formation in the Benin Basin. The overlying Agbada Formation is deltaic, consisting of intercalations of sand and mudstone which has prograded southwards over a distance of 300km since the Late Eocene epoch [7].The thickness of the Agbada Formation is up to 3500m [12].The lower Agbada Formation contains greater mudstone thickness, whereas by contrast the upper Agbada Formation contains greater sand thickness. The updip outcropping equivalent is the Bende-Ameki Formation (lower Agbada) and the lignite bearing Ogwashi-Asaba Formation (upper Agbada Formation). The Benin Formation, which is the youngest lithostratigraphic unit, consists of gravels, sands, and continental clays with thickness reaching up to 2Km deposited in a tidal influenced fluvial depositional setting. The sands of the Benin Formation are excellent aquifers.

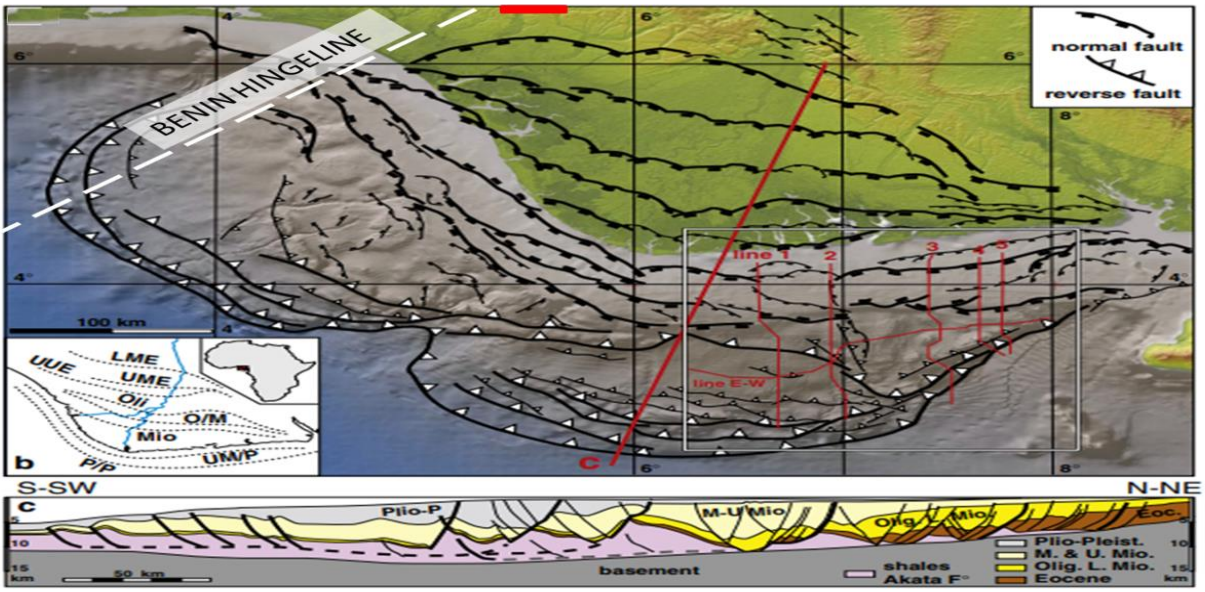

Fig. 1: Map of Niger Delta showing study area (red box), depobelts and structural domains (modified after[7])

1.2. Structural Framework:

The aforementioned lithic fill is contained within five (05) regional 'mega structures' or depobelts (Fig. 1), which are bounded by regional and counter regional faults[9,11]. The depobelts (from North to south) namely: the Northern Delta, the Greater Ughelli, the Central Swamp I & II, the Coastal Swamp and the Offshore depobelts. In addition, along an updip to downdip (N-S) transect three structural domains have been reported, namely: an updip listric growth fault dominated extensional domain; a middle or intermediate mud diapir dominated translational domain and a downdip thrust fault dominated compressional domain[7,13,14]. The structural framework of this is due to gravity spreading as the late post-rift sediments of the Agbada Formation rapidly prograded on the uncompact, overpressured muds of the early post rift Akata Formation[12]

1.3 Local Geology

The study area is located within the Northern Depobelt of the Niger-Delta Basin. It is underlain by the Imo Formation which is the lateral outcropping equivalent of the subcropping Akata Formation (Fig. 2). It was formed during the Thanetian[15] flooding episode, which blanketed the Maastrichtian to Danian sediments of the Nsukka Formation. The Imo Formation consists of predorminantly of dark to bluish grey mudstones with thickness in excess of 1000ft (this study), interbedded occasionally with ironstone, sand and limestone. The sand facies of the Imo Formation are aquiferous and artesian with warm groundwater reported from several locations. An investigation into the hydrocarbon generation potential of the Imo Formation using cuttings obtained from Nzam-I well revealed TOC values varying between 0.39 to 2.07 wt. % (av. 0.70 wt. %) and the predominance of immature Type IV kerogen[16]. This implies that the kerogen within

Imo Formation are reworked or oxidized, Immature with poor to fair potential for hydrocarbon generation**.** Facies analysis conducted on the Imo Formation exposed at Ebenebe–Awka axis, suggests a proximal shallow marine paleoenvironment with significant terrestrial influence was prevalent during the Thanetian[15]. Unpublished data by the authors reveal diagnostic index palynormophs such as: *Retidiporities magdalenensis and Longapertites vaneendenburg,* *Verrucatosporites usmensis*, *Ifecysta sp.*, *Kallosphaeridium cf. yorubaensis and Adnatosphaeridium sp*., which indicate Middle to Late Paleocene age for the sediments penetrated by the wells.

2. Materials and Methods

Eighty –four (84) ditch cutting samples were obtained from three (03) warm ground water wells (Fig. 2) drilled by STRUWASSA in Ofumwengbe Community (close to Okada), Edo state, Nigeria.

The samples were first evaluated for their lithological characteristics and subsequently tested for calcite using dilute HCl (0.5M). Varying degrees of effervescence were recorded ranging from zero efferevescence (0), weak effervescence (1), moderate effervescence (2) and strong effervescence (3). Twenty-five (25) samples were thereafter selected for bulk geochemical analysis which include Total organic carbon (TOC), Total inorganic carbon (TIC) and Total carbon (TC) analyses at the University of Florida stable isotope geochemistry lab, Florida, US, whereas twenty (20) samples were selected for determination of trace element at Activation Laboratory, Ontario, Canada.

3.

The experimental procedure for the determination of TC involves weighing approximately 50mg of pulverized material into tin capsules and heating same in an N.C. Technologies ECS 8020 elemental analyzer. The liberated CO2 gas is trapped and measured to give an indication of the TC present. TIC experimental procedure involves pre-treatment of approximately 15mg of sample with HCl in an AutoMate automated carbonate preparation device which is coupled onto a UIC 5017 CO_2 Coulometer. The CO_2 liberated following combustion of the decalcified sample is trapped and measured as TIC. TOC was thereafter computed from the difference between TC and TIC (i.e. TOC = TC – TIC).

4.

The experimental procedure for the measurement of U, Th involves fusing sample with sodium peroxide (1:6) in a Zirconium crucible. The fused samples are thereafter acidulated with concentrated HNO_3 and HCl and diluted before measuring with ICP-OES and ICP-MS.

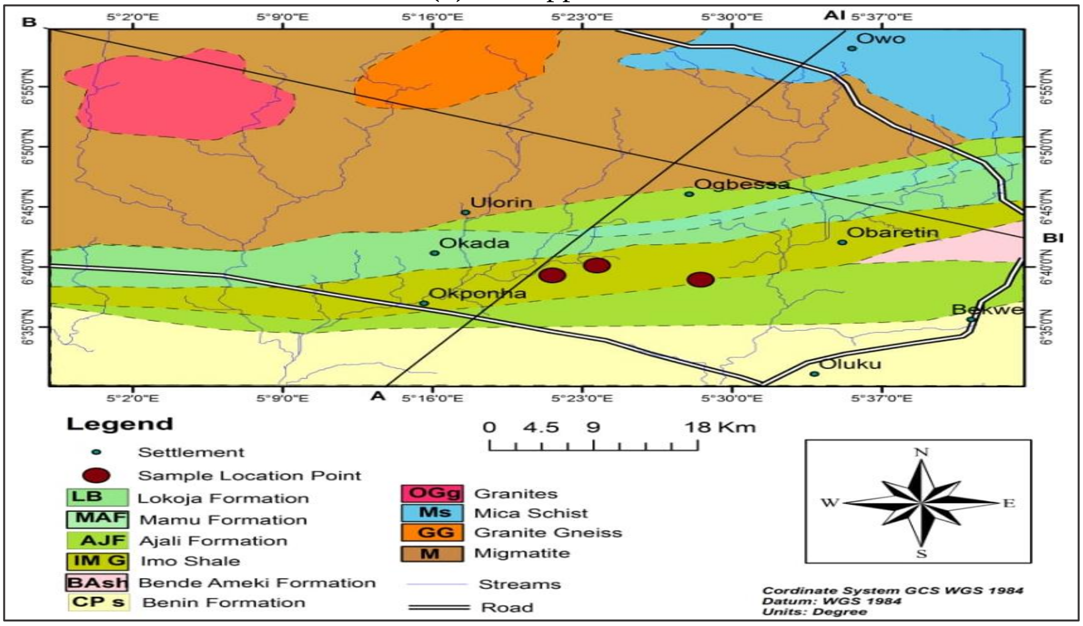

Fig. 2: Geological map of the study area with well locations

3. Results and Discussion

The results of the analysis are presented in Table 1 below.

The Uranium concentration in the sample varies from 2.3 ppm to 10.2 ppm, with mean and standard deviation values of 4.37 and 2.01 respectively. (Table 1, Fig. 9). Thorium concentration varies from 4.6 ppm to 13.5 ppm, with mean and standard deviation values of 9.40 and 2.43 respectively. The Total Carbon (TC) value ranges 0.53 wt. % to 6.88 wt. %, with mean and standard deviation values of 2.54 and 1.57 respectively. (Table1, Fig. 9). Total Inorganic Carbon (TIC) value ranges from 0.17 wt. % to 5.29 wt. % , with mean and standard deviation values of 1.45 wt. % and 0.74 wt. % respectively. Total Organic Carbon (TOC) value ranges from 0.05 wt. % to 3.26 wt. % (Table 1, Fig. 9). The mean and standard deviation of TOC were calculated as 1.10 wt. % and 0.74 wt.% respectively.

Table 1: Results of geochemical analysis

Sample No	TOC (wt. %)	TIC (wt. %)	TC (wt. %)	% $CaCO_3$ (TIC*8.33)	Degree of Effervescence	U (ppm)	Th (ppm)
EG 35ft	0.11	1.42	1.53	11.83	Strong ffervescence	2.6	9.8
EG 75ft	0.25	0.28	0.53	2.33	weak effervescence	-	-
EG 115ft	0.68	0.69	1.37	5.75	strong ffervescence	-	-
EG 135ft	0.99	1.28	2.27	10.66	moderate effervescence	-	-
EG 155ft	1.00	0.17	1.17	1.42	weak effervescence	-	-
EG 175ft	0.25	1.98	2.23	16.49	strong ffervescence	6.9	10.3
EG 205ft	0.57	0.77	1.34	6.41	moderate effervescence	4.3	10.9
EG 235ft	1.71	1.72	3.43	14.33	strong ffervescence	3.4	10.7
EG 275ft	0.05	1.7	1.75	14.16	strong ffervescence	7.2	7.9
EG 330ft	1.38	2.78	4.16	23.16	strong ffervescence	-	-
OK 65ft	1.35	2.15	3.50	17.91	strong effervescence	3.1	6
OK 115ft	0.34	4.65	4.99	38.73	strong effervescence	3.7	5.6
OK 200ft	0.81	0.42	1.23	3.50	strong effervescence	4.6	9.7

OK 245ft	1.47	3.85	5.32	32.07	strong effervescence	10.2	5.3
OK 285ft	1.59	5.29	6.88	44.07	strong effervescence	5.9	4.6
OB 65ft	3.26	0.14	3.4	1.17	weak effervescence	2.3	13.5
OB 125ft	0.8	1.48	2.28	12.33	strong effervescence	4.2	12.5
OB 195ft	1.14	0.78	1.92	6.50	strong effervescence	6.3	11
OB 395ft	0.99	0.21	1.2	1.75	moderate effervescence	3	11.7
OB 565ft	1.15	1.37	2.52	11.41	moderate effervescence	2.3	9.8
OB 675ft	0.91	0.24	1.15	2.00	moderate effervescence	3.6	10.4
OB 745ft	1.73	0.42	2.15	3.50	moderate effervescence	2.7	10.1
OB 865ft	1.15	0.48	1.63	4.00	moderate effervescence	3.6	10.3
OB 1085 ft	2.6	1.59	4.19	13.24	strong effervescence	3	7.9
OB 1115ft	1.14	0.32	1.46	2.67	weak effervescence	4.4	9.9
Mean	**1.10**	**1.45**	**2.54**	**12.06**		**4.37**	**9.40**
S.D	**0.74**	**1.40**	**1.57**	**11.66**		**2.01**	**2.43**

3.1 Depositional Setting:

The Imo Formation comprises primarily to light grey mudstones (dominant) and sands lithologic units (Figs. 3-5). The gross mudstone thickness, which is in excess of 1000ft (300m), the moderate carbonate content (up to 44%), observed TOC of ≥ 2 wt.% is common in areas with oxic bottom waters, high clastic dilution and abundant terrestrial organic matter[17-18][], which is suggestive of a shallow marine (shelf) environment. Data presented by[15] as well as unpublished palynofacies data from an ongoing research undertaken by the authors is congruent with the hypothesized paleodepostional environment

3.2 Implication For Origin Of Warm Ground Water:

Radioactive mudstones or 'hot shales' are deposited under anoxic to euxinic bottom waters and typically possess high TOC's, and high concentrations of redox sensitive trace elements, such as U and Th, which impart high Gamma radiation[19-21]. Mudstone units deposited in the Silurian Period such as: Tanezzuft Formation (Libya, Tunisia and Algeria), Qusaiba Shale (Saudi Arabia), Tanf Formation (Syria), Mudawwara Formation (Jordan) are good examples of 'hot shales'. The observed TOC and U data from the samples, the negative covariation between TOC and U, Th (Figs. 6a-b) indicate deposition in oxic bottom waters, and do not suggest the presence of radioactive mudstones. The heat source is believed to originate from a deeper source, perhaps from the basement and transmitted through the fault systems of the Benin hinge line, which sub crops near the study area (Figs. 1, 7). It has been reported that mudstones transmit heat slowly, as such act as thermal blankets, trapping and storing heat within sedimentary basins, ultimately resulting in anomalously high heat flows. [22] reported the geothermal gradient of the 5.5°C/100 m within the Akata (Imo) Formation is the highest within the Niger delta Basin. This implies that at a depth of 1000m, sediments of the Imo Formation may acquire temperatures in excess of 50^0C, which matches with the temperature of warm groundwater recorded from one of the wells under study. Furthermore, heat flow values across the five depobelts within the Niger delta Basin are variable with heat flow at the Northern delta depobelt being among the highest, averaging 51.49 mWm^-[23]. From the foregoing, it seems most probable that the warm groundwater occurrence around Ofumwengbe is a consequence of the aquifer system acquiring the heat trapped within the Imo Formation due to its low thermal conductivity.

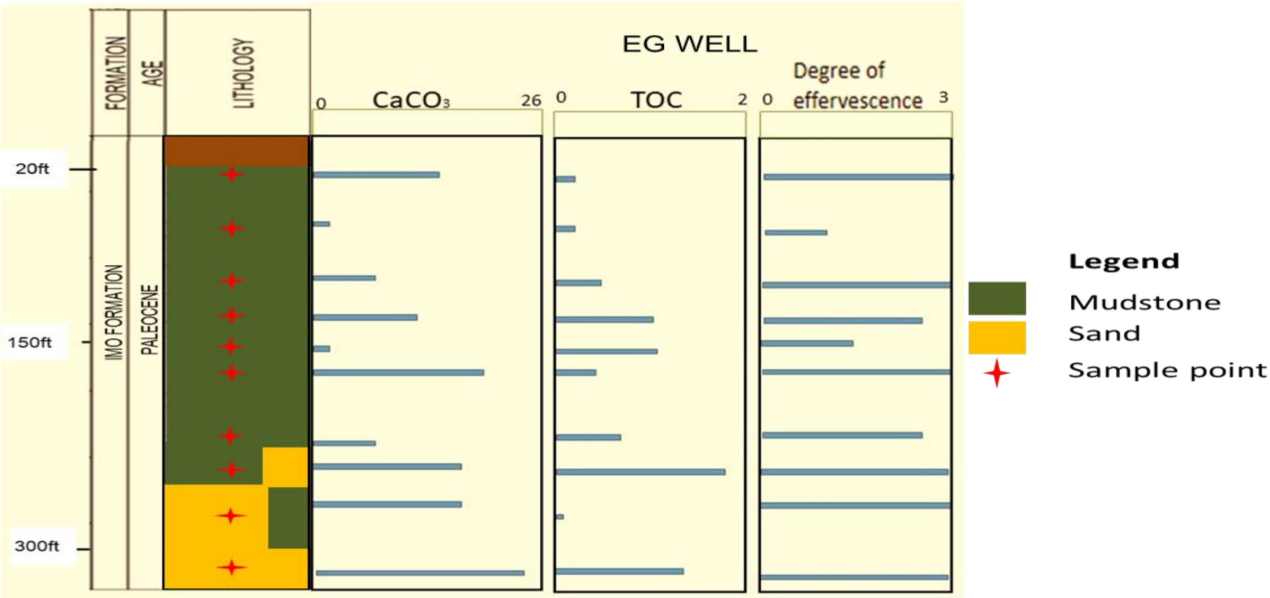

Fig.3. Lithologic section and geochemical log for EG well

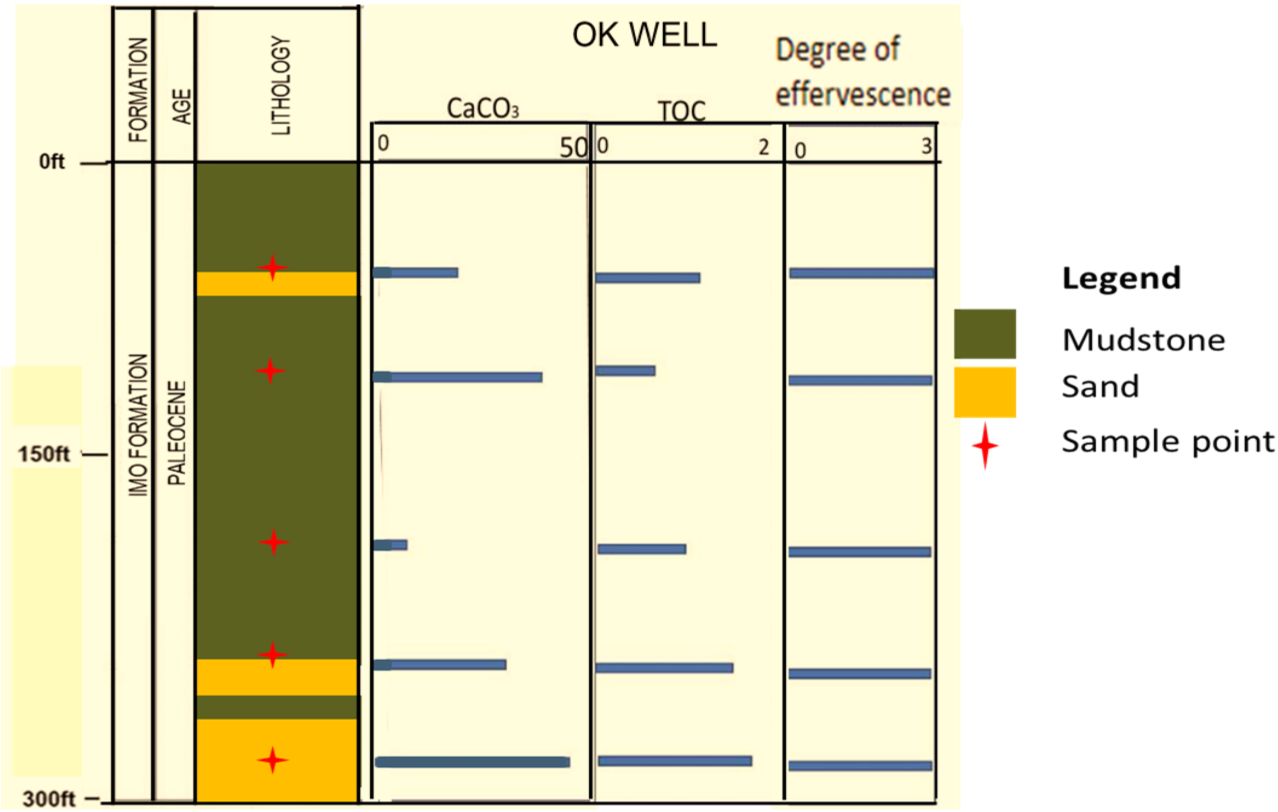

Fig.4. Lithologic section and geochemical log for OK well

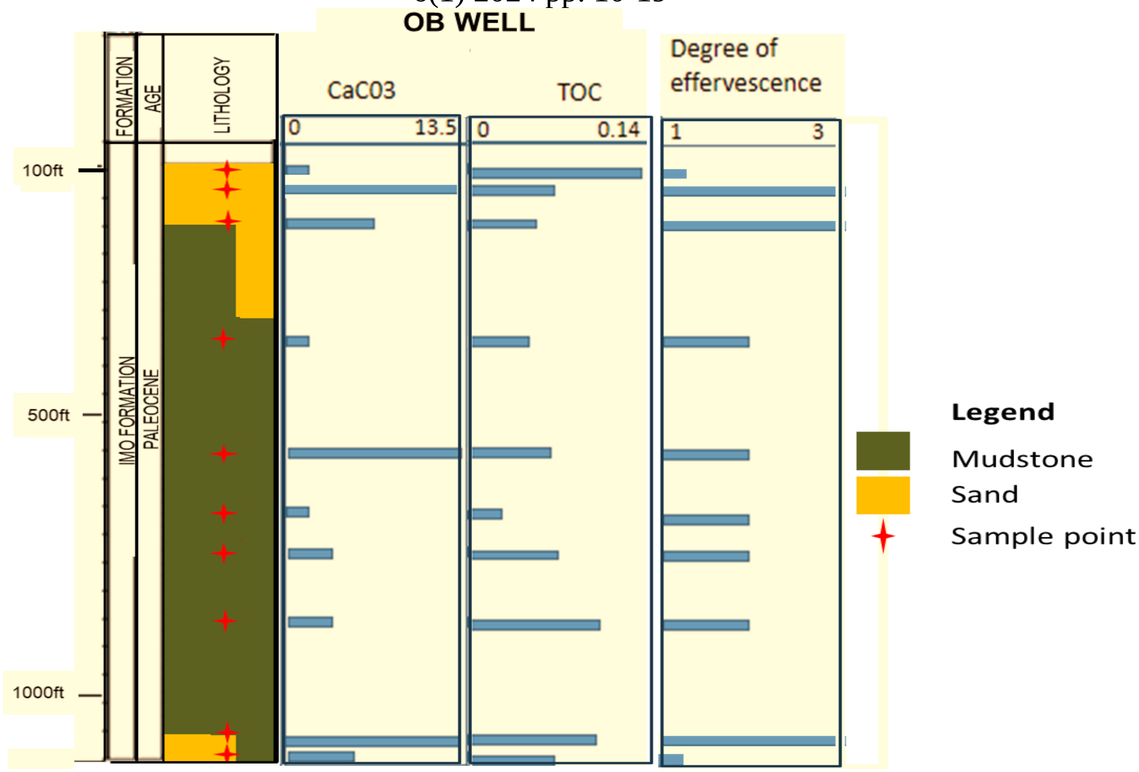

Fig.5. Lithologic section and geochemical log for OB well

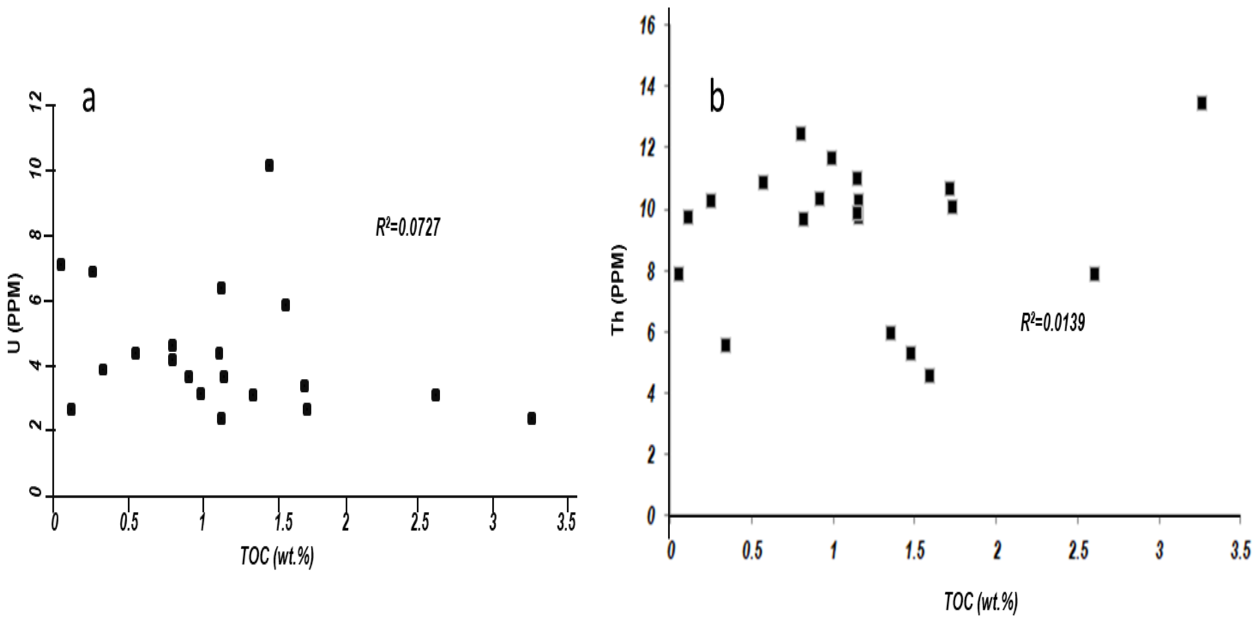

Fig.6 (a). Binary plots of TOC vs. U (b) Binary plots of TOC vs. Th

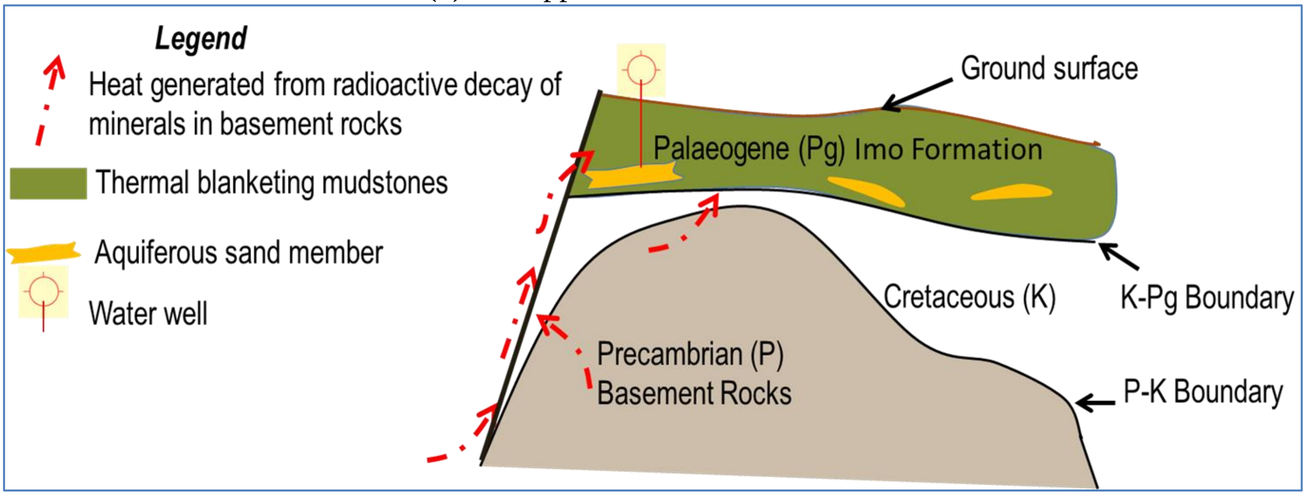

Fig. 7. Schematic diagram depicting the probable geological explanation for the origin of warm groundwater occurrence in the study area

4. Conclusion

The following under listed conclusions can be made From this study:

1) The Imo Formation was deposited under prevailing shallow marine paleoenvironment, with oxic bottom waters.
2) The mudstones of the Imo Formation are not 'hot shales' due to their low U, Th and TOC concentration.
3) The proximity of the wells close to subcropping basement fractures aid the occurrence of the warm groundwater.
4) The ability of thick mudstones to trap heat generated from the basement rocks and slowly disseminate same with time is hypothesized to be the reason for the hot groundwater occurrence

5. Acknowledgement

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