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Chemical evaluation and hydrodynamic interpretation of flammable gas leaching from the shallow water well in Chamchamal Town, Kurdistan, NE of Iraq

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ABSTRACT

A wonderful event had taken place in the Gurgayi Fatah Village (5 Km to the north of Chamchamal Town), when gas and water are blowouts from a shallow drilled water well. Scientists and people hurry to view and investigate this phenomenon. The current study attempts to interoperate the factors behind gushing water and gas. Samples of gas and water were analyzed for gas composition and $\delta\ ^{13}CH_4$ isotope, major and heavy metals, and environmental isotopes $\delta^{18}O$ and $\delta^{2}H$. The results of the hydrochemical analysis showed that Ca^{2+} and SO_4^{2-} are the dominant ions and the concentrations of heavy metals are below the detection limit. The values of $\delta^{18}O$ and $\delta^{2}H$ isotopes were -6.25 and -30.85 respectively indicating that the recharge of groundwater is recent. The dominant gas composition is Methane CH_4 with 84.5% volume per unit volume, while it characterizes by elevated hydrogen sulfide with a value of 17700 ppm.

The study revealed that the drilled water belongs to the first system (gravity hydrodynamic systems; where the water moves by the action of gravity from sites of high potential, and the major faults and fractures connecting the deep aquifers to the shallower. The high-pressure phenomenon is well known in Fatha Formation even more notable some oil wells along the foothill's zones.

Introduction

In September 2015 a water well was drilled by a farmer in Gurgayi Fatah Village to irrigate a nearby farm located about 5 Km to the northeast of Chamchamal Town, Fig. (1). When the drilled well depth has been reached 90 m water and gas were flowing out, someone has been ignited the gas, and therefore a fire with water is mixed giving an amazing phenomenon. The fire was continuously ablaze till now, but it has depleted and the mouth of the well sunken under the lake that built up around the drilled well area. Since then, the fire has been consuming about 2200 liter of gas per day. The area became an attractive place and the people visit the area daily to see the phenomenon, calling on the Kurdistan Regional Government (KRG) and some local and international organizations to prevent the resource from being wasted, pollute the environment, and causing health concern of the surrounding area. The gas consists of rich hydrogen sulfide methane which negatively affects the health condition of people around the water well as well as those who visit the area. The flowing water is characterized by milky color and hydrogen sulfide odor.

Foreign oil companies were not interested in investing gas associated with oil production in Iraq when the discovery of oil in the Baba Gurgur field in Kirkuk in 1927, and since that time the associated Iraqi gas is wasted by burning, in addition to the closure of many gas wells in some fields, including Kor Mor, Chamchamal, and Khasham Al Ahmar. Meanwhile, two exploration wells are drilled in the study area (CH-1 and CH-2) nearby to the current water well. The exploration well CH-1 located around 450 m SW to water well site, this well was drilled in 1929 near the crest of the dome to the total depth of 425 m, Rotary Table Kelly Bushing (RTKB) in transition beds of Fatha Formation, the well was

tested gas in the transition beds, due to the drilling problems the well was closed & plugged at187.4 m.
The well CH-2 locate in the SW flank of the structure around 900 m SW to the water well, this well was drilled in (1952) by Iraq Petroleum Company (IPC) to test the possibility of the presence of oil in the main limestone Tertiary reservoir of Kirkuk field to the total depth 2258 m in Dokan Formation. The well later deepened in 1953 to the total depth 2875 m in Lower Sarmord Formation, to confirm the presence of the Qamchuqa reservoir.
A similar event took place in August 1989 when an earthquake took place in the study area, spring water appeared and the water height was about 2.5 m which has same quality was as same as the water well, this spring is located about 300 m SE to the current water well.
A research team from the University of Salahaddin studied the subsurface geological conditions responsible for forming this spring [1] This study concluded that there is a cavity below the surface with dimensions 6.6 m and 15 m filled with rich sulfate water and the earthquake made some local faults that are responsible for emerging such spring.
Hydrogen sulfide (H_2S) is usually an undesirable part of natural gas. Where present, H_2S not only dilutes the proportion of hydrocarbon gas in the reservoir; it is very toxic and extremely corrosive to production equipment. The capacity to prognosticate the existence of H_2S in undrilled prospects would thus be a very useful tool in gas exploration [2, 3, 4].
This paper presents geochemical data of the natural gas and water, furthermore investigates the origin of hydrocarbon gas, hydrogen sulfide, and sulfate water based on the stable isotope compositions (CH_4, $\delta^{18}O$, and $\delta^{2}H$), hydrochemical data, and previous oil wells documents. Additionally, there will be attempted to determine the origin and mechanism that led to the high pressure in such shallow water well.

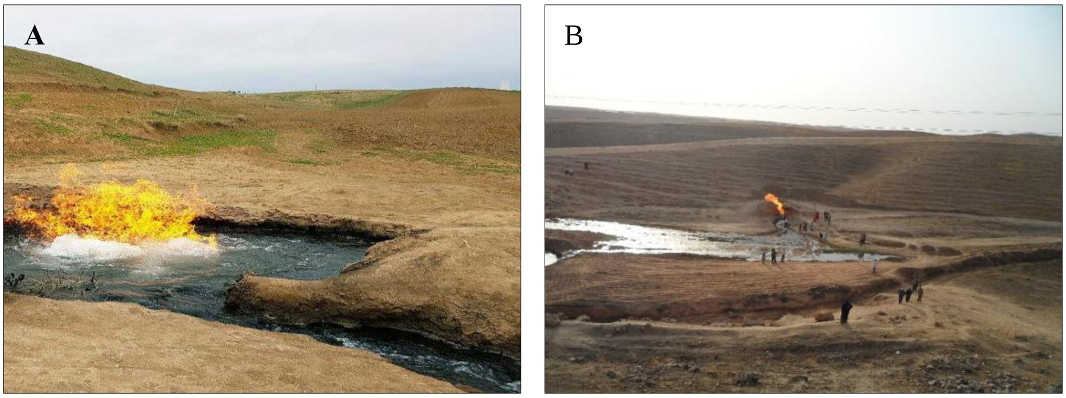

Fig. 1: A) Gushing pulses of water and flammable gas from the well B) Pond is formed by the flowing water

Location of the study area

The study area lies in Kurdistan region northeast of Iraq and is located within the intersection point of the longitude 44°51'34.62" E and latitude 35°33'52.24" N, the area elevated about 700 m above sea level, about 45 km to the Northeast of Kirkuk City, and 50 Km to the West-Southwest of Sulaymaniyah City, Fig. (2). The well is located in the crest of the gentle anticline of Chamchamal structure with a northwest-southeast trend parallel to the Bazian anticline.

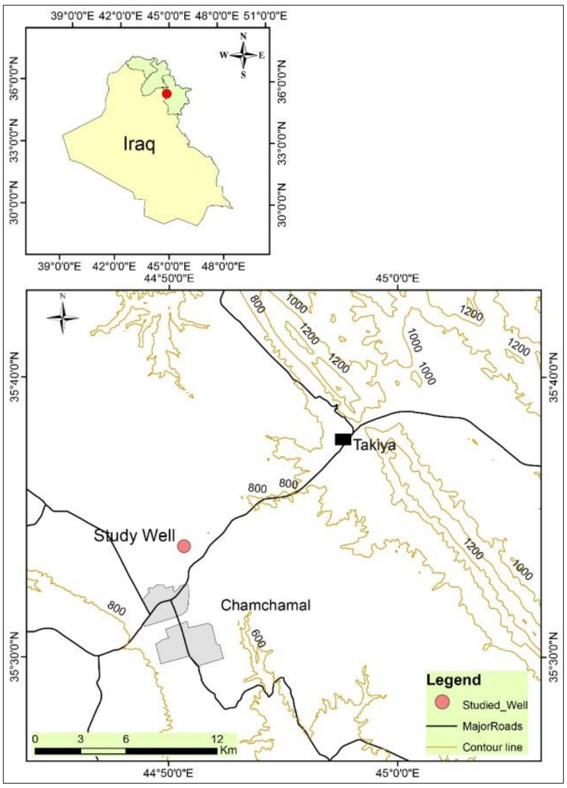

Fig. 2: The Location of the drilled well on the topographic map

Geological setting

Tectonically the study area is a part of the Butmah - Chamchamal sub-zone of the Foothill Zone, which is related to the unstable shelf units [5]. The Butmah – Chamchamal Subzone has a very conspicuous log and deep synclines with thick Pliocene molasses dominated by conglomerate between the prominent long and narrow anticlines ranges often not associated with longitudinal faults, with crestal parts being devoid of a Quaternary cover. There are many structural features in the study are like Chamchamal north double plunging anticline which extends from the northwest, near Palka Rash Village, toward the southeast at Qala Chogha Village. The axis of this structure is plunging towards Palka Rash in the northwest, while it is plunging towards Qala Chogha in the southeast. This structure is characterized by having a rounded crest and a gentle plunging feature. It is a double plunging anticline with an axial length of about 47 km-oriented NW-SE [6]. The anticline is normal and asymmetrical with a northeastward vengeance. The dips of the northeastern and southwestern limbs are 20° and 10° degrees respectively. The south block of this fault moves toward (NE) leading the course materials of Mukdadiya Formation to be pushed toward Chamchamal north anticline and the fine materials of the Injana Formation (North block) are pushed toward Gosht Qut Village southwest direction.

Geologically the study area is characterized by existing many geological formations, the oldest one is Fatha Formation (Middle Miocene-Tortonian) and the younger is Quaternary deposits, Fig. (3 &4).

Fatha Formation which the water well lies on it is characterized by the prevalent evaporitic (sulphatic and halogenous) facies. The rocks composing the Formation are anhydrite gypsum and salt, interbedded with limestone, marl, and relatively fine-grained clastics [7]. Also, there is red mudstone that acts as a cap rock for the underlying porous limestone intervals, which are well known as hydrocarbon reservoir pay zones in the area such Pila Spi, Shiranish, Kometan, Dokan, and Qamchuqa Formations. The thickness of the Fatha Formation in the study area is 448 m in the well CH.2 in Chamchamal (CH-2 final well report 1956 and 1961. The formation in CH.2 consists of four members; upper red bed 161 m, seepage bed 40 m, saliferous bed 136 m, and transition bed 111 m, [8], Fig. (5).

Injana Formation (Late Miocene) outcrops in the northeastern part of the study area east and northeast of Chamchamal city and on both sides of Shiwasoor intermittent stream northeast of the study area, forming the two limbs of the Chamchamal north double plunging anticline. The central part of the formation consists predominantly of uniform silty clay stones or marls with anhydrite in the NE side of the basin. The sands are derived from the rising Zagros and Taurus mountains [7] which are recognized clearly in the study area (East of Chamchamal). The sandstone beds consist of polemetic sandstone. According to [9], the thickness of the formation in the study area is approximately 650 m. The Mukdadiya and Bai Hassan Formations (Pliocene) are composed almost purely of terrigenous clastics from silt size to bounder conglomerates. In general, the grain size of clastics increases upward [7]. Bai Hassan Formation outcrops in the southwestern part of the study area (Bani Maqan Province) until Muafer Village and along with the main trend of the geological structures, while the Mukdadiya Formation, situated in the middle of the study area, is covered by fluvial fans and Quaternary deposits of maximum thickness that arrives at 120 m in some areas forming angular unconformity with underlain units. Quaternary deposits are generally composed of conglomerate, sand, and clay in different environments [10], it covers approximately 40% of the study area. Generally, the study area is located in the foothill zone; furthermore, it is characterized as a very broad and shallow syncline flank of Chamchamal north anticline, which is filled by Quaternary deposits in the inner part of the syncline, referred to, here, as the polygenetic synclinal fill. The major part of the study area is covered by this type of deposit. The thickness of this Quaternary veneer is variable but exceeds 120 m in some water wells [7]. Slope sediments are formed along the flanks of the structures. The sediments filling the synclines consist mainly of a mixture of gravel and clay. They form pediment deposits, consequently passing laterally into river deposits towards the center of the depression.

Hydrogeological setting

There are four aquifer systems in the study area belonging to different ages that are Middle Miocene, Late Miocene, Pliocene, and Quaternary systems. The Middle Miocene formation in the study area is represented by Fatha Formation, which is a complex intergranular-fissured multi-layered aquifer, of low production in siltstone intervals. In the lower parts, the presence of gypsum and anhydrite layers where karstic features are locally developed is observed which results in highly mineralized and sulfuric quality. The Middle-Miocene Unit appears only in limited geographical extends in the study area. The Late Miocene Unit in the study area is Injana Formation, characterized as an aquitard, which is a complex intergranular – fissured multi-layered aquifer of low production, developed and discontinuous in siltstone and sandstone intervals, interchanged with almost impermeable claystone [11]. The Pliocene water-bearing formations in the area consist of Mukdadiya and Bai Hassan Formations. Mukdadiya, is an intergranular aquifer of medium to high production locally, disconnected with semi-permeable siltstone or impermeable claystone covered by younger sediments and Bai Hassan is an intergranular aquifer of medium to high production locally, disconnected by impermeable claystone layers, partly confined, and covered by younger sediments, Bai Hassan Formation acts as a burier. The quaternary appears in the area as river terraces, slope deposits, and alluvium. The river terraces are an intergranular aquifer of medium production, locally disconnected with impermeable clay layers, partly semi-confined or confined, while slope deposits and alluvium are intergranular aquifers of medium to high production, fractioned by impermeable clay layers, mostly unconfined. Groundwater flow occurs from the Bani Maqan plateau, from west and southwest toward the Chamchamal plain that is located in the middle of the study area; Chamchamal City and Shorsh Collective Town are nested on this plane. The main aquifer in the study area is the Mukdadiya and Bai Hassan Formations, which are tapped by numerous supply wells to the surrounding communities. Groundwater is locally used for domestic and irrigation purposes in the area whereas surface water is mainly used for irrigation [12,13,14].

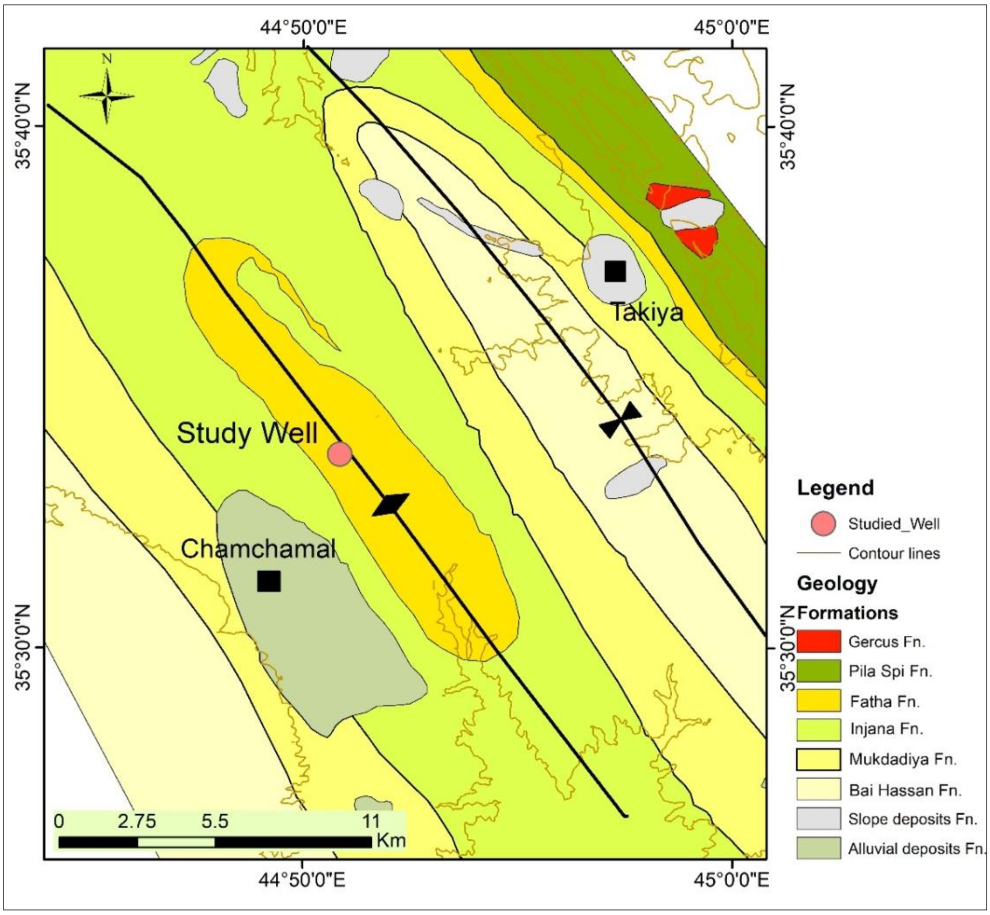

Fig. 3: Geological map of the study area (Adapted from [15])

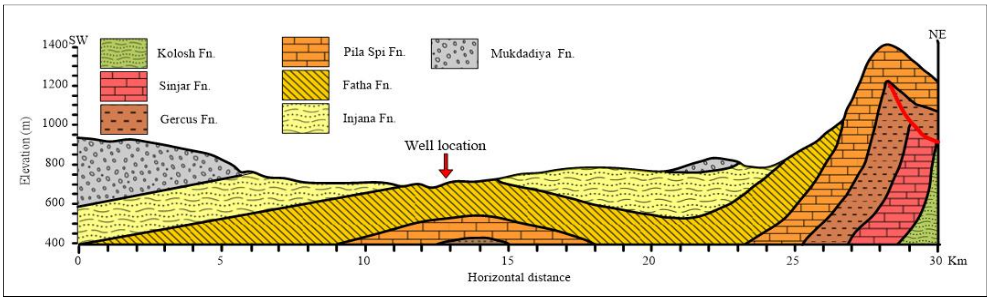

Fig. 4: Geological cross section along the study area (Adapted from [15])

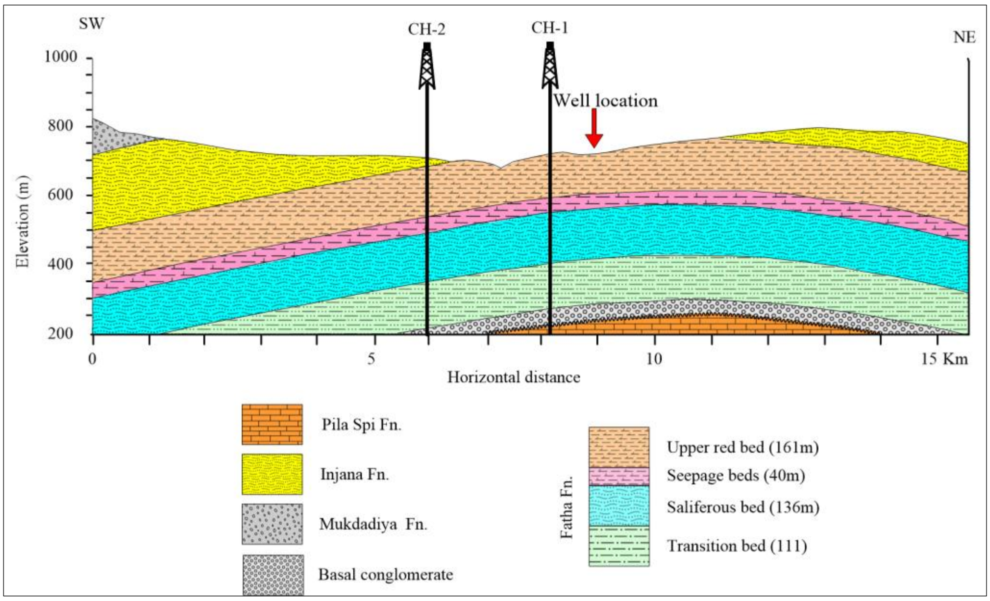

Fig. 5: Geological cross section of Fatha Formation in the well CH-2 [8]

Methodology

Gas sample analysis

Two gas and water surveys were conducted in May 2015 and November 2016 at the drilled water well. The gas sample was collected by pumping air through Tedlar Bags ESS for gas composition analysis, Fig. (6A). The gas samples were collected directly at the well's mouth by an L shape plumbing metal pipe connected by a funnel. The funnel was linked to the upper part of the outlet pipe of the well which the flammable gas flowing out, and the gas sample was collected by pumping into the bag in the other end of the L pipe. The analysis of the chemical composition of the gas was conducted by Kar Company using AC Hi-Speed Refinery Gas Analyzer) under the condition of 62.1 °C temperature and 331.2 psi pressure. The Hi-Speed RGA system contains six columns and is subdivided into three separate analytical channels. One channel determines helium and hydrogen; the second channel is used to determine oxygen, nitrogen, carbon monoxide, and carbon dioxide. The third channel separates the hydrocarbons on the PLOT column using the FID for detection

The isotopic composition of the $\delta\ ^{13}CH_4$ was conducted by Royal Holloway University's Earth Sciences Department. Besides, CO_2 concentration of the air was measured near the drilled well by a CO_2 meter Air CO_2ntrol 3000, Fig. (6B). ^{13}C stable isotopic composition analyzed on a Thermo-Finnigan Delta Plus Mass Spectrometer in Archaeology Department at the University of Reading, UK. The isotopic values are reported in per mil (‰) relative to Vienna Pee Dee Belemnite (VPDB).

The CH_4 and CO_2 gases were analyzed using a gas chromatograph at Royal Holloway's Earth Science Department using a protocol applied in [16]. The analysis was done by an aliquot of a 10 cm^3 air sample, which was taken out of Tedlar bags and injected into a flame ionized detector gas chromatograph. Later, it was heated at 240 °C and equipped with an 80/100 mesh, 1.8 m long, 1/8″ (3 mm) diameter Chromosorb 102 packed column, and N_2 carrier. A catalytic reactor connected to the end of the chromatographic column performed the reduction of CO_2 to CH_4; the accuracy of the measurements is 1.5%. The GC was fitted with a Flame Ionization Detector (FID) for CH_4 and a Thermal Conductivity Detector (TCD) for CO_2. Standard gas mixtures were used for 3-point calibration curves to convert signals measured on the GC to concentrations.

Water sample analysis

Chemical-physical parameters, conducted. In situ measurement of electrical conductivity, temperature, and pH measured done using the multi-parameter device (Fisher AP85 and AP75).

The samples are collected using 250 ml and 50 ml polyethylene bottles for major and trace elements analyses respectively. The samples for heavy metals analysis are first filtered using a 0.2 µm filter to get rid of colloids and then acidified by adding a few drops of high purity HNO_3 acid. All samples were then stored in a cool box at 4 ºC until they were later analyzed in the laboratory. The major ions (Ca^{2+}, Mg^{2+}, HCO_3^-) are analyzed titrimetrically, while (Na^+, K^+) analyzed by flame photometer. The (SO_4^{2-}, PO_4^{3-}, NO_3^-) analyzed colorimetrically using the [17] standard methods. Chloride ion is analyzed by Ion chromatography (ICS-1600) at the Ministry of Science & Technology (Baghdad) Lab. The NO_3^-, PO_4^{3-}ions are tested using Spectrophotometer.

For environmental isotopes, one water sample was collected in September 2015 for analyzing their isotopic composition ($\delta\ ^{18}O$ and $\delta\ ^{2}H$). The water sample was collected in a 60 ml polyethylene bottle with polyseal cap.

The environmental isotopes ($\delta\ ^{18}O$ & $\delta\ ^{2}H$) tested at the Ministry of Science & Technology Lab. Using liquid water isotopes analyzer method. results are reported in the usual δ notation relative to the Vienna Standard Mean Ocean Water (V-SMOW) standard, where $\delta = [(R/RV\text{-}SMOW) - 1]/1{,}000$ (R represents either the $^{18}O/^{16}O$ or the $^{2}H/^{1}H$ ratio of the sample, and RV-SMOW is the $^{18}O/^{16}O$ or $^{2}H/^{1}H$ ratio of the V-SMOW standard; [18, 19]. The precisions of the measurements for stable isotopes analyses were ±0.1 and ±1 ‰ for $\delta^{18}O$ and $\delta^{2}H$, respectively.

Fig. 6: A) Tedlar Bags ESS for gas composition analysis B) CO_2 meter Air CO_2ntrol 3000

Results and discussion

Hydrochemical properties of water

The water samples have a milky color and bitter taste with H_2S odor with (7.8 mg/l) and (8.2 mg/l) concentrations. The water sample that took in November slightly acidic, with a value of 6.95, while the first sample is slightly alkaline with a value of 7.24, Table (1). Electrical conductivity ranges from 3440 to 4190 µS/cm. Ca^{2+}, Na^+, and $Mg^{2+}$are the dominant cations present in the water with a mean value (241 mg/l), (79 mg/l), and (72.8 mg/l). Sulfate is a predominant anion with the mean value (888 mg/l), Bicarbonate and chloride are also present in considerable amounts with mean values (219 mg/l) and (108 mg/l). The lithology in the study area fully reflected the chemistry of water; the gypsum layers of Fatha Formation have a significant effect on the water quality, and considered to be the sources of Ca, and SO_4^{2-} ions. The water samples belong to one geochemical group which is Ca- SO_4^{2-} type waters. The concentrations of (Pb, Cd, Cu, Ni) are below the detection limit except for Cu.

Table 1: Physio-chemical properties and heavy meals concentration of water samples

Parameters	Units	7/11/2015	18/5/2016
T	ºC	24.3	21.5
pH		6.9	7.24
EC	µs/cm	4190	3440
TDS	mg/l		
Ca^{2+}		267	215
Mg^{2+}		79.6	66
Na^+		95	63
K^+		1	0.8
SO_4^{2-}		993	783
Cl^-		127.4	89
HCO_3^-		228	210
CO_3^{2-}	mg/l	0	0
H_2S		8.2	7.8
PO_4^{3-}		0.21	0.18
NO_3^-		0.9	0.5
Pb		B.D	B.D
Cd		B.D	B.D
Cu		0.007	0.006
Ni		B.D	B.D*
B.D: below detection			

Groundwater origin

The origin of the groundwater is interpreted according to the value of $\delta^{18}O$ and $\delta^{2}H$ isotopes and plotting the hydrochemical data on the [20] diagram.

For the evaluation of the data, two reference lines were plotted into the same graph. One of these lines, the "global meteoric water line" (GMWL), is based on numerous precipitation data from locations around the globe. The equation $\boldsymbol{\delta^2H = 8.13 \cdot \delta^{18}O + 10.8}$ **‰ VSMOW**, published by [21], is the updated version of [22] original findings.

The second one "local meteoric water lines" (LMWL) is derived from isotopic data for 55 precipitation events during the period December 2009 to June 2010 at the Bazian Meteorological Station in the Basara basin which closes to the study area conducted by [23]. The equation $\boldsymbol{\delta^2H = 7.7 \cdot \delta^{18}O + 14.4}$ **‰.** Accordingly, it was expected, that the sample from the drilled well plot near that line, Fig. (7). The well samples isotopic composition Table (2), which is slightly depleted $\delta^{18}O$ and $\delta^{2}H$ values, may indicate a more-recently recharged component and indicating that the aquifer is receiving water from Bazian recharge area.

When the hydrochemical data plotted on the Sulin graph Fig. (8), the water samples are located near the deep meteoric water origin. The relatively high values of the Na^+ related to their derivation from meteoric water and cation exchange with clay minerals of Fatha Formation.

Table 2: Isotope data for gas and water samples

Name	^{18}O ‰	^{2}H ‰	D-excess ‰	$\delta^{13}CH_4$ ‰	STD
S1	-6.25	-30.85	19.15	-33.52	0.064

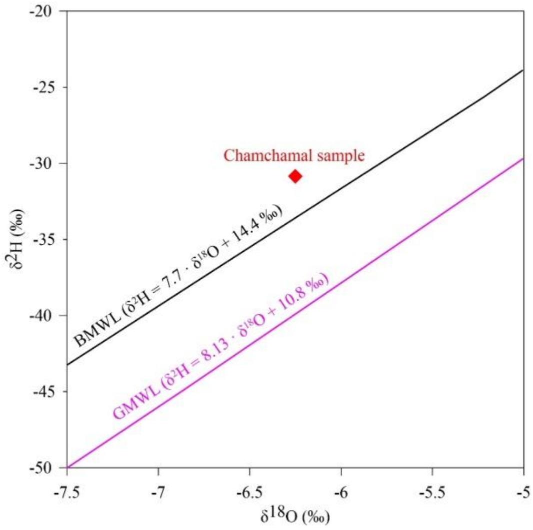

Fig. 7: Environmental isotopic composition of water sample

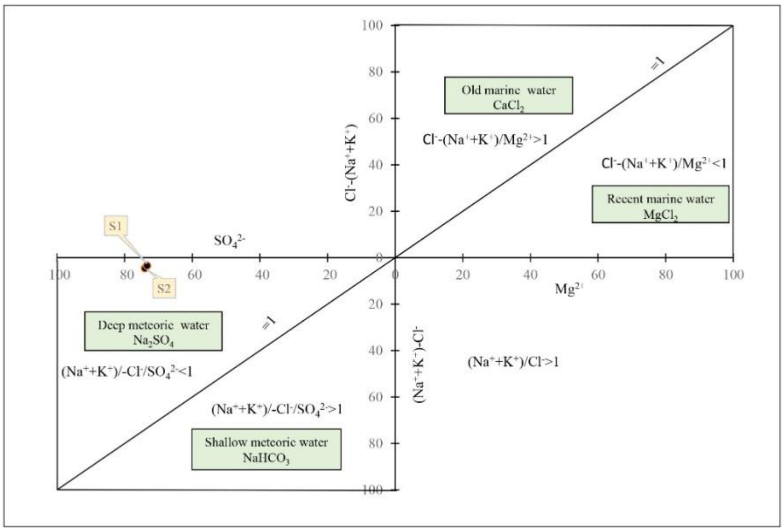

Fig. 8: Sulin plot showing the origin and type of the water sample

Gas Seepage

The seep gas is gashed with the water in Chamchamal shallow well in Lower Fras aquifer belongs to the gas accumulation in the underlain reservoirs as a cap gas over sulfurous water in the crest of the anticline. The origin of this seep is thermogenic gas that had accumulated in a deeper reservoir and had migrated upward through faults or zones of weakness.

According to the final report of the well CH-2, the fourth unit of Fatha Formation (Transition Beds), which had been penetrated between the depths 418 to 529 m. The upper part of this unit consists of a succession of thick beds of anhydrite with some gypsum interbedded with thin bands of limestone and marls. While the lower part of the unit consists of a thick bed of limestone (25 m), and strong gas presence. This information had been documented in this unit whereas drilling wells CH-1, and CH-2.

Also, according to the final drilled well CH-2 report [8], the Upper Qamchuqa Formation showed two porous dolomite intervals from 2374.4 – 2387.8 m and from 2397.3 – 2427.4 m which on inspection smelled of sweet gas. Besides in Shiranish Formation is between 1981.2 and 1996.4 m, the condensates wet gas was encountered when the well was put on test, and Kometan Formation gas shows of the order 4100 lbs/sq.in was encountered at 2012.3 m.

From the chemical analysis of the gas, Table (3) the result shows that the gas is a type of natural hydrocarbon gas, which is classified as wet gas with a high rate of light gas components (C_1, to C_3) especially Methane (CH_4), with very low amounts of other heavier components.

The geochemical data have been compared with the gas of Tertiary reservoir in Kor Mor (gas field is located in the south, 50 km). The quality of the gas in both fields is very similar in terms of chemical composition; both gases contain a high percentage of methane contents approaching the limits of 80%, in addition to the similarities in the rates of inorganic gas compounds such as O_2, CO_2, and N_2.

The main difference in both gases is the hydrogen sulfide (H_2S) content, where the Chamchamal shallow well gas is characterized by unusual H_2S content, while all indicators and documents related to wells CH-1 and CH-2 approve that this gas is sweet in origin, and this high percentage of H_2S in this gas is due to its mixing with sulfuric water in the Fatha beds, Methane acts as a carrier gas for hydrogen sulfide, whose generation must be related to the sulfate beds in Fatha Formation.

Table 3: Comparison between gas chemical composition in Chamchamal and Kor Mor gas fields

Type of Gases/ Concentration	Composition	Formula	Kor Mor field	Chamchamal field
			In % volume per unit volume	In % volume per unit volume
	Hydrogen Sulfide	H_2S	0.01	1.77
Non-hydrocarbon gases	Oxygen	O_2	0.0241	0
	Carbon Dioxide	CO_2	0.2562	3.25
	Nitrogen	N_2	0.165	0.41
hydrocarbon gases	Methane	CH_4	84.467	78
	Ethane	C_2H_6	8.192	8.87
	Propane	C_3H_8	3.3636	7.29
	I Butane	$i\text{-}C_4H_{10}$	1.3715	0.41
	n Pentane	nC_5H_{12}	0.5465	0.13
	n-Hexane	C^{6+}	1.5142	0.12
	Test condition Temperature = 62.1 °C, Pressure = 331.2 psi			

Hydrodynamic System

The origin and mechanism that led to the high pressure in such shallow well related to the hydrodynamic patterns in the aquifer. According to [24]; The Tertiary-Jurassic sections in Iraq, governed by two hydrodynamic systems: by gravity and by high-pressure zones.

Regarding the gas-water blowout in Chamchamal shallow well, it is related to the first system (gravity hydrodynamic systems; where the water moves by the action of gravity from sites of high potential, namely the Zagros foothills zone, and the outcrops, where the well site lower than the highly fractured limestone beds of the Pila Spi and Fatha Formation itself exposed 10 km NE, along the Bazian mountain (anticline), the difference in the height between the aquifer and the outcrop is around 600-800 m, where they recharged the aquifers.

The vertical movement of formation water in the basinal area where artesian phenomena exist is effectively possible, favored by major faults and fractures connecting the deep aquifers to the shallower. The high-pressure phenomenon is well known in Fatha Formation even more notable some oil wells along the foothill's zones, during the penetrating this formation, have faced unusual pressure. For example, in well Mass-2 (Sangaw Area) the pore pressure increased suddenly from 8-11 ppg in Injana Formation to 18 ppg in Fatha Formation. Also, the same cases of high pressure in Fatha Formation. were noticed in Kor Mor field, they were forced to increase the density of the mud from 9.7 ppg in Injana Formation to 14-15 ppg to control any kick from this formation during the drilling. Besides the sediments are overlain by the saliferous cap rock of the Fatha Formation, the potentiometric surface is abnormal.

The hydrodynamic systems are related to the geometry of the sedimentary basin; also, factors other than compaction (for example, the existence of Miocene saliferous beds, tectonic forces, temperature, etc.) may be involved in the development of high pressures in the Tertiary aquifers of the north and NE of the Mesopotamian basins [24].

It is worth noting that in 1989 a similar geological event took place near the current site (around 300 m SE) when a spring of water exploded as a result of an earthquake in the region, and the water eruption continued for about a year and then gradually quenched.

A research team from the University of Salahaddin studied the subsurface geological conditions responsible for forming this spring [1]. This study concluded that there is a cavity below the surface with dimensions 6.6 m and 15 m filled with rich sulfate water and the earthquake made some local faults that are responsible for emerging such spring.

Since the previous site was structurally lower than the current location, the water flow was alone without gas, because the water channel was below the gas-water contact (out of the gas cap).

H_2S Origin

Transformations between different sulfur species can occur through chemical or biological pathways. However, the abiotic route usually is significantly slower [25]. The microbial sulfur cycle is simplified as in Fig. (9).

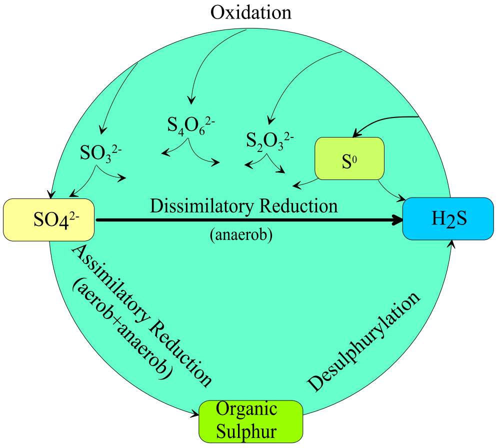

Fig. 9: The microbial sulfur cycle [26]

Methane acts as a carrier gas for hydrogen sulfide, whose generation must be related to the kerogen, oil, and/or the gypsum formations. In general, H_2S in petroleum reservoirs can originate from three processes: bacterial sulfate reduction (BSR), thermal decomposition of sulfur compounds in kerogen or oil, and thermochemical sulfate reduction (TSR). Bacterial sulfate reduction and thermal decomposition of sulfur compounds generally lead to low levels of H_2S in gas (<3–5%) [27]. Thermochemical sulfate reduction is the only process able to produce larger amounts of H_2S and it is dominant in the presence of evaporites (mainly anhydrite) in contact with limestone at temperatures generally above 120^oC [2]. Temperatures down to 80^oC, however, have also been reported [28, 29]. The basic TSR reaction is [2]:

$$\text{Gypsum} + \text{Hydrocarbons} \longrightarrow \text{Calcite} + H_2S + H_2O \pm S \pm CO_2 \text{..........(1)}$$

The dominant reaction involves methane:

$$CaSO_4 + CH_4 \longrightarrow CaCO_3 + H_2S + H_2O \text{..........(2)}$$

The basic BSR can be described by the following reaction [29]:

$$2CH_3O + SO_4^{2-} \xrightarrow[\text{desulthydrase}]{\text{Bacteria}} 2HCO_3^- + H_2S \text{..........(3)}$$

The responsible bacteria for this reaction is Desulfovibrio Desulfuricans [3], this species may exist in a wide range of temperatures ranging from 10 to 110 °C. So, the origin of hydrogen sulfide is from two sources, the first is from TSR and the second is from BSR. The gypsum layers of Fatha formation are the source of sulfate for such a reaction. Many conducted studies in the surrounding area and another area of this case study reveal the presence of Desulfovibrio desulfuricans species in groundwaters [30, 31, 4].

Conclusions

This study shows the effect caused by the hydrodynamic patterns in the aquifer (gravity and by high-pressure zones) on the gas-water blown out in Chamchamal shallow water well.

The high-pressure zone is famous whereas the Fatha Formation exists in some oil wells along the foothill's zones. Furthermore, the lithology of this formation affects the hydrochemical properties of the water well and is considered to be the sources of Ca, and SO_4^{2-} ions.

The isotopic composition of the water revealed that the groundwater is slightly depleted $\delta^{18}O$ and δ^2H values, which may indicate renewable water and indicating that the aquifer is receiving water from Bazian recharge area. While the Sulin classification indicates the deep meteoric water origin of the water and the elevated concentration is a result of cation exchange with the contents of clay minerals of Fatha Formation. The gas type of drilled well is wet gas with a high rate of light gas components (C_1, to C_3) especially Methane (CH_4), with very low amounts of other heavier components and it is similar to other neighboring gas fields like Kor Mor gas field, but the only difference is the high content of hydrogen sulfide gas which is generated from the Fatha Formation.

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التقييم الكيميائي والتفسير الهيدروديناميكي للغاز المشتعل والمتدفق من بئر المياه الضحلة في مدينة جمجمال، كردستان، شمال شرق العراق

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الملخص

في شهر آب 2015 ، حدثت ظاهرة غريبة في قرية گورگيي فتاح (5 كم شمال قضاء جمجمال) عندما انفجر الغاز والماء من بئر ضحل اثناء الحفر. سارع الباحثون وعامة الناس إلى مشاهدة وتحري هذه الظاهرة.

تحاول هذه الدراسة تحليل هذه الظاهرة وفهم العوامل الكامنة وراء تدفق المياه والغاز معا من خلال اخذ العينات من الغاز والماء لتحليل مكونات الغاز ونظائر $\delta\ ^{13}CH_4$ ، والعناصر الرئيسية والثقيلة، والنظائر البيئية $\delta\ ^{18}O$ و $\delta\ ^{2}H$. أظهرت نتائج التحليل الهيدروكيميائي ان ايونات Ca^{2+} و SO_4^{2-} هما السائدان وأن تراكيز العناصر الثقيلة أقل من حد كشف الجهاز. كانت قيم نظائر $\delta^{18}O$ و $\delta^{2}H$ هي −6.25 و −30.85 على التوالي مما يشير إلى أن المياه الجوفية ذات تغذية حديثة، و ان غاز الميثان CH_4 هو الغاز الشائع لتركيب الغاز الكلي، حيث يشكل 84.5 % من وحدة الحجم الكلي، بينما يتميز بارتفاع كبريتيد الهيدروجين ذات قيمة 17700 جزء في المليون.

أوضحت الدراسة أن المياه المحفورة تنتمي إلى النظام الأول من الأنظمة الهايدروداناميكية المعروفة بنظام الجاذبية الهيدروداناميكية؛ حيث يتحرك الماء بفعل الجاذبية من مناطق عالية الجهد (الجبال العالية)، وان الكسور والتصدعات الرئيسية تربط طبقات المياه الجوفية العميقة بالمياه الضحلة.

ان ظاهرة الضغط العالي التي ادت الى تدفق الماء معروفة جيداً في بعض الطبقات التابعة لتكوين الفارس الاسفل، وهي ظاهرة مسجلة في بعض آبار النفط على طول مناطق الطيات الواطئة.