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Geomorphology, Geology and Tectonics of Jabal Sanam, Southern Iraq

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Abstract

Jabal Sanam is an outstanding geomorphological feature in south of Iraq located 50 Km southwest of Basrah city; along the border with Kuwait. It stands high in a vast flat plain with elevation of 140. 61 m (a.s.l.). The relief difference between the highest point; on top of Jabal Sanam and the surrounding flat plain ranges from (108 –127) m. The E – W and N- S diameters of Jabal Sanam are 355.97 m and 489.45 m, respectively, whereas, the E – W and N – S diameters of the surrounding first circular rim are 1524.11 m and1857.90 m, respectively. The exposed rocks in the surroundings belong to the Dibdibba Formation (Pliocene – Pleistocene); show clear Hogback and Cuesta forms. The rocks of the Nfayil Formation (Middle Miocene) are exposed in the near surroundings of the intruded body; they are crushed, deformed and faulted. All the exposed rocks along the rims show clear dipping towards the outer rim forming dome like structure. Beds of gypsum and black dolomite are also exposed in the central part of the dome, most probably intruded from deep lying beds. Other crushed rocks; some of them are igneous are also present, especially in the central part of the intruded body. The estimated age of those crushed rocks is Infra-Cambrian, as indicated from pollen and spores found in coal seams within the exposed sequence.

The presence circular rims surrounding Jabal Sanam may indicate multi rising processes of the exposed sequence of the intruded body. All the previous works confirm the origin to be a salt plug; using gravity data. However, the current study hasused evidences of Neotectonic activity to support the salt plug assumption too.

Keywords: Jabal Sanam, Salt diaper, Harmuz Salt, Isolated hill, Iraq.

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1 Introduction

The southern part of Iraq is a flat nature, which forms the southern extension of the vast Mesopotamian Plain and the eastern extension of the Iraqi Southern Desert. Within the vast plain is about 20 – 30 m in elevation; above sea level, there is an isolated hill with maximum elevation of 140.61 m (a.s.l.). It is located about 10 Km west of Safwan town and 50 Km southwest of Basrah city (Fig.1), whic is called "Jabal Sanam". Jabal in Arabic language means a mountain and Sanam is the hump of camel, since the isolated hill in the flat plain looks like the camel's hump.

The study area is located in the extreme southern part of Iraq; along the Iraqi – Kuwaiti international borders (Fig.1). The highest point on the top of Jabal Sanam is located at a point with latitude of 30° 07′ 34.19″ N and longitude of 47° 37′ 32.60″ E. The outer surrounding elevated area has almost a circular form, whereas the inner elevated area; Jabal Sanam is an elliptical form with the sharp end pointing towards NNE (Fig.2).

Many researches have studied the origin of Jabal Sanam since early seventies of the last century, but unfortunately those pioneer works are not available. Nevertheless, many theses are considered as well documented sources for different aspects of Jabal Sanam. Among those studies are: [1-7]studied Jabal Sanam and concluded that it is of a salt origin, mainly depending on regional gravity data.

More recent studies, like [8-12] all concluded that the origin of Jabal Sanam is a salt dome or diaper. They used different indications for their conclusions, but the majority depends on gravity data and the presence of Infra Cambrian rocks crushed and mixed with others rocks; such as igneous rocks and black dolomites with some iron inclusions in the complex body of Jabal Sanam.

Jabal Sanam is the unique salt diaper form in Iraq although many oil fields in the southern part of Iraq are associated with negative gravity residual [13]; like Buzurgan oil field is attributed to salt intrusion [14].

The aim of this study is to elucidate the origin of Jabal Sanam with detailed geomorphological, geological and tectonic description of the feature. Also to discuss the available literature dealt with Jabal Sanam and to achieve the soundest origin depending on geomorphological, geological and tectonic evidences.

To acquire the aim of this study, different materials are used, studied and interpreted as integration study. The used materials are:

- Topographical maps at scale of 1:100000 to measure some geomorphological parameters of Jabal Sanam.
- Geological maps of different scales to indicate the exposed geological Formations.
- Google Earth and Flash Earth images and HERE Maps to indicate different geomorphological and tectonic parameters and evidences, which are used to confirm the acquired data in the current study.

Fig.1: Google Earth image of the study areaTopographical maps at scale of 1:100000 to measure some geomorphological parameters of Jabal Sanam.

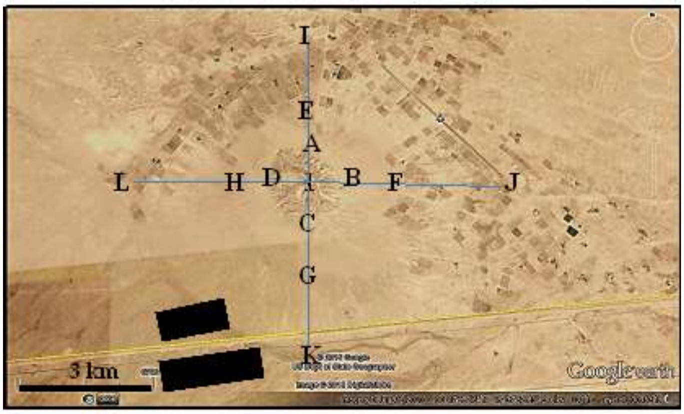

Fig.2: Google Earth image of Jabl Sanam. 1 is the highest point. 1L, 1I, 1J and 1K are four axes along which different parameters are measured

2 Geological Setting

The main geological aspects are reviewed briefly, hereinafter.

2.1 Geomorphology

Following UN Environmental Programme's definition of "mountainous environment"[15], Jabal Sanam is an isolated hill. The measured parameters of Jabal Sanam using topographic map at scale of 1:100000 and available Google Earth and FLASH Earth images are presented in the Table (1).The main drainage pattern in Jabal Sanam is not radial; as it is supposed to be; it is partly dendritic with longitudinal valleys that run either SE – NW or NW – SE (Fig.4). The dendritic pattern is developed due to some medium tough rocks, which are highly crushed, whereas the longitudinal pattern is developed due to presence of faults.

Many geomorphological units are developed in Jabal Sanam, the main units are:

- Hogbags and Cuestas: These are developed on the circumference of the intruded body (Fig.4), the first outer rim within the rocks of the Nfayil and Dibdibba formations; both of them include alternation of soft and hard rocks. However, some faint traces of fans also can be seen around Jabal Sanam.

- **Alluvial Fans:** Two sets of alluvial fans are developed around Jabal Sanam. The first set is between the intruded body and the first circular rim (AF1), whereas the second set is developed between the first and second outer rims (AF2). In both cases, the fans are developed better when Hogbags and Cuestas are developed (Fig. 5). The developed alluvial fans (Figs. 5 and 6) indicate a wet to semi dry climates and drop in gradient between the limits of the intruded body, the first ridge and the second one. Moreover, they indicate the presence of a lot of soft rocks and/ or crushed rock fragments, which were carried out by the valleys and deposited when a drop in gradient occur.

Table 1: Morphological parameters and characters of Jabal Sanam
(For indication, see Figure 2)

Diameter (see Fig. 2)	Length (m)	Remarks
D – B	1248	E – W diameter of the intruded body
H – F	2340	E – W diameter of the first outer rim
L – J	5720	E – W diameter of the second outer rim
A – C	1604	N – S diameter of the intruded body, as slightly inclined towards NNW
E – G	3120	N – S diameter of the first outer rim
I – K	5200	N – S diameter of the second outer rim
Elevation	**Meter**	**Remarks**
Point 1	160.61	The highest point in Jabal Sanam
Point A	83.64	The limits of the intruded body are very clear (A – B – C), which gradually become obscure (Fig.3 Left). The north and south poles of the body are almost with same height, whereas the height difference between the western and eastern poles is 7 m
Point B	55.15	
Point C	62.12	
Point D	83.03	
Point E	36. 96	The limits of the first outer rim are clear only from A – B; apart from that part; the limits gradually become obscure (Fig.3 Middle). The northern pole of the first outer rim is 8 m lower than the southern pole, whereas the height difference between the western and eastern poles is about 20 m
Point F	35.45	
Point G	40.60	
Point H	54.84	
Point I	19.39	The limits of the second outer rim are clear only between A – B – C (Fig.3 Right), which are represented by circular valley, apart from that part; the limits gradually become obscure. The northern pole of the second outer rim is 9 m lower than the southern pole, whereas the height difference between the western and eastern poles is about 13 m
Point J	15.15	
Point K	28.48	
Point L	27.57	

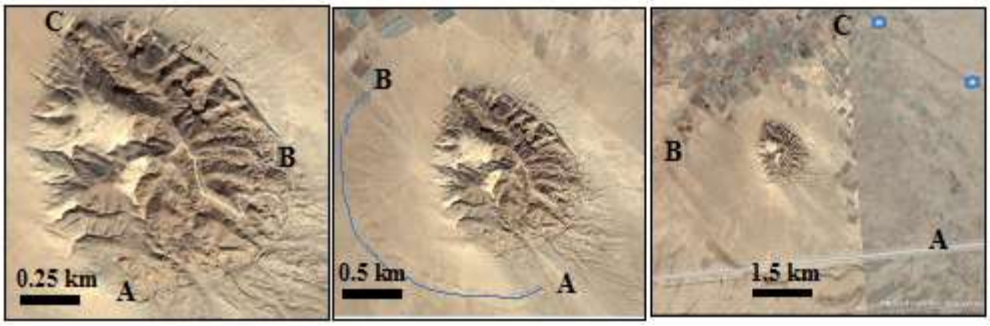

Figure 3: FLASH Earth image. Left) The intruded body, Middle) The first outer rim, Right) The second outer rim.

Figure 4: FLASH Earth image of Jabal Sanam showing the drainage patterns.

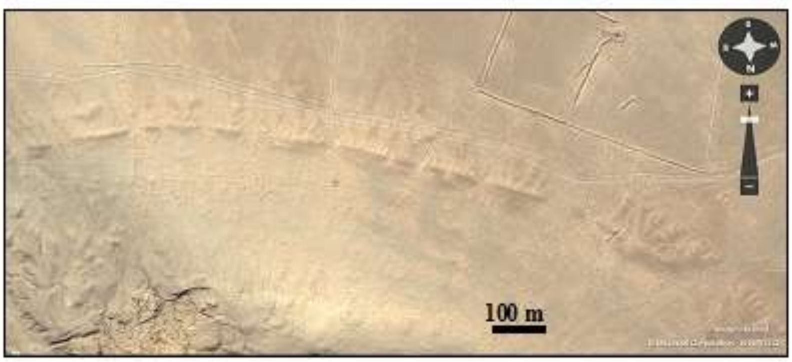

Figure 5: Flash Earth image (facing south) showing Hogbags and Questas.

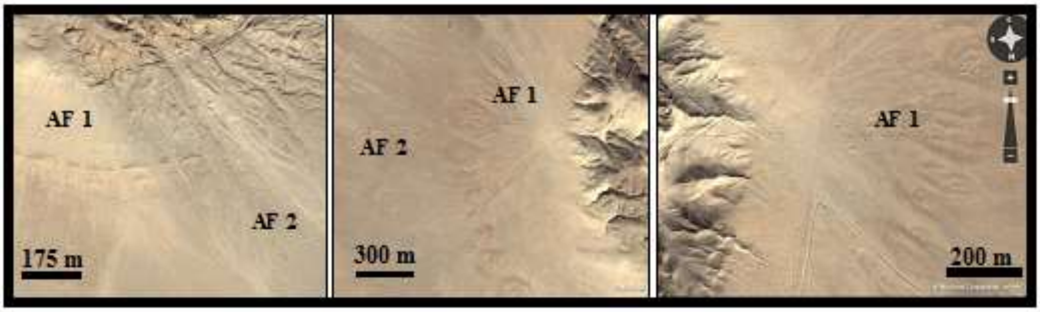

Fig.6: FLASH Earth images, Left) Southeastern side, Middle) Northwestern side, Right) Western side . Note the developed alluvial fans around Jabal Sanam.

2.2 Stratigraphy

The exposed rocks in the outer rims of Jabal Sanam belong to the Dibdibba Formation (Pliocene – Pleistocene), which consists of alternation of white, coarse sandstone; occasionally pebbly, fine conglomerates; the pebbles are mainly of quartz, and reddish brown claystone. The rocks of the Nfayil Formation (Middle Miocene) are exposed surrounding the intruded body and are partly crushed. The formation consists of alternation of green marl alternated with fossiliferous limestone and dolostone; usually three cycles are developed.

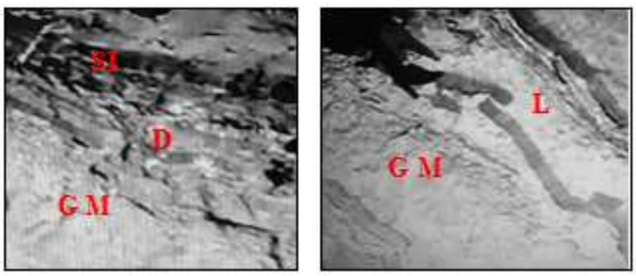

Figure 7: The main exposed rocks in Jabal Sanam, dolostone (D), limestone (L), green marl (GM) and sedimentary iron (SI) [after 16].

The main body of Jabal Sanam consists of a mixture of rocks, black algal dolomite,anhydrite and altered dolerites. Two dolerite samples were studied by K-Ar method revealed 570 ± 10 Ma and 580 ± 10 Ma dating, respectively [7]. The negative gravity residuals associated with the structure strongly suggests that it is underlain by Infra- Cambrian salt and formed the Sanam salt plug [13].
Some of the dolostone beds in the intruded body include sedimentary iron, which is deposited due to hydrothermal fluids with high iron concentration. The main type of iron is the hematite [1 6] (Fig.7). They believe that all those crushed rocks were raised from a depth of about 6 Km with the salt plug that underlies the intruded body.
The cap rock on Jabal Sanam is characterized by the presence of evaporitic sequence, where gypsum forms large part of this sequence. The field observations

showed that gypsum occurs in form of massive beds and veins. Four petrological types of gypsum are recognized; alabastrine, selenite, fibrous, and rocky gypsum. The examination of 61 thin sections besides the X-ray analyses proved that the available gypsum represents the dominant mineral with few to trace amount of anhydrite, dolomite and quartz. Petrographically, four types of gypsum textures are also identified; alabastrine, porphyroblastic, fibrous and granular. All these textures suggest a secondary origin of Jabal Sanam gypsum due to the hydration of pre-existing anhydrite. The hydration occurs when the cap rocks approach the ground surface. The connate and groundwater form the main source of hydration water [17].

The near surroundings of Jabal Sanam are covered by different types of Quaternary sediments (Fig.8). They all consist of different rock fragments disintegrated and washed out from the exposed rocks in the intruded body with admixture of sand, fine pebbles and rare clay. They are represented by slope; alluvial fan and valley fill sediments, their thickness range in few meters.

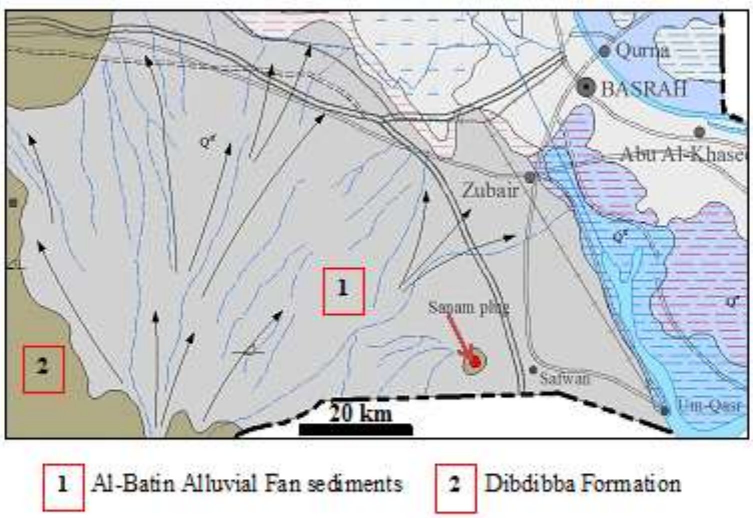

Figure 8: Geological map showing Jabal Sanam and surrounding area [after 20]

2.3 Tectonics and Neotectonics

All the previous works mentioned in the current text confirm that Jabaj Sanam is a salt plug originated from Humuz salt series. According to [12,18], "the diapiric salt structures beneath the folds in Iraq have pierced the overlying sedimentary sequence to different stratigraphic levels, but have reached the surface only in one locality, to the south of Basrah city, known as Jabel Sanam". Similar to other igneous rock fragments that have been reported in southwest Iran salt structures [19], it is believed that these rocks were stripped off the basement and brought to the surface by the upward movement of the salt [12,18].

The presence of the Late Precambrian – Early Cambrian Hormuz Salt [19,20] and its active movement in the north of the Arabian Gulf region, in general and in the southern part of the Mesopotamia Plain, in particular is the reason behind the development of these folds, a good example is Buzurgan Oil field [21].
The presence of two circular rims around Jabal Sanam is other indication for it is origin is a salt plug. The exposed rocks in the circular rims are dipping away from the intruded body in all directions. The dip angle varies from 15 ° to 90° (Figs. 5 and 6).

According to [8] Jabal Sanam is a type of salt plug that stems as a conduit from a deeper diapiric structure. The effect in depth that such diapirs might have had on the formation of anticlinal oil traps in southern Iraq is evident. The rocks constituting the Sanam Structure belong to the Infra-Cambrian, possibly an equivalent of the Hormuz Salt Series of the Arabian Gulf region. Overall the rocks of the Sanam Structure are heavily fractured and shattered. The type of fractures includes joints, fault, gashes and veins. The rocks in the core has several thrusts indicative of compression, while in the upper limestone and gypsum beds exhibit tension gashes and normal faults indicative of extension.

The Sanam Structure consists of two parts; the first is a subsurface pillow or salt dome, which was formed at a depth of 6 Km in the Early Cretaceous and continued to grow in the Tertiary. The second part is a salt plug at the surface which is an expression of a conduit that took off in an oblique upward piercement (15° off nadir to the east) from the top of the deep salt dome in the Late-Tertiary and reached the surface in the beginning of the Quaternary (Pleistocene). A structural and geomorphological expression of the oblique piercement of the salt plug is shown in the field and on aerial photographs by the formation two arc-ridges around the Sanam Structure in its western part [8]. The authors are in accordance with [8] concerning the scenario of the salt tectonics; but do not agree the estimated dating of reaching the salt plug to the surface during Pleistocene. This is attributed to the presence of many faults that have dissected the exposures of the Dibdibba Formation of Pliocene – Pleistocene. Therefore, the authors estimate Late Pleistocene – Holocene age.

Although many workers have dealt with the origin of Jabal Sanam and all of them confirmed it is of salt origin; however, none of them mentioned about the presence of neotectonic activity in Jabal Sanam and referred to evidences indicating the activity.

Figure (9) shows clearly two longitudinal faults (AB and CD), both have NW – SE trend with clear offsetting the rim of the intruded body and dissecting the Quaternary sediments. The Fault AB (Figures 9 Upper and 10) is a normal fault with the northeastern block being the downthrown side and estimated thrown of 7 m. Whereas the Fault CD (Figures 9 Lower and 10) is a strike slip fault with right dextral type; since it has moved forward.

In Figure (9 Lower), another two faults with NW – SE trend have dissected the rim of the intruded body and obviously changed and shifted the main valleys. Both Faults (EF and GH) have shifted the main two valleys westwards. The former has also cause bifurcation of the valley downstream, which is abnormal case, whereas the latter has caused acute meandering of the valley after abandoning the old course.

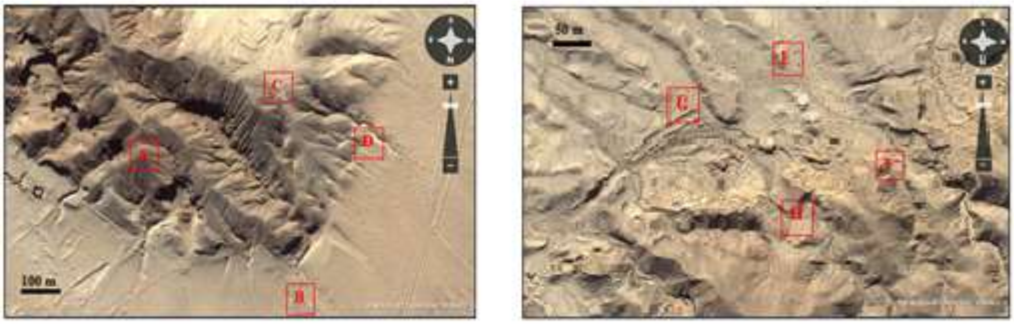

Figure 9: FLASH Earth images (facing south) of Jabal Sanam showing Neotectinic activity. Left) Northwestern rim dissected by 2 longitudinal faults (AB and CD), Right) Southeastern rim dissected by 2 longitudinal faults (EF and GH) and have shifted the valleys.

Figure 10: FLASH Earth image of Jabal Sanam.
Note the extensions of the faults.

3 Characteristics of Jabal Sanam

Jabal Sanam is a salt plug [1,2,3,4,5,67,8,10,20] with an elliptical shape with the sharp end forwarded to NNW, with long and short diameters of the intruded body of 489.45 m and 355.97 m, respectively. It surrounded by two circular rims; although part of the rims are not clear. The longest and shortest diameters of the first rim are 3120 m and 2340 m, respectively. Whereas, those of the second (outer) rim are 5200 m and 5700 m, respectively (Table 1 and Fig.2 and 10). The measured diameters and elevation points in certain locations (Table 1 and Fig.2) show that Jabal Sanam is not a symmetrical plug; both in the intruded body and the two rims. It is slightly inclined eastwards. The highest point is 140.61 m (a.s.l.); located at 30° 07′ 34.19″ N and longitude of 47° 37′ 32.60″ E, whereas the surrounding flat plain is at elevation ranges from (108 – 127) m.

The exposed rocks in the intruded body are limestone, dolostone, gypsum and green marl, with very rare igneous rocks. Some sedimentary iron is impregnated in the limestone and dolostone by hydrothermal fluids. All the exposed rocks are highly crushed. In the surrounding rims, clastics of the Dibdibba Formation and marl and limestone of the Nfayil Formation are exposed.

Neotectonic activity is clearly visible in Jabal Sanam; indicated by shifting of: **1)** the rim of the intruded body, **2)** Quaternary sediments, and **3)** main valley courses (Figs.9 and 10).

4 Discussion

The evidences that confirm Jabal Sanam is a salt plug are discussed hereinafter in details.

4.1 Occurrence of Infra-Cambrian Rocks

The presence of Infra-Cambrian rocks and dolerite fragments [5] in the core of Jabal Sanam surrounded by Miocene – Pleistocene rocks are good indication that those rocks are exposed on surface due to ascending forces from deep horizons. One of the possibilities of ascending forces that have pierced the overlying rocks and have reached the surface is a salt plug.

4.2 Regional Salt Occurrence

The presence of the salt in the southern parts of Iraq is confirmed by many workers. [1,4] used gravity data to confirm the presence of salt below the intruded body in Jabal Sanam and confirmed that it is a salt plug. [5,6,7] studied the available gravity and other geophysical data and confirmed that Jabaj Sanam is a salt plug. [8] also confirmed that Jabl Sanam is a salt plug from studying field and geophysical data. The – ve gravity residuals in Jabal Sanam strongly suggest they are underlain by Infra-Cambrian salt [4].

The presence of the Late Precambrian – Early Cambrian Hormuz Salt [20,21] in southern part of the Mesopotamia Foredeep andnorth of the Arbain Gulf, and its subsequent active halokinesis movement is the reason behind the development of the folds, which are mainly oil fields. The diapiric structures beneath the folds have pierced the overlying sedimentary sequence to different stratigraphic levels, but have had reached the surface at only one locality known as Jabal Sanam [18]. The exposed dolerite rock blocks and fragments of Precambrian (?) age in the core of the domal structure of Jabal Sanam, which are thought to be stripped off the basement and brought to the surface by the upward movement of the buoyant salt confirm presence of salt beneath Jabal Sanam.

Aqrawi et al. [22] mentioned that most oil bearing structures of south Iraq are associated with – ve gravity residuals. Together with black algal dolomite and anhydrite, these features suggest continuity with the Hurmuz Series in the southern part of Iraq, and more especially in Jabal Sanam, where a lot of black dolomite beds are exposed as crushed rocks in the core and top of of the dome. Al-Yasi et al. (2014) also confirmed by using geophysical data that Buzurgan oil field that is located south of Iraq is developed due to salt activity. This confirmation also supports the assumption of regional salt in the extreme southern part of Iraq.

4.3 Presence of Sedimentary Iron in the Rocks of Jabal Sanam

[5,23,24] confirmed the presence of mineralized iron oxides' bands with shiny crystals (possibly hematite) spread over parts of Jabal Sanam. The ironstones in Jabal Sanam show a wide spread distribution mainly in the eastern and southeastern parts. The colours are brown to reddish brown, yellow to reddish yellow, depending upon the Fe^{+3} oxides content, which are about 52%; however, [25] showed that the Fe content of Jabal Sanam ironstones ranges from (30 – 95) %. The obtained X-ray and ultraviolet diffraction patterns and atomic absorption revealed the dominancy of Hematite mineral. It is believed that these ironstones originated by the decomposition of Precambrian basement: basic, ultra basic igneous and metamorphic rocks by the action of hydrothermal solutions that accompanied the pierecment of Jabal Sanam Soltan et al., 2007) The presence of ironstone within the exposed dolomite beds in Jabal Sanam (Fig. 7) is also confirmed by [16]. The presence of ironstone confirms the presence of hydrothermal solutions, which most probably have ascended with the salt plug that had pierced the overlying rocks and reached to the surface, otherwise how to explain the presence of the iron stone in those sedimentary rocks with the presence of the domal structure.

4.4 Presence of the Domal Shape with Circular Rims

The shape of Jabal Sanam with the surrounding elevated areas (Fig. 2, 4 and 10) that had formed two circular rims with radial dip toward the periphery and with diameter of about 5.7 Km for the outer rim and 2.34 Km for the inner rim, as well radial drainage pattern along the slopes are good indications for the presence of a domal structure. One of the possibilities of forming a domal shape is a salt plug. The asymmetry of the inner rim and the outer circular form, as well the limits of the intruded body (Table 1, Fig. 2) indicate that the domal shape may be of salt origin, since majority of salt domes are not symmetrical.

4.5 Presence of Neotectonic Activity

The surrounding areas of Jabal Sanam and the southern part of Iraq is known to lack local Neotectonic activity [26,27] as it is shown in the Neotectonic map of southern part of Iraq (Fig. 11). Therefore, the presence of the domal form, which represents Jabal Sanam and the two developed circular rims in which the rocks of the Dibdibba Formation (Pliocene – Pleistocene) (Figs. 2, 4 and 10) are good indications for presence of neotectonic activity in Jabal Sanam vicinity. This assumption depends on the fact taht rocks of the Dibdibba Formation (Pliocene – Pleistocene) are folded and show clear dip towards the outer circumference. The Neotectonic map (Fig.11), shows the amount of down ward and upward movements by means of colored contour lines. The map shows that the surrounding area is regionally down ward area with amount of up to – 500 m, since Middle Miocene. Moreover, the recognized faults (Fig.10) are all active faults since they have dissected the developed Cuestas and Hogbags in the first circular rim (Fig.12) along which the Dibdibba Formation is exposed (Fig. 8) of Pliocene – Pleistocene age. Accordingly, the faults should be younger than the exposed rocks; either Late Pleistocene or even Holocene. Therefore, are considered as Neotectonic activity.

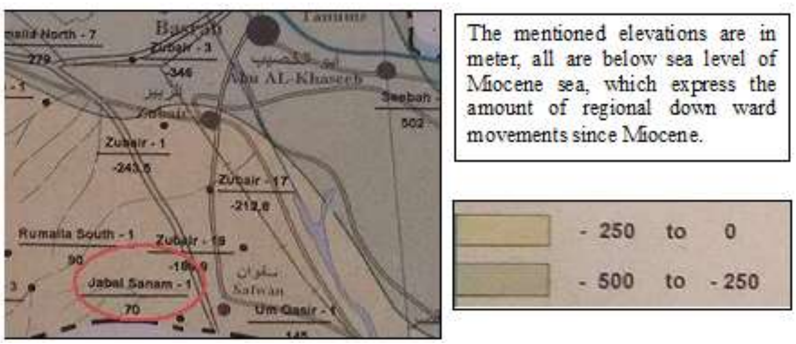

Figure 11: Neotectonic map of Jabal Sanam vicinity [28].

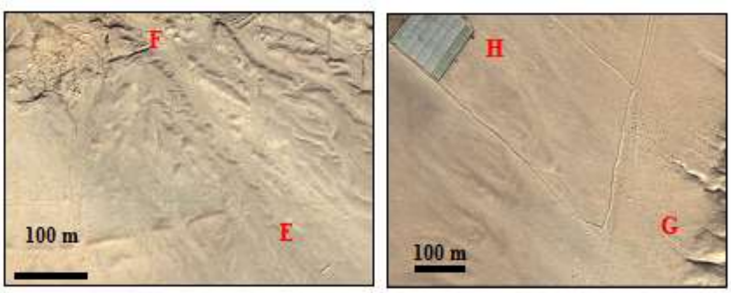

Fig.12: EARTH Flash images. Left) Active fault EF, Right) Active fault GH.
Note the disappearance of the Hogbags and Questas on right side of the two faults.(For location of the faults refer to Figure 10)

The recognized faults (Fig.10) have clear traces within the whole effected area by the salt plug intrusion; until the outer rim. This is clear evidence that the salt plug is most probably still moving upwards even after development of the two circular rims.

The authors believe that the first (inner) rim was developed during Middle Pleistocene. This assumption is attributed to the developed Hogbags and Cuestas in the Dibdibba Formation (Pliocene – Pleistocene) along the first rim. With continuous upward movement, the second rim was developed in form of a circular valley, but it is not a continuous circular form surrounding the whole effected area. This assumption is attributed to decrease in the rate of the uplift; therefore, no rocks were exposed on surface, as it is along the first rim. Moreover, with continuous upward movement of the salt plug, which has less energy for pushing up the rocks, many faults were developed (Figs. 10, 12 and 13) within the intruded body and have crossed the first rim only. The two sets of faults on the northwestern and southeastern sides of the intruded body show clear uplift movement. This is confirmed with the removal of the uplifted parts (between the two sets of faults, Fig.13) of the Hogbags and Cuestas due to active erosion and deposition of alluvial fans and other colluvial and alluvial sediments instead of the exposures of the Dibdibba Formation. The two faults (EF and IJ, Fig. 13) are clearly showing a horst structure that coincides with the up growing of the salt plug during Late Pleistocene and even in Holocene. The reason why many longitudinal faults were developed within the salt plug and not a circular upward form; as it was since growing of the salt plug is beyond the scope of the current study. According to [28] when a salt layer becomes too thin to be an effective detachment layer, due to salt movement, dissolution or removal by faulting, the overburden and the underlying sub-salt basement become effectively welded together. This may cause the development of new faults in the cover. Salt welds may also develop in the vertical direction by putting the sides of a former diapir in contact.The authors adopted this assumption in explaining the development of the faults. Moreover, according to [29] typical structures of active diapirism are a central crestal graben flanked by flaps that rotate upward and outward. Reverse faults can separate the flaps from the overburden. Normal faults create the crestal graben and propagate downward. New faults form farther outward as the dome arch becomes more intense. Emergence of the dome will not occur unless the dome is very wide or tall relative to the overburden's thickness [29]. The authors also adopted this assumption in development of the recognized faults within the intruded body of Jabal Sanam and their extension outwards until the first circular rim.

4.6 Presence of – ve Gravity Residual

Many workers [1,2,4,5,6,7,8,13,23,24] have confirmed the presence of – ve gravity residuals below Jabal Sanam, which indicate materials with low specific gravity; consequently indicating presence of salt below the involved area. The presence of salt in subsurface with the presence of elevated domal shape with surrounding circular two rims are good indication for salt tectonics, consequently confirms that the origin of Jabal Sanam is a salt plug.

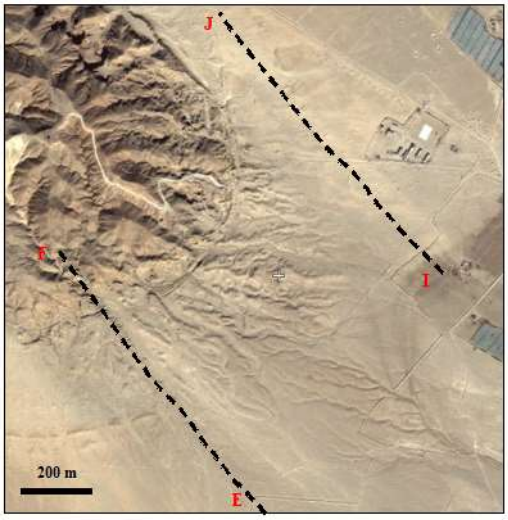

Figure 13: FLASH Earth image showing two faults forming a horst structure.

4.7 Presence of Gypsum on the Top of Jabal Sanam

The presence of gypsum beds on the top of Jabal Sanam may indicate its salt dome origin. This is attributed to the fact that as a salt dome reaches near the surface, the water-bearing sediments cause the halite to dissolve and produce an anhydrite residue that accumulates in the upper portion of the dome. As the dome continues to rise, inline pressures compact the anhydrite into rock form. Near the ground surface, percolating groundwater tends to rehydrate the anhydrite rock and forms gypsum. Gypsum is a common occurrence with near-surface portions of salt domes [30].

4.8 Abnormal Drainage System

Many valleys in the southern part of the intruded body have changed their courses due to Neotectonic movements (Fig. 9). Moreover, one of the valleys has bifurcated into two main courses; towards downstream, which is very rare case since valley courses join together towards downstream. Such abnormal behavior may indicate a local uplift that had caused this phenomenon. The estimated age for this movement is during Holocene. This assumption is attributed to the fact that sediments of valley floor and flood plain, which are Holocene – Recent in age, are affected.

4.9 Presence of Alluvial Fans

Many alluvial fans are developed around the intruded body by the flowing valleys in all directions. The presence of more than one stage of alluvial fans on the slopes that surround Jabal Sanam also may be an evidence for a local uplift movement, which has had caused change in the gradient; consequently more than one stage of alluvial fans were developed (Figs. 6 and 10).

4.10 Integrated Discussion

Almost all the aforementioned discussed aspects dealt with the presence of salt under Jabal Sanam, although different authors have used different aspects to prove that, but the main used data are those of negative gravity anomalies. However, the current authors have used the indications of Neotectonic to be added to the already existing indications to confirm the origin of Jabal Sanam. The Neotectonic evidences are used in the current study for the first time to confirm the origin of Jabal Sanam. Since the concerned area is located within the Inner Platform (Stable Shelf) of the Arabian Plate [31] so it is almost stable tectonically. Moreover, from regional Neotectonic point of view, the concerned area is of down warping nature [26,27] since the Late Miocene. Therefore, the only possible upward local movement that has caused uplifting of the concerned area (Neotectonic movement) in a dome like form surrounded by two rims is a salt plug. Otherwise, no relevant explanation can be found for the presence of the dome like structure with the presence of igneous rocks and rocks of Infra- Cambrian age within the exposed sequence of Jabal Sanam.

5 Conclusions

As already aforementioned that many workers have proved that Jabal Sanam is a salt plug. Almost all of the previous workers have used gravity data to confirm that Jabal Sanam is of salt dome origin.

The only new evidence; as a conclusion that proves the origin of Jabal Sanam is a salt plug is the evidences of Neotectonic activity in the concerned area. These evidences are:

- Presence of longitudinal faults that have dissected the intruded body, some of them form horst structure.
- The faults have dissected the Quaternary sediments, represented by colluvial sediments.
- The faults have dissected outcrops of the Dibdibba Formation of Pliocene – Pleistocene age.
- The upwards movement of the faults has caused the disappearance of parts of the inner rim. This is attributed to uplifted parts, which were eroded; consequently disappeared.
- Presence of two stages of alluvial fans in the circular elevated area surrounding the intruded body of Jabal Sanam.
- Shifted valley courses and bifurcation of a valley towards downstream.

Moreover, the authors conclude that the salt plug is still active, as indicated by the change of the some valley courses and their sediments, which are Holocene – Recent in age.

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