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Petrology and stratigraphy of pre-Cambrian Hormuz Series outcrops in Jabal Sanam structure - the oldest surface rocks in Iraq

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Abstract

Detailed geological field investigations have been done at Jabal Sanam structure Southern Iraq. More than 150 rock and mineral represented samples were collected, and 130 thin sections of these samples were prepared and examined microscopically. An accurate mineralogical study of these rocks by the analysis of 15 samples with the X-ray diffraction technique. A large number of sedimentary rocks were distinguished through field observations and petrographic studies, such as gypsum, limestone, dolomite, red and green marl, sedimentary ironstones, chert, and salts. Various types of igneous and metamorphic rocks, such as dolerite, schist, slate, and metamorphic sediments, were found as beds or fragments intruded with the evaporite rocks of Jabal Sanam. Distinct mineralizations of hematite, pyrite, and dolomite minerals were observed in these successions. It was also noted that these rocks were subjected to varied geological processes of different degrees that affected their original rock characteristics such as diagenesis, metamorphism, deformation, and dissolution processes. A petrological, stratigraphic, and tectonic correlation has been made with similar structures spread through the region (Iran and Arabian Peninsula) in light of their composition, which, in general; consists of infra-Cambrian evaporates of Hormuz Series. This study supports the previous geological studies on this salt structure and shows a great similarity between the rocks of Hormuz Series Complex and those of Jabal Sanam, which may be considered in terms of stratigraphy and petrology as equivalent rock units. Thus, these rocks may be suggested as the oldest rocks exposed above the earth's surface in Iraq.

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1. Introduction

Jabal Sanam is a piercement salt plug crops out in southern Iraq as a dome structure and forms a unique geological phenomenon (Fig.1A) [1]. This structure is located at the eastern fringe of the flat Dibdibba desert (Fig.1B). Jabal Sanam reaches about 100 m above the surrounding areas and about 150m above sea level, close to the Iraqi-Kuwait Borders (Fig.1C). It lies about 45km southwest of Basrah city and 8 Km west of Safwan village, in location 30̊ 08′ 00″N and 47º 37′ 00″E of the Dibdibba plain. Physiographically, it located in the Unstable Shelf area which is part of the Mesopotamian zone according to Iraq physiographical segmentation [2].

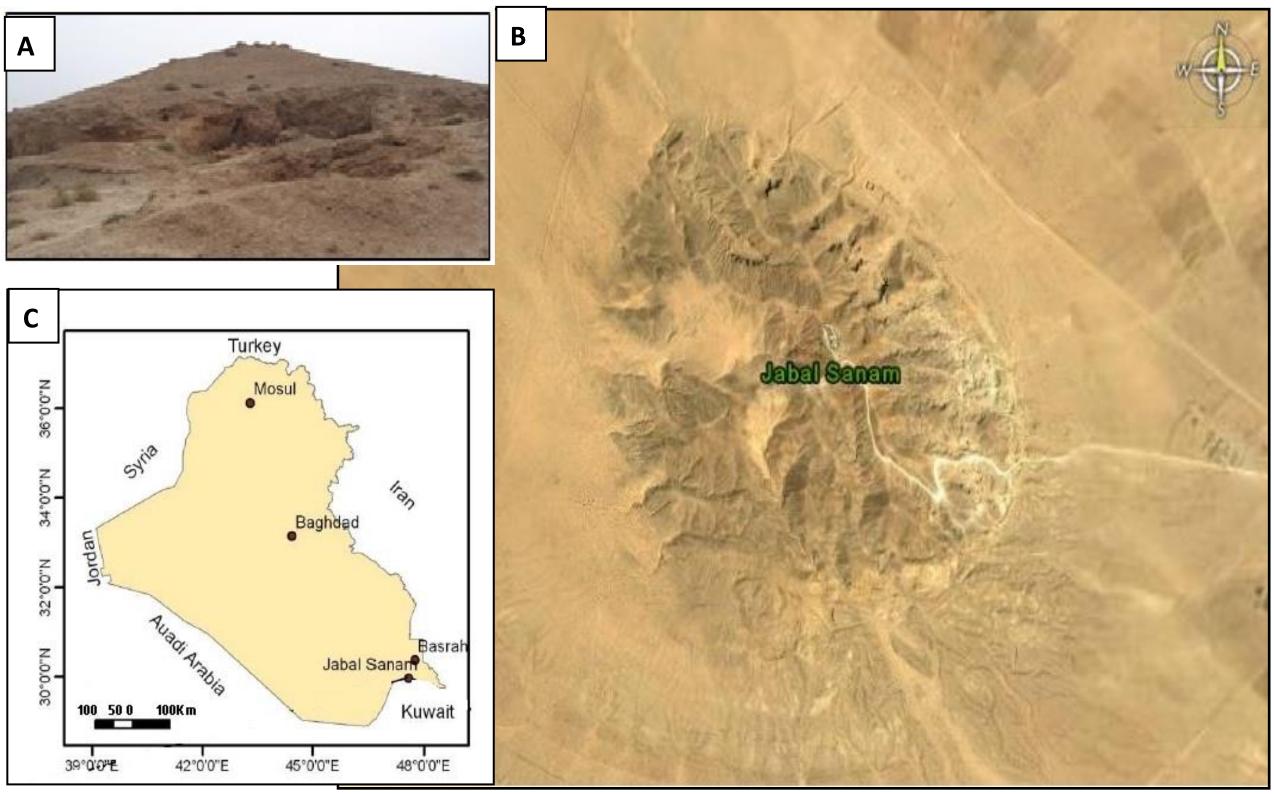


Fig.1: (A) A side view of Jabal Sanam, (B) Satellite image of Jabal Sanam showing its domal shape (google Earth), (C) Location of Jabal Sanam southern Iraq.

For many decades, Jabal Sanam represented a geological phenomenon of great ambiguity, attracted several national and international researchers. All of them attempted to present a reasonable explanation for this abnormal geological phenomenon in the heart of Dibdibba plain. Only a little information about the structure was available, and limited studies have been published about it. The first study on the rocks of Jabal Sanam was made by Williams in 1949 [3], who suggested that Jabal Sanam is just a salt plug of which its top parts crop out at the surface and composed mainly from evaporites rocks and it had general properties similar to that wide distributed structures of Hormuz evaporitic series in Arabian Gulf area.

[4] and [5] concluded that Jabal Sanam is a salt plug and it contains mainly two Zones. The outer zone, which is represented by the clastic sediments of Dibdibba Formation as cline ridges around the structure, and the central zone which comprises old dolomitic sediments. The stratigraphy and general geology of Jabal Sanam were described in generally by Al-Naqib, 1970 [6], who described four main units of the lithological succession of Jabal Sanam, which are from the top to bottom: Dibdibba Formation's clastics unit, Limestone unit, Gypsum unit, and Green/ Red Marl unit. The main unit in the structure was the gypsum unit, while there are many types of sedimentary rocks which appear as brecciated rocks and rock fragments. The exposed rocks were problematic in their age determination because of fossil's lacking and disturbed lithological features. This problem was unsolved till now. Buday and Jassim found igneous rocks in the structure and they dated these rocks to be around 580-575 M.Y. based on the radioactive methods[1], in other words, these igneous rocks are of Cambrian age, and there was a debate whether the major part of the structure belongs to Cambrian or it is pre-/post-Cambrian, besides that: to which extent that the relationship between Jabal Sanam rocks and Hormuz evaporites can be equivalent.

The previous studies and researchers refer that the oldest rocks exposed at the earth surface in Iraq belong to Khabour Formation of Middle-Late Ordovician age in the western desert area of Iraq, which comprises thin-bedded – fine-grained quartzite, siltstone, and shale [1 and 2]. The rocks of Jabal Sanam were brought to the surface as a result of salt injection through the sedimentary column from deep oldest rocks levels which necessitates this rock type is the oldest rocks exposed in Iraq. This study is an attempt to prove the total petrological and stratigraphical similarity between the rocks of Jabal Sanam and, well-known, well-aged dated evaporative rocks of Hormuz Series in the area, thus we can determine the final origin of Jabal Sanam rocks, and infer whether these rocks are the oldest exposed rocks in Iraq.

2. Methodology

The fieldwork stage included several field visits to Jabal Sanam to conduct a detailed geological survey of the structure, conducting a detailed study of the most important structure features, trying to determine the ideal sampling stations on the base map of the area (Fig.2), to draw the dimensions of the geological map and its stratigraphic sequence and finally compared it with characteristics of Hormuz salts sediments, after examining and studying the most important and latest available references about the geological and petrographical properties of this expanded formation. More than 150 rock and mineral samples were collected representing the variable rock types that were initially identified in the field. The laboratory study included the study of the hand specimens, their classification, the preparation of more than 130 rock thin sections and their mineralogy and petrography study to diagnose their rocks, mineral types, and the most important petrographic phenomena in them, as well as the analyses 15 rock and mineral samples using the X-ray technique in the laboratories of the Physics Department at the College of Science/ University of Basrah, using a device of the type (Phillips) and according to the conditions shown below:

Current (I)	:	20 mA
Rated Voltage (V)	:	40 k.v.
Severity range (R)	:	1 kit per second (C.P.S)
Copper target	:	(Cu Kα)
Copper target wavelength	:	1.5419 (Å)

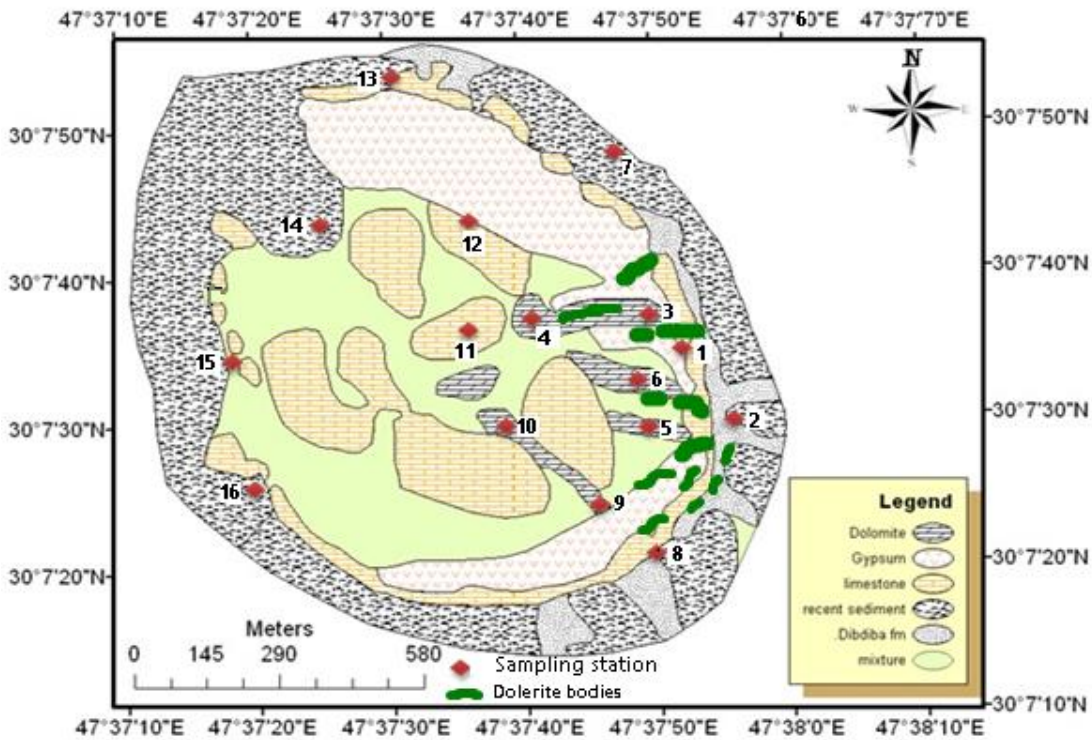


Fig.2: Geological map of Jabal Sanam with location of sampling station modified by [7, 8].

3. Result and Discussion

3.1 Lithological Succession of Jabal Sanam Cap Rocks

Jabal Sanam has lithological complexity and a large variation in its rock components. The reconstruction of a lithological and stratigraphical succession of the structure is very difficult. This is due to the major part of the rocks, which Jabal Sanam comprises; forms a cap for the salt dome. The rocks outcrops at Jabal Sanam are considered complex types because of significant differences in thickness and dips of the beds from place to place and many parts of them disappear under the slopes of the sediments as a result of severe distortion by the effect of salt intrusion [7]. So, the reconstruction of the lithological succession was needed to make a composite section comprises of the best outcrops which must be not less than 7 stations [9]. The detailed fieldwork and petrological properties of Jabal Sanam components showed that this structure contains three major lithological units (Fig.3):

1.Brecciated limestone Unit: This unit represents mainly the top central part of the structure (Fig.4a) in general, although it appears cline-like ridges in the outer ends of it, especially in the western and southwestern parts (Fig.2), Where Dibdibba clastics overlain it. This unit represents about 8% of Jabal Sanam lithological succession (Fig.3). And corresponds to the third unit described by Al-Naqib [6] in his division of lithological succession of Jabal Sanam. He divided this unit into three subdivisions of limestone rocks. The recent studies such as Soltan, 2003 [7] showed that the rocks of this unit are very complex, highly brecciated and consist of a mixture of white and sometimes buff coloured limestone (Fig.5. 3a), as brecciated rock fragments of different sizes with angular and nodular appearance, or as powder connected by muddy or sandy cement materials, and there was a thought to be of Dibdibba Formation in their origin, or its parts of sedimentary rocks which were intruded by the salt plug while moving upward with other lime, gypsum, and ferruginous materials. This unit also contains blocks and fragments of different types of rocks randomly spread in the structure.

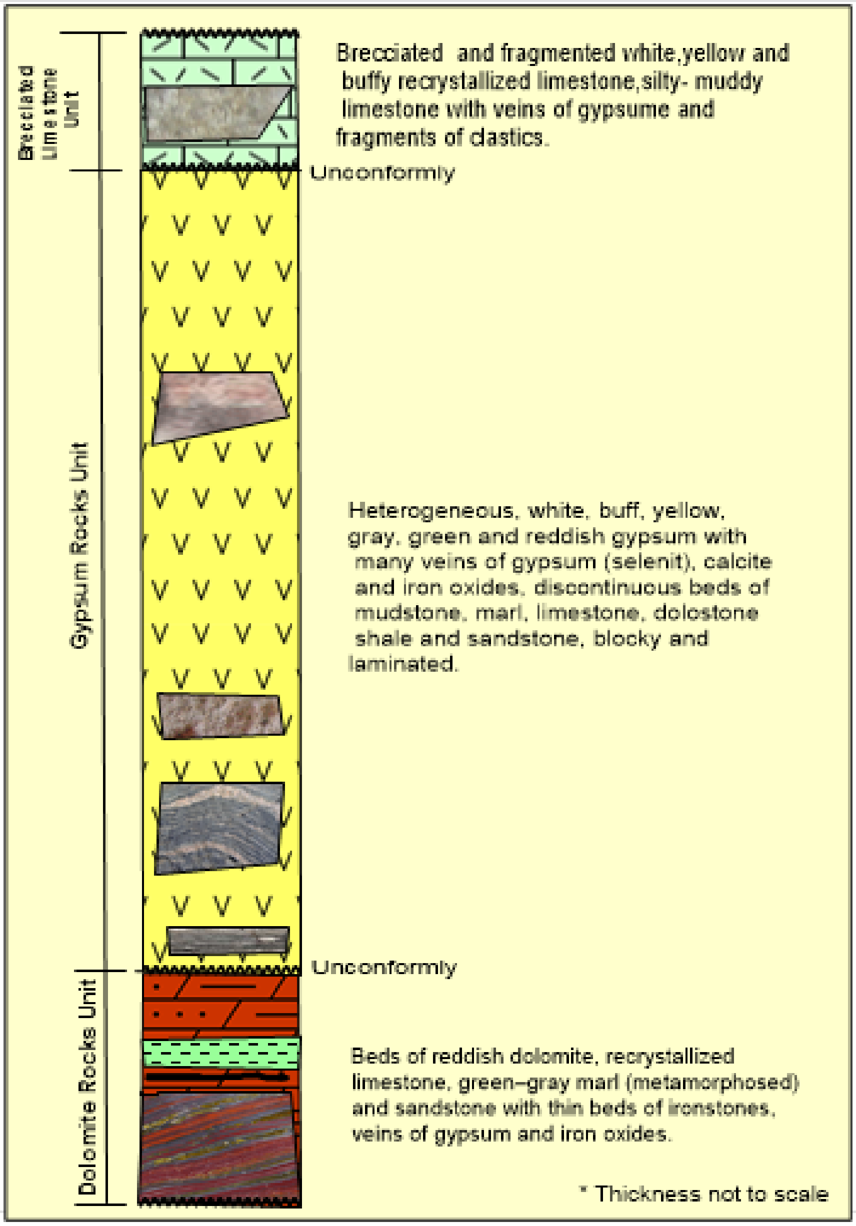


Fig.3: Proposed stratigraphical column of Jabal Sanam.

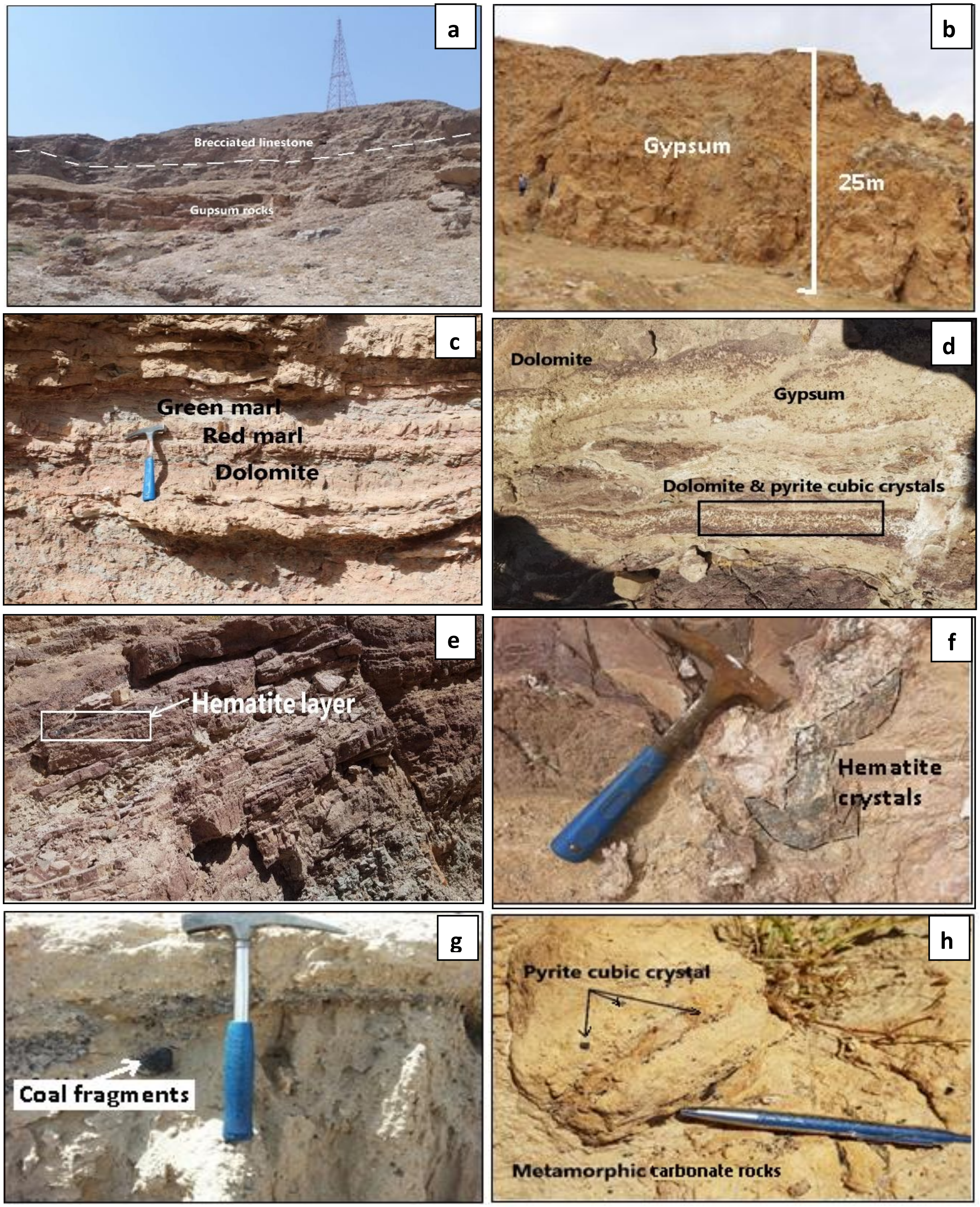


Fig.4: (a) Brecciated-limestone unit and Gypsum unit contact, (b) Gypsum unit's large outcrops (c) Dolomite unit beds, (d) Dolomite and pyrite cubic crystals in dolomite unit, (e) Banded ironstones in dolomite unit, (f) Hematite shiny crystals in dolomite unit, (g) Coal fragments with gypsum rocks, (h) Pyrite mineralization in metamorphic limestone.

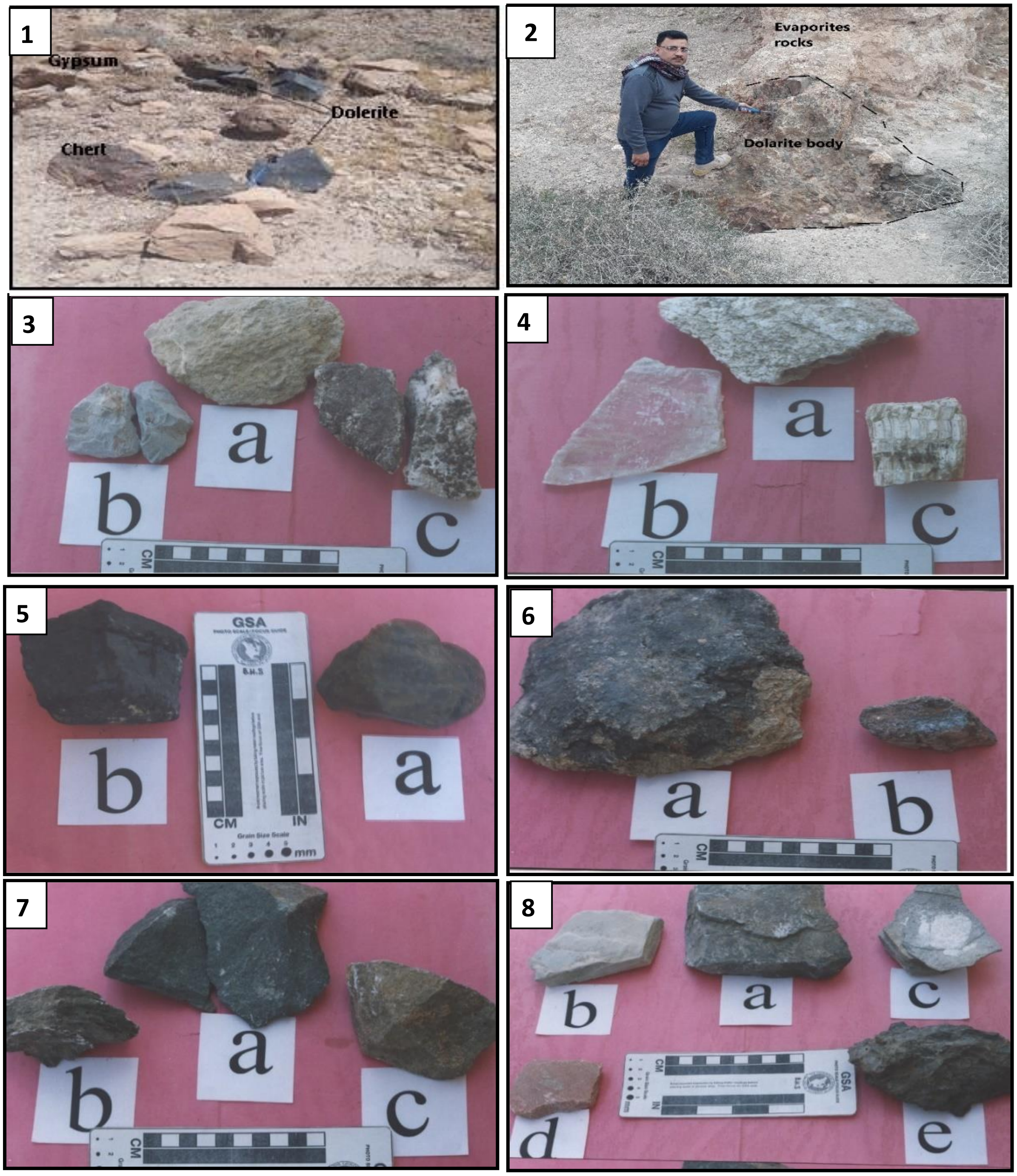


Fig.5: **1.** Large blocks of dolerite igneous rocks distributed in Jabal Sanam**.** **2.** Part of dolerite dyke outcropped in southern valley in Jabal Sanam. **3.** Rocks of limestone and dolomite units (a) limestone (b) green marl (c) dolomite **4.** Gypsum types in gypsum unit (a) Rock gypsum (b) Selenite (c) Fibrous gypsum **5.** (a) Chert (b) Coal **6.** (a) Hematite mineral (b) Ironstone **7.** (a) dolerite (b schist (c) meta-dolerite **8.** (a) slate (b) metamorphosed mudstone(c) phyllite (d) marble (e) quartzite.

They vary from dark gray-coloured compacted shale, chert, marl, sandstone, and grits of sand with clays, that is cemented by lime or gypseous materials. All these rocks might be brought from deeper layers and exposed to the surface by the intrusion of Jabal Sanam. These rocks and their minerals can be found in many parts of this unit. So, Al-Naqib division of this unit became less advantageous, especially after some excavations for new roads at Jabal Sanam lately, unveiled new evidence of well-exposed rocks in the site. The carbonate rocks of this unit characterized by its contents, which are composed mainly of calcite with a micritic texture (Fig.6.1), which is affected by recrystallization possess, and sometimes shows sparite crystals, in particular, at points of high porosity. Most of these rocks can be classified under the group III according to Folk's classification of limestone [10], which contains micrite facies essentially with orthochemical composition. This indicates that these rocks are deposited at a high rate of deposition for micrite lime mud unaffected with currents [11, 12], Also there are many fine crystals of dolomite, quartz, and gypsum as cement materials (Fig. 6.2) which can be used as an indication to identify the sedimentary environment [13]. The microscopic study of these rocks shows the absolute absence of fossils or organic relics, thus supports the chemical origin of these rocks [7].

2. Gypsum Unit: Gypsum Unit is the most important unit in the lithological succession of Jabal Sanam, which represents about 71% of the unit's succession (Fig.3). It is composed mainly of gypsum rocks which are mono-mineralic gypsum rocks, with a secondary amount of calcite, dolomite, and iron oxides (Fig. 8A). These rocks are characterized by massive appearance, with good lamination in some cases, whereas they appear as large outcrop in some old quarries at the structure, particularly in the north and northwesterly parts, they gain thickness up to 25m (Fig.4b). There are four types of gypsum rocks in this unit [14] which are: Microcrystalline (alabastrine) (Fig. 5(4a)), crystalline (selenite) (Fig. 5(4b)), fibrous (satin-spar) (Fig. 5(4c)), and rock gypsum as blocks or beds of invariant thickness, and take shapes of different structures such as veins and nodules (Fig. 4b). Petrographical examinations showed many types of textures in these rocks such as alabaster (Fig. 6. 3, 4), porphyroblastic (Fig. 6(5)), fibrous (Fig. 6(6)), and granular textures (Fig. 6(7)). It is thought that the origin of these rocks was diagenetic processes, especially the gypsification processes of anhydrite rocks (Fig. 6(8)) [7, 14, 15].

3. Dolomite (Dolostone) Unit: Represents the lower part of the succession and the core rock of the structure which is situated at the central part, while the other units are located directly upwards.

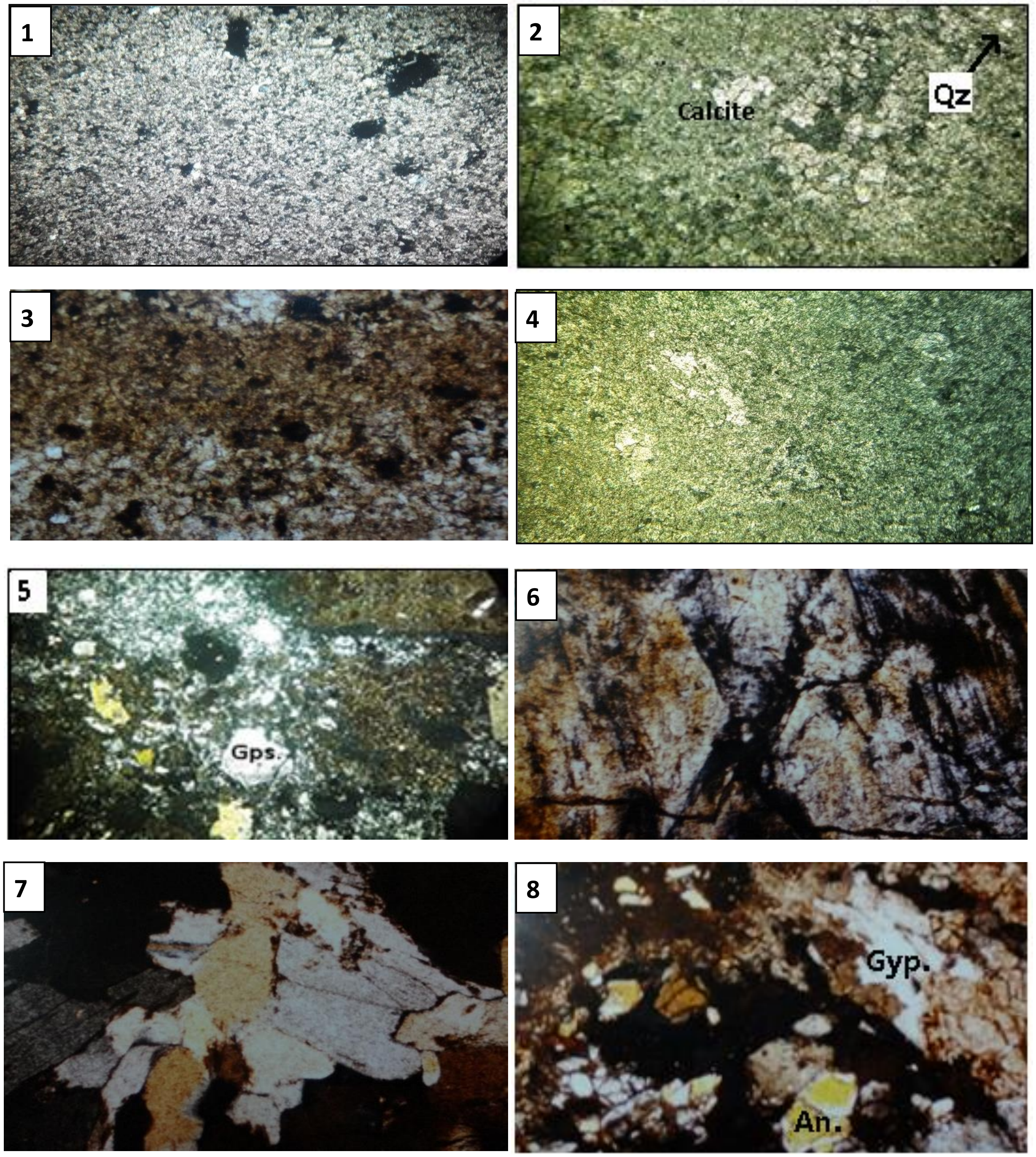


Fig.6: **1**. Limestone rocks with micrite texture **2.** Silica and calcite cementing materials in limestone rocks **3.** Alabastrian gypsum with microcrystalline texture **4.** Alabastrian gypsum **5**. Porphyroblastic texture in gypsum rocks **6.** Fibrous texture **7.** Granular texture in gypsum **8.** Gypsification between anhydrite to gypsum minerals (All photos 40X P.P.L).

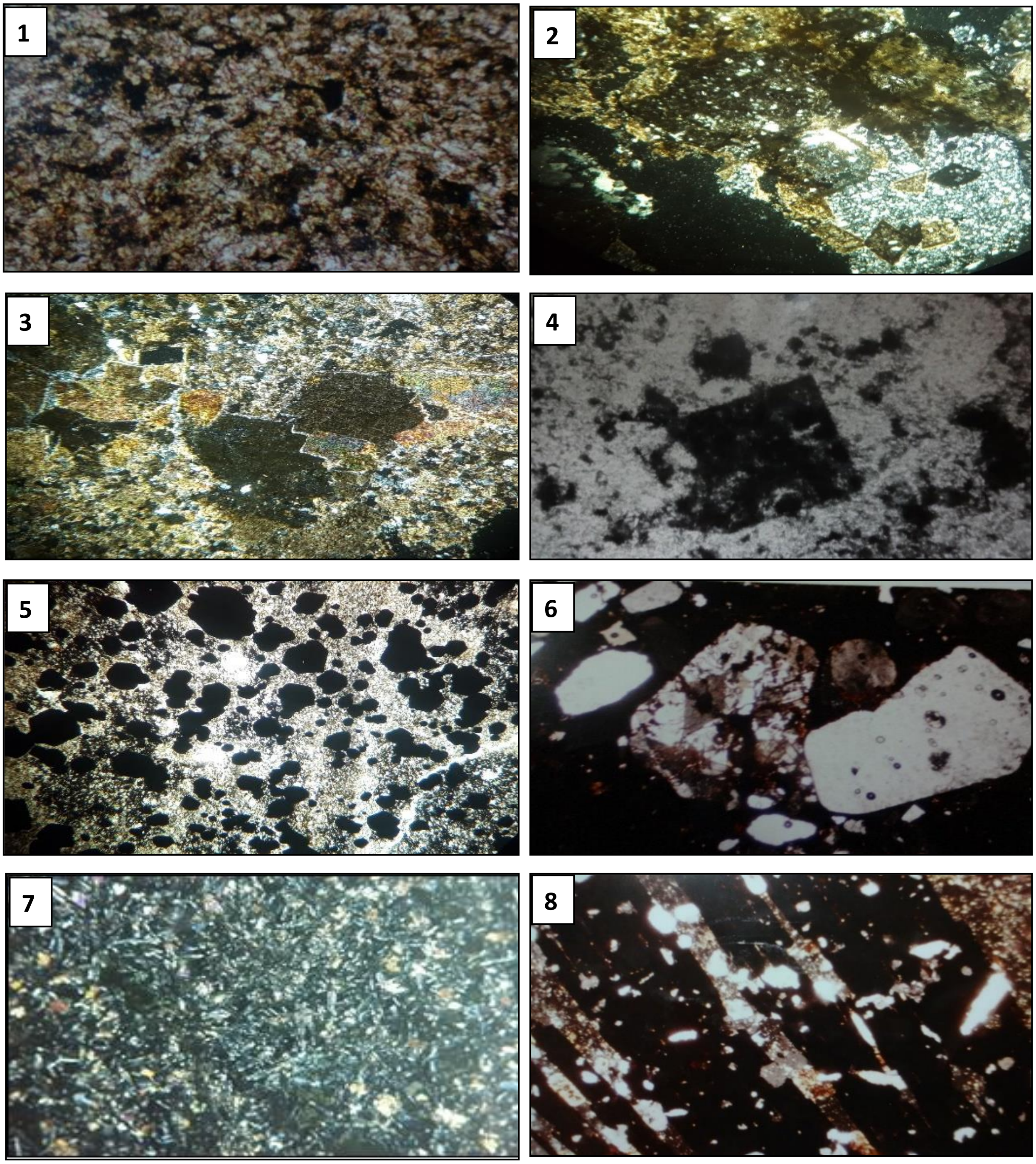
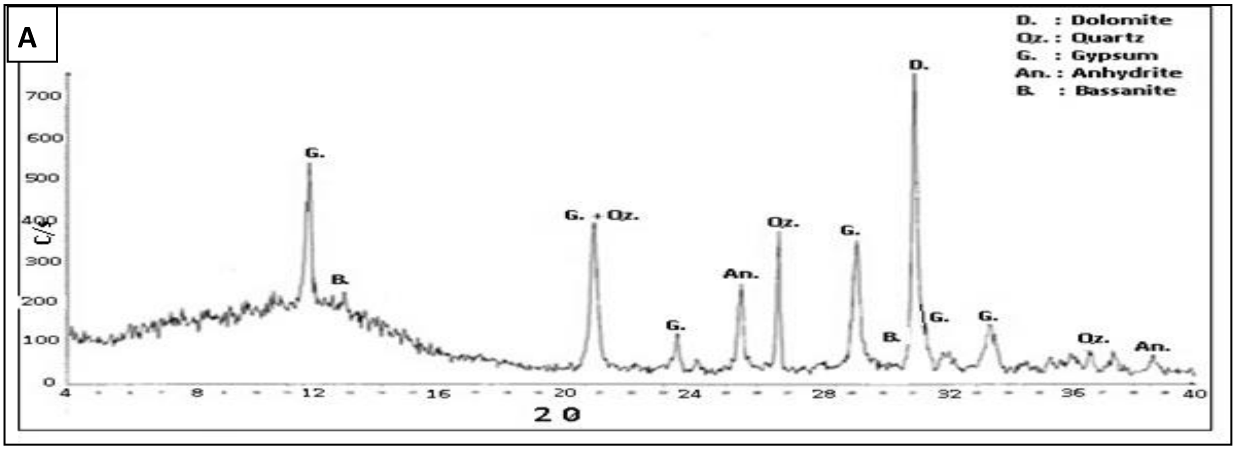
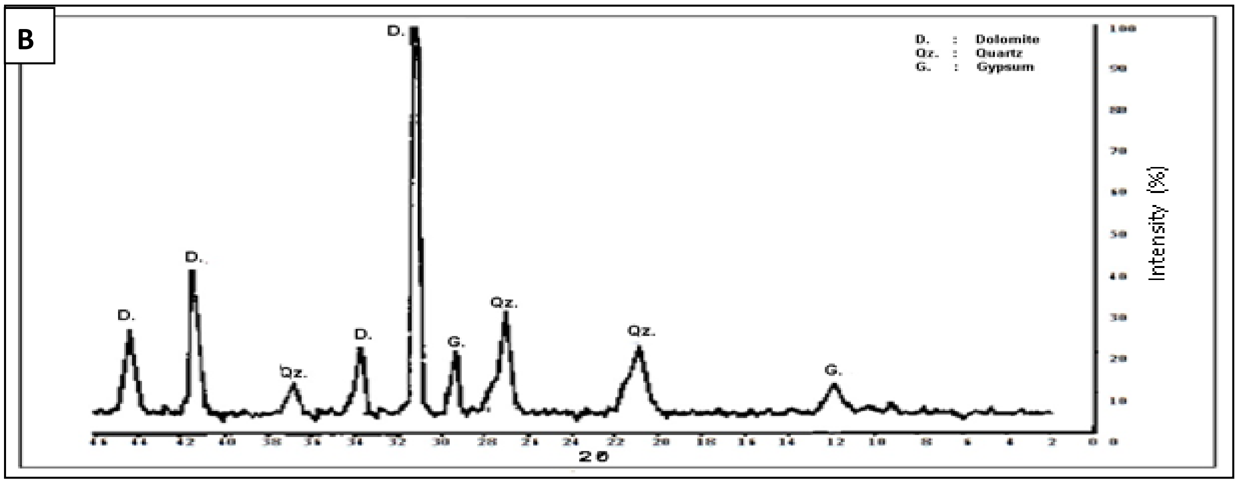


Fig.7: **1.** Dolomite minerals in dolomite rocks **2**. Rhombic crystals of dolomite in dolomite rocks **3.** Replacement of calcite by dolomite minerals **4.** Euhedral cubic grain of pyrite in dolomite rocks **5.** Pyrite euhedral crystals in metamorphic rocks **6.** Chert rock with mono and polycrystalline grains **7.** Plagioclase laths and pyroxene grains in dolerite igneous rocks **8.** Biotite black grains in Jabal Sanam schist rocks (All photos 40X P.P.L).





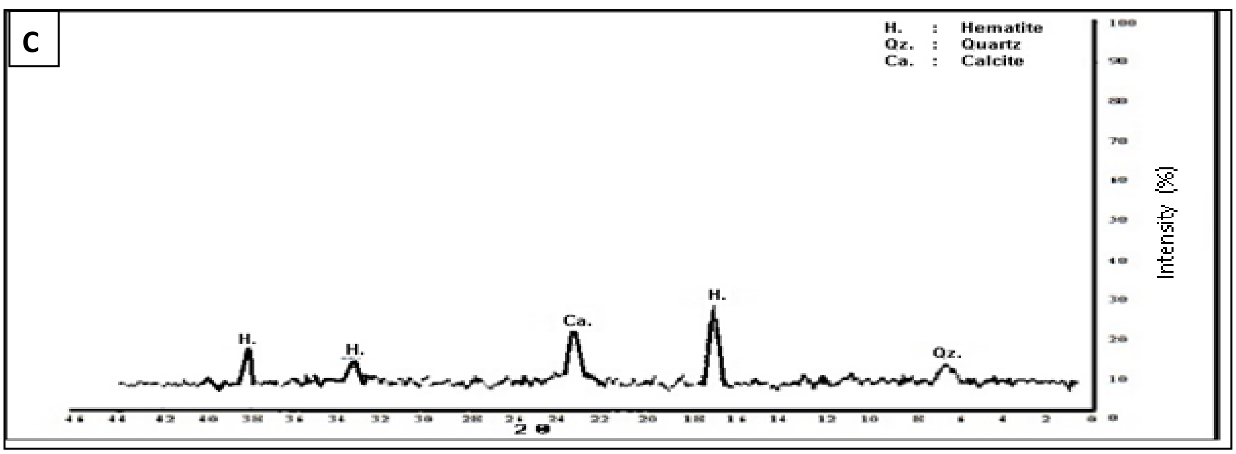


Fig.8: X- Ray diffraction analysis of (A) Gypsum rocks, (B) Dolomite rocks, (C) Ironstone rocks.

The rate of surface exposure for this unit is about 21% of the structure (Fig.3). This unit is composed of many secondary types of rocks, ranging in their thickness from 2-30cm, with well-bedding at some outcrops (Fig. 4c). These beds suffered from intense faulting and fracturing, and in some places the distortion caused by the intrusion of the salt plug of Jabal Sanam, so they lost most of their lithological properties of the layered rocks. Dolomite Unit contains the following types of rocks:

1.Dolomite (Dolostone); these rocks represent the major type of rocks and consist of dolomite mineral with other minerals such as calcite, quartz, gypsum, and iron oxides (Fig. 8B). Dolomite rocks in some beds have a high degree of crystallization as large crystals (Fig. 4d), euhedral dolomite (Figs. 5. 3c and Fig. 7.1, 2, 3) reflected typical dolomitization conditions [16].

2. Clastic rocks: these rocks represent prominent, green– red marls (Fig. 5. 3b), beds which are characterized by their hardness and the variation of their thickness (Fig.4c). Microscopically, these rocks consist of fine quartz, calcite, clays, dolomite, and hematite, with euhedral grains of pyrite (Fig. 7. 4,5) and some marl rocks as well. There are many types of other clastic beds such as sandstone and mudstones which were deformed and faulted in most cases.

3. Sedimentary ironstones: as an important phenomenon in this unit of which they were seen as many thin beds of ironstones (Fig.4e), and consist mainly of iron oxides (hematite), quartz, calcite, and clay minerals. Sometimes they take flaky shapes and shiny luster (Fig.4f) of thickness up to 2cm (Fig. 5. 6a, b). Soltan and co-workers [17] studied these rocks in detail and this study showed that they contain mainly hematite mineral about 52% (Fig. 8C). The high proportions of iron sediments in this unit may be attributed to the interaction with oxides deposits at Jabal Sanam by mean of chemical fluid activity for ages of geological time [18].

4. Meta-Sedimentary rocks: the lowermost part of the lithological succession of Jabal Sanam represents by several beds of sedimentary rocks suffered from a low degree of burial metamorphism and by hydrothermal solutions (Fig. 4h). It’s believed that mudstones, marl, shale, limestone transformed to slate, phyllite, and metamorphosed limestone respectively, by the effect of high temperature and pressure at great depths before and during the intrusion of the salt plug into the surface [7 and 19].

3.2 Exotic rocks in Jabal Sanam:

Jabal Sanam rocks represent a very heterogeneous complex of rocks variable in types and origins, came from the fracturing and deformation of the total stratigraphic column in this area, by the effect of salt plug intrusion to the earth surface, and pull parts of this column as different types, fragments, blocks, and segmented rock beds…etc., which is distributed in many areas in the structure [7 and 20]. Among the most important types of rocks recorded here are the following:

1. Sedimentary exotic rocks: Many different kinds of sedimentary rocks spreading in the structure variable in types, size, colours, origin, and stratigraphic referential. One of the noticeable sedimentary rocks that distributed in Jabal Sanam were the blocks, fragments, and widespread chert rocks, that have characterized by dark brown-brown colours (Fig. 5. 5a), composed of microcrystalline quartz and some iron oxides (Fig. 7. 6) (Fig. 9A). The absence of any fossils remains in thin sections of these rocks with microcrystalline textures signed the chemical origin of these rocks. Another unexpected type of rocks in this geological area were fragments of coal stones (Anthracite) (Fig. 5. 5b), which found in some places in the structure (Fig.4g), may belong in age to Late Devonian–Early carboniferous according to palynology information of these rocks [7]. Some distinct sedimentary structures that spread in Jabal Sanam in the form of silicate and lime nodules and geodes, which were grown by solutions penetrated between rocks of varied chemical composition [21].

2. Hard exotic rocks: In Jabal Sanam also, many kinds of hard rocks (igneous and metamorphic rocks) were tripped. Some of these rocks were imported from the surrounding areas, but the majorities represent one of the compositional rocks of Jabal Sanam. Igneous dolerite (diabase) large blocks and fragments (Fig. 5.1) (Fig. 5.7a), separated especially in the southeastern parts of the structure (Fig. 2), as a result of the segmentation of large dykes or veins (Fig. 5.2) outcropping there by the force of deformation associated with the evolution of the salt plug [22]. This dolerite body was described for the first time by Macfadyen in 1938 [1and 5] and its age determined radioactively about 580 M. Y. ago by Buday and Jassim in 1987 and recently described in more detailed by Soltan, 2003[7]. In thin sections, these rocks are composed mainly of plagioclase, pyroxene, hornblende, and accessory amounts of iron oxides (Fig. 9B) with a special ophitic texture (Fig. 7.7). Also, in Jabal Sanam some sorts of metamorphic rocks of different origins were recognized such as schist (Fig. 5. 7b) (Fig. 7.8), meta-dolerite (Fig. 5. 7c), slate (Fig. 5. 8a), metamorphosed mudstone (Fig. 5. 8b), phyllite (Fig. 5. 8c) (Fig. 9C), marble (Fig. 5. 8d), and quartzite (Fig. 5. 8e). The petrographic characteristics of these rocks indicate that it is metamorphosed thermally and regionally, by the effects of high temperatures of igneous

bodies or by burial and deformation of the rocks under high depths before and during the injection of rocks to the surface.

3.3 Hormuz Evaporites Series

Infra-Cambrian salt in south-east Iran and the Persian Gulf appears to surface by piercement salt plugs structures. There are about 200 piercement salt plugs in the Iranian part of this area (Fig.10) [23 and 24], 6 salt domes in Oman are called Oman group, 7salt domes in UAE [25], and one salt dome southern Iraq called Jabal Sanam.

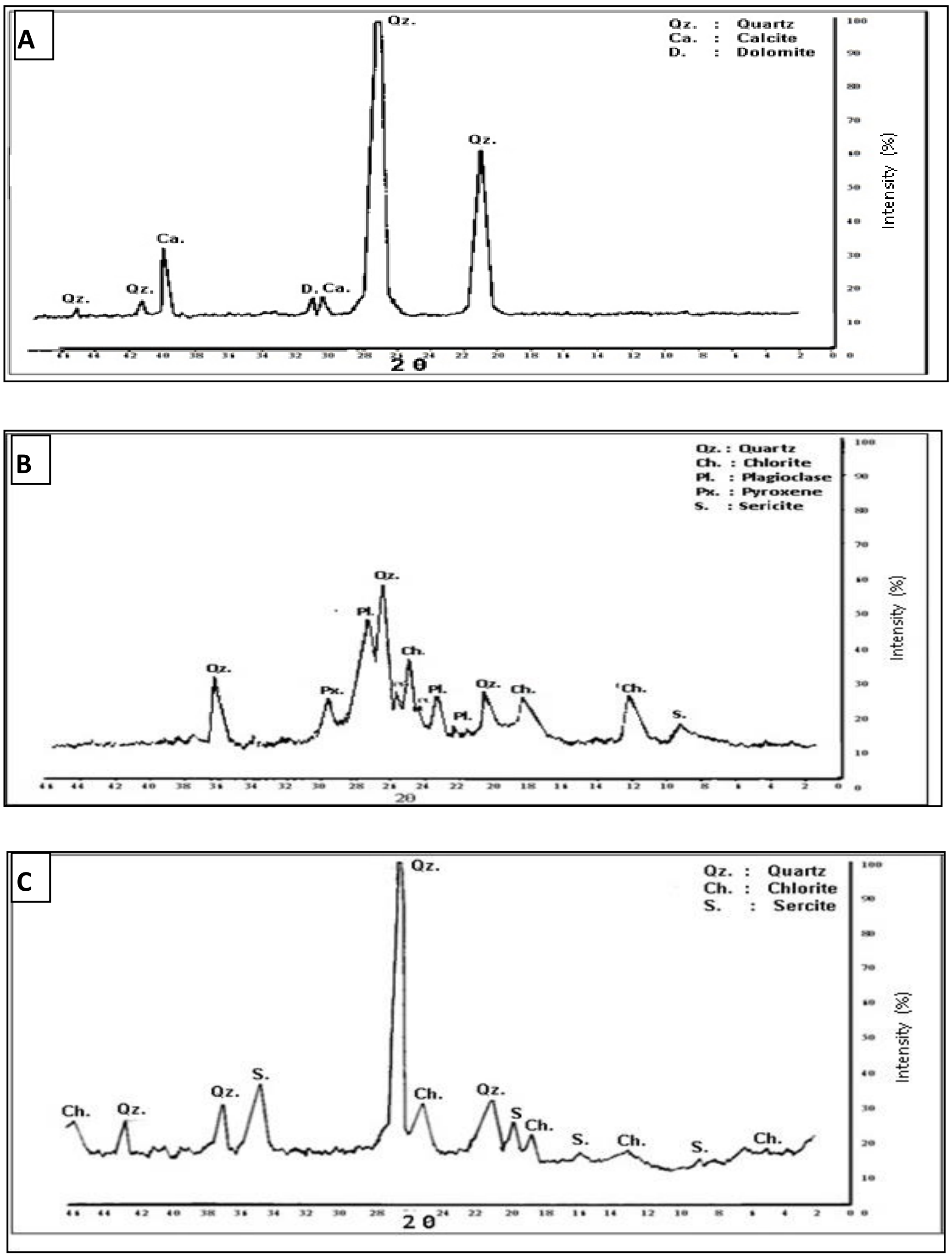


Fig. 9: X- Ray diffraction analysis of (A) Chert rocks (B) Dolerite rocks (C) Phyllite metamorphic rocks.

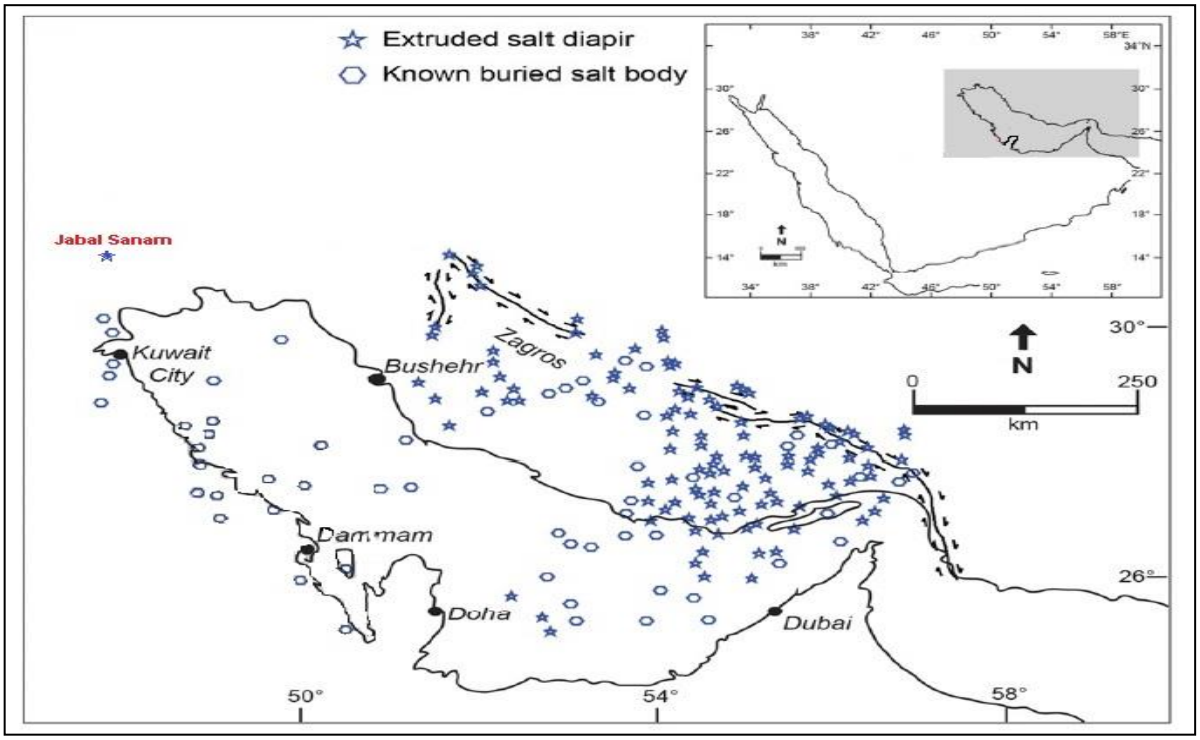


Fig. 10: Distribution of salt structures in Arabian Gulf and South-Western Iran modified by [24].

The term Hormuz Evaporitic Series refers to the heterogeneous complex sequence of sedimentary, igneous, and some metamorphosed rocks deposited in widespread basins in the Arabian Gulf region (Fig.11) [26]. The age of these rocks has been the subject of much discussion by many researchers; so many ages were suggested for these rocks. Finally, the use of radiometric dating has shown that the Hormuz Series and its equivalents rocks are of late pre-Cambrian age [27, 28, and 29]. This series outcrops only in most surface piercement salt structures in southern Iran and the Arabian Gulf region. Hormuz Series is characterized petrologically by the following points:

1. A variable sedimentary rocks are characterized by cyclic precipitation with features that remain discernible despite broad fracturing and effective tectonic events as a result of their translation from great depths. The full cycle begins with dark carbonate rocks (mostly dolomite) covered with gypsum followed by salt and finally varied shale [28, 16].

2. Spreading of igneous bodies and fragments as dikes or veins especially mafic rocks like dolerite in many Hormuz salt structures which sometimes partitioned and have lenticular or eye shapes [27, 28, 19].

3. Many metamorphic rocks beds or fragments were described in these structures which suffered from variable degrees of contact regional metamorphism like greenstones, marble, and schist...etc. [27, 28, 22].

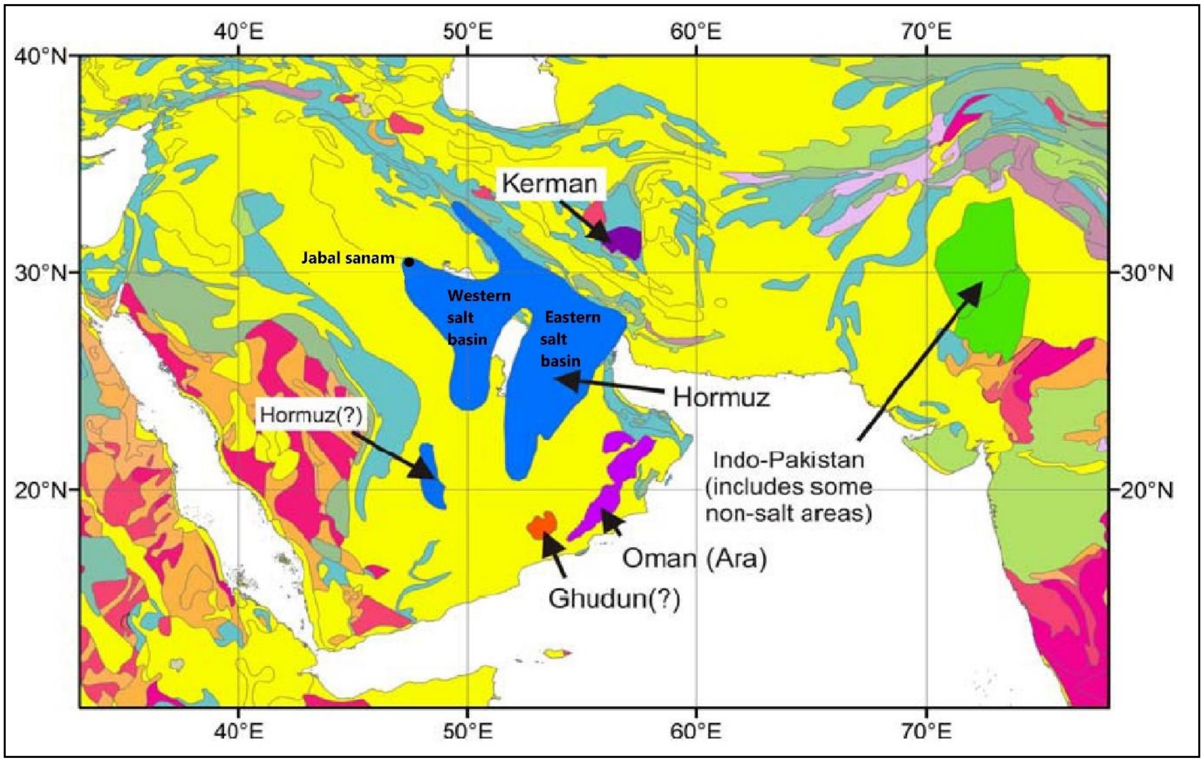


Fig. 11: Spreading of Infra-Cambrian Hormuz salt basins in Arabian Gulf and Arabian Plate areas modified by [26].

The complete absence of fossils or biological remains in sedimentary beds rocks except some trilobites found in rock fragments represent recent ages than the age of Hormuz which carried it from the stratigraphical column during the evolution of these salt plugs [27 and 28]. One of the most characteristic criteria of these rocks was the occurrence of mineral ores and thin beds of shinny crystals of hematite and other iron oxides, distributed in many parts of these structures [28, 18]. The salt structures are among the geological phenomena prevalent in the Arabian Gulf region and the southwestern part of the Iranian plate (Fig.10). It is believed that most of these structures were formed during two major tectonic phases, the first phase was the pre-Alpine Phase (Jurassic-Cretaceous) and the second phase called the Zagros Phase at the end of the

Tertiary age, coinciding with the beginning of the red sea opening movement [27, 29, 30]. Soltan and co-workers believed that Jabal Sanam passed through several stages from the beginning of the intrusion of Hormuz salts [31] which represent the basic component of this composition and the catalyst for its emergence, until the arrival of the salt plug's cap rocks to the earth surface. It is believed that the composition of Jabal Sanam is still in the process of growth and development with the continuation of the tectonic movement in the region, and this is what was evidenced by recent studies of geomorphological changes and satellite images of the structure [32]. The stages proposed by [31] for the growth and development of this salt plug can be summarized as below [33]: During the late Cretaceous-Miocene periods, the area of the Hormuz salt basin was tectonically active, as a result of the continental collision between the Arabian and Iranian plates [34]. This collision during Alpine Orogeny (Miocene), was affected on the Hormuz salts and its accompanied sediments (lagoon evaporites) [35] (Fig. 12(1)). This tectonic influence re-activated the faults in the basement rocks of the region, which grew from the Najd and Hejaz orogeny during the Infra-Cambrian period. The resulting horst structures caused central folding and thinning of the sides of the Hormuz salt layers and the overlying sedimentary layers [36] (Fig.12(2)). This thinning process inside of the salt body caused the primary salt plug to grow. Folding played a dual role in reducing the thickness of sedimentary layers and reducing hydrostatic pressure within the center of the fold compared to the surrounding areas. Consequently, the surrounding salt flowed out, and then accumulated in the center of the salt fold, and the salt flow continued creating a salt pad (Fig. 12(3)). Since the salt is characterized by plasticity and compliance with external stresses, while the compressed sediments surrounding it are solid and susceptible to breakage, which helped the cause of the formation of cracks and a weak area that contributed to the continuity of the salts rushing to the surface of the earth in Pleistocene (Fig.12(4)). Salt tends to move upward in the same way as the lighter fluid rises through a heavier liquid above it, because salt rock has a relatively uniform density regardless of depth, while the average density of other sediments shows a marked increase with the pressure of the burden especially less than 2000 foot depth [37], While the displaced heavy sediments move simultaneously towards the peripheral sink (Fig. 12(5)). The depth of Hormuz salt is more than 10 km [1, 38], so the density of the salt will be much less than the overlying sediments. Hence, there will be a state of imbalance causing salts movement upward.

It was noted that the exposure of the gypsum unit in the northeastern region of Jabal Sanam with large thicknesses more than the southwestern part, and the sharp inclination of the installation slopes on the eastern side, as well as the presence of layers of Dibdibba Formation along the eastern side of Jabal Sump and their absence on the western side, could indicate that Jabal Sanam plug penetrated the sedimentary column in this area down to the surface of the earth in a diagonal rather than vertically (Fig. 12).

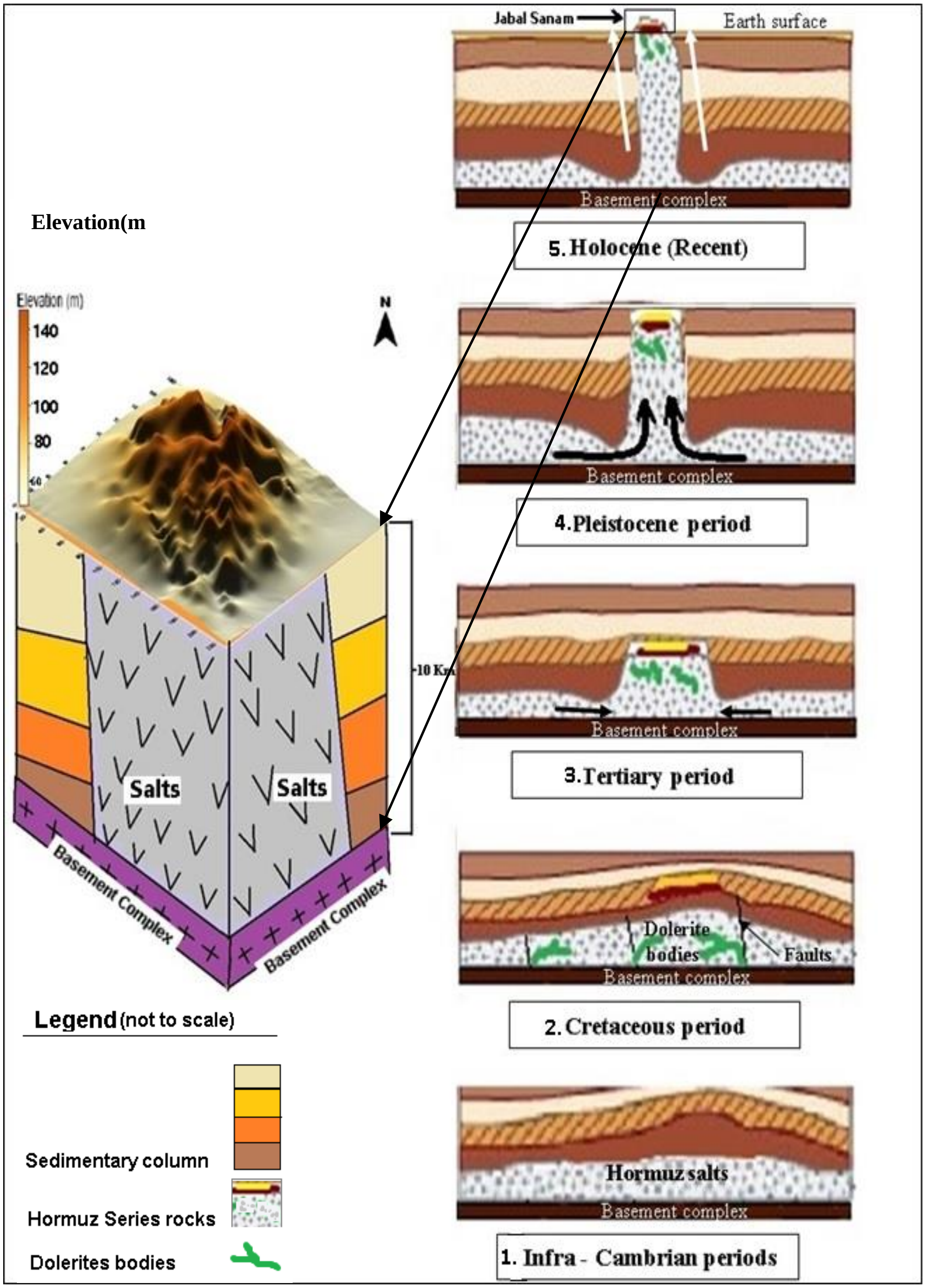


Fig.12: Proposed evolution stages of Jabal Sanam structure.

Conclusions

1. The lithological succession of Jabal Sanam rocks which consist of three main units (Dolomite Unit, Gypsum Unit, and Brecciated-limestone Unit), and the other fragments of detached rocks in the structure, represent different parts of the general stratigraphical succession in this area of the Arabian Plate, dates from pre-Cambrian age to the recent time.
2. The process of reconstructing an accurate stratigraphic sequence of Jabal Sanam is a difficult and complicated process due to the great deformation and fragmentation that the salt plug rocks were subjected to during their rush towards the surface of the earth from the lower sedimentary layers.
3. The great similarity in petrographic, mineralogical, stratigraphical, and geomorphological components between the components of Jabal Sanam and the components of Hormuz salt domes in this area, makes it one of these structures that are similar in their ages and how they originated.
4. The highly distributed fragments of igneous rocks and other types of rocks which formed directly from base rocks represent a very important, rich, and direct source of information about basement rocks in southern Iraq and the entire region.
5. The fact that Jabal Sanam rocks that outcropped on the surface (especially sedimentary rocks) are part of the sediments of the Hormuz Series of a pre-Cambrian age, makes it the oldest geological formations exposed on the surface in Iraq.

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صخارية وطباقية منكشفات سلسلة هرمز ماقبل الكامبيرية في تركيب جبل سنام واقتراحها كأقدم الصخور المنكشفة فوق السطح في العراق

المستخلص:

أجريت تحريات جيولوجية ميدانية مفصلة في تركيب جبل سنام جنوبي العراق. تم جمع أكثر من 150 عينة تمثل الصخور والمعادن ، وتحضير 130 شريحة صخرية رقيقة لهذه العينات المختلفة. تم إجراء دراسة مجهرية ومعدنية دقيقة لهذه العينات بتحليل 15 عينة بتقنية حيود الأشعة السينية. ميزت انواع مختلفة من الصخور الرسوبية في هذه المنطقة من خلال الملاحظة الميدانية والدراسة الصخرية كالجبس والحجر الجيري والدولوميت والمارل الأحمر والأخضر والحجر الحديدي الرسوبي والتشيرت والأملاح. تم العثور على أنواع مختلفة من الصخور النارية والمتحولة مثل الدوليرايت ، والشست ، والأردواز ، والرواسب المتحولة على شكل طبقات أو شظايا متداخلة مع صخورالمتبخرات في جبل سنام، وقد لوحظت تمعدنات مميزة من معادن الهيماتيت والبايريت والدولوميت في هذه التتابعات. كما لوحظ أن هذه الصخور تعرضت لعمليات جيولوجية متنوعة بدرجات متفاوتة أثرت على خصائصها الصخرية الأصلية مثل التحور ، والتحول ، والتشوه ، والانحلال. تم عمل مضاهاة صخرية وطباقية وتكتونية مع تراكيب مماثلة منتشرة في المنطقة (إيران وشبه الجزيرة العربية) في ضوء تكوينها والتي تتكون بصورة عامة من متبخرات سلسلة هرمز ماقبل الكمبرية. تدعم هذه الدراسة الدراسات الجيولوجية السابقة على هذا التركيب وتظهر تشابهاً كبيراً بين صخور سلسلة هرمز وصخور جبل سنام التي يمكن اعتبارها من حيث الطبقية والصخور كوحدات صخرية مكافئة. وهكذا فإن هذه الصخور تمثل أقدم صخور مكشوفة فوق سطح الأرض في العراق.