

Hypogene Processes of the Gypsum Beds in Sangaw Sinkholes, Kurdistan Region, NE-Iraq

Bakhtyar M. Ameen
Department of Geology
College of Science
University of Sulaimani

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ABSTRACT

The Sangaw region is located at the western part of Zagros orogenic belt at the boundary between Low and High Folded Zones, Sulaimani governorate in Kurdistan region. The area characterized by low amplitude folds that are trending northwest southeast and arranged in an echelon pattern. The exposed formations are Eocene Pila Spi (limestone), middle Miocene Fat`ha (lagoon) and Upper Fars (clastics) formations. Many large and small sinkholes are found around Ashdagh anticline; some of them about 50 m in diameter and about 30 m deep. Some are developed into complicated cave systems with collapse blocks and breccias in addition to narrow passages and fissures. The largest of them is located directly to the west of Darzilla village at the southeastern plunge of Ashdagh anticline. The sinkholes occur in Fat`ha and in the Pila Spi Formations. The walls of the sinkholes are covered by secondary gypsum, sulfur, bitumen and secondary calcite. Inside the cave collapse, breccias and blocks with lensoidal stratified clayey sediments as weathering product could be seen. The water is acidic (pH=4) inside the caves and discharges as large spring (200L/S) with white milky color; it is called in the local Kurdish language, "Awa Spi" which means white stream. The weathering of the carbonate rocks is intense inside the cave and appears as honeycombs and rills mark which have very rough surface with dull color. The sinkholes were produced from the dissolution of thick gypsum and limestone beds. The origin of these caves has been proposed to be hypogenic speleogenesis due to the presence of gypsum and bitumen. These materials with the aid of bacteria enrich the water with H₂S which acidifies the water and precipitates the sulfur and secondary gypsum on the cave wall. The formation of H₂SO₄ by oxidation of H₂S is the main reason that aids the sinkhole hypogene generation in Sangaw area. A realistic model is drawn to interpret and connect the following:

1- The stratigraphy and structure of the area encourage the generation of underground stagnant pond suitable for reacting with the emanating H₂S necessary for the hypogene generation of the sinkholes and precipitation of secondary native sulfur

and gypsum.2- dissolution of gypsum and its reduction by bacteria. 3- upward migration of bitumen from nearby oil traps(hydrocarbon accumulation).

عمليات الهايوجين في طبقات الجبس في منخسفات سنكاو، إقليم كردستان

شمال شرق العراق

بختيار محمد أمين

قسم علوم الأرض

كلية العلوم

جامعة السليمانية

الملخص

تقع منطقة سنكاو في الجزء الغربي من حزام زاكروس الأوروغيني على الحد بين نطاقي الطيات المنخفضة والطيات العالية في محافظة السليمانية في إقليم كردستان. تتميز المنطقة بطيات متداخلة ذات سعة منخفضة تمتد شمال غرب - جنوب شرق. التكوينات الظاهرة في المنطقة هي تكوين ألبيلاسبي (الأيوسين) وتكويني ألفتحة والأنجاجة (المايوسين الأوسط و الأعلى على التوالي). العديد من المنخسفات تتواجد حول طية أشداخ المحدبة، يبلغ قطر بعضها ٥٠ م وعمق ٣٠ م ، بعض هذه المنخسفات قد تحول إلى كهوف معقدة وغير منتظمة تحتوي على أنهيارات وتكسرات صخرية بالإضافة إلى الممرات والشقوق الضيقة. أكبر هذه الكهوف يقع مباشرة إلى الغرب من قرية دارازيلا عند الغاطس الجنوبي الغربي لطية أشداخ المحدبة، تكون هذا المنخسف في تكويني ألفتحة وألبيلاسبي. جدران الكهف مغطاة بالجبسوم ألتانوي وألكبريت ألتانوي والقيرو الكالسيت ألتانوي. في داخل الكهف تتواجد الأنهيارات وألتكسرات الصخرية، كما يمكن ملاحظة طبقات عدسية من الترسبات الطينية كنواتج لعمليات التجوية. مياه الكهف حامضية وذات لون حليبي تتدفق من ينبوع كبير وبمعدل (٢٠٠ لتر/ثا) وتسمى باللغة الكردية المحلية (أواسبي) وتعني المياه البيضاء. تجوية الصخور الجيرية شديدة داخل الكهف بحيث تظهر وكأنها محفورة كأقراص ألتحل وذات سطح خشن ولون معتم. وقد أفترض نشوء هذه الكهوف إلى عملية الهايوجينك ألتحويرية بسبب تواجد الجبسوم وألقير. بوجود هاتين المادتين وبمساعدة ألبكتريا يغتني الماء بكبريتيد الهيدروجين (H₂S) الذي يجعل مياه الكهف حامضية ويؤدي إلى ترسيب ألتانوي ألتانوي وألكبريت ألتانوي على جدران الكهف. تكون حامض ألكبريتيك (H₂SO₄) بذوبان كبريتيد الهيدروجين (H₂S) في الماء وهو السبب ألتانوي لكون المنخسفات الهايوجينية في منطقة سنكاو. وقد تم رسم موديل لتفسير وربط ألتعطيات ألتالية:

- ١- طباقية وتركيبية المنطقة ساعدا في تكوين برك تحت أرضية راكدة وملائمة لعليات التفاعل مع أنبثاق غاز كبريتيد الهايدروجين الضروري لتكوين المنخسفات الهايوجينية وترسيب الكبريت والجسوم.
- ٢- ذوبان الجبس وأختزاله بواسطة البكتريا. ٣- هجرة ألقير إلى الأعلى من المصائد النفطية القريبة (التجمعات الهايدروكاربونية).

INTRODUCTION

The studied area is located within Sulaimaniya Governorate in northeastern Iraq, at an area between High Folded and Foothill Zones. The large sinkhole is located directly at south eastern Ashdagh mountain about 1km northwest of Darzilla village (Fig. 1,2) at latitude $35^{\circ} 08' 38''$ N, $45^{\circ} 16' 44''$ E, with elevation 686 m. Other small caves are found around Ashdagh anticline. The sinkholes also exist at the toe of southeastern limb of Sagma anticline. The sinkholes occur in Fatha and Pila Spi Formations. The Fat`ha Formation (previously known as Lower Fars Formation) was deposited during Middle Miocene evaporitic lagoon and has widespread outcrops in the northeastern Iraq (Fig. 3 A). The formation consists of cyclic alternation of clastic-carbonate-evaporite and marly rocks and it changes mostly to carbonate-evaporites in the basin center. The thickness of gypsum unit in the studied area is about 5 m.



Fig. 1: Google Earth picture of part of middle east, Iraq, Kurdistan region part of NE-Iraq, with approximate location of the Sangaw Sinkhole.

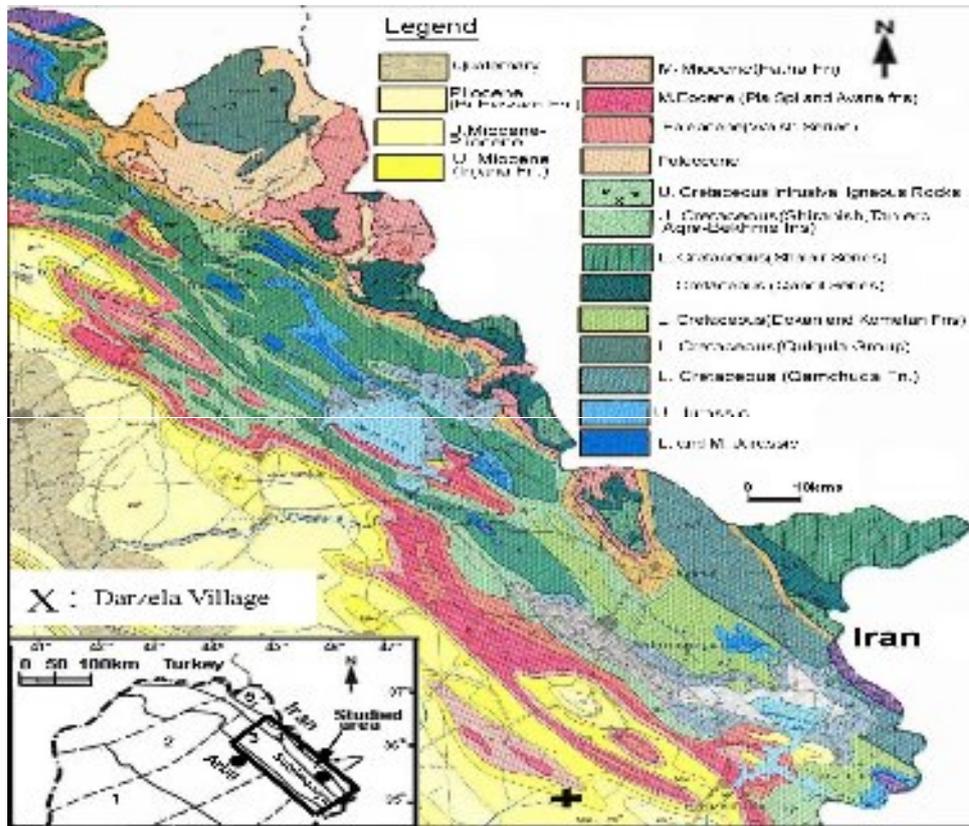


Fig. 2: Geological map of the studied area (Modified from Sissakian, 2000) showing location of the studied area.

The formation was originally described from Iran by (Busk and Mayo, 1918) (in Bellen *et al*, 1959). Dunnington (1958) has drawn isopach Facies map for the distribution of the formation in Iraq (Fig. 3B). In the basin periphery, the strata of the formation are onlapping unconformably on either Late Eocene Pila Spi Formation or on the Oligocene units. The upper contact is gradational with Upper Fars Formation and most probably (somewhat) diachronous (Bellen *et al*, 1959). Due to this onlapping the formation is missing in most parts of the High Folded Zone. The formation in the studied area mainly consists of cyclic repetition of red claystone, marl, gypsum and occasional limestone and sandstone. The maximum thickness of the formation reaches up to 600m in the central depositional area, which is lying on the Foothill Zone (Buday, 1980). The lower contact of the Fat'ha Formation is mostly unconformable with Pila Spi Formation in the northeastern margin area (Buday, 1980, 280p).

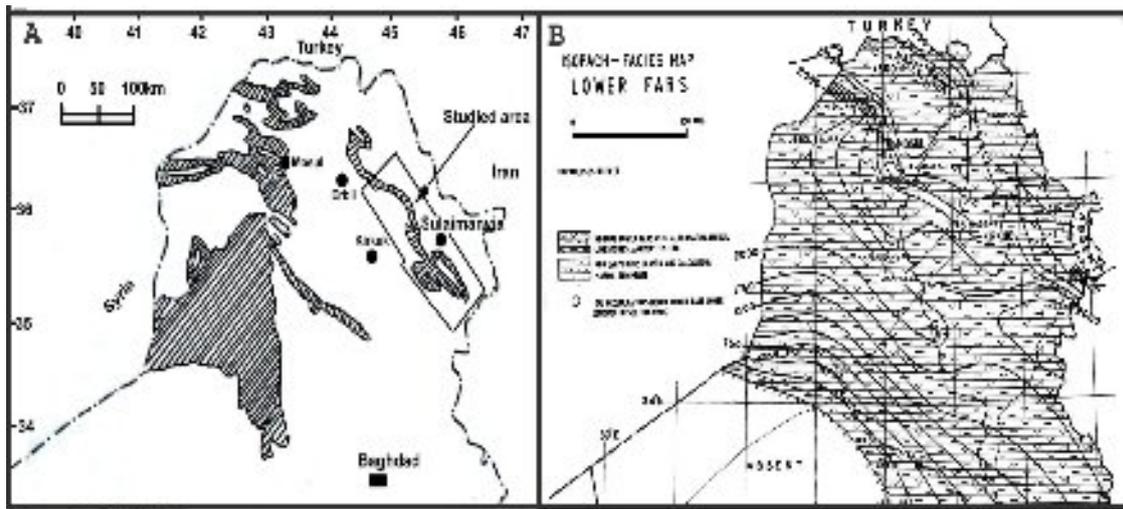


Fig. 3 **A:** Location map of the studied area and outcrops distribution of the Fat`ha (Lower Fars) Formation (modified from Sissakian, 2000).
B: Isopach-Facies map of Lower Fars Formation (Dunnington, 1958).

Maala (2009) studied the karst development in Hadher plain of Iraqi Al-jazera Area; he designated the development due to the collapse of top layer after dissolving of underlying rocks in Euphrates Formation, or due to dissolving of gypsum layer of the Fat`ha Formation. Al-Dabbagh and Al-Naqib (2009) studied the sinkholes within the upper part of the upper member of Fat`ha Formation at Mosul Dam.

They mentioned that the recent sinkhole is a product of fault crossings. There has been much discussion about the processes involved in the development of hypogene gypsum caves in sedimentary basin, and some has involved caves both in limestone and gypsum in sedimentary basins and caves in deformed limestone (Klimchouk 1996, 2000, 2007).

The Ordinskaya underwater cave which is situated at the district of the Perm region of Russia is the longest gypsum underwater cave in the World; the length of under water passages is more than 4500 m., it belongs to the Irenskiy region of gypsum and gypsum-carbonate karst (Lavrove, 1999, Lavrove *et al.*, 2005). The aim of the present study to provide evidence for hypogene speleogenesis in gypsiferous beds and to discuss the associated speleogenetic processes of geological framework in Sangaw area.

GEOLOGICAL SETTING

The studied area is mainly located at the boundary between High Folded and Foothill Zones (Buday 1980, Buday and Jassim 1987, Jassim and Goof 2006). It is bounded to the northeast by high amplitude anticlines, within the High Folded Zone,

changing gradually to low amplitude anticlines, inside the Foothill Zone. The Fat`ha Formation is well exposed at the southwestern limb Zimnako, Gulan, Sagrma anticlines, and Darbandi Bazian. In these localities, the outcrops of the formation form flat irons and stratigraphic ribbons geomorphologic features (Fig. 4). The basin was developed from the basin fill of the Neo-Tethys and collision of the Iranian and Arabian Plates. In the studied area the Fat`ha Formation is underlain directly by the Pila Spi Formation and is overlain by the injana Formation. The black acidic water (pH=4) which occurs inside the cave (Baba Shekh, 2001), to dissolves a high amounts of milky lime and becamesit self milky water when discharged as a source of Awa Spi river drown in the south of sinkholes, bitumn seepage from older layers is mixed with milky water, (Fig. 8A). due to the normal fault in the area (Fig. 5A).

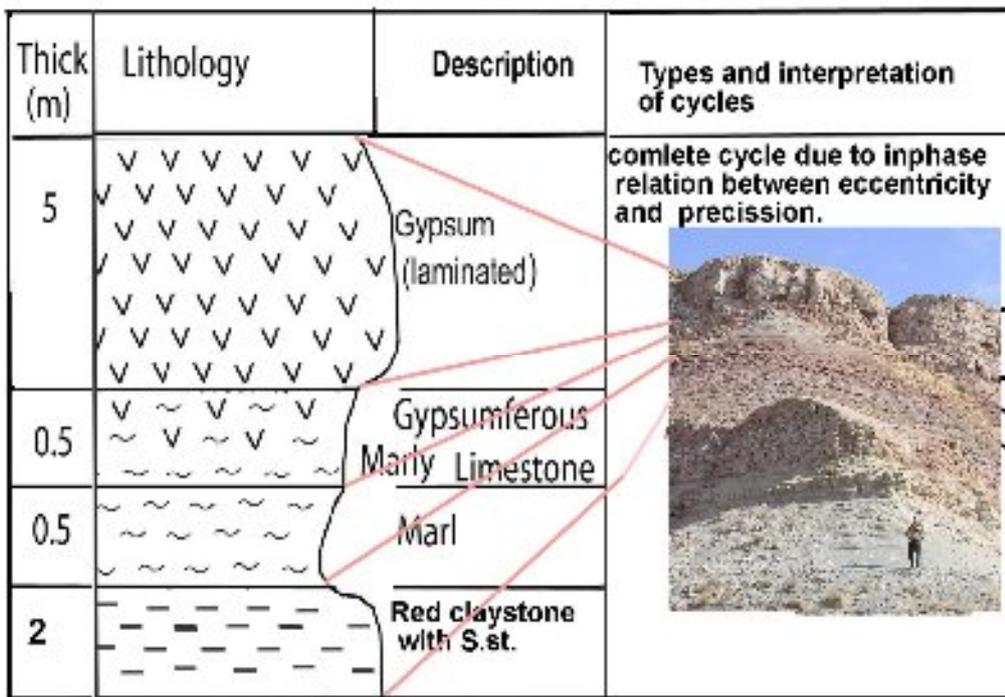


Fig. 4: An ideal cycle of Fat`ha Formation at the top of the Awa Spi section for which the lithologies and sequence stratigraphy are shown.

Sometimes blind river could be seen in the studied area due to its disappearance, where the river interflow into some caves then after more than 50 m reappears especially near Hassan Kalosh village. The area is characterized by the main regional fault (Fig. 5A) and geomorphologically by a series of longitudinal valleys depressions(fig. 6B). All of these sinkholes have relationship with the surface and represent geomorphological features(Fig. 6B).

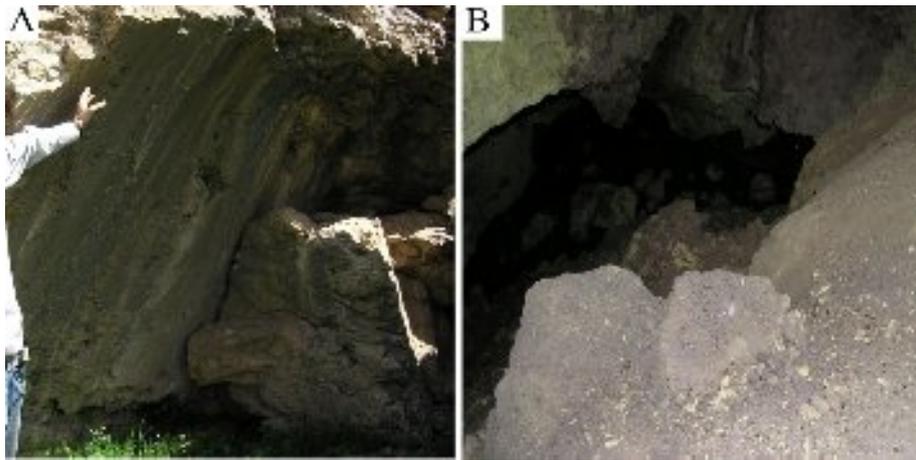


Fig. 5A: Normal Fault at the studied area B: Collaps breccias, Sangaw sinkholes

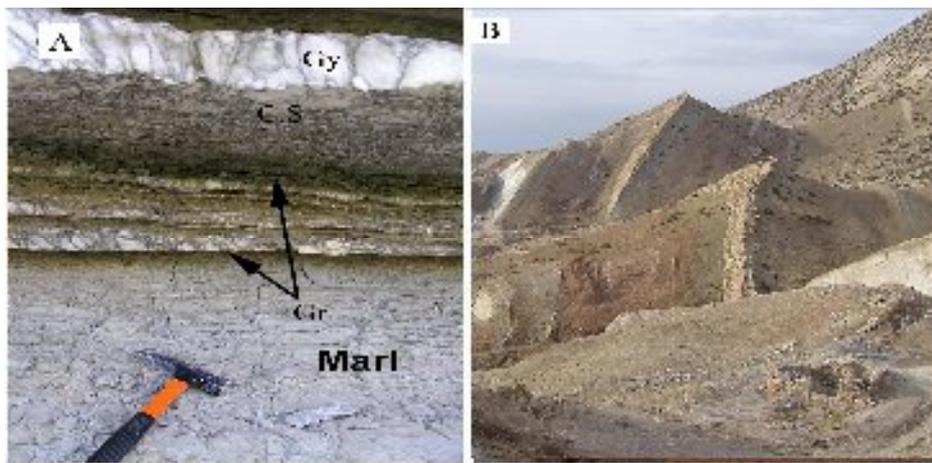


Fig. 6 A: Two ideal cycles of depositions: red claystone (C.S), green marl (Gr) and gypsum (GY) at southeastern plunge of Sagma anticline. B: Common geomorphologic feature (iron flats) formed by limestone and gypsum beds (southeast limb of Qishlagh anticline).

CHARACTRISTICS OF HYPOGENE CAVES

The main factors leading to the formation of hypogene caves are the texture of the rocks, climatology and the presence of overlying deposits. The texture is largely responsible for determining the abundance of certain forms with respect to others. Most hypogene and partially hypogene caves are extinct due to the fact that rising fluids are no longer pass through them .Some hypogene caves show evidence of recent activity or contain waters that are slightly elevated in temperature (15 °C),

aggressive ores are degassing (Dublyansky *et al.*, 2009). In basinal setting the geological structure suggests a source for the fluids responsible for the origin of extinct hypogenic caves (Klimchouk 2007).

Karst features in Sangaw sinkholes occur at the surface outcrops (Fig.7A). Karst collapse sediments consist mainly of breccias and blocks (Fig.5B) with lensoidal stratified clayey sediments as weathering product. The weathering of the carbonate rocks is intense inside the cave and appears as honeycombs and rill marks which have very rough surface with dull color. (Fig.8B). Sangaw sinkholes are of various diameters and depths. The largest sinkhole is about 25 m high and 50 m width with 30m sub horizontally deepening by three stages. Sangaw sinkhole pattern are recognized by different forms of network cave plains, holes and narrow caves and characterized by blind terminations at the ends of cave segments and show no sign of lateral flow.

Major horizontal and vertical passages at the wall and floor are restricted to a few places with sequence of chambers linked by much smaller passages in Sangaw cave(Fig.7C). The wall cover generally consists of secondary gypsum, sulfur, bitumen and secondary calcite; smaller caves with similar patterns have been reported in the area.



Fig. 7A: The Largest Sinkhole in Sangaw area B: Darzilla Village and Awa Spi river C: narrow passage linked chambers inside the large sinkhole.

GEOLOGICAL CHARACTERIZATION OF GYPSUM KARST OF THE STUDY AREA

In the characterization of gypsum karst, the intention is to cover virtually all the possibilities from the stratigraphic and structural standpoints. Thus, there is a description of widely varying gypsiferous karsts, made up of Triassic to Miocene materials, some with a complex tectonic configuration and others hardly affected by folding. The gypsiferous karsts described, and their most significant geological characteristics, are as follows (Calaforra, 1998):

- 1- Karsts in gypsum are composed of gypsiferous levels with the essential characteristic of very continuous marly interstrata between the layers of gypsum, which decisively affect the speleogenesis of the area.
- 2- Karsts are made up of very chaotic gypsiferous materials containing a large quantity of heterometric blocks of varied composition. The presence of hypersoluble salts at depth is significant in the modification of the hydrochemical characteristics of the water and in the speleogenetic development of the karst.
- 3- The influence of dolomitic intercalations in the sequence is crucial to the speleogenesis of the area and this, together with intense tectonic activity, has led to the development in this sector of the deepest gypsiferous cavity in the world (Calaforra, 1998).
- 4- The cavities developed in gypsiferous conglomerates, following structural discontinuities have enabled contact between carbonate and gypsiferous levels, and so we may speak of a mixed karstification: a karst in calcareous rocks and gypsum.

Finally, considering the relation between climatology and the development of karstic forms studied in gypsum in New Mexico (Hill, 2000), where there is an extensive outcrop of Permian gypsum, both micro and macrocrystalline, situated on a large platform almost unaffected by deformation, and where the conditions of aridity are very similar to those found in the gypsiferous karst of Sorbas (SE-Spain). (Kempe, *et al.*, 2009) studied hypogene karstification of the gypsum beds in Al-Daher cave in northern Jordan, and they mentioned that processes similar to those which formed the cave in Mexico by (Hill, 2000).

In the studied area, the ideal cycle of Fat'ha Formation consists of red claystone or sandstone, green marl and gypsum or limestone. This ideal cycle can be seen in many places, but in most cases many incomplete cycles could be seen, which consists only of two lithologies such as red claystone - marl, marl- gypsum and red claystone (Fig. 4).

In Sangaw sinkholes, the gypsum layers have an average thickness of more than 5 m and, usually occurs as thick gypsum beds covered by limestone beds, together with the fracturing in the zone, determining the development of the gypsiferous cavities.

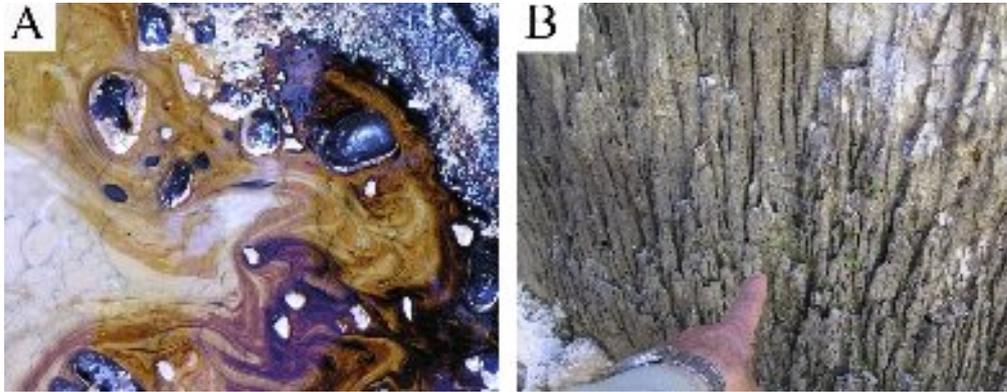
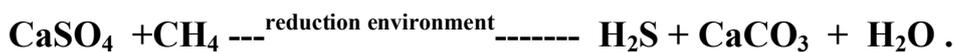


Fig. 8 **A:** Bitumn mixed with Awa Spi river **B:** The weathering of the carbonate rocks appears as honeycombs and rills mark which have very rough surface with dull color.

GEOLOGICAL FRAMEWORKE OF KARST

Andriani and Walsh (2005) classified the sinkholes into six types, the Sangaw sinkholers are related to dissolution type. The origin of Sangaw sinkholes has been proposed in this study to be of acid (pH=4) (Baba Shekh, 2001) hypogenic speleogenesis due to the presence of H₂S rich springs both in the cave and of the surface elsewhere in the area. The hydrological and chemical conditions with processes involved and suggests that hypogenic dissolution of evaporate (gypsum) beds is the best phenomenon in the caves creation. The cave apparently formed by upward solution of the groundwater body in a hypogene setting by (Klimchouk, 2007) he studied some caves in Ukraine as indicated by the following equations



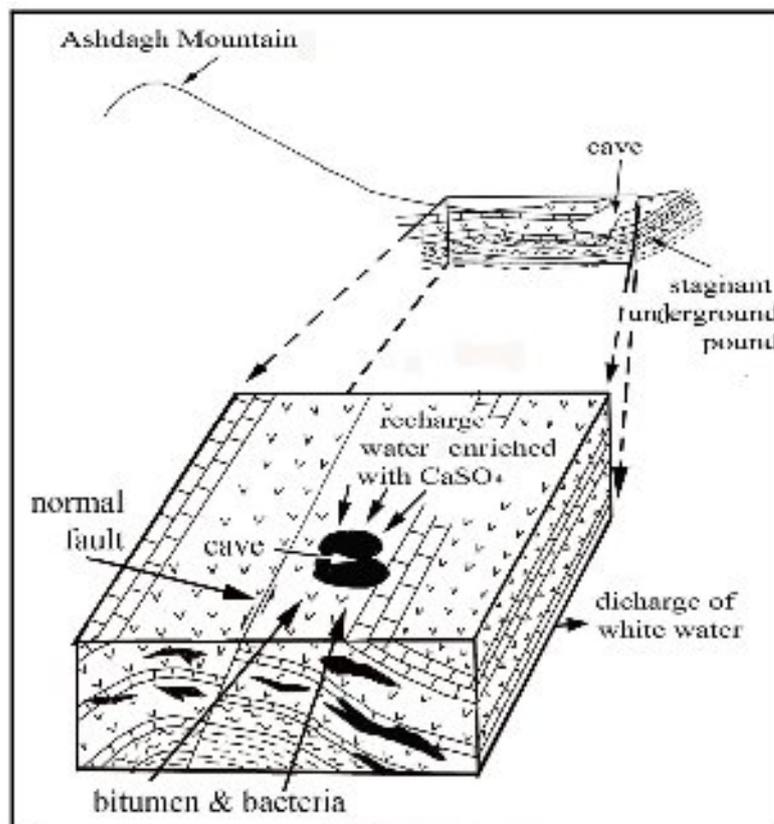


Fig. 9: Conceptual model of the present study showing the effect of stagnant underground pond ,recharge water enriched with CaSO₄ and upward migration of bitumen from nearby oil traps in Sangaw sinkhole, Ashdagh mountain.

The hypogene processes have relation with Sangaw cave formation, due to the reasons that the strata composed of salt rock and gypsum and due to the dissolution by water containing H₂S(acid water).The solution capacity etched out the cave must have came from upwelling ,deeper waters in natural convection and carried H₂S which reacted with O₂ carried down by sinking surface seepage water according to the following equation:



Sulphuric acid dissolution represents one of the possible mechanism associated with deep seated hypogene cave development. The sulphuric acid is being produced through the oxidation of H₂S.

The ground water rising into the cave through the permeable beds, due to the stratigraphy and structure of the area which are generated an underground stagnant pond for occurrence of the reaction that emanating enough H₂S for hypogene

generation of the sinkholes and precipitation of secondary native sulfur and gypsum. Upward migration of bitumen is from the nearby oil traps (Fig. 9).

Sangaw Sinkholes probably formed by hypogene processes similar to caves which formed in New Mexico at Guadalupe mountain and Al-Daher sinkholes in Jordan.

DISCUSSION AND CONCLUSIONS

Klimchouk (2007) described carbonates containing hypogene caves in Brazil do not conform to the typical geological situation of multilayered aquifers. Although subsurface geology is still poorly known in some areas, there is limited potential for the existence of transmissive beds enclosing the carbonates. The low permeability of underline formations limits both the magnitude of regional ground water systems and ascending flow towards the limestone, rising flow would have to be concentrated in localized flow paths, such as faults or joints. At Predjama Cave in Slovenia actual faults themselves do not appear to be important for guiding hypogene development, but shear planes adjacent to faults (Osborne 2008), do appear to be important, and particularly in the many examples of hypogene caves located directly adjacent to faults. The basinal setting of the geological structure suggests a source for the fluids responsible for the origin of extinct hypoginic cave.

Sangaw sinkholes patterns are recognized by different forms of network cave plain, holes and narrow caves are characterized by blind terminations at the ends of cave segments and show no sign of lateral flow. Major horizontal and vertical passages at the wall and floor are restricted to a few places with sequence of chambers linked by much smaller and narrow passages in Sangaw cave. The wall cover generally consists of secondary gypsum, sulfur, bitumen and secondary calcite, smaller caves with similar patterns have been reported in the area.

Karst collapse sediments consist mainly of sulfate and detritus limestone, also with a lensoidal stratified clayey sediments as weathering product could be seen in the area. The weathering of the carbonate rocks is intense inside the cave and appears as honeycombs and rills mark which have very rough surface with dull color. The Sangaw sinkholes are related to dissolution type, because the origin of Sangaw sinkholes has been proposed to be acid hypogenic speleogenesis due to the presence of H₂S rich springs both in the cave and as surface spring elsewhere in the area. The hydrological and chemical conditions with processes involved suggest that hypogenic dissolution of evaporate (gypsum) beds is the best phenomenon in the caves creation. The cave apparently formed by upward solution of the groundwater body in a hypogene setting

All Sangaw sinkholes occur in areas underline by impermeable units such as marl. The impermeability of underlying formations limits both the magnitude of

regional ground water systems and ascending flow towards the limestone. Rising flow would have to be concentrated in localized flow paths, such as major faults or joints. There are great similarities between the Sangaw Sinkholes and caves which formed in New Mexico at Guadalupe mountain and Al-Daher sinkholes in Jordan.

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