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Compatibility Between Geology and Sustainability on the Right Side of Mosul City

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ABSTRACT

In recent decades, geologists around the world have been more interested in connecting geology and sustainability. This has led geologists to organize conferences and seminars to encourage academic research on the subject. Since the study area is undergoing urban expansion and there are plans to extend the city, this study included some of this tendency. The geology of the area was investigated in this study through several naturally occurring outcrops or as the result of drilling operations carried out during the construction of infrastructure. By following the rock beds of the area from north to south to the right side of Mosul, other areas that are suitable for construction and have good resistance were identified, as well as hazardous areas, those that may be exposed to dissolution and collapse, and those that are linked to future sustainability and suggested solutions. Subsurface rocks, which are the basis for construction, and the possibility of their sustainability were described. It was found through rock outcrops that the northern areas near the river consisted of beds from limestone, gypsum, and marl, topped by beds of Traces, up to a thickness in some areas of about 7 m, while the Fatha Formation, which consists of sequences of limestone, gypsum, marl, and red clay, covered most of the study area, it was noted that reductions and collapse occur in the areas where gypsum is subjected to melting, which leads to a collapse of the beds above it. The research pointed to the importance of rock masses of marl and gypsum that appear during drilling and leveling operations during the establishment of construction in the sustainability of these materials as they can be exploited as building materials or decoration. It is also possible to exploit weak areas that are not suitable for construction by establishing squares or green areas, which increases the chances of environmental sustainability of the city.

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قابلية تطبيق الجيولوجيا في الاستدامة على الجانب الأيمن من مدينة الموصل

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الملخص

في العقود الأخيرة، اهتم الجيولوجيون في جميع أنحاء العالم بشكل أكبر بربط الجيولوجيا بالاستدامة. مما دفع الجيولوجيين إلى تنظيم المؤتمرات والندوات لتشجيع البحث الأكاديمي حول هذا الموضوع. وأن منطقة الدراسة تشهد توسعًا حضريًا وهناك خطط لتوسيع المدينة، فقد تضمنت هذه الدراسة بعضًا من هذا الاتجاه. تم التحقيق في جيولوجية المنطقة في هذه الدراسة من خلال عدد من المكاشف الطبيعية أو نتيجة لعمليات الحفر التي أجريت أثناء إنشاء البنى التحتية. ومن خلال تتبع طبقات الصخور في المنطقة من الشمال إلى الجنوب إلى الجانب الأيمن من الموصل، تم تحديد المناطق الأخرى المناسبة للبناء والتي تتمتع بمقاومة جيدة، وكذلك المناطق الخطرة، وتلك التي قد تتعرض للتحلل والانهيار، وتلك المرتبطة بالاستدامة المستقبلية والحلول المقترحة. وتم وصف الصخور تحت السطحية التي تشكل أساس البناء، وإمكانية استدامتها. وقد تبين من خلال المكاشف الصخرية أن المناطق الشمالية القريبة من النهر تتكون من طبقات من الحجر الجيري والجبس والمارل تعلوها طبقات من الترسبات النهرية يصل سمكها في بعض المناطق إلى حوالي 7م، أما تكوين الفتحة والذي يتكون من تتابعات من الحجر الجيري والجبس والمارل والطين الأحمر فقد غطى معظم منطقة الدراسة، ولوحظ حدوث انخفاض وانهيار في المناطق التي يتعرض فيها الجبس للذوبان مما يؤدي إلى انهيار الطبقات التي تعلوها، وأشار البحث إلى أهمية الكتل الصخرية من المارل والجبس التي تظهر أثناء عمليات الحفر والتسوية أثناء إنشاء البناء في استدامة هذه المواد حيث يمكن استغلالها كمواد بناء أو زينة، كما يمكن استغلال المناطق الضعيفة التي لا تصلح للبناء بإنشاء ساحات أو مساحات خضراء مما يزيد من فرص الاستدامة البيئية للمدينة.

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Introduction

The increase in the rate of population growth in the city of Mosul necessarily required planning for its expansion, in addition to the damage that the city suffered during the wars, especially during Liberation operations in the year 2017, where the largest part of the destruction was on the right side of the city of Mosul. The city of Mosul in Nineveh Governorate, in the north of Iraq is characterized by dividing it into two sides by the passing of the Tigris River, the right side and the left side. The right side uplifted through the displacement resulting from the fault that the area was exposed to, this uplifting led to changes in geological properties and the erosion of the exposed formations of the right side, resulting in erosion of the Injana Formation from the right side block, while the Fatha Formation appears in most areas on the right side, in addition to the sediments of the flood plain and river terraces (Adeeb, 1988).

It is known that the Fatha Formation consists of a succession of marl, gypsum, limestone, and mud, this makes it exposed to dissolving processes that result from the presence of gypsum and marl. Here lies the importance of land sustainability and suitability for construction. The sustainability of buildings has become a necessity in light of the global trends for the sustainability of buildings and cities, the work to achieve sustainable development must be accompanied by rationalization of the consumption of natural resources and not depleting them, most geological studies have little or no participation in the increasing societal transformation towards sustainable development (Emhanna, 2023).

The Sustainable Development Goals were set out in the 2030 Agenda for Sustainable Development United Nations resolution adopted by all United Nations member states in 2015, there are 17 goals supported by 169 targets and 231 unique indicators to allow for measurement of progress Edited. Relating geology to sustainability requires a new and unconventional kind of geologist scientist (Mulder and Cordani 1999). (Gill, 2017) raised the point that it is important to demonstrate how geology contributes to the sustainable development of other pertinent fields, decision-makers, and development professionals.

The role of engineering geology in the field of sustainable development is important, as it relates to science and engineering, the natural and built environment, and the past, present, and future. The role of engineering geology in solving environmental problems caused by human activities and in the ability to withstand natural hazards has been recognized by the International Association of Engineering Geology and Environment (Lagesse, et al., 2022), which defined engineering geology as a science dedicated to the investigation, study, and solution of engineering and environmental problems that may arise as a result of the interaction between geology and the work of and human activities as well as for the prediction and development of measures to prevent or address geological hazards (Lagesse, et al., 2022).

Engineering geology has a role in sustainable construction and infrastructure development that provides basic societal needs such as transportation, water, sanitation, and energy supply. (Lagesse et al., 2022). Thacker et al. (2018) noted that infrastructure systems contribute to approximately 81% of the SDGs in all 17 goals. This study relied on relating the geology of the study area to determine the depression places and the sustained of buildings as part of the use of geology in the face of natural hazards to avoid the destruction of buildings over time or when exposed to earthquakes as a result of the weakness of their foundations and the adoption of correct methods of construction to avoid subsequent treatments to avoid future additional expenses, in addition to the sustainability of raw materials that are usually within or around the study area, that often include gypsum, gravel, sand, and limestone, which have been used since ancient times and there are still many quarries, sustainability of these raw

materials are necessary for subsequent generations by recycling them from previous structures (Al-Jawadi et al., 2022).

The study aims to employability geological applications in sustainability in Iraq in line with the development taking place in the countries of the world for risk management, economy, and natural resources by studying the relationship between geological characteristics and rock sustainability in the study area for urban development in recent times and the future, especially that the city is about to expand.

Location of study area

The study area is located on the right side of the city of Mosul in the Nineveh governorate north of Iraq, as shown in (Fig. 1). Showing lines of longitude and latitude on a map.

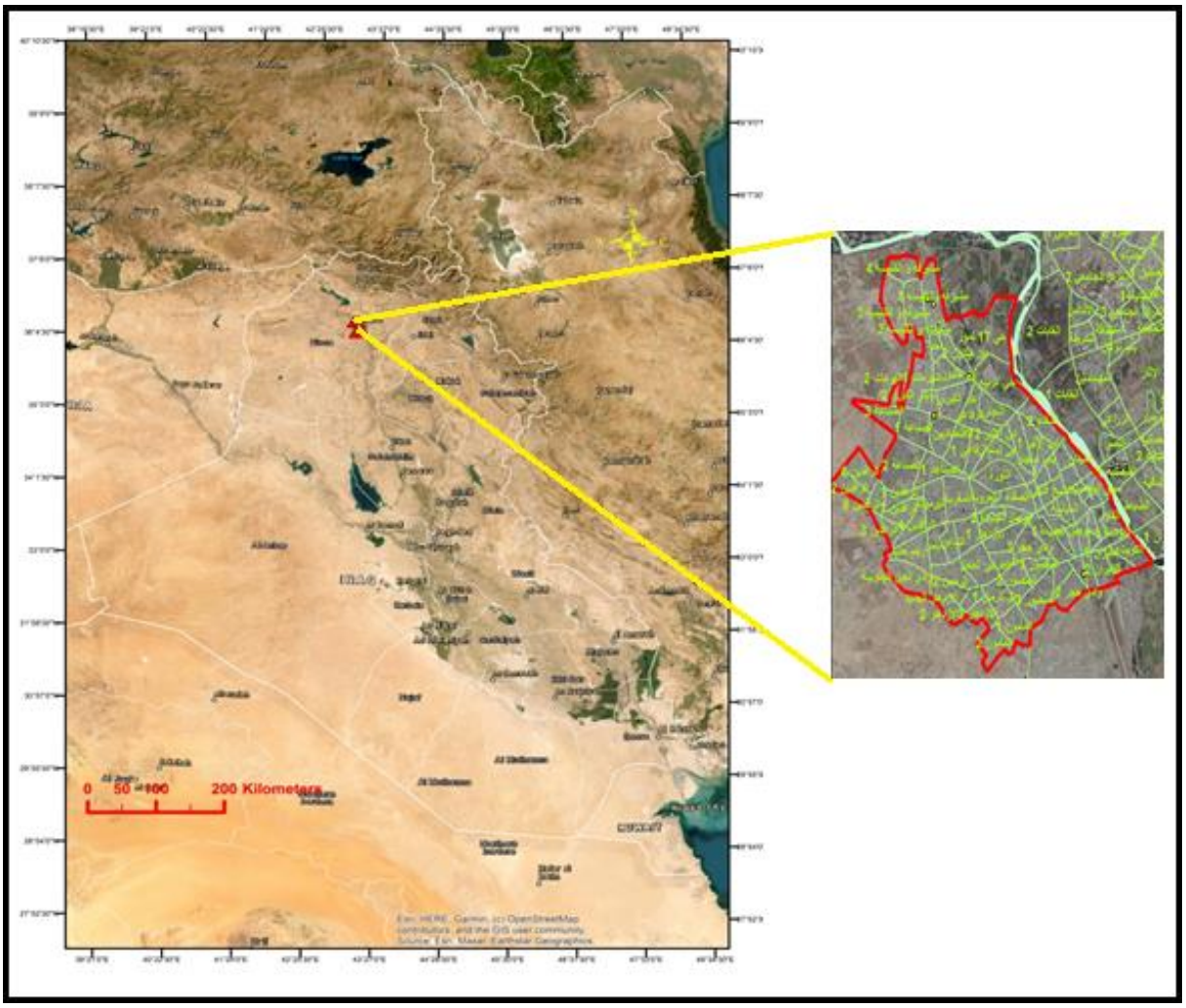


Fig. 1. The location of the study area in Iraq.

Stratigraphy of the study area

The age of the rocks in the study area ranges from the Middle Miocene to the Quaternary (Pleistocene – Holocene) and is represented by the Fatha Formation and the Quaternary sediments.

Fatha Formation

Fatha Formation is composed of successive irregular cycles of greenish-gray, reddish-brown mudstone, limestone, and gypsum, while the age of the formation is (Middle Miocene), the upper contact with Injana Formation is transitional (Bellen et al., 1959). The type section of this formation is located in the Fatha region, (15) km north of Baiji city in the area where the Tigris River crosses the Makhoul-Hamrin mountain (Jassim and Goff, 2006). The formation appears in the Shikhan anticline with a thickness of about (60) m, and consists of a succession of red or green thick marl with sandstone or siltstone in the upper part of the section, while in the lower part, it consists of sandstone, limestone, and mudstone. The lower contact of the Fatha Formation conforms with the Jeribe Formation (Ibraheem et al., 2023), an age in the Middle Miocene proposed by the Orbulina datum (Mahmood and Shakir, 2024). The upper contact between the Fatha and Injana formations is gradual and conformable (Al-Juboury, 2009). In this study, the contact was determined, with the last appearance of green marl of the Fatha Formation and the appearance of sandstone bed of the Injana Formation. In the study area Fatha Formation exposed in the most of middle area of the Mosul city right side, (Al-Janqli, 2024) Deduced a surface geological map from merging geological survey maps using the arc-gis program (Fig. 2).

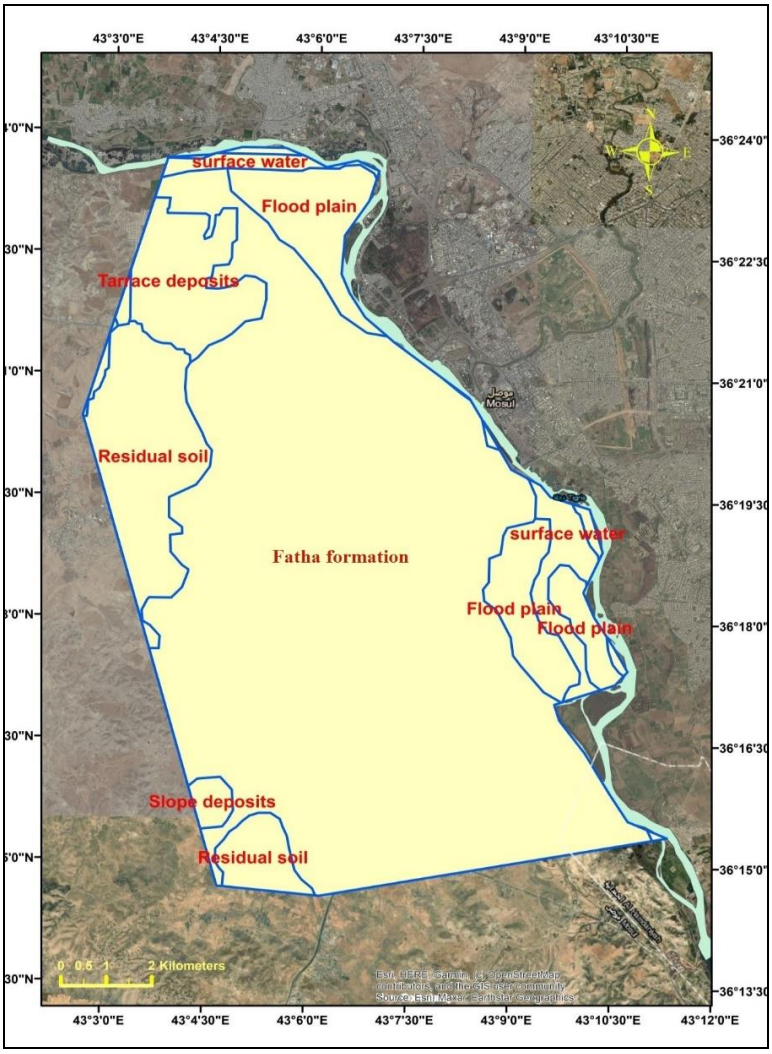


Fig. 2. Geological distribution surface map of the study area (the Iraqi Ministry of Industry and Minerals, Iraq Geological Survey, geological map panels of (Mosul, Qayyarah, Erbil and Mahabad, Sinjar Syria, Haditha Kirkuk, and Wadi Al-Meah), on a scale of 1: 250,000,1995, modified by Al-Janqli, 2024)

Quaternary deposits

Quaternary deposits in Mosul city and its suburbs vary from one region to another the Quaternary deposits are comprised of Pleistocene and Recent deposits. These include Gravel and sand bars deposits, Floodplain deposits in (the Hawi AL-Kanisaa area and Al-Danadn – Nabi-sheet area), river traces deposits, and loamy soil deposits (Adeeb, 1988), in addition to the extensions of the accumulating surfaces of the gastric folds located to the east, northeast, and west of the city (Al-Jaber, 1997).

Geotectonic of the study area

Iraq is divided into three main tectonic zones according to stratigraphic, topographic, and structural features (Fig. 3). The thrust zone in the far northeast, the folded zone in the north and northeast, and the unfolded zone in the center and southwest of Iraq (Bolten, 1959**).** Mosul City is located in the Low Folded Zone (Fouad, 2015).

According to (Ditmar, 1971) Mosul City is characterized by the presence of terrace deposits as well as evaporate deposits dating back to the Middle Miocene.

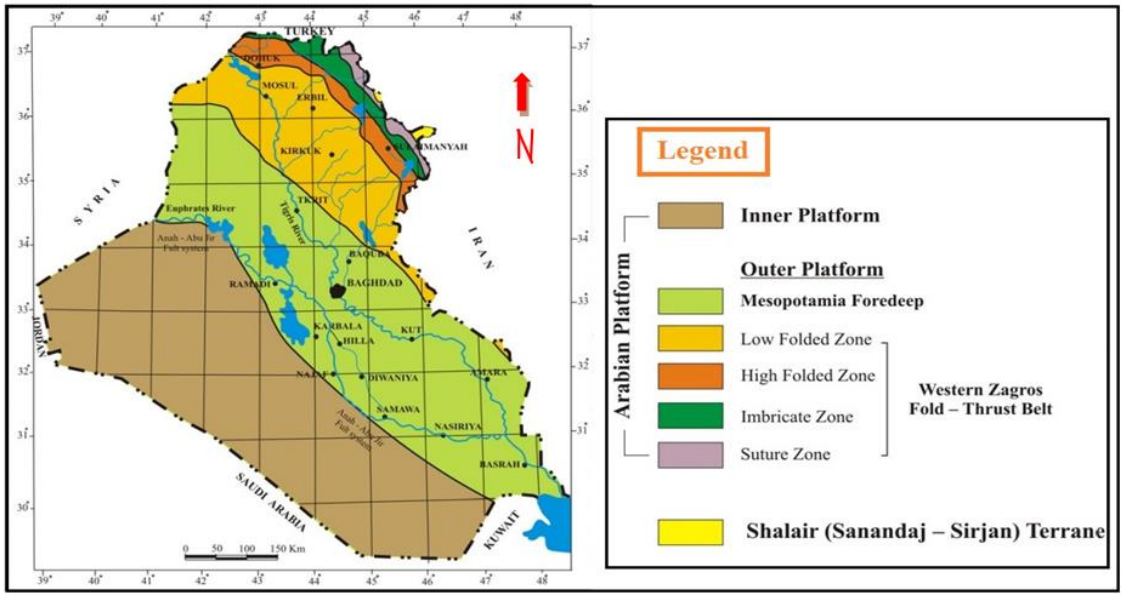


Fig. 3. Tectonic divisions of Iraq (after Fouad, 2015)

Structural geology of the study area

The right side of Mosul has five faults that are divided based on the directions of the studies (Adeeb, 1988) for stratigraphy and structure. There are two longitudinal faults from northwest to southeast: The Church's Hawifault and the Mosul Hammam ALAlil fault, and two faults, the Wadi Uqab fault and the Mshirfa fault, which extend east-west. The fifth fault is a transverse fault known as the Ibn Al-Atheer fault. The path of the Tigris River and the bank's topography have both been significantly impacted by these faults, which have considerably changed the western bank. The floodplain sediments are exposed parallel to the Tigris River from west to east, and end at the Martyrs Bridge (the third bridge), then reappear at the Nineveh Bridge (the fourth bridge), and its width increases to Al-Ghazlani, then narrows again, to end under the influence of the Mosul-Hammam Al-Alil fault.

The other exposed parts represent lower members of the Fatha Formation whose characterized by flatted beds and slopes not exceeding two degrees eastward except for some anomalies nearing the fault areas. Adeeb (1988) pointed out that 29 valleys are descending

from high-altitude areas in the northern and northwestern parts of the city towards the Tigris River basin, and some of them may end inside the city.

Al-Jaber (1997) mentioned generally that Mosul city and its suburbs are characterized by their simple and uncomplicated geological structures, and there are deep faults occurred in the city, which caused the movement of rock units vertically and horizontally, which led to the rise of some parts and their deformation, in addition to their impact on the course of the river and caused the exposure of river terraces in all parts of the basin.

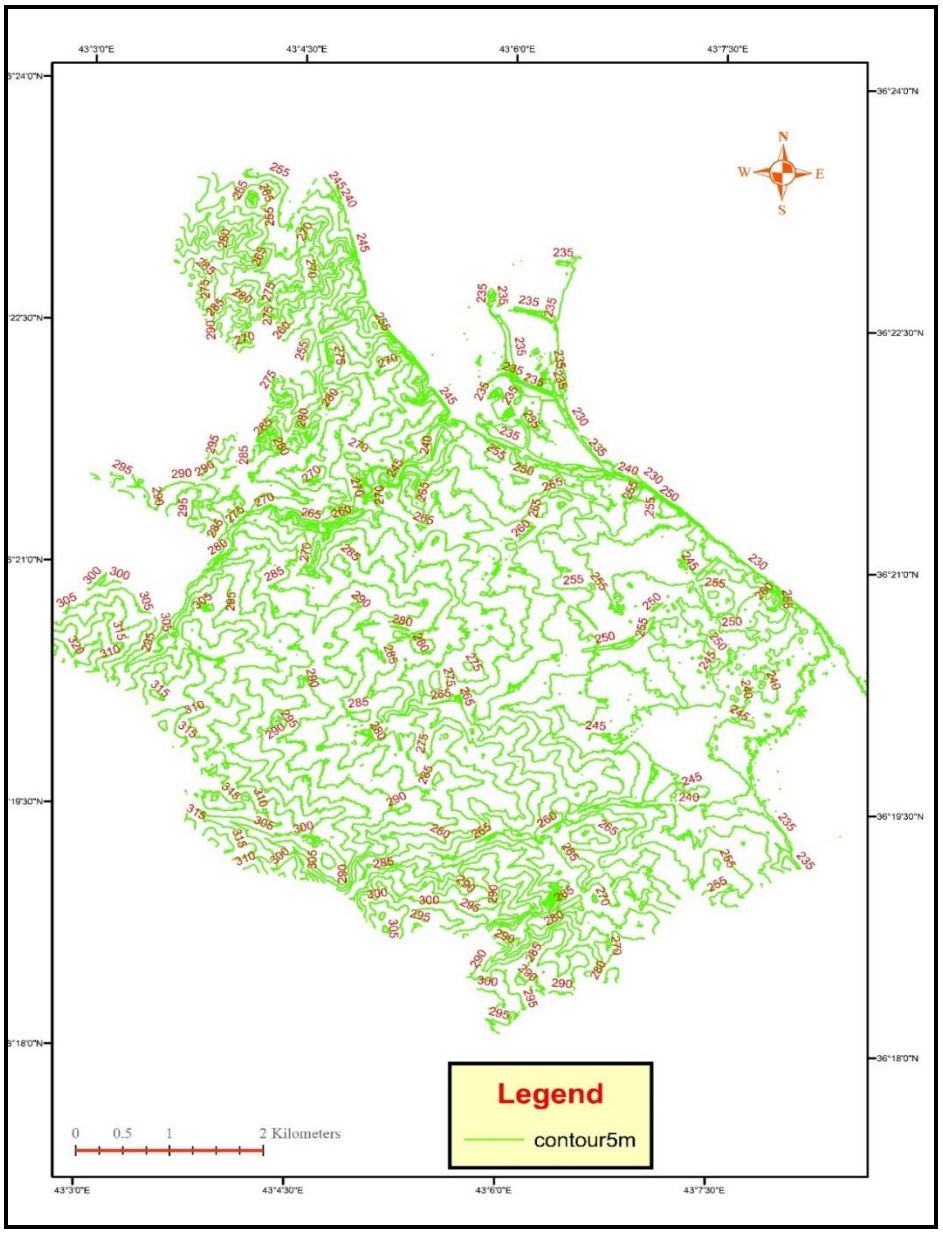


Fig. 4. A contouring map for Mosul's right side by ArcGIS program with 1m intervals.

In this study, contour lines of height level were drawn with a contour interval of 1 m using the ArcGIS program (Fig. 4), in which it appeared that the areas of convergence between the contour lines of the heights are identical to the sites for the faults and valleys that were identified in the field by (Al-Adeeb, 1988) and (Al-Jaber, 1997).

Mosul has several structures that appeared through a visual interpretation of the space scenes, they were: The Mosul Hamam Alil fault, Mshirfah fault, Wadi Uqab fault, and Atshan-Ain Al-Safra fault, this fault is shown in (Fig.5).

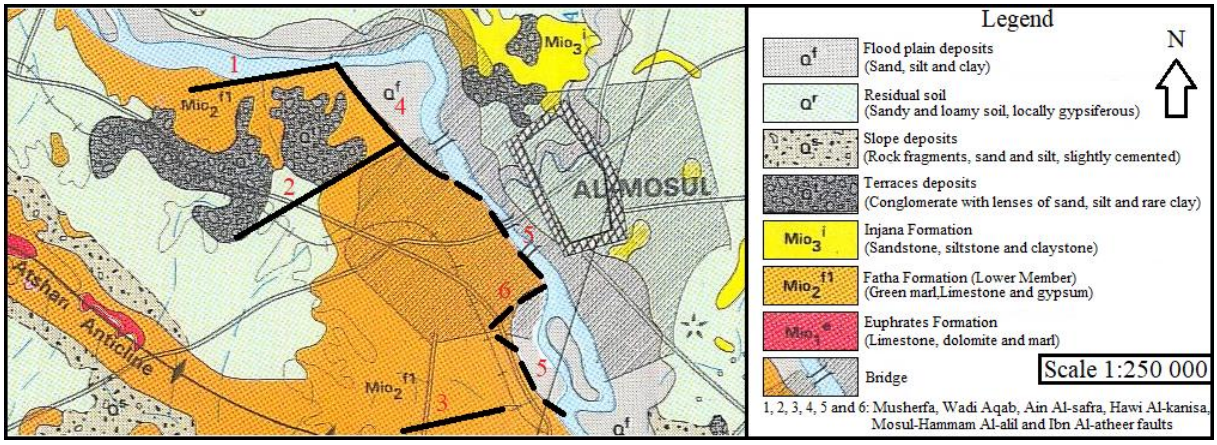


Fig. 5. Mosul geological and structural map modified from (Adeeb, 1988 and Sissakian, et al., 1995)

Methodology

The locations of the outcrops were determined using the Geographical Position System (GPS) and projecting their locations on the map using the ArcGIS 10.6.1 program and determining the rock beds through the fieldwork for the outcrops in the identified locations, measuring the thickness of the rock beds and describing them in the field, as well as taking samples for making a thin section and describing the samples under polarized microscope.

Result and discussion

The outcrops were chosen from the right side of Mosul from north to south, as shown in (Fig. 6), as it was noted that the outcrops in the Mshairfa area are characterized from the bottom of the section by the presence of marl and then limestone and finally with terraces, which may thickness reached in some areas to about (7 m) (Fig.7) as the sediments of terraces gradient fine toward up where the coarse is at the bottom. The size of the gravel with diameter about (25 cm) grading to fine gravel and the sand (Fig 7).



Fig. 6. The beds of Msherfa outcrop MB on the right side of Mosul city.



Fig. 7. The grading in size of the terrace bed in the Musherfa outcrop (Msherfa-C).

In the Tammoz area, gypsum appeared during the excavation operations carried out by the Ninevah Governorate Sewerage Directorate, the stratified sequence of rocks starting from the bottom with gypsum (2m) and then the green marl about (2.5m) followed by filling materials with a thickness of about (5m).

The effect of Wadi Uqab on the rocks in the region was observed through the presence of high porosity and fractures on the thin section of the sample taken from the gypsum, in which the clear effect of weathering processes was shown (Fig. 8a).

The other outcrop in the Wadi Uqab area is the Mosul-Tal Afar road (T2), as it was noted that the beds extend horizontally and tend towards the northwest-southeast, and consist of a stratified succession starting from the bottom with gypsum with a thickness of about (1 m), which appears under the polarized microscope of the thin section that it is gypsum containing little anhydrite (Figure 8b).

Followed by a bed of green marl which was intrusive with a bed of block of limestone thickness of (1.2m), it was noted that the upper part of the limestone consists of foraminifera thickness of about (20cm) a thin section taken from limestone, it appeared under a polarized microscope that the sample consists of oolitic limestone with low porosity, which is classified according to Dunham classification as wackestone (Fig. 8c). It is followed by a bed of marly limestone, which appears in the thin section under a polarized microscope that it is composed of limestone containing clay mineral resulting from erosion as well as the presence of wide porosity as a result of weathering (Fig. 8d). Then topped by a bed of red clay and then the green marl and finally topped by the yellow marl (Fig 9) shown the beds in the outcrop.

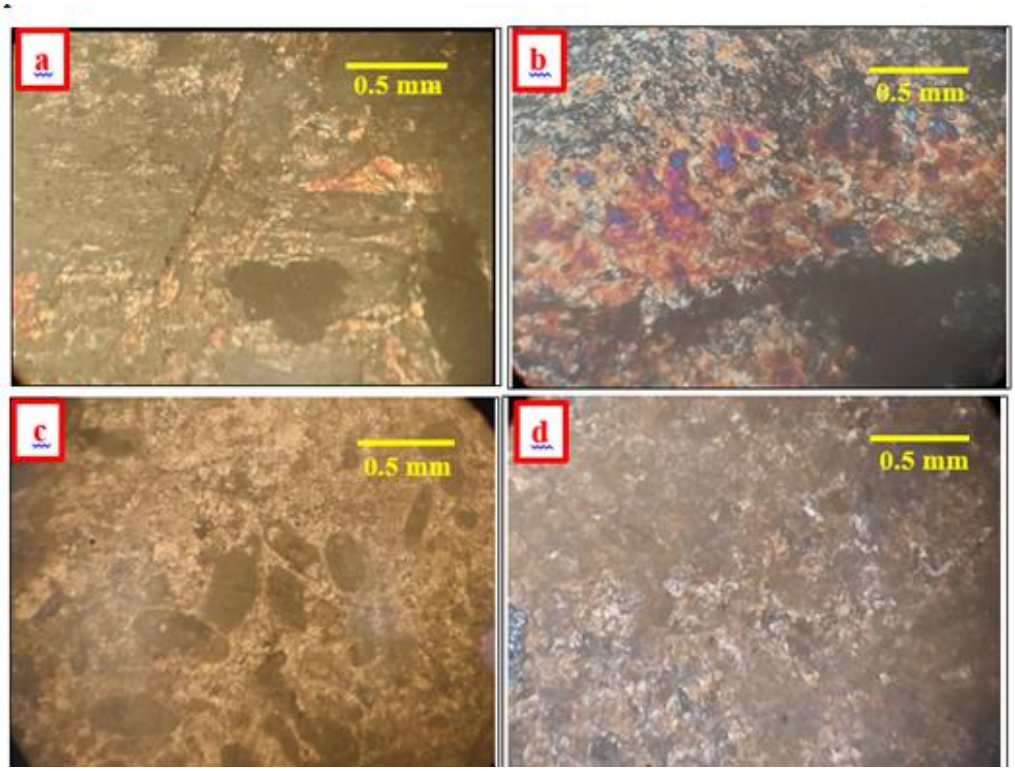


Fig. 8. Thin sections of Fatha Formation rocks under a polarized microscope with 50X, a: gypsum from outcrop T1; b: gypsum from outcrop T2; c: prose limestone in outcrop T2 d: sample of mass limestone in the outcrop T2.

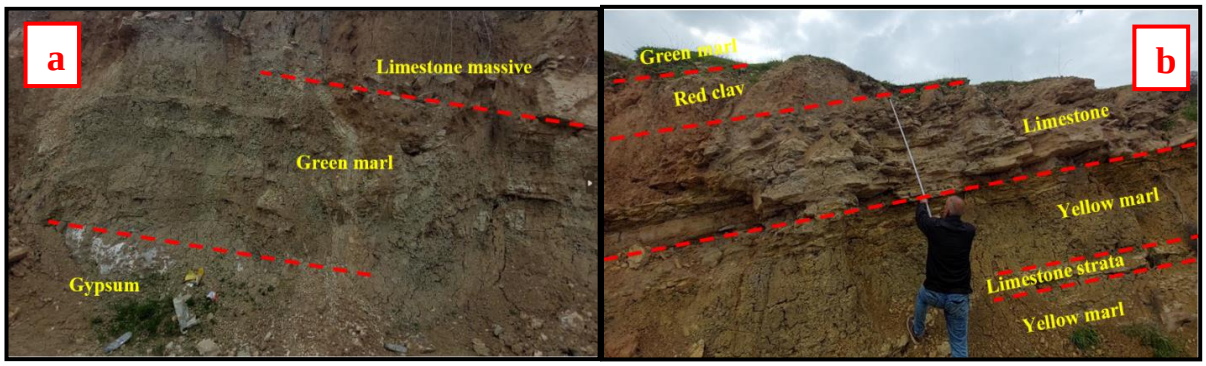


Fig. 9. a: bed of gypsum, green male, and limestone in T2 outcrop, b: beds of outcrop T2.

In the Wadi Hajar area, the outcrop showed the presence of a bed of gypsum with a large thickness of more than (3m), which extends Underground (Fig. 10 a) and appears in the section the presence of joint spacing in gypsum about (3cm) filled with red clay and found channels resulting from dissolution of gypsum have spacing about (7cm) filled with intrusive marl. It was found in the area of large sinkholes resulting from the gypsum dissolution, which extends more than (5m) in length and a depth of about (3m), and it has been noted that the presence of these sinkholes in the areas of the edges of the outcrops has caused dangerous slips as they form areas of weakness and subsidence of rocks (Fig. 10 b).



Fig. 10. a: gypsum bed in the outcrop W of Wadi Hajar region, b: Karst result from gypsum dissolution.

The gypsum bed is topped with a bed of green marl with a thickness of (70 cm), followed by another bed of gypsum with a thickness of (2.5 meters), then a bed of yellow marl with a thickness about (2 m), and then a bed of mass limestone with a thickness about (1 m), in which spacing joint appears about 3 meters between one and the other. It is topped with a bed of green marl with a thickness of (2 m) and then limestone contains foraminifera with a thickness of about (1 m) covered with a bed of soil with a thickness of about (20 cm).

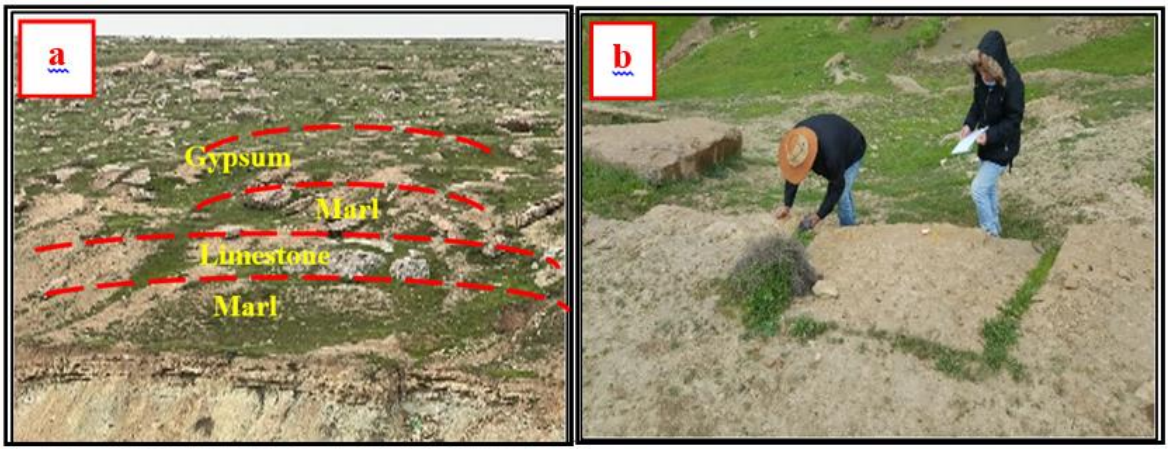


Fig. 11. a: the lithological of Al-Bosif outcrop B, b: The joint space of limestone in Al-Bosif outcrop B.

In the area of Al-Bosif, (B) the beds of the green marl are successive with a thickness (4m) topped by beds of limestone thickness (1.2m) and then of gypsum with a thickness (4m) topped by a green marl with a thickness of (2m) and finally there are at the top rock blocks of limestone with a thickness of about (1m) containing foraminifera and these rock blocks are regularly divided spacing joint between each other, the direction of the first set be 332 and the second set towards 232 and them dip direction is mostly perpendicular and the spacing between the first set is about (1.6-2.2m) while the second set is about (1.2-3m) (Fig. 11a and b) show the rock sequence in situ and the joints between the limestone beds respectively.

As for the site Ain al Iraq BC resulting from the excavation operations of a Turkish Company to make towers near the Ain Al Iraq compound beside the Baghdad-Mosul road, the

outcrop depth is about (19m), it was noted that the gypsum beds at the bottom of the section had a high thickness about 8.5m (Fig. 12).



Fig. 12. The beds of Ain-AlIraq –BC outcrop.

Followed by a bed of green marl with a thickness (1.5m) and then a bed of limestone with a thickness of about (1.5m) yellow marl with a thickness of (2m) and then masses of limestone containing foraminifera with a thickness of (1.2m) have large voids up to (1cm), a bed of red clay topped with a thickness of (1m) and then a bed of marly limestone with a thickness about (3m), followed by a bed of red clay with a thickness about (3m), finally a bed of soil about (20cm) thickness.

It has been noted in the stratified section of the outcrop (Ain Al-Iraq BC) that the presence of beds of limestone and marl has been exposed to collapse as a result of the dissolution of gypsum, which led to subsidence beds of limestone and marl above it and the emergence of tension joints with a width of about (30cm) and height up to (130cm) (Fig. 13a) shows the collapse that occurred in the areas of a beds marl and limestone subsidence as a result of dissolution of gypsum. These spacing joints are filled with marl (Fig. 13b)

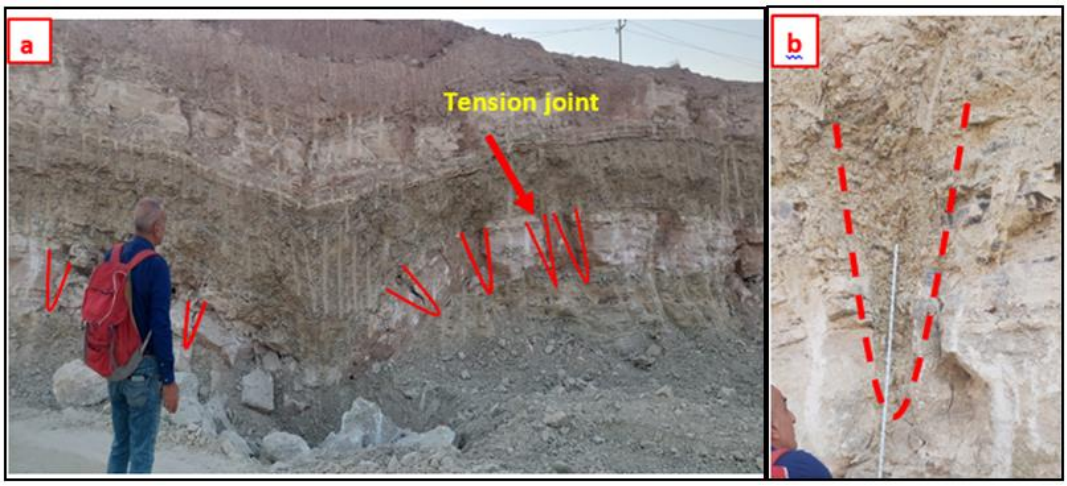


Fig. 13. a: collapse in the beds of limestone and marl a: set of tension joints due to collapse filled with gray marl b: joint shape with width 30 cm and high 130 cm.

The other two outcrops are located in the Ain Al Iraq compound, nearly to the (Ain Al Iraq BC) they are (Ain Al Iraq 3) and (Ain Al Iraq 4). The Ain Al Iraq 3 outcrop consists of marl beds containing a secondary gypsum composition with a (3m) thickness, topped by a bed of green marl with a thickness of about (80cm) and then blocks of limestone with a thickness of about (70cm) containing foraminifera covered by a bed of soil with a thickness of 2m.

As for Ain Al Iraq4, it consists of a section with a low height of about 2m, consisting of blocks of limestone with a thickness of about (75cm) containing foraminifera and exposure to erosion appears on it clearly and is covered with a bed of soil about one meter.

The other outcrop is located to the south in the Furqan compound, in which the green marl appears from the bottom with a thickness of about (2.5 m) topped by gypsum, which forms a tuberous shape with a diameter of more than (10 cm) and is surrounded by marl, the thin section of the gypsum sample shows that it consists of gypsum containing with marl (figure 14). The gypsum bed is followed by a bed of light brown marl with a thickness of about (1-1.5m) topped by a bed of limestone with a thickness of (0.5 m), the thin section under a polarized microscope of a limestone sample shows the presence of cavities in limestone some of them are filled with calcite, others are open pores (Fig. 15) and the last bed is represented by the soil resulting from the process of erosion of rocks in the area.



Fig. 14. Gypsum in Furqan outcrop which forms a tuberous shape.

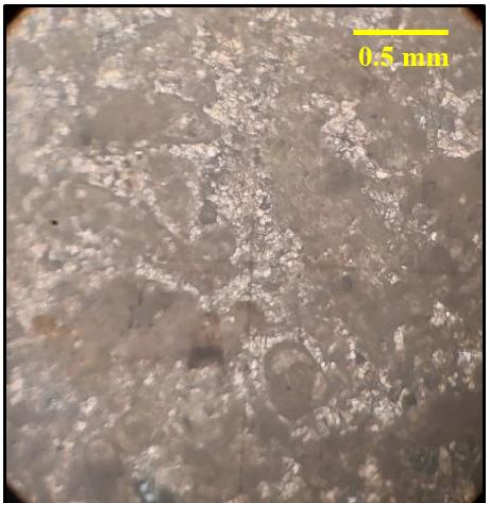


Fig. 15. Thin section of Fatha Formation rocks under polarized microscope with 50X from outcrop Al-Furqan compound for limestone sample.

The other site is in the area of Athba (Athba1) near the Al-Uqrab control, which appeared during the excavation operations of the gate of the University of Nineveh and the section appears a green marl from the bottom with a thickness of about (1m) topped by the yellow marl with a thickness of about (1.5m) has been intrusive by a bed of gypsum which is of the needles type with thickness (30cm), and then bed from blocks of limestone contain the foraminifera with thickness of about (40-50cm) and also appear overlapping in marl and red clay (Fig. 16).



Fig. 16. The outcrop of Al-Athba 1 at Nineveh University Gate.

The last site is in the valley area in Athba (Athba2) it appears in the valley outcrop that the section from the bottom consists of light brown marl with a thickness of about (3m) topped by a bed of about (10cm) of marl, which contains crystals of anhydrite (the crystal size more than 3 mm), under a microscope the thin section of this sample show that these crystals are surrounded by marl from the sides (Figure 17a), these bed topped by a bed of limestone about (30cm), which contains foraminifera has appeared clip of it under the microscope They contain argillaceous marly and pores resulting from partial dissolution and are filled with calcite (Fig. 17b). Followed by a bed of soil with a thickness about (1.7m).

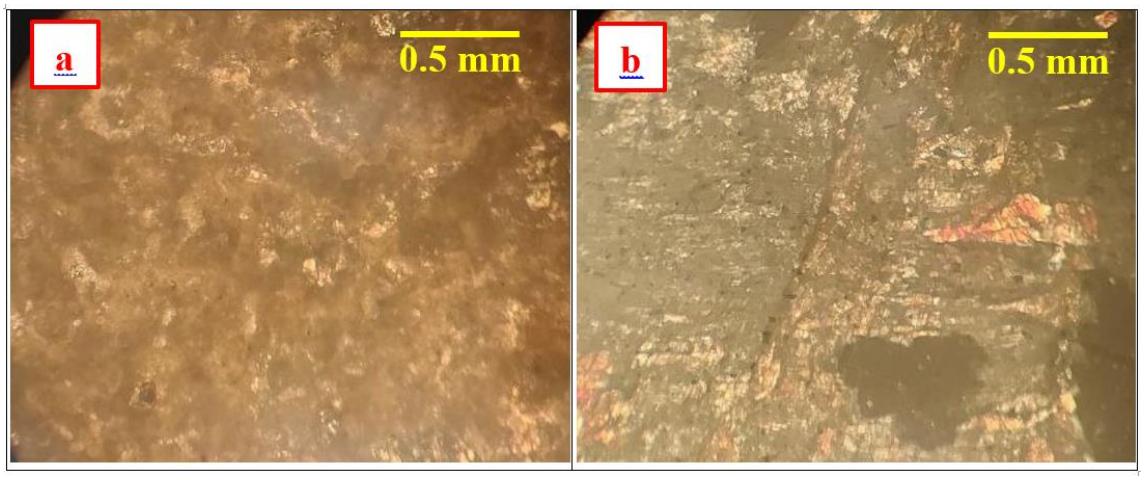


Fig. 17. Thin section of Fatha Formation rocks under a polarized microscope with 50X from outcrop Athba2.

It is noted in the region the presence of many sinkholes resulting from the dissolution of gypsum, which leads to the collapse of the beds of marl and limestone above and formed karsts as in (Fig. 18a) and noticed that there are neck points appear in the soil of in the valley (Fig. 18b) this phenomenon indicates the presence of secondary tectonic movements in the region.



Fig. 18. a: karst in Al Athba Valley due to gypsum dissolution and collapse of marle and limestone above it; b: neck point phenomena in the soil of Al Athba Valley.

Previous, areas have been identified that can constitute risk areas as a result of dissolved gypsum, especially when gypsum is exposed to surface water or erosion as a result of groundwater or water leaking from sewage water, and these studies can participate in finding solutions for the sustainability of these areas through guidance for the work of a suitable sewage pipe network to reduce water leakage and rock erosion under buildings, which leads to their weakness and the collapse of buildings in the future. Underground urban areas are as environmentally sensitive as the surface. Difficult land conditions cost the investor's time and money through project excesses and expensive engineering solutions. Therefore, sustainable solutions had to be achieved by relating geology (lithological science) and its properties (physical, chemical, or hydrological properties). If the geological model is not continuously improved, it will produce unrepresentative ground models and unreliable predictions (Royse et al., 2013).

The current study is a part of PhD dissertation by Al-Ojar in 2024 on geotechnical investigations on the right side of the city of Mosul, through fieldwork tours and engineering examinations, soil quality for the construction was determined from physical and engineering properties and a final geotechnical map for the right side of the city of Mosul for different depths. The final map divides the land between very weak to very good for construction to a depth of 3.5 m (Al-Ojar et al., 2024) has suggested that is possible to exploit the weak areas to be green spaces, which increases the sustainability of the city's urban planning.

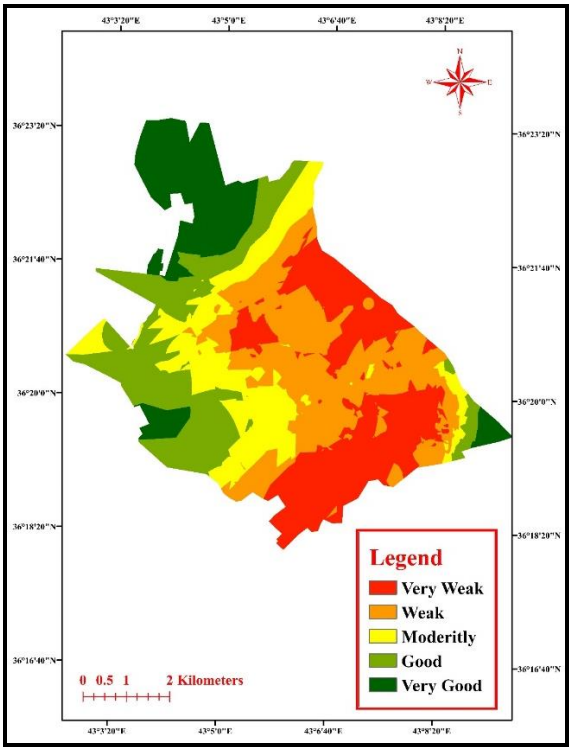


Fig. 19. The Final geotechnical map of bed Tow L2 to the depth of 3.5m according to the AHP method showing the quality of the ground material in the Mosul right side.

Conclusion

Fatha Formation is exposed in most areas of the right side of the Mosul City, and along the riverside, which is occasionally covered by sediments of floodplain and river terraces. The Fatha Formation consists of a succession of gypsum, marl, and limestone, in addition to the presence of red clays. Gypsum beds have been dissolved, marl and red clay beds have been swelled, and limestone beds have been collapsed. Therefore, these beds were identified and need attention for the drainage of water through them and attention to the foundation of buildings It is conceivable that areas classified as not good for construction will be exploited by converting them into parking or green spaces, which will raise the level of sustainability of the city. The sediments of the floodplain and river terraces were finning upward making the area well quality for building and encouraging construction on it. During the excavation and leveling operations for the establishment of constructions, there was a large mass of gypsum and limestone, these blocks can be used as building materials or decorations, which will contribute to the sustainability of rock materials benefiting from them,

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