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Badush Dam, NW Iraq: A Geological Study

Varoujan K. Sissakian[1], Nasrat Adamo [2], Nadhir Al-Ansari[2], Sven Knutsson[2] and Jan Laue[2]

Abstract

The river Tigris flows from Turkey towards Iraq in its northwestern part dissecting the whole Iraqi territory. During 1981– 1986 a very large earth fill dam was constructed, which is Mosul Dam impounding the flow of the Tigris River. It is the largest dam in Iraq and one of the largest in the Middle East. The geological conditions of the dam site and surroundings, however, are not suitable due to thick exposures of the Fatha Formation, which consists of marl, clay, limestone and gypsum. The gypsum and limestone beds are highly karstified causing severe problems to the dam foundation. Mosul dam suffers from serious problems due to the presence of karstified rocks; therefore, the Ministry of Irrigation in Baghdad, decided to construct a protection dam downstream of Mosul Dam; it is called Badush Dam. The geological conditions at Badush Dam site are the same as those at Mosul Dam site, which means the foundations of the dam are located on karstified rocks. Therefore, grouting works were planned and designed and it was partly performed from the beginning of the construction in 1988. The construction of the dam; however, stopped in 1991 due to the consequences of the First Gulf War. The constructed parts of the dam are (30 – 40) %. In this study, we have presented the main problems, which will cause real danger to Badush Dam, if its construction is re-started, and we have suggested many requirements to avoid any hazard that may cause the collapse of Badush Dam.

Keywords: Badush Dam, Mosul Dam, Karstification, Gypsum rocks, Grouting, Iraq.

1 Introduction

[1] University of Kurdistan, Hewler, KRG, Iraq, and Private Consultant Geologist, Erbil, Iraq.
[2] Lulea University of Technology, Lulea, Sweden

Badush Dam is planned, designed and located NW of Mosul city at about 16 Km, and 40 Km downstream from the existing Mosul Dam (Fig. 1). Badush Dam is a protection dam to protect the lives of the people living downstream and to keep the infrastructures safe, in case of the collapse of Mosul Dam which could occur due to severe karstification problems existing at the dam site and its foundations.

The main aim of the current study is to present the most updated study on the geological conditions, which exist in Badush Dam site, besides giving suggestions to enhance the safety of the dam in case the Iraqi Ministry of Water Resources (which has replaced the Ministry of Irrigation) decides to continue the construction of the dam, which was started in 1988 and stopped in 1991 due to the consequences of the First Gulf War.

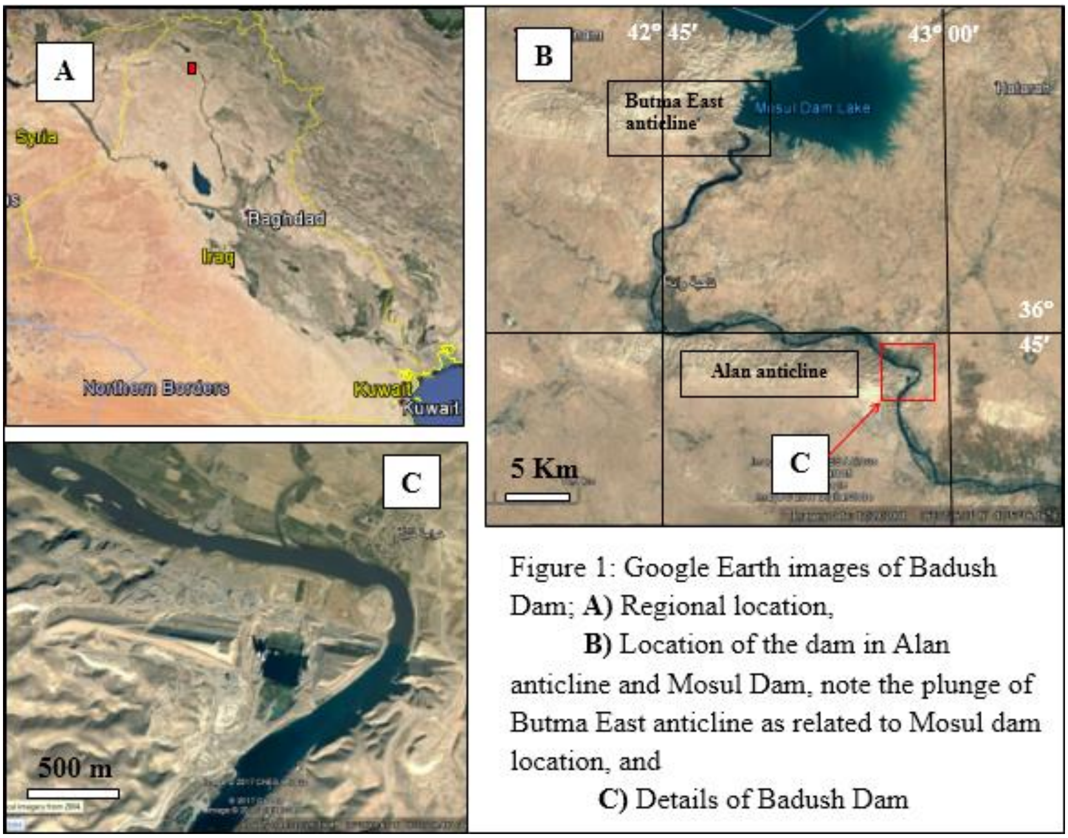

Figure 1: Google Earth images of Badush Dam; **A)** Regional location,
B) Location of the dam in Alan anticline and Mosul Dam, note the plunge of Butma East anticline as related to Mosul dam location, and
C) Details of Badush Dam

Figure 1: Badush Dam Location

2 Materials Used and Methods

In order to achieve the main aim of this study the following materials were used:

- Topographic and geological maps of different scales of the studied area and near surroundings.
- Google Earth, FLASH Earth, and DEM images.
- Many different reports and published articles concerning Mosul Dam.

The geological maps and reports were used to indicate the geological conditions in Badush Dam site and its foundations. The reports and published articles, which were concerned with Mosul Dam were reviewed to indicate the main problems in Mosul Dam site, and they were compared with those of Badush Dam site. The knowledge of the authors in the details of the dam present problems was useful also. In addition, the geological conditions of both dam's sites are utilized in conducting the current study.

3 Previous Studies

The following are the main geological works carried out in the site of Badush Dam and near surroundings:
Muhi Al-Deen et al. [1] conducted geological mapping of Badush Dam site and far surroundings. They indicated that the dam site is covered by the rocks of the Fatha Formation, which includes karstified gypsum beds. Fouad et al. [2] conducted detailed geological survey of Badush Dam site and surroundings and reported about the details of the karstified gypsum beds of the Fatha Formation. Sissakian and Ibrahim [3] compiled the Geological Hazards Map of Mosul Quadrangle at a scale of 1:250000 and considered that the dam site area and near surroundings are within the karstified areas. Al-Ansari et al. [4] presented different geological data about Mosul Dam, which has the same characters and geological conditions as Badush Dam. Sissakian et al. [5, 6] gave more details on the geology and karstification of Mosul Dam site. Adamo et al. [7, 8] wrote about the grouting techniques and existing problems in Mosul Dam site. Al-Dabbagh and Al-Naqib [9] reported about different scientific aspects of Mosul Dam. Moreover, many articles and scientific reports are conducted, which deal with different safety aspects of Mosul Dam; all are the same as those in Badush Dam. Among them are, but not limited to; Washington Group International [10], Wheeler et al. [11], Wakeley [12], and U.S. Army Corps of Engineers [13].

4 Geological Setting

The geological setting of Badush Dam site and surroundings are briefed hereinafter, using the best available data including Geomorphology, Tectonics and Structural Geology, and Stratigraphy [2, 14, 15, 16]. The geological map of the dam site is presented in Fig. (2).

- Geomorphology: The main geomorphological units are those of Alluvial Origin; flood plain and river terraces, the sediments of both units are used in the construction of the dam. Within the Structural – Denudational units, the depositional and erosional glacis are rich in gypsiferous cement. Also anticlinal ridges and flat irons are well developed in the Fatha Formation. Within the Solution Units, sinkholes of different shapes, sizes and activities are well developed in both the Euphrates and Fatha formations. Due to the very active karstification, the limestone beds of the Fatha Formation exhibit false dipping towards the karst forms; due to collapse of the beds towards the existing caves and fractures.

- Tectonics and Structural Geology: The studied area is located in the Low Folded Zone of the Outer Platform, which belongs to the Arabian Plate. It is a part of the Zagros Thrust – Fold Belt [15]. Alan anticline on which Badush Dam is located is a double plunging anticline with almost E – W trend (Figs. 1 and 2), the southern limb is slightly steeper and the eastern plunge is located east of the Tigris River, i.e. east of Badush Dam (Fig. 2).

- Stratigraphy: The exposed geological formations and main Quaternary sediments are briefed hereinafter and presented in Fig. (2).

Euphrates Formation (Lower Miocene): The formation is exposed in the core of Alan anticline; it consists of well bedded, hard limestone and marly limestone. The rocks are highly karstified. The thickness of the formation ranges from (26 – 50) m. The foundation of the dam rest on the rocks of this formation; therefore, the foundations will suffer from karstification, which will increase in activity after filling of the reservoir.

Fatha Formation (Middle Miocene): The formation forms the bulk of Alan anticline and surrounding areas; it is divided into Lower and Upper Members. Both members consist of cyclic sediments of green marl, limestone and gypsum, with reddish brown claystone in the Upper Member. The gypsum and limestone beds are highly karstified. The foundations of the dam rest on these karstified rocks. The thickness of the formation ranges from 117 m at the left bank and 350 m at the right bank.

River Terraces (Early Pleistocene): The terraces are accumulated in different parts, especially north of the Tigris River. Three levels are developed. The pebbles of the terraces consist of limestone, silicate and igneous and metamorphic rocks, cemented by gypsiferous and sandy cement **Residual Soil (Holocene):** The residual soil covers large parts of the surroundings of Badush Dam. It is reddish brown, clayey and gypsiferous soil.

Flood Plain Sediments (Holocene): The flood plain sediments are developed along the Tigris River. The sediments consist of sand, silt and clay.

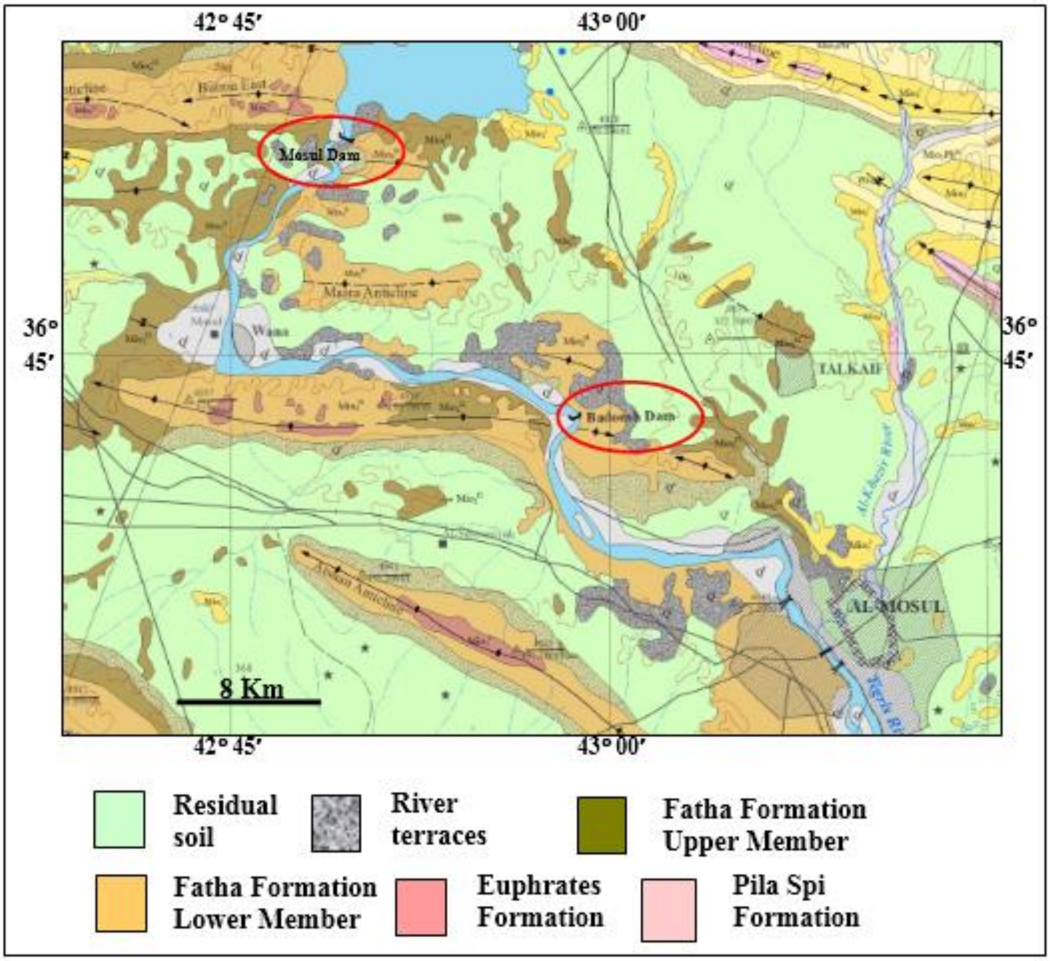

Figure 2: Geological map of Badush Dam site and near surroundings (After [16])

5 Badush Dam

- Historical Review

During the first filling of Mosul Dam reservoir, large amount of seepages appeared from under the main dam in the river section and the saddle dam at the left bank. Seepage water showed heavy dissolution of gypsum from dam foundations [17]. The Ministry of Irrigation received in 1985 the report of a flood wave study in case of Mosul Dam failure, indicated the colossal volume of the wave and the unprecedented dimensions of the catastrophe that could follow [18]. The decision was taken, therefore, in 1987 to build a dam downstream of –Mosul Dam as a protection dam from this wave. The selected site at 40 km south of Mosul Dam was called Badush which was the name of a nearby village

The basic design consideration~~s~~ were to build the dam to be high enough to have a reservoir with a capacity of 10 billion cubic meters which is equal to the volume of the Mosul Dam flood wave [19]. This resulted in proposing a dam crest level of 312 m (a.s.l.). The design of the earth fill dam indicates clearly the temporary nature of its use [19].

- Characteristics of Badush Dam

Badush Dam is an unfinished multi-purpose combined earth fill and concrete buttress gravity dam on the Tigris River. The percentages of the completed works range between (30 – 40) % (Fig. 3). If completed, the dam's designed main purpose is to provide protection from the failure of the unstable Mosul Dam upstream [4]. The dam has a height of 103 m, length of 3730 m, volume of earthfill of 6.1×10^6 m^3, and reservoir capacity of 1.0×10^7 m^3. Badush Dam is designed by Enerjoproject according to a contract with the Iraqi Ministry of Water Resources. At its maximum level, Badush reservoir can hold $1.0 \times 10^7 m^3$, enough to absorb and pass Mosul Dam wave, according to the flood wave study completed in 1985 [18].

Figure 3: The constructed concrete part of Badush Dam

6 Badush Dam Expected Problems

The problems of Mosul Dam site have been presented in many previous papers [4, 5, 6, 7, 20, 21]. The same problems which exist in Mosul Dam site may exist in Badush Dam site too, as the geological conditions are the same at both dam sites (Fig. 2). If the re-construction of Badush Dam is to be started again, then the same problems that exist in the site of Mosul Dam will be faced in Badush Dam site if the suggestions and the recommendations given by Sissakian et al. [22] are not considered. The recommendations emphasize on the importance of detecting the true depth of the deepest karstified gypsum and/ or limestone beds.

The main problems are briefed hereinafter.

1) ***Karstified Rocks***: The main problem in Badush Dam site as well as in Mosul Dam site is the karstification. The gypsum and limestone beds in both Fatha

and Euphrates formations; respectively are highly karstified as may be seen in Figs. (3 and 4) [4, 5, 6, 21, 22, 23, 24, 25, 26].

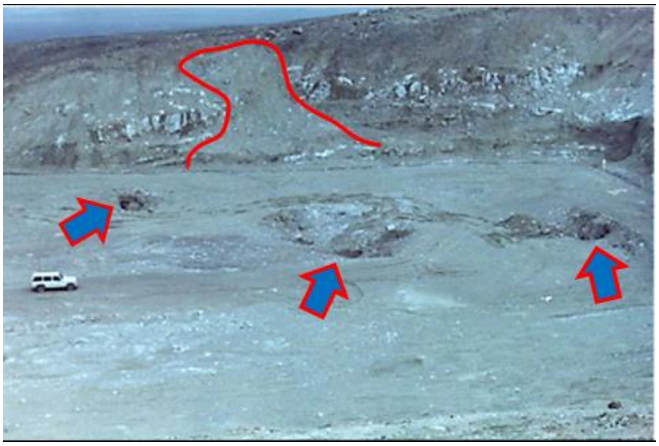

Figure 3: Karstified gypsum beds in an industrial site south of Badush Dam site, about 15 Km. Note the absence of the gypsum bed (white colored) in the facing cliff; surrounded by the red line. The three arrows point to three sinkholes found in the floor of the site.

2) ***Lithological Succession***: To design a relevant and good grouting program or a diaphragm wall, it is necessary to know the true lithological succession in the dam site. Accordingly, to know the deepest karstified rocks in order to decide on the required depth of the grouting boreholes or the diaphragm; whichever is constructed. The thickness of the Fatha Formation in the left side is about 100 m [27]; whereas, in the right side of the dam it is about 300 m [1]. This large difference in thickness should be taken into consideration in the adopted design solution, otherwise the same grouting problems which exist in Mosul Dam site will be faced in Badush Dam site also.

Figure 4: Karstified gypsum beds, south of Badush Dam site, about 15 Km. Note the absence of the gypsum beds (white dashed line) due to karstification limited by the red line. The arrow point to circular feature on the surface, it indicates the presence of karst blow the circular feature.

3) Grouting Program: One of the significant actions taken to overcome the karstification in engineering sites is grouting [13, 28]. However, negative effects of grouting on the engineering structures are also common [29,30].

Construction of large grout curtains is always accompanied with the building of dams in karstified areas. Thousands of tons of materials are injected into the underground karsts. Some of the used materials in grouting may be toxic, neurotoxin or carcinogenic; therefore, their use should be done with care. Accordingly, intolerable leakage of karst reservoirs can occur over the lifetime of a dam site [30].

In Mosul Dam, grouting programs were implemented at different parts in at different depths and following different grouting techniques and using different materials [4, 7, 8, 17, 20, 31]. The implemented grouting in Mosul Dam; however, has not been successful hitherto, although extremely large quantities of different grouting materials and grouting mixes and techniques were used [4, 7, 12, 17]. This is attributed; mainly to the miss-interpretation of the true karst line depth [17], in addition to lack of knowledge of the true nature of the brecciated gypsum beds present in the foundation. The authors understand that the same grouting materials and techniques were used in Badush Dam as in Mosul Dam [8]. Accordingly, the same negative results may occur at this dam site if the construction is to be continued with the present design without further investigations and examination, especially after filling of the reservoir and in the same manner; as it happened at Mosul Dam [7].

7 Results

The dam is planned to be a protection dam in case of the failure of Mosul Dam, which is 40 Km upstream from Badush Dam as its main function.

The geological conditions of Badush Dam are exactly to the same of those existing in Mosul Dam, although Badush dam axis is almost parallel to the axis of Allan anticline (E – W) and dam is located in its axial part, at its eastern plunge area (Figs. 2 and 5). Therefore, the same existing karstification problems in Mosul Dam will face in Badush Dam if the construction is completed using the same type of foundation treatment without further investigations and examination as recommended by Sissakian et al. [22]. The most significant thing is to discover the true depth of the deepest karstified rocks, in order to design the grouting boreholes or diaphragm wall according to the depth, which should be deeper than the deepest karstified beds.

Figure 5: Google Earth image facing south. Note the uncompleted Badush dam and its location in the axial part of Allan anticline

8 Discussion

Badush Dam is planned and designed in a karst region. Therefore, gypsum and limestone beds of the Fatha and Euphrates formations will continue in dissolution forming subsurface caverns of different shapes, sizes and depths; as it is the case in Mosul Dam. Such problems induced in engineering structures are well known and their solutions are as very risky tasks [32]. A typical example is Mosul Dam and if Badush Dam’s construction is resumed, it will be, then, another typical example of a bad design, unless careful considerations are given to the foundation problems. Even though, very detailed geophysical and geological investigations are normally carried out, the possibility for dam failures cannot be eliminated [32]. It is worth mentioning that Fouad et al. [2] have conducted detailed geological survey in Badush Dam site and surroundings aiming for investigation of sulphur deposits. Among their significant findings were the tilting and/ or collapsing of the limestone beds of the Fatha Formation in different directions; apart from the local dip. This was attributed to the collapsing of the limestone beds towards the subsurface existing karst forms leading to hindering of the karstified gypsum beds (Fig. 6). This finding was mentioned by Sissakian and Abdul Jab’bar [25]. The presence of such phenomena gives a first impression that no gypsum beds exist in the area and may be misleading for the absence of the gypsum in the considered site.

In the karst environment, with its highly random distribution of dissolution features, some uncertainties always remain. Mosul Dam is a good example, since leakage problems started even before completion of the impounding [7]. According to one of the geologists who had worked in the Grouting Department of Badush Dam (Personal communication with Mr. Basman Zadoian, 2017), the average depth of the drilled grouting borehole was 100 m. It is worth mentioning that the thickness of the Fatha Formation in the eastern side of the dam is 100 m [27], whereas in the western side is 300 m [1]. It is clear from the mentioned thicknesses that the depth of the karstified gypsum beds is more than the depth of the drilled grouting boreholes. Accordingly, the used grouting materials did not reach to the deepest karstified beds. The dissolution problem in such case will continue and the used grouting materials will fail in filling the caverns in the deepest dissolved beds of the karstified gypsum and limestone beds below the grouting level.

If the Iraqi Ministry of Water Resources decides to resume the construction of Badush Dam as a protection dam; just to store and pass the initiated wave from the collapse of Mosul Dam, then the current design of the dam is relevant. Otherwise, the dam will face the same existing problems in Mosul Dam. Therefore, the recommendations stated by Sissakian et al. [22] apply here and should be considered carefully. The most significant recommendation is to know the accurate depth of the deepest karstified gypsum and/ or limestone horizon bellow the foundations of the dam. Accordingly, to design the depth of the grouting boreholes to penetrate the last karstified bed at least by 10 m in the case of using the dam for permanent storage and not as a protection dam only.

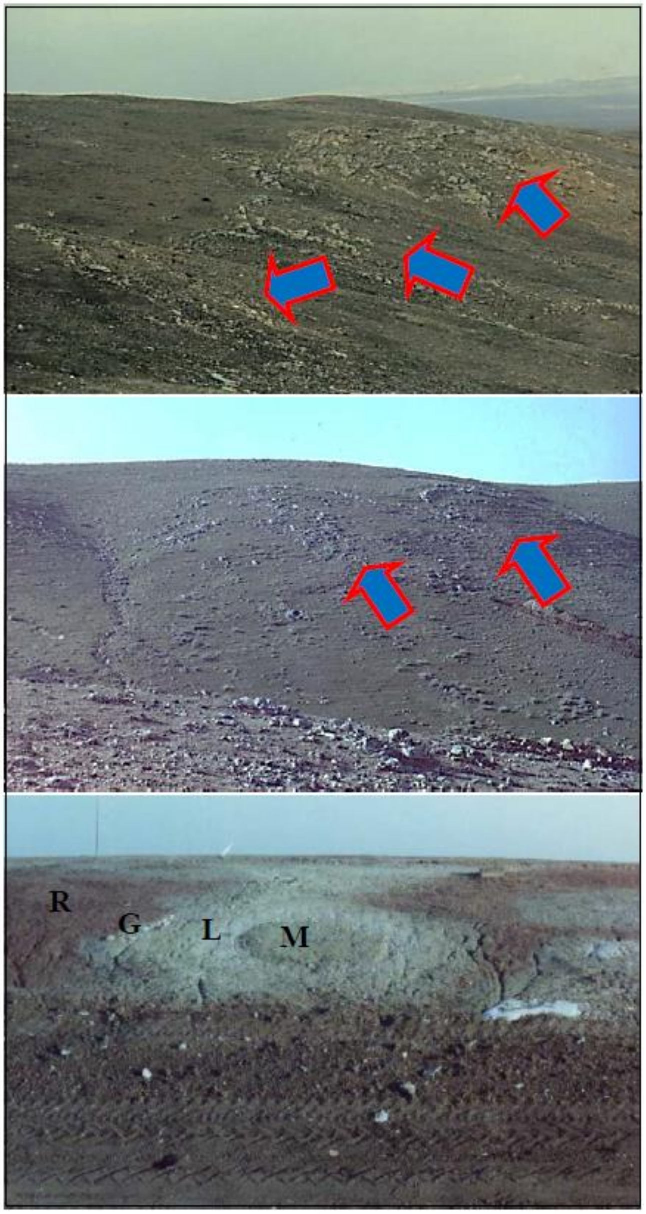

Figure 6: Three scenes of karstified region 15 km south of Badush Dam site.
Top: Collapsed limestone beds hindering the karstified gypsum beds. The arrows point to collapsed limestone beds with crescent like forms. Note that no gypsum beds can be seen. **Middle:** Slope showing collapsed limestone beds in form of crescent shapes. Note there are no gypsum beds along the whole slope due to the collapse of the limestone bed. The arrows point to the collapsed limestone beds. **Bottom:** A small sinkhole filled by green marl (M), followed by limestone (L), karstified thin white gypsum (G), and followed by red claystone (R); as appeared due to a road cut along a road to Badush village. Compare the size with the traces of shovels tire.

9 Conclusions

1. If Badush Dam will perform as a protection dam only, then the present design is relevant.
2. If the decision is taken to resume works in Badush Dam as a replacement of Mosul Dam, then intensive geological investigations must be carried out to obtain the depth of the deepest karstified gypsum and limestone beds accurately. This cannot be done unless the lithological column in the dam site and near surroundings is accurately known.
3. The designed grouting boreholes of 100 m depth will not be sufficient to seal the existing karst caverns, because the thickness of the Fatha Formation is more than 250 m, especially in the right side of the Tigris River.
4. The location of the axis of Badush Dam almost coincides with the axis of the symmetrical Allan anticline. This is a positive factor since the distribution of the exerted forces by the water of the reservoir will be distributed almost equally on both sides of the dam.
5. Badush Dam and Mosul Dam have the same type of geology and foundation conditions. Both are located within the Fatha Formation and both foundations are characterized with dense karstic conditions. These foundations are prone to dissolution within the karst and possible formation of sinkholes under the dam and in the reservoir and can lead to the failure of the dam.

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