

## Geophysical and Geological investigation of the Delga proposed Dam Site, Qala Diza, Sulaimani City, Kurdistan Region, NE-Iraq



**Bakhtiar Q. Aziz, Salahalddin S. Ali\*, and Kamal H. Karim**

University of Sulaimani, Faculty of Science and Science Education, School of Science, Geology dept. \*[salahsulus@yahoo.com](mailto:salahsulus@yahoo.com).

### Abstract:

The use of two geophysical methods and geological study in the investigation of the geological setting is aimed at evaluating the feasibility of the area for establishing a dam foundation and reservoir. 2D resistivity tomography was conducted on abutments while GPR was used on the river terraces in the trough of the valley. The framework and mutual relations of the geophysics, stratigraphy, lithology, structure, hydrogeology and geotechnique are used to study feasibility of a segment of river valley for dam building. The study is aided by detail and uptodate geological maps and geological cross sections which are all base on field data and geophysical measurements. This proposed dam is located at the southeast Delga village and about 20.0 km upstream of Dokan reservoir on little Zab River and about 19.5 km from the Iraqi-Iranian border. The dam site and surround areas are located in the Imbricated Zone which characterized by southwest overturning of the folds. The dam site is located on one of the overturned syncline in which Shiranish and Kometan Formations are exposed and the foundation and abutments of the dam are located on latter formation. The trend of the dam axis is N80W and the dip of the strata of the Kometan Formation is nearly parallel to the dam axis. This structure relation with dam axis improves water tightness and stability of the dam abutments against sliding and collapse. The 2D resistivity tomography and GPR survey showed that there are underground weak zones (cavern and fractured zones) in restricted limited area. The site is water tight as the river descended inside fresh Kometan and Shiranish Formation.

### I. Introduction

During the last two decades, Kurdistan and Iraq were suffering from a drastic drought condition, which caused several problems to the entire region. During these years, the available water resources were not sufficient for human, livestock and agriculture in many areas. Even without draught, the amount of precipitation and water runoff change dramatically annually.

In Kurdistan and Iraq, the demand for electricity increase, this increase, annually reaches more than 15% which is reflecting the rapid growth of population and economy in the region. Therefore,

construction of a dam on the Little Zab River to generate electricity will be of high economic value. Originally, the location of the dam is indicated by General Directorate of Dam and then the conducting of geological study is decided by the same directorate.

The integration of geophysical investigations and geological study is aimed to delineate the geophysical/geologic features such as overburden thickness; bed rocks morphology, fractures/seepage channels in the subsurface thus, enabling the evaluation of the feasibility of the area for establishing a dam and reservoir. 2D Electrical resistivity

tomography and GPR methods are the most effective and environmentally friendly approaches to evaluate engineering sites generally and particularly for evaluating dam sites.

Dams intended for water and electricity supplies require a low tolerance of seepage losses. Besides, the design of dam structures must be adapted to the existing site conditions (Ajayi et al., 2005) to minimize the losses. Failure to do any of these may invariably result in unplanned seepage and/or total collapse of the structure (Olorunfemi et al., 2000a, b). Biswas and Charttergee (1971) examined causes of dam failures worldwide and discovered that 25% of the failures were due to geotechnical problems associated with seepage, inadequate seepage cut-off, faults, settlements and landslides.

## II. Location and Geomorphology of the site:

The Delga dam site had been selected at about 20.0 km upstream of Dokan dam reservoir and about 19.5 km from the Iraqi-Iranian border. It is located southeast Delga village, about 10 km, southeast of Qala Diza town and about 5.0km southeast of Nuraddin village, (See Fig. 1 and 2). The selected dam axis is trending N80W, which is nearly normal to the trend of the Little Zab River or the valley trend. The dam axis is located between the following geographic coordinates: Left Bank: 36° 06' 3.8" N, 45° 10' 21" E, Right Bank: 36° 06' 7.1" N, 45° 10' 12.55" E.

The area consists of elevated mountains ranges that extending along northwest - southeast trend. The main mountains are Asos and Bolfat which are bound the dam site and reservoir from south and northeast respectively.

The proposed dam site and the reservoir area are located in the deep and large v-shaped valley that is located between the

aforementioned mountains, see Fig. (3). Passing through the dam site, Little Zab River valley extends from Dokan reservoir to the Iranian border near Mawat town and has the direction of N30W. Inside Iran it further extends for about 30 km toward northeast and northwest. In the valley, the river flows with highly meandering pass. The meandering of the river is due to lithologic and structure differences in the valley in which the water always select the more erodible route (soft or fractured rocks) (Fig.1).

The river valley is collecting water from parts of Iraqi and Iranian Kurdistan regions. The area of the watershed includes the northeastern part of the Sulaimani governorate in Iraq while Eastern Azirbainjan and Sannandaj governorates of Iran constituents part of catchment areas (Fig.2). The drainage pattern of the catchment area valley is dendritic pattern which has elongate shape that its length and width are about 150 and 30 kms respectively. The length of the catchment area is nearly parallel to Iraq-Iran border. The catchment area has an area of about 7313.6 km<sup>2</sup> and the annual rainfall exceeds 700 mm. The elevation of the river bed at the proposed dam is 554 m.a.s.l, while the highest point in the catchments area has an elevation of 2505 m.a.s.l.

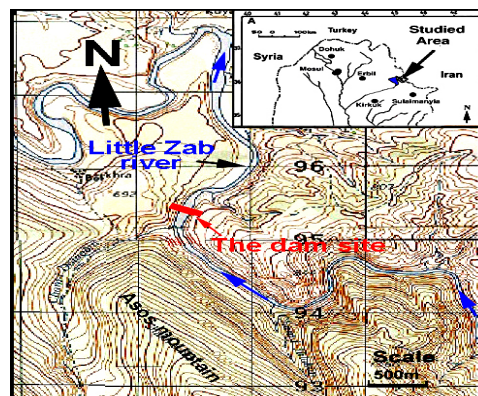


Fig.(1) Location map of the proposed dam the dam axis is N80W

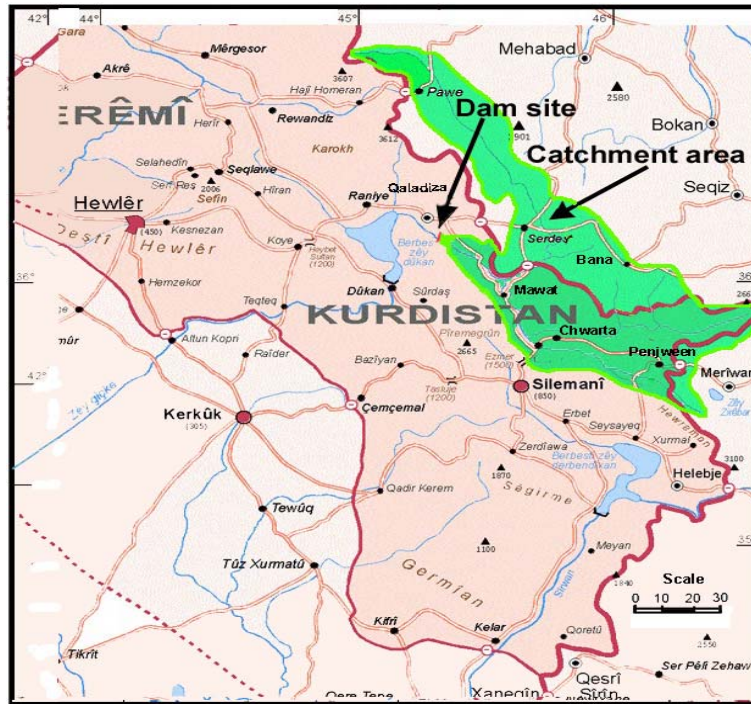


Fig. (2) - General Map of Kurdistan Region shows locations of the proposed dam and its catchment area inside Iraq and Iran.

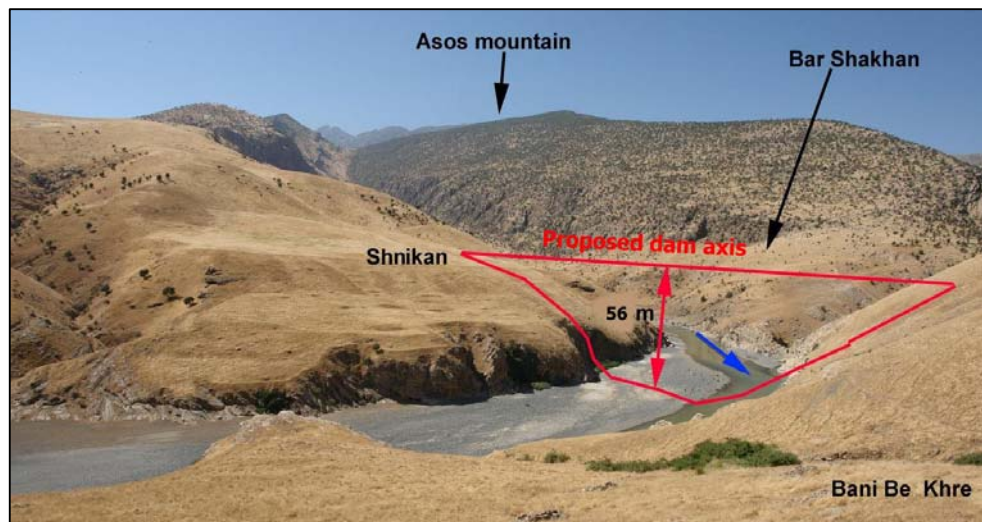


Fig. (3) - General view of the dam site, the blue arrow indicates the flow direction of the Little Zab River (Photographed toward upstream, from the Bani Be Khre hill)

### III. Geology and structural setting of the Dam site

The dam site is located in the Imbricated Zone of Buday (1980) and Buday and Jassim (1987). This zone is equivalent to the Balambo-Tanjero Zone which is suggested by Jassim and Goff (2006), (Fig.4). The proposed site is very close to the boundary between Imbricated and Thrust Zones, part of the reservoir and most of the catchment area is located in the Thrust Zone and Sanandij-Serjan Zone. From the field observation, the imbrication is very clear in which, stratigraphic units (the formations) are stacked obliquely toward southwest. Due to this imbrication, the recognition of the synclines and anticlines is very hard.

Many of anticlines are asymmetrical with southwestern limbs steeper than the northeastern ones. The strata suffered from intense deformations especially those are located within the axis of synclines due to imposed stress of Iranian Plate. In the axis of the syncline, there are relatively soft sediments, therefore deformed intensely while the core of the anticline is protected by thick carapace of hard carbonate rocks. The stresses generate many thrust and reverse faults in the area. Near the dam site, anticlines have been stacked together as very thick packages, which are mostly overturned toward southwest. Only one overturned syncline can be recognized, the axis of which run nearly in an east-west direction under the proposed dam site. The recognition is aided by presence of outcrops of the Shiranish Formation. All exposed formations belong to Early and Late Cretaceous which consists of Shiranish, Kometan and Qamchuqa Formations.

Dips of stratas of the formations are variable as their values increase progressively toward southwest and reach maximum value at the lower limb (left

bank of the river at the dam site or left abutment of the dam). From surface measurements, the amount of the dips direction of right abutments is about 45. The left abutment (when one looks upstream) contain small folding that cause variable dip angles but the mean amount is about 15 degrees. These variable dips are due to the existence of the massive Qamchuqa Formation at the south and southwest of the dam site (Fig.5 and 6).

### IV. Geology and structural setting of the Reservoir area

The reservoir is situated in a narrow valley with steep slopes elongates for about 21.8 kms from the dam site to the south of Kon Ganau village. The reservoir is mainly sited on the Kometan and Qamchuqa Formations, while a small part of it is sited on Shiranish Formation upstream the dam site near Labana Village, (Fig.7, 8 and 9).

Near Labana village the reservoir becomes wider; this wideness is due to the occurrence of Shiranish Formation, which is softer and more erodible than Kometan and Qamchuqa Formations. Therefore, in this place Shiranish Formation is suffered from more down and lateral cutting in addition to accumulation of the river bed alluvial deposits.

At about 3 kms upstream the dam site and due to presence of some faults and the conjugate set of discontinuities, unstable blocks of Qamchuqa Formation form a cliff on the left abutment (Fig. 10 and 11). Probable rockslides are expected in this area after impounding. Such slides (if happened) will cause unhelpful wave actions in the reservoir.

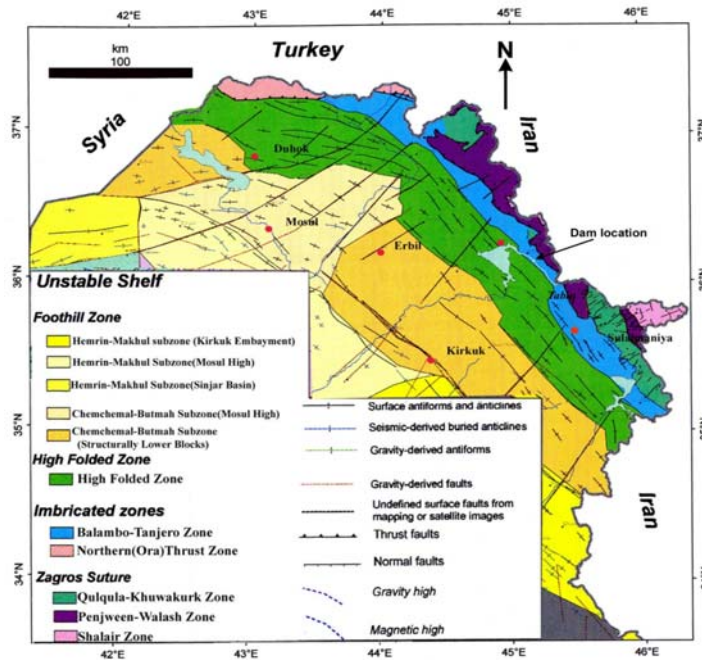


Fig. (4) - Tectonic zones and structural elements of the unstable shelf units (Jassim and Goff, 2006).

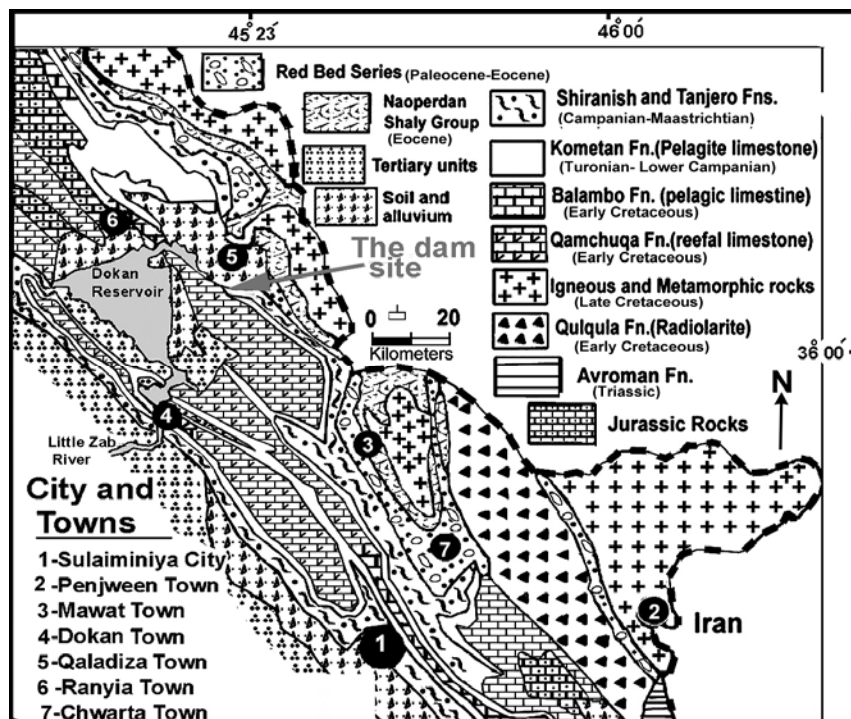


Fig. (5) – Geological map of Northeastern Iraq (Karim et al, 2012 and Sissakian, 2000)

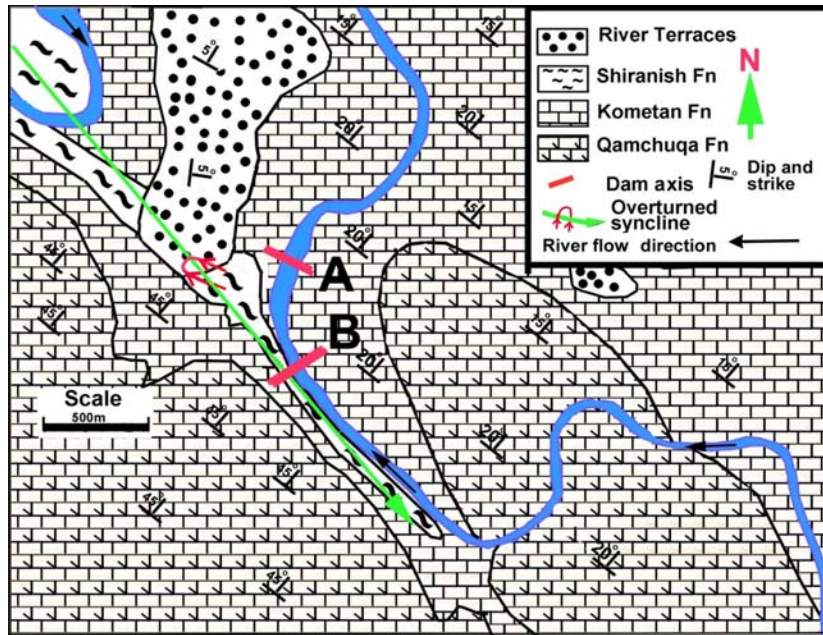


Fig. (6) Geological map of the area around the dam shows overturned synclines (Green Arrow).A) geologic cross section of the dam site in the figure 14), B) is a geologic cross-section about 600 upstream of the dam (See fig.15)

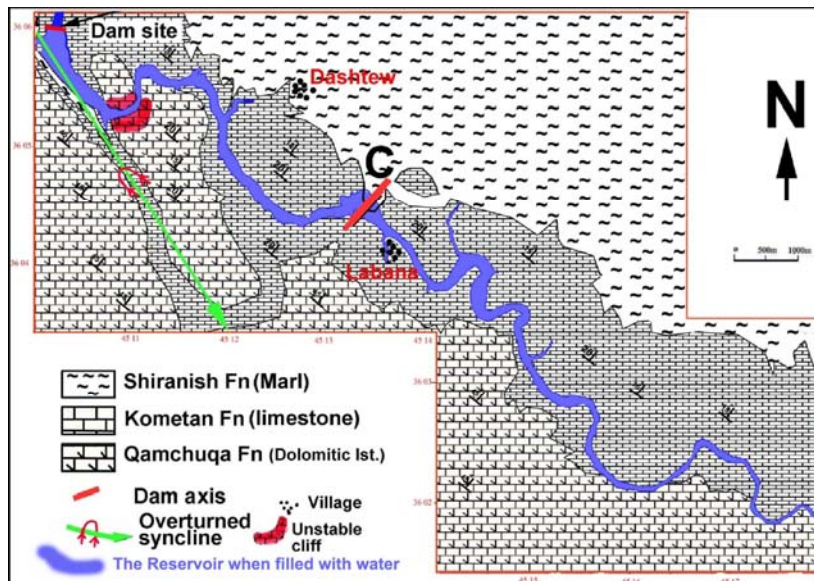


Fig. (7) Geological map of the reservoir area.

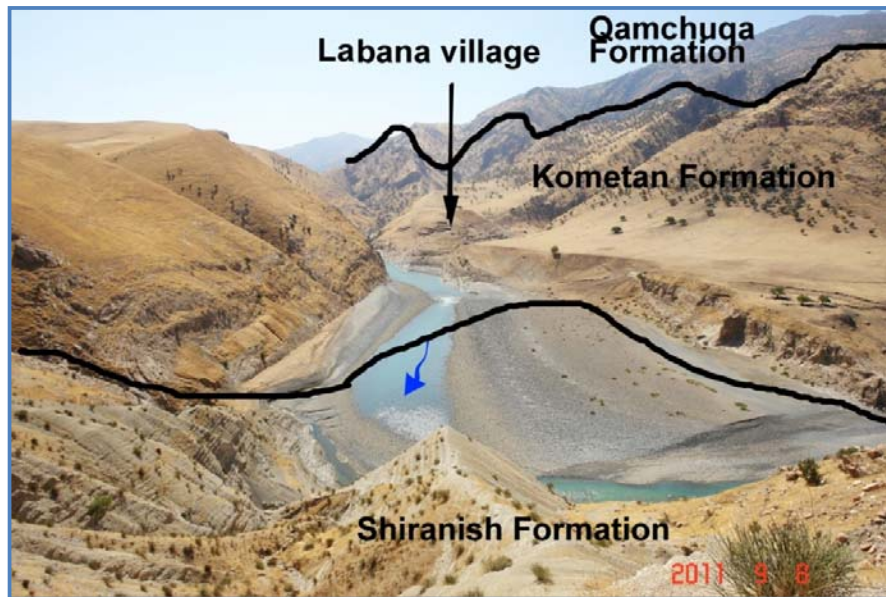


Fig. (8) - Upstream view of Little Zab River at the northwest of Labana village Showing outcropped formations and river bed coarse deposits (as point bar deposits)

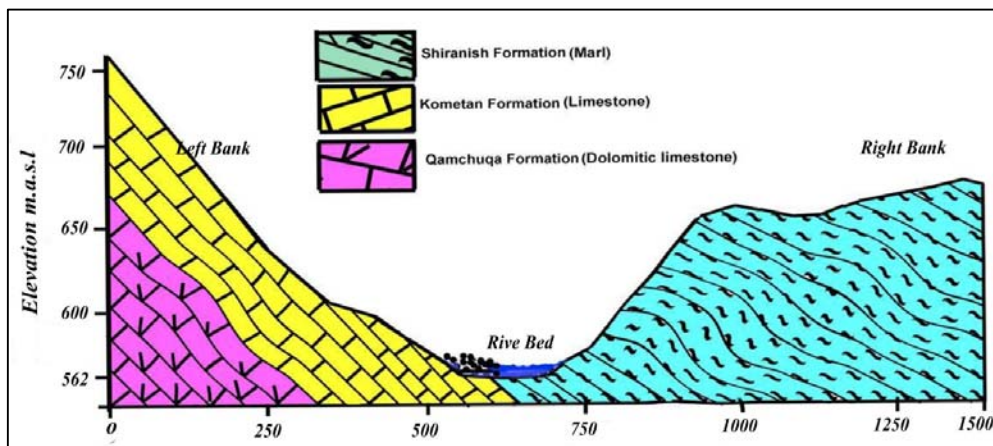


Fig. (9) A Geological cross section of the valley about 300m downstream of Labana village (see section C on the geologic map of Reservoir in the figure 18).



**Fig. (10) Possible unstable blocks on the left abutment of the river at about 3.5km upstream dam site (see the next photo for detail of the unstable block).**



**Fig. (11) The unstable blocks in the photo (17A), this photo is taken from right shoulder of the dam site and far from the dam for about 3kms (partially zoomed).**

## V. Stratigraphy

The following three formations are exposed at the dam site and the reservoir area:

### Shiranish Formation - Late Campanian – Maastrichtian

In the dam site area, the thickness of Shiranish Formation is not known due to the fact that its

lower and upper contacts with both Tanjero and Kometan Formations are not exposed in a stratigraphic succession, but it is most possibly very close to the thickness of the section of that near Dokan dam site, which is about 220 m thick. The formation is not exposed at the dam site (does not exist even below the surface, neither below the left nor below right bank (left and right abutments of the dam). It is exposed at about 200m upstream of the dam site where it intensely deformed so that the measurement of attitude is not accurate and change rapidly (Fig.12) but the mean is about N45/30 (Fig.6). It is most possibly exists downstream of the dam site too, but covered with alluvial deposits. At the left bank, Shiranish Formation is located under the Kometan Formation. It is exposed in the reservoir near Labana village (Fig.8 and 9).

### Kometan Formation - Turonian- Early Campanian

The Upper Cretaceous Kometan Formation (Turonian- Early Campanian) is widely exposed in the Imbricated and High Folded Zones in northeastern Iraq, (Bellen et al, 1959, Buday, 1980 and Jassim and Goff, 2006). According to Karim and Taha (2008), the formation is deposited during post drowning phase. While Karim et al, 2008, concluded that its contact with overlying Shiranish Formation is gradual and conformable.

The formation is composed of medium bedded (200 - 600 mm) pelagic limestone. The total thickness of these beds may reach more than 250m due to imbrications (stacking of several folds together as one southwest imbricated package) (Fig.12).

The thickness of Kometan Formation is not known in the area of the dam site, due to the fact that the formation is show imbrications and its thickness increased several times than the original ones. Moreover than that, its lower and upper contact with both Shiranish and Qamchuqa formations mainly tectonic and not well exposed. But it is most possibly very close to the thickness of the section of the type locality (at Kometan village in the Naudasht valley), which is only about 35km far from the dam site.

At the dam site, the formation makes up the whole mass of the right and left abutments of the proposed dam site (Fig.12). The dips angles are different for left and right (when one looks upstream) abutments which are 15 and 40 degrees respectively (Fig.14). The directions of dips of both abutments are nearly same (N45E). About 200m to the upstream, both Shiranish and Qamchuqa Formations are exposed (Fig.13 and 14). The reason for this type of stratigraphic situation is due to overturning of the strata by imbrication, where the project area is located between the thrust and Imbricate Zones.

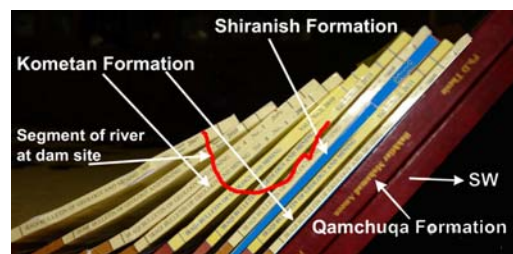


Fig. (12) Simple model to show imbrication of formations at dam site.

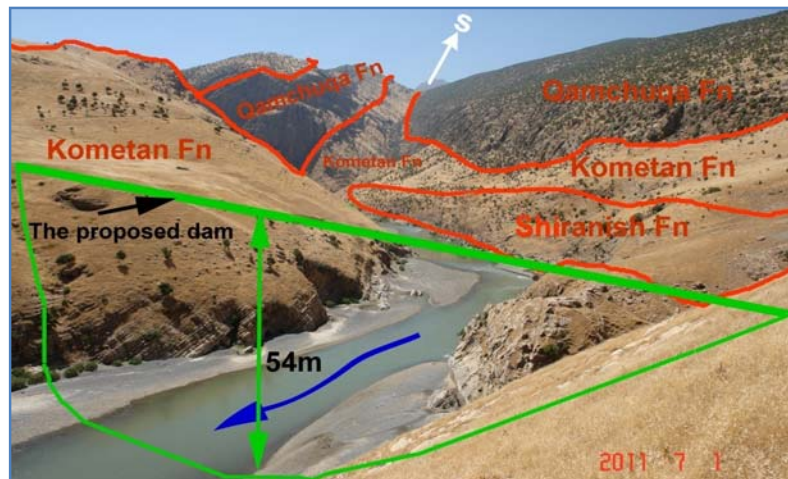
Shiranish is located in core of overturned syncline. The two limbs of syncline cannot be identified due to intensely squeezing. This is true for anticlines. These all folds and beds form the northeastern limb of Asos Anticline.

**Qamchuqa Formation (Valanginian-Cenomanian)**

Qamchuqa Formation (Early Cretaceous) consists of thick succession of dolomite and limestone. This succession consists of about 650 meters of alternation of well-bedded, grey colored, dolomite and light grey limestone or dolomitic limestone. The name of Qamchuqa Formation is derived from the name of Qamchuqa village, which is located directly to the southwest of the type section, about 45Km northwest of Sulaimaniya city in

the High Folded Zone. According to Buday (1980), the Upper and the Lower Qamchuqa Formations have been renamed as Mauddud and Shuaiba Formations, respectively, in the middle and southern Iraq. The same authors mentioned that, in Iran, the correlative formations are Dariyan (Aptian) and the Albian part of Sarvak Formation of the East Zagros Mountains in Iran.

In the proposed dam site, Qamchuqa Formation is exposed on the left bank of the river but it is so far that the foundation of the dam does not strike this formation, (Fig. 10, 11 and 13). Only a small part of the reservoir floor will be on this the formation which locates near dam site to the east. This formation with Kometan and Shiranish Formations make the northeastern limb of Asos anticline.



**Fig. (13) Perspective view of upstream of the dam site shows exposed Formations. It is clear from the left abutment that the apparent dip of the Kometan Formation is about 15 degrees toward down stream**

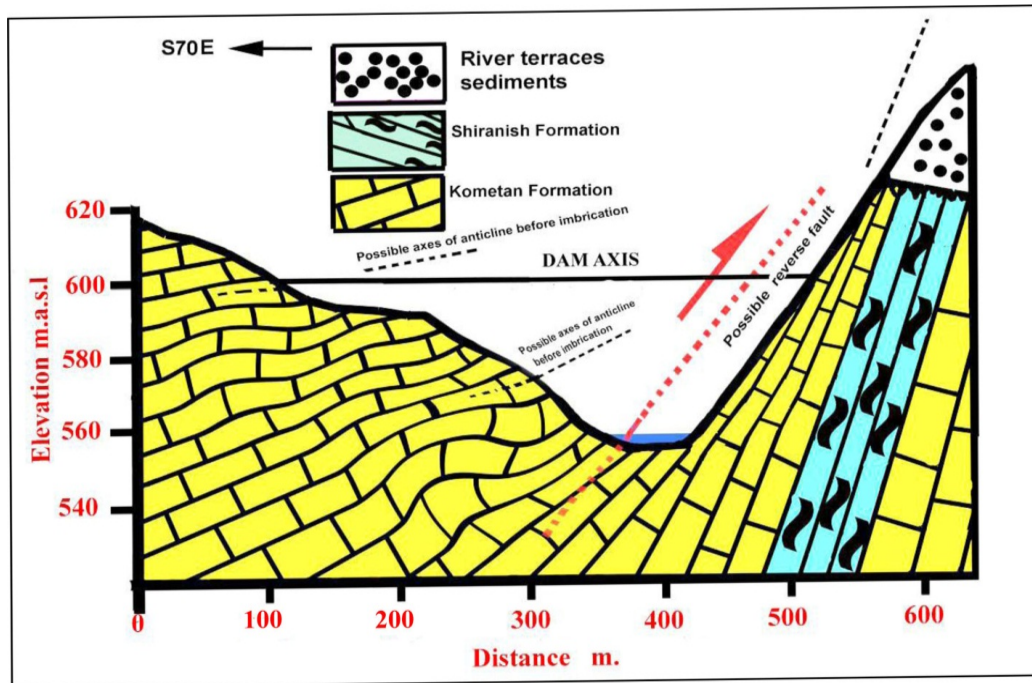


Fig. (14) A Geological cross section of the valley at the dam site as seen from downstream (see section A on the geologic map of dam site in the figure 15)

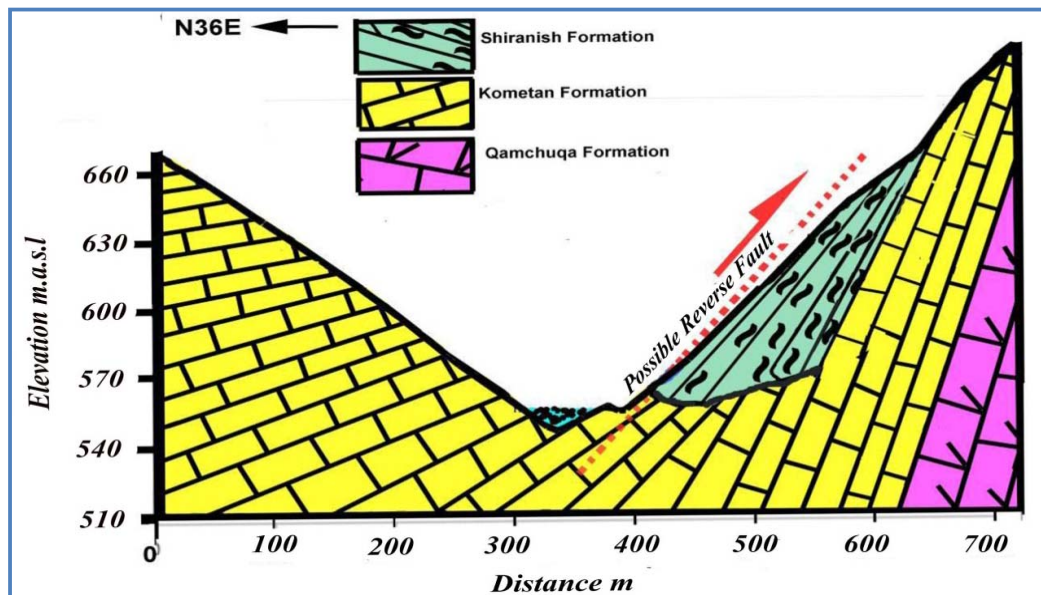


Fig. (15) A Geological cross section of the valley at 600m upstream of the proposed dam site (see section B on the geologic map of dam site in the figure 15).

## VI. 2D Resistivity Tomography Methodology

The fieldwork for performing the 2D resistivity survey started at 1/8/2011 and ended at 24/8/2011. Relying on geological survey four profiles was conducted. They are covered the whole area under consideration as shown in Figs (16). The length of each profile of 2D survey is equal to 390 m, Winner-Schlumberger technique was used, the survey carried out by using electrode spread equal to 10 meters, accordingly the maximum depth of investigation approach 65 m.

## VII. Interpretation

2D model interpretation was performed using the last new version of software package "RES2DINV" version 3.54.53. It performs smoothness-constrained inversion using finite difference forward modeling and Quasi-Newton techniques (Loke and Dahlin, 2002).

### Profile -1:

The inverse section of the sounding shows appearance of three distinguishes zones or layers. The first is a layer of low resistivity ranging from 35 to 80 Ohm.m. This layer shows a wide range of resistivity due to its components, which composed of clay, silt and limestone fragments of different size from weathered surface of Kometan Formation, Fig (17).

The top soil layer has thickness ranging from zero beneath the electrode No.1 on the left abutment of the area to about 5 m beneath electrode No. 40. The thickness of this layer is increasing gradually toward southeastern part of the area.

The second layer show high resistivity ranging from 80 to 1200 Ohm.m. It is detected at depths ranging from zero (exposed to surface) to 5 m. This layer

representing dry zone of Kometan Formation, it is extending to the lower part of the inverse section which is about 64 m depth. A fracture zone of low resistivity was identified between electrodes 17 to 22, the low resistivity of this zone may refer to existence of clay or marl within the fractures. Beneath the depth of about 50m the resistivity of Kometan Formation decreasing gradually to about 40 to 80 Ohm.m due to existence of groundwater at these depths.

### Profile - 2:

The inverse section shows similar subsurface geological situation as the first sounding, three distinct zones have been detected, Fig (18). The first layer has moderately low resistivity and small thickness ranging from zero below the electrode (1) at the northeastern part of the area to about 4 m below the electrode (40) at the southwestern part of the area. This layer show resistivity ranging from 40 to 70 Ohm.m, it is composed mainly of clay and weathered product of limestone rocks of Kometan Formation.

The second layers is of high resistivity, it is composed of dry limestone of the Kometan Formation, the resistivity of this layer ranging from 80 Ohm.m to 1200 Ohm.m. A fractured zone have been detected between electrodes 10 to 16, it is show lower resistivity than the surrounding limestone rocks due to existence of clay and marl filling the fracture zone.

The third zone (blue color) is representing a layer of low resistivity of Kometan Formation due to existence of groundwater. The depths of water table ranging from 38 m below electrode 10 to depth of about 47 m below electrode 30.

**Profile - 3:**

Approximately about (5-15m) of the upper part of the inverse section composed of clay mixed with coarse materials of river terraces, which have high resistivity ranging from 100 to 250 Ohm.m, Fig (19). Maximum thickness of river terraces occurs at the beginning of the section beneath electrodes 1 to 6 as well as beneath electrodes 26 to 40.

The second layer is representing Shiranish Formation, it is appearing below depths of about 5 to 15 m, and the resistivity of this layer is ranging from 17 to 250 Ohm.m. The wide range of resistivity of Shiranish Formation is due to the two main components of this formation, low resistivity Marly component and high resistivity Marly limestone components. A low resistive materials detected at depth of around (30 m) and below electrodes (29 to 33). It is most probably represent clay or marl lenses. A part of Kometan Formation is detected beneath electrodes 20 to 28 and below depth of about 52 m.

**Profile - 4:**

It is about 390 m length extending NE-SW, the first electrode plotted at NE end of the profile and electrode No.40 at the SW end, as shown in Fig (20).

This section shows similar subsurface geological situation as the first and second sounding, three distinct zones have been detected. The first layer is of moderately low resistivity has thickness ranging from 25 m below the electrode 4 at the northeastern part of the area to about zero below the electrode 18. This layer is representing a marly component of the Shiranish Formation. The second layers is of high resistivity, it is composed of limestone of Kometan Formation, the resistivity of this layer ranging from 70 Ohm.m to 900 Ohm.m, this layer extends below the whole area under consideration.

The third zone is representing a saturated layer of Kometan Formation; it shows lower resistivity due to existence of groundwater. The depth of groundwater table is ranging from 48 to 58 m.

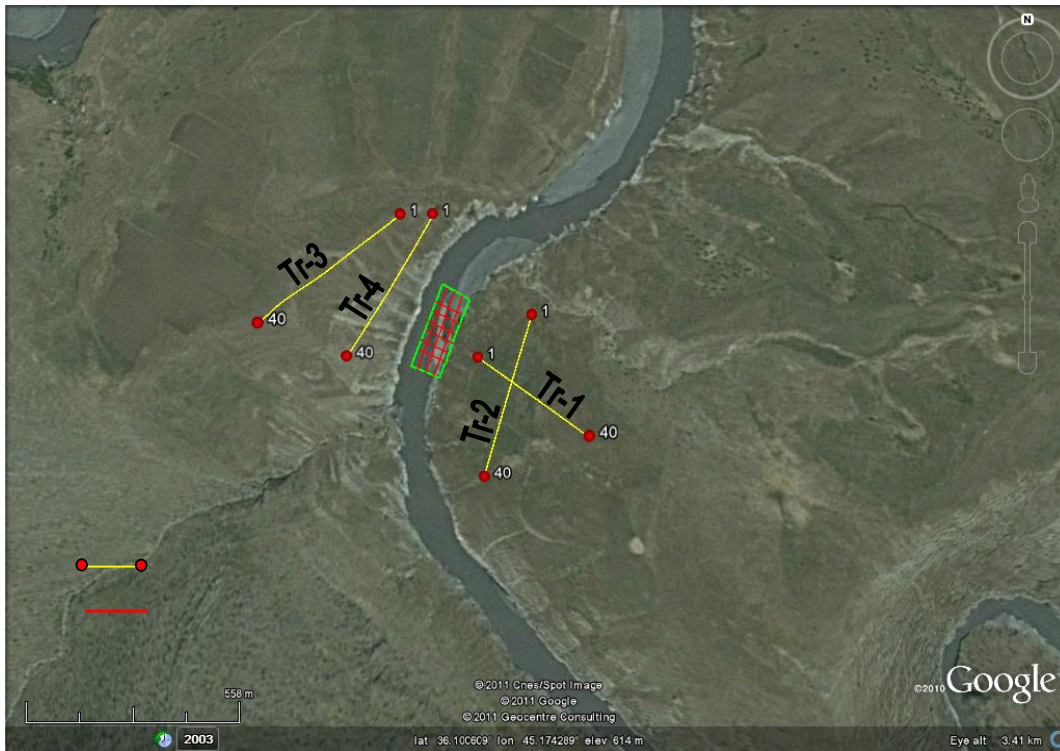


Fig (16) Location of the area showing 2D traverses and GPR Profiles.



Fig (17) Transportation of Resistivity instrument.

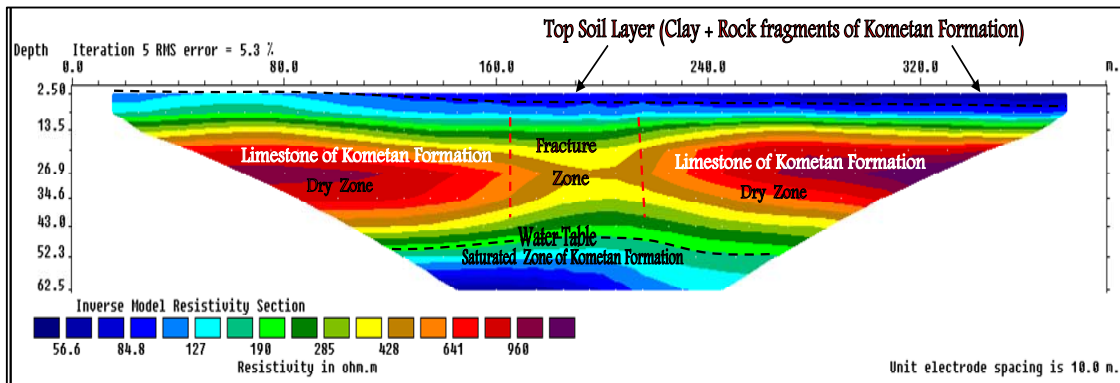


Fig (18) Interpretation of 2D sounding of the Traverse-1

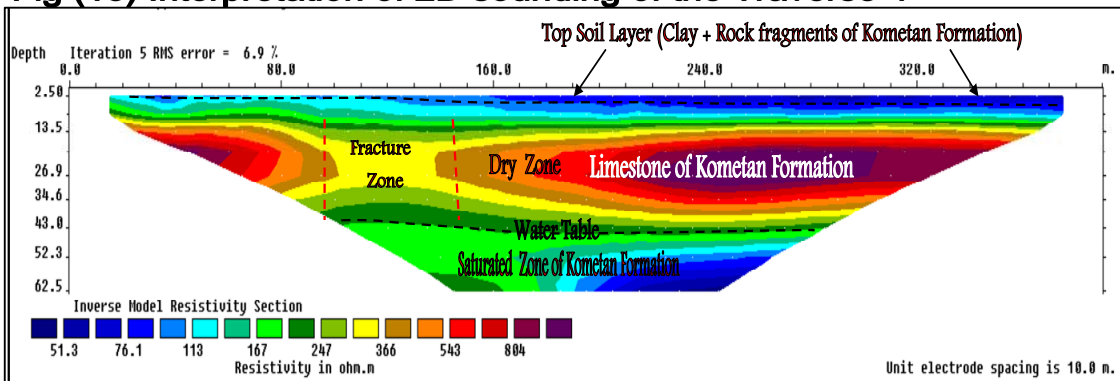


Fig (19) Interpretation of 2D sounding of the Traverse-2

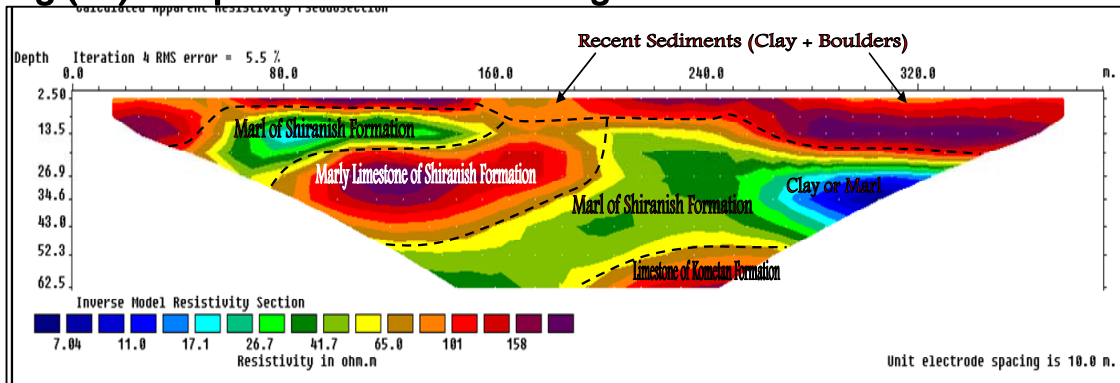


Fig (20) Interpretation of 2D sounding of the Traverse-3

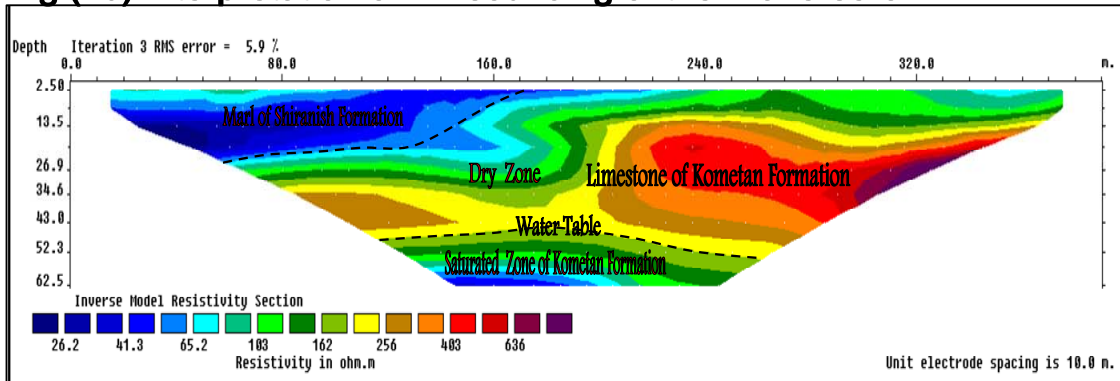


Fig (21) Interpretation of 2D sounding of the Traverse-4

## GPR Survey Methodology

The survey was carried out using a RAMAC2, GPR SYSTEM consisting of a Model PR- 8304 profiling recorder with automatic gain ranging, graphic, magnetic tape data recording and a copper-foil dipole antenna having a center operating frequency of 50 MHz. Data collection was carried by using 'Ground vision' software, measurements were made along two sets comprise 10 profiles, Fig (22, 23). The first set trending NW-SE as the strike of the rock outcrops while the second set bearing NE-SW they are normal to the first set. The length of the survey lines was ranging from 45 to 170 m. Data collected were processed using software (RadExp) to produce 2D radar gram in time scale and depth. Frequency filters and triple time varying gains were used to get good quality data Prior to producing the time section, all data were filtered for background removal and to remove the DC current effect and multiplied by gain functions to overcome the attenuation effect of the earth materials as well as to minimize the noise effects.

## INTERPRETATION AND DISCUSSION

The top layer of all the GPR section is representing river terraces composed of boulder, sand and rock fragments of limestone of the Kometan Formation. The thickness of this layer in the profile-1 is ranging from 3 m at the beginning of the section to about 10 m beneath the end of the section, as shown in Fig (24).

The lower part of the radar image shows a weak reflection zone that is attributed to saturated zone of the limestone rocks of the Kometan Formation. Some strong multiple reflections were recorded within the limestone rocks due to surface undulation.

All others profiles are similar in geological point of view to the profile-1, the top layer is representing river terraces composed of boulder, sand and rock fragments of limestone of the Kometan Formation. The thickness of this layer is ranging from 0.5 m to about 10 m through the whole investigated area by GPR survey, as shown in Fig (24).

A hyperbolic shape is detected beneath profile-8 at horizontal distance equal to 50 m which representing a cave within the limestone rock of Kometan Formation, it is detected at depth equal to 8 m. The detail of GPR profiles are listed in the table-1.

S	Name of Profile	Length of Profile (m)	Depth of Komitan Fm.	Remark
1	Profile-1	61	3-10	-
2	Profile-2	61	2.5-9	-
3	Profile-3	56	2.5-10	-
4	Profile-4	67	6-11	-
5	Profile-5	60	7-9	-
6	Profile-6	61	5-8	-
7	Profile-7	150	9-10	-
8	Profile-8	153	5-6	Cavity detected
9	Profile-9	141	9-10	-
10	Profile-10	61	6-10	-



Fig (22) Location of the GPR Profiles.



Photo (23) Location of the investigated area with Profiles Foundation

The proposed dam site is selected to be placed on Kometan Formation at both abutments. The right abutment of the dam, geo-mechanically, has a high strength (about 50-100MN/m<sup>2</sup> MPa). It is classified as a hard rock. This is true for left one too.

Bedding dips of Kometan Formation at the left (when the dam is see from downstream) abutment are directed as neutral as concerned to the stability of this shoulder.

This is due to the fact that the dips are directed towards N45E at an amount of 0-30 degrees. These large dip variations, under the right abutment are attributed to occurrence of a small syncline, which in some cases cause reversing of the dip direction toward S45W. These attitudes of dips help excavation of this shoulder without resulting sliding or block falls. The block fall may depend on other mechanical discontinuities. But it is possible that will have more or less negative effects on water tightness as there is apparent dip (about 15 degrees) of beds of Kometan Formation toward downstream which is clear from the fig. (13).

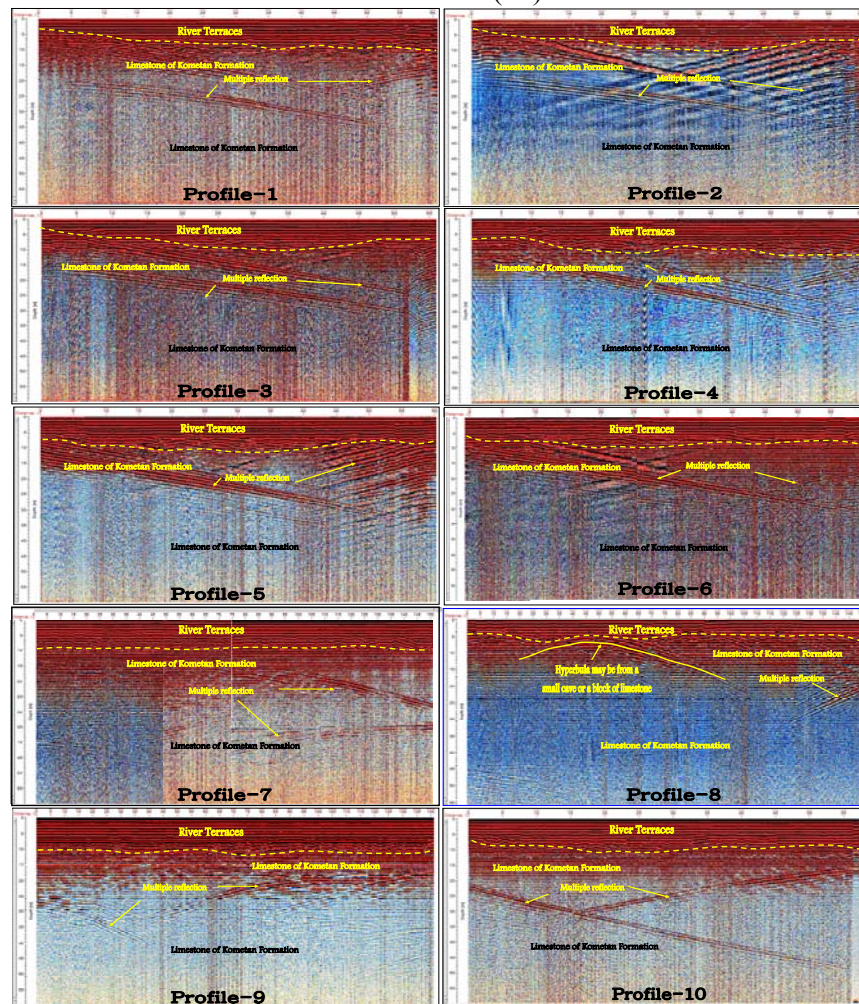


Fig. (24) Interpretation of the GPR profiles.

The outcrop is mostly covered with talus deposits, therefore the dip and direction have been measured only for a limited area where the outcrops exist. This is valid for the dam foundation too, which consists of Kometan Formation but mainly covered.

The only clear discontinuities are the bedding joints, which have very tight aperture ( $<0.1$  mm), when the weathered mantle (surface layer) is removed. Other joints are not clear because there are no fresh outcrops in the area such as newly excavated road cuts to make accurate measurements.

Information obtained from survey shows that Kometan Formation is apparently water tight in the both abutments, but this is to be proved by drilling and in-situ permeability tests, absence of caverns and fissures (karstification) will improve the impermeability of foundation. Apparently no caverns or karstification feature have been detected in the Geophysical survey, which have been carried out recently in the dam site.

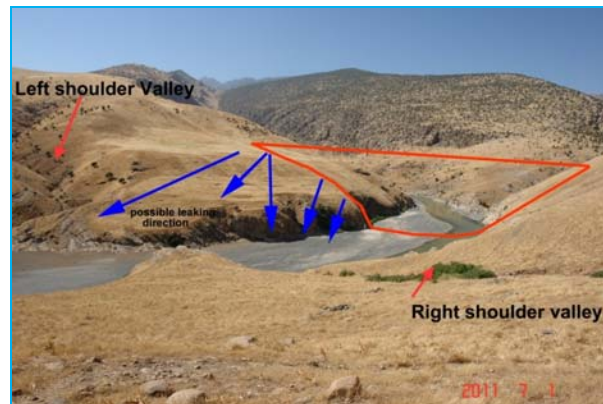
In the left abutment, arrangement of the beds has high tilt (dip) angles, (more than 45 degrees); the dip angles are nearly equal to the slope angle, which is not favorable as concerned stability. This will possibly cause a bedding plain sliding during excavations for removing weathered Kometan surface layers (Fig.13 and 14).

The right shoulder (when one looks upstream from dam downstream) consists

of both Kometan and Shiranish Formations with no clear contact relation between them. It is possible that the contact between the two is tectonic or it may be stratigraphic. Shiranish Formation is located under Kometan Formation due to imbrications and overturning processes. The presence of Shiranish Formation at depth is only a hypothesis that must be validated through boreholes or geophysical surveys. Due to the closeness of these two formations from the thick and massive Qamchuqa Formation, they are deformed and fractured and strongly compressed against Qamchuqa Formation that forms the Asos Mountain (Asos anticline).

The area around the dam site is located in the zone of the relatively active earthquakes but the largest recorded one in the region has a magnitude less than 5 on Richter scale. But large magnitudes earthquake are occurred in the neighboring countries such Iran and Turkey where 7 magnitudes are happened. As the dam is relatively large, therefore the risk of earthquake must be taken into consideration and the dam must be so designed to resist an earthquake of 8.5 magnitudes.

Generally speaking the engineering properties of the formations are nearly similar to the formations on which the Dokan dam had been placed. This similarity includes suitable water tightness (imperviousness) and high compressive strengths of the formations.



**Fig. (25) Apparent dip directions (toward downstream) at the dam site and the two small valleys that are located downstream of both shoulders. The possible water leakage is shown in blue arrow.**

### VIII. Conclusions & Recommendations

1. Based on the 2D resistivity Tomography as well as from the surface geological survey point of view, it concluded that up to depth of about 65 m are fairly competent and can support a dam construction, as related to stability and water tightness, this survey is to be supported by the results obtained from Geophysical survey and subsurface investigations. Presence of the two small valleys is to be taken into consideration in the hydraulic design of the dam. The two valleys are located about 500 to the downstream of the both shoulders.
2. The dam foundation of left abutments consists of Kometan Formation. The dip is directed nearly normal to the dam axis (the dip ranges between 14 and 45 degrees, the trend of dam axis is N80W), which improves water tightness and stability of the dam abutments against sliding and collapse.
3. The foundation of the right abutment (When seen toward upstream from downstream) consists also of Kometan Formation. The dip is nearly directed normal to the dam axis at a dip angle is about 45 degrees (nearly same as slope angle). Direction and amount of the dip may cause sliding of the slope during excavation of the weathered surface layers of the Kometan Formation.
4. From surface deformations, a possible reverse fault (not active) is expected and must be investigated by drill holes.
5. Alluvium accumulations cover the valley bottom, the thickness of alluvium is ranging from 2m to 11m according to the result obtained by GPR survey.
6. Both abutments of the proposed site are so thick that give maximum stability.
7. The 2D resistivity tomography investigation conducted on the proposed Delga dam site shows that the right abutment is covered by fairly thick superficial river terraces (overburden) materials while the left abutment is covered by fairly thin superficial river terraces. The thickness of these sediments ranging from 5.0 m to 15 m, it covers top of the right abutment and overlaying Sheranish Formation. It may cause some problems such as block toppling or sliding during the dam construction. Presence of this terrace has to be taken into account in designs.

8. The fractures zone detected in the 2D inverse sections 1 and 2 on the left abutment are confined and may pose no serious threat, as well as the small cavity detected beneath GPR profile-8 at depth 8 m can fill by cement through the grouting process.
9. Unstable blocks at the 3 km distance upstream the dam site are to be taken into consideration and treated during dam construction.

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