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Hydrogeological investigations by surface geoelectrical method in hard rock formation — a case study

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Abstract: The major portion of Kermanshah, a state in the west of Iran, comprises hard rocks such as limestone, schist, marly limestone, slates, diorites and andesites etc. The sedimentary rocks are repeatedly folded and faulted. The depth of the basement topography is shallow to deep in hard rock terrain. The state possesses an area of 24,434 sq. km. The present study aims at delineating the hydrogeological framework in hard rock terrain by using interpreted results of electrical resistivity data generated by the author in reconnaissance field visits. The VES conducted at 50 locations.

INTRODUCTION

Hard rock in groundwater terminology constitutes a group of rocks lacking primary or intergranular porosity and are included as those geological formations the drillability of which is low. The secondary porosity developed as a result of physical forces and chemical reaction forms a well definable aquifer system. The dynamics of groundwater i.e. occurrence, movement and interactions is well understood in porous medium, but however in hard rocks it is still beset with many problems.

In Kermanshah state (Fig. 1), over two third of the surface area is occupied by hard rocks. The major parts of the area is covered by carbonate rocks, mainly of Asmari (Oligo-Miocene) and Shahbazan (Eocene-Oligocene) formations. These rocks are extensively karstified (Sahabi *et al.*, 1998).

An attempt has been made in this study to delineate hydrogeological framework of the hard rock formation.

HYDROGEOLOGICAL SET UP

The area is covered by: (1) Jurassic formations (schist, limestone vulcanized dolomitic limestone, (2) Jurassic-Cretaceous formations, (3) Recent and sub-recent sediments (clay and alluvium mixed). Average annual rainfall of the state is about 500 mm. Figure 2 shows regional geological map of the area. Detailed study of borehole lithology data and geophysical data reveals that the depth of alluvial burden ranges from 20 m to 150 m bgl. The depth to water table is 5 m in hilly area and reaches up to 35 m in alluvial deposits. The groundwater potential is estimated to be at about 1.3 Milliard m^3.

SURFACE GEOPHYSICAL SOUNDINGS

Of the several geophysical methods, direct current electrical resistivity has found the greatest application to hydrogeology (Zohdy *et al.*, 1974). To record resistivities of the subsurface formation, current is sent into the ground through two electrodes and resulting potentials are measured with the help of two other electrodes. There are several electrode arrangements (configurations) of current and potential electrode dispositions of which Schlumberger and Wenner are in common use Keller & Frischmecht (1966) and Telford *et al.* (1979) has described the different configurations in use.

Geophysical method is an effective tool for ascertaining subsurface geologic framework of an area (Keller and Friscknechdt, 1966; Griffiths and King, 1965; Zohdy *et al.*, 1974). One of the most widely used methods of geoelectrical exploration is known as the resistivity method. Modern developments in resistivity data interpretation have considerably increased the depth of investigations with reasonable accuracy up to depths of about 500 m.

Vertical Electrical Soundings (VES) data was conducted with Schlumberger configuration at three regions of hard rock formations. A few selected VES field curves are presented in Figure 3. The maximum current electrode was kept between 400–500 m. The field apparent resistivity data for different values of AB/2 have been processed and sounding data have been interpreted quantitatively and geologically as described by Kunetz (1966), Bhattacharya and Patra (1968), Zohdy (1989). The interpreted quantitative resistivity data of VES sounding has been carefully compared with the available lithology and resistivity ranges adopted for different geological formations. The geoelectrical section from the interpreted earth model data was prepared as shown in Figure 4.

SALIENT HYDROGEOLOGICAL FEATURES OF HARD ROCK FORMATIONS AND EARTH MODEL

During the course of the investigation a correlative study between resistivity characteristics and subsurface lithology were made. This also helped in recommending

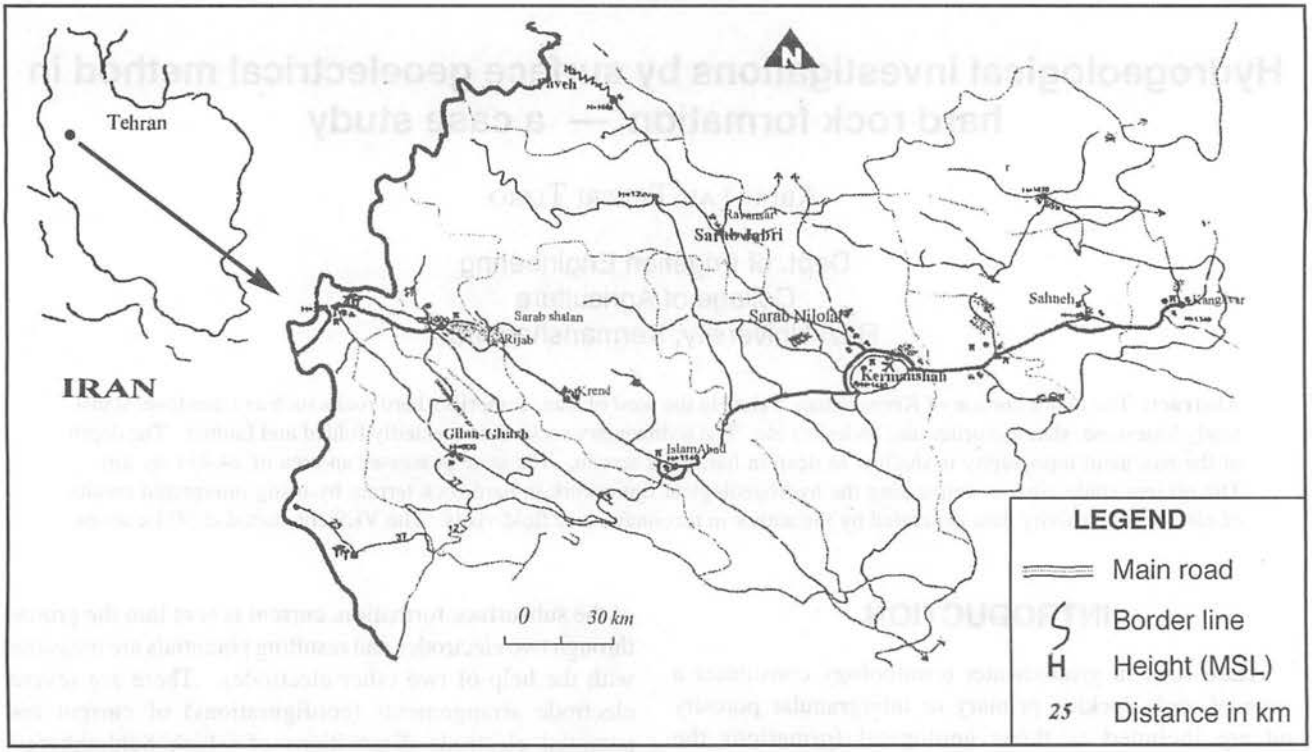

Figure 1. Index map of study area.

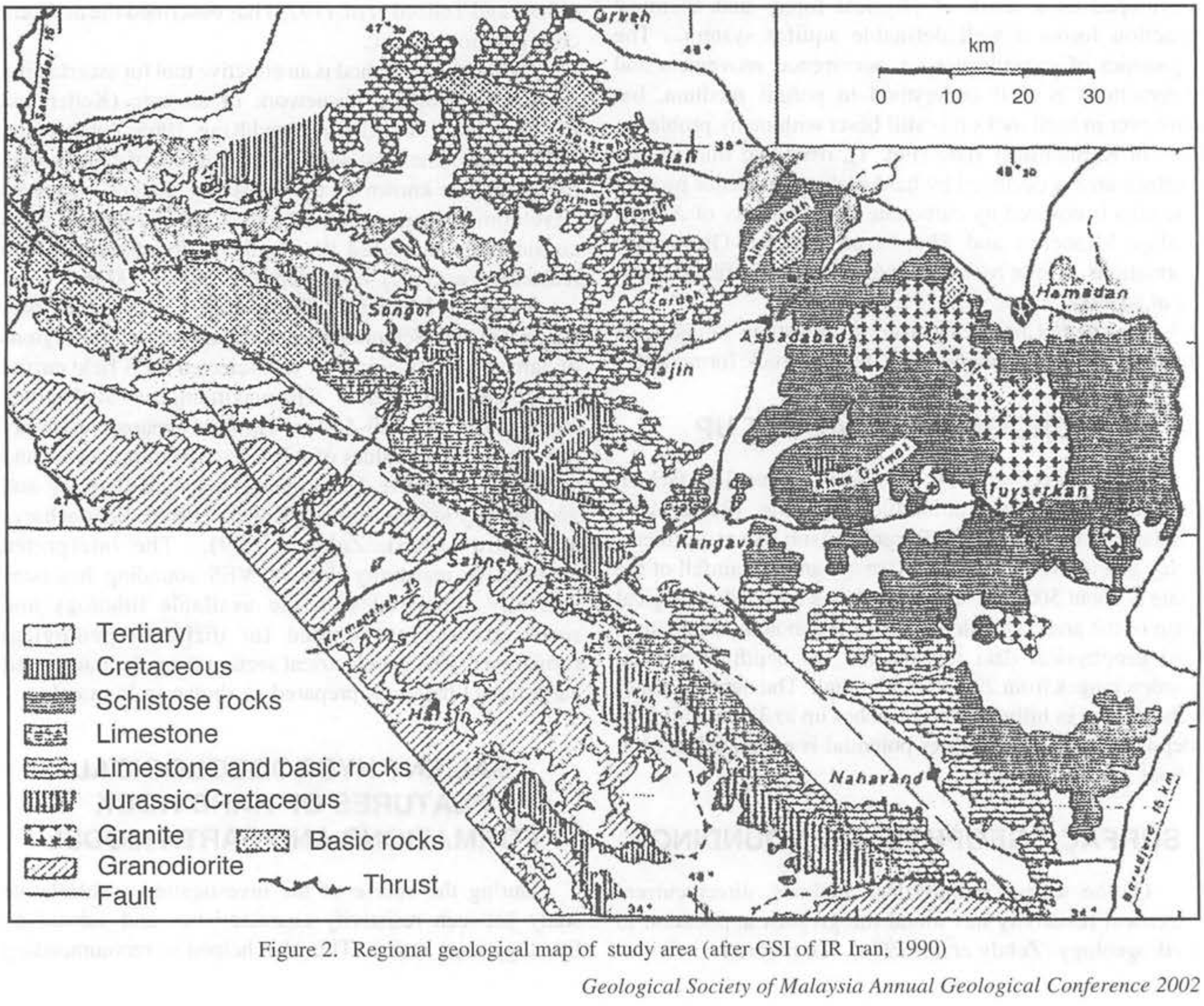

Figure 2. Regional geological map of study area (after GSI of IR Iran, 1990)

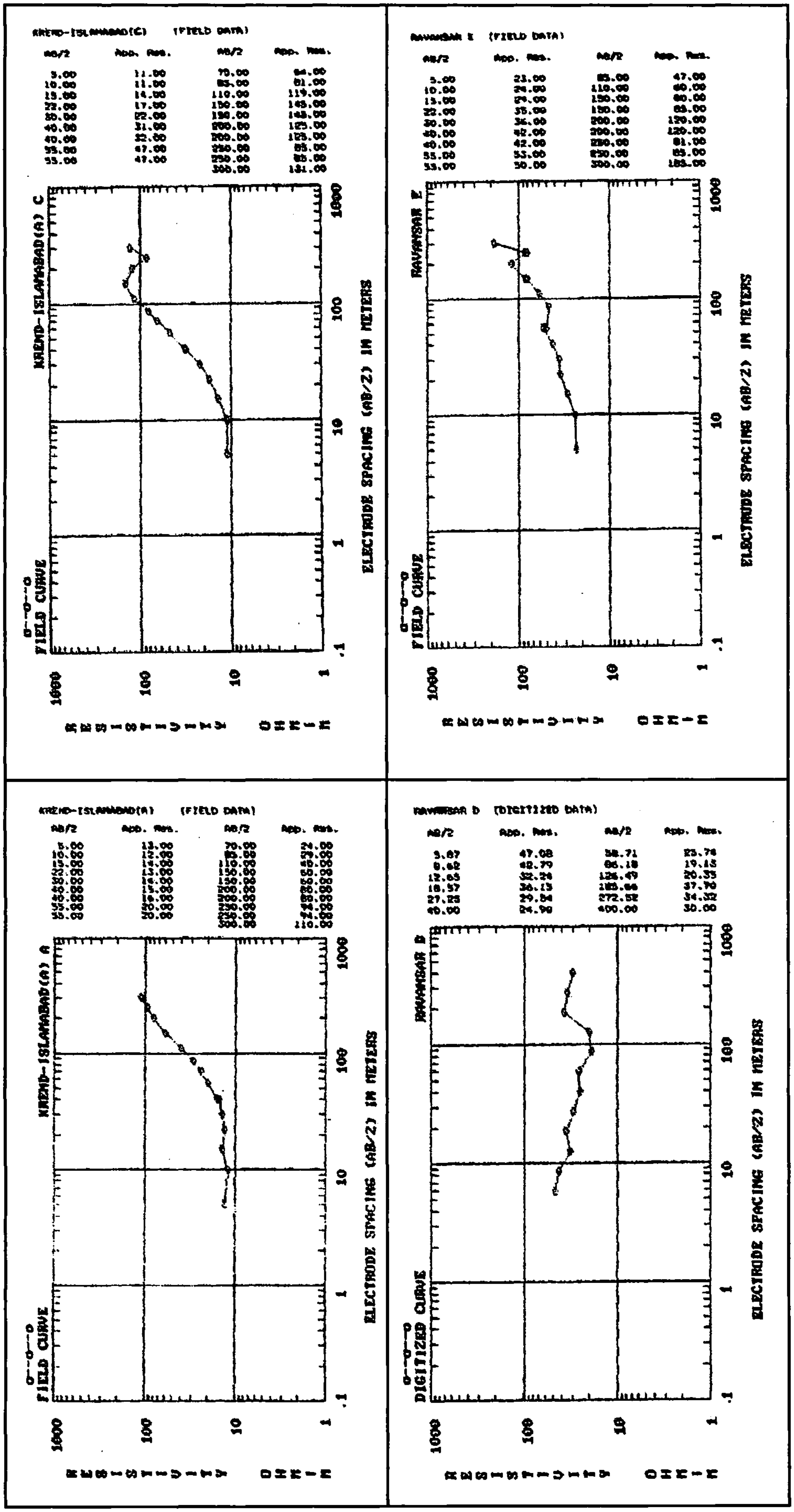

Figure 3. Few selected Ves Field Curve.

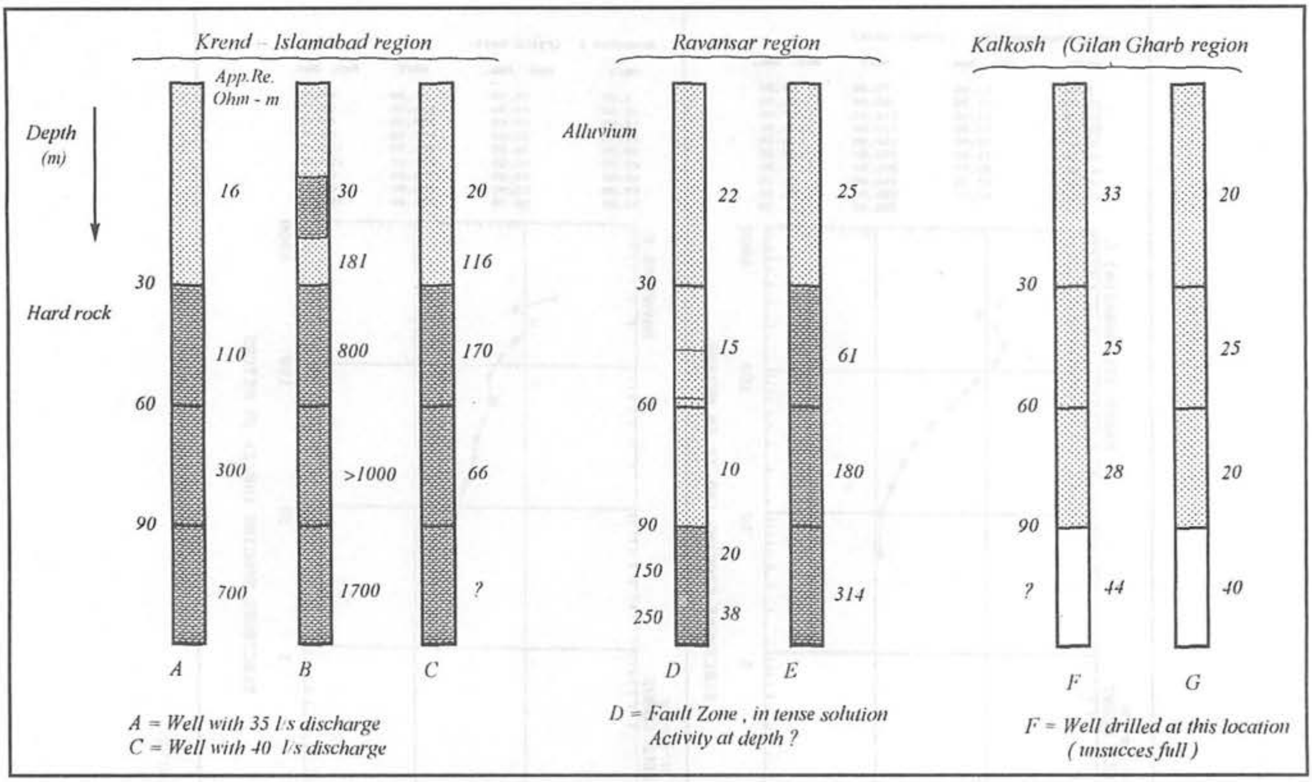

Figure 4. Schematic geoelectrical sections.

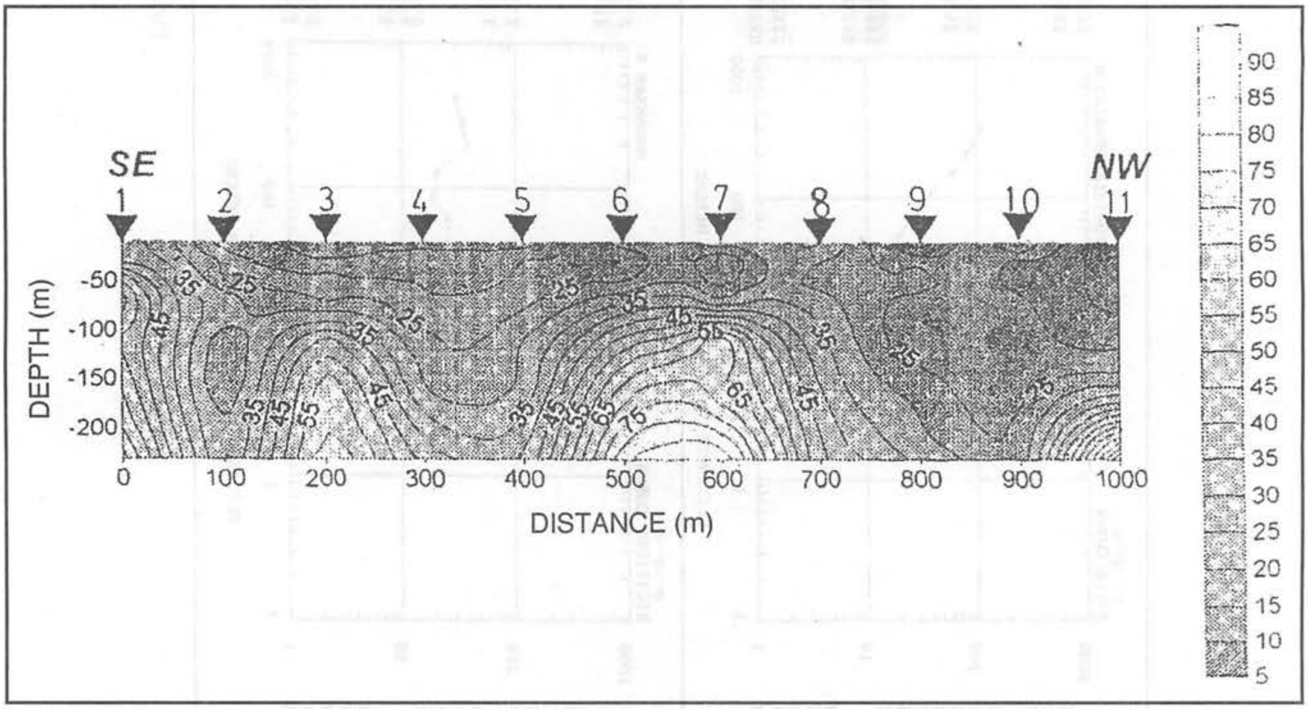

Figure 5. Apparent resistivity pseudo-section of Kalehkosh.

well sites in hard rock of carbonate formations. The carbonate rocks, primarily limestone and dolomite occur in the Kermanshah province. They range in texture from extremely fine grained to granular varieties and consist mostly of mineral calcite. The carbonate rocks in the area attain a thickness of several square kilometers and it contains interbeds of shale or shaly limestone or marl and marly limestones. The limestone differs from most other rocks in that they are highly soluble in water rich in carbon dioxide. Dolomites are less soluble but they are also been subjected to intense solution activity.

The soluble property of the rocks given rise to development of manifested topographic and hydrologic features. These include enlarged joints with rounded edges, wavy ridges and pitted surface. Percolation of groundwater through intergranular interstices and fractures has enlarged the openings and has become a large cave. The cave of Quri Qaleh with 13 km in length is a very impressive located on the road of Kermanshah-Paveh (Fig. 1). The collapse of unsupported beds above large caverns in some areas has left depression or sinkholes and development of internal drainage around it. Lithology, topography and structure have controlled the developments of secondary porosity and permeability in carbonate rocks in the area. Large topographic inequalities with in the area favours deep circulation of groundwater and solution activity in deeper levels. This can be clearly observed in Sarab Qanbar and Sarab Nilofar (two springs with about 1,000 to 1,500 l/s discharge). The structure and tectonic activity has an important control on determining the behaviour of carbonate rocks. Therefore, different factors combining have given rise to karstic features. In the Rijab area, dissolution of the Asmari limestone has produced karstic features. The rocks in the area have been extensively karstified and have formed important groundwater resources throughout the area. In this study it was found that geoelectrical method is an efficient tool and can be helpful in deducting the karstified zones. Vertical electrical sounding were carried out in three regions of Kermanshah province namely Krend-Islamabad, Kalkosh (Gilan Gharb) and Ravansar area.

The compact limestone in Krend region shows a very high resistivity of the order of 120–800 ohm-m. The reduction in resistivity values in the region to indicate for groundwater occurrence was not observed, but after drilling of few wells, successful well with 40 l/s yielding was obtained. Figure 4 shows the geoelectrical sections of few selected locations. It is observed that the presence of solution cavities within the limestone as a good aquifer, cannot reduce the resistivity very much and the best water yielding limestone may show a resistivity of the order of few hundred ohm-m.

The limestone formation in Ravansar area are marly although karstification is noticed in limestone. Different factors has given rise to karstic features. In general, the formations are vertical to gently dipping; solution activity is intense in some places along fault zones. The groundwater occurs in the limestone in the joints and solution cavities in some parts but the increase in the clay and chalk content in the limestone has effected the permeability of the formations. Therefore the aquifers are likely to be less productive. Geoelectrical survey was conducted to study the aquifer characteristics of limestone formations. It was found that the resistivity values decreases up to depth of 250 m bgl and there is a sudden increase in much deeper zones at 250 bgl (Fig. 4). These show the solution activity has probably extended to great depths.

In Kalkosh region the limestone formations have almost vertical dips, due to topographical factor the process of karstification is not pronounced in the limestone sequences. The coating of insoluble clay minerals on the carbonaceous rocks has also reduced the effective area open to attack by the acid water. Figure 5 shows a selected profile of apparent resistivity pseudo-section of Kalkosh area. No remarkable resistivities values are noticed in these locations.

CONCLUSION

Major parts of Kermanshah is comprised of carbonate rocks which has attain a thickness of several square kilometers and the structure and tectonic activities have given rise to karstic features. The presence of solution cavities as observed in Krend region could not reduce the resistivity values very much. The existence of karstification has to be established by drilling wells at depth of 300 m bgl at Ravansar region. In Kalkosh region the thick limestone sequences has not undergone the process of karstification.

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