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GEOPHYSICAL INVISTAGATION FOR
GROUNDWATER AQUIFER IN THE JORDAN
VALLEY

Potential sites for brackish water usage:

SMART Partners: Al-Balqa' Applied University
(BAU)

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INTRUDUCTION

The Jordan Valley (JV) is a part of the Dead Sea Transform (DST), a plate boundary zone which separate Arabian and African Plates (Fig.1). The DSF extends from The Red Sea in the south to Sea of Galilee (Lake Tiberius) in the north. The fault is a left lateral, comprised of a zone of en-echelon strike-slip faults. Motion along the DST initiated in the Miocene and has cumulative lateral displacements of about 105 km (*Quennell, 1958; Freuned et al., 1970; Garfunkel, 1981*). Due to different extensional forces along the DST a deep depression has formed such as Aqaba- Elate, Wadi Araba, Dead Sea and JV.

The Jordan Valley is a 110 km long morphotectonic features that that extends from the northern shoreline of the Dead Sea to the Sea of Galilee (Fig. 2). The eastern escarpment of the JV can be sub-divided into distinct terrains zones. These are, (1) the highlands (800 m-1000 m above sea level), (2) the escarpment, encompassing the east slope of the valley (up to 800 m above sea level), (3) the foothills from -200 m to the sea level, (4) the rift valley floor, the JV floor is gradually slopes from 220 m below sea level in the north (Sea of Galilee) then heading southward to the northern shore of the Dead Sea (about 420 m below sea level). The JV floor is mainly composed of Lisan formation of Quaternary, undifferentiated Neogene formation, talus deposits, fan deposits and terrace deposits. Underlain by several sub basins filled with marine and continental sediments. The Jordan Valley comprises several separate small basins (Jericho (Shuna) basin, Damia, Bet-Shean and Bakura.

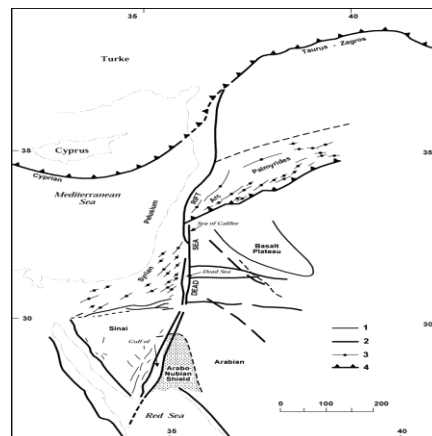


Figure 1. General Structural Setting

The Jericho basin plunges westward and terminates against a west dipping strike-slip fault. A buried monocline parallel to the fault segment was found and served as independent evidence for a local compression (Rotstein et al., 1991). Al-Zoubi et al. (2006) found the same kind of structure on the Jordan side and called it the Al- Kharar monocline. They suggested that this is a young active structure, which formed as a result of compression in the Shuna area due to the motion along the transform fault. In addition, several normal active faults were also found within the valley.

The Damia basin is a shallow and complex structure with several parallel faults at the edge and within the basin. The Bouguer gravity and the seismic data indicates that the major fault is buried under a few hundred meters of sediments, where the surface geology and the abrupt stream course change indicate the recent activity in the area (Garfunkel, 1981).

The Bet-Shean basin as a part of Mallaha structure (middle part of the Jordan Valley) was formed under transpression resulting from lateral slip combined with friction and pressure in this area (Belitzky, 2002). The transpression in this area produced counterclockwise rotation of the major fault. This rotation is combined with lateral slip on the east-west faults.

The purpose of the SMART II project to determine the sustainable quantity and quality of groundwater targeting the shallow (alluvial) and deep aquifers in the Jordan Valley and to increase the total amounts of water in the Jordan Valley for human needs. As well known that, the main economic activity in this region is agriculture, which depends on local water resources and the way to alleviate the deficit is to consider using water sources of different qualities, such as brackish water and treated effluent. Where the target of our research team is to conduct a full hydrogeological study of the brackish water resources in the alluvial aquifers and to develop a better understanding deeper aquifer systems in the project area. The study shall determine the availability of the brackish groundwater in the alluvial aquifers and possible utilization from the deeper aquifer zones as well both in terms of quantity and quality according to the criteria of safe yields.

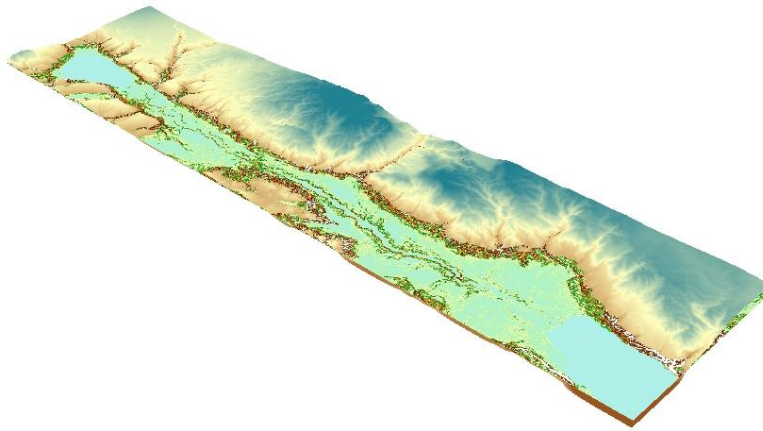


Figure 2: 3D model of Jordan Valley Depression.

ASSESSMENT OF GEOLOGY AND HYDROGEOLOGY

During the last decades, the area in general was studied by numerous researchers such as (Picards, 1931; Quennell, 1958; Daniel *et al.* 1963, Freund *et al.*, 1970; Neev and Hall, 1979; Garfunkel, 1981; Zak *et al.* 1981; ten-Brink *et al.*, 1993 and 1999; Belitzky, 2002; Schultze *et al.*, 2000, Al-Zoubi *et al.*, 2001, 2002, 2006, 2007).

The JV depression as a rift valley bordered by two faults. The western boundary fault was noted as the oldest tectonic element in the study area and the eastern boundary fault of the Dead Sea Basin extends up to the NE corner of the Dead Sea and then. This fault bends to the east, where, however, only normal throw is evident.

The sedimentary section of the study area is subdivided into two parts. The pre-rift section from Paleozoic to Early Tertiary age and a syn-rift (syntectonic) section of Miocene to recent age. Three relatively deep boreholes were drilled in the study area. Jericho 1 is the deepest borehole, located on the pre-rift Senonian chalk/chert in the western side of the basin and reaching Oxfordian limestone/shale at 1644 m depth, whereas the Jordan Valley 1 (JV-1) started in Pleistocene rift sediments and penetrated about 1000 m to reach the top of the Jurassic (Fig. 2). The Jordan valley 2

(JV-2) borehole penetrated about 1400 m, where the top of the Early Cretaceous was found at a depth of 1367 m bgl (Fig.2). The topmost section of this well down to 560 m, including the young syntectonic sediments and late Pleistocene Lisan Marl Formation cropping out in the Jordan valley (Shawabkeh, 2001). The detailed geological description shown in table 1.

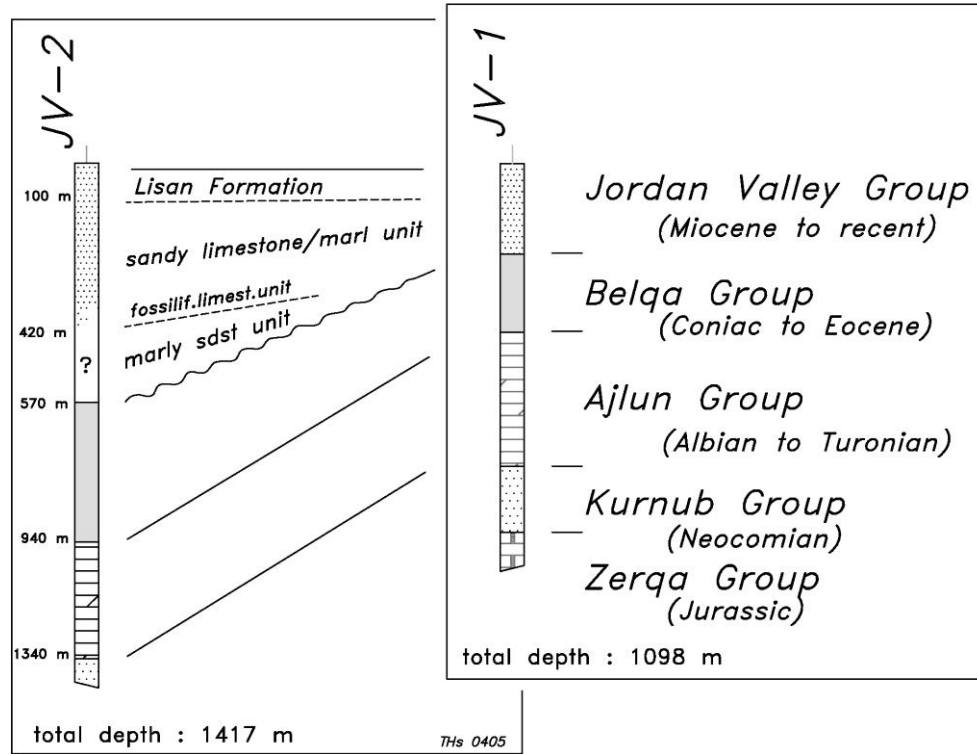


Figure 2. JV-1 and JV-2 borehole

The pre-rift sediments such as Triassic, Jurassic and Cretaceous system are mainly distributed and exposed along the escarpment that defines the eastern boundary of the area. This type of rocks Triassic, Jurassic and Cretaceous system is generally distributed in the NE-SW direction. This system has folding axes in the same direction. The folds are gentle and are both synclines and anticlines (Muneizel *et al.* 1993). The system well bedded horizontally or gently dipping step down into the JV in a series of faults in the same direction as a major boundary fault.

The Triassic and Jurassic systems consist of Zerqa Group, which subdivided into two formations Z1 and Z2. The Z1 formation related to Triassic period and consists of sandstone, calcareous, limestone, shale and gypsum. The Jurassic formation Z2 mainly

consists of limestone, marl, dolomite, sandstone and shale. This formation distributed in the JV side wadis (*Toll, 2007*).

The Cretaceous system consists of the Kurnub group K, which lies with conformity on the Azab formation Z2 of Zarqa group. The K group is a predominantly deposits at the base of Cretaceous and subdivided into two units. The lower one massive white sandstone with thin dolomite and shale bands, where the upper one is varicolored sandstone containing thin intercalations of limestone, shale, dolomite and marl.

The Kurnub group is overlain with conformity by deposits of upper Cretaceous – lower Tertiary.

The Upper Cretaceous – Lower Tertiary systems has been divided into two groups. The lower one is termed Ajlun group and the upper part is named Belqa group.

The Ajlun group falls within the Cenomanian and Turonian epochs and outcrops extensively along the escarpment of the JV. The group is essentially a carbonate sequence and consists of seven litho-stratigraphic subdivisions (A1-7). These divisions based in water bearing characteristics of the sediments and separate the sequence on the aquifers and aquicludes.

The Belqa group ranges in age from Santonian to Upper Miocene. The carbonate rocks of this group are conformable with the underlying Ajlun group. In the study area the group subdivided into two formations B1 and B2 and its exposures occur mainly along the escarpment in the Northern part of the JV. Both formation B1 and B2 could be recognized as an aquifer.

The Upper Tertiary system is an undifferentiated formation of the JV group, where it consists of mainly conglomerates and marl. The deposits of this formation associated with the tectonic activity which initiated the rift valley. The JV groups lie unconformable on the older systems and are overlain by Quaternary system.

The Quaternary system consists of the Lisan formation and recent sediments. The Lisan formation is lacustrine deposits and lies unconformably on the older system in the JV the Lisan formation appears not deformed by the tectonic activity.

The Recent superficial deposits are composed of fan, talus and terrace river deposits. The terraces cut at various stages in the formation of the wadis and covered with the terrace alluvium (Toll, 2007).

Several geological cross sections were drawn out, along the Jordan Valley are to show the geological layers and the structures within the study area. The Figures 3, 4, 5 and 6 demonstrate the geological cross sections including the coordinate of the starting point and the end points of the sections and the structures and the lithological layers. The directions of the cross sections that considered in this study are East-West. These geological cross section are the following:

Figure 4, shows the cross section in Karameh area

Figure 5, shows the cross section in Salt area

Figure 6 and 7, , shows the cross section in Deer Abo Seed Area and Northern part of Northern Showneh Area

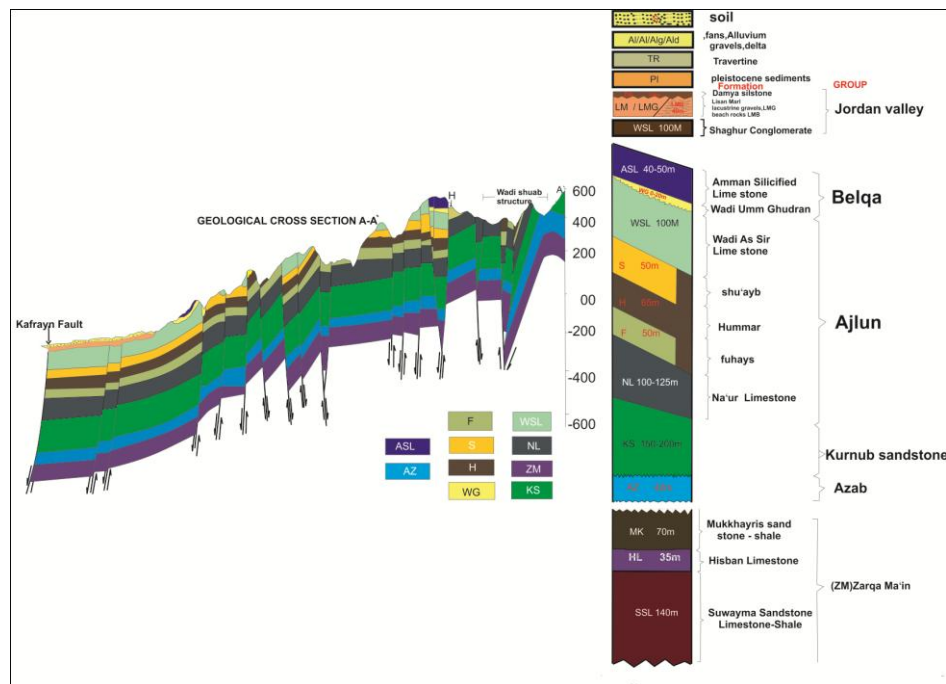


Figure 4. The Geological cross section at the Karameh Area

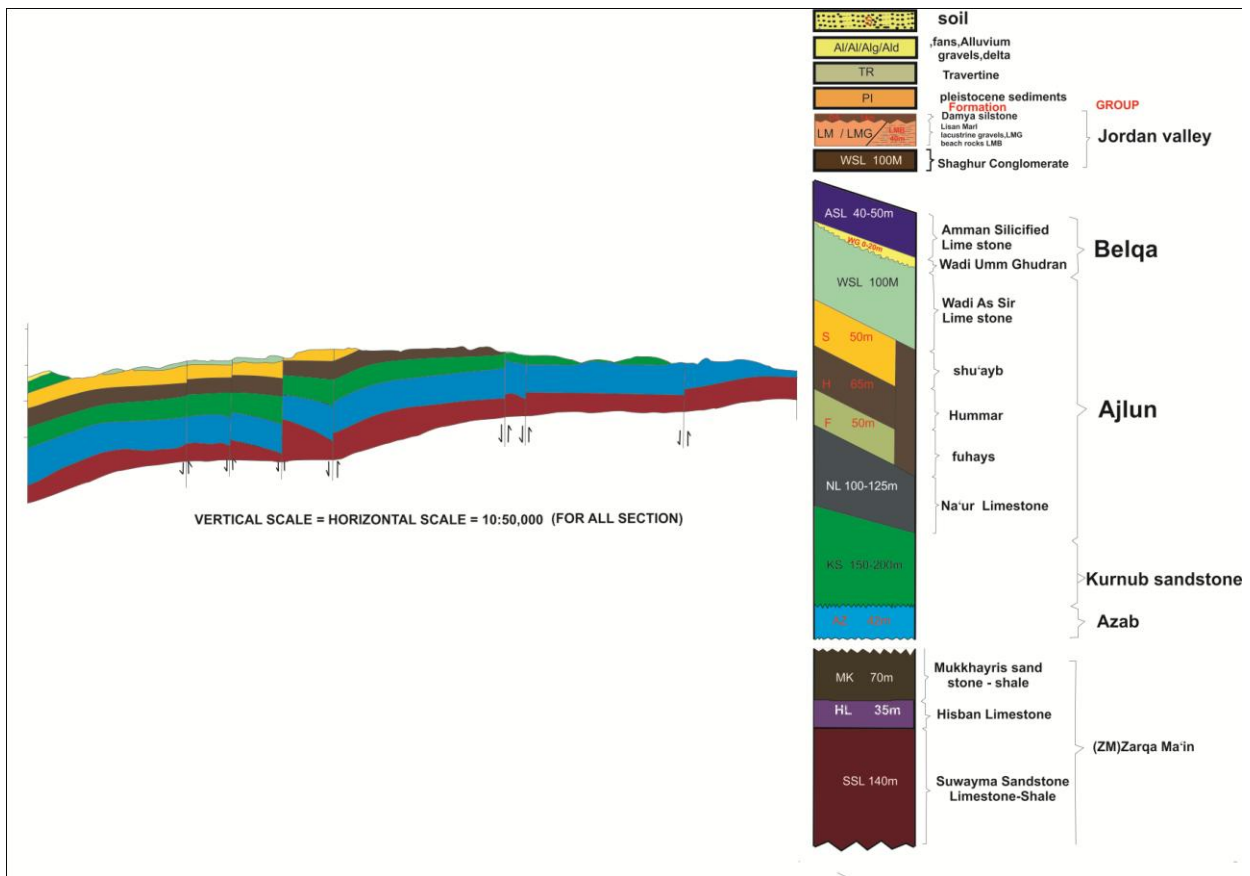


Figure 5. The Geological Cross Section at the Salt area

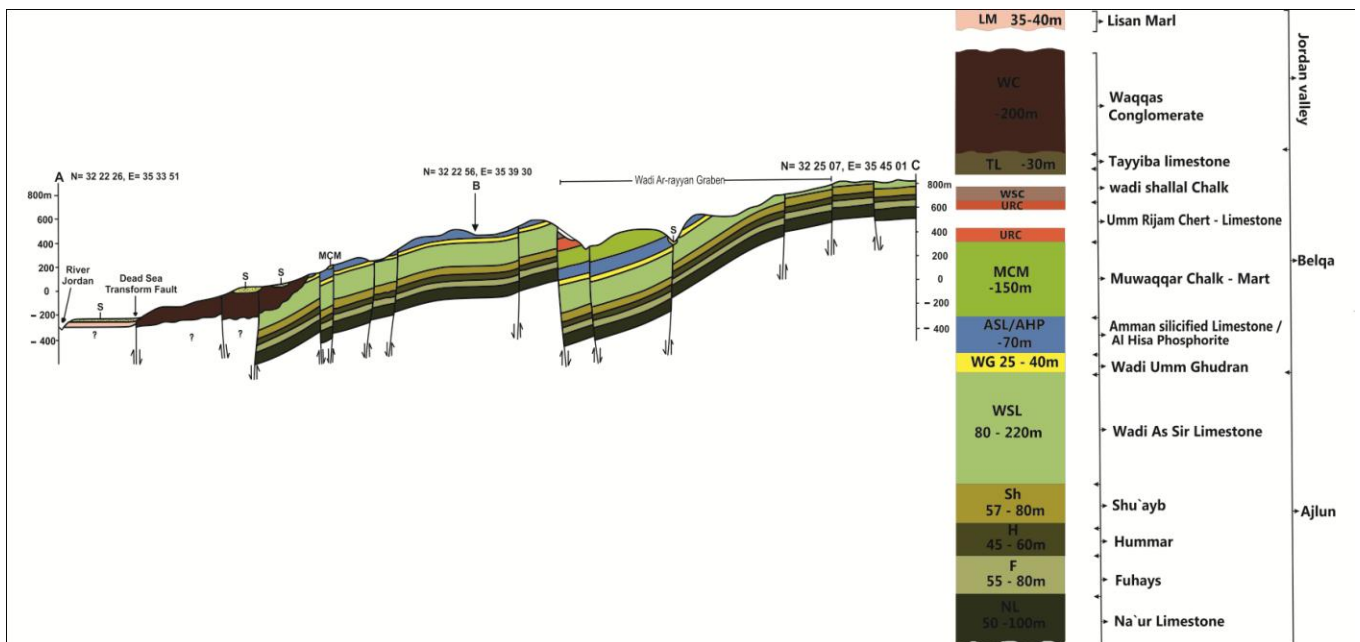


Figure 6. The Geological Cross Section at the Deer Abu Seed

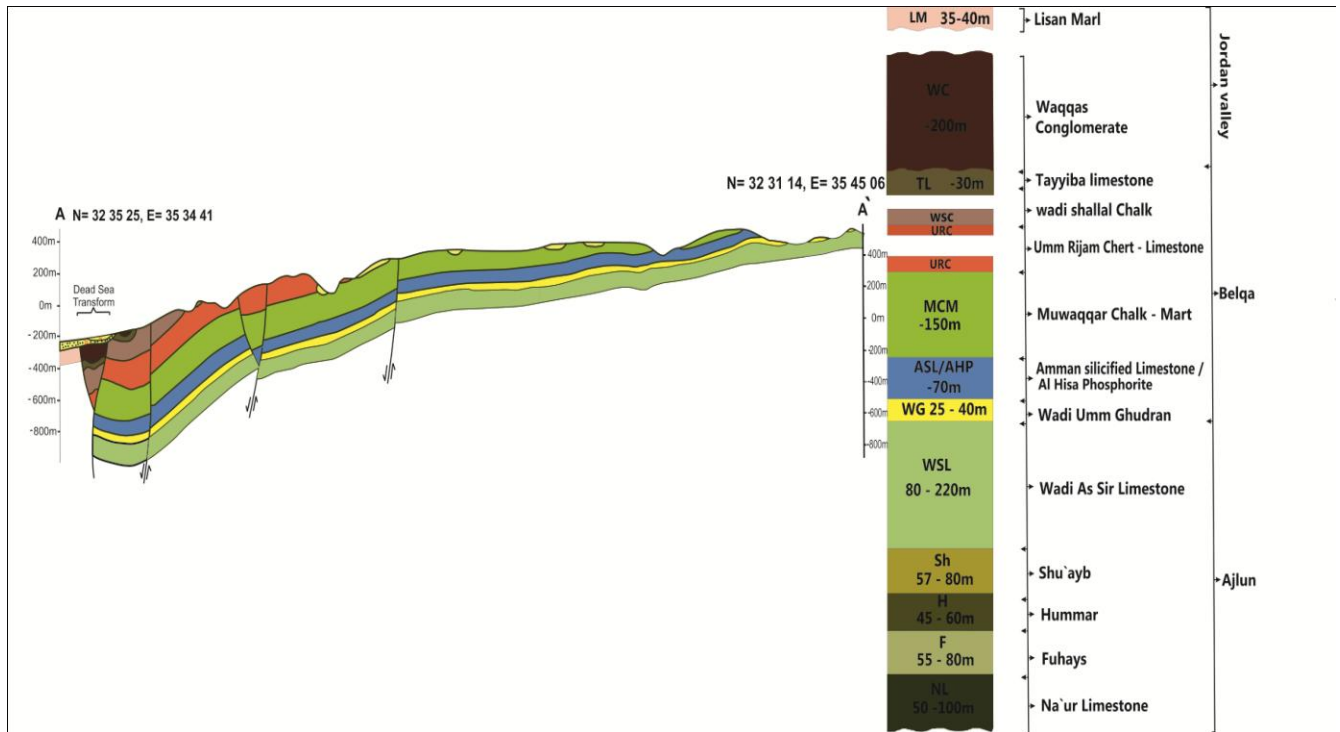


Figure 7.The Cross Section of the North Showneh Area

Table.1 Geological description of the area

Period	Epoch	Group	Formation	Symbol	Lithology
Quaternary	Holocene	Jordan Valley	Fan Alluvium, river deposits, Terrace, Talus	J	Sand, Clay, Gravel
	Pleistocene		Lisan Marl		Marl, Clay, Gravel, Gypsum
Tertiary	Pliocene		Balqa Group		Undifferentiated
	Miocene				
	Oligocene				
	Eocene	Amman Silicified		B2	Silicified Limestone, Chert
	Paleocene	Wadi Ghudran		B1	Marl, Marly Limestone
Upper Cretaceous	Maestrichtian				
	Companion				
	Santonian				
Upper Cretaceous	Turonian	Ajloun Group	Wadi Essir	A7	Limestone
	Cenomanian		Shueib	A5-6	Marly Limestone
			Hummar	A4	Limestone
			Fuhais	A3	Marl, Shale
			Naur	A2-1	Marly limestone
	Lower Cretaceous	Albian	Kurnoub Sandstone		K
Aptian					
Neocomian					
Jurassic		Zarqa Group	Azab	Z2	Limestone, Marl, Dolomite, Sandstone, Shale
Triassic			Ma'in	Z1	Sandstone, Limestone, Shale, Gypsum

Surface Water

The Jordan Valley itself is a globally unique morphotectonic structure. To the east, the valley rises into a range of primarily sandstone mountains running from the north (reached 1300 m above sea level, Ajloun) to the south (Fig. 8). The escarpments to the east and west are cut by wadis (valleys and semi-dry river basins), Figure 8, created from the flood flows which drain from the highlands into the valley floor. Wide and dramatic alluvial fans have been formed at the mouths of these wadis.

The Jordan Valley floor has been almost completely developed for agricultural purposes. The aquifer could be recharged from four sources, from precipitation which averages 100 to 400 mm annually; from irrigation water returns; from base flow and springs which seep from the foothills of the rift side wadis and water captured in dams constructed from the rift side wadis. Water stored in the reservoirs could be used to recharge the ground water to reduce evaporation losses. These dams are the following: Al-Karama dam, Shueib Reservoir, King Talal Dam, Azab, Zeglab, and the Yarmouk River basin.

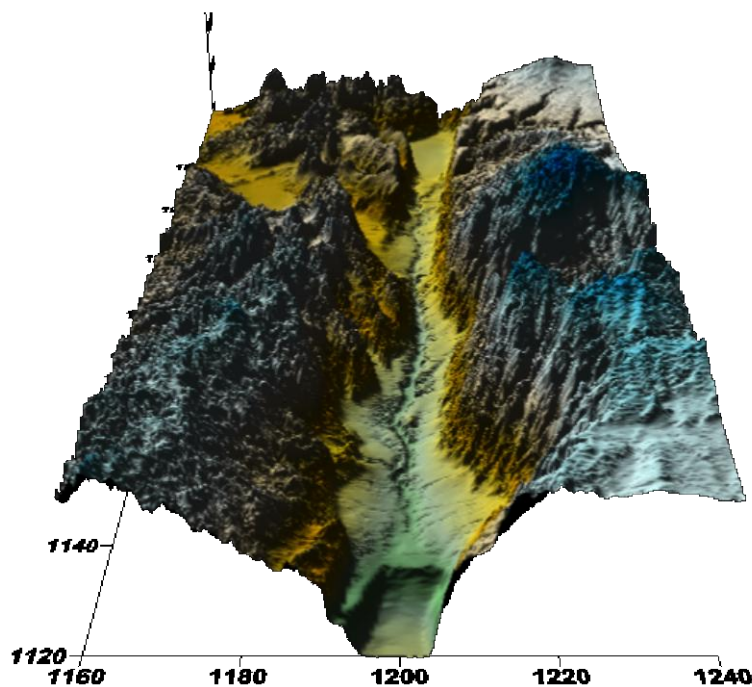


Figure 8. The JVand its Escarpment

The catchment area of the basins is approximately around 10000 square kilometers. The basins generally receive moderate to relatively high amounts of precipitation (approximately 200 mm to more than 500 mm per year), Figure 9, where Figure 10 shows the major surface water basins in Jordan and Figure 11, present the map of the side wadies of the JV.

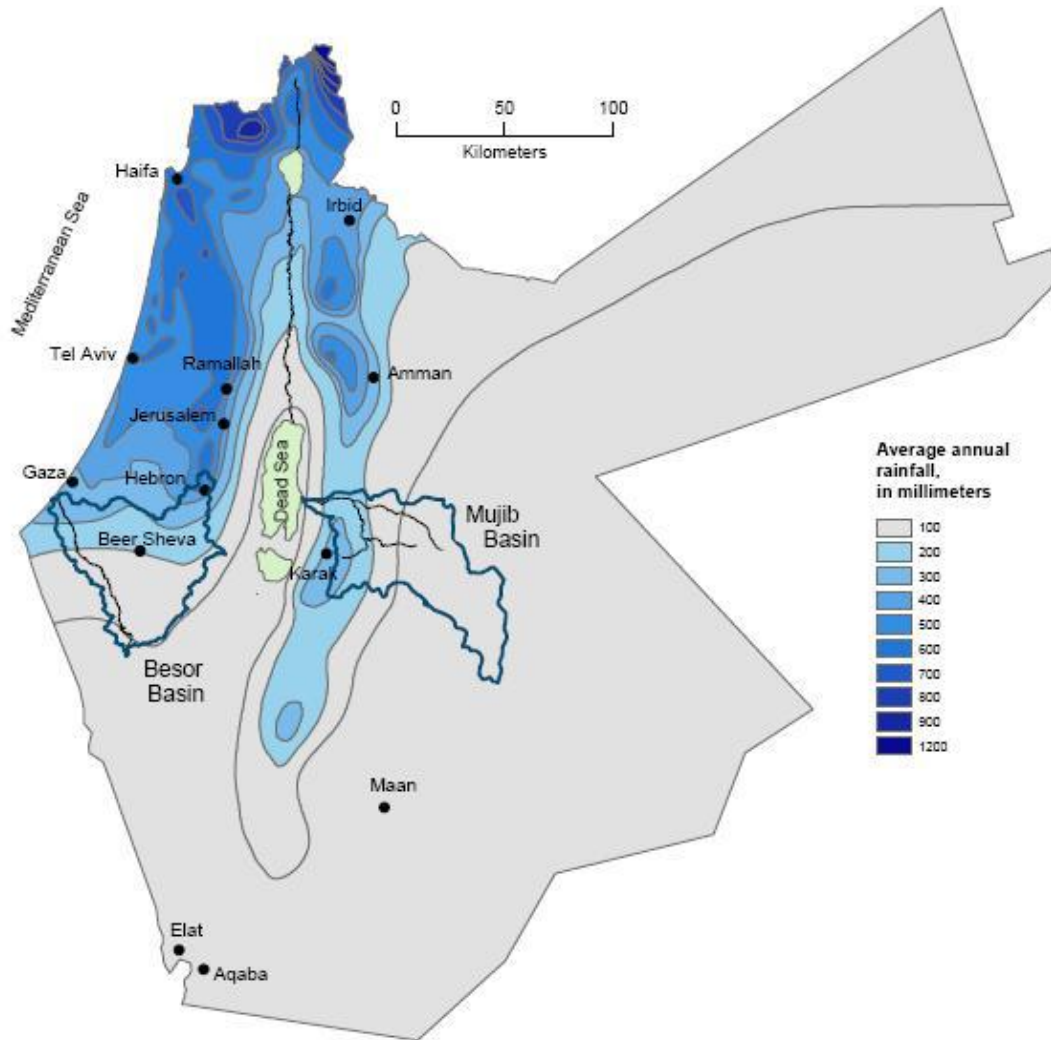


Figure 9. Average annual rainfall in millimeters



Figure 10. Major surface water basins in Jordan.

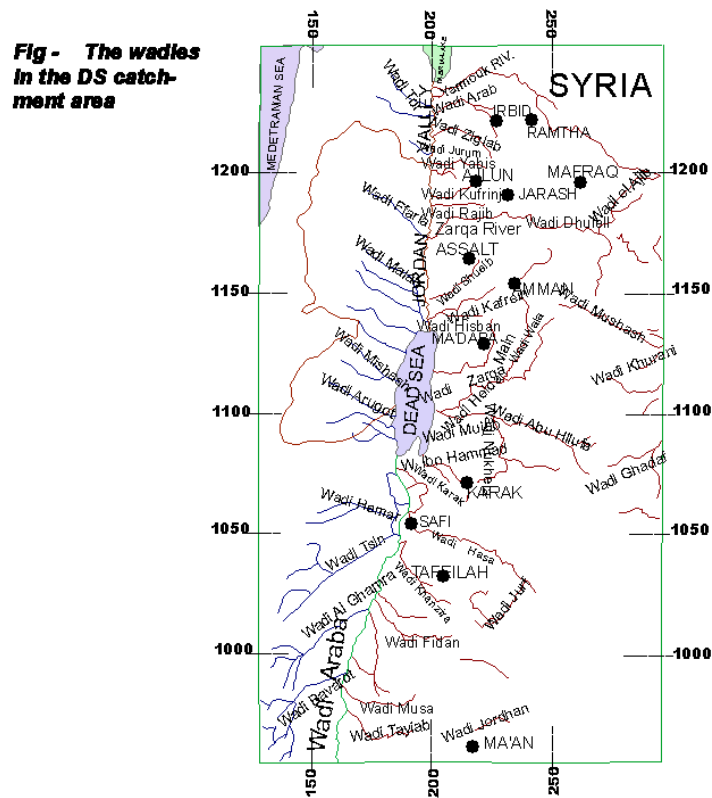


Figure 11. Map of the side wadies of the Jordan Valley

The climate change predictions indicate a reduction in surface water runoff of 10 – 30% by the middle of the century and by 20 – 50% by 2010. This would lead to a significant reduction in surface flow of the wadis and streams in the study area. The combination of the decline of rainfall and runoff will reduce the groundwater recharge significantly.

SURFACE GEOPHYSICAL DATA

The various shallow geophysical methods were carried out along the JV to increase our knowledge of the shallow aquifer in the JV. The shallow geophysical method proves that it is possible to penetrate up to about 150 m of the JV sediments in order to estimate the depth of shallow aquifer, to estimate the aquifer properties (water content and permeability), to monitoring the variation of water contents with the time, to delineate buried wadis and ancient channels and to delineate water boundary between fresh and saline water.

Prior to performing the shallow geophysical survey such as Continuous Vertical Electrical Sounding (CVES), Nuclear Magnetic Resonance (NMR), Ground Penetrating Radar (GPR) and Electromagnetic Radiation (EMR).

The goal of geophysical study are the following:

- 1-Delineation shallow active faults and fractures.
- 2-Estimate the depth of the shallow aquifers.
- 3-Estimate aquifers properties (water content, permeability).
- 4-Monitoring the variation of water contents with time.
- 5-Delineation buried wadis and ancient channels.
- 6-Delination the boundary between fresh and saline water.

GEOELECTRICAL DATA

Continuous Vertical Electrical Sounding (CVES)

The CVES used to investigate the variation of the electrical resistivity with depth for hydrogeological goals. The whole procedure is based on the assumption that the subsurface has a horizontal stratigraphy. In other words it consists of discrete, horizontal, homogeneous and isotropic layers.

The 2-D electrical imaging survey used large number of electrodes connected to a cable used as multi- electrodes cable. The measurements were read automatically by an electronic switching unit along the resistivity profile. Wenner–Schlumberger array is a mixture between Wenner and Schlumberger arrays by which the resistivity changes in the horizontal direction, as well as the horizontal direction can be detected along the survey profiles (Pazdirek and Balha 1996).

The apparent resistivity for Wenner –Schlumberger array:

$$\rho = \pi n (n+1) a R$$

Where (R) is the measured resistance, (a) is the spacing between the (Pi) electrodes and (n) is the ratio of the distance between C1-P1 and P1-P2 electrodes.

The depth of investigation increased as the spacing between the potential electrodes P1-P2 is increased 2a and the measurements are repeated for n equals to 1, 2, 3, 4, 5 and 6. The P1-P2 spacing is increased and the same sequence measurement repeated (Fig. 12).

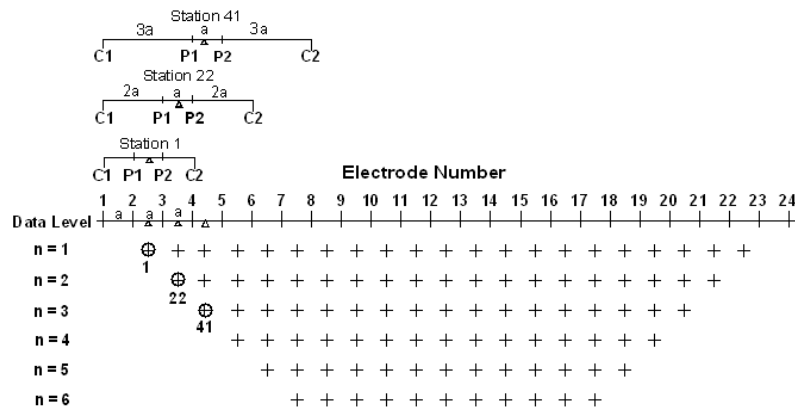


Figure 12. The arrangement of electrode for a 2-D electrical survey and pseudo section data pattern for the Wenner-Schlumberger arrays.

Fifty two of CVES profiles were carried out along the JV (Fig. 13) using Syscal –Pro system (IRIS instruments) with 48 multi- electrodes system. The electrodes arranged along the profile with a between them is fixed to be 5 m.

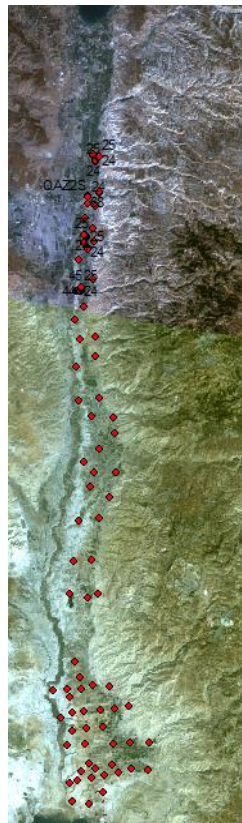


Figure 13. The CVES location

DATA PROCESSING

The resistivity data was processed using RES2DINV program that automatically generates a two-dimensional resistivity model for subsurface from electrical imaging surveys (Griffiths and Baker 1993; Loke 1996; Loke and Baker 1996). The program can handle large data sets collected with large number of electrodes and can account the topographical effect along the survey lines (Loke 2000).

The Root-Mean-Square (RMS) error quantifies the difference between the measured resistivity values and the calculated from true resistivity model. The average RMS error of the profiles was less than 10% due to the presence of unconsolidated dry alluvial at some sites.

Vertical Electrical Sounding

In addition to the CVES the forty five Vertical Electrical Sounding VES stations were collected during the last 4 years with a maximum AB/2 separation of 400 m. The distribution of the VES stations in the study area is shown in Figure 15 A, B and C. The collected data were interpreted through partial curve matching techniques, using theoretically calculated master curves. This information (layer parameters) was used to interpret the sounding data through a 1-D inversion technique (i.e. RESIX-IP, Interpex Limited, Golden, Co.). The RESIX-IP inversion technique is an interactive, graphically oriented, forward and inverse modeling program.

CVES RESULT

The result of the interpretation of the CVES profiles presented in Figures 14 A, B and C. Where the section shows clearly some of buried wadies, channels, faults and saturated zones. .

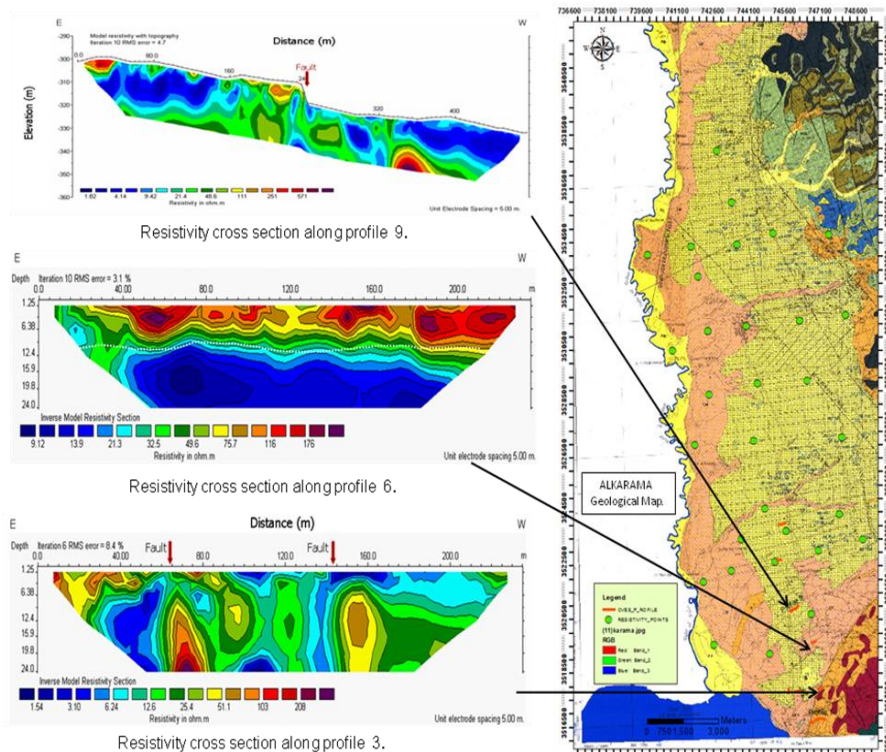


Figure. 14A. The CVES location map in the southern part of the JV and CVES sections

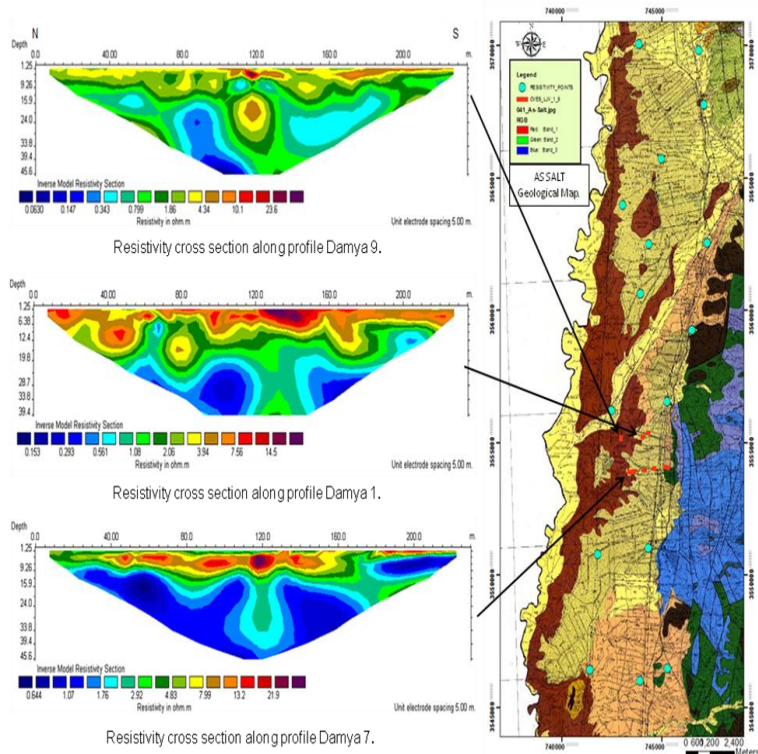


Figure.14B. The CVES location map in the central part of the JV and CVES sections

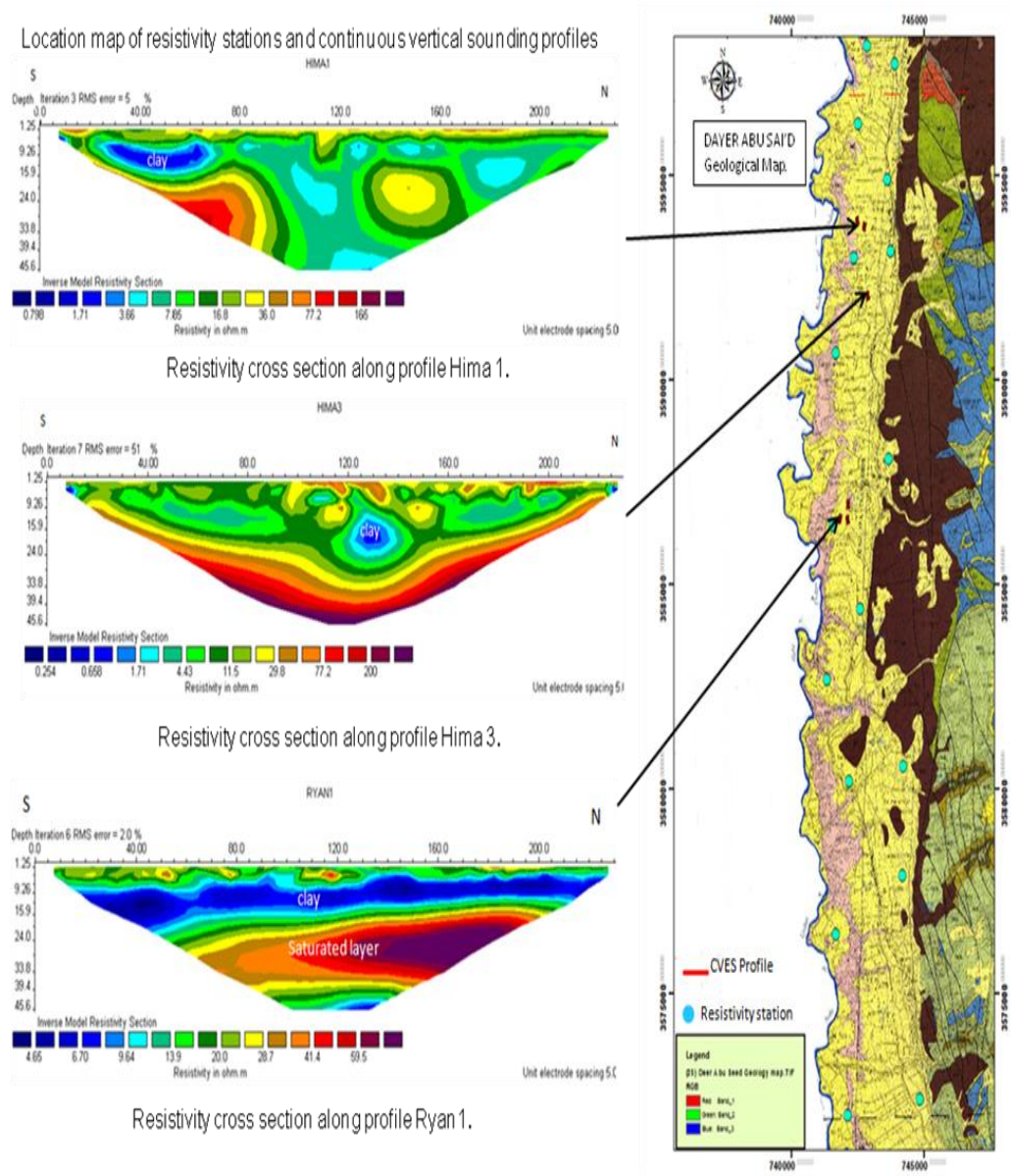


Figure. 14 C. The CVES location map in the northern part of the JV and CVES sections

VES Results

To study the subsurface resistivity distribution of the area, iso-resistivity maps at different depth from the earth surface are presented (Fig. 15, 16 and 17). Three depth levels, these are 25 m (Fig. 15), 75 m (Fig. 16) and 100 m (Fig. 17) were selected. Zones of different resistivity values are grouped in terms of relatively high (>80 Ohm.m), moderately high (40-80 Ohm.m), moderately low (15-40 Ohm.m), low resistivity (1-15 Ohm.m) and very low resistivity (< 1 Ohm.m).

In order to make a meaningful interpretation of conditions pertaining to the resistivity characteristics of the study areas, the relatively high resistivity was found in the eastern side of the study area along the rift shoulder. It is worth to note that in some places this zone became wider especially in the south eastern part of the JV basin. This zone became narrower with the depth. The zone of moderate high resistivity and moderate low resistivity occupied the central part of the rift (Jordan side). These two zones have a width of about 6 km in the southern part of the study area and less than 2 km in central part of the JV. It is worth to note that the wider part of this zones it might be related to the water seepage from Wadi Kafreen and Wadi Shuayb.

The low resistivity zone and very low resistivity zone, were proceeding from the northern end of the Dead Sea northwards along the Jordan River covering the central part of the rift (Fig. 15, 16 and 17). It is worth to mention that the boundary of the above mentioned zones in general agreed with the faults trends, which are cutting the study area (the area occupied by these zones became wider with the depth penetration). In order to have a clear opinion of the resistivity structure with depth, three resistivity cross-sections in the southern part of the JV were demonstrated in Figure 20, 21 and 22.

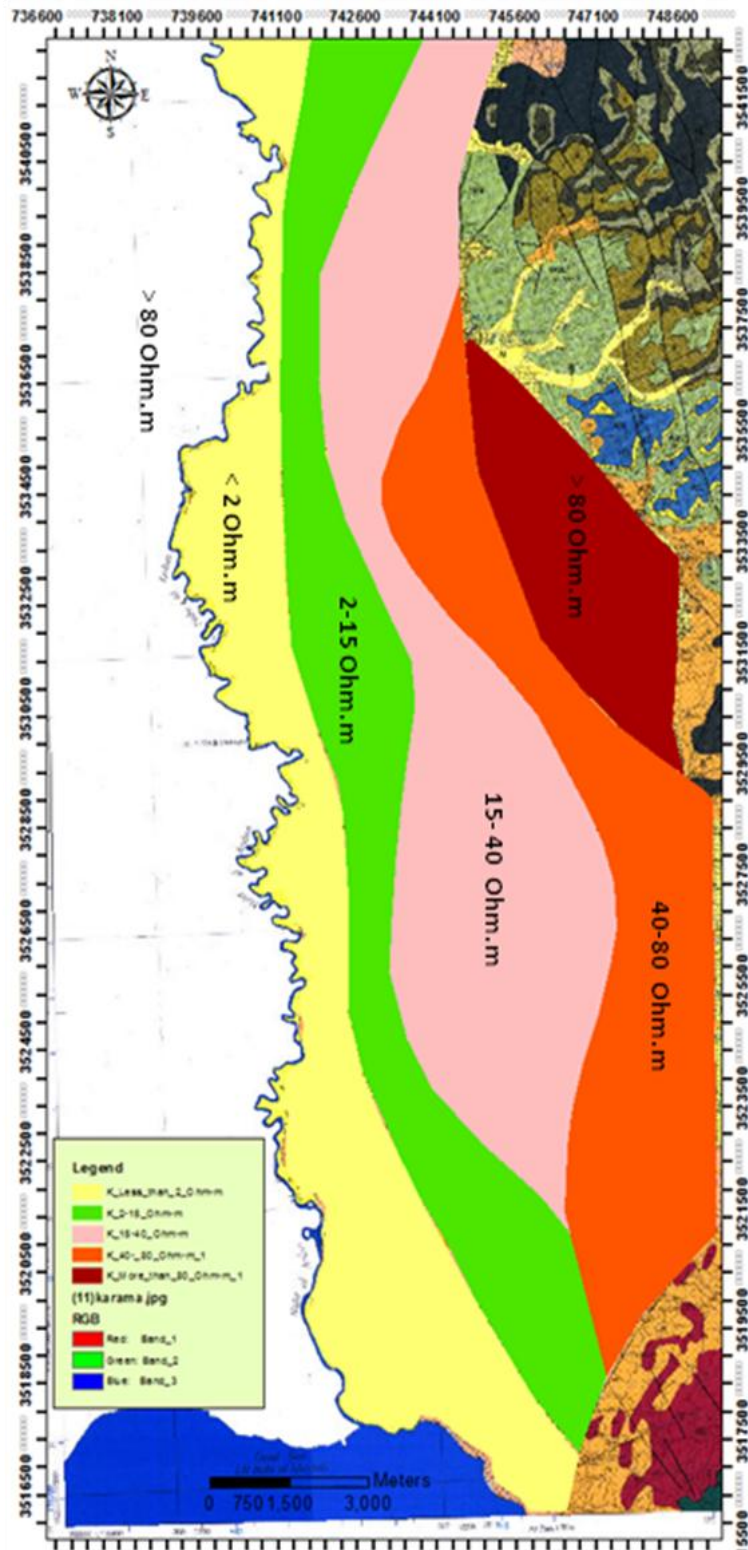


Figure 15. Resistivity Distribution map at a depth of 25 m

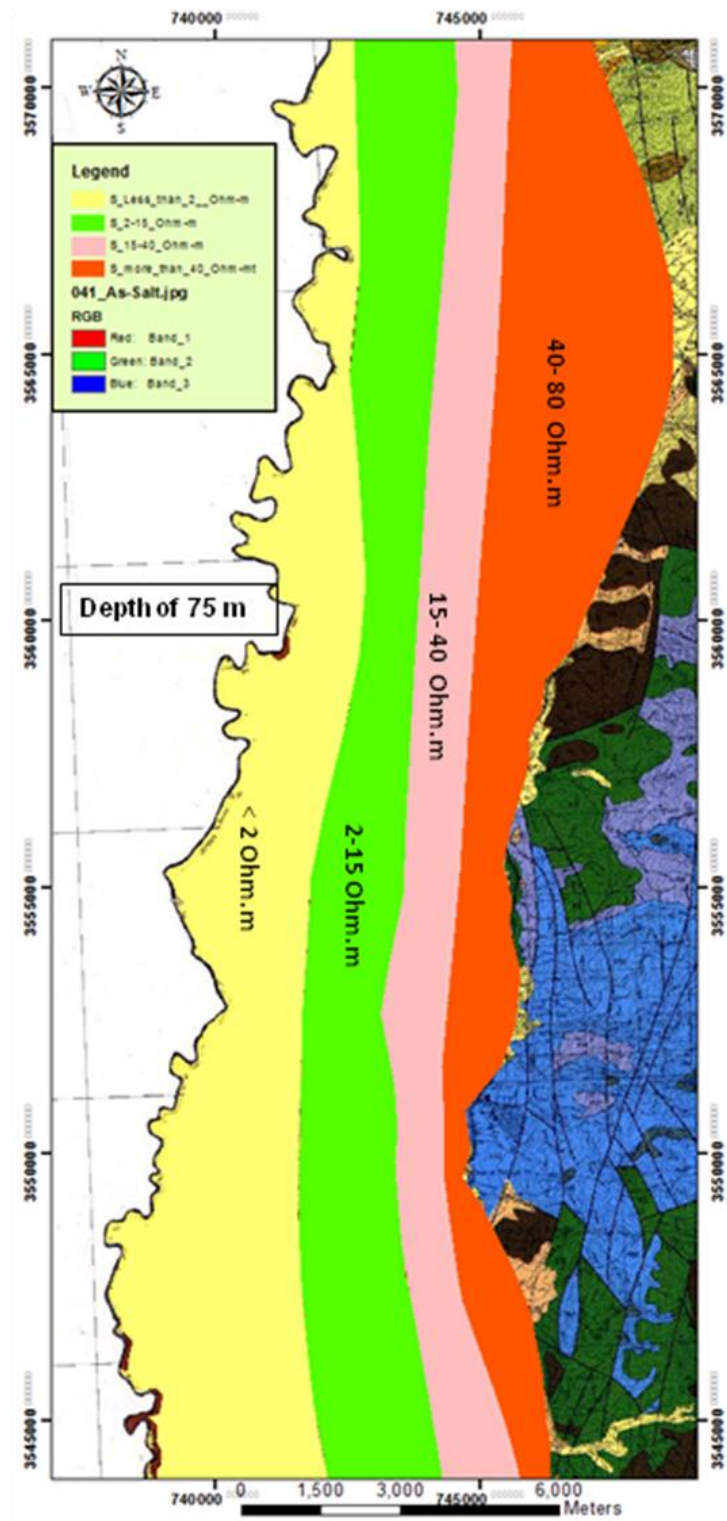


Figure 16. Resistivity Distribution map at a depth 75 m

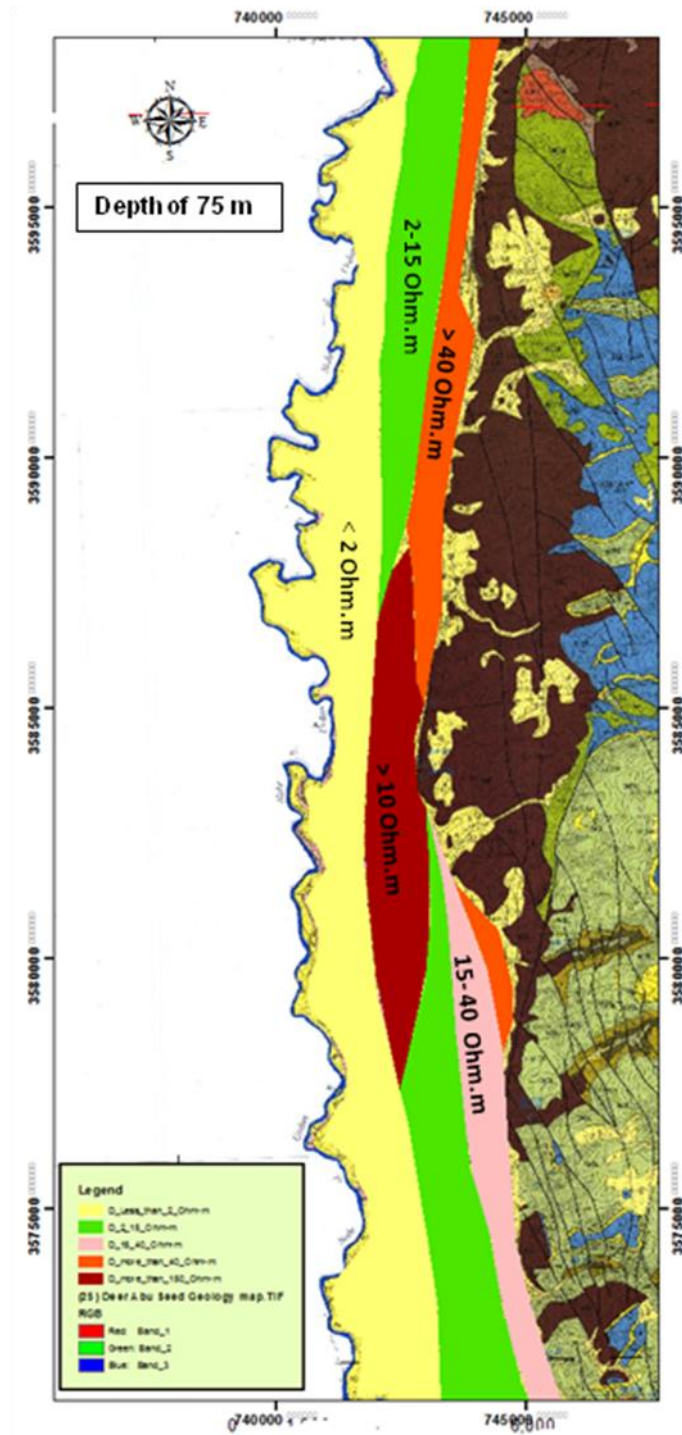


Figure 17. Resistivity Distribution map at a depth 100 m.

Profile 1 is about 10 km long and it has an approximate orientation of E-W direction. The profile crosses the study area in the southern part and is nearly perpendicular to the direction of the general geological structure of the area. The resistivity cross-section along this line is presented in Figure 18. As can be seen, the eastern part of the section are marked by a high moderate resistivity (40-80 Ohm.m) along all the vertical section with a top thin layer of high resistivity (>100 Ohm.m). The moderate low, low and very low resistivity occurred in the western side of the profile and dipping parallel to each others.

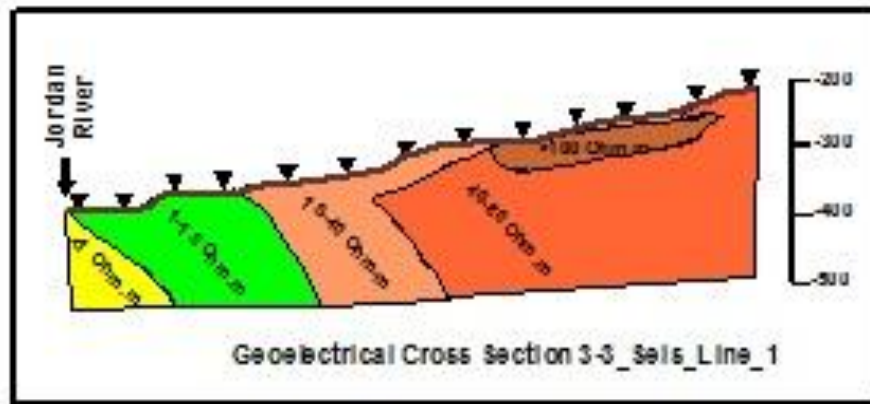


Figure 18. Geoelectrical Cross section 5 km to the north of the Dead Sea shoreline, described the resistivity distribution in E-W direction in vertical scale.

Profile II is located in the central part of the study area, crossing the Shuna village and oriented in the E-W direction. The high resistivity layer occurred in the eastern side of the profile and extends to central part of it. The high resistivity could be divided into two parts. The thin one covered the eastern side and penetrates to a depth of about 80 m, with the resistivity value more than 120 Ohm.m and thick part in form of lens with the average resistivity value 80 Ohm.m and extends to the center of the profile. In the western side of the profile a very low resistivity value occurred in formed a Dom shape. The central parts of the profile have low moderate resistivity value less than 15 Ohm.m (Fig. 19).

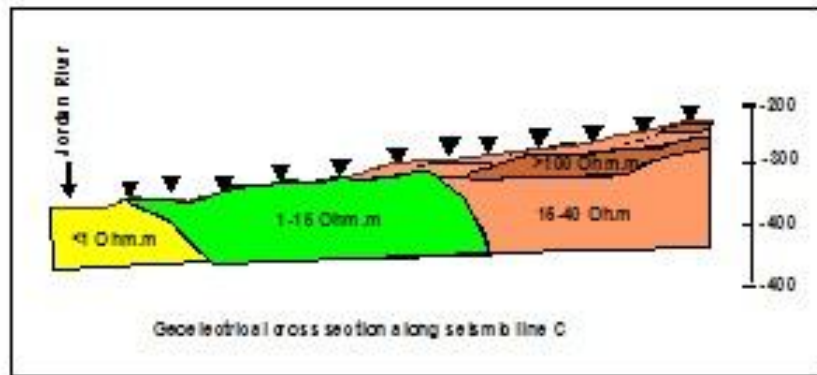


Figure 19. Geoelectrical Cross section 10 km to the north of the Dead Sea shoreline, described the resistivity distribution in E-W direction in vertical scale.

Profile III is located in the south of Karameh in E-W orientation. The vertical section of this profile shows that the resistivity is more differentiated than the southern one. A thin layer with the high resistivity occurred at a depth of about 45 m in form of lens in the eastern end of the profile. The lens is located between the moderate resistivity value (<40 Ohm.m), Figure 20.

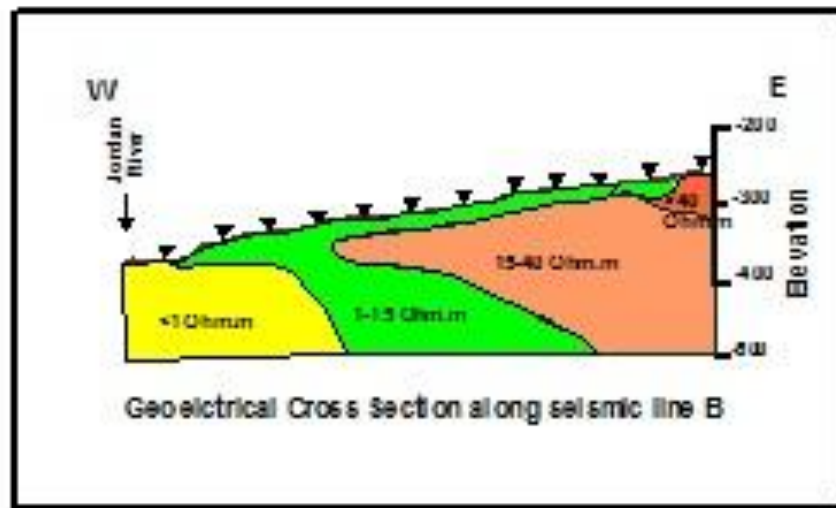


Figure 20. Geoelectrical Cross section 17.5 km to the north of the Dead Sea shoreline, described the resistivity distribution in E-W direction in vertical scale.

NUCLEAR MAGNETIC RESONANCE (NMR)

Nuclear magnetic resonance NMR or proton magnetic resonance PMR a new geophysical technique, which allowing direct noninvasive ground water detection from the surface. Twenty NMR (PMR) station were measured along the JV (Fig. 21) using the 100 m square loop. The location of these stations was chosen with minimal noise from power lines and other types of cultural activity. The maximum depth of penetration was approximately 100 meter.

PMR measurements allow to estimation the water content of saturated and unsaturated zones of the shallow subsurface layer indirectly. The result helped to estimate the aquifer properties such as porosity, permeability and transmissivity.

The collected data were processed using NUMIS-PLUS inversion software. The field sounding curve which represents the maximum measured amplitude of the signal (nanoVolt) versus pulse moment (Ampere per millisecond).

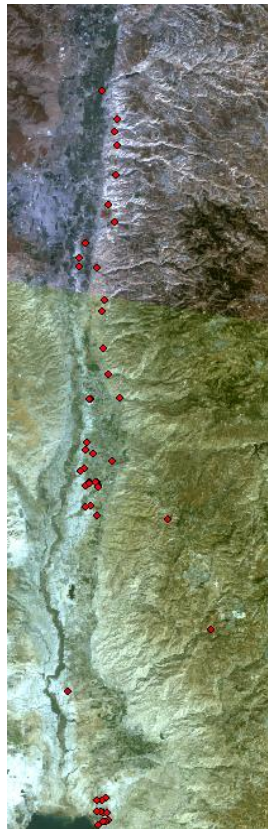
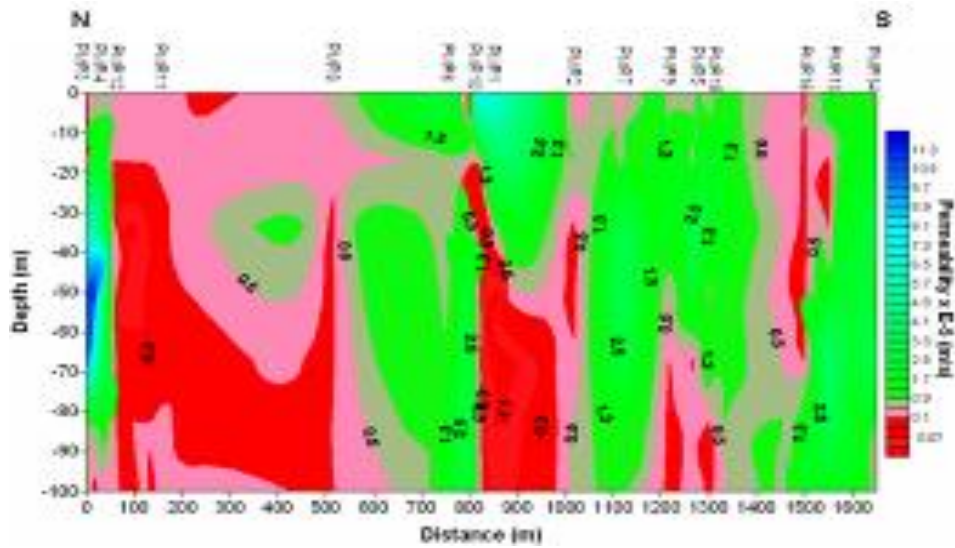
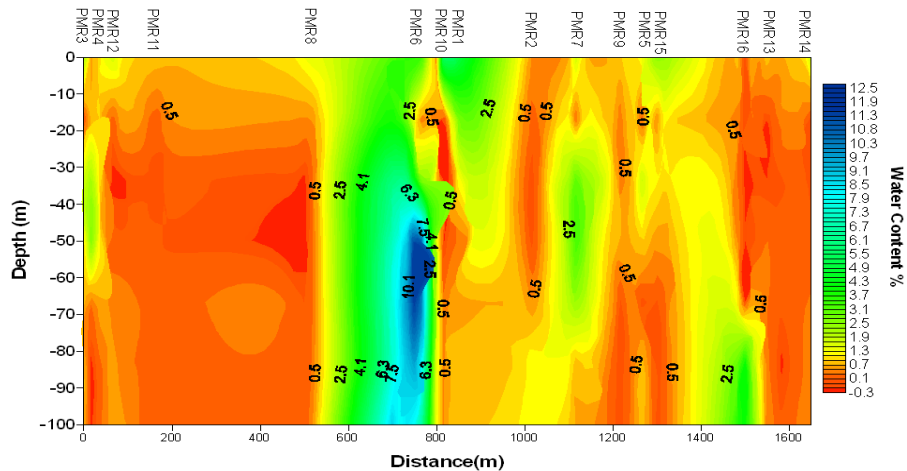


Figure 21. Location Map of NMR & TDEM

The result of the NMR measurements shows that, the permeability along the JV basin could be divided to three groups as shown in (Fig. 22). The low values permeability zone with the values less than 10^{-5} m/s and represents low permeability materials such as clay and silt. The moderate zone with the value ranges between 10^{-5} to 10^{-4} m/s and represent a low moderate permeability materials such as fine sand. The high value zone, more than 10^{-4} m/s which, represent high permeability materials such as coarse sands. Figure 23 A, B and C also shows the location and the results of NMR in the central part of JV.



A



B

Figure 22, A and B. NMR results, A, section represent of permeability and B, represent water content.

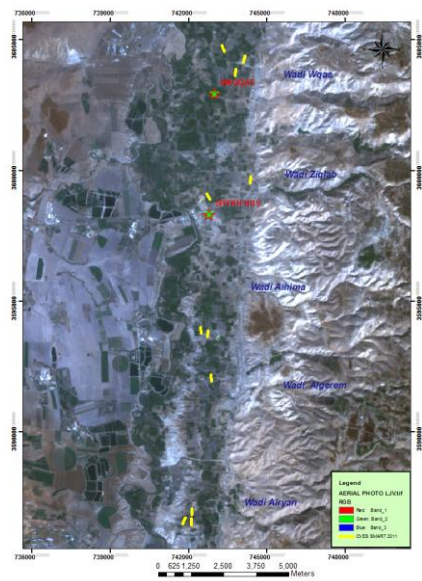
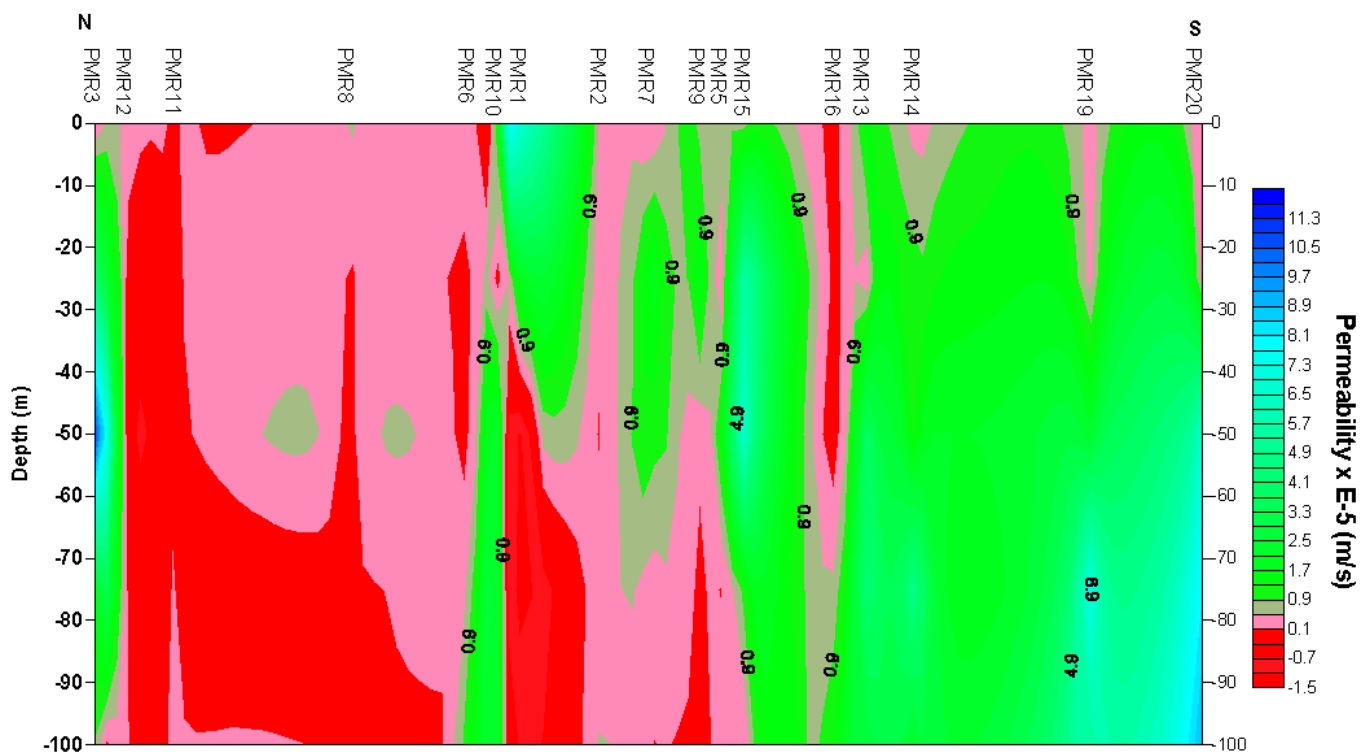
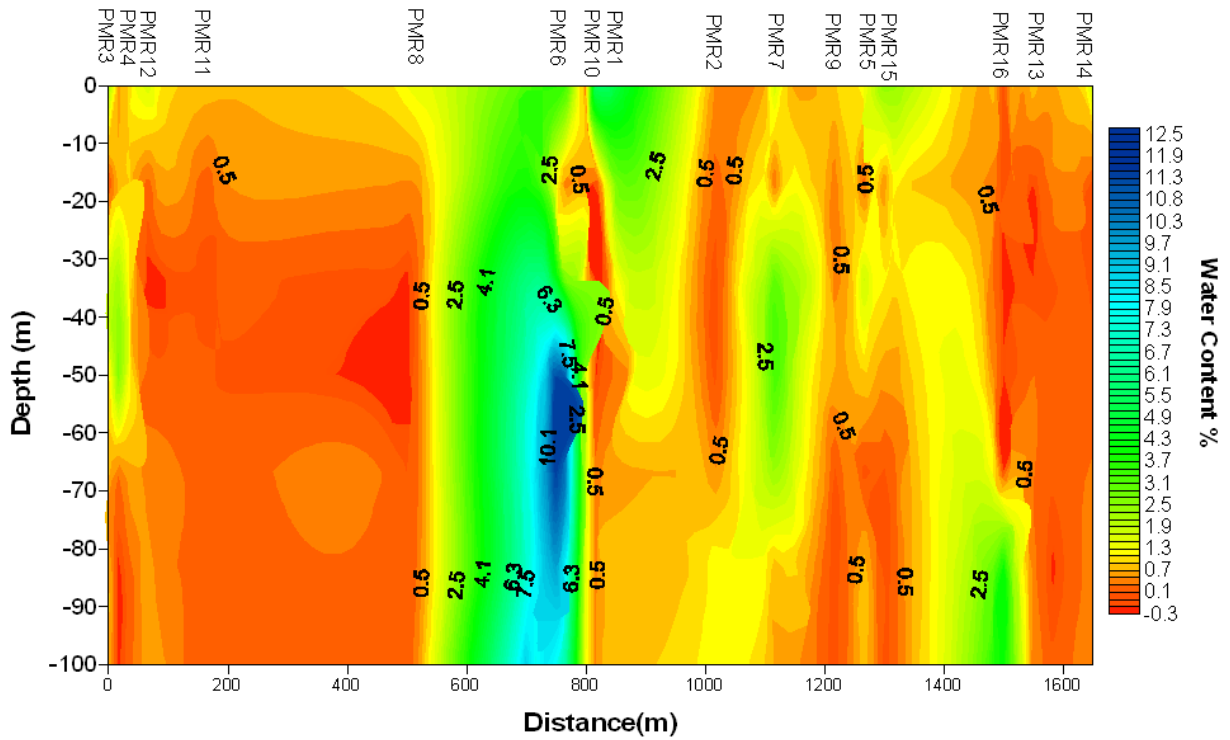


Figure 23 A. Location map of NMR in the central part of JV



B



C

Figure 23, B and C. NMR results, A, section represent of permeability and B, represent water content.

Based on the NMR measurements the water content percentage distribution with depth along the JV basin shows that, there are two water content zone, which are relatively high one and relatively low one (Fig. 24).

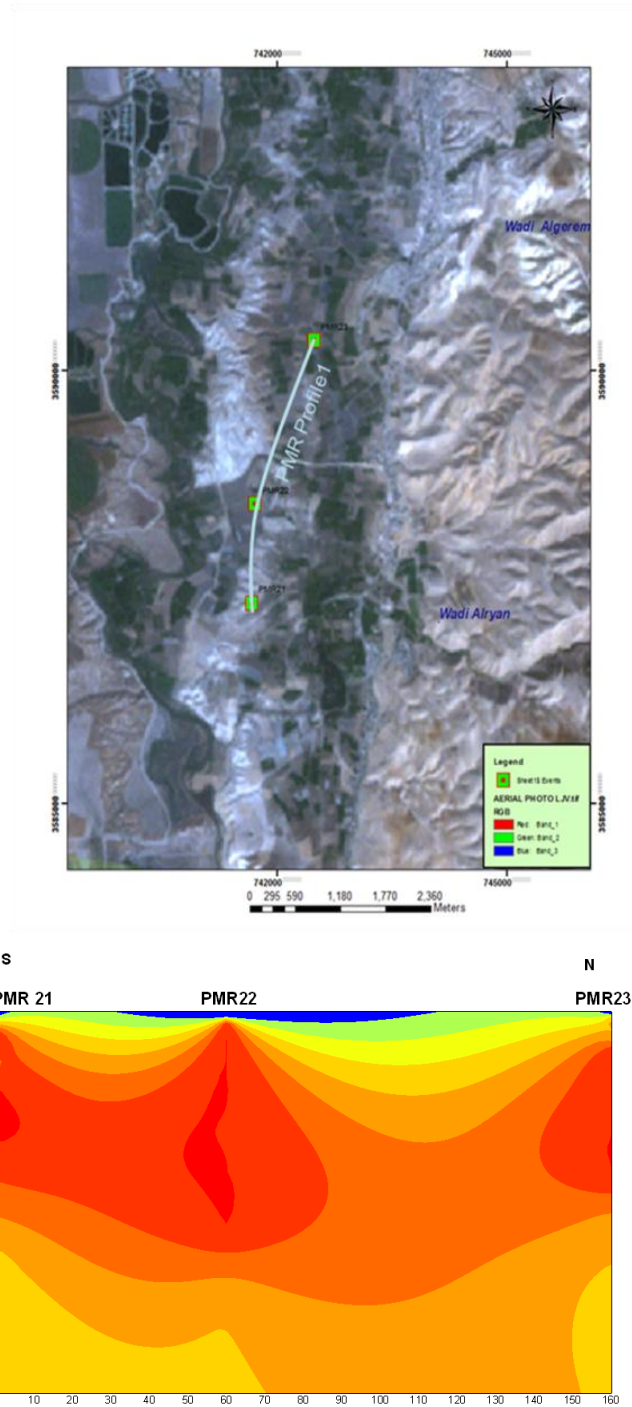


Figure 24. NMR profile location and the results shows two water content zones.

TIME DOMAIN ELECTROMAGNETIC METHOD (TEM)

The transient electromagnetic or TEM technique, which is sometimes called time-domain EM (TDEM) or pulse EM (PEM, EMP), can be used for vertical depth sounding or profiling. The equipment consists of a transmitter and receiver, which can be contained in a single box (with an external power source for the transmitter) or used with separate transmitter and receiver enclosures. The depth of exploration attained in a vertical sounding configuration can vary from 10's of meters to over 1000 meters, depending upon transmitter loop size, available power from the transmitter, and ambient noise levels.

Thirty two TEM sounding were distributed in the study area using TEM equipment using central loop configuration. In each TEM station a square loop 100 X 100 m placed horizontal on the surface..

Data processing and Interpretation

The data were processed and interpreted using TEM-RESEARCHER program.

The first step in data processing is to average the emfs that are recorded at opposite receiver polarities. Then, the records at different amplifier gains and frequencies are combined to give a single composite transient decay. After the composite transient decay has been calculated for each measuring point, then the late stage apparent resistivity's are calculated. Corresponding one dimensional inversion models were calculated for each station. Three TEM section were constructed in the study area.

The time domain electromagnetic shows that a very resistivity at the depth between 90 and 290 m. that means that there are a geological layer contains a salty water or a clayey rocks (Fig. 25)

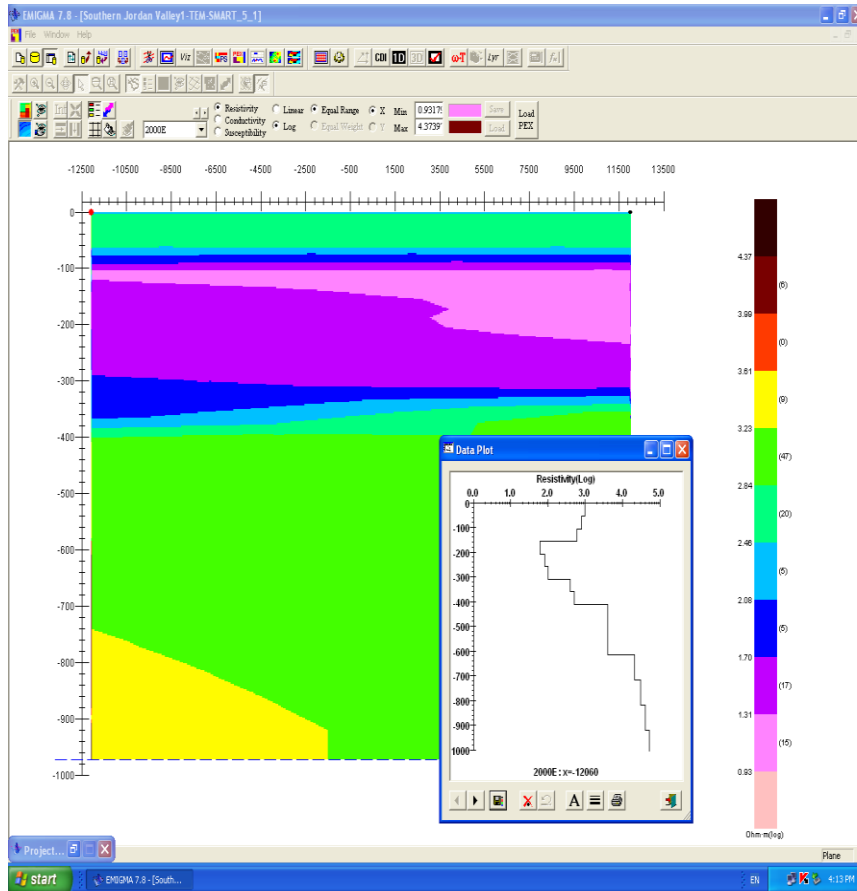


Figure 25. The TEM resistivity with the depth at the southern part of JV

Ground Penetrating Radar (GPR)

The GPR survey was carried out using the SIR-20 instrument. Two types of antenna were used, 40MHz and 100 MHz Twenty five GPR profile were conducted along the JV basin in order to delineate the water saturated zones, buried wadis channels and the wadis fan.

The significant result of three GPR in several profiles will be illustrated in (Fig. 26). The cross section along the profile (Fig. 26) shows an excellent example for buried channels. Figures 27, Demonstrate the water saturated zone and the water table in the southern part of the JV basin.

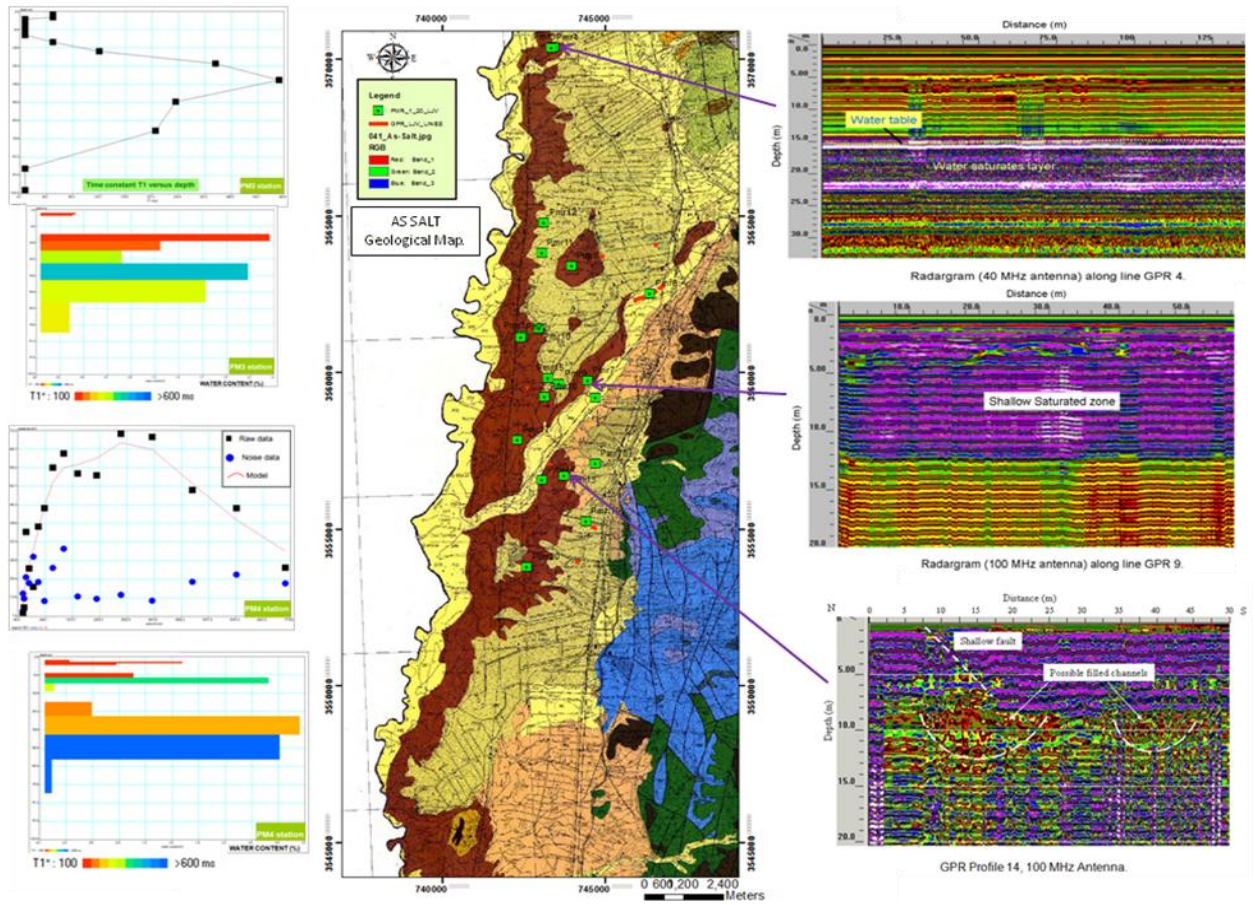


Figure 26. Location map of the GPR and three GPR profiles in the right side.

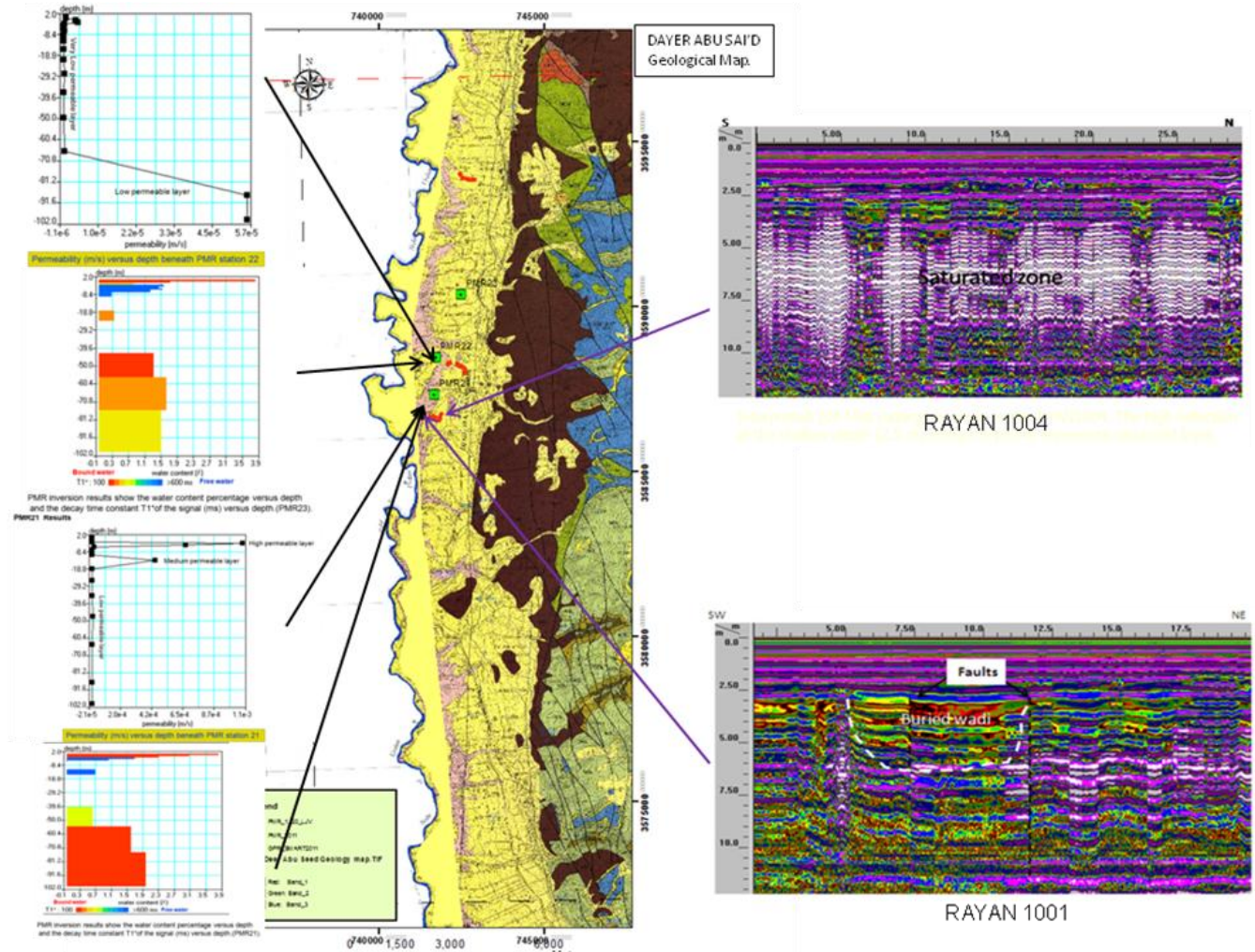


Figure 27. Location map of the GPR and three GPR profiles in the right side.

GPR RYAN1001 profile runs from SW to NE, a shallow buried wadi about 2.5 m deep and 7.5 m wide. Two faults detected along the profile the first one located at 7.5 m horizontal distance represents reverse fault, the second fault located at 12. m horizontal distance represents normal fault.

GPR RYAN1003 profile runs from S to N, the radar cross sections shows water saturated zones represented by high reflection of the electromagnetic waves between 3 to 8m deep.

Electromagnetic Radiation (EMR):

The EMR methods used to determine the active faults and regional stress fields. The EMR signal recorded in zones where high or shear stresses occur. Survey was conducted using EMR CERESKOP. Twenty five EMR profiles with different length and directions were conducted along the JV (Fig. 28).

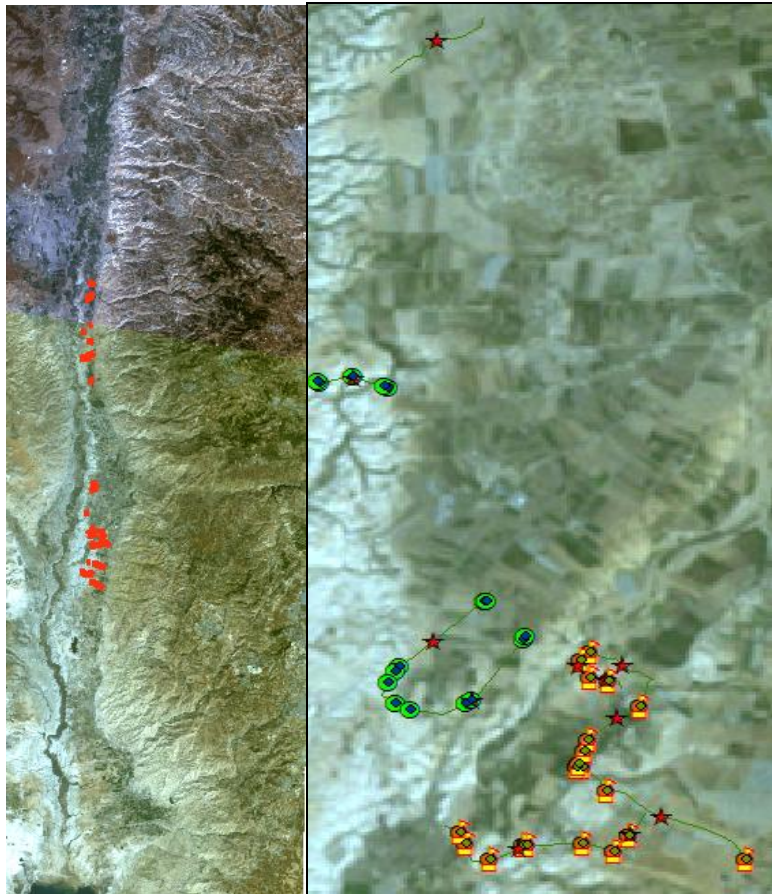


Figure 28. Location map of EMR

The high values of energy represent high emitting of electromagnetic waves due the presence of shallow cracks. The survey reveals different shallow cracks and shallow fault the assist the infiltration if the irrigation water from the surface (Fig. 29).

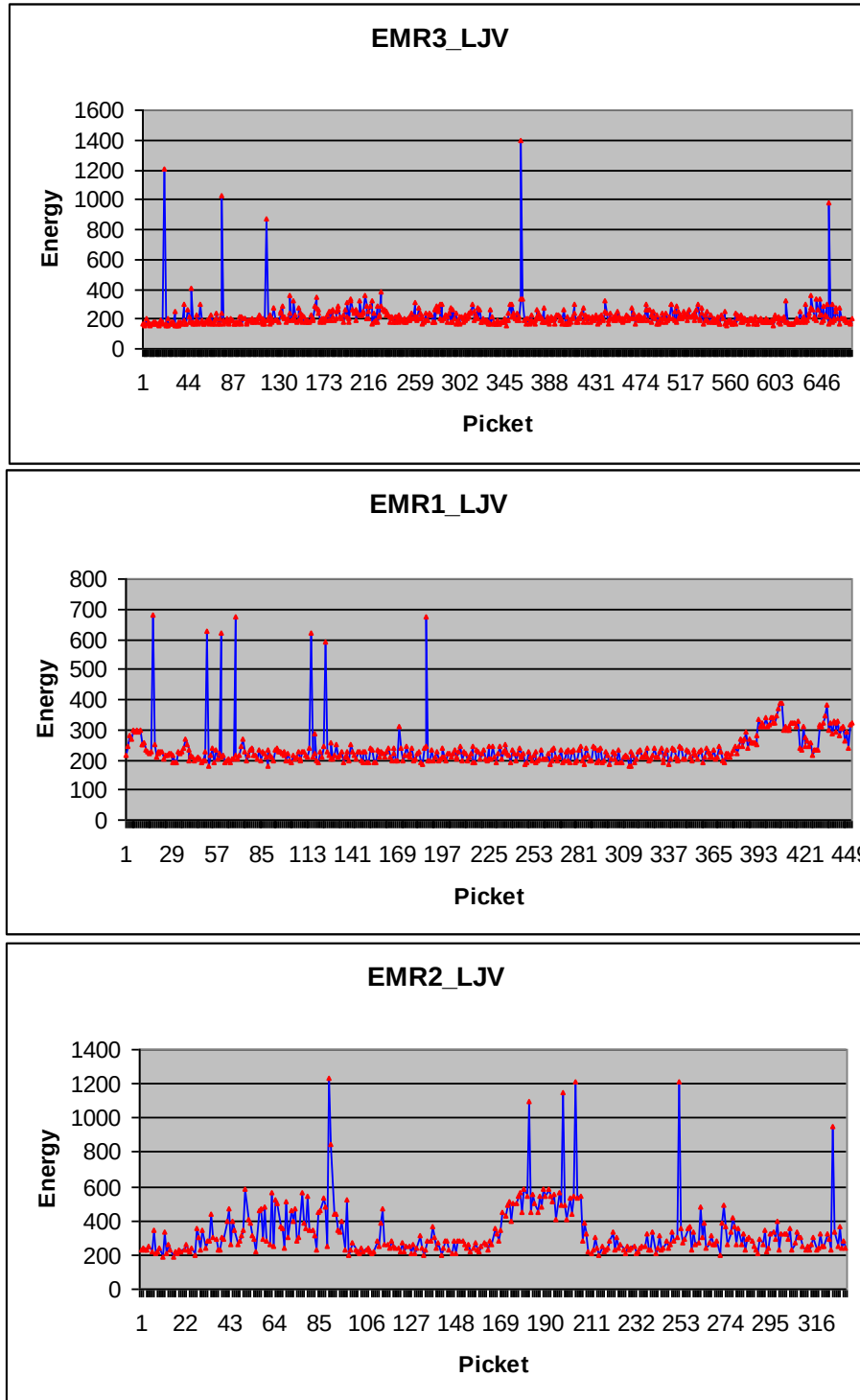


Figure 29. EMR anomaly along the profiles

Recommendations

1. In the Jordan Valley, the permeability as determined from NMR ranges from $(1.5 \text{ to } 13) \times 10^{-5} \text{ m/s}$. and the water content ranges from 0.5% to 13%.
2. Groundwater flow generally originates from the eastern escarpment and is directed westwards towards the axis of the Jordan Valley. Where in southern part of the JV the groundwater flow is towards the Jordan River and to the Dead Sea.
3. The JV as a part of the rift created by tectonic activity and cutting faults in the Rift zone bring the deep aquifer into direct contacts with shallow aquifers and artesian conditions occur
4. The eastern part of the Jordan River basin, the salinity increases from 2000 to more 7000 mg/l (comparing with the resistivity value).
5. Regarding the shallow geophysical survey (VES, CVES, NMR and GPR) the maximum depth was penetrated referring to be less than 200 m. The differentiation of the subsurface resistivity is very difficult in the study area due to the environmental deposition of recent sediments. The dramatically changed on geological and environmental history referred to very complicated and active tectonism. In addition the side wadies sediments complicated the situation. Therefore, we can judge about the increasing of the resistivity value from the western to eastern sides of the JV basin. This could be referring to the increasing of the distance between the hydrostatic level of the Jordan Valley and occurrence of water bearing sand and wadi sediments.
6. Based on the geological cross section and water wells drilled in the study area, we can divide the resistivity groups in vertical scale for the following: very low resistivity related to the Lisan marl formation. The low and moderate low resistivity value could be related to the salty clay continents formation. The moderate high and high resistivity value could be related to the alluvial deposits and may be order sediments related to Belqa' Group (Coniac to Eocene).
7. From the groundwater point of view the study area could be considered to be good aquifers. The Hydrogeological classification (aquifer and aquiclude) of the Quaternary sediment depends at rocks formation. The coarse clastic and unconsolidated coarse clastic of middle Pleistocene and upper Pleistocene along the rift valley and unconsolidated

clastics of the wadi sediments of Holocene. These two types could play a role of the main aquifers and situated western and eastern side of the rift valley. The well cemented and hard rock's of the lower Pleistocene form a good aquicludes. If these hard rocks are faulted due to tectonic movement, then could be aquifers.

8. The obtained resistivity value helped us to judge about the quality of the groundwater aquifers. The zone with resistivity value less than 1 Ohm.m. Occupied by sediments of low permeability and remained us with the Dead Sea water and closed to the Jordan River. The zone of the resistivity value of about 1 - 15 Ohm.m. Contains less saline water and concentrate in the central part of the study area. This zone is overlap with the previous one in the shallow depth. The resistivity value ranging between 15 up to 80 Ohm.m could be related to the brackish and thalweg groundwater. The high resistivity value related to the fresh water feeding from wadis from the upper aquifer (mountains aquifers). This groundwater occurred in form of lenses, tongues and channels. The zones above mentioned could be interfingering each other's due to the groundwater recharges, surface runoff, and infiltration, tectonic and human factors.

9. Figures 16, 17 and 18 shows the resistivity distribution which reflect the water quality, where the brackish water located mainly in the central zone along the JV. The maps could be leads to the following conclusions: (1). The fresh groundwater found at a depth of less than 30 m below ground surfaces, where fresh water saturated sediments up to 125m. (2). The Brackish Groundwater where found bellow and up to 150 m below ground surfaces, where the brackish to saline and saline could be found bellow.

10. The alluvial aquifer in the central part of the JV has limited resource availability due to variability of the aquifer deposits, where the northern and southern part of JV indicates a greater potential of groundwater exploitation.