

High PH Water in Maqarin Area / Jordan .

(Occurance , mineralization , genesis)

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Abstract

High pH waters, up to 12.5 are encountered in the Maqarin area, the extent of the aquifers containing the waters as well as their origin are discussed. Their presence is attributed to the dissolution of portlandite and other low temperature minerals resulted from retrograde metamorphism.

The high hydroxide, sulfate and calcium concentrations as well as some trace metals are related to the effects of the spontaneous combustion of the organic matter in the Bituminous Marl Formation.

The groundwater in both Amman and Bituminous Marl Formations flow towards the Yarmouk River. The confined water in both formations form an effluent to the Yarmouk River although the permeabilities are low; 3.6×10^{-3} cm/sec for Amman Formation and 5.0×10^{-5} cm/sec for the Bituminous Marl Formation. The water issuing from both aquifers mixes with the main baseflow of the river originating from the basalt aquifer and with high pH waters from the vadose zone.

The thermal water discharged in the area is formed during ascendance by mixing of deep hot water and waters from the Amman and Bituminous Marl Formations as well as the high pH water from the vadose zone. This explains the differences in temperature and composition of the discharged water.

INTRODUCTION

This study was carried out in the surroundings of the Maqarin Dam Site. It lies in the Yarmouk River Valley at the Syrian - Jordanian border, 16 km. north of Irbid City and about 25 km to the east of the Jordan Valley (Fig 1). The topography of the area is rugged and ranges in elevation from 30 to 400 meters above sea level. The valleys in the area are V-shaped indicating their recent history.

On the Yarmouk River with a baseflow of $3.5 \text{ m}^3/\text{sec}$ and a flood flow which may reach more than $200 \text{ m}^3/\text{sec}$ a dam with a capacity of more than 400 MCM is suggested.

The unurbanized catchment area of the Yarmouk River extends in both Jordan and Syria. The rock units covering the surrounding area of the proposed dam are the main factors affecting the water chemistry.

Previously no detailed hydrochemical or surface water studies were carried out in this area. Only few ground water samples from certain aquifers were analysed by Natural Researchs Authority (NRA) during pumping tests of some wells. Few samples from adits, boreholes and springs were analysed by Harza Engineering Company during the period 1977 and 1979. Chalky Limestone Formation springs in the upper reaches of Wadi Shallala are sampled occasionally and analysed by the NRA.

Ground water studies were carried out by Harza Overseas Engineering Company in the last few years. Boreholes were drilled by Backer and Harza Engineering Company in 1955. Another group of boreholes were drilled by Energyproject in 1966. Most of the boreholes and all the adits as well as detailed geological mapping for the reservoir area were completed by Harza Engineering Company in 1980. The petrography and chemistry of some rock units in the area were studied by Amira, 1980; Nassir, 1980 and Khoury and Nassir, 1982.

The presence of high pH - water initiated this work. The lack of information about the hydrochemical properties of surface and ground waters encouraged the authors to carry out this study which should give a detailed account about the relationship between the geochemistry of the rock units and the hydrochemistry of surface and ground waters. The high pH in some waters and its effect on other waters is also studied . The results could directly lead us to some thoughts and estimates about the expected water quality in the reservoir of the proposed Maqarin Dam. The ground water resources of the Yarmouk River are also quantitatively discussed and evaluated.

Geological Setting

Geology:

The bituminous limestone of the Maqarin area is a part of the Upper Maestrichtian - Lower Paleocene Chalk-Marl Unit deposited in an elongated sedimentary basin striking N to NW (Fig.1). Fig.2 shows a generalized stratigraphic column in the area. Rocks can be divided into three major groups; Cretaceous - Tertiary, basalt, and Quaternary rocks.

Cretaceous-Tertiary Rocks:

a: Amman Formation (B-2).

The lower part (52 m thick) is known as the cherty portion. It consists of bituminous marls with black chert and limestone bands. The upper portion (6.5 - 10 m thick) consists of massive, hard, fractured, fine grained, highly fossiliferous bituminous marl with sandy limestone.

b: Bituminous Marl Formation:

The Amman Formation is conformably overlain by the Bituminous Marl Formation. The total thickness mapped in the further surroundings of the Maqarin area is about 200 meters (Wiesemann & Abdullatif, 1963, Bender, 1968). The rocks are considered as a part of the Chalk-Marl

Unit of Danian- Maestrichtian age (Bender, 1968). The Bituminous Marl Formation consists of argillaceous, fine grained limestone with common microfossils.

Rocks of the Bituminous Marl Formation are slightly to moderately fractured. The fractures are healed with calcite. In some places the joints are filled with pyrite.

C: Altered and Brecciated Rocks:

On the left flank of the Yarmouk River, an unusual brecciated and altered rock unit can be traced from Wadi Sidjin eastwards to the damsite and then to about 1900 meters towards Wadi Shallala to the south east. This unit is highly heterogeneous in fabric, texture and rock type. A metamorphic zone is found in this rock unit (Kheury & Nassir, 1982). High and low temperature minerals such as wollastonite, spurrite, anorthite ettringite, portlandite ect. were recorded (Kheury 1984).

D: Chalky Limestone Formation:

This formation can be divided into three units;

- I. Lower Chalky Unit (190 m thick). The lower portion is about 15 meters in thickness and forms a cliff of massive homogeneous limestone known as the main cliff (Harza, 1979). It is overlain by soft sediments of argillaceous limestone with variable amounts of organic matter.
- II. Cherty Unit (30 - 40 m thick). It overlies the lower chalky unit and consists of chalky limestone with many thin chert bands.

III. Upper Chalky Uint (170 m thick) . It is similar to the Lower Chalk Unit in its petrographic composition but it is softer and more chalky.

Basalts:

Basalts are found to cap the area on the right side of the Yarmouk River and parts of the left side. These basalts are related to final (sixth) flow of pleistocene age (Bender, 1968).

Recent Deposits:

Recent deposits in the studied area consists of unconsolidated wadi fill and residual soils.

Structures:

The Maqarin damsite area is affected by small scale tectonics. Rocks are almost horizontal or gently dipping. Major faults are completely absent.

I. Folds:

The Bituminous Marl Formation was brought to a higher elevation more than any other place in the Yarmouk Valley, by a northeast- southwest trending anticline. This anticline is plunging to the northeast (Wieseman and Abdullatif 1963). On the southeastern flank, the rocks dip 18-20° to the southeast . The extent of this limb is about 2 km, after that the

layers flatten out. The northwestern limb rocks dip to the northwest with angles less than 10° .

II. Faults:

Faults are not very common in the Maqarin area. They are mostly traced in adits with throws of some 5 meters. The fault with the highest displacement (40 m) in the area trends $N 65^{\circ} W$ to the north of Wadi Shallala (Harza, 1979).

III. Joints:

Two sets of joints are prevailing in the area of Maqarin, with NW-SE and N-S trends. Polygonal and vertical jointing is also prevailing in the basalts.

Field and Laboratory Work

Field Work:

A total amount of 110 samples of surface and groundwater sources were collected for chemical analysis. The location of sampling sites are shown in Fig (3). The samples located outside the mapped area are given with their coordinates in Table (1). The pH was checked in the field using 0.1 range pH- paper. Temperature, and electric conductivity were also measured in the field during sampling. Discharge of the Yarmouk River as well as precipitation over the area were measured at station AD-5, by the Surface

Water Division / NRA. Water level measurements in the boreholes were carried out by the Jordan Valley Authority / Dams Directorates in the period between 1978 to 1981.

Laboratory Work:

The analysis of the water samples were carried out in the laboratories of the Department of Geology and Mineralogy at the University of Jordan.

Alkalinity was determined by titration with hydrochloric acid standard solution using phenolphthalein, methyl orange and a mixed indicator of methyl red and bromocresol green.

Calcium and magnesium were determined by titration with standard solution of EDTA Na- salt (Titriplex, III) using murexide as indicator for calcium and eriochrome black T for the total magnesium and calcium (Brown et al, 1974).

Chloride was determined by titration with mercury nitrate $Hg(NO_3)_2$ standard solution using diphenylcarbazone as indicator.

Sodium and potassium were analysed by using Eppendorf flame photometer after diluting the samples to reach the optimal range of accuracy. Spectrophotometry was used to determine nitrate and sulphate, using Perkin Elmer 555 spectrophotometer, at wave lengths of 206 nm and 492 nm respectively. Trace metals were analysed by atomic absorption spectrophotometer, Jarrel-Ash model 850 after concentration of samples by evaporation to one fifth of the original volume.

HYDROLOGY

Rainfall:-

From the isohyetal map of Jordan (Climatic Atlas of Jordan, 1971). The average annual precipitation over the studied area was calculated to be around 450 mm. Precipitation measurements at station AD-5 in the period between 1974 and 1980 showed a minimum precipitation of 191 mm in 1978/1979 and a maximum of 665 mm in 1979/1980.

Surface Water Discharge:-

Discharge measurements were carried out at station AD-5 on the western boundary of the studied area. The amount of the water discharged as baseflow at station AD-5 during the period 1968-1980 showed a maximum of $220 \times 10^6 \text{ m}^3$ in 1968/1979 and a minimum of $153 \times 10^6 \text{ m}^3$ in 1978/1979. The average baseflow is calculated to be about $181 \times 10^6 \text{ m}^3$ yearly with a standard deviation of $17.8 \times 10^6 \text{ m}^3$ year. The baseflow in each year was calculated as the difference between maximum and minimum amounts of stored groundwater. (Using Maillet's eq, 1905). The maximum stored amounts of groundwater in the year 1968 to 1980 range between $364 \times 10^6 \text{ m}^3$ / year (1979/1980) and $262 \times 10^6 \text{ m}^3$ (1978/1979) with an average of $319 \times 10^6 \text{ m}^3$ / year and standard deviation of $34.7 \times 10^6 \text{ m}^3$ / year. The minimal yearly stored amounts of ground water in the same period (1968-1980)

ranged between $198 \times 10^6 \text{ m}^3$ (1979/1980) and $76 \times 10^6 \text{ m}^3$ (1977/1978) with an average of $137 \times 10^6 \text{ m}^3$ year and standard deviation of $34.6 \times 10^6 \text{ m}^3/\text{year}$.

The source of groundwater consists of one aquifer or more without any sudden serious decrease in the amount of groundwater yielded by any one of the major aquifers. The main source of the Yarmouk River water is the basalt aquifer. Minor amounts of groundwater are supplied by the artesian Amman Formation and by the Bituminous Marl Formation as inferred from the chemical composition of the water and the piezometric map of Amman Formation (Abdul- Jaber 1982).

EVAPORATION:-

The average annual temperature is 21.5 C° (Climatic Atlas of Jordan, 1971). The average temperature during the rainy months (from the beginning of November to the end of April) is 14.5 C° .

Evaporation was calculated using Wundt and Turk equations and found to be 408 mm.

The evaporation precipitation ratio is 488/450 which means that 90.5% of the precipitated water is lost by evapotranspiration. Infiltration was calculated to be 17 mm yearly (Abdul - Jaber, 1982).

GROUNDWATER:

The four water bearing rock formations present in the studied area are discussed below:

1- Amman Formation

This formation is highly fractured with relatively high secondary porosity and permeability. The permeability ranges from 10^{-5} cm/sec to more than 3.7×10^{-3} cm/sec (Harza, 1979).

2- Bituminous Marl Formation:

This formation is of very low permeability. It is considered as a good aquiclude. In the area of Maqarin dam site, the formation is partly fractured and form a semi-aquifer with measurable permeability. Water pressure tests in this formation gave a permeability of 5.0×10^{-5} cm/sec at the Syrian side and a permeability of 1.0×10^{-5} cm/sec at the Jordanian side (Harza, 1979) Within the upper part of the Bituminous Marl Formation, on the left side of the river, high pH waters are found as perched water. They seep down the slopes towards the Yarmouk River.

3- Chalk Marl Formation:

This formation lies within the unsaturated zone. It was not possible during the period of this study to determine its permeability. Although the rock type indicates very low permeability , springs are issuing from this formation in the surrounding area as Ain Quelbe, Ain El-Trab and the springs of Wadi Shallala.

4- Basalt Flows:

The basalts form good aquifers. Most of the Yarmouk River baseflow and springs are derived from this aquifer.

GROUNDWATER MOVEMENT:

Waters from Amman Formation, Bituminous Marl Formation and from the Vadose Zone discharge towards the Yarmouk River. The water of the confined Amman Formation seeps upwards through fractures and joints in the Bituminous Marl Formation to the Yarmouk River. Based on measurements of the piezometric level data in the boreholes penetrating the Amman Formation in March 1980, groundwater contour lines are drawn. Figure 4 shows that the groundwater flow is directed towards the Yarmouk River. On the northern side, the water moves towards the south with a gradient range between 0.022 and 0.029. On the southern side, the water moves northwards with a gradient of 0.075. Along the river bed, the flow in this formation coincides with that of the river, mainly from east to west with a gradient range between 0.034 and 0.039. The high pH water in the Vadose Zone at the southern side of the Yarmouk River seeps down along slopes and fractures towards the river.

HYDROCHEMISTRY:

In the Maqarin area, the different waters vary in their physical and chemical properties. The pH value of the water ranges from 6.5 (boreholes

BV-2) to 12.5 (Adit A-6). The electric conductivity which generally reflects the total dissolved solids (TDS) in water shows a range between 450 mhos (Boreholes FS-35) and more than 8000 mhos (Adit A-6). The TDS in borehole FS-35 is 265 ppm, in adit A-6 is 1200 ppm and in boreholes S-3 is 2160 ppm. The TDS of S-3 has the highest value measured in the area, its electric conductivity is 2600 mhos. Most of the waters in the area show low nitrate content and a weak to strong H_2S odor. The temperature of the water ranges between $23.5\text{ }^{\circ}C$ (boreholes FS-36) and $34.5\text{ }^{\circ}C$ in the thermal springs between 20-4 (at the Syrian side of the Yarmouk River).

YARMOUK RIVER WATER:

The Yarmouk River water is mainly discharged from the basalts at Zeizoun and Mezerib spring in Syria (Harza, 1978 and 1979). During times of base flow the chemical composition of the water is nearly stable with a TDS ranging from 420 to 490 ppm. The TDS decreases to about 260 ppm during floods (samples collected on 10.11.80 and 29.1.81 Table 2).

In trilinear representation (Languth, 1966), all the analysed samples plot at the center of the diagram, concentrated in the area of alkaline earth water with increased portion of alkalies and prevailing chloride (Fig.5).

The TDS of the Yarmouk River water is low. All trace metals are found in very small concentrations. They range from below the detection limit up to

500 ppb (January, 1981). The results of the heavy metal analyses are given in Table 3.

2- High pH Seepages:

This water percolates through the vadose zone on the left slopes of the Yarmouk River. It is characterized by its high pH values (12.5) which makes it a unique type of water. High pH waters of different origins were recorded in Greece (Papastamatik, 1977), USA (Barnes et al, 1972), Oman (Barnes et al 1978). High pH value waters are found in adits; A-6 and AFS-2, travertine zone seepage at the south of Wadi es Sidjin.

The TDS of this water is relatively high and ranges from 1128 ppm (Adit A-6, June 1981) to 2068 ppm (Boreholes FS-1). From the chemical point of view, this water is considered rich in its calcium hydroxide and calcium sulphate.

Hydroxide, sulphate and calcium contents range from 176 ppm (Adit A-6) to 682 ppm (Boreholes FS-1), from 223 ppm (Adit - A-6) to 451 ppm (Wadi Sidjin seppages) and from 418 ppm (Adit A-6) to 924 ppm (Boreholes FS-1) respectively. In most samples magnesium was not detected although some samples show very low concentrations (Table 4).

In a trilinear representation (Languth, 1966) this water plots in the area of alkaline earth water with prevailing hydroxide, where the hydroxide group substitutes the bicarbonate group in this type of water (fig 6). Two samples were collected in 1977 from adit A-1 and adit A-4 and analysed in the Natural Resources Authority Laboratories (Harza 1978). These two samples correlate directly with the authors results. When the high pH water comes in contact with the atmosphere, it absorbs the atmospheric carbon dioxide, and calcium carbonate precipitates. Travertine, stalactites, stalagmites and carbonate cement result in the cementation of gravels. They are the results of calcium carbonate precipitation.

The high pH water seeps down slopes towards the Yarmouk River. Along joints and fractures, it mixes with water of the Bituminous Marl Formation and most probably with the artesian water of Amman Formation. These mixing processes are accompanied with complicated reactions and result in giving the mixed types of waters. This mixing is considered later in the discussion. The high pH water is also characterized by its high Cr, Cd, Ni, Pb, Mo, and Co, contents (Table 5). In Wadi es Sidjin seepage, the Cr concentration is 600 ppb, Cd, reaches up to 10 ppb, Ni 75 ppb, Pb 95 ppb, Mo 80 ppb and Co 50 ppb.

3. Springs.

In the Maqarin area chemical and cold water springs are present.

3.1: Thermal Springs.

Three springs with a temperature of 32 to 35 C⁰ are present on the Syrian side of the Yarmouk River. They range in their TDS from 480 ppm to 746 ppm and give distinctive H₂S odor (Table 6). The pH of these springs is quite normal; around 6.8.

Spring No.2 with a temperature of 32 C⁰ and a TDS of 485 ppm and spring No. 9 with a temperature of 32⁰C and TDS of 573 plots in the area of alkaline earth water with increased portion of alkaline and prevailing bicarbonate. Spring No. 4 with temperature of 34.5⁰C and TDS of 747 ppm plots in the area of alkaline earth water with increased portion of alkalies and prevailing chloride (Fig 7 , Table 6).

3.2 Cold Springs.

a: Springs of the Chalky Limestone Formation: Three samples from Ain Quelbe, two samples from Ain Shalaq and two samples from Ain Umjrain have been analysed in the period between 1972 and 1978 by the Natural Resources Authority. During the period of this study one sample from each spring, Ain Quelbe, Ain et Trab, Ain Ba'boul and Ain Sombal where collected and analysed (Table 6). The later two springs are located in the lower reaches of Wadi Shallala. Water of these

spring has a normal pH of 6.8 and an E.C. value of about 420 mhos in (Ain Ba'boul).

Ain et Trab and Ain Quelbe are characterized by their low TDS ranging from 258 ppm to 281 ppm. Table 6 shows complete chemical analysis of these two springs water. Ain Quelbe water plots in the area of alkaline earth water with prevailing bicarbonate, and Ain et Trab water plots also in the area of alkaline earth water with increased portion of alkalies and prevailing bicarbonate (Fig 8).

Other springs of the Chalky Limestone Formation are located in Wadi Shallala , they issue from the same rock unit as Ain Quelbe and Ain et Trab springs. Their TDS ranges from 345 ppm, in Ain Shalaq to 606 ppm in Ain Ba'boul. The TDS of the latter is higher than the above mentioned springs.

Ain Ba'boul and Ain Sombol samples plot in the area of alkaline earth water with prevailing bicarbonate. Spring No. 7 water is slightly shifted to the area of alkaline earth water with bicarbonate and chloride. The last three samples could be chemically correlated with those of Ain Quelbe. Ain Shalaq samples with TDS of 387 ppm plot in the area of alkaline earth water with increased portion of alkalies and prevailing bicarbonate. Ain Umjrain samples which show higher TDS (400 to 439 ppm) plot in the area of alkaline earth water with increased portion of alkalies and prevailing chloride (Fig 8).

b: Basalt springs: Two samples from springs issuing from the basalt sequence on the Syrian side of the Yarmouk River were collected and analysed. Both waters discharge with a temperature of 20.5°C and show different chemical composition. Ain Ghazala has a TDS of 248 ppm and a pH value of 6.5. It plots in the area of alkaline earth water with increased portion of alkalies and prevailing bicarbonate. On the other side, Ain Quseir with a TDS of 590 ppm and a pH value of 8.5 plots in the area of alkaline earth water with increased portion of alkalies and prevailing chloride (Fig 7).

c: Ain el Mardashia: This spring is located about 1 km to the northeast of Maqarin Station. It issues from wadi fill gravels covered with cultivated soil., Its TDS content is 780 ppm and chemically plots in the area of alkaline earth water with increased portion of alkalies and prevailing chloride (Fig 7).

d: Spring Number 3: It issues from wadi fill gravels few tens of meters to the west of the bridge at Maqarin(Fig 3.). Its chemistry is similar to that of the Yarmouk River water with a TDS ranging from 327 ppm to 479 ppm (Table5.). It plots in the alkaline earth water area with increased portion of alkalies and prevailing chloride or it is shifted slightly into the adjacent area of prevailing bicarbonate showing nearly negligible difference. (Fig 7).

The thermal and cold springs of this area show low concentrations of heavy metals; usually below 30 ppb with the exception of iron which reaches about 396 ppb (Table 7).

4. Amman Formation:

Fifteen boreholes penetrating this formation were sampled in the period between August 1980 and June 1981. Water of this formation has a pH value of 6.5 to 7.4, only borehole FS-34 shows a pH of 12.0. This is due to mixing with high pH water which seeps through joints and fractures.

Water of Amman Formation has a temperature range between 24.5 C^o (Borehole FS -32) and 30C^o. (Borehole FS -35). The mean temperature of the collected samples is 26.75C^o.

The Amman Formation water ranges in its TDS from 250 ppm (Borehole FS-35 in September, 1980) to 680 ppm (Well-W5 in Sept, 1980, Table 8). The nitrate content of the water is very low. The water is accompanied by strong H₂S odor (Borehole FS-37).

On the trilinear representation of Languth, water of Amman Formation shows a wide range in its composition. Some samples plot mainly in the area of alkaline water with prevailing chloride while others plot in the area of alkaline earth water with increased portion of alkalies and prevailing bicarbonate. Only two samples plot in the area of prevailing chloride (fig 9).

Heavy metals are generally found in trace concentration. With the exception of iron and zinc which show higher concentrations. The maximum concentration of Fe is 1050 ppb (Well - NRA-8), Zn 1600 ppb, (FS-26), Ni 83 ppb (FS-36) and Pb 53 ppb and 557 ppb in borehole FS-34 and well NRA respectively (Table 9).

5. Water of the Bituminous Marl Formation:

Water percolating in this formation contains in most the cases a TDS below 600 ppm. With the excepting boreholes FS-47, S-26, S-3, and FS-70 which show TDS values of 141 ppm, 1014 ppm, 1079, 2165 ppm, and 709 ppm respectively (Table 10). Water of this formation shows a low nitrate content and is accompanied with H_2S odor. The pH values of the water percolating through the Bituminous Marl Formation is normal and range between 6.5 (Borehole BV-2) and 8.5 (Borehole S-41).

Borehole S-8 shows a high pH value of 12.5 due to mixing with the high pH water. The Bituminous Marl Formation water has a temperature range between $24\text{ }^{\circ}\text{C}$ (Borehole FS-70) and $29.5\text{ }^{\circ}\text{C}$ (Borehole HV -7). The mean temperature of the collected samples is $27.5\text{ }^{\circ}\text{C}$. This formation plots in different area on the trilinear digram. The highest number of samples plot in the area of alkaline earth with increased portion of alkalies and prevailing bicarbonate. Few samples plot in both of alkaline water with prevailing chloride and alkaline earth water

with increased portion of alkalies and prevailing chloride. One sample plots in the area of alkaline earth water with prevailing chloride (Fig 10).

Table 11. shows the trace metal analyses of the Bituminous Marl Formation water. The metals Cu, Cr, Ni, Co, and Mo are found in trace concentrations and reach up to 50 ppb. Some samples show higher concentration of one or more trace metal, for example borehole FS-47 has 74 ppb Mn, 70 ppb Ni and 62 ppb Mo. Lead (pb) shows the widest range of concentrations which range between zero in borehole BV-2, S-29 and HV-3 to 1001 ppb in borehole FS-5. The highest concentration in metals concentration is displayed by both iron and zinc; where iron reaches a concentration of 1.8 ppm (Borehole FS-71) and zinc is as high as 18 ppm (Borehole FS-5).

DISCUSSION:

The results of the chemical analysis are plotted on logarithmic composition diagrams. The quality of the water is then determined by calculating the hardness, the sodium percentage and the sodium adsorption ratio (SAR).

Yarmouk River Water:

The baseflow of the Yarmouk River seems to originate from a major aquifer feeding the river with a fixed hydrochemistry. This water shows mostly parallel lines on the concentration composition diagram (Fig 11) indicating the same source of water during all seasons of the year. The composition of flood water deviates from that of the base flow and a general decrease in concentration of Mg and SO_4 is measured. The composition of the Yarmouk River base flow water as well as during flood flow times shows that $Na > Mg > Ca > K$ and $HCO_3 > Cl > SO_4$. Only a sample collected in March 1981 during a flood showed that $Ca > Mg$ and that a decrease in SO_4 concentration took place.

The quality characteristics of the Yarmouk River water are summarized in Table 2. According to Sawyer and McCarty classification (1967), the water of the river is moderately hard. The major ion concentration of this water lies below the limits recommended by the WHO (1971) for drinking water.

In respect to the classification for irrigation and because of its high sodium percentent which reaches (59%) this water is classified as permissible (Table 10). According to Richard's classification (1954) this water lies in the area of low sodium hazard (S_1) and medium salinity hazard (C_2).

High pH Water:

This type of water is present in the vadose zone of the metamorphosed rocks at the upper part of the Bituminous Marl Formation. The high

TDS of this water is a reflection of high Ca, SO_4 and OH concentration coming from the dissolution of lime portlandite $Ca(OH)_2$ and gypsum $CaSO_4 \cdot 2H_2O$ (Khairy and Nassir 1982).

This water type shows variation in composition without any systematic variation and could be attributed to differences in the thickness of the percolated metamorphic rocks, contact time of the water and rock, degree of metamorphism, exposure of the water to the atmosphere, the local presence of the retrograde percolated metamorphic minerals such as portlandite and the mixing with other types of water. The variation in composition can be considered as different degrees of dilution of high TDS water.

The high pH water in the studied area follows the relation $Ca > Na > K > Mg$ and $OH > SO_4 > Cl$ with the exception of two samples; the first sample collected in May 1981 from adit A-6 (fig 12 a) where Mg is a little higher than K; the second sample collected from travertine zone seepage (fig 12b) with Cl concentration higher than SO_4 . The concentration composition diagram (fig 12c) of this water type shows parallel or coinciding lines. This indicates that these waters belong to one original water type with definite composition which is then diluted by different portions of the meteoric water. Calcium and hydroxide ions are the two major constituents of this water type. They correlate well with the TDS. Wadi es Sidjin seepage samples show Ca and OH correlation coefficients with the TDS of 0.97 and 0.99 respectively.

The high pH water is characterized by its high TDS, Ca, OH, SO_4 , Cr and Mn. Ni and Cd are slightly higher than other elements. The high trace metal content is attributed to the dissolution of low temperature minerals which incorporate some base metals in structure (Kheury and Nassir, 1982). The Bituminous Marl Formation rocks concentrate also base metals which are associated with the organic matter (Amireh, 1979). The solubility of these metals could be increased as a result of the spontaneous combustion of the organic matter. Line spurrite, wellstomite, anorthiteetc are among the newly formed minerals.

Retrograde metamorphism is still active in the area (Kheury, 1984) and the action of the circulating water in high and low temperature minerals is taking place. The effect of the high pH water on the high temperature minerals could result in extracting such elements. Chromium rich low temperature minerals such as velenskite, ettringite, green gypsum ... etc were recovered (Kheury and Nassir, 1982, Kheury et al, 1984). Water quality criteria for this water is represented in Table 13. Complete heavy metal analysis is shown in Table 5. According to Sawyer and McCarty classification, this type of water is very hard, and is not suitable for domestic and drinking purposes due to its heavy metal, Ca and OH contents which exceed the WHO limits.

Although this type of water is with low sodium percentage, its use for irrigation is doubtful due to its high TDS (WILCOX 1955). According to Richard (1954), this water is classified as low sodium hazard water (S1) but with high salinity hazard, C3 type.

Spring.

a: Thermal Springs.

The temperatures of springs No. 2, and 4., is 32, 32 and 34.5 C^o and their TDS is 480, 573 and 747 ppm respectively. The TDS of these waters is a function of both Na and Cl content. Both of them correlate with the TDS, with a correlation coefficient of 0.98 and 0.99 respectively. Comparing these results with the chemical composition of the thermal well of "Shuna" which was drilled by the Jordan Valley Authority in the northern Jordan Valley- shows that the water of this well has a lower TDS than expected. It has a TDS of 531 ppm while the temperature of the water is 56^oC. Sodium and chloride in the water of "Shuna" well correlate with their concentration in the thermal springs. The low TDS of Shuna well water compared with that of the thermal springs indicate that the water of the thermal springs is a mixture of three components; low TDS high temperature deep water with higher TDS cold meteoric water and lower TDS cold meteoric water.

The chemical composition of the thermal springs water shows the relationship $Ca > Mg > Na > K$ and $HCO_3 > Cl > SO_4$. This relationship is also valid for the thermal water of Shuna well (Fig. 13).

The concentration composition diagram shows mainly parallel lines except for spring No. 2 where Ca and SO₄ are higher than expected.

The concentration composition diagram of the Shuna thermal well shows just the same trend but without parallelity in the lines.

The source of this water is assumed to be a deep water body with lower salinity and higher temperature than that of spring No.4. The water of El Hemme seems to be much closer in its composition to the original water. It has both higher temperature and TDS as well as higher Na and Cl. The original water is then diluted in different ratios with recent meteoric waters resulting in lower temperature and some times lower TDS of the mixed water emerging from the springs.

The water of the thermal springs has a chemical composition which lies within the limits of the WHO for drinking water (Table 6). This makes the water after aeration to get rid of the H_2S gas suitable for drinking and domestic purposes. Technical problems may arise due to the high hardness of this water type which is considered as very hard according to Sawyer and McCarty (1967) classification. According to Wilcox (1955) this water type is classified as permissible. According to Richards (1954) it is classified as low sodium hazard water (S1) and high salinity hazard water (S3).

b: Normal Cold Water Springs.

b.1: Chalky Limestone Formation.

The concentration composition diagram of these springs enable their

division into groups:

I. Springs of the lower reaches of Wadi Shallala : This group includes three springs emerging from the lower Chalky Unit of the Chalk Marl Formation.

The water has the relationship $Ca > Mg > Na > K$, and $HCO_3 > SO_4 > Cl$. Only in the Ain Sombal water $Cl > SO_4$. The concentration composition diagram shows almost parallel lines indicating the same aquifer and origin (Fig. 14).

II. Springs of the upper reaches of Wadi Shallala : This group includes Ain Shelaq, Ain Umjrain, Ain Quelbe and Ain et Trab. These springs emerge from the upper Chalky Unit of the Chalk Marl Formation. The water of these springs shows the relationship of $Ca > Na > Mg > K$, and $HCO_3 > Cl > SO_4$ (Fig. 15).

It is concluded that the water of Ain et Trab has the same origin of Ain Shelaq and Ain Umjrain waters. The higher sodium and chloride contents in Ain Shelaq and Ain Umjrain is perhaps due to mixing with waste waters of an inhabited area. This is evidenced by the relatively high NO_3 concentration in Ain Shelaq and Ain Umjrain waters which reach 46 and 56 ppm respectively.

The water of the lower reaches of Wadi Shallala Spring (group I) can be correlated with the water of Ain Quelbe. The difference in TDS can be explained by the duration of contact between the water and the rock, to reach equilibrium. Higher concentrations of Ca and Mg in the water of lower Wadi Shallala Springs and Ain Quelbe could be also explained accordingly.

The water of the Chalky Limestone Formation springs is hard to very hard. The major and trace constituents are within the limits of the WHO standards for drinking water (Table 7) and is suitable for drinking and domestic purposes. The infiltration of cesspool waste water to the aquifer could effect the water quality. This is evidenced by two samples collected from Ain Shelaq and Ain Umjrain where NO_3 concentration exceeded 45 ppm.

According to Wilcox (1955), this water can be classified as good to permissible for irrigation purposes. According to Richards classification (1954) the water shows low sodium hazards (S1) and low to medium salinity hazard (C1 - C2).

b.2: Basalt Springs.

Ain Ghazala shows the same chemical composition as the Yarmouk River with the relationship of Na Mg Ca K, and HCO_3 Cl SO_4 and with parallel lines on the concentration composition diagram (Fig. 16). This indicates that the Yarmouk River water is mainly derived from the basalt aquifer.

Only the water of Ain el Quesir with a TDS of 590 ppm a relationship of Ca Na Mg K, HCO_3 Cl SO_4 and with NO_3 content of 85 ppm differs from both Yarmouk River and Ain Ghazala waters. This is attributed to the concentration of the basalt water with domestic waste water of the villages located in the catchment area of the spring. The high Na, Cl and NO_3 contents suport. All concentration of the chemical constituents are lower than the WHO limits for drinking water. Only Ain el Quesir has a higher NO_3 content (53 ppm) than the WHO recommendations.

According to the classification of Sawyer and McCarty (1967) water of the basalt aquifer is moderately hard to hard. According to Wilcox classification (1955) for irrigation the basalt water is classified as good to permissible. When using the Richards classification (1954) this water is with low sodium hazard (S1) and low to medium salinity hazard (C1 - C2).

Amman Formation Waters:

Water samples collected from Amman Formation show that the water percolating in this formation is heterogenous in its chemical characteristics.

The different boreholes show different hydrochemical composition but the same borehole over the study period shows similar results and nearly fixed chemistry.

This inhomogeneity in the hydrochemical composition is a result of mixing of the Amman Formation water with the water seeping from the metamorphosed zone. This results in heterogenous mixtures of the Amman Formation water and other waters each with different composition. This fact results in giving each borehole its own system of mixing and therefore its own hydrochemistry. Except between SO_4 and TDS, no correlation was detected between the different ions and TDS expressing the heterogeneity of the water. The correlation coefficient between TDS and SO_4 was calculated to be 0.97.

Because of mixing the concentration composition diagrams show, very confusing patterns.

According to the major ion concentration all the waters of Amman Formation contain chemical constituents within the limits of drinking water recommended by the WHO (1971). These waters are medium hard to very hard (Table 14). Some trace metals reach concentration are higher than WHO

standards. The highest concentration for Pb and Zn with values 575 ppb and 15 ppm in NRA - A and FS - 21 respectively (Table 9). According boreholes FS - 34, FS- 17, FS- 21 and well NRA -A - Wadi es Sidjin are not recommended for drinking purposes.

For irrigation purposes this water ranges in its classification according to Wilcox (1955) from good to doubtful. Waters of the following boreholes and wells are doubtful in their use for irrigation: FS-32, FS-63, NRA - A, FS-34, and HV-11. According to Richards classification (1954) the Amman Formation water is classified as of low sodium hazard (S1) and low to medium salinity hazard (C1 - C2) except the water of borehole FS-34 which classifies as of high salinity hazard.

Bituminous Marl Formation Water

Water samples collected from boreholes penetrating the Bituminous Marl Formation show heterogenous chemical composition. It changes from one borehole to another as in the case of the Amman Formation Water. This is mainly related to the effect of dissolution of minerals in the metamorphosed zone with their heterogenous nature. Water passing through the metamorphosed rocks mixes in different ratios with the water of Bituminous Marl Formation to produce heterogeneity. The water of this formation

reaches 27 °C. The higher temperature could also be attributed to exothermal reactions such as oxidation of the sulfides and organic matter. The source of the H₂S is attributed to the reduction of SO₄ to sulfides again.

The water collected from the same borehole over the year shows a similar chemical composition (Fig.17), while that of different boreholes shows a heterogenous chemistry.

Variations in water chemistry encountered within this formation could be attributed to the presence of organic matter, sulphides and to prograde and retrograde metamorphic minerals.

The pH of the water of the Bituminous Marl Formation is normal with the exception of borehole S -8 which reaches 12.5 and could be a result of mixing with high pH water.

The concentration of the major ions in the Bituminous Marl Formation waters is mainly within the limits recommended by the WHO for drinking water with the exception of borehole S-26 where 59 ppm NO₃ exceeds the WHO limit of 45 pp. Although the H₂S concentration is low it has a strong odor which makes the water objectionable. The trace metal concentration differs from one sample to another, Cu, Mn, Co, Cr, Ni, Cd, and Mo show low concentrations lower than recommended upper limit of the WHO for drinking water. Zn (5.0 ppm) and Pb (50 ppb) values are higher than the WHO of standards.

According to Sawyer and McCarty (1967), the Bituminous Marl Formation water is moderately hard to very hard. The above discussion shows that this type of water is not always suitable for drinking and domestic.

According to Wilcox classification (1955) for irrigation water the Bituminous Marl Formation water ranges from good (HV-2) to permissible (HV-5A) to doubtful (FS-71) (Table 15). According to Richards classification (1954) for irrigation water, it is classified as of sodium hazard (S1), but with medium to high salinity hazard (C1 - C2).

SUMMARY and CONCLUSIONS

The major surface water body; the Yarmouk River water, is mainly derived from the basalt aquifer in Syria. This is evidenced by the fixed hydrochemistry of the baseflow hydrograph analysis.

Water from thermal springs, Amman Formation and Bituminous Marl Formation has a deep source which is mixed in different ratios with meteoric water and with meteoric water passing through the metamorphosed rocks.

The mixing ratios differ from one sampling site to another due to the magnitude of permeability of the Bituminous Marl Formation . Spring waters

perculating through the Chalk Marl Formation are meteoric

This study enabled us to draw the following conclusions:-

1. The baseflow water of the Yarmouk River is mainly the water discharged from the basalt springs at Zeizon and Mezarib in Syria mixed with minor amounts of water discharged from the Amman and Bituminous Marl Formation.
2. The stored ground water in the catchment area ranges from 76 MCM to 364 MCM at dry and wet seasons respectively.
3. The Bituminous Marl Formation forms a semiaquiclude confining the water of the Amman Formation which rises to the surface if trapped by breaches. No infiltration takes place from the Yarmouk River to the underlying formation as the water moves upwards through the semiaquicludes and joins the Yarmouk River due to the artesian nature of the aquifer in the Yarmouk River reaches.
4. The ground water gradients are 0.022 to 0.029 on the northern side of the Yarmouk River and 0.035 on the southern side of the river.
5. The permeability of the Amman Formation ranges from 3.6×10^{-3} to 3.7×10^{-5} cm/ sec and the permeability of the Bituminous Marl Formation ranges 1.0×10^{-5} to 5.0×10^{-5} cm/ sec.
6. The hydrochemistry of the Yarmouk area is highly affected by the metamorphism which resulted from the spontaneous combustion of the Bituminous Limestone rocks in the area.

7. Waters of Amman Formation and Bituminous Marl Formation are derived from a deep source of water with TDS and temperature higher than the recorded values at the sampling sites.
8. The deep water is mixed in different ratios with high pH meteoric through joints and fracture.
9. The high pH- water is the meteoric water passing through the metamorphosed rocks rich in portlandite, gypsum and other soluble retrograde metamorphic minerals.
10. The fixed chemistry of each borehole water and the different chemistry of the different boreholes water are due to the magnitude of permeability of the Bituminous Marl Formation which governs the amount of meteoric and high pH-water portions mixing with artesian water.
11. Water of the Chalk Marl Formation springs is meteoric water passing through the Chalk Marl Formation rocks.
12. Trace metals in the groundwater are derived from the bituminous rocks containing originally high concentrations.
13. The high Cr in the high pH water is the result of spontaneous combustion of the bituminous rocks where Cr is liberated from the organic matter and fixed again in retrograde metamorphic minerals.

14. Yarmouk River water and the water of most springs are suitable for domestic and irrigation purposes.
15. Waters of Amman and Bituminous Marl Formations range from suitable to unsuitable for domestic purposes.
16. High pH waters of high Ca, OH, SO_4 , and trace metals concentration are not suitable for both domestic and irrigation purposes.
17. Pollution is starting to take place and affect the surface aquifers and immediate measures should limit the discharge of waste water into the aquifers, these aquifers would be soonly made unsuitable to be used as fresh water sources.
18. The present conditions indicate that the collected water in the proposed Maqarin Dam would be suitable for the different purposes including domestic uses.

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Table (1): Location of sampling sites not
plotted on the map.

Sampling Site	N	E
Spring No.4	237,799.2	232,676.9
Ain El Merdashia	236,451.49	233,397.96
Spring No.7		
Ain Ba'bul	234,380.0	233,402.2
Ain Sombal	235,118.8	233,229.0
Ain et Trab	229,900	226,900
Ain el Quseir	Springs Issue from the basalts in the Syrian side.	
NRA-Saham Exp.234.000	234.000	222.000
Travertine zone seepage	236,981.7	232,739.96
Ain Quelbe	231.600	231.000
Ain Shelaq	221.000	230.400
Ain Um jraïn	221.200	240.100

Table 3: Trace Metal Composition Yarmouk River Water.

Location	Date	pH	T.D.S p.pb.m	Cu p.p.b	Mn p.p.b	Cr p.p.b	Ni p.p.b	Zn p.p.b	Pb p.p.b	Fe p.p.b	Co p.p.b	Cd p.p.b	Mo p.p.b
Y.R.	3.8.80	6.5	421.11	7.23	4.93	11.35	11.32	0.0.5	19.63	0.194	5.17	N.D.	N.D.
"	9.12.80	6.5	273	11.6	13.6	29.1	18.3	20	21.1	497	12.4	N.D	14.7
"	12.3.81	6.8	279	7.6	2.0	11.8	15.3	20	N.D	147	10.8	N.D	15.5
"	22.4.81	—	393	6.6	5.0	17.4	14	50	20.1	151	14.0	1.6	12.7
"	25.5.81	9.0	454	2.8	6.6	2.0	6.8	10	12.5	297	17.9	1.8	15.1

Y.R.: Yarmouk River

N.D.: Not detected

—: Not determined

Table 4: Chemical Composition of the High pH water in adits.

Sample No.	-	-	-	-	-	seepage	seepage	seepage	seepage	seepage	seepage
Date	1.81	12.3.81	22.4.81	25.5.81	23.6.81	5.8.80	1.81	12.3.81	22.4.81	23.6.81	14.2.77
Source	Seepage										
T	—	—	—	—	—	29.0	—	—	—	—	—
pH	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Ca ⁺⁺	480.96	444.89	438.88	426.85	418.84	815.63	545.29	456.91	454.91	795.59	611.22
Mg ⁺⁺	zero	zero	zero	8.51	zero	zero	zero	1.22	zero	zero	7.30
Na ⁺	67.37	67.82	66.67	70.69	65.29	39.08	45.98	48.28	39.08	47.46	59.77
K ⁺	25.27	12.90	14.47	18.91	18.77	21.11	15.69	17.60	13.69	24.53	20.33
Total Cat. meq/l	27.89	25.48	25.53	25.56	24.22	42.94	29.61	25.45	24.75	42.40	34.22
CO ₃ ⁻	30.01	108.04	36.01	18.01	18.01	108.04	30.01	66.02	36.01	24.01	15.61
HCO ₃ ⁻	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OH ⁻	328.29	239.84	278.73	278.96	278.96	523.97	365.72	243.24	284.41	534.11	395.31
Cl ⁻	76.29	71.29	72.27	72.28	95.05	91.76	90.23	87.13	69.71	93.07	108.51
NO ₃ ⁻	3.05	4.20	3.03	2.42	zero	8.86	10.65	10.75	6.66	7.44	0.00
SO ₄ ⁻	274.85	223.34	312.00	388.39	232.95	238.23	260.30	293.94	324.39	321.43	451.48
Total An. meq/l	28.16	24.43	26.41	27.17	24.53	42.09	30.64	25.25	24.85	41.46	36.22
T.D.S.	1289.62	1175.97	1126.06	1285.02	1127	1866.94	1363.84	1225.08	1140.89	1847.64	1669.53

Cont. Table (4). T.Z*.

Sample No.	FS-1	T.Z*	AFS-2	A-1	A-4								
Date	5.8.80	16.8.80	5.8.80	5.9.77	6.9.77								
Source	seepage	seepage	seepage	seepage	seepage								
T	24.5	-	24.5	-	-								
pH	12.5	12.5	12.5	12.5	12.5								
Ca ⁺⁺	923.84	735.47	679.36	710.10	310.62								
Mg ⁺⁺	zero	6.08	3.65	zero	7.30								
Na ⁺	45.98	124.15	50.58	59.77	68.97								
K ⁺	20.33	75.85	20.72	21.90	14.47								
Total Cat. meq/l	48.62	44.04	36.63	38.59	19.47								
CO ₃ ⁻	36.01	162.05	60.02	42.33	18.31								
HCO ₃ ⁻	0.00	0.00	0.00	0.00	0.00								
OH ⁻	682.10	435.46	474.58	523.06	175.88								
Cl ⁻	101.04	253.63	74.23	95.74	92.91								
NO ₃ ⁻	2.25	32.94	8.16	7.75	2.86								
SO ₄ ⁻	223.34	204.61	204.61	356.38	286.26								
Total An. meq/l	48.64	42.64	36.38	42.41	19.77								
T.DS.	2068.17	2030	1575.93	1774.70	0977.58								

* Travertine zone

Table 5: Trace Metal Composition of High pH Waters.

Location	Date	pH	T.D.S	Cu	Mn	Cr	Ni	Zn	Pb	Fe	Co	Cd	Mo
	p.p.m	p.p.b	p.p.b	p.p.b	p.p.b	p.p.b	p.p.b	p.p.m	p.p.b	p.p.b	p.p.b	p.p.b	p.p.b
Adit A-6	10.1.81	12.5	—	11.97	8.90	415.82	39.88	0.03	49.09	0.085	24.37	5.04	42.69
"	10.1.81	12.5	1289.62	5.51	7.83	467.81	27.61	0.08	47.32	0.184	38.20	6.54	32.30
"	12.3.81	12.5	1175.97	5.58	4.33	425.12	22.21	0.03	31.02	0.056	37.94	5.96	32.39
"	22.4.81	12.5	1226.06	6.18	7.38	437.35	25.62	0.05	55.97	0.120	33.51	5.89	28.42
"	25.5.81	12.5	1285.02	8.62	6.21	419.48	20.07	0.02	38.56	0.133	38.96	6.93	28.42
"	23.6.81	12.5	1127.87	6.79	2.76	400.70	18.79	0.02	41.97	0.125	47.53	6.35	27.63
W.S. Seepage	5.8.80	12.5	1866.94	17.54	6.38	523.32	67.41	0.10	95.79	0.081	39.65	9.76	49.60
"	10.1.81	12.5	1363.86	—	7.99	466.05	31.43	0.11	59.40	0.139	41.52	7.46	44.10
"	12.3.81	12.5	1225.08	8.37	5.39	348.76	24.64	3.06	48.13	0.143	36.39	5.97	39.00
"	22.4.81	12.5	1140.89	8.17	8.18	383.98	21.35	0.02	43.85	0.090	31.74	6.54	26.50
"	23.6.81	12.5	1847.46	7.52	10.01	635.78	29.47	0.05	73.72	0.125	52.21	10.06	26.84
Tr. Zone	16.8.80	12.5	2030.24	33.13	14.02	422.74	66.00	0.13	81.96	0.113	38.94	8.54	38.07
"	5.8.80	12.5	2868.94	16.71	19.42	161.08	75.53	0.10	81.15	0.161	50.22	9.91	80.77
"	25.8.80	12.5	1575.93	14.48	16.18	265.46	59.65	0.10	69.19	0.096	36.81	9.76	46.38

N.D: Not detected.
 —: " determined.

Table 6: Chemical Composition of the Springs Water.

Sample No.	Spring No.4	Spring No.9	Spring No.2	Ein el Qusier	Ein Ghazala	Ain-Um Jrain	Spring No.7	Ain-Ba'doul	Ain-Sombel	Ain Quelba	Ain et Treb	Ain Shelaq
Date	4.8.80	4.8.80	4.8.80	24.9.80	24.9.80	21.7.79	6.9.80	6.9.80	6.9.80	10.11.80	9.9.80	21.7.79
Source	Spring	Spring	Spring	Spring	Spring	Spring	Spring	Spring	Spring	Spring	Spring	Spring
T	34.5	32.0	32.0	20.5	20.5	—	22.50	23.00	23.00	—	24.0	—
pH	6.9	6.8	6.8	8.5	6.8	—	6.80	6.80	6.80	—	6.8	—
Ca ⁺⁺	88.18	72.14	90.18	78.16	20.04	52.10	104.21	128.26	110.22	68.14	68.14	60.92
Mg ⁺⁺	52.29	42.56	30.40	25.54	15.61	10.46	23.10	41.34	20.67	7.30	7.30	11.68
Na ⁺	91.96	66.90	41.38	85.06	46.91	57.48	22.99	41.38	22.07	15.17	22.99	39.08
K	4.69	7.84	5.87	3.91	5.74	1.56	2.74	2.35	3.13	2.35	0.78	1.56
Total Cat. meq/l	12.82	10.19	8.95	9.80	4.43	6.00	8.17	11.66	8.24	4.72	5.02	5.74
CO ₃ ⁻	0.00	0.00	0.00	0.00	0.00	2.40	0.00	0.00	0.00	0.00	0.00	10.20
HCO ₃	427.14	488.16	366.12	213.57	152.55	147.67	378.32	390.53	372.22	207.47	225.77	138.06
OH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	177.33	96.91	64.95	133.41	44.33	81.56	39.18	79.39	61.86	22.68	22.68	54.25
NO ₃ ⁻	1.07	0.64	0.60	136.19	18.71	39.69	6.69	6.40	11.46	24.90	22.30	32.34
SO ₄ ⁻⁻	117.46	42.75	68.25	40.80	16.20	31.70	62.69	111.91	28.82	14.40	6.45	19.21
Total An. meq/l	14.42	11.43	9.25	9.75	4.59	—	8.80	11.07	8.64	4.38	4.38	5.79
T.D.S	746.55	573.02	484.69	589.86	247.74	350.86	450.76	606.40	444.34	258.68	263.53	326.70

Table 7: Trace Metal Composition of the Springs Water.

Location	Date	pH	T.D.D p.p.m	Cu p.p.b	Mn p.p.b	Cr p.p.b	Ni p.p.b	Zn p.p.m	Pb p.p.b	Fe p.p.b	Co p.p.b	Cd p.p.b	Mo p.p.b
Spring No.4		6.9	746.55	5.32	17.81	7.22	15.65	0.01	18.60	0.063	9.60	2.34	N.D.
No.9		6.8	573.02	5.53	6.30	3.44	12.99	0.02	21.70	0.123	13.29	1.64	N.D.
No.2		6.8	484.69	4.68	20.27	3.44	13.65	0.02	N.D	0.076	5.91	2.44	N.D.
Quseir		8.5	589.86	13.65	25.02	3.09	15.55	0.09	23.81	0.371	N.D	1.51	N.D.
Ghazalah		6.8	247.74	2.58	4.83	7.20	8.11	0.02	15.87	0.180	N.D.	1.00	8.38
No.7		6.8	450.76	6.46	3.78	6.18	29.65	0.03	19.16	0.086	9.94	1.79	N.D.
Ba'boul		6.8	606.40	8.07	25.08	19.27	7.41	0.02	27.67	0.196	N.D.	1.79	20.65
Sombal		6.8	444.34	6.68	4.85	4.00	31.17	0.04	17.03	0.080	N.D.	2.93	8.26
et Trab		6.8	502.86	6.93	5.12	2.74	12.17	0.02	12.27	0.052	5.94	0.97	N.D.
Quelbe		6.8	258.68	8.89	9.01	4.31	19.61	1.59	55.91	0.122	12.46	2.17	N.D.

N.D. Not detected.

Table (8): Chemical Composition of Amman Formation Waters.

Sample No.	FS-36	FS-52	Borehole Well FS-35	NRA-W.S	HV-11	FS-4	FS-34	FS-37	FS-17	FS-26	FS-63	FS-62	FS-32	FS-18
Date	9.12.80	4.8.80	9.9.80	7.9.80	10.9.80	10.8.80	9.9.80	1.81	4.8.80	8.9.80	9.9.80	9.9.80	2.10.80	9.9.80
Source	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.	G.W.
T	—	26.5	30.0	26.0	29.0	29.0	26.5	—	26.5	27.0	25.0	26.0	24.5	28.0
pH	6.80	6.50	7.1	6.8	7.0	6.8	12.0	6.8	6.8	7.5	12.0	7.1	8.2	7.1
Ca ⁺⁺	96.19	76.15	3.65	106.21	14.03	90.18	206.41	90.18	104.21	68.14	44.09	42.08	22.04	49.09
Mg ⁺⁺	27.97	40.13	3.65	32.83	9.73	30.40	3.65	35.26	37.70	6.88	3.65	9.73	10.94	25.04
Na ⁺	63.91	75.87	64.37	71.27	105.29	41.38	108.05	52.88	72.85	101.16	78.17	71.27	64.87	61.84
K ⁺	1.65	10.95	6.65	12.90	7.42	5.87	333.52	2.74	4.69	7.04	14.86	6.65	8.29	7.43
Total Cat. meq/l	9.92	10.68	4.87	12.83	6.31	8.93	23.83	9.77	11.57	8.12	6.28	6.17	5.03	7.28
CO ₃ ⁻	0.00	0.00	36.01	0.00	12.00	0.00	0.00	421.00	463.75	42.71	0.00	24.01	24.01	12.00
HCO ₃ ⁻	402.73	256.28	67.12	292.90	42.71	366.14	0.00	421.00	463.75	42.71	0.00	79.33	54.92	36.61
OH ⁻	0.00	0.00	0.00	0.00	0.00	0.00	45.93	0.00	0.00	0.00	8.51	0.00	0.00	0.00
Cl ⁻	79.39	109.29	80.42	143.31	168.03	64.95	90.73	77.33	86.60	113.41	113.41	79.39	59.80	68.05
NO ₃ ⁻	1.00	0.75	2.18	2.46	2.60	0.60	10.97	1.00	0.89	3.52	3.80	2.28	5.84	3.31
SO ₄ ⁻	42.48	138.09	6.45	152.74	12.00	68.25	760.32	45.59	65.87	144.57	84.60	69.00	58.20	6.24
Total An. meq/l	9.74	10.18	4.70	12.06	6.13	9.10	23.47	10.05	11.42	7.77	6.27	5.78	4.69	6.90
T.D.S	512.31	580.17	256.45	685.20	352.46	484.69	1625.60	515.48	603.71	489.29	387.10	347.08	281.45	238.77

Table(9): Trace Metal concentration of Aman Formation Waters.

Location	Date	pH	T.D.S ppm	Cu ppb	Mn ppb	Cr ppb	Ni ppb	Zn ppm	Pb ppb	Fe ppm	Co ppb	Cd ppb	Mo ppb
FS-36	Jan.81	6.8	512.31	3.88	19.74	N.D.	16.57	4.14	16.10	0.682	13.29	1.76	7.36
FS-35	Sept.80	7.1	265.45	18.67	11.65	6.87	17.51	3.19	53.18	0.361	N.D.	1.77	19.86
NRA-W.S	Sept.80	6.8	685.20	9.07	22.75	6.51	21.51	1.11	54.67	0.316	13.45	1.86	14.07
HV-11	Sept.80	7.0	352.46	11.33	19.05	17.14	10.82	4.82	37.70	0.633	N.D.	3.43	11.43
FS-37	Jan.81	6.8	515.48	3.47	14.73	4.64	13.17	7.49	15.10	0.443	12.39	1.93	11.04
FS-52	Aug.80	6.5	580.17	5.01	25.35	5.09	14.82	0.02	22.04	0.121	8.86	N.D.	N.D.
FS-34		12.0	1625.60	13.60	11.65	8.31	48.51	5.87	527.73	0.268	34.18	22.98	40.55
FS-4	Aug.80	6.8	458.60	6.17	15.62	5.16	19.31	1.72	N.D.	0.199	13.29	2.44	36.00
FS-17		6.8	603.70	6.60	34.25	5.85	17.31	4.31	14.47	0.529	5.91	2.73	N.D.
NRA-B		11.5		9.75	30.61	71.27	28.09	0.05	37.17	1.054	13.45	2.42	14.90
FS-23		7.5	489.29	16.27	87.95	7.95	22.88	6.06	162.91	0.613	N.D.	0.97	11.59
FS-25		9.5		20.27	9.75	9.76	25.17	1.00	59.04	0.261	N.D.	1.94	18.21
FS-10		6.8		10.40	7.04	7.59	18.61	4.04	44.83	0.610	10.62	2.26	14.07
FS-60		12.0	387.10	16.53	41.45	2.12	19.33	7.05	281.25	0.420	11.15	1.77	23.17
FS-62		7.01	347.08	13.60	5.96	1.45	16.78	3.80	43.98	0.233	N.D.	N.D.	10.76
FS-21		7.5	432.71	16.00	14.36	3.25	15.68	15.28	227.05	2.636	N.D.	3.22	N.D.
FS-18	7.1	7.1	238.81	21.07	17.92	4.80	29.07	6.15	150.34	0.527	N.D.	3.46	8.28
FS-22		7.4		41.72	23.61	7.20	30.42	10.51	169.64	0.338	26.01	2.42	48.00
FS-32		8.2	281.45	21.48	6.97	4.67	24.00	2.55	125.79	0.160	N.D.	N.D.	10.67
NRA-A		6.8		25.34	32.24	6.68	21.89	15.82	557.60	1.034	4.96	5.33	N.D.

Cont. Table 10

Sample No.	S - 70	BV - 4	S - 18	FS - 70	FS - 47	ES-9	S - 8	S-26	S-3
Date	24.9.80	25.9.80	10.9.80	8.9.80	7.10.80	10.9.80	10.9.80	10.9.80	10.9.80
Source	25.0	26.0	28.0	Borehole	Borehole	Borehole	Borehole	Borehole	Borehole
T	—	—	—	24.0	27.0	27.0	26.0	28.0	28.0
pH	6.9	8.5	7.0	6.8	6.8	6.8	12.5	7.0	6.8
Ca ⁺⁺	122.24	18.04	14.03	20.06	370.74	92.18	262.52	140.28	416.83
Mg ⁺⁺	31.62	8.51	13.38	25.54	26.75	29.18	4.86	36.05	71.74
Na ⁺	108.28	38.62	71.27	91.96	64.37	45.98	63.91	202.08	188.75
K ⁺	5.81	10.56	9.78	25.02	22.29	12.12	14.47	7.43	5.87
Total Cat. meq/l	10.56	3.55	5.15	8.14	24.07	9.31	16.65	18.98	35.05
CO ₃ ⁻	0.00	30.01	12.00	24.07	0.00	0.00	90.03	0.00	0.00
HCO ₃ ⁻	231.88	36.61	36.61	109.84	451.55	353.92	0.00	201.37	451.55
OH ⁻	0.00	0.00	0.00	0.00	0.00	0.00	18.71	0.00	0.00
Cl ⁻	103.10	57.74	89.70	107.04	84.39	50.52	101.06	213.42	362.91
NO ₃ ⁻	3.38	3.38	2.53	2.88	6.20	3.52	3.72	59.00	9.36
SO ₄ ⁻	219.50	6.24	60.60	121.20	610.46	92.40	454.36	319.88	883.75
Total An. meq/l	11.34	3.87	4.83	8.02	22.59	9.21	16.47	17.83	36.18
T.D.S	909.87	191.40	291.40	465.97	1410.98	502.86	1013.64	1078.83	2164.90

Table: 11 Trace Metal Composition of the Bituminous Marl Formation.

Location	Date	pH	T.D.S	Cu	Mn	Cr	Ni	Zn	Pb	Fe	Ce	Cd	MO
		p.p.m	p.p.m	p.p.b	p.p.b	p.p.b	p.p.b	p.p.m	p.p.b	p.p.m	p.p.b	p.p.b	p.p.b
HV-5A	Aug, 80	6.5	5.70	6.81	41.37	8.25	17.98	0.04	20.67	0.360	5.91	2.89	25.38
AV-2	Aug., 80	6.8	505	4.47	36.44	4.13	22.64	0.09	17.57	0.446	88.12	2.27	28.85
BV-2	Aug., 80	6.5	466	8.51	14.80	5.85	3.33	0.04	17.57	0.249	7.39	2.19	27.69
HV-10	Aug., 80	6.5	421.3	9.36	14.52	3.10	16.32	0.04	16.53	0.120	N.D.	1.02	17.21
HV-8	Sept., 80	6.8	545	7.47	48.81	7.19	24.68	11.76	86.86	0.505	N.D.	1.59	13.71
AV-1	May, 81	7.4	381	2.75	28.64	19.52	15.37	3.16	31.34	0.857	11.69	1.39	N.D.
HV-2	Aug., 80	6.8	383	10.00	13.15	7.22	20.64	3.59	21.70	0.325	N.D.	3.90	N.D.
S-29	Aug., 80	6.8	520	5.32	11.51	2.75	13.65	1.41	14.03	0.088	8.86	1.46	N.D.
HV-7	"	6.8	394	5.53	30.14	2.06	11.99	0.24	N.D.	0.393	19.94	1.71	13.85
FS-47		6.8		48.27	74.49	17.71	69.67	19.05	84.19	0.227	31.15	5.09	62.07
FS-70		6.8	466	11.47	70.43	3.25	12.77	0.33	33.89	0.477	6.37	N.D.	N.D.
FS-26		7.4	489	16.27	87.95	7.95	22.61	6.06	162.91	0.613	N.D.	0.97	11.59
S-20		8.0		16.09	14.09	15.18	26.63	6.44	159.63	0.673	12.74	2.42	16.55
S-8		12.5	1009.9	19.57	13.65	12.69	37.52	4.21	102.18	0.623	23.78	4.35	135
S-26		7.0	1078.83	15.45	28.44	7.54	61.52	8.80	117.06	0.931	26.75	3.26	54.1
FS-71		7.2	410.13	26.27	36.68	5.49	20.96	15.32	136.86	1.876	N.D.	1.50	N.D.

Sent. . Table 11.

Location	Date	pH	T.D.S	Cu	Mn	Cr	Ni	Zn	Pb	Fe	Co	Cd	MO
		p.p.m	p.p.m	p.p.b	p.p.b	p.p.b	p.p.b	p.p.m	p.p.b	p.p.m	p.p.b	p.p.b	p.p.b
S-18		7.0	291.57	12.10	14.22	10.63	12.17		39.68	0.593	N.D.	1.00	N.D.
S-41		8.5	283.09	15.19	16.49	2.74	10.97	6.87	101.19	0.423	N.D.	N.D.	N.D.
S-70		6.9	709.87	9.01	46.64	6.17	23.66	3.69	48.61	0.250	N.D.	1.51	24.3
AV-5		8.2		21.37	13.08	7.90	19.94	14.91	754.84	0.512	N.D.	1.51	N.D.
BV-4		8.5	224.97	24.98	24.70	8.62	13.18	14.60	1119.04	0.710	N.D.	1.22	6.10
BV-5		6.8		20.99	61.02	13.65	40.56	12.38	560.53	0.781	13.29	4.51	8.38
FS-5		8.5		15.80	21.50	6.83	27.38	17.96	1001.03	0.781	N.D.	2.52	41.11

Table 12 Water quality of Yarmouk River water.

Date	TDS ppm	% Na	Hardness ppm as CaCO ₃	SAR
3.8.80	453.07	59.24	85.07	2.52
9.12.80	273.53	37.63	114.91	1.41
12.3.81	279.76	46.50	151.36	1.89
22.4.81	393.55	48.28	174.83	2.46
25.5.81	454.06	49.08	195.08	2.60

Table 13 Quality of high PH Water

Sample No.	Date	TDS PPM	Hardness 48 CaCO ₃ PPM	% Na	SAR
W.S. Seepage	5.8.80	1866.94	2138.79	5.22	0.33
"	1.81	1363.84	1363.84	6.89	0.54
"	12.3.81	1225.08	1147.48	10.02	0.62
"	22.4.81	1140.89	1147.24	8.20	0.51
"	23.6.81	1847.98	1988.98	6.37	0.47
Adit A-6	1.81	1289.62	1227.33	12.87	0.84
"	12.3.81	11175.97	1127.19	12.87	0.89
"	22.4.81	1226.06	1097.20	14.22	0.33
"	25.5.81	1285.02	1102.02	13.93	1.41
"	23.6.81	1127.87	1047.10	13.71	0.88
Borehole FB-1	5.8.80	2068.94	2449.21	5.18	0.42
Travertube Zone/1	6.8.80	2030.24	1863.60	48.51	1.25
Adit AFB-2	5.8.80	1575.93	1713.37	7.45	0.53
Adit A-1	5.9.77	1774.70	1775.25	8.34	0.62
Adit A-4	6.9.77	0977.58	806.48	17.31	0.92

Table (14) Quality of Amman Formation Water

Sample No.	Date	TDS	Hardness as CaCO ₃ (ppm)	% Na	SAR
FS-36	9.12.80	512.31	355.15	28.43	1.48
NRA-W.8	7.9.80	685.20	469.95	14.00	1.43
FS-4	4.8.80	458.60	320.04	28.33	1.29
FS-52	4.8.80	580.17	354.91	33.52	1.35
HV-11	10.9.80	352.46	74.97	76.23	5.30
FS-34	9.9.80	1625.80	530.99	55.52	2.00
FS-17	4.8.80	603.71	415.10	28.26	1.55
FS-36	8.9.80	489.29	195.28	57.00	2.90
FS-63	9.9.80	387.10	125.19	60.19	3.00
FS-62	9.9.80	347.08	145.09	53.00	2.60
FS-18	9.9.80	238.77	217.89	39.56	1.80
FS-32	2.10.80	281.45	99.95	60.24	2.80
FS-37	1.80	515.48	370.02	24.26	1.20
FS-74	24.9.80	469.22	84.91	57.34	2.94

Table (15): Quality of Bituminous Marl Formation Waters.

Sample No.	Date	TDS	Hardness as CaCO ₃ PPm	% Na	SAR
HV -SA	3.8.80	569.91	360.0	27.96	1.44
HV -2	3.8.80	382.69	305.05	21.09	0.86
AV -1	25.5.81	379.89	244.89	22.68	0.94
HV -8	24.9.80	544.50	375.14	24.45	1.20
HV -10	3.8.80	421.32	295.09	21.57	0.93
HV -7	4.8.80	398.95	275.06	25.17	1.03
ES -9	10.9.80	502.86	350.09	24.81	1.20
AV -2	13.8.80	504.66	315.14	33.68	1.69
BV -2	3.8.80	466	355.21	21.11	0.9
S -3	10.9.80	2164.90	1336.21	23.85	2.3
S -8	10.9.80	1017.64	176.23	18.92	1.10

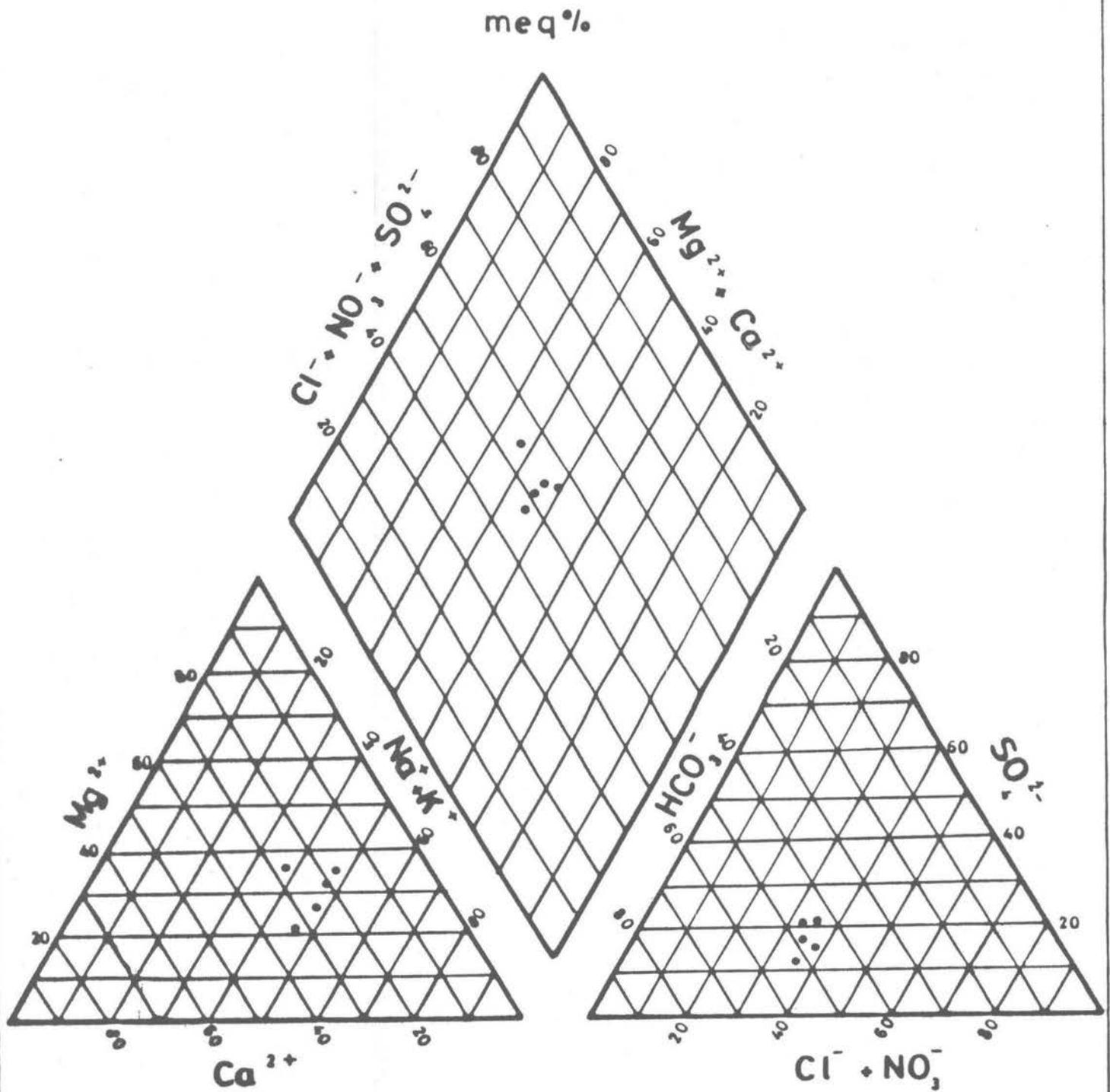


Fig. 5 Trilinear plots of the major ion chemistry for the Yarmouk River.

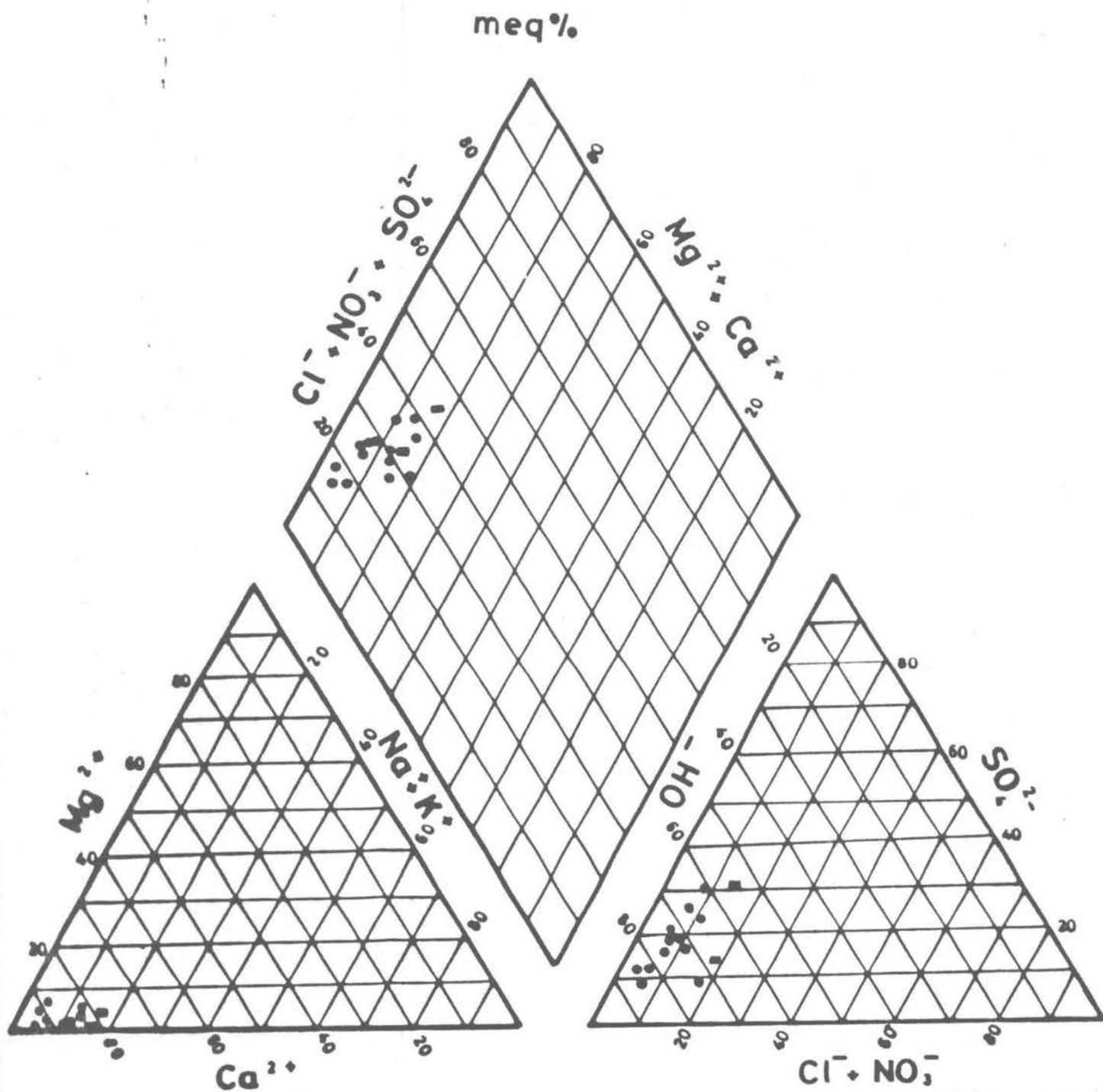
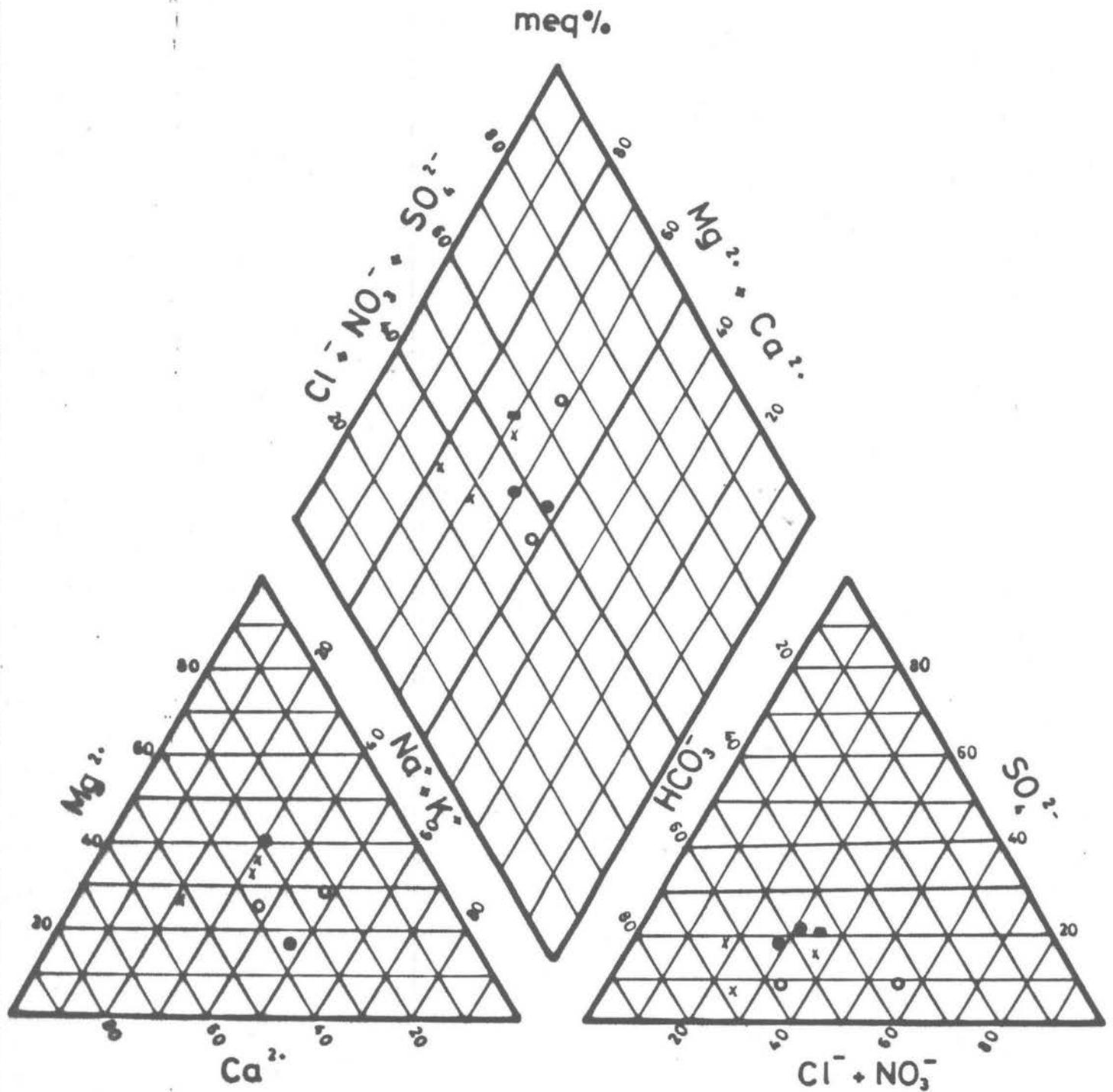


Fig. 6 Trilinear plots of the major ion chemistry for the High PH Water samples.

- The analysed samples during the study.
- Harza, 1978 samples.



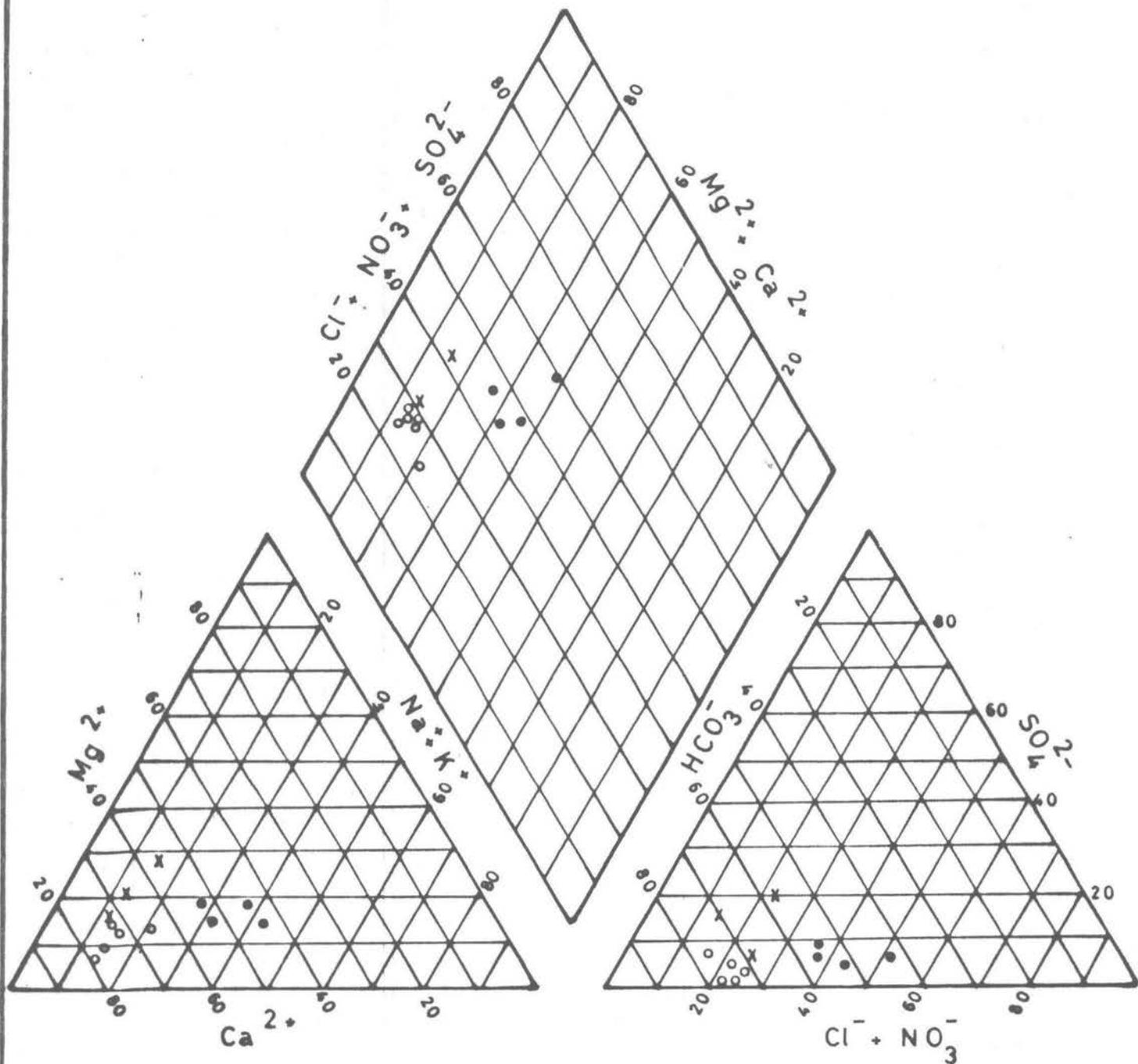
x Thermal springs

o Basalt springs

● Spring No. 3

■ Ain el Mardasheya

Fig. (7) Trilinear plots of the major ion chemistry for springs.



- Ain Qelbe and Ain el Trab samples
- × Springs of the lower reaches of wadi Shallala
- Springs of the upper reaches of wadi Shallala

Fig. (8) Trilinear plots of major ion chemistry for Chalk Marl Formation springs water.

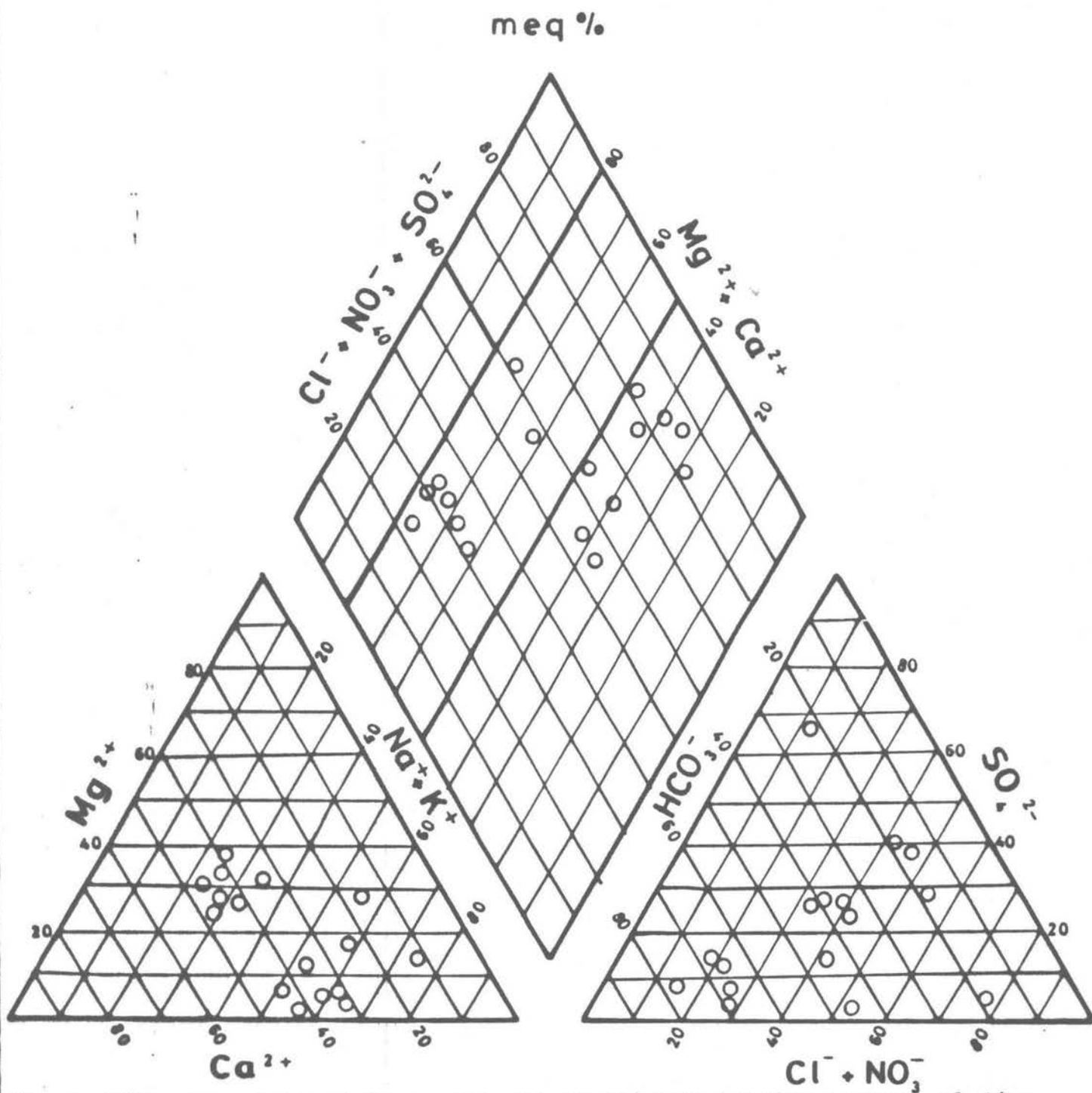


Fig. 9 Trilinear plots of the major ion chemistry for the water of the Amman Formation boreholes.

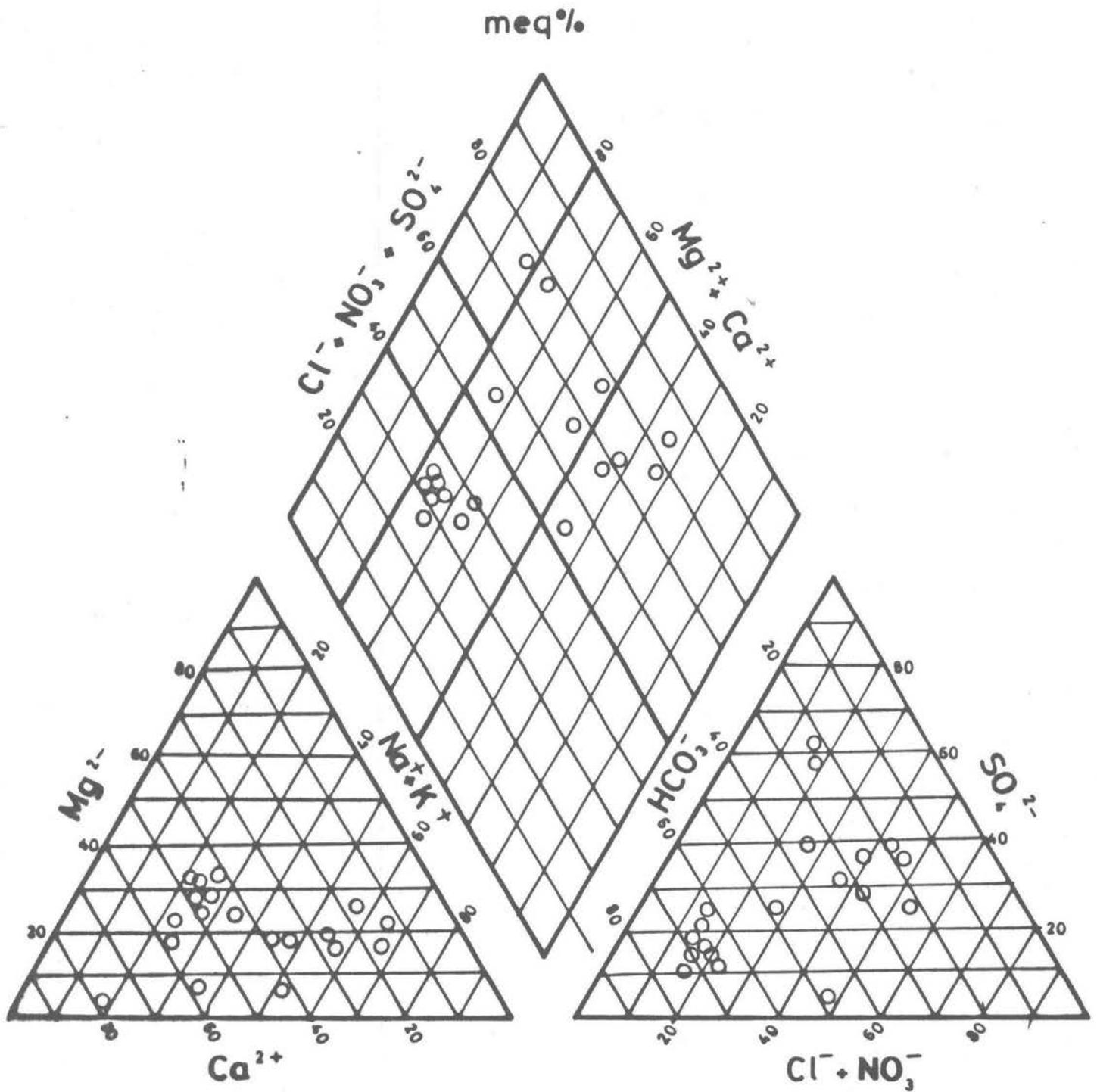


Fig.10 Trilinear plots of the major ion chemistry for the water of the Bituminous Marl Formation boreholes.

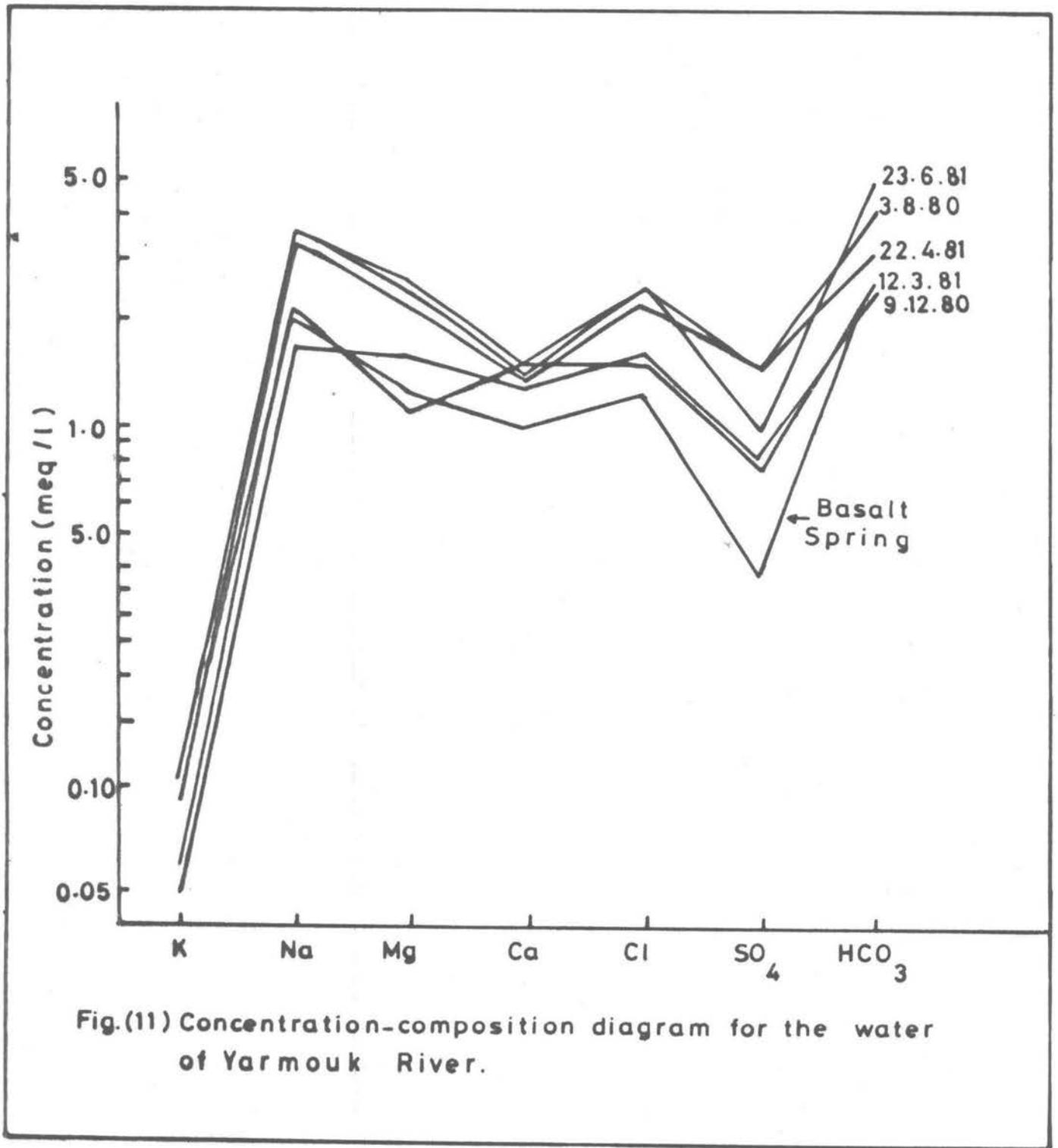


Fig.(11) Concentration-composition diagram for the water of Yarmouk River.

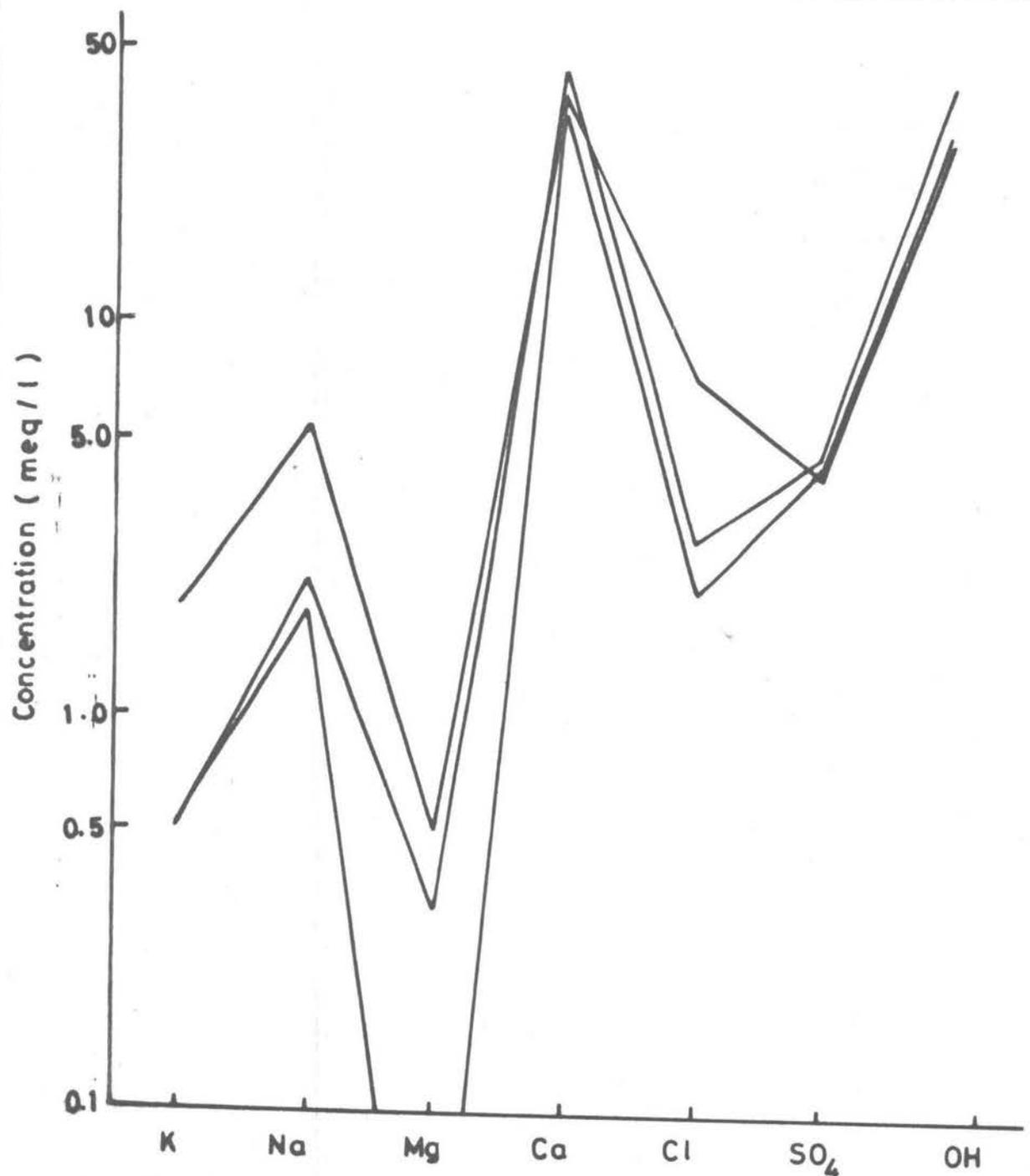


Fig. (12c) Concentration - composition diagram for other High PH Water.

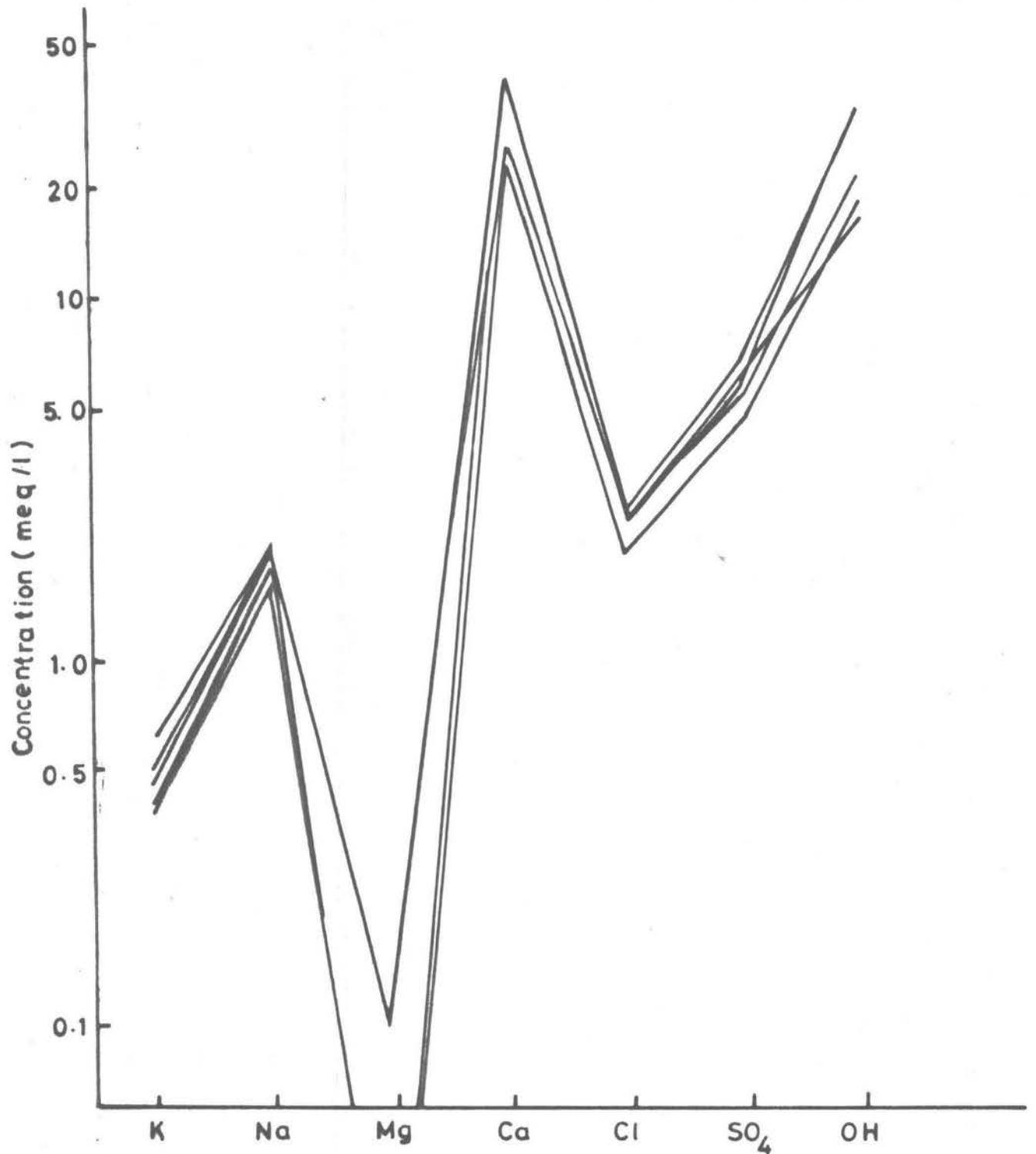
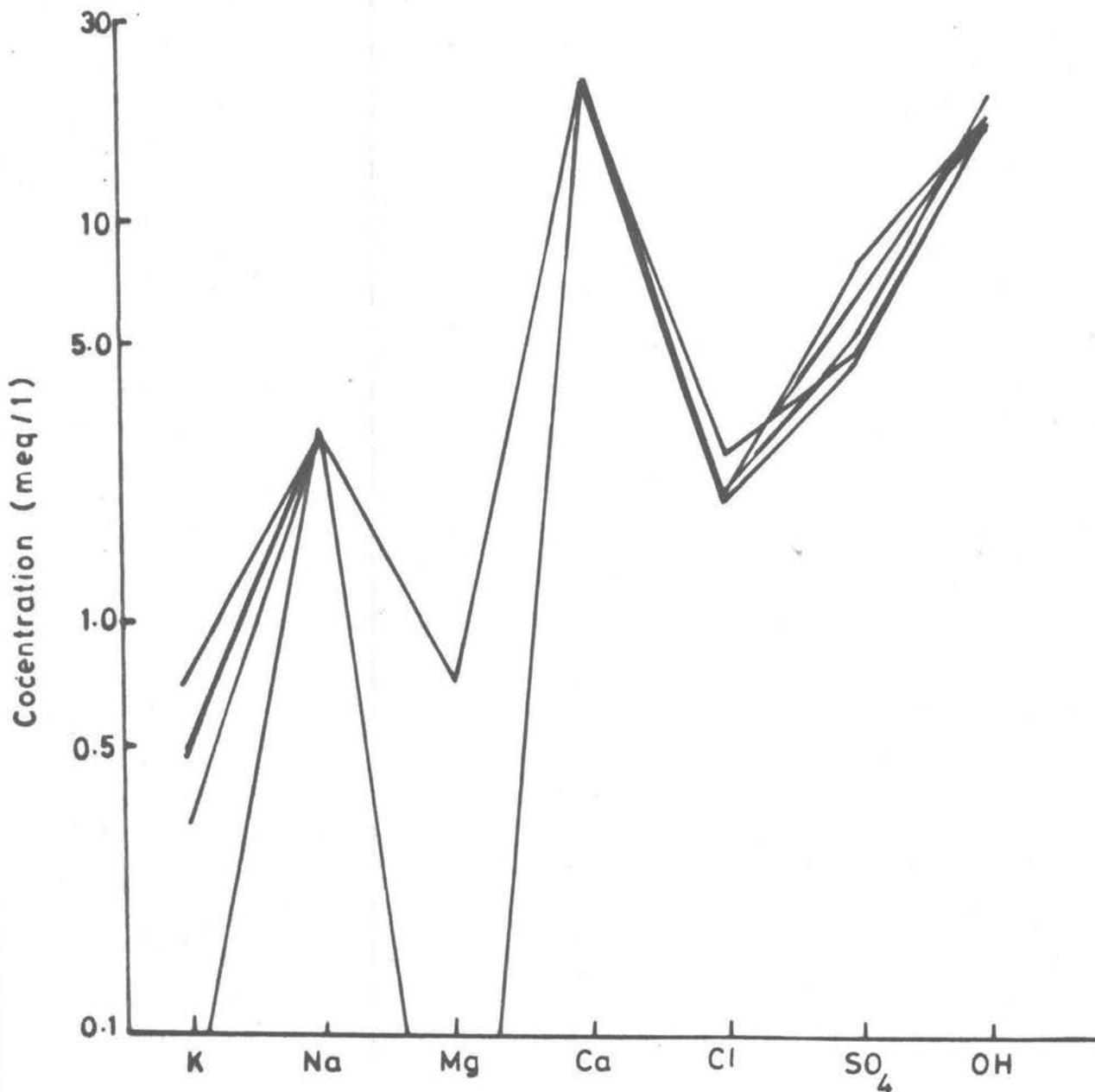


Fig. (12b) Concentration-composition diagram for Wadi es Sidjin Seepage water.



Fig(12a) Concentraion - composition diagram for adit A 6 water

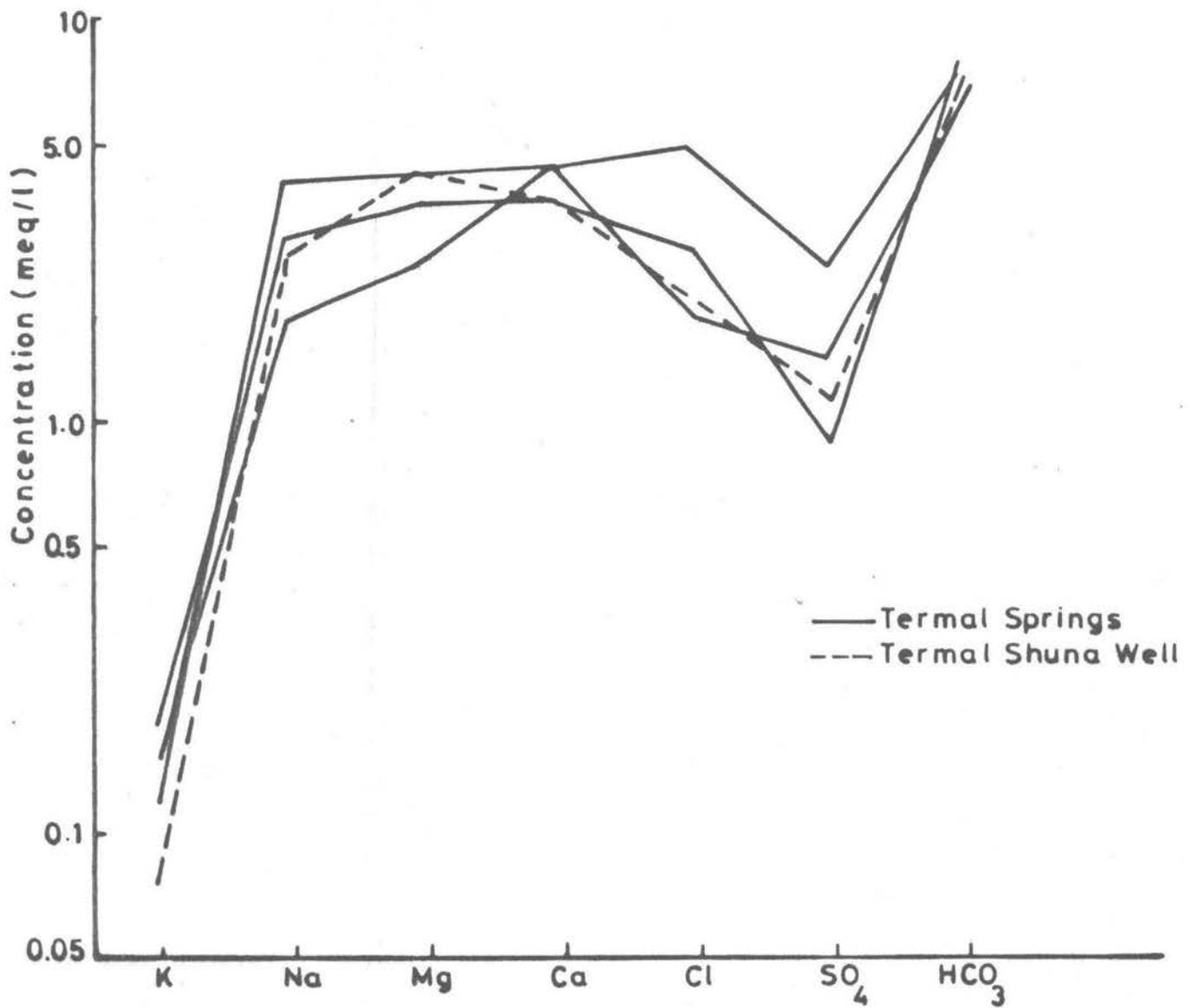
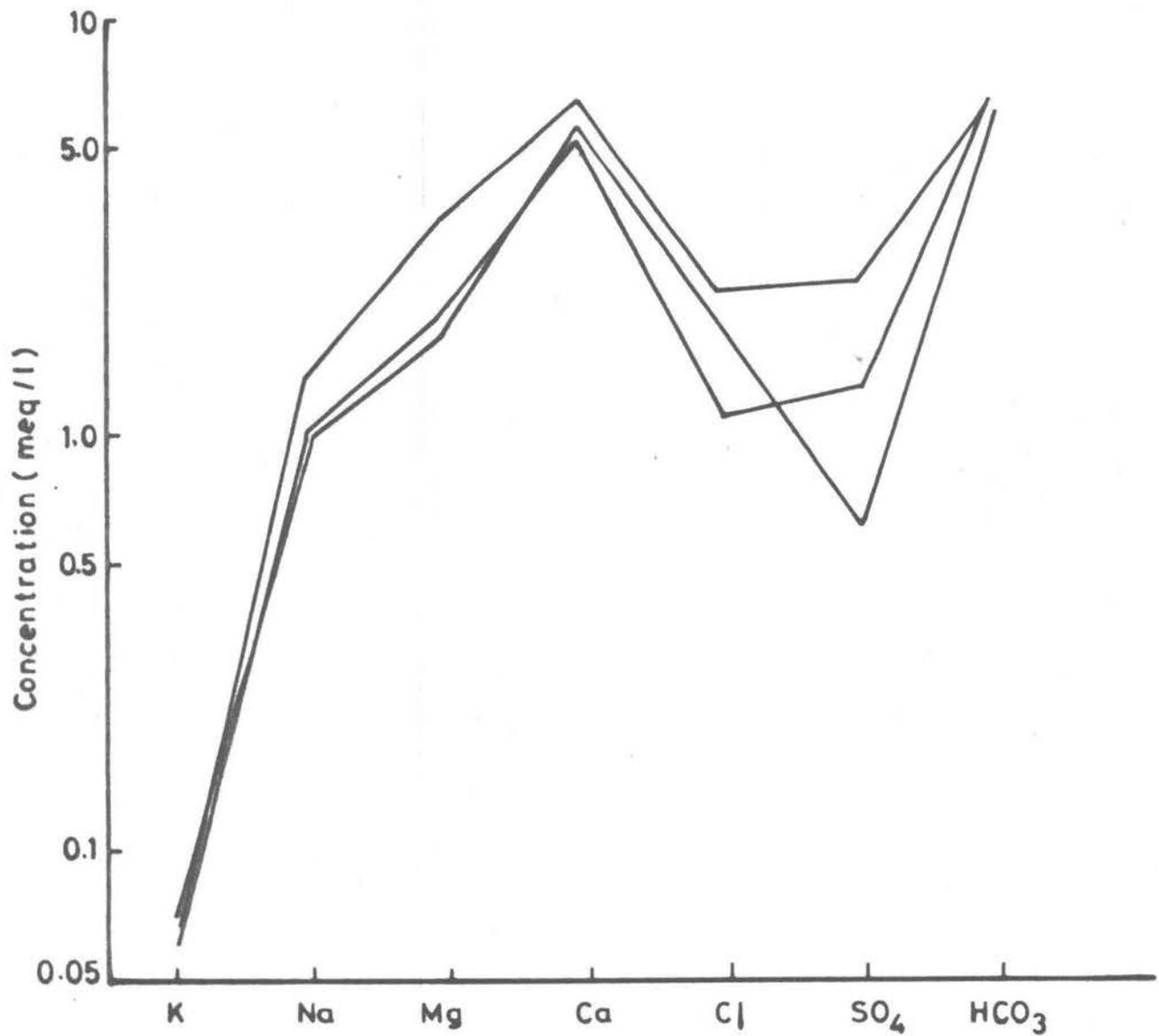


Fig (13) Concentration - composition diagram for Thermal Springs in the study area and Thermal Shuna Well .



Fig(14) Concentration composition diagram for Springs of lower reaches of Wadi Shallala .

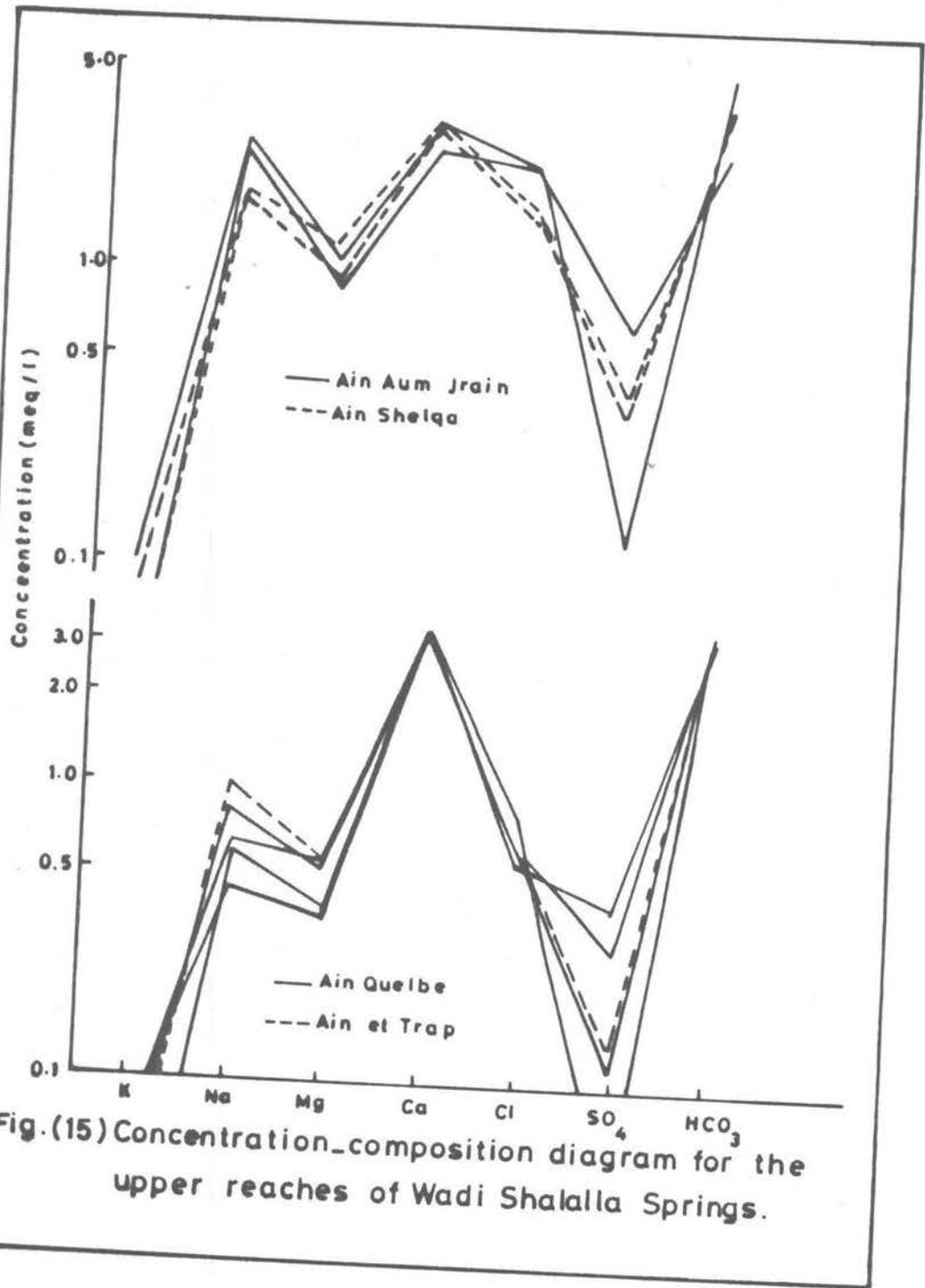


Fig.(15) Concentration-composition diagram for the upper reaches of Wadi Shalalla Springs.

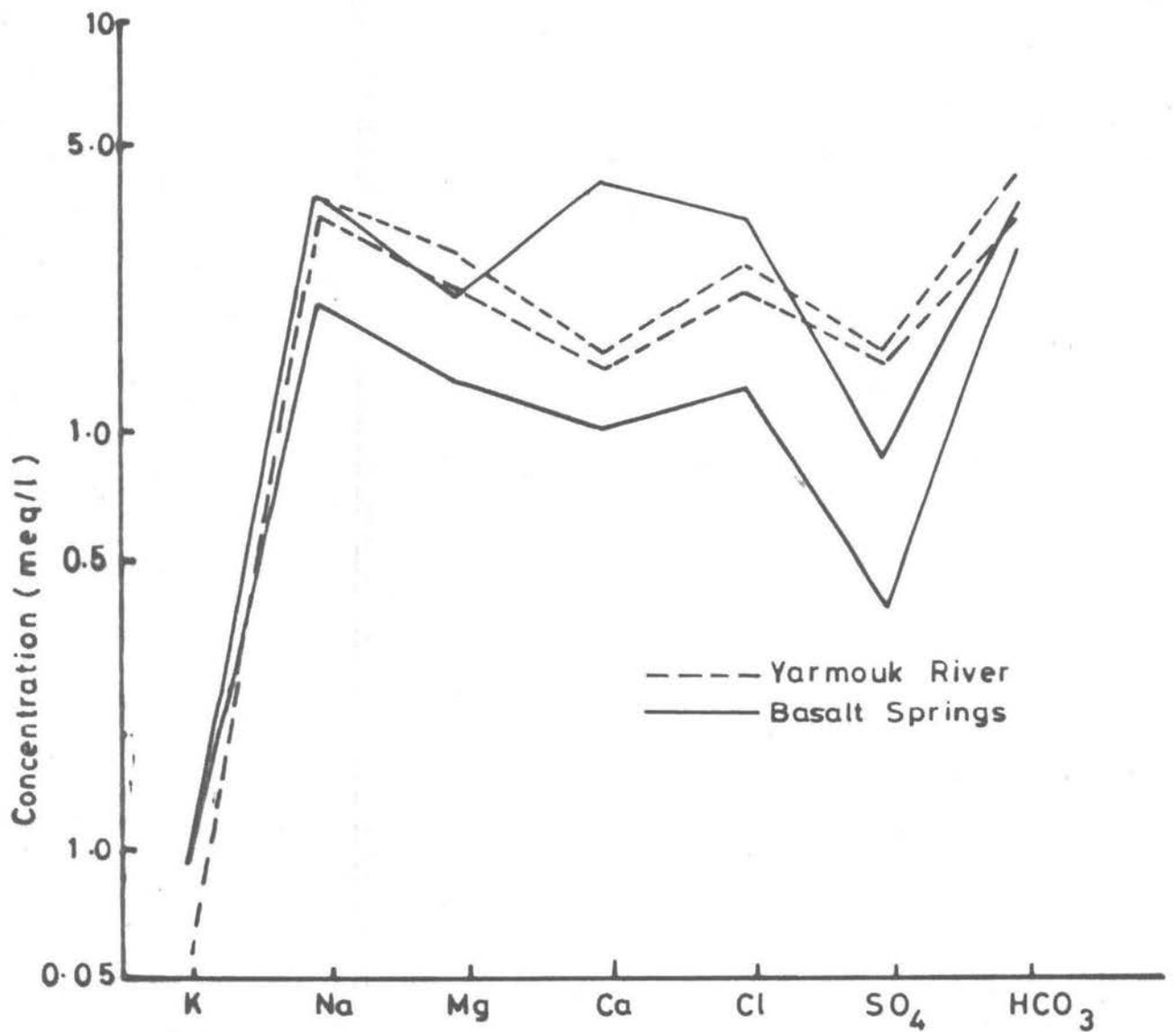


Fig (16) Concentration-composition diagram for the water of basalt springs and Yarmouk River.

UPPER - CRETACEOUS		LOWER - TERTIARY		PLIESTOCENE	
24 m	B-1			SOIL	
62 m	B-2	AMMAN FORMATION		BASALT	
220 m	B-3	BITUMINOUS-MARL FORMATION			
			190 m	B-4,5	CHALKY L.S. FORMATION
					LOWER CHALKY UNIT
					UPPER CHALKY UNIT
			35 m		
			170 m		

Fig(2) COLUMNAR SECTION IN THE MAGARIN AREA

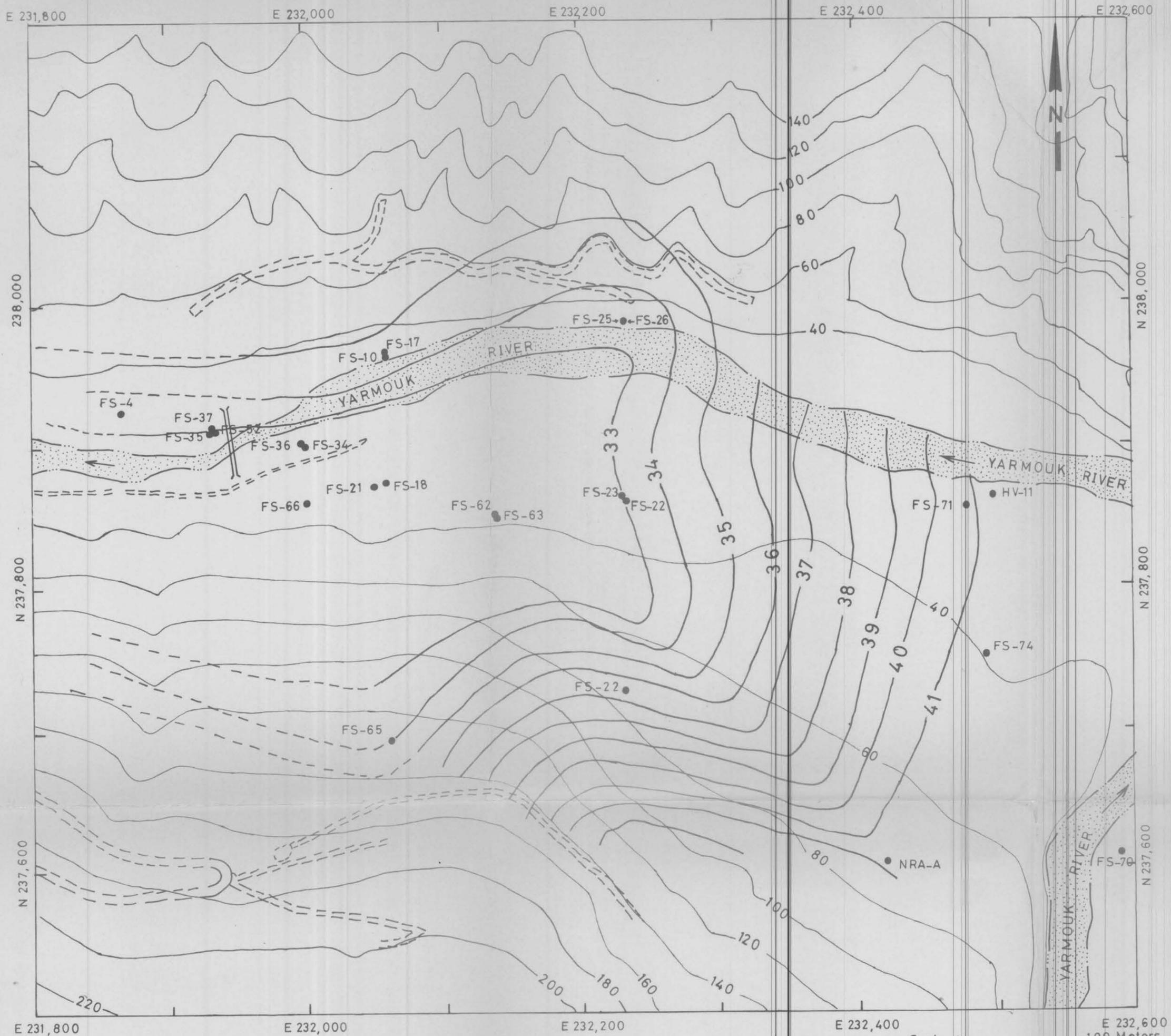


Fig (4) AMMAN FORMATION PIEZOMETRIC LEVELS CONTOUR MAP (MARCH 1980)

Scale 0 100 Meters

- 100 — CONTOUR LINES (ASL) IN METERS.
- ROADS.
- YARMOUK RIVER.
- 37 — PIEZOMETRIC LEVELS (ASL) IN METERS.
- BOREHOLES.
- INFERED PIEZOMETRIC LEVELS.

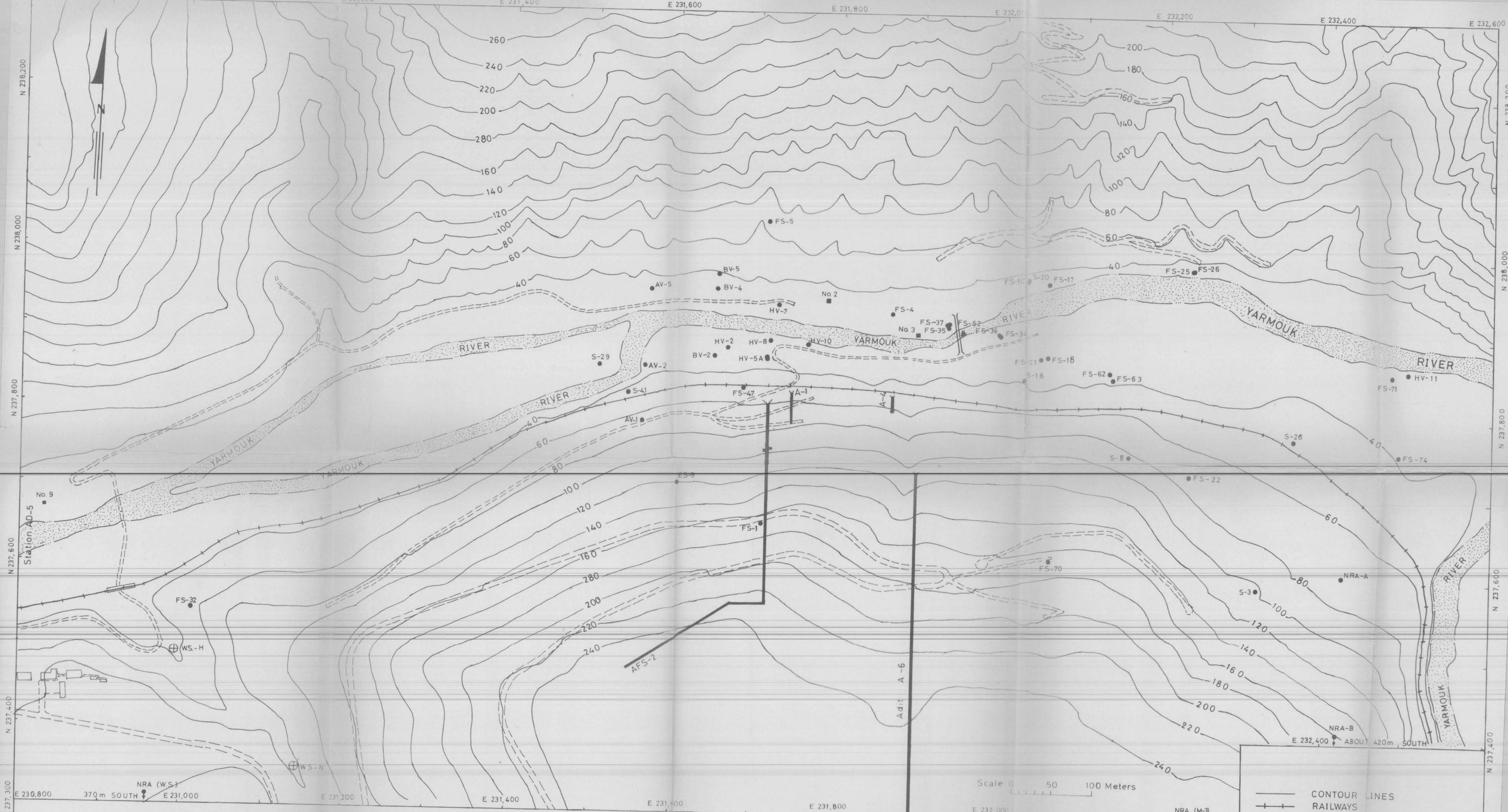


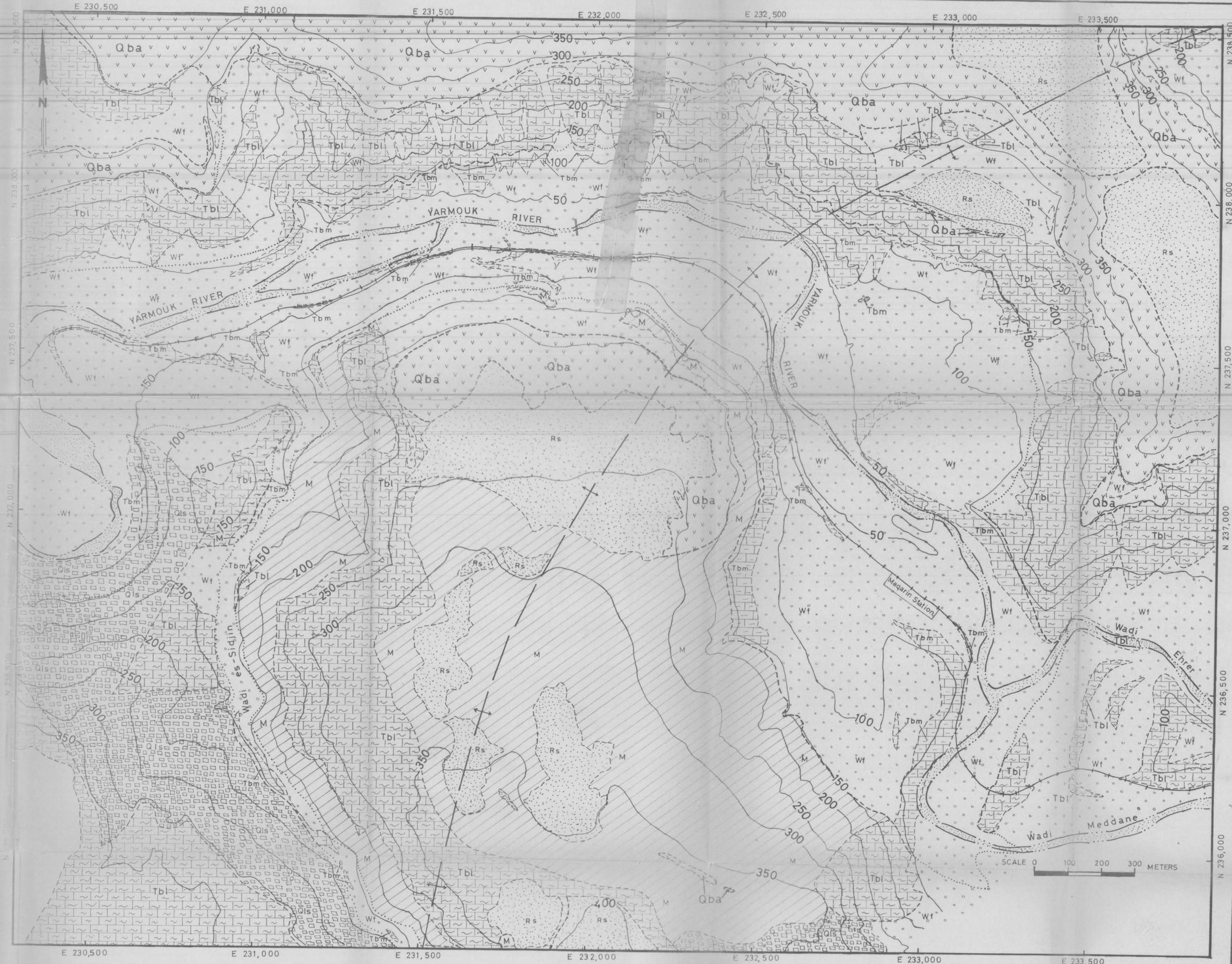
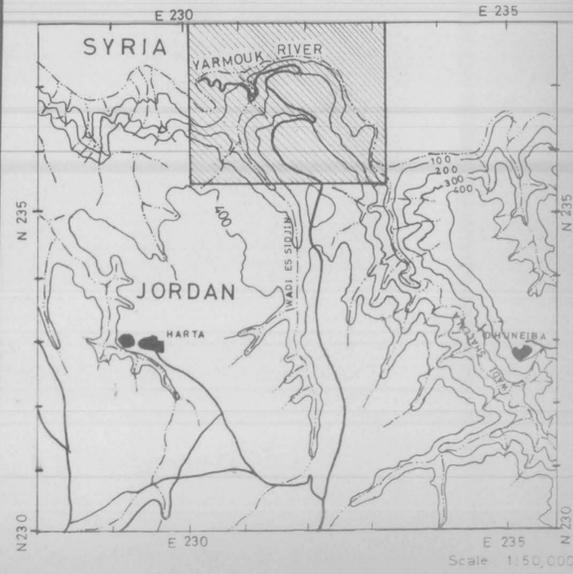
Fig (3) LOCATION OF SAMPLING SITES

- CONTOUR LINES
- +— RAILWAYS
- - - ROADS
- YARMOUK RIVER
- ADITS
- BORE HOLES
- ▲ RIVER SAMPLES
- SPRINGS
- ⊕ SEEPAGES

Fig. (1)

GEOLOGIC MAP OF THE STUDY AREA.

MODIFIED AFTER HARZA OVERSEAS ENGINEERING COMPANY 1979



- Residual Soil.
- Quaternary Basalt.
- Chalky Limestone Formation.
- Altered and Brecciated Rocks.
- Bituminous Marl Formation.
- Recent Slopewash Sediments and Wadifill.
- Landslides and Slumps.
- Contour Lines.
- Yarmouk River.
- Geologic Contact.
- Inferred Geologic Contact.
- Axis of the Anticline.

SCALE 0 100 200 300 METERS