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GEOPHYSICAL AND HYDROCHEMICAL STUDIES OF THE GROUNDWATER AQUIFER IN ASH SHAMIYAH AREA, MAKKAH DISTRICT, WESTERN SAUDI ARABIA

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Detailed investigations including resistivity, seismic and magnetic measurements and one borehole was conducted. Horizontal Electrical Profiles (HEP) were also carried out to determine the thickness of the alluvial deposits. The combinations of vertical electrical sounding (VES), horizontal electrical profiling (HEP), and drilling led to the identification of the different groundwater bearing horizons in the area of study. The geo-electrical cross-section indicates that the groundwater occurs in two aquifers. A shallow unconfined aquifer is composed of alluvial deposits at 22 m depth, underlain by a weathered basaltic unit. A deep confined aquifer is found at a depth of about 150 m that is composed of gravelly sandstone. A test borehole penetrated two saturated zones: a shallow alluvial deposit unconfined aquifer at 20 m, and a deep gravelly sandstone confined aquifer associated with faulting at 120 m. The static piezometric surface stabilized at 44 m and the drilling resulted in a productive well. The borehole information agreed well with the yield interpretation. Abundant fresh groundwater was found in the northern part of the study area with the highest yield. Significantly, the majority of the groundwater was found within the deep confined gravelly sandstone aquifer, rather than in the shallow unconfined aquifer. The interface between fresh and saline water was delineated. The groundwater in the southern part was contaminated by saline connate water, therefore for such areas deep boreholes are recommended.

INTRODUCTION AND GEOLOGIC SETTING

Ash Shamiyah area lies about 60 km N to NE of Jeddah city (Figure 1). It lies between latitude 21° 78' to 21° 88' N and longitude 39° 46' to 39° 62' E. The average rainfall amounts to around 100 mm per year, the average evaporation rates exceed 2000 mm per year. From a geologic point of view, the Ash Shamiyah area contains Precambrian-Cambrian basement complex, Cretaceous-Tertiary sedimentary succession, Tertiary-Quaternary basaltic lava flows, and Quaternary-Recent alluvial deposits.

Precambrian Rocks

The Precambrian rock units in the study area have been studied by different authors (Al-Shanti, 1966). Moore and Al-Reheili (1989) classified the Precambrian rocks of the Ash Shamiyah area into Late Proterozoic basaltic to rhyolitic volcanic and volcanoclastic and epiclastics of primitive island-arc type, that have been injected by intrusive bodies of different ages and compositions. These rock units are divided into the Zibarah, Samran, and Fatima groups (sedimentary rocks). According to Petter Johnson (2006), the detailed geologic map of Ash Shamiyah area (Figure 2) shows the following rock units which are described here:

The unassigned Neoproterozoic rocks are represented by the oldest unassigned granodiorite and tonalite (utg) comprised of plagioclase-rich granitoids. These intrusive rocks are in the extreme western part of the study area.

The Cryogenian layered rocks are represented by the Samran Group (sa), 'Samran series' (Nebert, 1969) and 'Samran metavolcanic formation' (Rexworthy, 1972), and underlie the northwestern part of the Jiddah terrane. These rocks are present in the eastern and northwestern part of the study area and are metamorphosed to greenschist and locally amphibolite facies. It

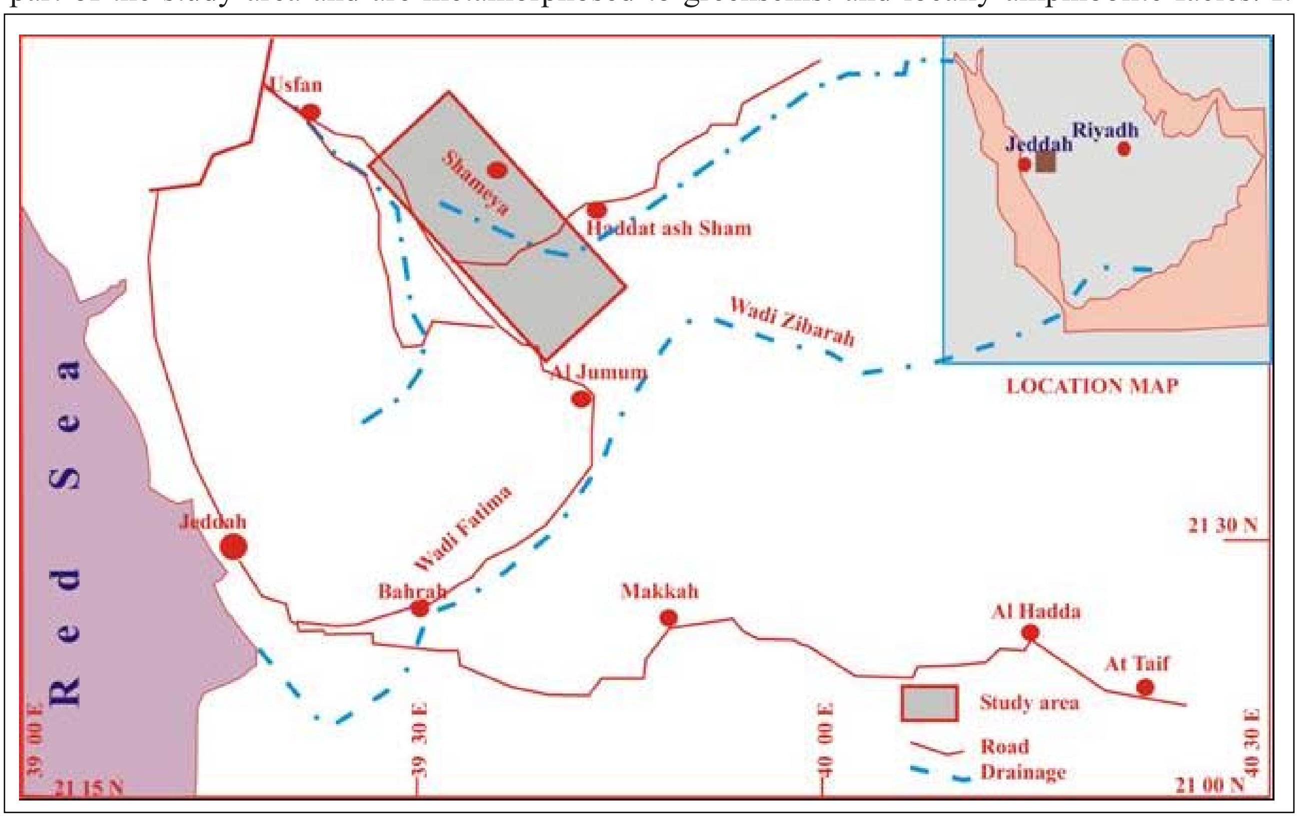

Figure 1. Location of Ash Shamiyah area.

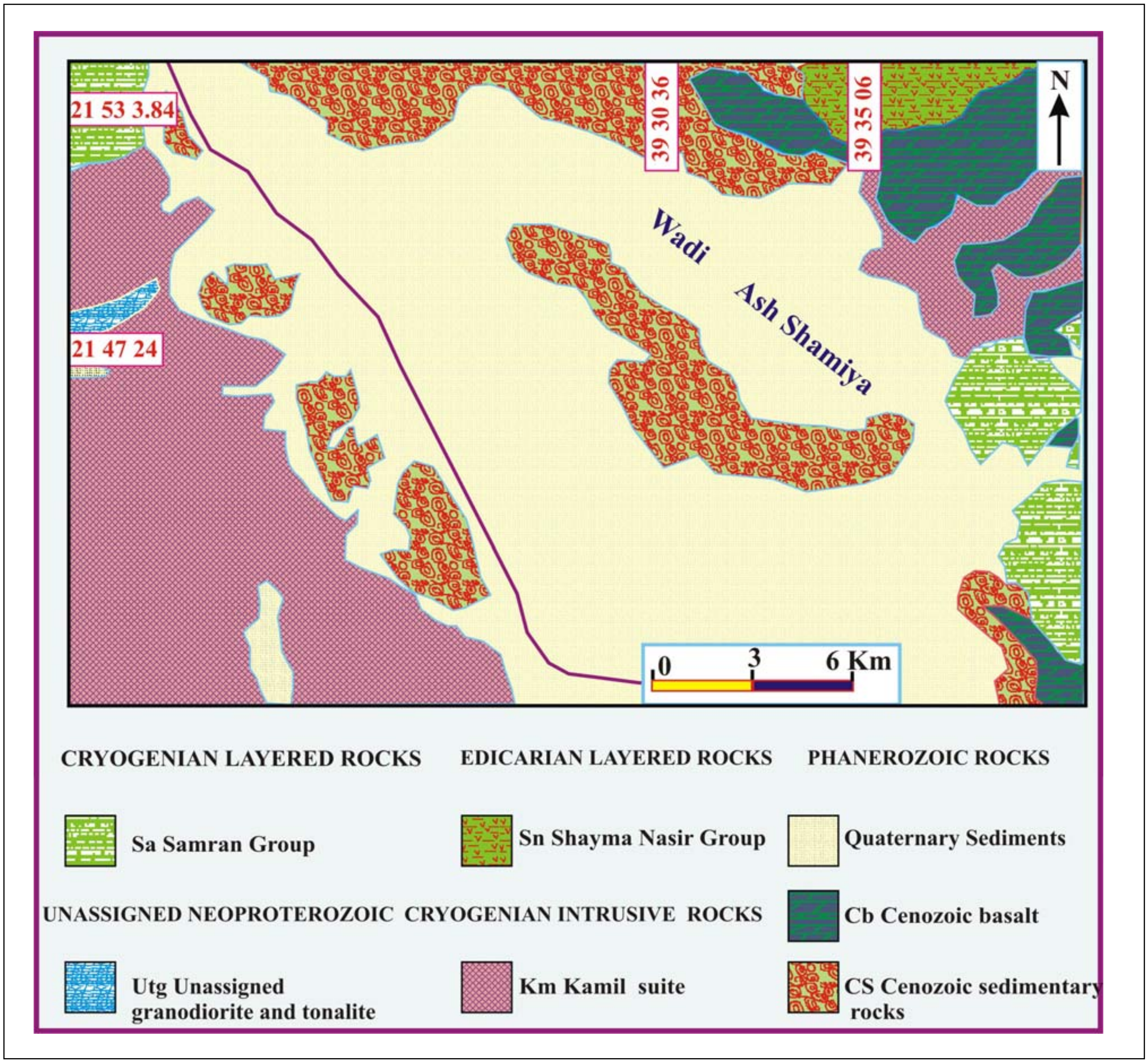

Figure 2. Detailed geologic map of Ash Shamiyah area.

includes mafic to felsic lavas and volcaniclastic rocks, graywacke, polymict conglomerate, shale, siltstone, chert, marble, quartzofeldspathic schist, mica schist, and amphibole schist.

The Cryogenian Intrusive Rocks are represented by the Kamil Suite (km) (Ramsay, 1986; Moore and Al-Rehaili, 1989) consisting of mafic, intermediate, and felsic plutonic rocks of calc-alkalic and locally trondhjemitic affinities widely exposed in the northeastern and western parts of the study area. The suite intrudes already deformed layered rocks of the Samran and Zibarah groups and plutonic rocks of the Makkah batholith. The suite includes tonalite and trondhjemite, diorite and quartz diorite, lesser amounts of granodiorite and quartz monzonite, and minor monzogranite.

The Edicarian layered rocks are represented by the Shayma Nasir Group (sn) (Ramsay, 1986) and crop out in small exposures at the northeastern corner of the study area. The group is weakly metamorphosed and relatively undeformed. They include polymict conglomerate; basaltic, andesitic, dacitic, and rhyolitic lava, tuff, and agglomerate; and red-brown arkosic, volcaniclastic, and calcareous sandstone.

Cenozoic Rocks (CS)

The Cenozoic sedimentary rocks are exposed beneath a cover of flat-lying lavas and Quaternary deposits. Brown et al. (1963) originated the names Shumaysi and Usfan formations for these sedimentary sequences after Karpoff (1957 a,b). Spincer and Vincent (1984) divided the Shumaysi Formation into the Haddat Ash Sham, Shumaysi, Khulays, and Buraykah formations (Figure 3). Moor and Al-Reheili (1989) grouped these four formations together with the Usfan formation, and Sita formation of Pallister (1982 a,b and 1986) into the Sugah group. This group of sedimentary rocks is preserved in three north-northwest trending, asymmetric depositional troughs which are the Sham (Haddat Al-Sham-Barzah area), Sugah (Wadi Al-Sugah), and Shumaysi (Wadi Al-Shumaysi) troughs.

Haddat Al-Sham Formation occurs at its type locality about 60 km northeast of Jeddah. It measures about 480 m in thickness. Its beds dip to the northeast at an angle of 10^{o}-18^{o}. The sedimentary sequence of Haddat Al-Sham Formation consists of clastic rocks dominated by sandstones, shales, mudstones, oolitic ironstones, and occasionally conglomerates. The formation has been divided into three members (Zeidan and Banat, 1989): a lower, middle and an upper member.

The Usfan Formation measures about 180 m and lies conformably on Haddat Ash Sham rocks. The formation has been divided into three members (Zidan and Banat, 1989): a lower, middle and an upper member. The lower member consists of shale, mudstone, marlstone, sandstone, limestone and dolomite. The middle member consists of very fine-to-fine quartz sandstone and an upper part of conglomerate layers. The upper member consists of remarkably finer sediments composed of very fine-grained sandstone, siltstone and shale.

The Shumaysi Formation is essentially made of siliciclastic rocks of sandstone, siltstone, mudstone and shale. Common pebbly sandstone and conglomerate layers occur in the basal parts. The total thickness of Al-Shumaysi formation varies from about 74 to 183 m. Al-Shanti (1966) divided the formation into three members based on its vertical lithological variations: lower, middle and upper members. The age of the formation is Eocene-Oligocene (Al-Shanti, 1966; Moltzer and Binda, 1981).

The Khulays Formation outcrops are encountered in the Sugah trough. According to Spincer and Vincent (1984), the Khulays Formation is unconformable on the Shumaysi Formation in Harrat Nuqrah but conformable on the same formation toward the southern end Sugah trough. The Khulays formation consists of alternating red, brown smectite clay, siltstone and fine- grained structure less sandstone with marly limestone.

Tertiary-Quaternary Rocks

Cenozoic Basalt (Cb)

Basalt lava flows form discontinuous caps overlying the upper levels of both the basement complex and the sedimentary rocks. They are preserved in three north-northwest trending, asymmetric depositional troughs which are the Sham, Suqah and Shumaysi troughs. These troughs are bounded in the north by faults downthrown to the west and in the west by an unconformity at the base of the easterly dipping strata.

Quaternary deposits

Quaternary deposits cover large parts of the study area. They principally occur in the large drainage basins of Ash Shamiyah area. The principle units of the Quaternary rocks are the terrace gravel, alluvial fan deposits, talus deposits, alluvial sands and gravels of wadi beds, and some eolian edifices. The thickness of these deposits varies widely from one place to another.

GROUNDWATER OCCURRENCE

Several hydrogeological research investigations have been conducted in the Jeddah area and its surroundings since the early 1970s. Groundwater exploration investigations were mainly sponsored by the Ministry of Agriculture and Water and were executed through governmental agencies and some foreign geological authorities. Italconsult (1967) drilled three boreholes in the study area

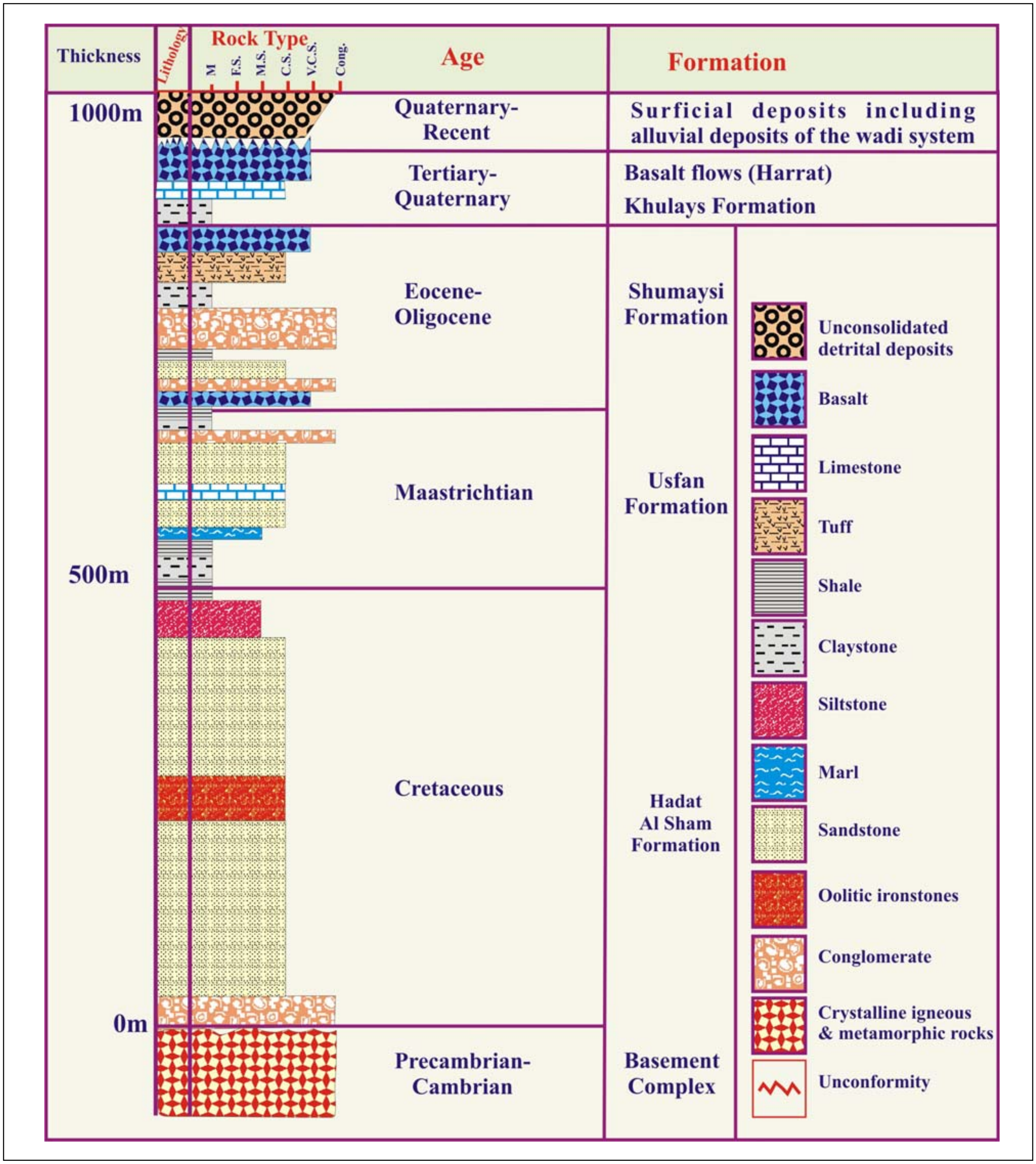

Figure 3. Stratigraphic succession of Ash Shamiyah area.

to determine the thickness of the alluvial deposits and the depth to the basement complex. They encountered the crystalline bedrock at a depth of 22 m southeast of Usfan, whereas in Wadi Al-Shamiyah the bedrock was at a depth of 36 m. Al Khatib (1977) carried out a detailed hydrogeological and geophysical investigation of the Usfan area and concluded that the main aquifer in the area consists of alluvial deposits, while the Shumaysi sandstone was considered an aquitard. The saturated thicknesses in the wadis Al-Shamiyah, Fayidah, and Ghoulah were found ranging between 12-16 m, 7-16 m, and 10-60 m, respectively.

Kotb et al. (1988) gave a general overall view of the hydrochemical characteristics of groundwater in the Usfan Basin including the study area. Groundwater samples were collected from 21 sites in the wadis and plains and were analyzed for major and minor dissolved ions. Results indicated that the groundwater is of the Cl-Na type.

El-Nujaidi (1978) in his M.Sc. thesis discussed the hydrogeological potential of Wadi Khulays and its tributaries. Hacker and Kollman (1984) discussed the general geology, geomorphology and hydrogeology of the wadi system east of Jeddah. In these studies the genesis of the apparently atypical drainage course of Wadi Al-Sugah was investigated. The chemical composition of the groundwater herein is generally $Na\text{-}Cl\text{-}S0_4$. Recently, Hussein and Bazuhair (1992) studied the groundwater condition in the Haddat Ash Sham-Al Bayada area. They pointed out that the groundwater within the classic Cretaceous-Tertiary members moves under a hydraulic gradient of $6.4x10^{-4}$ with an average transmissivity of 180 m^2/day and a maximum coefficient of storage of $l.lxl0^{-3}$. Hussein et al. (1993) shed some light on the groundwater availability in the Khulays Basin.

Qari and Sen (1994) showed many useful properties of the fracture map interpreted from Landsat-TM imagery in southwestern Saudi Arabia. They provided various regional fracture pattern maps, which help to identify safe sites for engineering activities and potential groundwater recharge and movement. Sorman et al. (1994) coupled the remote sensing techniques with hydrologic modeling to estimate peak discharge on small size catchments in southwestern Saudi Arabia. Al-Bassam (2005) studied the combinations of vertical electrical sounding (VES), horizontal electrical profiling (HEP), and drilling in the different areas of Haddat Ash Sham, Ash Shamiyah and Al Suqah. He concluded that these methods of study made a valuable contribution to the identification of groundwater resources in these areas, and the resistivity soundings clearly identified the lithological depths and the water-bearing zones. Al Garni et al. (2008) interpreted the resistivity sounding curves and cross sections of W. Lusb- Haddat Ash Sham area, and they found a clear picture of the probable location of the water table, the water quality, and possible structure of this area.

Objectives

This paper aims to give a detailed picture of the hydrogeological and hydrochemical characteristics of the Ash Shamiyah area and to assess the interaction between the alluvial aquifer and the underlying aquifers. The following main objectives are proposed for this paper: 1) identifying the groundwater bearing horizons in the study area in both the wadi alluvial deposits and the Cretaceous-Tertiary sedimentary succession, 2) defining the aquifers configurations and geometries, including the identification of buried structural features, and 3) identifying the saline and fresh groundwater zones and their interface and determining the spatial variability in the groundwater quality, as well as the processes controlling such variability.

Methodology

This paper is of a multidisciplinary nature where the results of the geological, geophysical, and hydrochemical investigations will be integrated together to achieve the previously mentioned objectives. The reconnaissance fieldwork together with the information available from published geological work furnished a tentative appraisal of the hydrogeological conditions in the study area. The subsurface information on the geology was made available by the test drilling, and the detailed structural mapping and analyses previously carried out in the study area. Hydrochemical methods mainly concentrate on groundwater occurrence, movement and distribution, and groundwater quality. The laboratory methods include complete chemical analyses for 22 water samples including the determination of the major ion concentrations Na, Ca, Mg, K, Cl, SO_4, HCO_3, and minor concentrations Fe, Pb, Mn, Si, Al, B, F.

Field Procedure

Resistivity Sounding

The resistivity measurements were conducted by using ELREC-T which is high power electrical equipment designed for AC/DC electrical exploration surveys, and includes transmitter and receiver in one single unit. ELREC-T has internal batteries for the supply of its electronic circuits. The power source is a motor generator 220 V - 50 HZ supplied 1200 W AC/DC converter and the output voltages available on this converter are 50 V, 100 V, 200 V, 400 V, and 800 V, and the maximum current available on each voltage 2.5 A.

In the Wadi Ash Shamiyah area, one long profile was made of 5 km. In this profile six resistivity soundings (3.1 to 3.6, Figure 4) were measured and the distance between soundings was 1 km (Table 1, Figure 7). The measurements were carried out in the direction parallel to the axis of the Wadi.

Results and Interpretation

The field sounding curves analyzed for this study were of two types. The first type of curve is a four-layer curve resulting from a four geoelectric layer section. The upper layer is present at a depth of about 5 m with high resistivity greater than 100 ohm/m. The second layer has moderate resistivity values (30-50) and is interpreted as an unsaturated aquifer at a depth of about 10 m. The third layer has low resistivity values and is believed to be saturated. It is interpreted as the upper unconfined shallow aquifer. The shallow water table varies in depth, between 10 and 50 m. The fourth layer has high resistivity values greater than 100 ohm/m representing the basement rocks. The basement rocks are deeper and the sedimentary rocks and are very thick due to the block faulting.

A detailed investigation that included resistivity measurements and test drilling was carried out in the study area. One borehole (Figure 5) was drilled and the location of the boreholes was based

Table 1. The VES numbers and location for each VES in Ash Shamiyah area.

Area	Traverse	VES	Location	
	No	No.	Latitude	Longitude
Wadi Ash Shamiyah	2	2.1	N21° 47′ 40.0″	E39° 35′ 28.0″
		2.2	N21° 47′ 53.0″	E39° 35′ 08.0″
		2.3	N21° 48′ 05.6″	E39° 34′ 39.2″
		2.4	N21° 48′ 16.6″	E39° 34′ 08.9″
		2.5	N21° 48′ 22.9″	E39° 33′ 30.9″
		2.6	N21° 48′ 49.6″	E39° 32′ 40.0″

on the resistivity results. Horizontal Electrical Profiles (HEP) were carried out to determine the thickness of the alluvial deposits.

The Ash Shamiyah geo-electrical cross-section (Figure 4) comprises the results and interpretation of VES 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6. The geo-electrical cross-section indicates that the groundwater occurs in two aquifers. A shallow unconfined aquifer is composed of alluvial deposits at 22 m depth, underlain by a weathered basaltic unit and a deep confined aquifer is found at a depth of about 150 m that is composed of gravelly sandstone. Block faults were encountered beneath VES 2.2 and VES 2.3; therefore soundings 2.2 and 2.3 represented the best two drilling sites. A test borehole was drilled at the location of VES 2.2 where it penetrated two saturated zones; a shallow alluvial deposit unconfined aquifer at 20 m depth, and a deep gravelly sandstone confined aquifer associated with faulting at 120 m depth (Figure 5). The static piezometric surface stabilized at 44 m and the drilling resulted in a productive well. The borehole information agreed well with the yield interpretation.

Ash Shamiyah Seismic profile (SS01SH)

This profile is 540 meters long and is located at N 65º W. The geophone spread is 230 meters long. The geophone interval is 10 m. There are six shot points; the first one, A , is at zero-offset location which is at one end of the geophone spread and is 105 m from the first geophone. The second shot point, B, is at 110 m from the zero-offset location and is at the midpoint between the first and the second geophone. The third shot point, C, is at the midpoint between geophones number 12 and 13, i.e. at the midpoint distance of the seismic spread and is 220 m from the zero-offset location. The forth shot point, D, is at the midpoint between geophones number 23 and 24, i.e. at the other end of the seismic spread and it is 330 m from the zero-offset location. The fifth shot point, E, is at 430 m from the zero-offset location. The sixth shot point, F, is at the other end of the seismic profile and it is 540 m from the zero-offset location.

Six shot points; SP-A, SP-B, SP-C, SP-D, SP-E and SP-F were recorded respectively in six files; SH3V0006, SH3V0007, SH3V0008, SH3V0009, SH3V0011 and SH3V0012. The interpretation of the seismic results for this profile using SIPT2 program reveals a depth model that has three

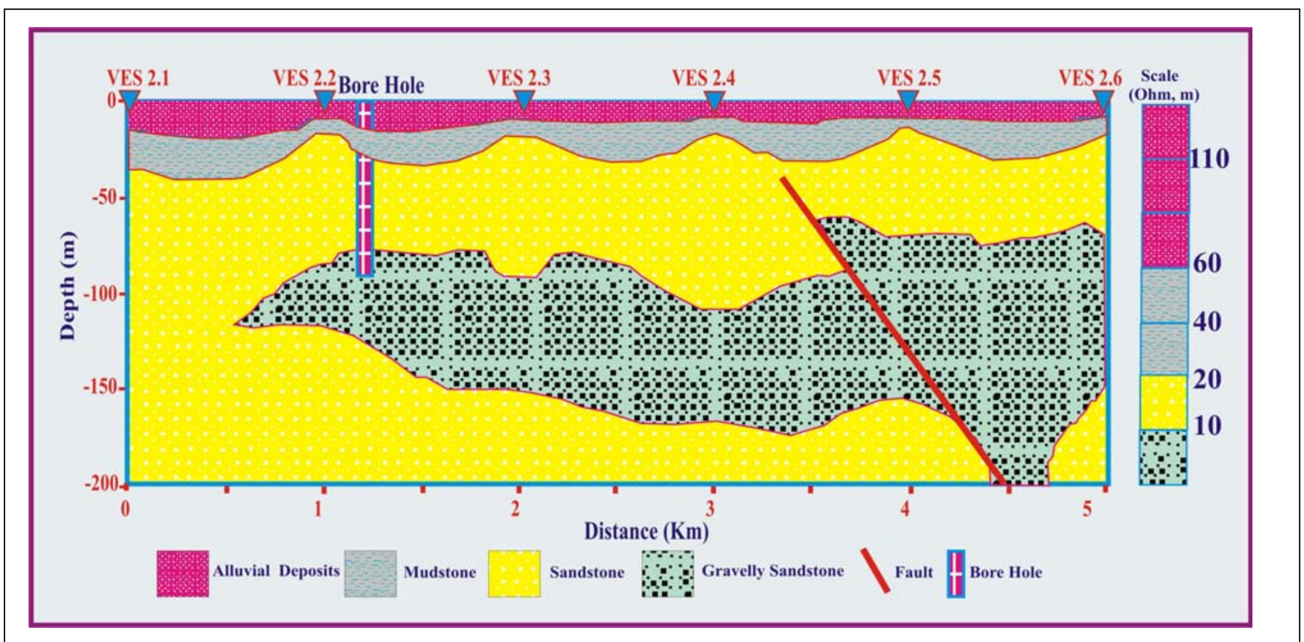

Figure 4. Ash Shamiyah geo-electrical cross-section.

layers with velocity contrast as shown in Figure 6. The average velocity of the first layer is 450 m/s and varies in thickness between 3 and 10 m. This layer is often dry wadi sediments, mainly sandy gravels, and is characterized by major regional variations in thickness and constitution, which are often related to changes of surface geology. The average velocity of the second layer is 1160 m/s and varies in thickness between 22 and 55 m. This velocity represents sedimentary rocks including sandstone and claystone. The middle layer is characterized by two block faults crossing the wadi. The average velocity of the third layer is 2500 m/s and represents sandstone rocks.

Ash Shamiyah Magnetic Measurement

In the Ash Shamiyah site, two magnetic profiles MG05 and MG06 were interpreted. The interpretation of the magnetic profile MG05, crossing the wadi, showing that wadi Ash Shamiyah is bounded by two faults. High magnetic responses correspond to the basaltic unit because of its occurrence in ultrabasic rock rich in magnetite. The depth of the buried basalt in Ash Shamiyah varies from 20 m to 100 m, beneath the basalt sill is the sedimentary rock. The low magnetic anomalies indicate that the sedimentary rocks at the bottom of the wadi are very thick. The spectral analysis of the total magnetic of profile MG06 shows that the thickness of the sedimentary succession ranges from 300 m upstream and 1200 m downstream westward. Multiple block faults affecting the sedimentary and basement rocks.

The sedimentary rocks at Ash Shamiyah unconformable overlie Precambrian rocks and are conformably overlain by basalt flow.

HYDROCHEMICAL STUDY

The pump-tested wells, the large and small diameter wells as well as the test well of the study area are shown in Figure 7. In the present study, 22 water samples have been collected from wells scattered all over the study area (Figure 7), all samples have been fully analyzed for major, secondary and trace constituents. The results are shown in Table 2.

Interpretation of Results and Chemical Modeling

Ash Shamiyah wells show low mineralization in groundwater quality according to electrical conductivity (EC), total dissolved solids (TDS), and total hardness as $CaCO_3$. The water has lower concentrations of calcium, sodium, chloride, nitrate, fluoride and iron.

X–Y Plots

The X-Y relationship summarizes the major ion chemistry of the study area. The relation between the different cations and anions is shown as well as the relation between EC and total hardness. Strong straight-line relationships are shown between TDS, EC (Figure 8A), total hardness/SO_4 (Figure 8B), TDS/Cl (Figure 8C), and Cl/Na (Figure 8D) relationships. Low correlation straight-line relationships are deduced from Table 2 between Ca/Cl and Mg/Cl. In summary, the main hydrochemical processes shown by these plots are recharge, evaporation, mineral dissolution, base-ion exchange, and limited mixing.

Water Types: Durov Diagram

The trilinear diagrams are best used to classify water types according to the most dominant cations and anions. The expanded Durov diagrams are used in this paper for its advantage over other trilinear representations. In Ash Shamiyah area, the hydrochemical facies are, in order of importance, facies no.8, no.5, no.6 and no.9 (Figure 9). This means that the hydrochemical

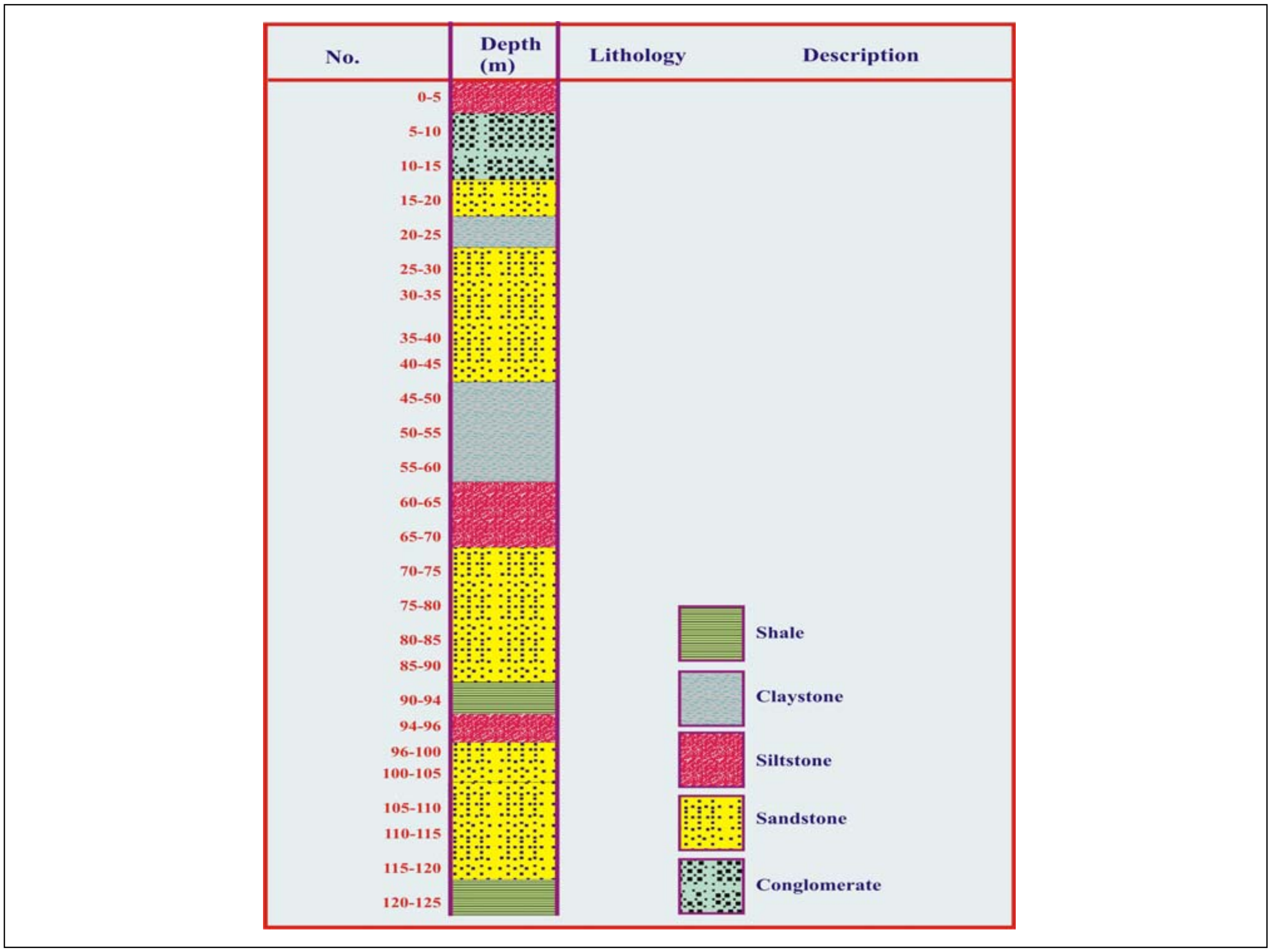

Figure 5. Subsurface succession in Ash Shamiyah bore hole (For location see Figure 7).

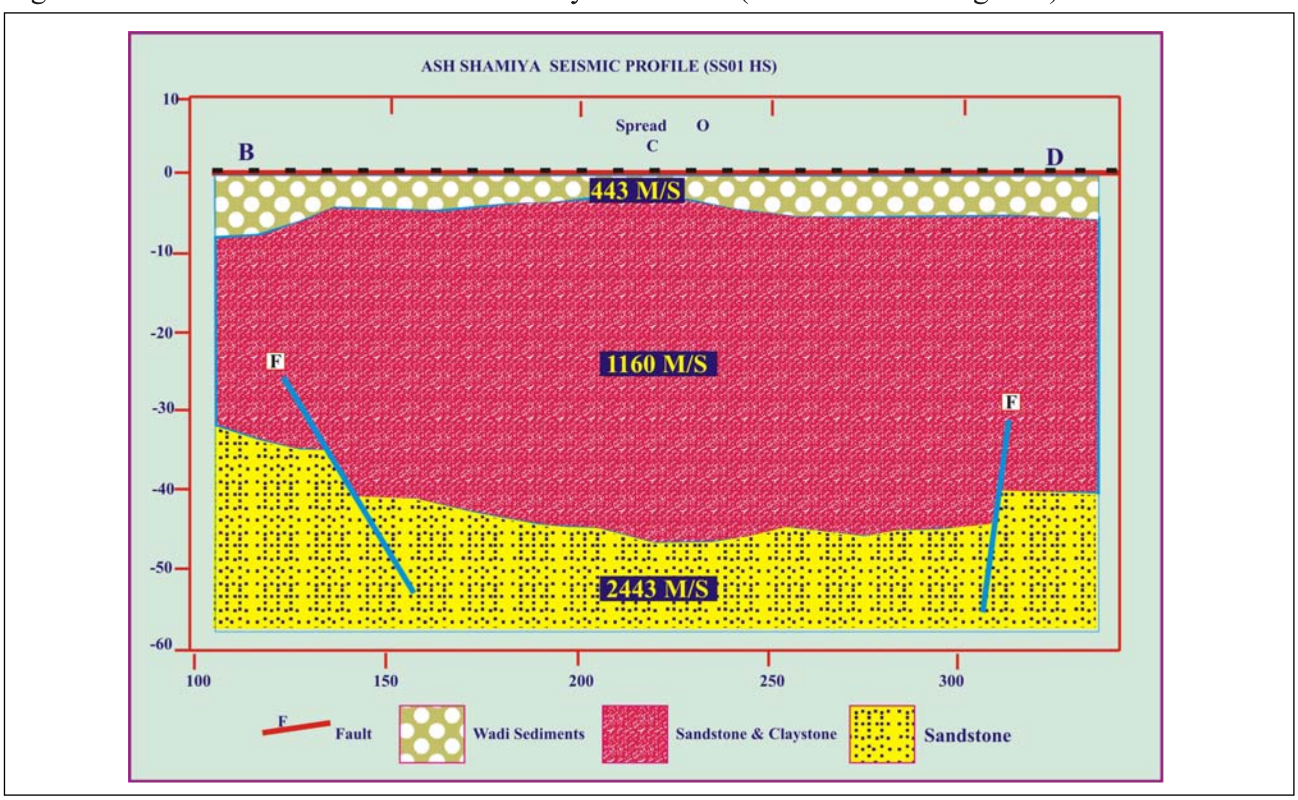

Figure 6. Depth model of Ash Shamiyah area.

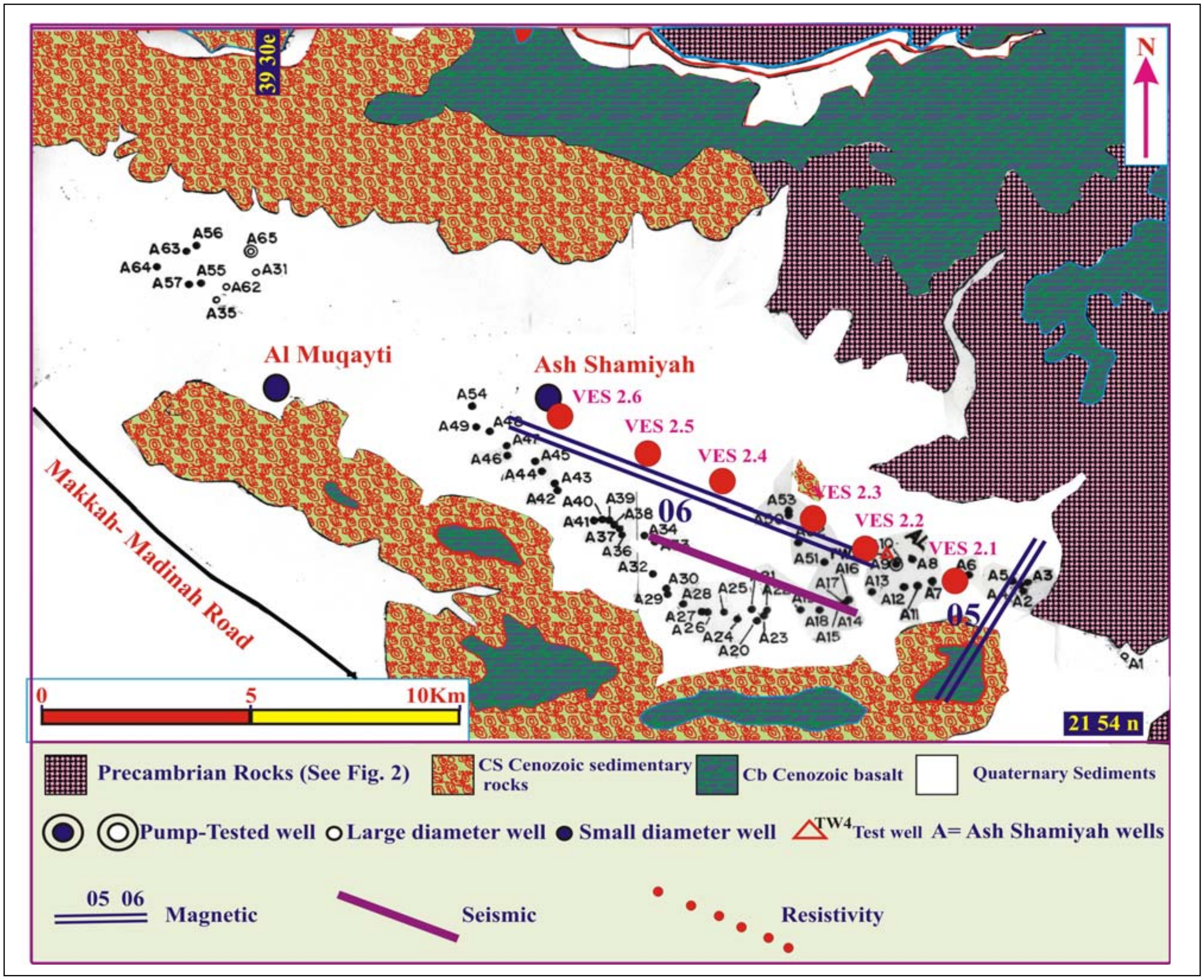

Figure 7. Location of the different types of bore holes and the different types of geophysical profiles in Ash Shamiyah area.

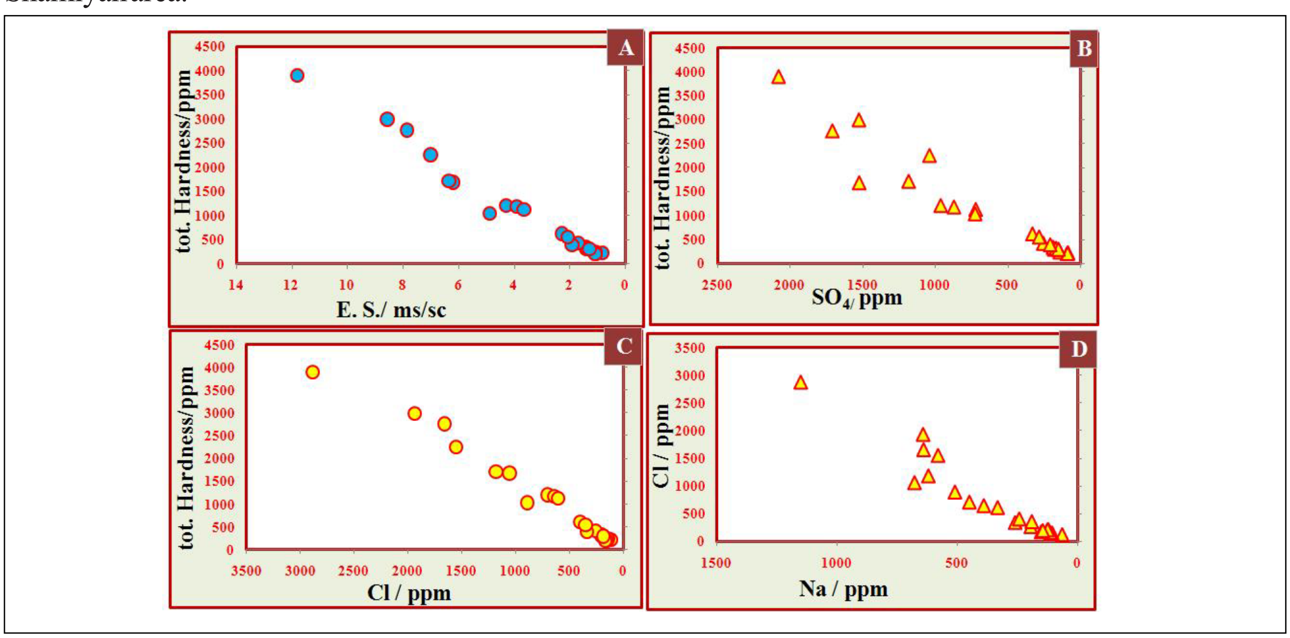

Figure 8. X-Y relationships between E.S. vs TDS; SO_4 vs tot. hardness; Cl vs TDS and Cl vs Na in Ash Shamiyah water.

Table 2. Data of chemical analyses for major, secondary and trace constituents.

Depth to water	pH at 25C	E.C. ms/cm	T.D.S (ppm)	Cations (ppm)				Anions (ppm)				T.Hard	Trace elements							
				Ca	Mg	Na	K	HCO3	CO3	SO4	Cl	Ca CO3	NO3	Fe	Mn	Pb	Si	Al	B	F
43.5	8.5	0.81	579	48.1	26.02	64.68	3.21	180.63	37.11	89.73	121.12	226.93	52.57	0.103	0.09	0.035	0.275	0.01	0.32	0.55
uk	8.4	1.07	694	58.92	23.35	106	2.6	241.18	14.23	145.7	150.11	243.04	65.34	0.051	0.008	0.019	10.03	0.003	0.79	1.41
uk	8.6	1.28	872	70.94	30.64	125	2.6	246	28.47	184.4	193.24	302.97	65.34	0.072	0.029	0.028	10.88	0.012	0.711	1.34
uk	8.5	1.38	906	66.93	34.78	125	4	216.7	31.31	180.28	205.86	309.92	88.6	0.113	0.065	0.028	11.13	0.012	0.311	1.08
43.9	8.6	1.05	662	32.06	31.62	114	0.2	221.6	31.31	95.49	158.36	209.79	55.4	0.017	0.013	0.022	12.31	0.001	0.29	1.08
43.7	8.7	1.06	642	30.86	31.86	152	0.8	236.29	31.31	92.2	170.67	207.78	46.51	0.006	0.007	0.007	10.68	0.007	0.65	1.02
uk	8.3	1.39	930	66.93	42.07	122	4	188.5	14.45	191.81	211.14	339.81	145.1	0.02	0.016	0.027	11.72	0.004	0.382	1.4
uk	8.3	1.36	904	65.33	38.18	125	3.6	197.12	31.31	171.23	205.86	319.86	103	0.022	0.016	0.026	11.5	0.001	0.31	1.02
uk	8.2	1.68	1168	81.36	53.5	195	4.1	213.03	14.45	259.31	263.93	422.75	105.21	0.023	0.009	0.031	10.7	0.002	0.581	1.21
ul	8.6	1.27	858	61.32	35.75	145	3.2	215.48	48.17	154.76	193.55	299.88	93.03	0.107	0.029	0.247	10.82	0.008	0.65	1.06
uk	8.1	4.28	3112	235.27	151.51	450	5.6	220.38	14.45	963.98	709.09	1209.37	238.11	0.005	0.001	0.078	6.05	0.026	0.881	1.29
uk	8.2	3.89	2854	231.26	146.65	390	5.4	181.2	14.45	873.42	645.75	1179.42	190.5	0.005	0.004	0.074	6.46	0.01	0.7	1.18
uk	8.2	3.63	2632	217.63	142.03	332.52	4.9	179.97	31.31	723.59	610.56	1126.4	221.5	0.032	0.004	0.072	6.78	0.008	0.681	1.3
53	7.9	6.17	4666	320.64	214.75	677.8	5.7	179.97	31.31	1524.5	1060.9	1682.08	249.18	0.05	0.012	0.049	3.66	0.133	0.86	1.35
uk	7.9	7.84	6066	522.24	355.07	640	7.1	164.06	14.45	1708.9	1659.2	2761.39	285.74	0.058	0.015	0.067	3.33	0.019	0.89	1.3
uk	7.9	8.55	6506	542.28	398.85	642	6.4	150.59	31.31	1526.2	1935.4	2990.99	331.14	0.071	0.008	0.074	3.41	0.011	0.835	1.39
uk	8.2	4.85	3364	196.39	133.03	510	3.4	155.49	31.31	727.71	892.08	1036.4	334.58	0.028	0.006	0.039	6.1	0.09	0.57	1.41
uk	8.2	6.33	4558	275.35	250.01	620	3.1	179.97	31.31	1184.5	1184.1	1713.42	443	0.02	0.008	0.049	3.84	0.023	0.68	1.36
uk	7.8	6.99	5122	379.56	317.62	580	4.8	192.22	31.31	1041.3	1553.6	2251.14	409.8	0.067	0.005	0.055	4.2	0.033	0.51	1.17
uk	8.4	1.9	1250	72.14	51.8	260	1.2	192.22	31.31	211.56	339.59	392.73	94.14	0.006	0.031	0.014	11.33	0.015	0.76	1.3
44.14	8.6	2.26	1450	117.43	79.53	242.5	3.4	183.65	48.17	333.4	404.69	619.45	88.6	0.059	0.036	0.017	9.42	0.019	0.28	1
47.3	8.6	2.06	1290	107.01	70.04	190.52	3.6	195.89	48.17	287.3	357.18	554.69	83.06	0.023	0.021	0.015	9.35	0.018	0.64	1
uk	8.1	11.7	9066	813.62	453.08	1150	3.6	131	31.31	2078.5	2880.3	3891.68	448.53	0.07	0.006	0.092	3.7	0.058	0.78	1.48

processes responsible for the groundwater quality are, in turn, reverse ion exchange, simple dissolution, with SO_4 and Na ions being dominant in facies no.6 indicating probable mixing influences, and only two samples of facies no.9 indicating end - point water for simple dissolution or mixing (Figure 9). It is worth mentioning that all the samples of the study area do not belong to facies no.1 or facies no.2. This shows that there is no indication of adequate recharge water. Partial ion exchange process is absent. In short, the main hydrochemical processes from the upstream to the downstream of the study area are simple dissolution, reverse ion exchange, ion-exchange and mixing.

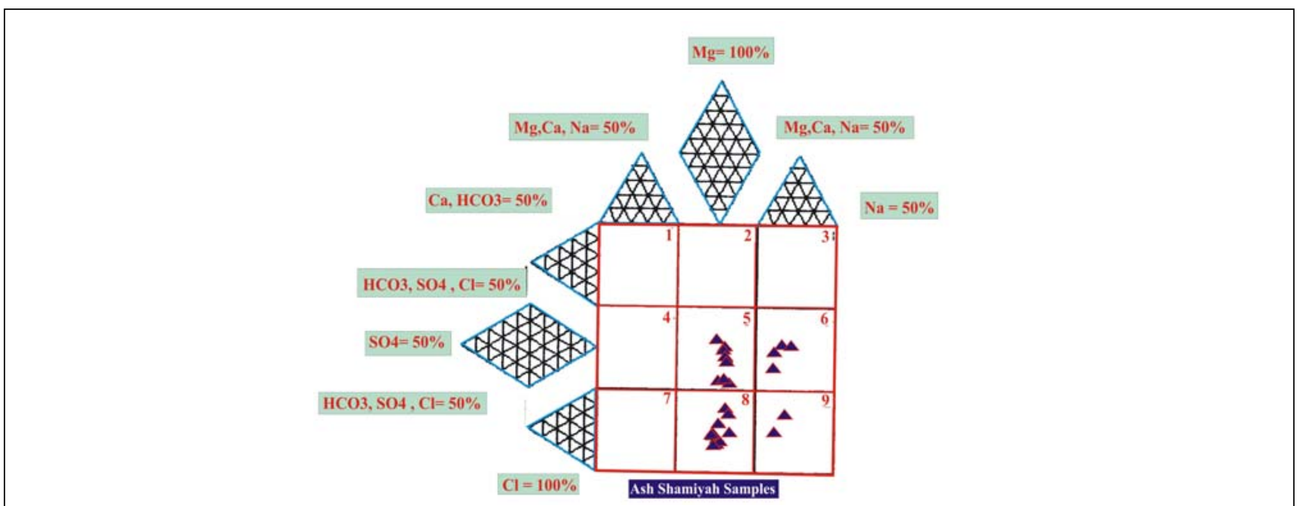

Figure 9. Durov representation of major ions hydrochemistry of Ash Shamiyah area

Areal variations of elements

Hydrochemical variation of elements included well location, electrical conductivity, TDS, calcium, pH, potassium, magnesium, sodium, chloride, bicarbonates, carbonates, sulfates, nitrates, manganese, iron, silicates, fluoride, boron, aluminum, lead, total hardness as $CaCO_3$ and water level as shown in the Table 2 and Figures 10, 11 and 12.

Groundwater level variation

The groundwater in the study area occurs within two main water-bearing units; the alluvium of the Wadi system under unconfined conditions and within the clastic layers of the Cretaceous sedimentary succession. The general groundwater flow in the aquifer system follows the surface drainage from areas of high potential to areas of low potential. Both the elevation and pressure heads define the direction of groundwater flow. Figure 10 A illustrates the groundwater level in the study area. The water level generally ranges from 80-90 m with some wells of deeper water level, especially those of the northwestern part of the study area (Figure 10A).

EC variation

The EC of the water samples collected from the wells of Ash Shamiyah area varies from 1 to 12 ms/cm (Figure 10B). The wells of the southeastern part of the study area (Figure 7) are generally of low EC values (1-2) while those of the central parts are generally of moderate EC values (average 3-4). The wells of the extreme northwestern part are of high EC values (10-12). This indicates the variation in the water salinities from the southeastern, central, and northwestern wells of the study area.

Total Hardness

The total hardness of the groundwater samples collected from the study area varies from 200 to 4000 mg/l (Figure 10C). It is observed that there is a strong correlation between the total hardness and EC (Figure 10B).

The $CaCO_3$ (Figure 10D) varies from 10 to 50 ppm. In the wells of the southeastern parts of the study area, $CaCO_3$ is nearly of the same values while the wells of the northwestern part of wadi Ash Shamiyah show high $CaCO_3$ values up to 50 ppm.

Major Ion Variations

The major cations and major anions in the study area vary spatially from place to place (Table 2; Figure 11 A, B, C, D). Generally chlorine shows very low values in the wells of the southeastern part of the study area (Table 2, Figure 11A). The wells of the central and northeastern part of W. Ash Shamiyah are of very high Cl content relative to those of the southeastern part. The calcium concentration has nearly the same behavior as Cl where the wells of the southeastern and northwestern parts are of low Ca content while those of the central part are of relatively high Ca content (Table 2, Figure 11B). Sodium shows nearly the same behavior of Ca where the wells of the southeastern and northwestern parts are of low Na content while those of the central part are of relatively high Na content (Figure 11C). The sulfate also shows low values in the wells of the southeastern and northwestern parts of W. Ash Shamiyah and characteristic high values in the bore holes of the central part (Figure 11D). The diagrams of the major ions variations (Figures 12 A, B, C, D) show a very clear strong relation between Cl and Na in one hand and the Ca and SO_4 on the other hand.

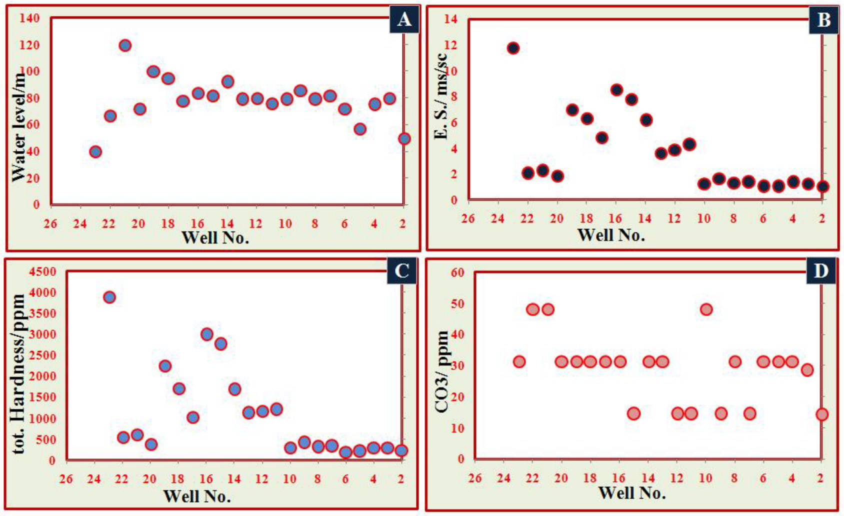

Figure 10. Water level, electric conductivity, TDS and $CaCO_3$ variation in Ash Shamiyah area.

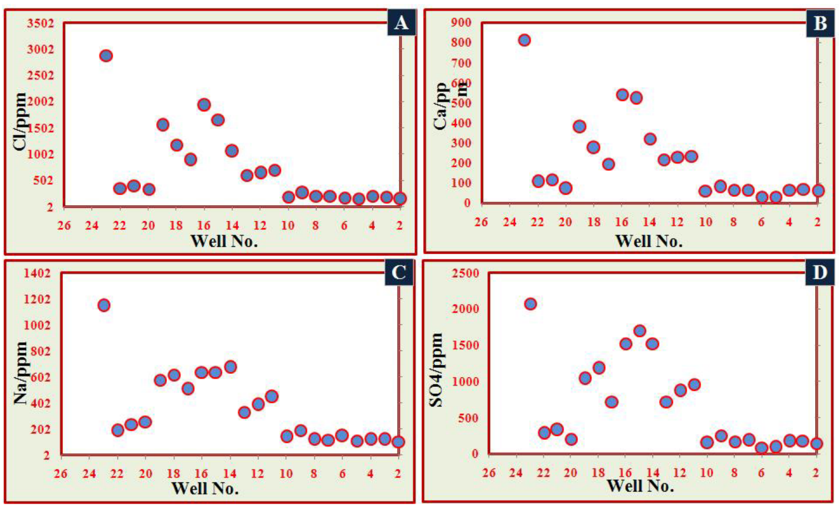

Figure 11. Cl, Ca, Na and SO_4 variation in Ash Shamiyah area

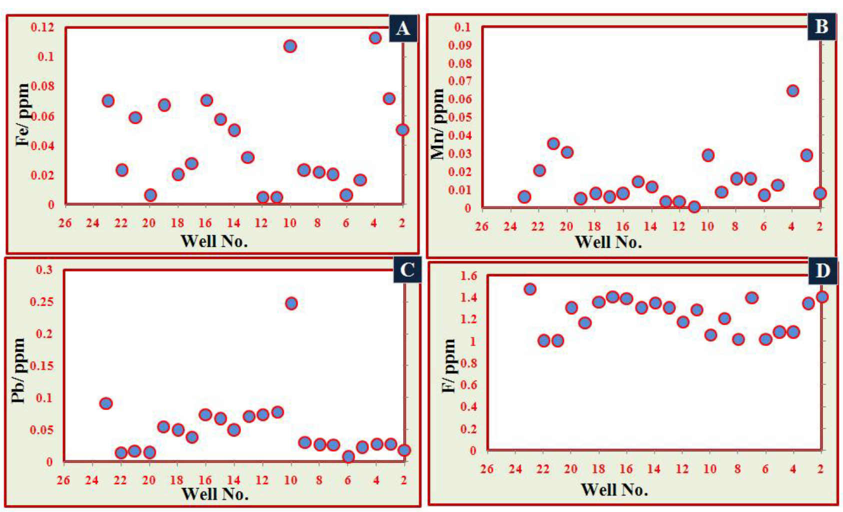

Figure 12. Variation of Fe, Mn, Pb and F in Ash Shamiyah water wells.

Trace elements variation

The trace element chemical analyses of Fe, Mn, Pb and F are illustrated by the variation diagrams of Figure 12 A, B, C and D. The Fe analyses (Figure 12A) show no trend of distribution where some bore holes are of low Fe content while others are of high Fe content. Only some wells in the southeastern part of W. Ash Shamiyah show a very high Fe content. The Mn analyses (Figure 12B) show a fluctuation where some wells are of high values while the others are of low Mn content. The Pb (Figure 12C) is nearly of the same values with some wells are of relatively high values. The F (Figure 12D) shows a low values in the wells of the southeastern parts and high values in the central parts and low values in the wells of the northwest.

DISCUSSION AND CONCLUSIONS

During the groundwater exploration in the area north and northeast of Jeddah, Italconsult (1967) drilled three boreholes in the study area and found the bedrock at depth of 36 m. Al Khatib (1977) argued that the main aquifer in the area consists of the alluvial deposits while the Shumaysi sandstone was considered an aquitard. Kotb et al. (1988) gave a general overall view of the hydrochemical characteristics of groundwater in the Usfan Basin and they indicated that the groundwater therein is of Cl-Na type. Recently, Hussein and Bazuhair (1992) studied the groundwater condition in the Haddat Ash Sham-Al Bayada area and concluded that the groundwater within the Cretaceous-Tertiary members moves under a hydraulic gradient of $6.4x10^{-4}$ an average transmissivity of 180 m^2/day and a maximum coefficient of storage of $1.1x10^{-3}$.

In the present study, the analysis and interpretation of the total magnetic intensity data show new evidence which supports the following:

1. The total thickness of the sedimentary succession in the study area varies from one locality to another and the maximum thickness is about 1500 meters, and it is interbedded with noncontinuous andesite-basalt lava flows.

2. In Wadi Ash Shamiyah area, a major fault is detected. This fault runs in a NW-SE direction along the length of the wadi, which has it's upthrow to the east and downthrow to the west. The displacement of the major fault is more than 2000 m.

3. The resistivity, seismic refraction and total magnetic intensity data show that the average depth of the non-continuous andesite-basalt unit ranges from 15 to 45 m. This agrees with data obtained from drilling at Wadi Ash Shamiyah (35 m).

The most important conclusions from the seismic refraction, resistivity and drilling borehole are:

a) The top layer is a dry sandy gravel with an average depth of 20 m in the Ash Shamiyah area. This layer is underlain by a thin clayey layer.

b) The groundwater in the Ash Shamiyah area occurs in two aquifers; a shallow unconfined aquifer composed of alluvial deposits at 22 m depth, underlain by a weathered basaltic unit and a deep confined aquifer found at a depth of about 150 m that is composed of gravelly sandstone. A test borehole was drilled and it penetrated two saturated zones: a shallow alluvial deposit unconfined aquifer at 20 m, and a deep gravelly sandstone confined aquifer associated with faulting at 120 m. The static piezometric surface stabilized at 44 m and the drilling resulted in a productive well. The borehole information agreed well with the yield interpretation.

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REFERENCES

Al-Shanti, A.M.S. 1966. Oolitic iron ore deposits in Wadi Fatima between Jeddah and Mecca, Saudi Arabia. Saudi Arabian Directorate General of Mineral Resources, Bulletin. 2, 51 p.

Al-Bassam, A.M. 2005. Resistivity methods for groundwater exploration in the Cretaceous-Tertiary sedimentary sequence, east of Jeddah, Saudi Arabia. The Electronic Journal of the International Association for Environmental Hydrology, V. 13, paper 19, pp.1-11.

Al-Garni, M., H. Hassanein and M. Gobashy. 2008. Geophysical investigation of groundwater in Wadi Lusab, Haddat Ash Sham Area, Makkah Al Mukarramah. (Abstract). 3rd International Conference on Water Resources and Arid Environments (2008) & 1st Arab Water Forum (16-19 November 2008).

Al-Khatib, E., 1977. Hydrogeology of Usfan district, Saudi Arabia. M.Sc. Thesis, I.A.G., King Abdulaziz University, Jeddah.

Brown, G.F., R.O Jackson, R.G. Bogue, and W.H. MacLean. 1963. Geology of the Southern Hijaz quadrangle, Kingdom of Saudi Arabia : Saudi Arabian Directorate General of Mineral Resources, Miscellaneous Geologic investigations MAP I – 210 A, 1 : 500,000 scale.

El-Nujaidi, H. 1978. Hydrogeology of Wadi Murwani-Khubys. M.Sc. Thesis, I.A.G. King Abdulaziz University, Jeddah.

Hacker, P., and W. Kollman. 1984. " Region around Jeddah and its hinterland – hydrochemistry of the groundwater." In: Jado, R., and J.G. Zotl (1984) Quaternary Period In Saudi Arabia, Vol. 2 : pp. 123 – 132, Springer – Verlag, Wien, New York.

Hussien, M.T., A.S. Bazuhair, and M.S. Al-Yamani. 1993. " Ground water availability in the Khulais Plain, Western Saudi Arabia. " ,Hydro – Sci Jour., Vol. 38 (3): pp. 203 - 213.

Hussien, M.T., and A.S. Bazuhair. 1992. Ground water in Haddat Al-Sham-AlByada Area, Western Saudi Arabia. Arab Gulf Jour. Sci. Res., vol. 10 (1):pp. 23 – 43.

Italconsult. 1967. Water Supply Surveys for Jeddah-Mecca-Taif Area. First interim report, Ministry of Agriculture and Water, Riyadh.

Johnson, P.R. 2006. Explanatory notes to the map of Proterozoic geology of western Saudi Arabia, technical report SGS-Tr-2006-4.

Karpoff, R. 1957a. Esquisse géologique de l'Arabie Séoudite, Bull. Soc. géol. France VI (1958) (6), pp. 653–697

Karpoff, R. 1957b. Sur I' existence de Meaestrichtien au nord de Djeddah (Arabie Soaudite): Compte remdus Hebdomadaires de Seances de I; Academie des Sciences 225, 1322-1324 .

Kotb, H., S.M. Saidi, and H. Hakim. 1988. "Hydrochemical characteristics of groundwater in the Usfan basin, Saudi Arabia. ", Jour. King Abdulaziz Univ.: Earth Sci., Vol.1:pp.113-132.

Moltzer, J.G. and P.L. Binda. 1981. Micropaleontology and palynology of the middle and upper members of the Shumaysi Formation, Saudi Arabia. Bulletin of the Faculty of Earth Sciences, King Abulaziz University, A: 57-76.

Moore, T.A., and M.H. Al-Rehaili. 1989. Geologic map of the Makkah Quadrangle, sheet 21D, Kingdom of Saudi Arabia. Saudi Arabian Directorate General of Mineral Resources, Geoscience Map GM-107C, Scale

1:250,000, with text, 62p. Jeddah, Saudi Arabia.

Nebert, K. 1969. Geology of the Jabal Samran and Jabal Farasan region, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Bulletin 4, 32 p.

Pallister, J.S. 1982a. Reconnaissance geologic map of the Harrat Tuffil quadrangle, sheet 20/39 B, Kingdom of Saudi Arabia : Saudi Arabian Deputy Ministry for Mineral Resources, Open-File Report USGS–OF–03–33, no text, map 1 : 100.000 scale.

Pallister, J.S. 1982b. Reconnaissance geology of the Shu' ayba quadrangle, sheet 20/39 A, Kingdom of Saudi Arabia : Saudi Arabian Deputy Ministry for Mineral Resources, Open- File Report USGS–OF–02–59, no text, map 1 : 100.000 scale.

Pallister, J.S. 1986. Geologic map of the Al Lith quadrangle, sheet 20D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Geoscience Map GM – 95,1 : 250,000 scale.

Qari, M.Y.H.T., and Z. Sen. 1994. Remotely sensed fracture patterns in he southwestern Saudi Arabia and qualitative analysis, Bull. of the Engineering Geology, No. 49 : 63-72.

Ramsay, C.R. 1986. Geologic map of the Rabigh quadrangle, sheet 22 D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Geologic Map GM-84, 49 p.

Rexworthy, S.R. 1972. Geology and mineralization of the Precambrian metavolcanics and intrusives of the Jabal Samran-Wadi Hawara region of the southern Hijaz: unpublished Ph. D. thesis, University of London, 239 p.

Sorman, A.U., M.Y.H.T. Qari, and M.M. Hassani. 1994. Estimation of flood peaks using remote sensing techniques; case study: Wadi Itwad, southwestern Saudi Arabia, Journal of King Abdulaziz University: Metrology, Environmental and Arid Land Agriculture Sciences, Vol. 5, pp 161-177.

Spincer, C.H., and P.L. Vincent. 1984. Bentonite resource potential and geology of the Cenozoic sediments , Jeddah region: Saudi Arabian Deputy Ministry for Mineral Resources, Open-File Report BRGM-O-F-02-34 , 34 p.

Zeidan, R., and K. Banat. 1989. Petrology, Mineralogy and Geochemistry of the Sedimentary Formations in Usfan, Haddat Ash-Sham and Shumaysi Areas, and their Associated Oolitic Ironstone Interbeds, North East and East of Jeddah, Saudi Arabia, King Abdulaziz University, Directorate of Research Projects 035/406 , 264 p.

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