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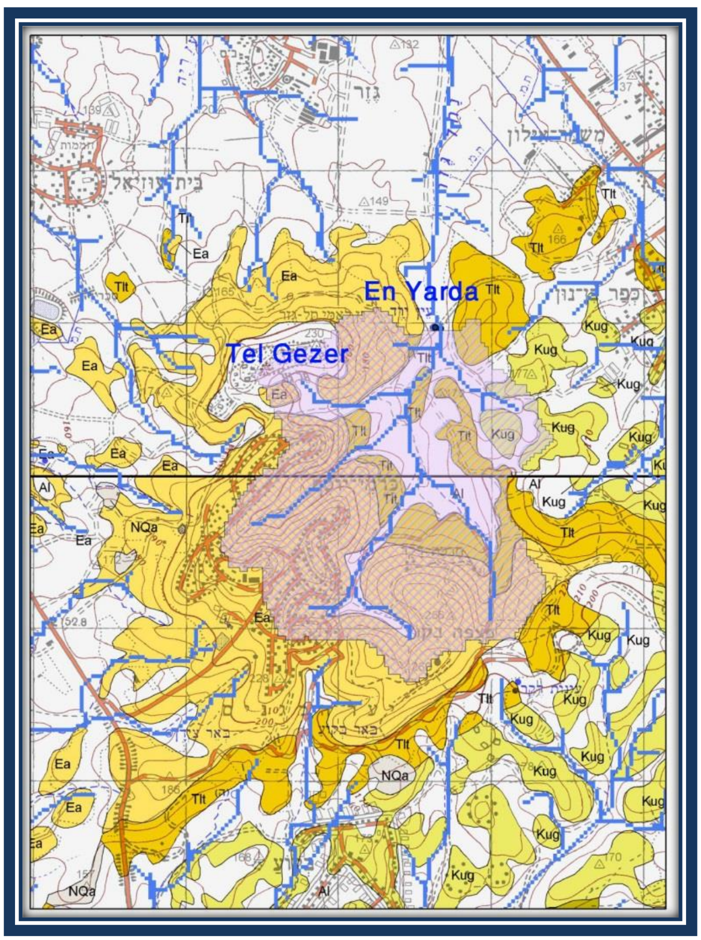

Report GSI/27/2017 Jerusalem, December 2017

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The hydrogeology of Tel Gezer

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Hydrogeological background

Tel Gezer is built on top of layers of Adulam Formation (the lower part of the Avedat Group) of the lower Eocene period (see geological map in figure 1), which consist mainly of chalk with some thin layers of chert lenses. The basic geology of the Tel was given by Bullard (1971). Below the Eocenic chalk lie the Taqiye Formation (the upper part of the Mt Scopus Group) of the Paleocene period, which consist of clayey and marly layers. Both units are of relatively low permeability and therefore do not act as aquifers. However, while the Adulam Formation is fractured and therefore can allow penetration of water (thus act as an aquitard – semi permeable unit whose characteristic is in between an aquifer and an aquiclude), the Taqiye Formation is built of impermeable layer and act as an aquiclude. In other parts of Israel, the rocks of the Avedat Group could be hard chalk and limestone and thus can serve as an aquifer (e.g. in the wester

n coast of the Kineret area) but this is not the case in Tel Gezer. Thus, in Tel Gezer site the water flow is mainly through fractures and joints and not in the matrix which is of low permeability. Similar flow in fractures occurs in the Avedat Group in other locations in Israel such as in the Ramat Hovav site.

The geological structure of the area around Tel Gezer site is relatively mild with a general dip toward the south west from Kfar Bin-Nun and Mishmar Ayalon toward Tel Gezer and Karme Yosef (Figure 2). However, this structure is not easily detected because of the poor exposures of the rocks which are covered by Nari and young alluvial sediment. In the diagonal tunnel of the water system, where good exposure of the Eocene rocks are found, a dip of ~10 degree can be observed.

The main aquifer in this part of Israel is the Mountain Aquifer (named also the Judea Group Aquifer or the Yarkon Taninim Aquifer) of the Cenomanian-Turonian period (Upper Cretaceous era), which is built mainly of limestone and dolomite with some marly layers. This aquifer is a karstic aquifer with water level of ~10 meter above sea level, as measured in several wells in the studied area (Figure 3). Besides that, there is a local smaller aquifer (or aquitard), of the Eocene rocks. This aquifer is, at places, not distinguishable from the local alluvial aquifer. The water level in this unit is ~160 meters above sea level (asl), which is much higher than that of the Judea Group Aquifer.

Springs in the surrounding of the Tel Gezer area

The main spring near Tel Gezer is the Yarda spring (En Yarda, see location in figures 2 and 3), which is located ~600 meters northeast from the eastern side of the Tel at elevation of ~150 m asl. This spring is flowing most of the year, except in the summer months, depending on the amount of rain in each specific year. The water is sampled from a cemented rounded well which was probably built during the first half of the 20th century by the British. The flow in this spring fluctuate from high levels in the winter and even large amount of overflow after rain event to very low level in the well in the summer to total dryness toward the end of the summer. It is difficult to estimate the yearly discharge of this spring because of these fluctuations. The specific hydrogeology of the spring is not so clear due to poor exposure. It seems that it is located in the upper part of the Taqiye Formation, within a lens of alluvial sediments and it gets its water from the local watershed which is built mostly of Eocenic rocks.

Another small local and seasonal spring was sampled in the southeastern part of Karme Yosef (named Karme Yosef spring, Table 1, Figure 3). This spring originates only shortly after significant rain event and is dry even most of the winter. It originates from Eocenic rocks of the hill of Karme Yosef. Another small spring is the Li spring with a small pool ~1.5 km west of Tel Gezer site, quite near a surface reservoir that may contribute some water.

A very interesting group of springs are found in the Abu Shusha site, some 500 meters south west of the southern part of the Tel. These springs are discharging only after heavy rain events, such as the event in winter 2012/13, in which they were sampled (Table 1). In most other times, no water is found here. This site is located on the ruins of the Abu Shusha Arab village which was abandoned in 1948. There are some evidences for artesian shallow wells in this area that continue to exist until the 1980's and were blocked in that period.

Formation of the cave – natural karstic or anthropogenic?

The cave, which is found at the lower part of the tunnel, does not seem to be natural cave because it is not found in karstic rocks. Unlike most natural caves in this region, which are found in the limestone or dolomitic rocks of the Judea Group, this cave in found at the top of the Taqiye Formation which is built of clayey and marl material which does not usually form natural karstic caves. Even the rocks above the cave (Avedat Group – Eocene era) consist of chalk which is of relatively low permeability and does not usually form karst. On the other hand, it is easy to dig such cave in the soft clayey material of the Taqiye Formation. It may also be possible that this cave was dug to allow more volume of water at times where flow of recharging water was slower, e.g. in the end of the summer. In that respect, it may have served as unique structure, something between a well or spring and an underground reservoir.

Hydrogeochemical studies

Water samples were taken for chemical and isotopic analysis. These include sampling several times of the Yarda spring, sampling of two springs in Abu Shusha area, sampling of the small Karme Yosef spring, sampling of water dripping in the cave (in winter 2013/14) and sampling of pore water from two sediment samples from the lower part of the tunnel, where water was reported to exist during the digging in the 1900's. The pore-water was extracted from the sediment by a press at the laboratory of the Geological Survey. In addition, water was sampled several times (last sampling in 2017) from the bottom of the tunnel.

The analyses included major chemistry of all springs (Table 1) and trace elements of selected samples (Table 2). Several analyses of the isotopic composition of oxygen and deuterium were also conducted.

The chemical analysis of the pore-water and the dripping water will be discussed separately due to their unique chemical composition.

The chemical results of the springs indicate the following: the Cl concentration and the total salinity are quite low and thus the water is suitable for drinking (Cl concentration of 66-147 mg/l, Table 1). The chemical analyses of the different springs show similar composition, implying that they belong to the same hydrogeological system. The most probable water source of these springs is the Eocene aquitard, which was recently studied by Goren and Burg (2012), whose water chemistry is quite similar to that of the water in the springs. Moreover, the chemical signature of the trace elements in the springs water (e.g. Ba, SiO_2) show a somewhat close affinity to that of water from the Eocenic aquifer (Zilberbrand et al., 2014) rather than to that of the regional Judea Aquifer. The isotopic composition of oxygen in the springs water is more similar to that of the coastal aquifer and the Eocene aquifer than to that of the Judea Aquifer.

But, this difference is not very significant since there is quite a scatter in each aquifer and there is an overlap between the different aquifers.

The chemical composition of the pore-water and the dripping water is very unique and very different from that of the springs. In general, this water has higher concentration of most major ions. Most striking is the high concentration of nitrate and potassium, which is not found in any other natural water source in Israel. Such high concentrations are most probably result of contamination in the site itself. Since it is unlikely that the pollution source is agriculture in the site of the Tel, the source of the pollution could be human or animal remains. This issue should be farther studied due to its uniqueness. The only known place where quite similar water chemistry was found is in the Palmahim area, in the unsaturated zone above the coastal aquifer (Zilberbrand, and Pankratov, 1997). There, high concentrations of potassium and nitrate were connected to animal waste. In the Gezer case, the high concentration is probably related to excretion of pigeons and possibly also bats. It is interesting to note that the isotopic values of this unique water was similar to that of the springs, indicating that the source of all water is local rain and the unique composition is due to processes of interaction with the material in the unsaturated zone on the way to the aquifer.

As explained before, water was also sampled at the bottom of the tunnel at two occasions. The first was in winter 2015, when plastic sheets were placed at the bottom of the cave and between the cave and the tunnel and second time was in winter 2017 at the end of the digging season from the bottom of the tunnel, after the tunnel was dug several meters below the level of 2013. The water that accumulated on the plastic sheet was of very small volume, showing that not much infiltration occurs currently, possibly due to change at the surface of the Tel. This is especially true since the sampling was done short time after a heavy rain event and still not much water was accumulated. Moreover, the chemistry of this water was not similar to that of the springs around the Tel. The sampling at the second occasion from the tunnel (in 2017) was done when digging reached the deepest point and some water was exposed at the bottom of the tunnel, in what might be the original pool at the Middle Bronze Age. Water was collected at two different dates from the pool (within clayey sediments) and analyzed for chemical composition, showing similarity in Cl concentration to that of the springs around the Tel. It is, therefore, possible that the digging at this stage indeed reached the small aquifer of the Eocene chalky rocks which was the aim of the ancient people. It should be noted that this water had high concentration of K, SO_4 which is probably the result of local pollution. Moreover, some of the water here is rain that comes directly through the tunnel and not through the sediment. The current water here is not of modern standard quality but it can be assumed that people in ancient time would drink water of lower quality if needed. Moreover, current water is subjected to local modern pollution (e.g. from agriculture field in general and from animal excretion specific to the Tel itself). Only farther and deeper digging can ensure this hypothesis but the quality of the water in this location exhibit a significant clue for the existence of good water in this point even in ancient time.

Preliminary estimation of water budget – regional and local budget of the Gezer site

Drainage areas

The following areas were examined:

Total watershed of Yarda spring – 3,595,000 m^2

Avedat + Mt Scopus – 2,596,235 m^2

Avedat – 1,931,095 m^2

Local drainage of Tel Gezer itself – ~300,000 m^2

The total area of the watershed of the Yarda spring, which is the area that drained into the spring itself was calculated with the GIS tools at the Geological Survey, taken into account the topography of Tel Gezer and it surrounding (Figure 4). The GIS tools were also used for the calculation of the specific areas of the different rock formations. In order to calculate the potential of water reaching the spring, it is necessary to estimate the recharge coefficient of this area, which is the amount of water that penetrate into the subsurface and does not undergo evapotranspiration or flow as surface flow. Since most of the rocks in this drainage basin are quite impermeable, a recharge coefficient can varies between 0.05 and 0.3 or even lower. This value should be multiplied by the amount of annual precipitation (~500 mm/yr) in order to get a rough estimation of the potential of water to the Yarda spring. Thus, the estimated amount of water is ~100,000-600,000 m^3/year, taking the total area and half of that taking the area of Avedat exposure only. The specific measurements of the discharge of the Yarda spring, that were done by the Hydrological Service in winter 1977-78 (Figure 5), yielded even smaller volume (~30,000 m^3), possibly indicating that the recharge coefficient is significantly smaller than the above values. In should be noted that these measurements were done only during one season and no recent data are available.

Regarding the water recharge potential of the Tel Gezer itself, above the elevation of lower part of the Eocene layers (178 m above sea level), similar calculation yields a recharge value of 8,300-50,000 m^3/year. This value is within the estimate of 20,000 m^3/year, consumed by 4,000 inhabitants, according to archeological consideration. It should be noted that the whole recharge area of the Tel could not be drained toward the tunnel and the cave, since parts of it drain to different directions, and it is therefore difficult to estimate the specific amount that could be obtained there. The above mentioned volume is thus a maximal value for this point. If surface drainage systems could have been built toward the location of the tunnel, then the volume here could approach this maximal volume.

Summary and conclusion

The groundwater level in this area is ~160 asl, and it is recharged locally by precipitation that infiltrate in this small drainage basin. There is no contribution from the lower main aquifer in this area of the Judea Group since its water level is much lower (~10 m asl) than that of the local aquifer. Chemical and isotopic results do not contradict this conclusion.

The average recharge from the precipitation in this local drainage basin of the En Yarda spring can amount to ~300,000 m^3/yr, which is more than the maximal measured value of water discharge in the Yarda spring. The recharge in the drainage basin of the Gezer Tel itself is of course much smaller, reaching an average value of ~20,000 m^3/year. Such a volume of water could support a community of ~4,000 inhabitants, assuming a value of 5 per year per person.

The water that was found at the bottom of the tunnel in May 2017 has similar chemical composition to that of the natural springs in the Eocene aquitard and thus supports the hypothesis that the people in ancient time indeed reached the local aquifer in this location. It is not clear why no water was accumulated on the plastic sheet after a rain event, possibly because of changes in the surface drainage system in recent years (possibly damaged during digging in the 1900's). So, the relevant question here is how many people could be supported by such volume of water. Is it possible that only small amount of water could be used here for emergency and the inhabitants depended on the water of Yarda and Shusha? In such case, it depends for how long they would need the water for emergency. Is it for one month? One year? Such assumption will determine the amount of people that could survive in this area. Even if there were other small springs in the Tel area, as was suggested by Reich and Shukrun (2003), these springs would not change significantly the water budget of the Tel. The issue of possible climate change, in which the period 3500 years ago was wetter, should be considered in detail but this period was probably not very much different from the current one.

In summary, the results of this study indicate that there is a small aquifer unit within Tel Gezer, which is part of the local aquifer which is built of chalky Eocene rocks. This aquifer unit has a small recharge, which is difficult to estimate but could possibly support several thousand ancient people (assuming the water consumption is about 5 m^3/yr per capita). The water within the Tel has low Cl concentration, similar to that of the springs in this area, but has much higher concentration of K and NO3 which is attributed to local pollution whose origin is probably decomposition of organic matter and excretion of animal. The groundwater flow in this local reservoir is relatively slow and therefore the local pollution remains within the cave and does not move away. This pollution is probably recent and did not exist in ancient times.

The finding of this study does not give a conclusive result regarding the basic understanding of the people in ancient times with regards to the science of hydrogeology. This topic is debated for several archeological sites in Israel, mostly in the Hatzor site (Weinberger et al., 2008). While the engineering part is very impressive, it is difficult to the determine whether the people in ancient time knew enough to expect reaching groundwater level in the location that it was found and or they were aiming at some springs in the area around the Tel. Nevertheless, the finding in Tel Gezer does not preclude the option that they did have basic hydrogeological knowledge of where groundwater can be reached.

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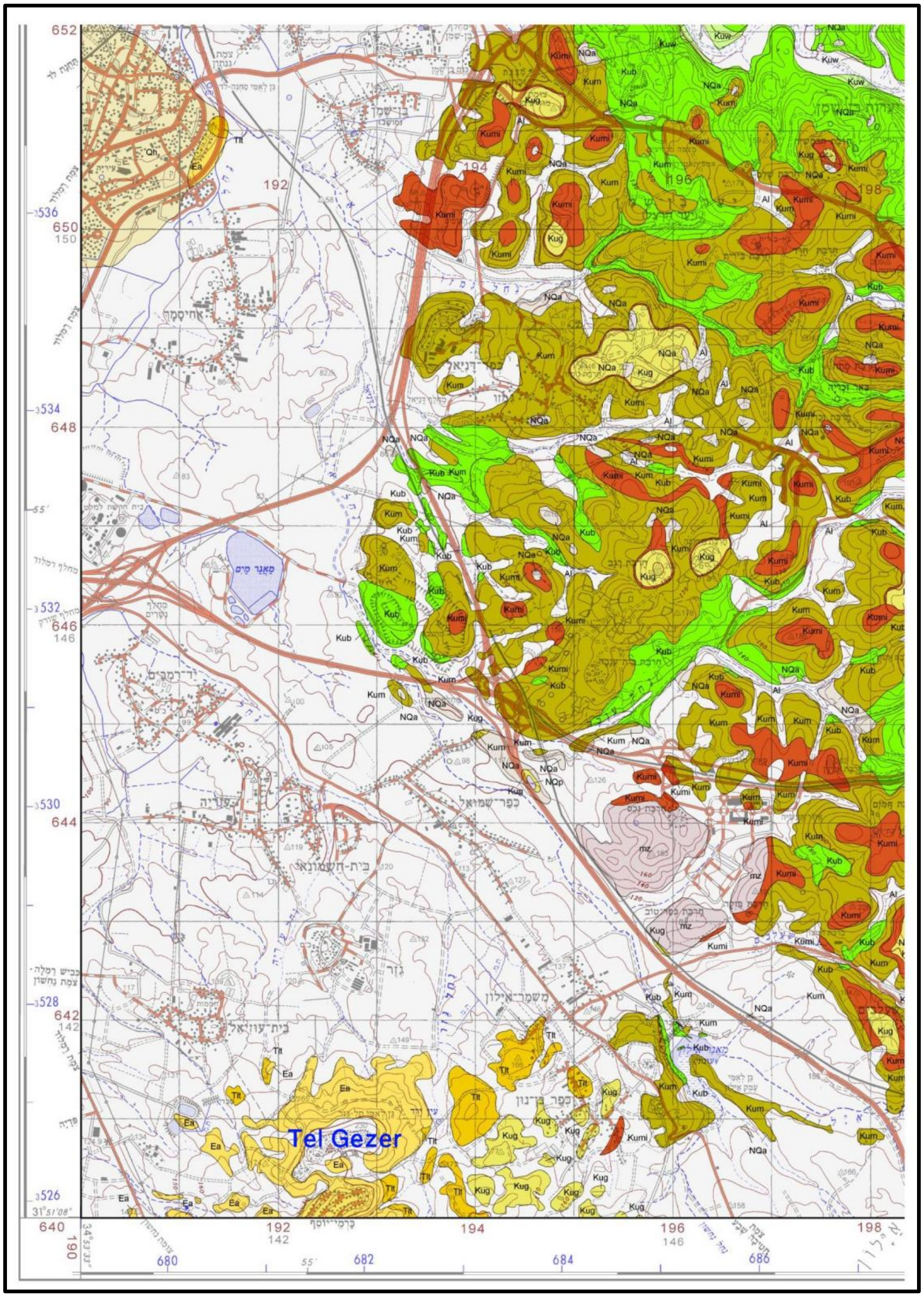

Fig 1a: Geological map of the Gezer area (from Yechieli , 2008)

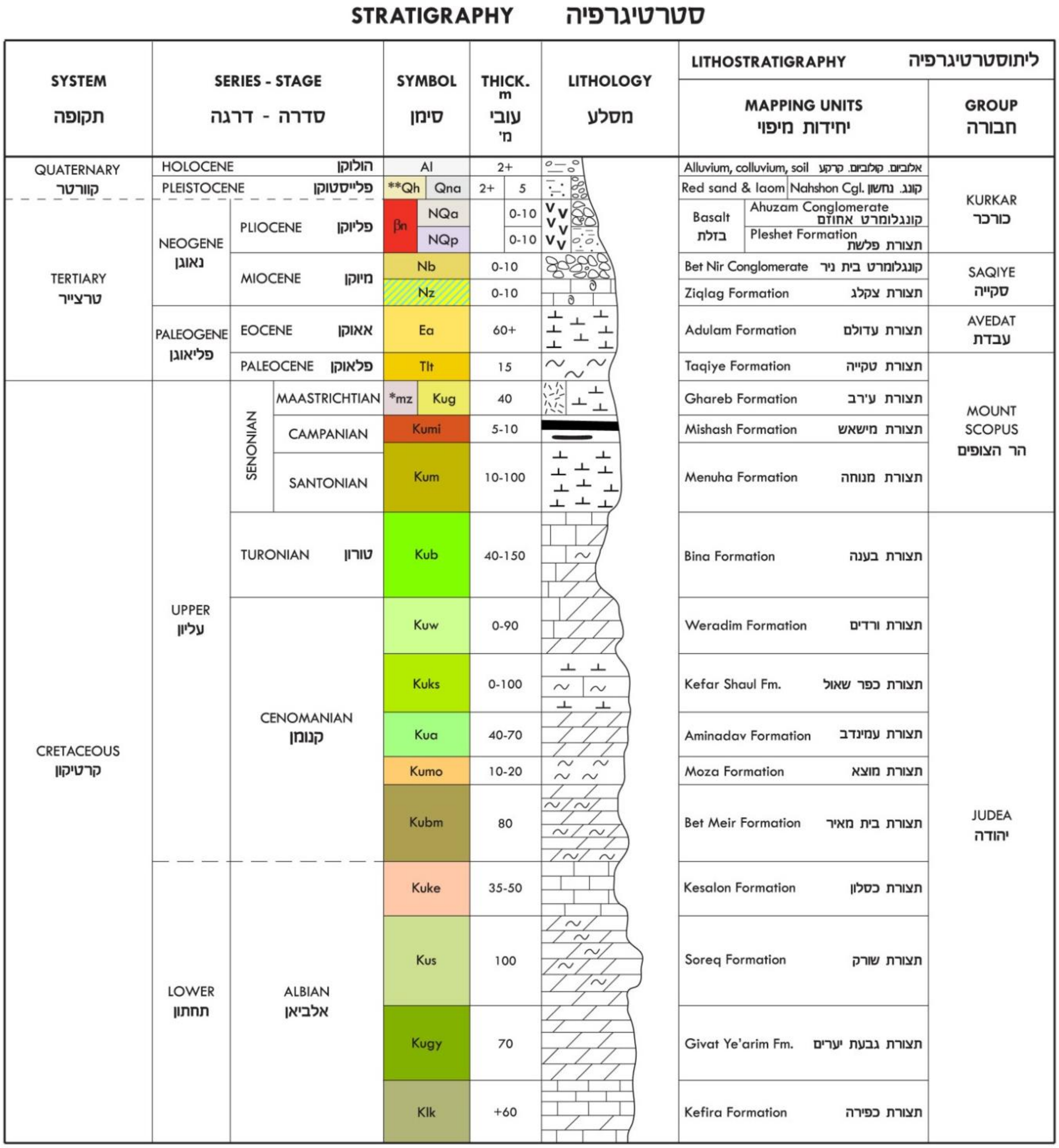

Fig 1b: Geological legend

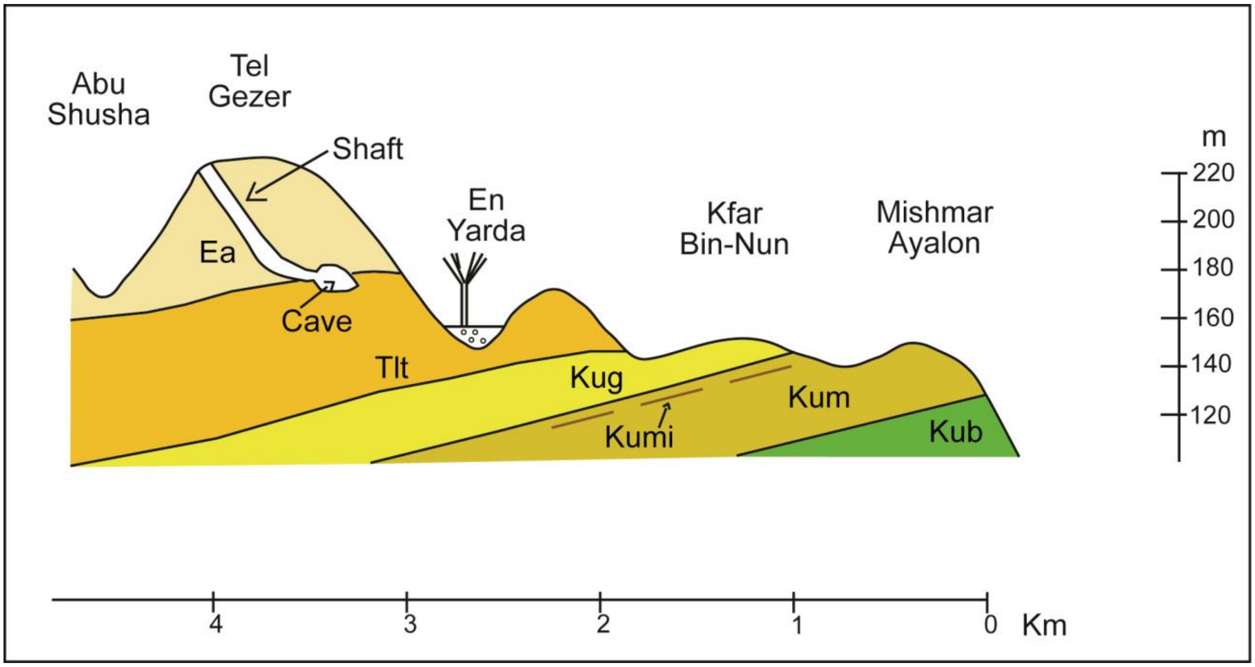

Fig 2: Geological cross section of Tel Gezer

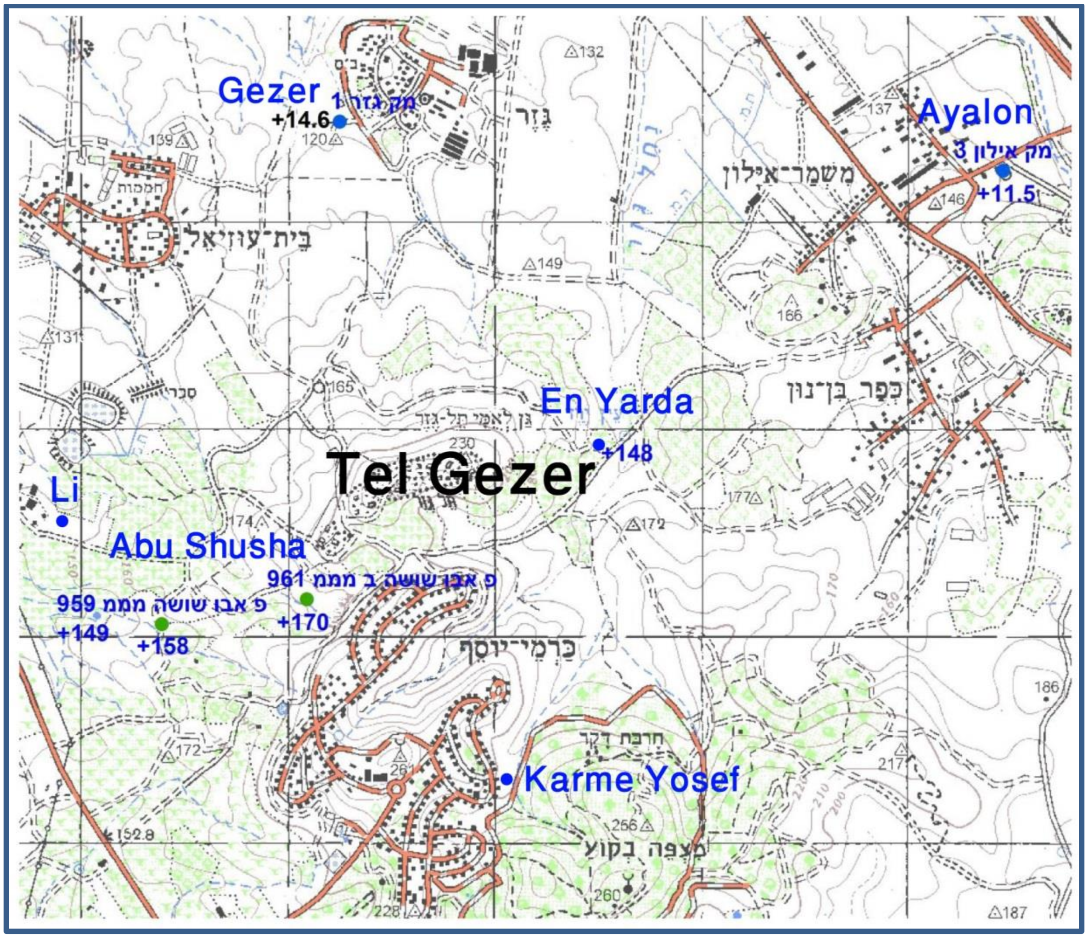

Fig 3: Topographic map with values of water level of the Judea Aquifer (Gezer and Ayalon wells) and the local aquifer, together with locations of En Yarda spring and the springs of Abu Shusha.

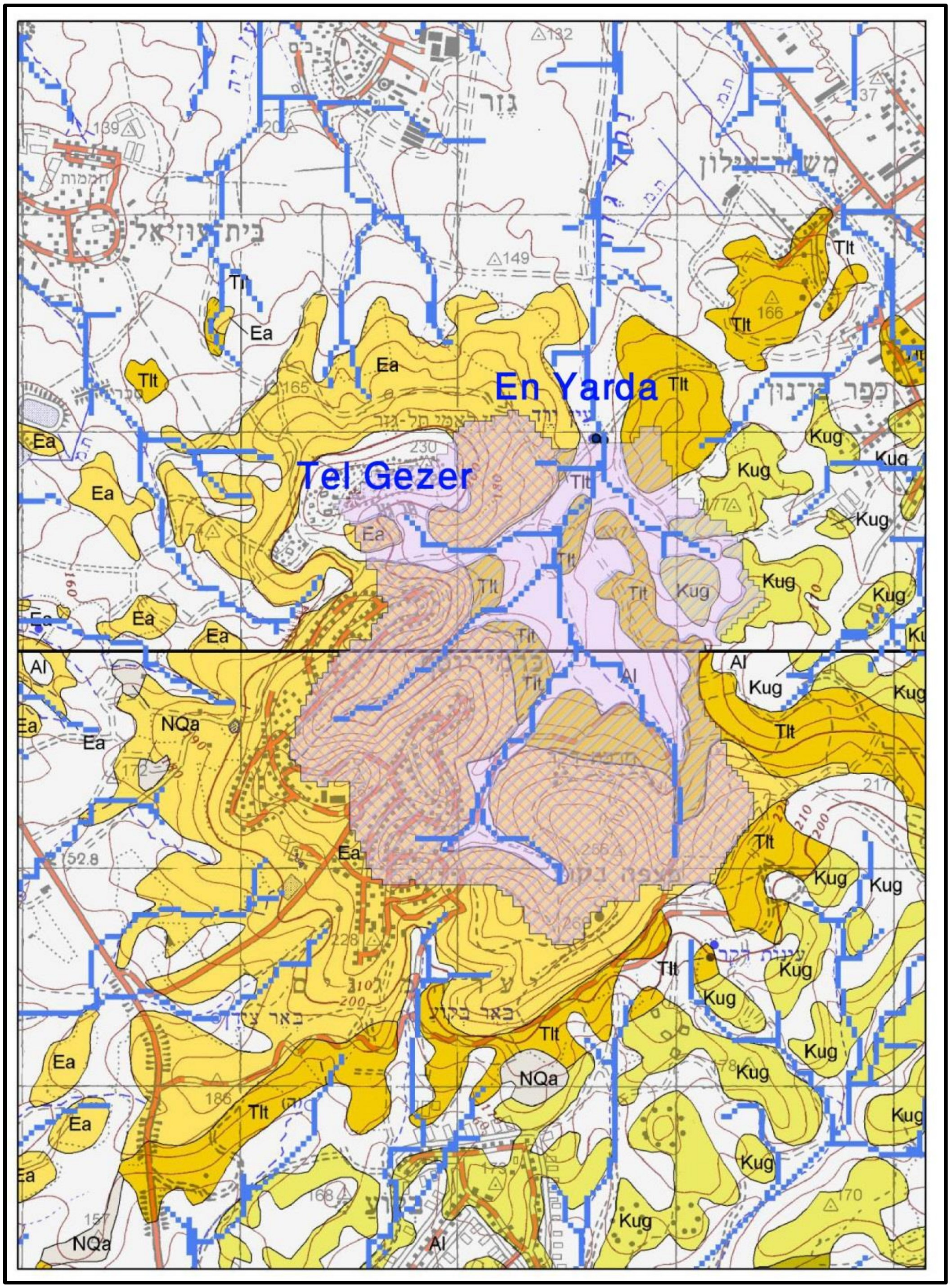

Fig 4: Map of the drainage basin of En Yarda (in shaded pinkish color) that was used for estimation of the volume of the annual water recharge from the amount of precipitation.

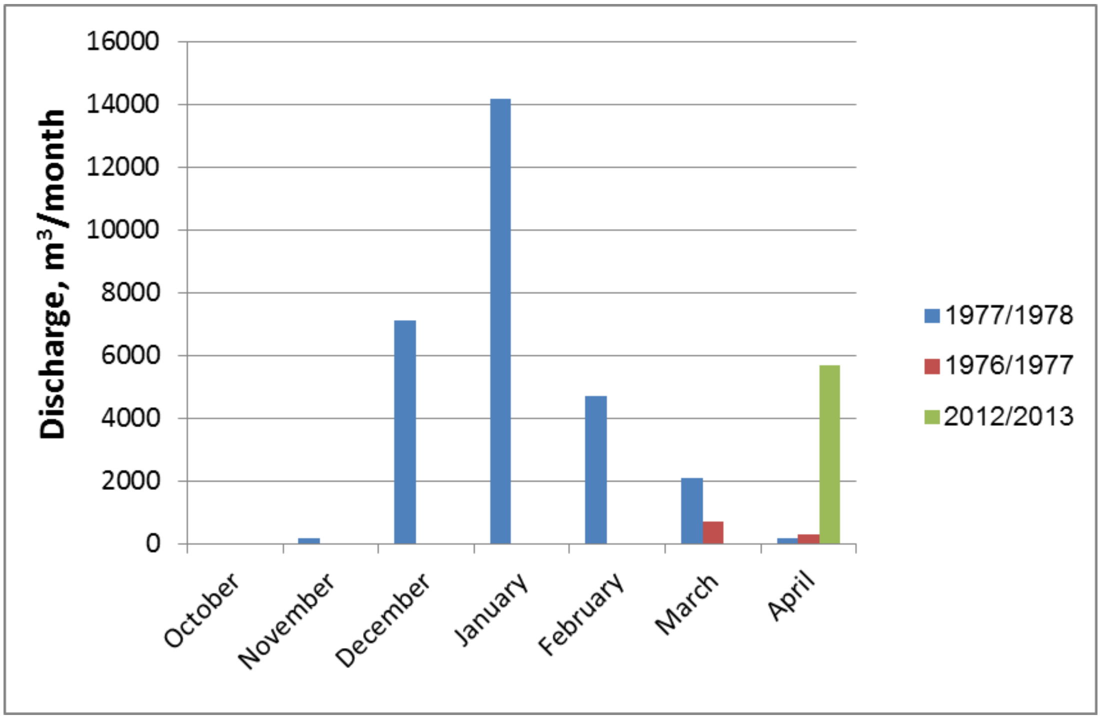

Fig. 5: Discharge of the Yarda spring (data from the archive of the Hydrological Service).

Table 1 – Chemical and isotopic composition of water in the Tel Gezer area, including springs, pore water and dripping water

Parameter / Sample	date	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Sr^{++}	Cl^{-}	SO_4^{--}	Br	HCO_3^{-}	NO_3^{-}	SiO_2	R.E.	$\delta^{18}O$	δD
		mg/l											%	‰	‰
En Yarda spring (1)	2/12/2013	142	18	50	11	0.9	147	27		313	69		0.4	-4.48	
En Yarda spring (2)	4/18/2013	138	19	50	11	0.9	139	27		323	70	55	0.1	-4.79	
En Yarda spring (3)	9/2/2014	134	15	42	11		134	25		294	60				
En Shusha-1 spring (1)	2/12/2013	148	16	36	17	0.6	66	31		478	4		1.5	-5.32	
En Shusha-1 spring (2)	2/12/2013	139	18	55	38	0.7	100	46		436	29		1.7	-4.74	
En Shusha-2 spring	2/12/2013	161	15	38	12	0.6	119	30		413	2.5	35	2.0	-4.50	
Karme Yosef spring	2/12/2013	148	14	37	0.7	0.8	131	21		330	14	63	2.1		
Li spring- SW of Gezer	6/4/2017	78	25	83	0.7	0.8	110	50	0.5	306	5	58		-1.36	-7.4
Water leaking in the tunnel	2013	190	54	183	392	1.4	390	260		290	640		0.7		
extracted water (1) - *1	6/15/2013	184	98	192	424	2	483	280			1130		1.7	-6.12	-25.2
extracted water (2) - *2	6/15/2013	216	100	205	396	2	447	445			1000		0.1	-5.79	-23.7
Gezer 22 - *3	5/21/2017	95	29	84	129	0.7	132	79	0.4	491	12	55		-3.14	-12.1
Gezer 1 YYW - *4	6/4/2017	86	27	85	138	0.7	138	140	0.5	377	24	51		-4.44	-21.6

*1 - extraction of water by squeezing muddy sediments at the bottom of the digging
*2 - extraction of water by squeezing muddy sediments at the bottom of the digging
*3 - water from the bottom of the shaft, digging in 2017
*4 - water from the bottom of the shaft, digging in 2017

Table 2 – analysis of trace elements in selected spring samples

Parameter / Sample	date	As	B	Ba	Cd	Co	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	Sb	Se	Sn	U	V	Zn
		ug/l																		
En Yarda spring (2)	4/18/2013	≤ 1	100	500	< 0.1	< 0.1	< 2	≤ 1	15	7	0.2	1.5	2	< 0.1	< 0.1	< 2	< 0.2	1.4	12	< 2
En Shusha-2 spring	2/12/2013	20	150	600	< 0.1	< 0.1	≤ 2	5	≤ 10	6	0.2	1.7	2	≤ 0.1	< 0.1	< 2	< 0.2	1.8	9	< 2
Karme Yosef spring	2/12/2013	2	80	625	< 0.1	< 0.1	< 2	≤ 1	15	5	0.4	0.2	< 1	≤ 0.1	< 0.1	< 2	< 0.2	1.1	10	< 2