HYDROGEOLOGICAL STUDY AND DISCHARGE FEATURES OF THE NIKSAR KARST SPRINGS (TOKAT—TURKEY)

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الخلاصة :

للتكوينات الصخرية الحديثة والقديمة خواص جيومائية هامة مثل النفاذية، وشبه النفاذية وعدم النفاذية. تكون الصخور الجيرية النَّفَّاذة عادة مرتبطة بتكوينات غير نَفَّاذة لم تتأثر بحركة تشويهات أديم الأرض، والتي بدورها تتصل لِتُكوِّن الينابيع الجيرية. نقّدم في هذه الدراسة العلاقة بين معامل الانتاج وبعض خواص الحوض المائي باستخدام طريقة التحليل الرسمائي للينابيع الجيرية. وتتحكَّم كمية انتاج الينبوع بنوعية حركة الماء (مثل الدفق الصفحي) والتَّقني في الحوض المائي. أظهرت التحليلات المترابطة علاقة ايجابية بين $(Q_t - Q_o)$ حيث Q_o سعة الخزان الابتدائية، Q_t السعة اللاحقة. هذه النتائج تُعزز خواص الينابيع الجيرية. وتعتبر مياه الينابيع الجيرية صالحة للاستخدام في البيوت وفي الصناعات الغذائية.

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ABSTRACT

The exposed Paleozoic and Recent units in the study area have various hydrogeological characteristics such as pervious, semipervious, and impervious. Pervious limestones and associated impervious formations that were not influenced by tectonic movement are connected to produce karst springs. This paper presents the relationship between the discharge coefficient and other aquifer properties by using the hydrograph analyses of the karst springs. The magnitude of the discharge of the spring apparently controls the character of flow (such as laminar) and conduit in the aquifer. The correlation analysis shows a positive relation between Q_0–Q_t, Q_0 – storage capacity, Q_t – storage capacity, and α – discharge change. These results enhances the properties of the karst springs. Both monthly and annual rainfall contribute to spring discharge. All karst springwaters are suitable for household and food industry uses.

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1. INTRODUCTION

The Niksar region is located between 40°28′ 25″ - 40°41′ 50″ N and 36°43′ 50″ - 37°10′ 25″ E, in the middle Black Sea region of Turkey (Figure 1). The geology of this area was studied by Seymen [1] and Taşkin [2], but there have not been many hydrogeological studies of the area. A hydrogeological study of the Ayvaz thermal spring in Niksar was carried out by Bulutçu [3] for curative purposes.

The study area displays a number of hydrogeological features, in that the groundwater circulation occurs in rocks from the Paleozoic to the Quaternary.

This paper aims to investigate the relationships between the hydrogeological characteristics of the aquifer formations and the various discharge coefficients (α) of the karstic springs, by using karst hydrograph analyses according to

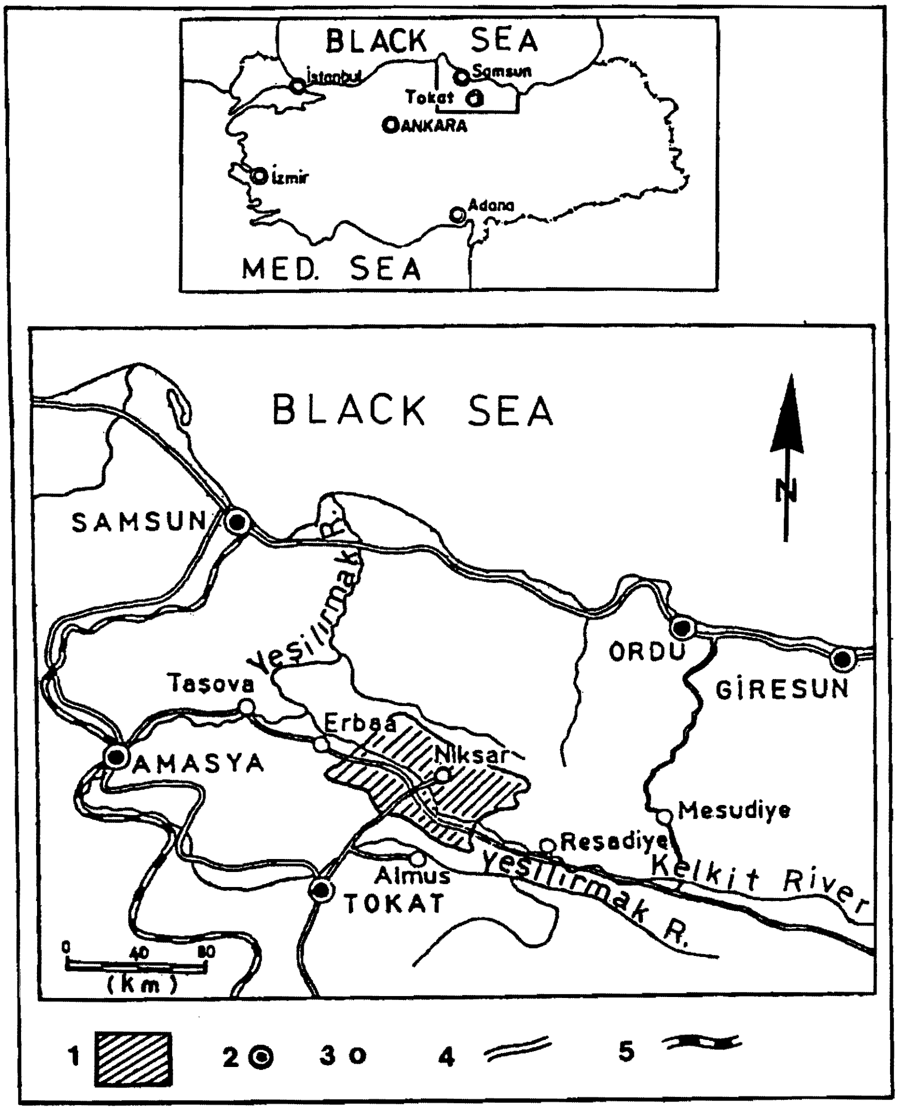

Figure 1. Location Map of the Study Area.
1. Study area, 2. Province center, 3. District center, 4. Highway, 5. Railroad.

Maillet's [4] equation. In addition, to show the relationship between α and other hydrogeological parameters, correlation analysis was carried out. Precipitation, discharge change (%), and discharge coefficient were correlated with type of aquifer by using Korkmaz's [5] method.

Karstic springs in the study area were monitored over a period of one and a half years. In the field studies, daily and/or weekly discharge data were measured from spring eyes and flow channels or in the captage, by using a current flow meter or triangular shaped weir or a specific volume meter. The geochemical samples of the rocks in the drainage area and the hydrochemical samples from the springs were collected and analyzed. According to the results of the springwater analyses, all karst springwaters have permanent drinkable, very good, and good qualitative waters [6]. Therefore, these waters can be used for household and food industry supply. Some springs have in fact been used for domestic purposes.

2. HYDROGEOLOGICAL SETTING

The exposed lithological units in the study area range from Paleozoic to Recent. These lithological units show different hydrogeological characteristics. Units of similar hydrogeological characteristics are qualitatively grouped as impermeable, semipermeable, and permeable (Figures 2 and 3).

In the area, the basal section is formed by the impermeable Paleozoic rocks. These are composed of quartz–chlorite–biotite schist, epidote–quartz–albite schist, and sericite–quartz–biotite schist. In some places, mudstone, marl, and tuff beds of Upper Maestrichtian age also form impermeable boundaries.

The semipermeable units are composed of conglomerate, sandstone, mudstone, and tuff and marl of Jurassic age. In addition, conglomerate, sandstone, mudstone, and limestones of Lower to Upper Lutetian age also form semipermeable units. Some continuous and intermittent springs of low discharge are fed by these units.

Among permeable units, the micritic, biomicritic, dismicritic, and intrasparitic limestones of Upper Jurassic–Lower Cretaceous age and the skeletal limestones of Upper Maestrichtian–Lower Paleocene age form the typical karstic aquifers. Many low and high discharge karstic springs emerge from these units (Figure 4).

Turkey is located on the Alpine tectonic belt. The tectonic setting is dominated by the dextral North Anatolian strike–slip fault (NAF) which has been active as a transform fault, separating the two minor plates of the Black Sea and Turkey since the late Miocene [7, 8].

The study area is located in the active North Anatolian Fault zone. Karstic limestones were affected by Miocene tectonics. Intensive tectonic processes produced extensive joint systems that provided access to water that could migrate into deeper sections of the limestones. Fragmentation of limestones, resulting from tectonic processes, represents the most important factor in karstification [9]. Consequently, the tectonic imprint seems to have a major control on the ultimate characterization of various hydrogeological aspects associated with karstic landscape. To confirm this factor, the frequency or rose diagram was assembled using 130 and 118 joint measurements and is in agreement with the orientation of the major jointing system observed in the area (Figure 5). In Upper Jurassic–Lower Cretaceous age limestones, dominant strike and slip are between N20–30W, N10E, and N70–80W. In Upper Cretaceous age limestones, dominant strike and slip are between N20–30W and N10E. The major jointing systems which influence the location of karst processes occur in the N–W direction. This orientation is favorable to the direction of the NAF zone.

The Niksar valley depression has developed due to young tectonic activity, dating back to the Miocene. This depression is filled with clastic sediments. The lower levels of this valley fill material are composed of weakly cemented conglomerate and sandstone with sandy gravel and clay lenses of Pliocene age.

The presence of clay lenses in alluvium forms confined aquifers under suitable hydraulic conditions. The upper levels of Quaternary alluvium are composed of gravel, clay, clayey gravel, and sandy gravel (Figure 6). An important aquifer has developed in the valley fill material. These materials show a random distribution both vertically and horizontally. The porosity values vary from 16% to 35% and the permeability values between 1.1×10^{-3} and 2.7×10^{-6} m/s. The valley is flat, average inclination is from zero to 2%. The general flow direction of the aquifer water is NE to SW. Precipitation and surface waters (Kelkit river) are the major sources of fluctuation in the water table (Figure 3).

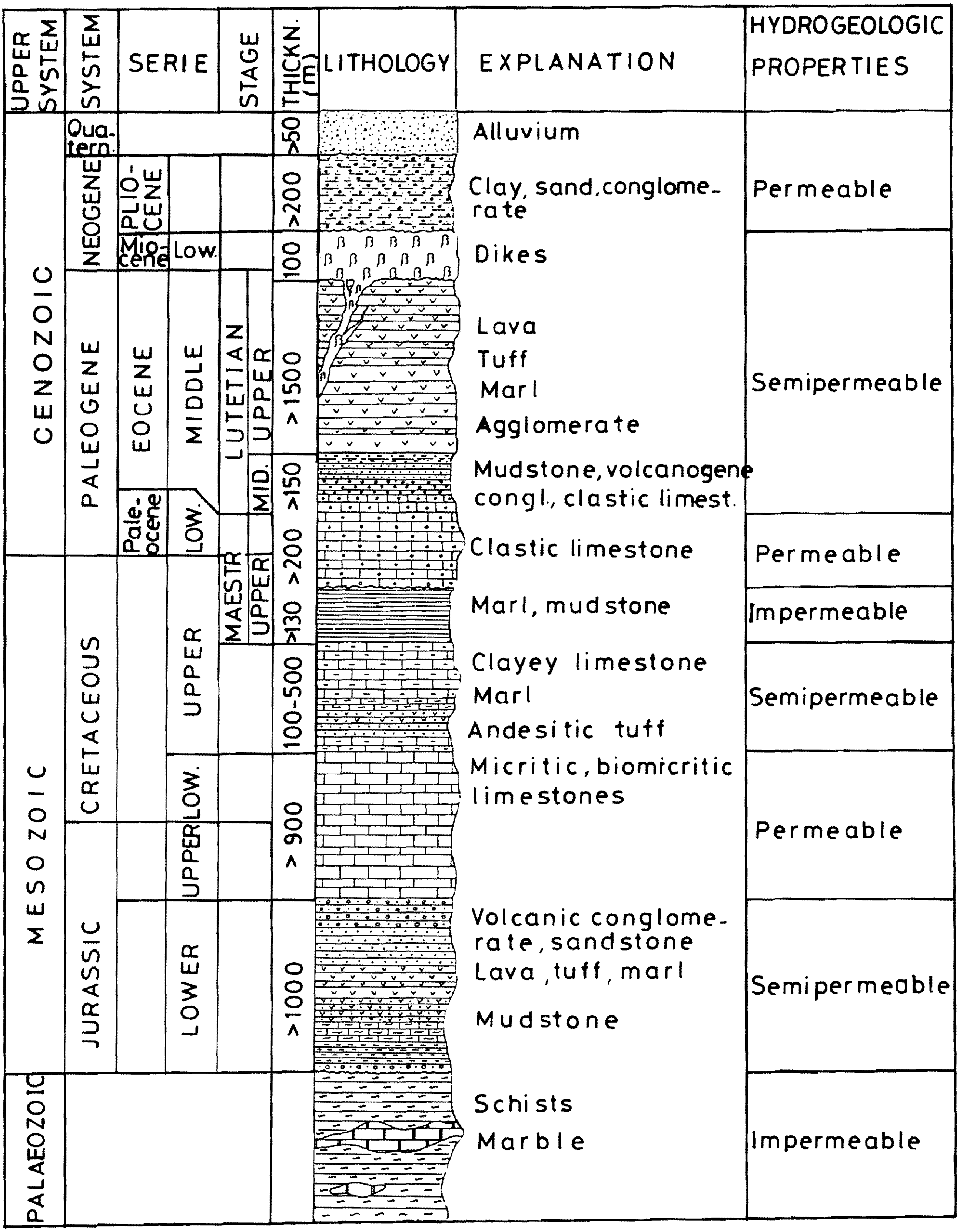

Figure 2. Stratigraphical Column Showing Geological and Hydrogeological Properties of the Study Area.

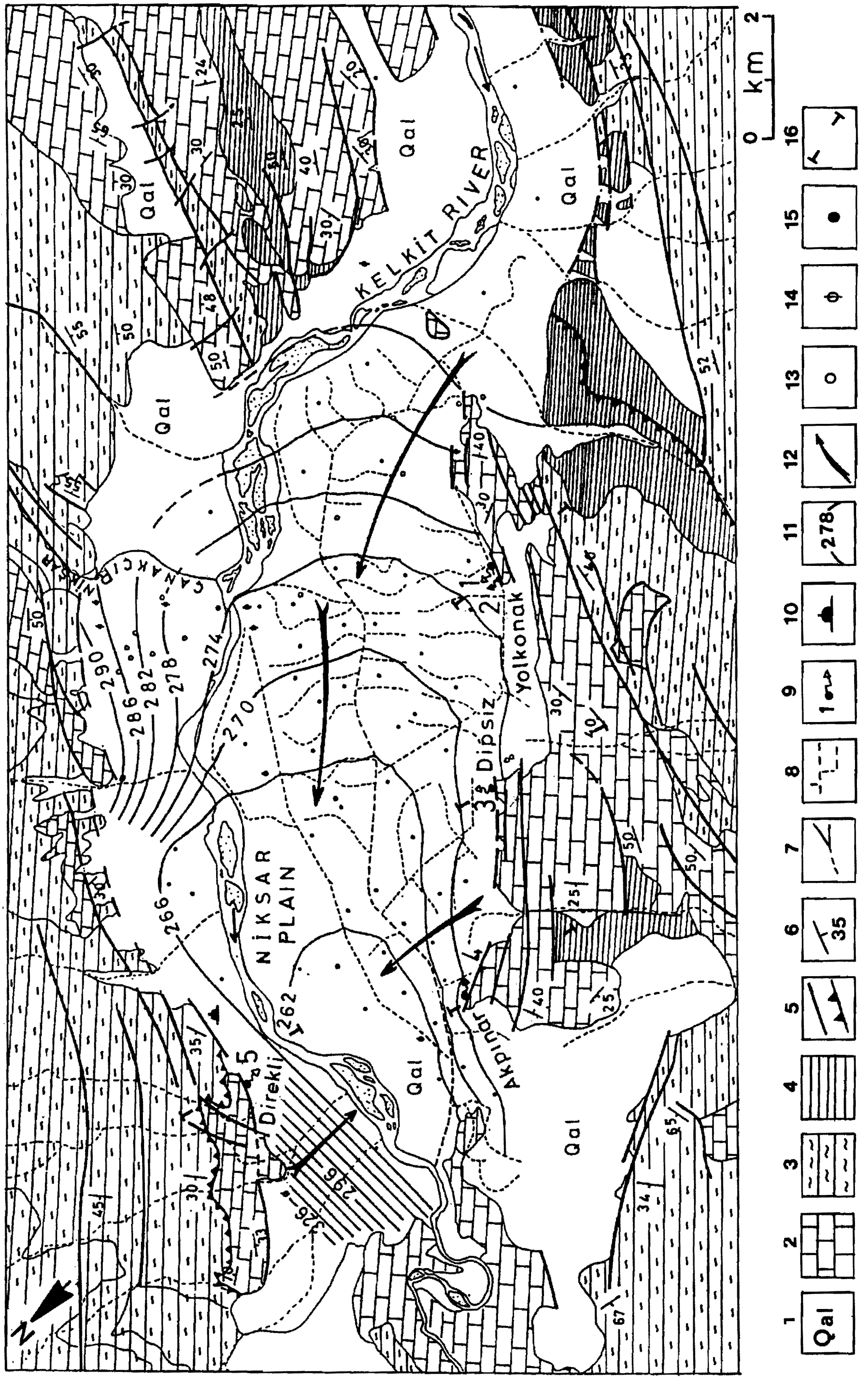

Figure 3. Hydrogeological Map of the Study Area.

1. Alluvium
2. Permeable formations
3. Semipermeable formations
4. Impermeable formations
5. Fault (Normal/Thrust)
6. Strike and dip of bed
7. Perennial and seasonal stream
8. Drainage canals
9. Karst spring
10. Hot spring
11. Groundwater level contours (m)
12. Groundwater flow direction
13. Dug well
14. Drilling well
15. Observation well
16. Cross-section line

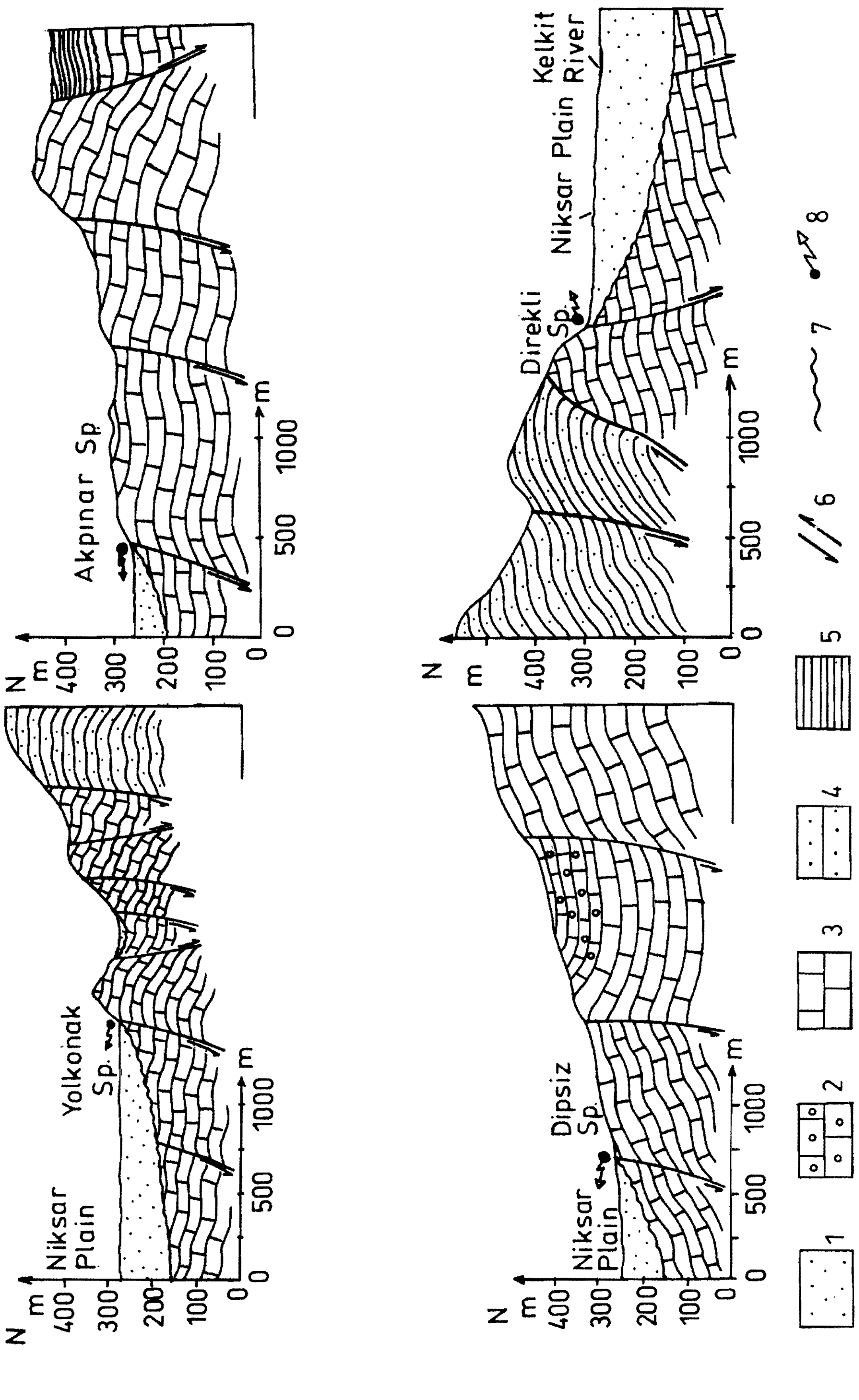

Figure 4. Hydrogeological Cross-Sections of the Karst Springs.

1. Alluvium-Permeable
2. Permeable karstic lower unit
3. Permeable karstic upper unit
4. Semipermeable unit
5. Impermeable unit
6. Fault (Normal/Thrust)
7. Disconformity
8. Karst spring

The average seepage coefficient of the Kelkit river is about 5%, which is selected on the basis of porosity, permeability, and the other hydrogeological properties of the river bed of the alluvium aquifer [6]. In the greater part of the Niksar valley the runoff is very low; however along the margin of the valley inclination is increased due to alluvium cones and the runoff is relatively increased in these parts of the valley. The alluvium aquifer recharges from both the north and south sides of the Kelkit river from the middle to the end of the Niksar valley. Also, geological and hydrogeological studies of the valley show that the Quaternary sediments are hydraulically connected only with the permeable limestones. That is, seepage has occurred from the karstic aquifers to the alluvium aquifer. Consequently, the discharge rates of the springs are not influenced by the flow in Kelkit river.

2.1. General Features of the Springs

Karst springs represent a natural exit for the groundwater to emerge at the surface of the Recent rocks. This exit is established within the hydrogeologically active fissures of the karst mass. The water comes to the surface through the porous rocks, which are practically insoluble and sometimes not karstified [10].

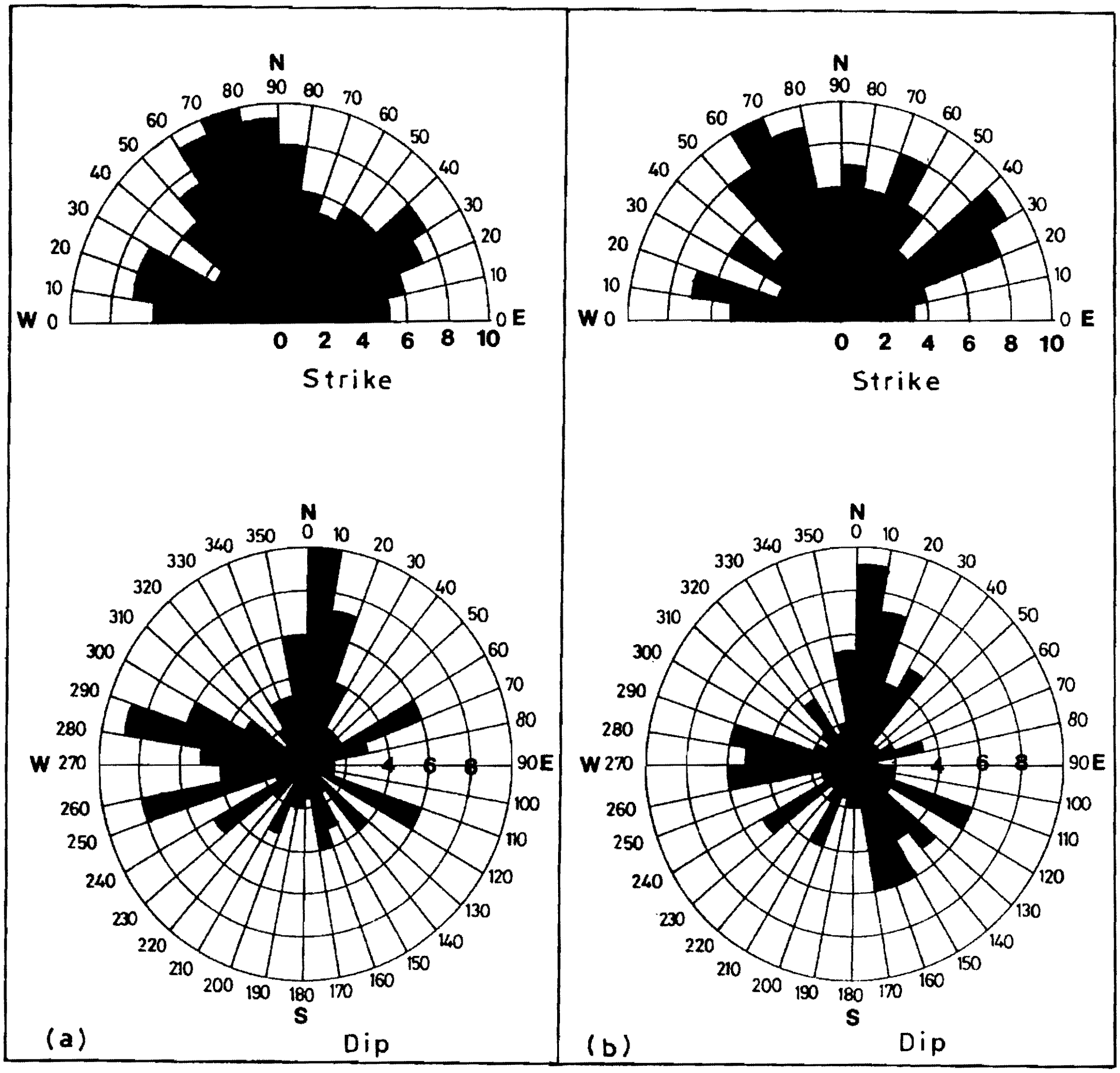

Figure 5. Frequency or Rose Diagram for the Fracturing States of Upper Jurassic–Lower Cretaceous (a) and Upper Cretaceous Limestones (b).

In the studied area, there are several karst springs drainages. We selected the important springs for study. Karstic limestones of different ages constitute the main recharge areas of the groundwater. There are numerous karst structures such as karrens, dolines, and solution cavities.

In the area of the springs, permeable limestones and associated impermeable formations are hydraulically connected by faults that act as pathways for the karst springs. The permeability of karstic limestones is controlled by secondary porosity due to fracturing. In the karst area, structural openings may continue to approximately 10–20 m depths. These openings provide the permeability for rainwater to seep through the karstic rock, and their water storage capacity is seemingly great [1] (Figure 4). Indeed, karstification is greatest at the surface and decreases with depth of a karst massif [9].

In the study area, karst springs emerge by fault or bedding planes (Table 1). The mean altitude of the springs is 277 m. They recharge from rainfall. The maximum discharges of the springs range from 54 to 428 l/s; minimum discharges from 10 to 68 l/s, and mean discharges from 25.83 to 233.37 l/s.

2.2. The Discharges of the Springs

It is possible to identify a karst underground system using analysis of karst spring hydrographs. This method has been used by various authors [4, 5, 9–19].

In the Maillet's [4] equation, the hydrograph of the baseflow of discharge of the karst spring in a long-lasting dry period with no precipitation may be approximated by a simple exponential relationship of the form:

$$Q_t = Q_o \times e^{-\alpha t}, \quad (1)$$

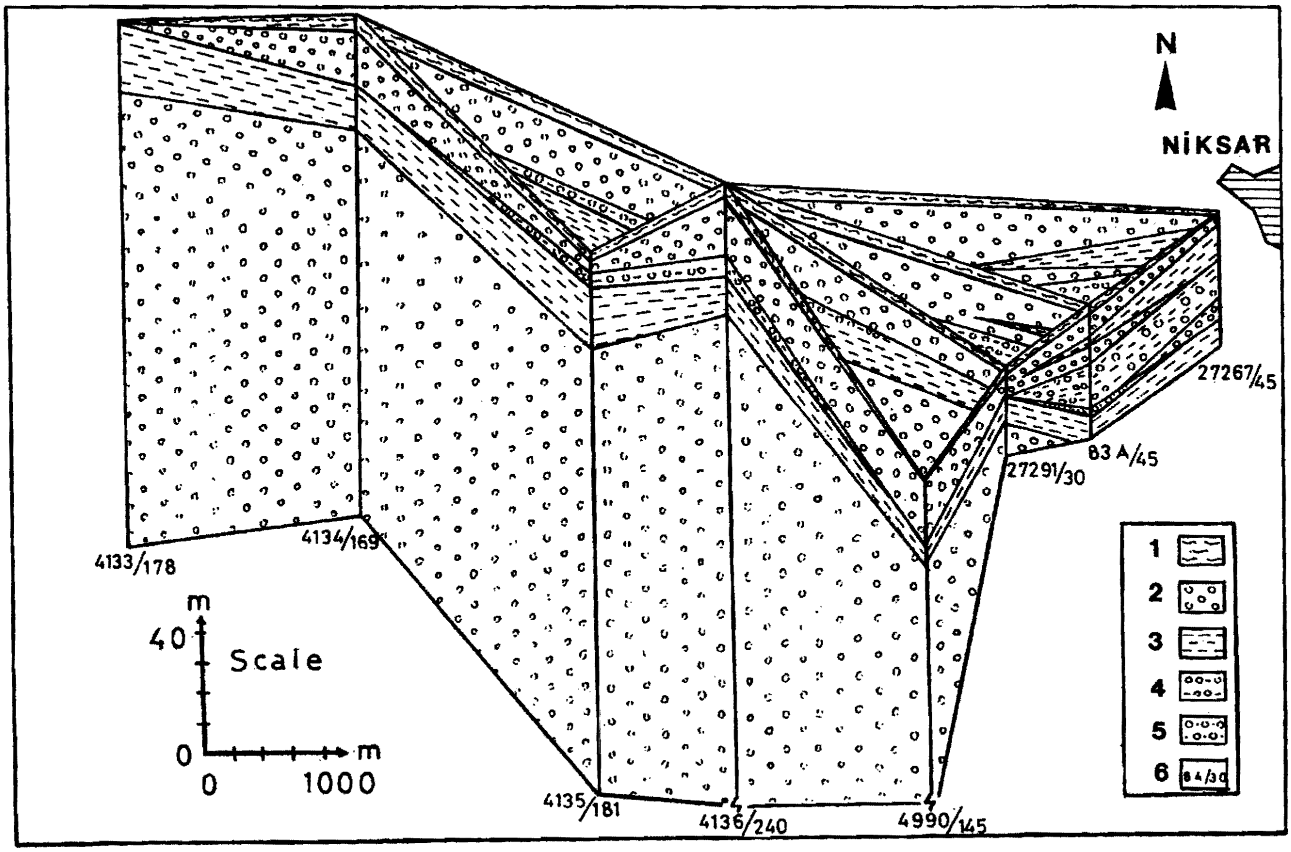

Figure 6. Panel Diagram Showing the Quaternary Valleyfill Sediments from Lithology Logs of Drills in the Niksar Valley.
1. Topsoil, 2. Gravel, 3. Clay, 4. Clayey gravel, 5. Sandy gravel, 6. Well no & Depth.

where Q_o is the discharge at the start of the recession period, Q_t is the discharge at time t, and α is a recession or discharge coefficient which depends upon the geological and morphological structure of the catchment analyzed [11, 13, 14]. The equation describes the discharge characteristic of a linear reservoir, *i.e.* one in which Q is proportional to V, with $Q = \alpha \times V$ rearranging and allowing for units gives [6, 7]:

$$V = (Q/\alpha) \times 86400 \tag{2}$$

where V = Storage capacity or dynamic reserve, m^3
Q = Groundwater discharge, $m^3\ sec^{-1}$; and
α = Discharge coefficient, day^{-1}.

The discharges of the springs were monitored from July 1986 to April 1988 [6]. The discharges data during this period are shown graphically in Figures 7–12. It is clearly seen that a relationship between rainfall and spring discharge exists. After the rainy season, the discharges from the springs increase.

Table 1. General Features of the Springs.

Name of spring	Altitude (m)	Type of spring (Bögli 1980)	Discharge Q(l/s) max.	Discharge Q(l/s) min.	Discharge Q(l/s) mean	Aquifer lithology
Yolkonak-I (1)	280	Bedding	275	5.5	94.7	Limestone
Yolkonak-II (2)	277	Bedding	428	68	233.37	Limestone
Dipsiz (3)	268	Bedding	290	62	167.35	Limestone
Akpinar (4)	270	Bedding	220	44	119.84	Limestone
Direkli (5)	290	Bedding	54	10	25.83	Limestone

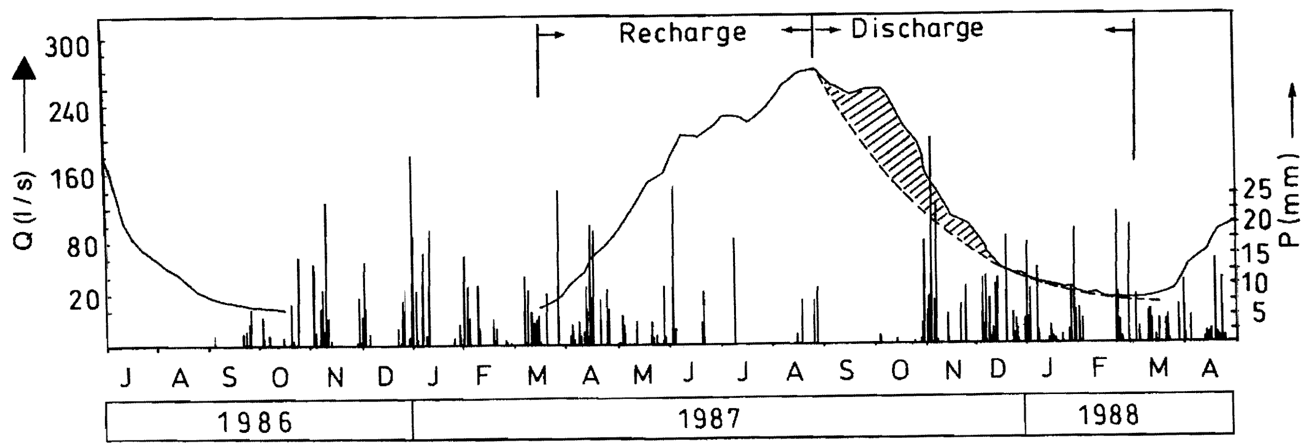

Figure 7. The Relationship Between Hydrograph and Discharge Curves of the Yolkonak-I Spring (B.f.r. = Base flow recession).

The magnitude of the discharge coefficient, α, indicates the character of flow in an aquifer. The term α is directly proportional to aquifer transmissivity, while it varies inversely with the storage and total volume of the aquifer [20].

Due to the complex properties of karst, there are two types of flow, *i.e.* slow or diffuse flow and turbulent or conduit flow [21, 22]. The discharge coefficients of the Yolkonak-II and Dipsiz springs are between 8.35×10^{-3} and 8.62×10^{-3} day^{-1} (Table 2). These springs are drained in a laminar regime mostly through karst fissures of small dimensions. The discharge coefficients of the Yolkonak-I, Akpinar, and Direkli springs are between 1.04×10^{-2} and 2.5×10^{-2} day^{-1}. In these springs conduit flow occurs, *i.e.* flow in larger fissures, through irregular karst conduits. Free porosity and the cross-sections of the flow channels are smaller [20]. This means that the water transportation is affected by a fast flow through a developed system, and the rates of discharges and transmissivities of the aquifers are greater. It is obvious that the aquifers with a discharge coefficient 10^{-3} day^{-1} have given more water than those with a discharge coefficient of 10^{-2} day^{-1} in the same recession period. Consequently, α changes with time in accordance with changes of flow conditions in the karst massif [11].

Correlation analysis has been applied to some parameters of the karst springs. The analysis shows: a moderate positive correlation ($r < 0.50$) between Q_t and total discharge; high positive correlations ($r > 0.50$) between Q_o and Q_t, Q_o and storage capacity, Q_t and storage capacity, and α and discharge change; a moderate negative correlation between Q_t and total discharge, a high negative correlation between $t-t_0$ and total discharge (Table 3). These results are logical and in agreement with the hydrogeological properties of the karstic aquifers.

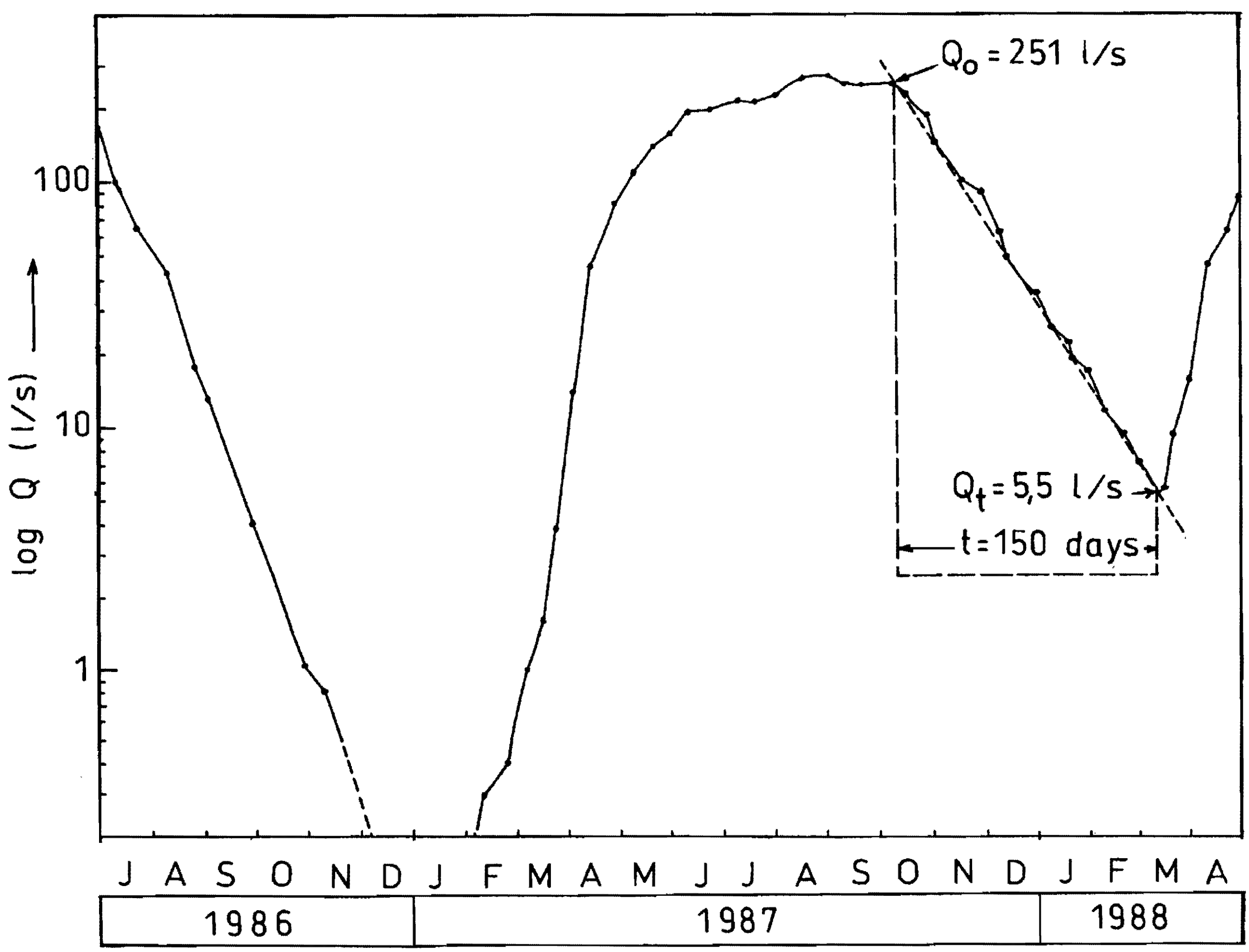

Figure 8. The Relationship Between Hydrograph and Discharge Curves of the Yolkonak-I Spring in Semilog Scales.

Table 2. Hydrograph Analyses of the Springs.

Spring Number	$t-t_o$ (day)	Q_o, Q_t (l/s)	Discharge coefficient, α (day^{-1})		Storage capacity (10^6m^3).	Average	Total discharge volume in the study period (10^6m^3)	Discharge change, % Q_c	
1	150	251–5.5	$\alpha = 0.0255$		0.83		2.10	98	
2	145 / 113	240–68 / 445–170	$\alpha = 0.00874$ / $\alpha = 0.0085$	$\alpha = 0.00862$	1.70 / 2.79	2.24	8.61	72 / 62	67
3	170 / 140	230–62 / 290–82	$\alpha = 0.0077$ / $\alpha = 0.009$	$\alpha = 0.00835$	1.88 / 1.99	1.93	6.50	73 / 72	72.5
4	156 / 90	180–44 / 220–75	$\alpha = 0.009$ / $\alpha = 0.0119$	$\alpha = 0.0104$	1.30 / 1.05	1.17	4.37	76 / 66	71
5	115 / 119	33–10 / 54–12	$\alpha = 0.0103$ / $\alpha = 0.0126$	$\alpha = 0.0114$	0.19 / 0.28	0.235	4.10	70 / 78	74

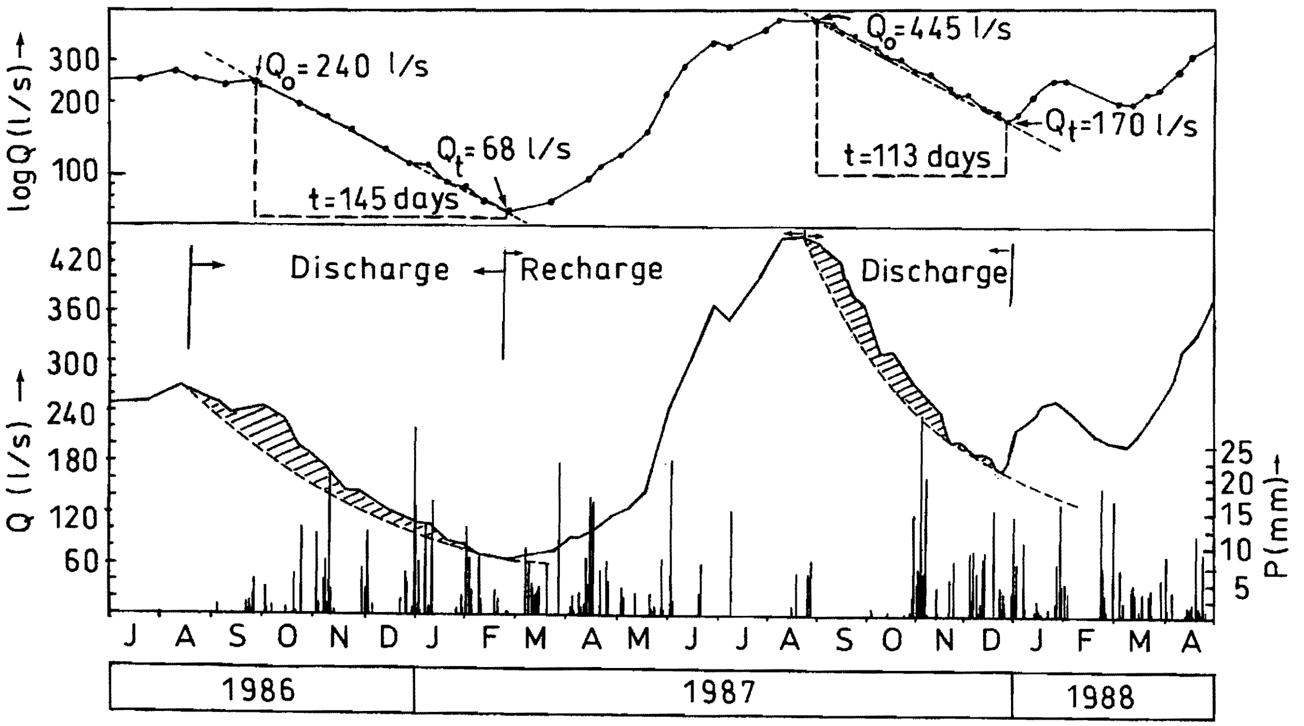

Figure 9. The Relationship Between Hydrograph and Discharge Curves of the Yolkonak -II Spring in Normal and Semilog Scales.

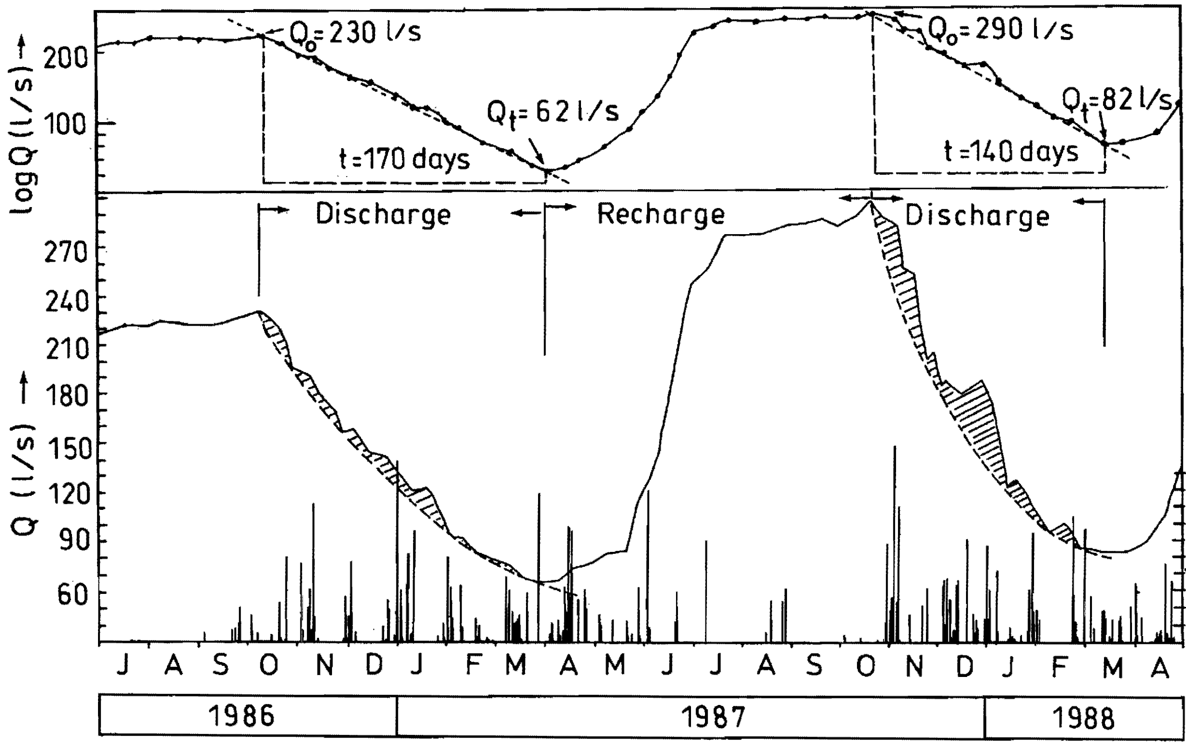

Figure 10. The Relationship Between Hydrograph and Discharge Curves of the Dipsiz Spring in Normal and Semilog Scales.

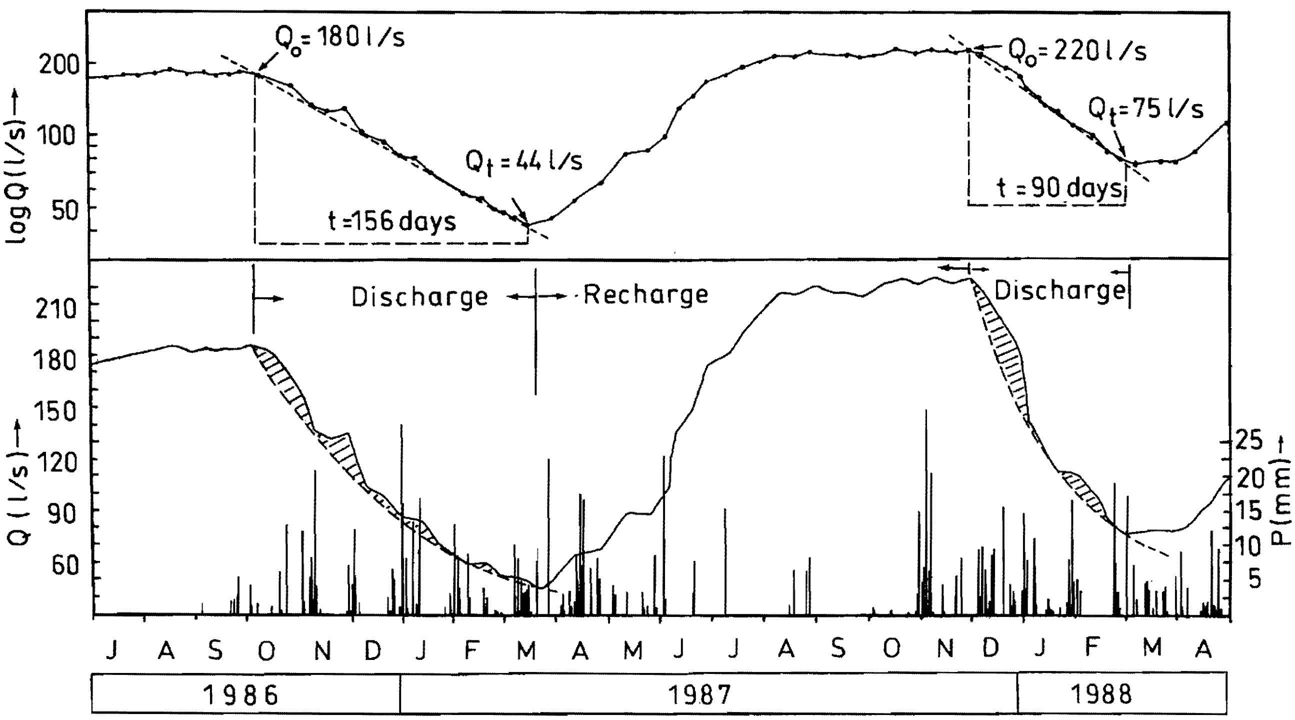

Figure 11. The Relationship Between Hydrograph and Discharge Curves of the Akpinar Spring in Normal and Semilog Scales.

2.3. The Discharge Changes (%) of the Springs

In order to calculate the discharge changes (%) for the springs we used the following formula.

$$Q_c = (Q_o - Q_t) \times 100/Q_o \quad (3)$$

where Q_c = Discharge change of spring (%).

Q_o and Q_t are the discharge at the beginning of the measurement period and at a time t.

Q_c values of the springs are given in Table 2.

The result (Q_c>92%) shows that the discharge and annual discharge volume of the Yolkonak-I spring relate to monthly rainfall and its aquifer corresponds to the fourth group [5]. The results (Q_c = 27–92%) for the other springs show that their discharges and annual discharge volumes relate to annual rainfall, and they correspond to the third group of springs (Figure 13) [5].

3. DISCUSSION

Maillet's [4] equation was defined for practical purposes and the formula has been developed for discharge from a porous medium (*i.e.* laminar flow), and assuming that the area from which the discharges occur is constant [11]. When applying this method, although it is more adequate than others, its results are valid only under certain very restricted conditions.

In the study area, karstic limestones were affected by Miocene tectonics, *i.e.* the karst medium is heterogeneous and it is difficult to define reliably the catchment areas of the springs. In addition, the karstic limestones are connected to the alluvium aquifer, as mentioned above. It is impossible to expect agreement with Bonacci [11], since the accuracy of the measurement data does not guarantee a precise and reliable result in the karst region. Consequently, the results of the hydrograph analysis must be interpreted with reservations.

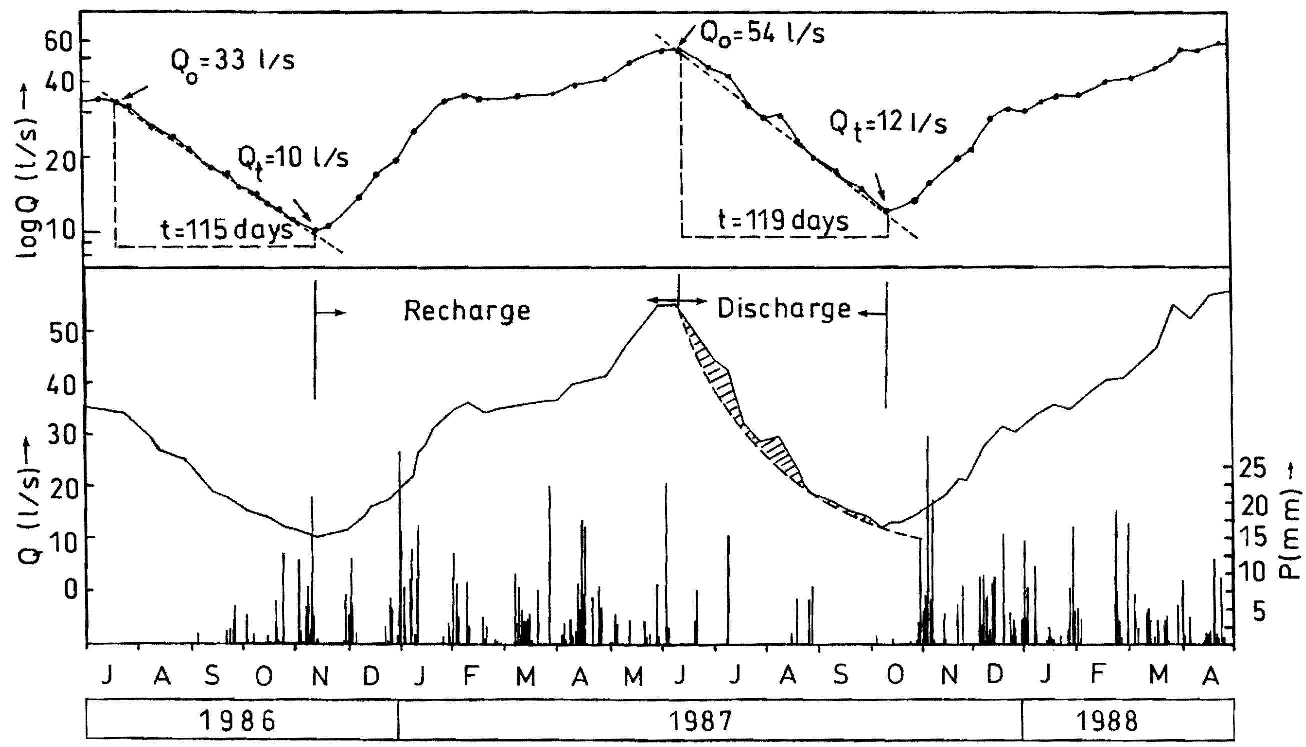

Figure 12. The Relationship Between Hydrograph and Discharge Curves of the Direkli Spring in Normal and Semilog Scales.

Table 3. Correlation Coefficient Relation Between Some Hydrogeological Parameters of the Karst Springs.

$t-t_o$						
0.08	Q_o					
0.145	0.93	Q_t				
0.034	−0.07	−0.18	α			
0.22	0.91	0.69	−0.43	Storage Capacity		
−0.75	0.27	0.47	−0.39	0.21	Total Discharge	
0.47	−0.21	0.07	0.88	−0.43	−0.40	Discharge Change

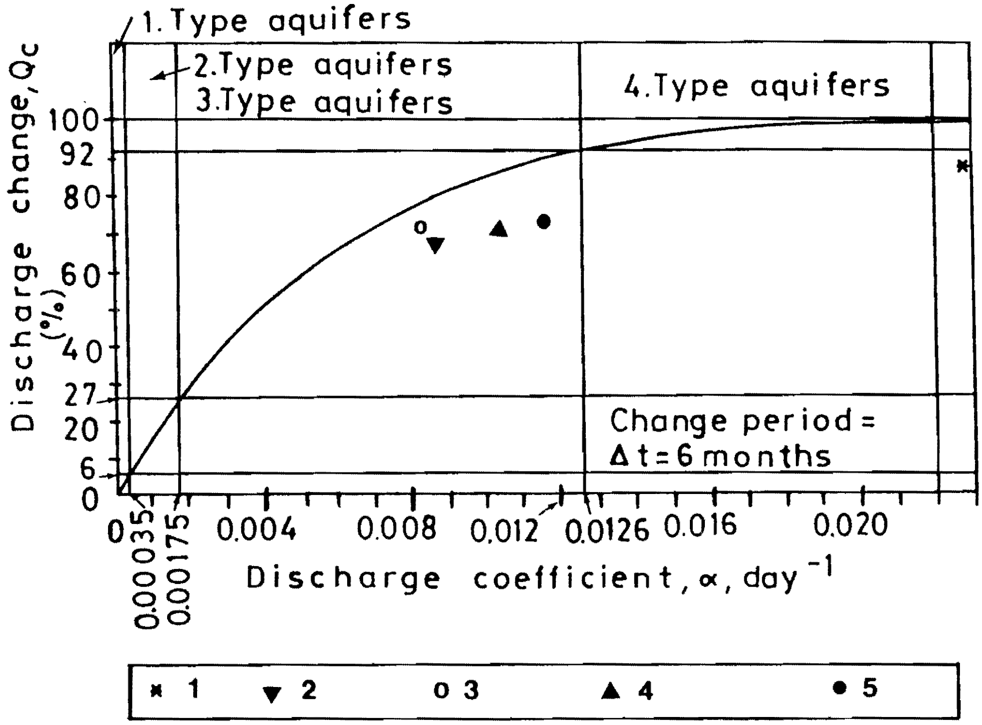

Figure 13. The Relationship Between Discharge Change and Discharge Coefficient [5].
1. Yolkonak -I, 2. Yolkonak-II, 3. Dipsiz, 4. Akpinar, 5. Direkli.

4. CONCLUSION

Karst springs emerge in the study area along the fault or bedding plane. Tectonic activity seems to have a major influence on the ultimate characterization of various hydrogeological aspects of the associated karst landforms.

The discharge coefficient changes with time in accordance with changes of flow conditions in the karstic aquifer. Those aquifers which have diffuse flow with 10^{-3} day^{-1} as the discharge coefficient give more water than the aquifers which have conduit flow with 10^{-2} day^{-1} as the discharge coefficient in the same recession period.

The correlation analysis, which agrees with the hydrogeological properties of the karstic aquifers, shows a positive relation between Q_o and Q_t, Q_o and storage capacity, Q_t and storage capacity, and α and discharge change.

Karst springwaters are drinkable. There is a relationship between rainfall and discharge, *i.e.* both monthly and annual rainfall contribute to the spring discharge.

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