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Some Data on the Hydrology of the Tabas — Shirgesht — Ozbak-kuh Area (East Iran)

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With 12 Figures and 2 Supplements (Beilage 1, 2)

Schlüsselwörter
Iran
Hydrogeology
Hydrochemistry
Springs
Groundwater
Arid areas

Contents/Inhaltsverzeichnis

Abstract

The major constituents Na, Ca, Mg and CO_3, Cl, SO_4 of about 150 springs and qanats were analysed and correlated to the results of geological mapping in the report area. There are waters of a chloride type and waters of a sulphate type, and waters of an intermediate type between the two, but no carbonate waters exist within the area. In spite of a precipitation (average ~100 *mm.* per annum) decreasing from north to south the intake area for the main aquifers of the whole region is situated in the southernmost mountains where thick masses of limestone and dolomite are exposed. No other rocks of the report area are suitable for the formation of groundwater. The main intake area supplies three big settlements and quite a few small villages, all of which have waters of low salinity ($<$15 mval/l) and of an intermediate anionic type. Small springs of higher salinity (15—120 mval/l) of a chloride as well as a sulphate type are closely related to certain mountain ranges and to special geological features, sulphate springs deriving mainly from Lower Devonian red beds, intermediate types from Upper Jurassic marls as well as from Paleozoic shales, siltstones and sandstones, and chloride waters from Liassic sandstones and Neogene evaporites. Waters of high salinity ($>$120 mval/l) always belong to the chloride type and are located on geological faults. In most waters of the intermediate type, and in some of the chloride ones as well, a small amount of alkali carbonate is found. Rain water, being affected by salt dust from the Kavir, has an average salt content of 3 mval/l and also contains a small amount of soda.

I. Introduction

Between 1963 and 1966 one of the main projects of the newly founded Geological Survey of Iran was the geological mapping of the mountain ranges bordering the Great Central Iranian Salt Desert (Great Kavir) to the east (Fig. 1). The results of that geological field work done by UN-experts and by young Iranian geologists have either already been published or are to be published in the near future (STÖCKLIN et al. 1965, RUTTNER et al. 1968, RUTTNER et al., in press).

During the mapping campaign in 1963/64 one of us (A. W. RUTTNER) did the geological mapping in the Shirgesht—Ozbak-kuh area; the other (A. E. RUTTNER-KOLISKO) accompanied the geological field party and investigated the waters of the area, mainly from a limnological point of view. Similar studies had been made earlier in the Ozbak-kuh region in 1960.

Water resources, which are scarce in that area, show a clear relation to the geology both in their geographical distribution and chemical composition. Since this relation leads to some general conclusions, which might be applied to other arid regions, we feel that our findings should be published in a special paper.

We are very much indebted to the Societé Minak for supporting all the work done in 1960; to the Geological Survey of Iran for providing the equipment and personnel for both of us during the field trips of 1963/64; to the Intern. Fed. of University Women for a Winifred-Cullis-Grant to cover the extra expences for limnological work; to the Water Irrigation Laboratory Amirabad, where part of the chemical analyses was carried out; to the Meteorological Department of Iran for most kindly supplying all the available meteorological data for the investigated area; and, last not least, to the Austrian Ministry of Education for generously giving leave of absence to both of us.

II. General Setting

1. Geography

Tabas is a small town and an oasis in the south of our area, famous for its beautiful gardens and well-known as a starting-point for expeditions to the Great Kavir and to the Lut (e.g. SVEN HEDIN, A. GABRIEL). The town is situated in a small desert basin at an altitude of only 630 *m.* above sea level.

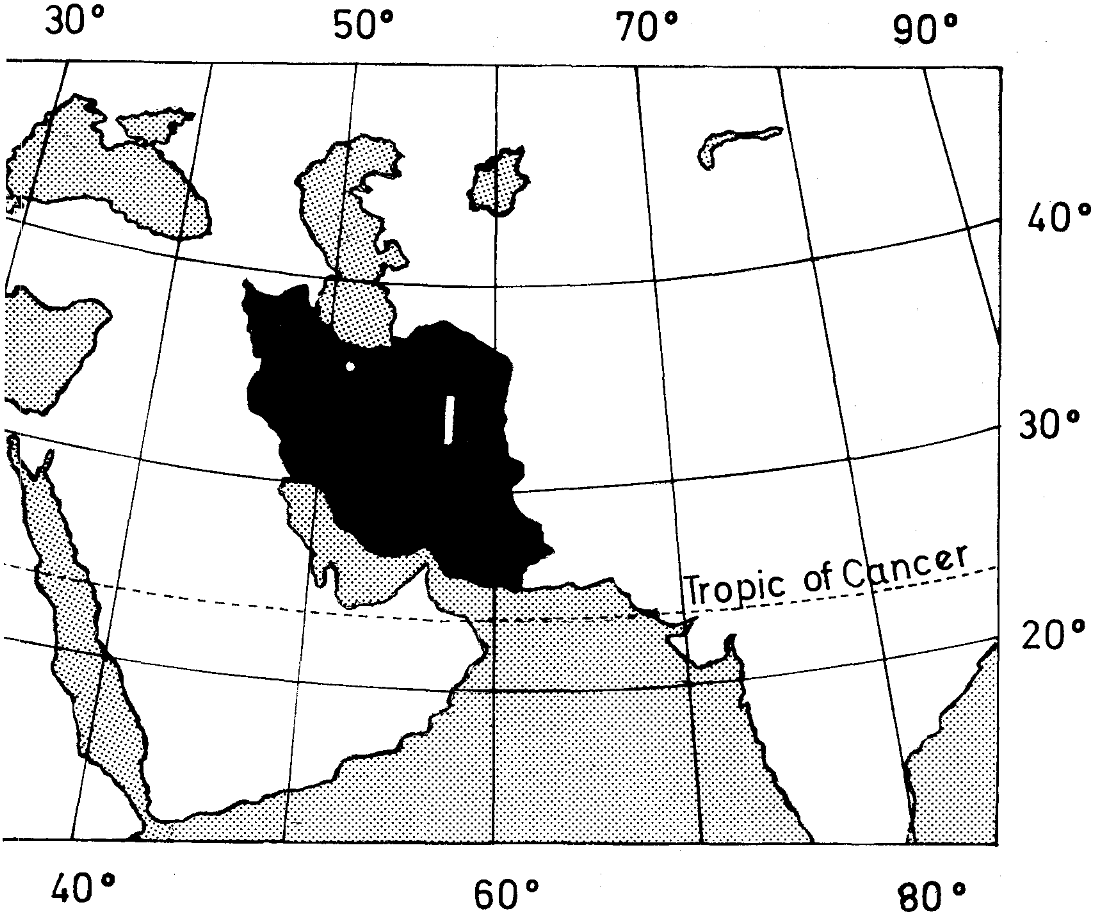

Fig. 1: Geographical location of the report area (white rectangle) within the boundaries of Iran (black).
Geographische Lage des Untersuchungsgebietes (weißes Rechteck) innerhalb der Grenzen Irans (schwarz).
O = Tehran

From Tabas a road leading to Sabzewar crosses the whole area from south to north. Shirgesht is a police station on this road, lying about 50 *km.* north of Tabas on the watershed between the Tabas basin and the Great Kavir at an altitude of about 1010 *m.* 80 *km.* further north is the lead mine of Ozbak-kuh, named after a small village north of the mine (1100 *m.* above sea level).

The Tabas—Shirgesht—Ozbak-kuh area can be reached either from the north (from Sabzewar on the main Tehran—Mashad road), or from the west (from Yazd on the main Esfahan—Kerman road), or also from Mashad via Ferdows. The distance from Tehran is about 1000 *km.*

On the whole, the character of the area is that of a typical central Iranian landscape: isolated mountain ranges and mountain groups are separated from each other either by basins or by plains. Between and near the mountains the plains consist of gravel fans, which slope down gently towards the basins. The Persian name for these gravel plains is dasht. The basins are filled with salt clay; such salt flats are called kavir.

Further, our area is characterized by its location between two large salt-desert basins: the Great Kavir to the west and the Kavir-e-Namak to the east. Because of an inlet of the Great Kavir north of Shirgesht the distance between the two salt deserts is no more than 50 *km.* at its narrowest point.

Despite this geographical position and in spite of the dry climate (see below), the area is nevertheless fairly populated. There are villages and even small towns in the dasht, and there are small settlements in the mountain valleys. Apart from the towns of Tabas and Boshruyeh, the biggest settlement is an assemblage of about 40 villages called Jolgeh ('fertile plain') accumulated east of the above-mentioned inlet of the Great Kavir. About 15.000 people are said to live there.

Except for the small Sardar River east of Tabas, no free-running natural watercourses exist in the Tabas—Shirgesht—Ozbak-kuh area. The settlements of the dasht are supplied with water by the so-called 'qanats'. These are underground drainage canals driven into the gravel fans of the dasht until they reach a ground-water horizon. This is an old Persian technique going back as far as about 1000 B. C. The qanats are usually several kilometres long and in some parts of Iran reach a length of several tens of kilometres. On the surface the course of a qanat is marked by a row of heaps of earth and gravel — like a row of huge molehills. These heaps consist of the excavated material brought to the surface by means of shafts sunk to the underground canal (Fig. 2).

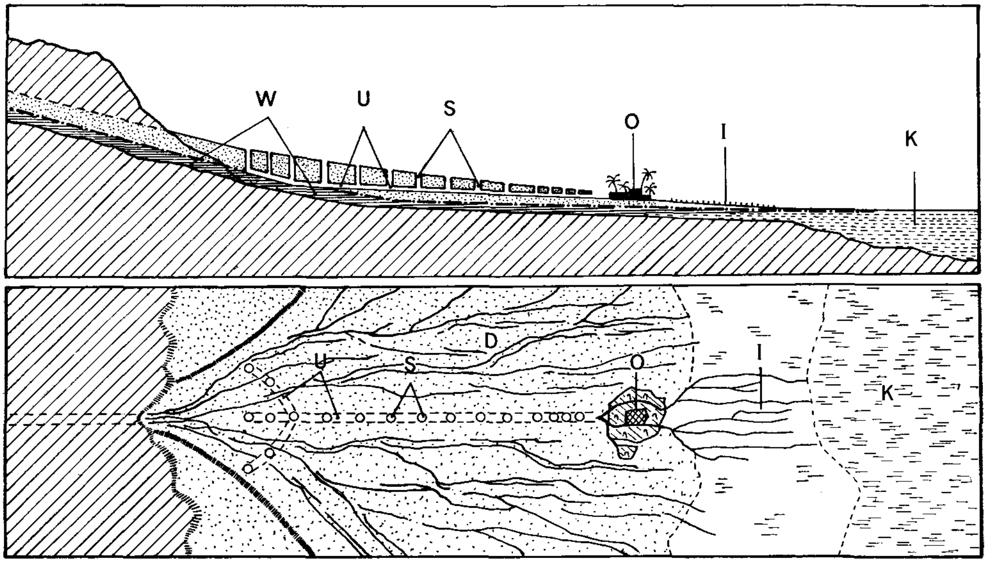

Fig. 2: Scheme of a qanat (after H. Bobek 1961). O = Oasis; I = Irrigated area; K = Kavir; D = Gravel fan of the Dasht; W = Water table; U = Underground canal; S = shafts.

Schema eines Qanats (nach H. Bobek 1961). O = Oase; I = bewässertes Gebiet; K = Kavir; D = Schotterfächer der Dascht; W = Grundwasser; U = Kanal; S = Schächte.

A qanat is dug in such a way that its direction is generally roughly parallel to the slope of the gravel fan and that the gradient is somewhat less than that of the surface slope. Settlements and fields watered by qanat water are mostly close to the mouth of the qanat; in some cases, however, the water from the qanat is conducted to the settlements in surface canals up to several kilometres long. In our area qanats supplying larger villages are estimated to discharge 20—50 *l/sec.*

The qanats and surface canals of the Tabas—Shirgesht—Ozbak-kuh area are shown on the map (Plate II) as far as they can be recognized on an aerial photograph. The watered and cultivated areas (fields, gardens, etc.) figure on the map as black patches showing the small amount of agriculture in that barren semi-desert region.

At the foot of the mountains and in the mountain ranges springs supply small settlements and grazing animals with water. Because of the dry climate the discharge of these springs is very small, except for a few ones which are subject to special geological conditions. Very often the water of the small springs is dammed up by men for the use of the flocks, to form small pools in several steps, to prevent the water from disappearing in the scree or in the gravel of the dasht.

Qanats and springs were the main objects of our hydrological investigations in the Tabas—Shirgesht—Ozbak-kuh area. In some cases we have included the water of isolated wells. It was not possible to make any exact measurements of the discharge of springs and qanats; all the data given in this paper concerning the quantity of water are based on rough estimation only.

2. Climate

According to the precipitation map of Iran (1959, Fig. 3) the Tabas—Shirgesht—Ozbak-kuh area is among the driest inhabited parts of the country, precipitation amounting to an annual average of 100 *mm.* only. Within the area there is a trend towards more pronounced desert conditions as one moves south and west. This trend is shown in the Table below, which gives mean values of the first five years of meteorological survey in this part of the country (1959—1963).

	Average Precipitation (millimetre/year)	Temperature ° C			Relative Humidity at noon %	
		Max	Min	Mean	Nov.—April	May—October
Sabzewar (north)	130	44	—11	16	35	23
Gonabad (east)	165	45	— 7	17	49	38
Tabas (south)	80	47	— 5	20	32	18

More important than this general trend are local microclimatic differences: places protected from the wind at the foot of the hills get much more rain than dasht plains open to kavir basins. Nearly all the precipitation is brought by westerly winds blowing across the salt desert; consequently, it has a salt content unusual in continental rain and comparable only with rain on oceanic coasts (cf. Chapter III, Chemistry). In summer-time the air is mostly somewhat hazy from dust carried into the atmosphere by ascending currents, but in winter the weather is normally clear, radiation high and a fresh wind blowing.

The measurements made in 1960 at the newly installed meteorological station of Tabas *) give a good impression of the general climatic conditions of the region although Tabas is known to be hotter and drier than other parts of the investigated area. The diagram in Fig. 4 shows the monthly mean values of temperature, the relative humidity at 6 a.m. and at noon, and the precipitation per month.

Most of the rain falls in spring (March—April) during a few — but heavy — thunderstorms; 20 *mm.* or more of precipitation within half an hour are not exceptional. The greatest part of such showers does not percolate into the ground, but forms sudden flood waves rushing through the dry valleys of the dasht to the salt marshes of the

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*) Data kindly provided by the Iranian Meteorological Department.

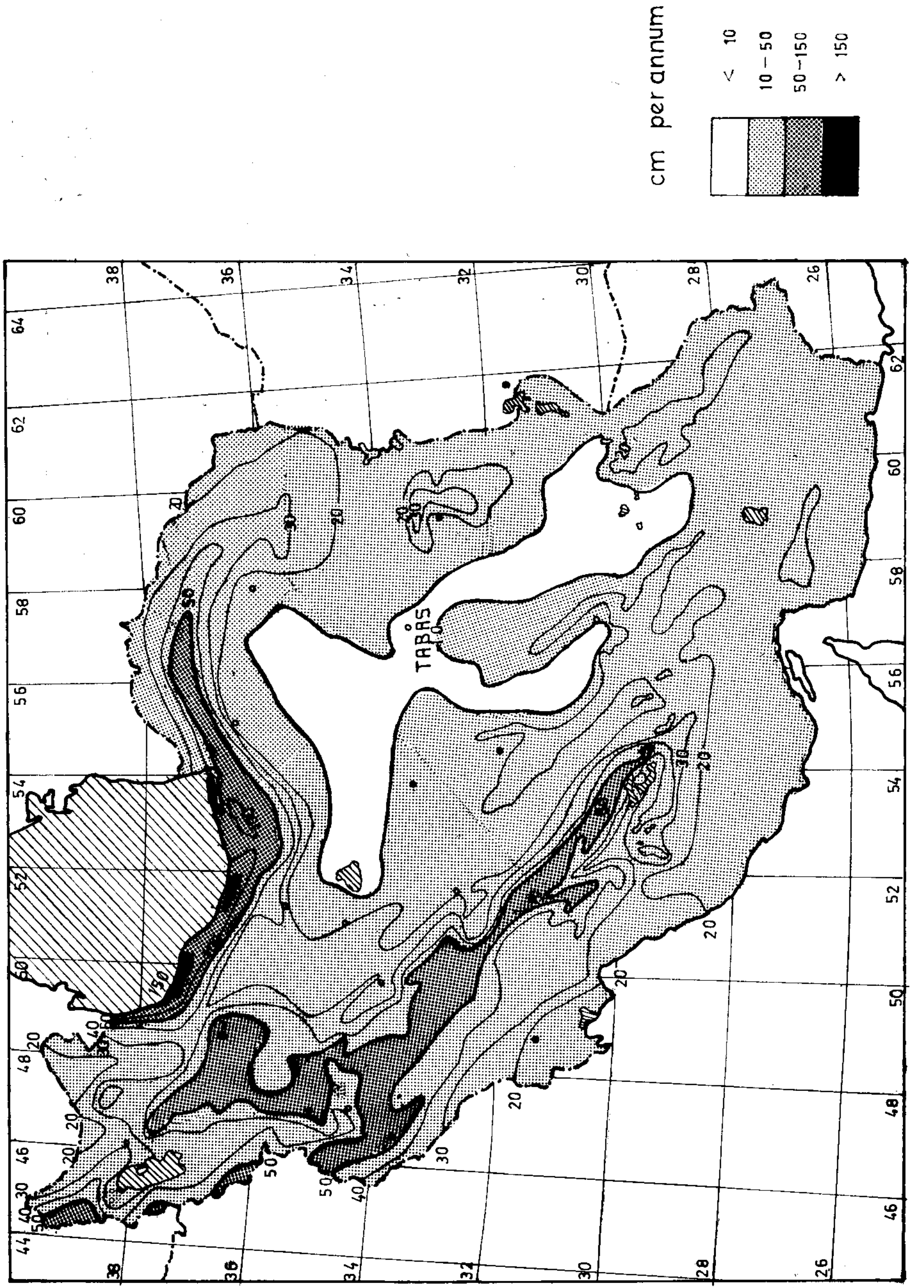

Fig. 3: Rainfall in the Iranian highland (simplified from the precipitation map edited 1959 by the Meteorol. Dep. of Iran).

Regenmengen im iranischen Hochland (vereinfacht nach der Niederschlagskarte des meteorol. Amtes Teheran 1959).

kavir. From June to October there is no rainfall at all. In winter some cloudy days may occur, during which snow or a steady drizzle provides most of the precipitation penetrating into the soil.

The average temperature ranges from +10° C in December and January to about 35° C in July; temperatures may reach a maximum of nearly 50° C at midday in summer-time (1960: 48.0° C) and drop to a minimum of nearly —10° C on mornings in midwinter (1959: —7.2° C). The daily fluctuations are also fairly great: in winter

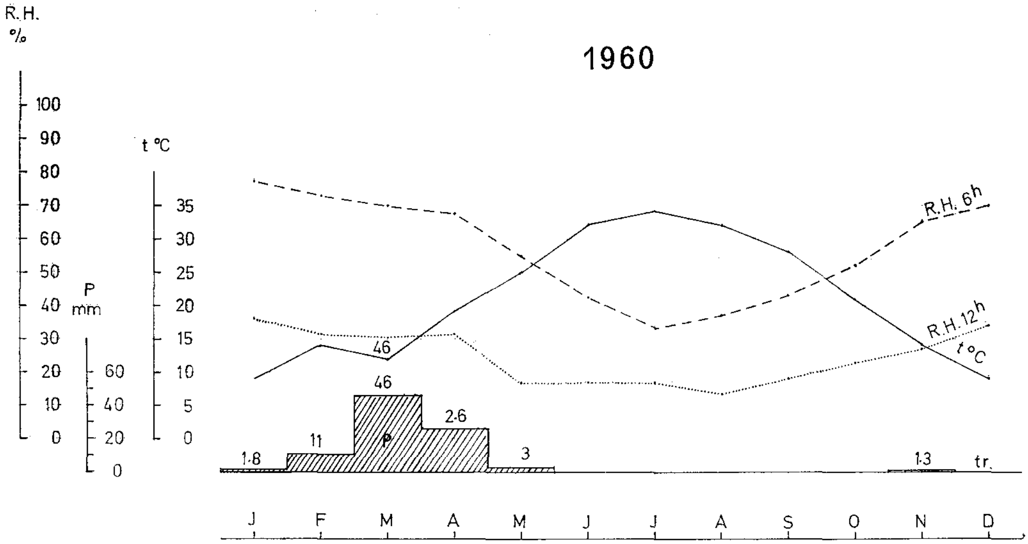

Fig. 4: Tabas Meteorological Station 1960:
Monthly precipitation (P), monthly mean values of temperature (t ° C) and relative humidity (R. H.) at 6 a.m. and at noon.

Jahresgang der Monatsmittel von Temperatur (t ° C) und relativer Feuchtigkeit (R. H.) von 6 und 12 Uhr und monatliche Niederschläge (P) in Tabas 1960.

we generally measured a difference of 10—12° C (max. 15.6° C) between morning and noon. No doubt, the daily fluctuation of temperature is even greater in summer, but we have no figures for that time of the year to prove it.

The relative humidity (% of damp saturation at a given temperature) is always low (cf. Fig. 4); even in the cold season it does not reach an average of 80% at 6 a.m., and it drops to an average below 40% at 6 a.m. in the summer. At noon the average humidity remains below 20% from May to October, and never exceeds 35%. During our stay we measured a minimum of 16% on 24th December 1963 at noon just before a big break in the weather (cf. Fig. 5).

Radiation during night might be strong enough to cause surface temperatures of the soil which are so low that the formation of dew is possible despite the scanty humidity of the atmosphere. No exact oberservations about this phenomenon are available for our region, but it is very likely that dew is one of the main water sources for the sparse vegetation in this semi-desert area.

Because of the low humidity, evaporation is extremely high. This factor plays a major rôle for the hydrology of the area as well as for the chemistry of its waters. Unfortunately, we are not able to present exact measurements of the amount of evaporation; according to COLE's diagram (1968, p. 425, Fig. 1) showing the correlation between the mean annual temperature, precipitation and evaporation per annum, our region could have 150—200 *cm.* net evaporation per annum, i.e. about 15—20 times the actual precipitation, climatic conditions which are typical for strong deserts. The only — superficial — indication we have concerning the amount of evaporation is the increase of salt concentration in small surface streams flowing from the mouth of a qanat to a village or from a natural spring through a set of man-made pools towards the kavir. In the latter case, such a stream never reaches the salt marshes, but ends somewhere in a pool, the water partly seeping away and partly evaporating. In one case the distance between the spring and the end pool was approximately 1 *km.*, and there we found an increase of concentration of 70%.

Quite different from the smooth curves (Fig. 4) representing the general character of the climatic conditions in the Tabas area were the daily changes of weather during the unusually cold winter of 1963/64, which we spent in the centre of our area near Shirgesht. In the course of this winter most of the palm-trees in the village were badly damaged, and some of them did not recover in the spring — a clear sign of exceptionally severe conditions. Fig. 5 shows our own meteorological measurements from mid-November to the beginning of February *). During this time there was a spell of six weeks with temperatures below freezing-point and a continuous snow cover. Three sudden breaks in the weather (11. 12.; 25. 12.; 20. 1.) were marked by a barometric fall of 10—30 millibar within a few hours, accompanied by an increase in temperature of 5—10° C and by a corresponding fall in humidity. As soon as the air pressure rose again, cold and wet air rushed in causing rain and snowfalls. According to our — approximate — measurements the amount of those winterly rains ranged from about 5—15 *mm.* in 24—48 hours, thus providing much more precipitation than usual to feed the ground-water of the area.

3. Geology

The mountain ranges and mountain groups of the area differ considerably from each other as far as their geological composition and structure is concerned. Consequently, we consider this region particularly suitable for a study of the mutual relationships between geological features and natural waters under the conditions of an arid climate.

Plate III shows the rocks and strata found in the Tabas—Shirgesht—Ozbak-kuh area in a simplified columnar section. The rock sequence exposed in the area comprises all systems, from the Pre-cambrian to the Recent, and represents a great variety of rocks; altogether this sequence of rocks would be nearly 15.000 *m.* thick.

Carbonate rocks of considerable thickness are represented by the Permo-Triassic Tabas Group and by the Upper Jurassic Esfandiar Limestone. As against that, dolomites and limestones of other formations play a minor part.

'Red Beds' **) occur in the Lower Cambrian (Lalun Sandstone), in the Lower Devonian (Padeha Formation) and in the Jurassic (Garedu Beds). A gypsum bed on top of the Padeha Formation, about 50 *m.* thick, should be specially noted. Neogene evaporites are common all over the area; they seem to have covered even larger areas formerly than they do today.

Shales, siltstones and sandstones are abundant in the Paleozoic and in the Jurassic. Large areas are built up of shales and sandstones of the Liassic (Shemshak Formation) and of slightly metamorphosed shales and sandstones, which are probably Upper Jurassic in age. Recent sand dunes are of some importance and, last not least, the gravel fans of the dasht.

Apart from these sedimentary rocks and deposits, Pre-Cambrian crystalline rocks (granite, gneiss, mica schist, phyllite) occur in the northern part of the area. Volcanic rocks are present in the Silurian and in the Tertiary, but only the Tertiary ones (andesite, dacite) cover larger areas.

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*) Relative humidity was calculated from the difference between a dry and a wet thermometer, which can be done above freezing-point only; the figures are therefore missing for temperatures below zero.

**) Deposits under arid conditions.

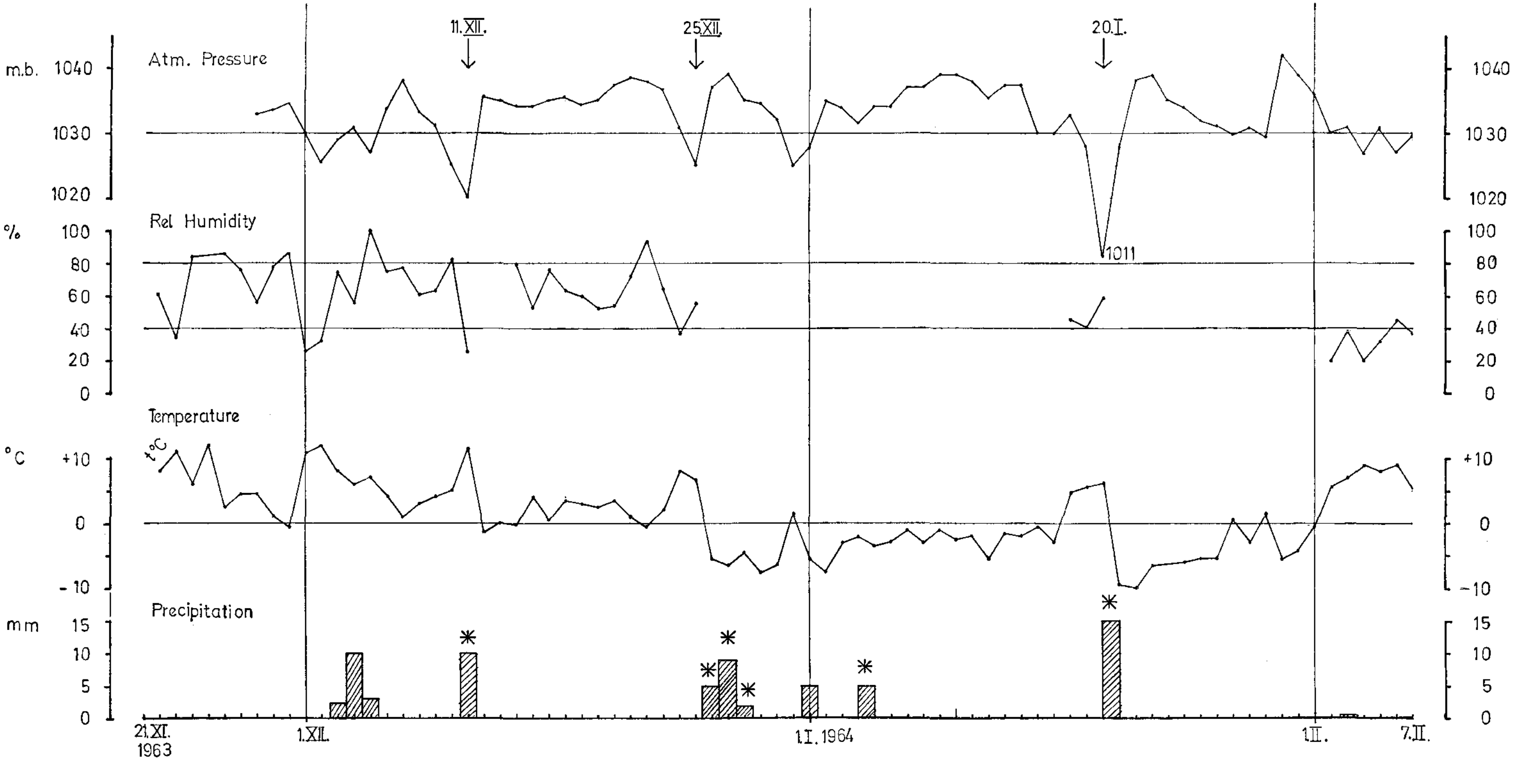

Fig. 5: Daily measurements (at 7 a.m.) of atmospheric pressure (millibar), relative humidity (% of saturation), temperature (t °C) and precipitation (mm) during the winter of 1963/64 in the Shirgesht Area. Severe weather breaks on December 11th and 25th and on January 20th are indicated by arrows; * = Snowfall.

Tagesgang von Luftdruck (Millibar), relativer Feuchtigkeit (Sätt.-%), Temperatur (t °C) und Niederschlag (mm), gemessen um 7 Uhr früh während des Winters 1963/64 im Gebiet von Shirgesht. Wetterstürze am 11. und 25. Dezember und 20. Jänner sind durch Pfeile angegeben; * = Schneefall.

During the Alpine Orogenesis strong folding and faulting took place. Most of the faults are ordinary vertical faults. Thrust faults could be observed in some places, but they are of importance only locally. On the other hand, a strong side-slip fault was identified in the area west of Shirgesht, and similar faults play an important rôle very probably also in the area north of Ozbak-kuh.

The structural pattern of the Tabas—Shirgesht—Ozbak-kuh area is characterized by a change of direction in the strike of the structural elements: from north-northwest in the south to north-northeast in the central sector of the area and, finally, to east-northeast in the north (cf. Plate II).

In the southern part of the area the basin of Tabas is bordered by two mountain ranges. The western range separates it from the Great Kavir. Only the northern end of this range is part of our area; we called it the Pirhajat Mountains after a village at their western foot. The range consists mainly of Permo-Triassic dolomites and limestones unconformably overlain by a thick Liassic (and partly Upper Jurassic) sequence of sandstones and shales. The Pirhajat Mountains are strongly cut by faults trending north-northeast and northwest. On the eastern side these mountains are bounded by the great side-slip fault mentioned above; the trend of this fault is north-northeast.

East of Tabas there is a high, steep ridge of mountains culminating in a peak called Kuh-e-Shotori (Camel Mountain) 2838 *m.* high, and the whole range is accordingly named Shotori Range (STÖCKLIN et al., 1965). This is the southernmost range of the area, and its general trend is north-northwest. Here Permo-Triassic and Jurassic dolomites and limestones predominate over Carboniferous and Jurassic shales and marls and Paleogene volcanics. The dolomites and limestones reach a thickness of more than 1000 *m.* As the result of folding and faulting they form long north-northwest trending ridges and rocky precipices.

Near Shirgesht part of the Shotori Range and most of the faults disappear below the dasht; but the eastern part of the range continues in a north-northeasterly direction as a narrow ridge, whose highest summit is called Kuh-e-Bam (1830 *m.*). Here limestone and dolomite are not as dominating as in the Shotori Range because part of the Upper Jurassic limestone changes into a marly facies. Permo-Triassic limestone and dolomite are exposed east and northeast of Shirgesht only; Upper Jurassic Esfandiar Limestone forms the narrow and steep ridge east of the village of Deh Now — Bam (Kuh-e-Bam proper).

The Shotori — Kuh-e-Bam Range, nearly 170 *km.* long, is the main range of the area. East of it lies the salt-desert basin of Kavir-e-Namak. Towards the Great Kavir in the west, however, the hills of the Derenjal Mountains (north of the village of Shirgesht) and, farther north, the Ozbak-kuh Mountains rise from the plain. These two mountain groups are completely different from the ranges described hitherto as far as their geology is concerned: they consist of Infra-Cambrian and Paleozoic rocks, and the Ozbak-kuh mountains show a complicated Schuppen-structure.

Geologically, these two mountain groups are the core of the area. Sandstones, siltstones, shales and red beds prevail, but most of the higher hills and peaks consist of dolomite or limestone. A striking lithological unit of the Derenjal Mountains is an irregular and chaotic mixture of dolomites, limestones, dolomitic shales, and basic volcanic rocks (Kalshaneh Formation, Middle Cambrian).

The structure of the Derenjal Mountains is that of an overturned anticline cut by a few faults. The Ozbak-kuh Mountains, on the other hand, are extremely faulted and partly thrust against each other; there pre-Cambrian crystalline rocks are also involved. Between the Ozbak-kuh Mountains and the Kuh-e-Bam Range there is a region of low hills, which consist of slightly metamorphosed sandstones and shales, probably Upper Jurassic in age.

In the part of the area farthest to the northeast crystalline rocks of the pre-Cambrian predominate. They consist of mica schist, orthogneiss, granite and phyllite. These rocks are overlain by a metamorphosed sequence of sedimentary rocks, which, besides phyllites and other schists, also contains dolomite up to several hundred metres thick; this sequence is probably Infra-Cambrian in age. The highest peaks of this mountain range — Kuh-e-Sarhangi and Zeber Kuh — are built up of that dolomite. Close to the southern border of the range Paleozoic rocks are folded and faulted into the crystalline pre-Cambrian; these Paleozoic rocks are the northeastern continuation of those of the Ozbak-kuh Mountains. Sandstones and shales exposed at the northern border of the range are probably Carboniferous in age. The general trend is east-northeast.

The isolated Sefid Kuh, situated northwest of Ozbak-kuh, consists of marble (Upper Jurassic ?) unconformably overlain by Cretaceous limestone. The hills east of this mountain are of slightly metamorphosed sandstones and shales (Jurassic ?).

III. Hydrochemistry

1. Chemical Methods

To characterize the chemical composition of springs and qanats in the investigated area the following data were established: temperature, electric conductivity, p_H, and the major ionic constituents, i.e. sodium, calcium, magnesium (cations), and alkalinity, chloride, sulphate (anions). Potassium is present, but in very low quantities (below 0.5 mval even in highly concentrated waters) as we know from previous investigations (RUTTNER-KOLISKO, 1964). Silicium, which may be important in some cases, is partly included in the value for alkalinity; nitrate was not considered, but seems negligible.

To get comparable values characterizing the ionic composition of a sample at a glance by means of a formula we used the portion of Na, Ca, and Mg given as percentage of the whole cation sum, and Alk, Cl and SO_4 as percentage of the anion sum, all values calculated in milli-equivalents per litre (Na/Ca/Mg — Alk/Cl/SO_4 mval%), (cf. Plate I a. II).

In order to be able to investigate as many springs as possible and to get an immediate impression of their chemical character we employed field methods for the determination of the major constituents listed above. From several representative waters out of each group of springs — and from doubtful cases as well — samples were taken back to Tehran to check the results of our field investigations by the usual routine methods, i.e. electric p_H-meter, gravimetric measurement for sulphate, and flammphotometer for sodium. The figures found by laboratory methods are marked in Plate I with a black dot.

During field work we applied the following methods:

1) Temperature: a normal water thermometer reading 0.1 degrees centigrade (° C).

2) p_H was only roughly estimated with indicator paper. Colorimetric measurements (MERCK, MICHAELIS) did not work in waters of higher concentration: the organic indicator substance reacted apparently with one of the ions in solution and always gave the same very dark blue colour.

3) Electric conductivity was measured with a battery Wheatstone bridge from Messrs. HARTMANN & BRAUN, Germany. The figures shown in Plate I represent $k_{18} . 10^{-6}$, i.e. reciprocal megohms/*cm.*^{2} at 18° C. It is well known that conductivity is in a nearly linear relationship to the total ionic content only in a low range of concentration — up to $k_{18} = 1000$. At higher concentrations the increase of conductivity is less than the increase of salinity. We avoided this difficulty by diluting the sample to a conductivity below $k_{18} = 1000$ and multiplying with the dilution factor. In this way, a sufficient correspondence between conductivity and total ionic content was obtained up to a salinity of about 30.000 p.p.m. since the ionic composition of the samples was similar in the investigated area (RUTTNER-KOLISKO, 1964). Consequently, the speedy measurement of conductivity could be applied over the whole range of the salt content of our samples, giving a valuable indication of the total ionic concentration.

4) Alkalinity (the concentration of weak acid salts) was measured in the usual way by titration with n/10 hydrochloric acid with methyl orange as indicator.

5) The standard sodium versenate method was used to determine the amount of calcium+magnesium (eriochrome Black T indicator) and of calcium alone (ammonium purpurate indicator). It was not possible to heat the samples to 70° as prescribed and, for this reason, the titration error was perhaps higher than usual; even so, the method proved satisfactory in the field. From the difference between Ca+Mg and alkalinity the amount of alkali carbonate was calculated. Samples which contained more alkali carbonate than 50% of their alkalinity value are marked in Plate I with a triangle.

6) Chloride determination was done by the routine method: silver nitrate titration with potassium chromate as indicator. Because of the high chloride concentration we used n/10 $AgNO_3$, but even so it was necessary in many cases to dilute the sample to ensure a sharp titration end-point.

7) For the determination of the total salt content we applied the ion-exchange method described by MACKERETH, 1963. First attempts with samples of high concentration showed rather uneven results: the exchanging capacity of the substance was apparently insufficient for these samples and was used up at an unequal rate in different parts of the exchanger column. After diluting the more highly concentrated salt waters to a conductivity below 1000.10^{-6}, 1000.10^{-8} however, the method worked satisfactorily. We used cation—as well as anion—exchanging columns, and the correspondence

proved to be fairly good. Allowing for field conditions and dilution errors, we took an incongruity of the anion and cation sum within ±10% to be admissible for our purpose. The samples analysed by the ion-exchanging method are marked in Plate I with an asterisk. The sulphate content was calculated as the difference between the anion sum and the Alk+Cl value. This means that other possible constituents are included in the sulphate value; since, however, we never found appreciable differences when checking with the routine sulphate method mentioned above, there is no indication of further major anionic constituents. The same is true for sodium, which was calculated as the difference value from the cation sum; it includes potassium as well, but nevertheless did not differ very much from the flammphotometric results. Calculated values are marked with a cross.

2. Chemical Results

The chemical data of about 150 waters found in the report area are computed in Plate I. We included all the springs, qanats and wells, but omitted ponds as their chemical constitution is very much influenced by biological processes and therefore of no value for our purpose. Only about half of these water-bodies could be shown on the hydrogeological map (Plate II), but our chemical conclusions are based on the whole of the material. In Plate I the waters are arranged in geographical groups, as far as possible each group belonging to one mountain range.

(a) Rain and 'sang-ab'

The analyses of rain-water and of various small rock pools (called 'sang-ab', i.e. 'stone water' in Persian) are to be found in Plate I, Group 9. As has been mentioned in a previous chapter (II. 2), rain falls only during a short time and is always laden with salt dust derived from the kavir. Even after a continuous rainfall of more than 24 hours— which probably occurs only once in several years — we found a concentration of precipitation water about ten times as high as that of 'exorheic' (ocean-drained) continental areas *). In general, the short and intermittent rains contain about 50 mg/l Na corresponding to a total salinity of approximately 2—3 mval/l (150—200 mg/l). Ca and Mg are also always present, but less than equivalent to alkalinity, which indicates that the desert rain-water of the report area invariably contains a small amount of alkali carbonate, whereas sulphate is entirely missing.

The small rock pools (sang-ab) are to be found mainly in limestone rocks. For a fairly short time after each rainfall they are filled with water which has washed over the mountain slopes and dissolved some of the salt dust and salt crust covering the surface of the rocks. The chemical constitution of this water gives a fair idea of the ionic content of the precipitation percolating into the rock fissures of the mountains.

Although the concentration of a sang-ab varies a great deal depending on precipitation and evaporation it is always considerably higher than that of the corresponding rain. We found an average salt content for sang-ab of about 5 mval/l; consequently, one cannot expect the concentration of any spring or ground-water within the whole area to be considerably less than 5 mval/l (~300 mg/l) total salinity.

The average ionic composition of sang-ab does not change very much with changing concentration; it is about 50 Na/35 Ca/15 Mg mval% for the major cationic constituents and 45 CO_3/35 Cl/20 SO_4 mval% for the major anionic constituents. This constitution is quite different from what we know of precipitation water in the humid climate of exorheic regions (HUTCHINSON, 1957). Moreover, the precipitation water of those areas has to penetrate vegetation-covered layers of humus where it becomes saturated with CO_2 and therefore able to dissolve calcium carbonate, which is the main constituent (about 75%) of inland waters in exorheic regions (Standard Composition

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*) Average Na-content for continental rain-water 0.3 *mg/l* according to HUTCHINSON, 1957.

Rhode, 1949). This source of weak carbonic acid is lacking in our desert area; consequently, the amount of dissolved calcium hydrocarbonate remains low, whereas the soluble salts of strong acids rise to a considerable amount. This different constitution of precipitation water should be kept in mind when considering the springs of the report area.

Na	0,4	0,3	1,0
Mg	0,0004	0,9	1,3
Ca	0,00005	0,006	1,5
	CO_3	SO_4	Cl

Fig. 6: Solubilities of salts in destilled water at 10° C relative to *NaCl = 1.* (After Cole 1968.)

Relative Löslichkeit verschiedener Salze in Aqua dest. bei 10° C, bezogen auf *NaCl = 1.* (Nach Cole 1968.)

Comparing the analyses of rain and sang-ab (cf. Table), one striking fact is the lack of sulphate in rain-water, the other the diminishing of alkali carbonate (or hydrocarbonate) in sang-ab waters. If one considers the solubility of the relevant salts (see Fig. 6) this finding suggests that gypsum is present in the surface film of the rocks, which is dissolved, simultaneously precipitating calcium carbonate. The small amount of alkali carbonate in rain, obviously derived from the kavir salts, gives a hint on the provenance of the soda content found in several springs with a low sulphate ratio (cf. Chapter IV, 2 d).

	$k_{18} . 10^{-6}$	mval			mval			Ion sum	Soda mval	Salinity
		Na	Ca	Mg	Alk.	Cl	SO_4			
Normal rain, 1 h	268	1.9	0.6	0.6	1.6	1.5	0.0	3.1	0.4	167
Sang-ab	430	2.4	1.7	0.8	2.0	1.6	1.4	5.0	0.1	282

(b) Springs and Qanats

The concentration of the waters found in our area ranges from the greatest possible dilution (i.e. nearly equal to rain and sang-ab) to a salinity of approx. 100 mval/ (~7 g/l or one fifth of sea-water concentration). There were, however, a few exceptions, namely very small natural springs in a special geological position (cf. Chapter IV, 2 c) rising to a concentration of 140 mval/l (~10 g/l) and even 265 mval/l (~16 g/l).

Plate I: Chemical analyses of springs, qanats and wells in the Tabas-Shirgesht-Ozbak-Kuh-region. + = reckoned values; · = measured by flamphotometric (Na), resp. gravimetric method (SO_4); * = values obtained by ion exchanging columns; ▲ = samples containing soda > 50% of alkalinity; ciphers in italics = extrapolated conductivity values; (s) = spring; (q) = qanat.

No. in the map	Sampling No.	Locality	Date	Temperature °C	Conductivity		Salinity mg/l	pH	Na		Ca	
					original	deluted			mval	mg/l	mval	mg/l
1. Sarhangi Range (and Doruneh)												
a. Doruneh												
	8	Saltriver 50 *km.* above Doruneh	22. 10. 1966	—	18.100	26.000	14.927	8·5	238 ·	5.474	0	—
	12	Saltriver below Doruneh	22. 10. 1966	—	70.000	178.000	96.264	8·5	1.360 ·	31.280	0	—
b. Sarhangi — north												
	112	Sorkh Kuh, 1	20. 11. 1966	11·2	1.751	1.975	1.208	—	14·7 ·	338	1·7	34
	114	Sorkh Kuh, 2	20. 11. 1966	17·4	1.860	1.975	1.250	—	14·9 ·	343	3·2	64
1	119	Narm, (q)	20. 11. 1966	19·5	2.010	2.330	1.654	—	14·4 ·	331	3·0	60
2	116	Yakhab, (q)	20. 11. 1966	18·0	2.156	2.420	1.682	—	18·0 ·	414	3·4	68
3	117	Yeylaq, (s)	20. 11. 1966	13·2	1.373	1.532	1.063	—	10·8 ·	248	2·1	42
	120	Neyzar, (q)	20. 11. 1966	13·4	3.043	3.200	2.243	—	27·8 ·	639	0·6	12
c. Sarhangi — south												
4	325	Cheshmeh Tohu, (s)	22. 4. 1964	19·5	1.594	1.760	1.186	7·4	18·2+	419	1·2	24
5	330	Chah Paliz, (q)	22. 4. 1964	20·0	1.043	1.113	796	7·4	11·8+	272	1·0	20
	333	Karimabad 1, (q)	22. 4. 1964	20·0	840	—	606	7·2	7·2+	166	2·0	40
6	336	Karimabad 2, (q)	22. 4. 1964	—	800	—	578	7·4	6·8+	156	2·0	40
	337	Cheshmeh Lizab 1, (s)	23. 4. 1964	20·0	4.783	5.800	3.844	7·4	48·0 ·	1.105	8·6	172
	342	Cheshmeh Lizab 2, (s)	23. 4. 1964	15·0	3.185	3.730	2.569	7·6	35·8 ·	823	3·8	76
7	343	Cheshmeh-e-Asbi, (s)	23. 4. 1964	15·0	2.610	3.345	2.026	7·1	29·6 ·	451	9·0	180
8	348	Cheshmeh-e-Sangiche, (s)	23. 4. 1964	21·0	6.244	7.330	5.333	6·9	76·6 ·	1.761	6·2	124
d. Kuh-e-Sefid												
9	300	Chah Tom, (well)	19. 4. 1964	15·2	5.218	6.100	4.010	7·3	62·0 ·	1.425	6·0	120
2. Ozbak-kuh Region												
a. Hills west Ozbak-kuh												
10	310	Garqab, (s)	20. 4. 1964	19·9	4.592	5.400	4.572	7·8	55·0 ·	1.265	2·8	56
11	301	Gerdab, (s)	20. 4. 1964	21·2	10.436	14.050	7.866	7·9	155·0 ·	3.565	2·6	52

Tafel I: Chemische Analysen von Quellen, Qanaten und Wasserschächten in der Tabas-Shirgesht-Ozbak-Kuh Region.

+ = errechnete Werte; · = gemessen mit Flammenphotometer (Na) beziehungsweise gravimetrisch (SO$_4$); * = Ionenaustauscher-Werte; Ziffern in Kursivschrift = extrapolierte Leitfähigkeitswerte; ▲ = Proben, die > 50% der Alkalinität als Soda enthalten; (s) = Quelle; (q) = Qanat.

Mg		Alkalinity (CO$_3$)		Cl		SO$_4$		Cation sum	Anion sum	mval — %	Soda	
mval	mg/l	mval	mg/l	mval	mg/l	mval	mg/l	mval	mval	Na/Ca/Mg—Alk/Cl/SO$_4$	mval	% of Alk.
16·2	194	2·85	86·5	180	6.408	57·6 ·	2.765	254+	240+	95/ 0/ 5 — 1/75/24	—	—
81·6	979	2·90	87·0	1.375	58.950	103·5 ·	4.968	1.442+	1.479+	95/ 0/ 5 —0·2/93/ 7	—	—
2·4	29	4·65	139·5	5·—	178	10·18 ·	489	18·8 +	19·83+	80/ 8/12 — 25/25/50	0·5	11
2·2	26	5·50	165·0	6·25	223	8·93 ·	429	20·3 +	20·68+	75/15/10 — 25/25/50	—	—
8·9	107	3·50	105·0	8·75	311·5	15·4 ·	739	26·3 +	27·65+	55/10/35 — 10/35/55	—	—
5·0	60	4·75	142·5	10·00	356·—	13·36 ·	641	26·4 +	28·11+	65/15/20 — 15/35/50	—	—
4·0	48	3·40	102·0	3·25	116·—	10·57 ·	507	16·9 +	17·22+	60/15/25 — 20/20/60	0·3	—
6·2	74	8·85	265·5	11·25	401·—	17·7 ·	850	34·6 +	37·80+	80/ 2/18 — 25/30/45	2·0	—
1·2	14	6·2	186	6·8	238	6·6 ·	317	20·6 *	19·6 +	90/ 5/ 5 — 31/36/33	3·8	60 ▲
1·0	12	5·7	171	2·7	95	4·5 ·	216	13·8 *	12·9 +	84/ 8/ 8 — 44/22/34	3·7	75 ▲
2·0	24	4·2	126	2·2	77	3·6 ·	173	11·2 *	10·0 +	64/18/18 — 42/22/36	0·2	5
1·8	22	4·2	126	2·2	77	3·3 ·	157	10·6 *	9·7 +	62/20/18 — 42/22/36	0·4	10
6·2	74	4·3	129	32·4	1.134	27·7 ·	1.330	62·8 +	64·4 +	76/14/10 — 7/49/44	—	—
3·6	43	4·3	129	14·0	493	21·2 ·	1.018	43·2 +	39·5 +	80/10/10 — 11/36/53	—	—
6·6	79	5·8	174	10·0	350	16·5 ·	792	35·2 +	32·3 +	57/25/18 — 19/31/50	—	—
5·8	70	11·0	330	49·4	1.728	27·5 ·	1.320	88·6 +	87·9 +	86/ 7/ 7 —13/55/32	—	—
4·4	53	5·9	177	47·8	1.673	11·7 ·	562	72·4 +	65·4 +	85/10/ 5 — 9/73/18	—	—
3·0	36	4·3	129	35·2	1.231	17·8 ·	855	60·8 +	57·3 +	90/ 5/ 5 — 7/62/31	—	—
5·4	65	9·5	285	94·0	3.290	13·3 ·	639	163·0 +	116·8 +	95/ 2/ 3 — 8/81/11	1·5	15

No. in the map	Sampling No.	Locality	Date	Temperature °C	Conductivity		Salinity mg/l	pH	Na		Ca	
					original	deluted			mval	mg/l	mval	mg/l
		b. Ozbak-kuh — east										
12	355	Cheshmeh Kerkesu, (s)	24. 4. 1964	19·0	3.298	3.500	2.921	8·3	39·7+	914	4·8	96
	119	Cheshmeh Sard 1, (s)	21. 4. 1960	18·0	2.483	2.800	1.977	8·3	22·7 •	523	5·1	103
	126	Cheshmeh Sard 2, (s)	21. 4. 1960	20·5	2.536	2.886	2.158	8·2	24·2 •	558	4·2	84
13	150	Cheshmeh Huk, (s)	24. 4. 1960	22·4	3.222	4.180	3.177	8·0	22·8 •	522	14·4	288
	362	Cheshmeh Huk, (s)	24. 4. 1964	21·0	3.492	4.670	3.177	8·0	22·6+	520	16·0	320
14	157	Saltspring (s) near Huk	24. 4. 1960	—	18.123	26.000	16.197	8·0	192·5 •	4.430	30·1	602
	366	Saltspring (s) near Huk	24. 4. 1964	—	17.933	27.350	16.749	7·4	185·5+	4.266	41·9	838
	160	Cheshmeh Khasimeh, (s)	24. 4. 1960	17·2	3.295	3.790	2.630	8·3	31·4 •	722	4·2	84
		c. Ozbak-kuh — west										
15	92	Cheshmeh Taqshiru, (s)	14. 4. 1960	12·0	2.648	3.020	2.284	8·0	17·0 •	391	12·0	240
16	29	Ma'dan-e-Bala nr. Qal'eh, (q)	3. 4. 1960	18·0	2.980	3.550	2.619	8·0	19·3 •	443	13·6	272
17	87	Cheshmeh Senjedu, (s)	14. 4. 1960	16·8	1.021	—	708	8·1	5·8 •	133	4·0	80
	63	Chah Farizu, (s)	10. 4. 1960	—	9.156	13.200	10.292	8·0	133·0 •	3.060	23·6	472
18	59	Cheshmeh Mohammad Beik, (s)	10. 4. 1960	14·3	1.176	1.246	812	8·3	9·1 •	209	2·2	44
	50	Cheshmeh Hassan Tofangi, (s)	10. 4. 1960	16·2	3.580	4.050	2.789	8·1	36·0 •	828	5·0	100
	315	Cheshmeh Hassan Tofangi, (s)	21. 4. 1964	15·0	3.819	4.457	2.882	7·8	36·0+	828	5·4	108
19	18	Cheshmeh Bad Bad, (s)	1. 4. 1960	16·8	10.482	13.100	8.514	8·5	131·5 •	3.025	4·4	88
	319	Cheshmeh Bad Bad, (s)	21. 4. 1964	14·2	10.670	13.578	8.798	8·3	136·5+	3.140	3·6	72
	67	Cheshmeh Khormu, (s)	12. 4. 1960	17·2	6.964	9.875	6.620	8·0	63·8 •	1.467	23·7	474
20	406	Cheshmeh Lokeni, (s)	2. 5. 1964	21·0	4.845	6.940	4.819	7·9	49·0 •	1.127	17·2	344

Mg		Alkalinity (CO_3)		Cl		SO_4		Cation sum	Anion sum	mval — %	Soda	
mval	mg/l	mval	mg/l	mval	mg/l	mval	mg/l	mval	mval	Na/Ca/Mg—Alk/Cl/SO_4	mval	% of Alk.
4·0	48	7·6	228	21·6	757	18·3 ·	878	48·5 *	47·5 +	82/10/ 8 — 16/45/39	—	—
4·3	52	3·0	90	11·0	392	16·7 ·	802	32·3 +	30·8 +	70/16/14 — 10/35/55	—	—
5·3	64	4·0	120	11·2	399	17·6 ·	845	33·8 +	32·8 +	72/12/16 — 12/34/54	—	—
10·4	125	1·9	56	10·2	363	37·6 ·	1·805	47·7 +	49·7 +	48/30/22 — 4/20/76	—	—
8·8	106	4·5	135	10·8	378	35·8 ·	1·718	47·4 *	51·1 +	52/30/18 — 9/20/71	—	—
34·8	418	2·8	85	182·—	6.485	86·9 ·	4.170	258·0 +	271·7 +	75/12/13 — 1/67/32	—	—
36·2	434	4·7	141	200·—	7.000	84·8 ·	4.070	263·6 *	289·5 +	71/16/13 — 2/69/29	—	—
7·3	88	3·8	112	17·2	613	20·7 ·	994	43·0 +	41·7 +	72/10/18 — 9/41/50	—	—
6·3	75	2·8	85	10·2	363	22·3 ·	1.070	35·4 +	35·3 +	48/34/18 — 8/30/62	—	—
7·9	95	1·5	45	11·5	410	28·0 ·	1.343	40·9 +	41·0 +	50/30/20 — 4/28/68	—	—
3·4	41	2·2	65	4·9	175	5·1 ·	245	13·2 +	12·1 +	44/30/26 — 19/40/41	—	—
14·2	170	3·7	110	41·0	1.460	104·0 ·	4.995	171·4 +	148·7 +	78/14/ 8 — 2/27/71	—	—
1·5	18	5·7	180	5·4	193	3 4 ·	163	12·8 +	14·5 +	72/17/11 — 38/36/26	2·0	35
4·5	54	4·1	122	19·4	691	20·2 ·	970	45·7 +	43·7 +	79/11/10 — 9/44/47	—	—
5·0	60	6·0	180	19·6	698	21·0	1.008	46·4 *	46·6 +	78/12/10 — 14/42/45	—	—
9·8	118	9·5	285	83·0	2.953	42·1 ·	2.020	145·7 +	134·9 +	90/ 3/ 7 — 7/61/32	—	—
9·2	110	11·0	330	86·5	3.010	44·5 ·	2.136	149·3 *	142·0 +	91/ 3/ 6 — 8/61/31	—	—
15·0	180	2·5	75	36·0	1.282	65·0 ·	3.120	102·7 +	103·5 +	62/23/15 — 2/36/62	—	—
11·6	139	2·6	78	27·6	966	45·1 ·	2.165	77·8 +	75·3 +	63/22/15 — 3/37/60	—	—

No. in the map	Sampling No.	Locality	Date	Temperature °C	Conductivity		Salinity mg/l	pH	Na		Ca	
					original	deluted			mval	mg/l	mval	mg/l
		d. Gushkamar Valley										
	28	Cheshmeh Zoludu, (s)	24. 10. 1966	20·4	4.496	4.750	3.242	8·5	43·5 •	1.000	1·3	26
21	396	Cheshmeh Baghal, (s)	30. 4. 1964	18·8	5.958	8.630	5.317	8·4	69·8+	1.605	4·1	82
	388	Gushkamar 1, (s)	30. 4. 1964	17·0	2.016	2.720	1.869	7·9	16·0+	368	9·0	180
22	391	Gushkamar 2, (s)	30. 4. 1964	—	2.516	3.065	2.347	7·7	19·8 •	456	12·0	240
	393	Gushkamar, (q)	30. 4. 1964	22·0	3.553	4.470	3.396	7·9	30·6 •	704	16·4	328
23	394	Cheshmeh Padeha, (s)	30. 4. 1964	18·0	1.475	2.110	1.222	8·3	14·7+	338	3·0	60
	399	Cheshmeh Sibzar 1, (s)	1. 5. 1964	21·0	2.665	3.255	2.361	7·8	23·2+	534	9·5	190
	402	Cheshmeh Sibzar 2, (s)	1. 5. 1964	18·5	2.317	2.905	2.092	7·0	19·6 •	451	7·9	158
	404	Cheshmeh Siah, (s)	1. 5. 1964	23·0	1.893	2.200	1.524	7·9	20·7 •	477	2·0	40
		e. Ozbak-kuh — south										
24	368	Cheshmeh Shir, (s)	25. 4. 1964	21·0	2.538	2.910	2.527	7·2	35·5+	816	3·0	60
	25	Cheshmeh Shir, (s)	23. 10. 1966	20·4	2.820	3.057	1.849	8·5	23·3 •	536	3·0	60
25	372	Cheshmeh Estalkhaq, (s)	25. 4. 1964	15·0	11.276	15.600	9.169	7·0	125·0+	2.875	18·6	372
		3. Kuh-e-Bam Range										
		a. Abid										
26	376	Abid, (q)	25. 4. 1964	18·0	3.938	5.090	3.143	7·1	45·0 •	1.035	4·8	96
	19	Abid, (q)	23. 10. 1966	20·6	4.512	4.945	2.761	9·0	38·8 •	892	4·6	92
	24	Abid, (s)	23. 10. 1966	19·0	7.050	8.459	4.788	8·0	66·0 •	1.518	4·6	92
27	380	Khadrin, (q)	25. 4. 1964	21·0	3.985	5.050	3.220	7·0	46·2 •	1.063	6·0	120
	16	Khadrin, (q)	23. 10. 1966	21·8	4.412	4.845	2.722	9·0	35·3 •	812	6·4	124
		b. Kuh-e-bam — west										
28	209	Bam, (q)	7. 5. 1960	22·0	379	—	263	8·2	2·4 •	56	1·5	30
29	219	Abkhorak, (q)	11. 5. 1960	23·8	1.548	1.580	1.091	8·2	13·3 •	306	2·7	54
30	184	Cheshmeh-e-Khormayu, (s)	5. 5. 1960	21·3	5.740	6.940	4.551	8·5	70·0 •	1.610	2·6	52
	385	Cheshmeh-e-Khormayu, (s)	29. 4. 1964	21·5	6.160	7.940	4.707	6·9	75·2 •	1.730	2·4	48
31	177	Cheshmeh-e-Gholah, (s)	4. 5. 1960	17·5	1.655	1.810	1.262	8·4	15·2 •	351	2·3	45
32	216	Cheshmeh Neyzar, (s)	9. 5. 1960	—	1.345	1.352	932	8·4	12·8 •	295	1·4	28
33	198	Ozbak-kuh II, (s)	6. 5. 1960	22·5	2.000	2.120	1.627	8·3	27·5 •	633	1·8	37
34	196	Cheshmeh-e-Paderakhti	6. 5. 1960	22·0	2.237	2.435	1.751	8·7	25·0 •	575	1·5	30

Mg		Alkalinity (CO_3)		Cl		SO_4		Cation sum	Anion sum	mval — %	Soda	
mval	mg/l	mval	mg/l	mval	mg/l	mval	mg/l	mval	mval	Na/Ca/Mg—Alk/Cl/SO_4	mval	% of Alk.
5·0	60	7·45	223·5	18·0	641	26·9 •	1.291	49·8 +	52·35+	87/ 3/10 — 15/35/50	1·1	15
8·5	102	11·0	330	20·0	700	53·2 •	2.552	82·4 *	84·2 +	85/ 5/10 — 13/25/62	—	—
6·2	74	3·9	117	7·6	265	18·0 •	865	31·2 *	29·5 +	50/30/20 — 14/26/60	—	—
6·0	72	4·2	126	8·6	301	24·1 •	1.152	37·8 +	36·9 +	52/32/16 — 11/23/66	—	—
3·6	43	3·9	117	14·2	497	35·6 •	1.707	50·6 +	53·7 +	60/32/ 8 — 8/26/66	—	—
3·0	36	5·1	153	4·0	140	10·3 •	495	20·7 *	19·4 +	72/14/14 — 25/22/53	—	—
5·5	66	4·4	132	8·6	301	23·7 •	1.138	38·2 *	36·7 +	61/25/14 — 12/24/64	—	—
5·1	61	4·5	135	7·6	265	21·3 •	1.022	32·6 +	33·4 +	61/25/14 — 13/23/64	—	—
3·2	38	7·0	210	8·0	279	10·0 •	480	25·7 +	25·0 +	80/ 8/12 — 28/32/40	1·8	25
3·0	36	4·3	129	17·2	602	18·4 •	884	41·5 *	39·9 +	86/ 7/ 7 — 10/43/47	—	—
3·1	37	4·25	127·5	16·0	570	10·8 •	518	29·4 +	31·05+	80/10/10 — 15/50/35	—	—
10·3	124	4·1	123	101·0	3.540	44·5 •	2.135	156·9 *	149·6 +	80/12/ 8 — 3/67/30	—	—
3·2	38	3·1	93	32·4	1.122	15·8 •	759	53·2 +	50·8 +	85/ 9/ 6 — 6/63/31	—	—
2·7	32	3·3	99	26·0	926	15·2 •	730	46·1 +	44·5 +	85/10/ 5 — 5/60/35	—	—
4·2	50	3·7	112	48·0	1.709	27·2 •	1.306	74·8 +	78·9 +	86/ 7/ 7 — 5/60/35	—	—
2·0	24	3·6	108	30·4	1.065	17·5 •	840	54·2 +	52·6 +	85/11/ 4 — 7/57/36	—	—
1·6	19	3·0	90	25·0	890	16·4 •	787	43·1 +	44·4 +	80/15/ 5 — 5/55/40	—	—
0·7	8	2·2	66	1·3	41	1·3 •	62	4·6 +	4·8 +	50/35/15 — 46/27/27	—	—
1·6	19	2·8	84	9·0	321	6·4 •	307	17·7 +	18·1 +	75/15/10 — 15/50/35	—	—
3·8	46	5·3	158	44·4	1.580	23·0 •	1.105	76·6 +	72·7 +	91/ 4/ 5 — 7/61/32	—	—
3·0	36	8·1	243	42·4	1.484	24·3 •	1.166	80·6 +	74·8 +	95/ 2/ 3 — 11/57/32	2·7	35
4·6	55	6·1	183	5·4	192	9·3 •	446	22·2 +	20·8 +	69/10/21 — 29/26/45	—	—
1·5	18	4·0	121	6·2	221	5·2 •	249	15·8 +	15·5 +	80/10/10 — 35/40/25	1·1	30
1·7	20	4·4	133	10·6	377	8·9 •	427	31·1 +	23·9 +	90/ 5/ 5 — 18/44/38	0·9	20
3·6	43	8·8	258	8·2	293	11·5 •	552	30·2 +	28·5 +	83/ 5/12 — 31/29/40	3·7	4

No. in the map	Sampling No.	Locality	Date	Temperature °C	Conductivity		Salinity mg/l	pH	Na		Ca	
					original	deluted			mval	mg/l	mval	mg/l
	c. Kuh-e-Bam — east											
35	101	Neygenan 1, (q)	14. 12. 1963	—	863	—	572	7·0	7·8+	180	1·5	30
	106a	Neygenan 2, (q)	14. 12. 1963	—	915	—	608	7·0	8·1+	186	1·3	26
	107	Neygenan 3, (q)	14. 12. 1963	21·2	1.050	*1.050*	623	6·5	9·0+	207	1·7	34
36	112	Zardeh, (s)	14. 12. 1963	19·2	1.180	*1.250*	826	7·0	9·6+	221	2·2	44
	125	Saltstream south of Neygenan	19. 12. 1963	—	4.246	*4.800*	3.231	7·0	49·5+	1.140	1·8	36
37	128	Eshqabad, (q)	20. 12. 1963	—	520	—	319	6·8	4·2+	97	1·4	28
	129	Mohammadabad, (q)	20. 12. 1963	—	800	—	445	6·5	6·6+	152	1·8	36
38	114	Hosseynabad, (q)	14. 12. 1963	12·6	4.570	6.540	3.426	7·0	49·6 •	1.141	4·2	84
	127	Ahmadabad, (q)	19. 12. 1963	—	3.857	*4.440*	2.827	6·3	43·4+	1.005	2·0	40
39	120	Hajadabad, (q)	19. 12. 1963	23·0	2.137	3.035	1.484	6·5	20·0 •	460	1·7	33
40	86	Esfak, (q)	5. 12. 1963	19·8	1.128	*1.300*	636	6·5	8·4+	193	2·3	46
	92	Yahiabad, (q)	5. 12. 1963	—	1.154	*1.350*	644	7·0	7·5+	172	2·4	48
	81	Sa'adabad, (q)	5. 12. 1963	—	722	—	502	7·0	6·7+	145	1·4	28
4. Jolgeh												
41	60	Chah-e-Kavir, (q)	27. 10. 1966	24·8	4.152	4.665	2.769	9·0	39·5 •	909	2·0	40
	61	Sechahyeh, (q)	27. 10. 1966	21·6	4.861	5.138	3.210	8·5	44·0 •	1.012	1·6	32
42	55	Deh-e-Luk, (q)	27. 10. 1966	23·8	3.348	3.742	2.480	9·5	32·8 •	754	1·9	38
43	54	Deh-e-Alkhani, (q)	27. 10. 1966	—	1.972	2.010	1.302	9·0	15·5 •	356	3·1	62
	53	Bushtaryeh, (q)	27. 10. 1966	24·0	1.700	1.884	1.139	8·5	13·65 •	314	1·9	36
	174	Mianabad, (q)	8. 1. 1964	—	861	—	532	7·2	8·3+	191	0·5	10
44	172	Hudar, (q)	8. 1. 1964	—	780	—	395	7·0	5·8+	133	0·6	12
	173	Nazirabad, (q)	8. 1. 1964	21·2	1.385	1.550	909	7·3	15·0+	345	0·6	12
45	212	Vakilabad, (q)	31. 1. 1964	21·0	1.200	1.414	704	7·4	11·2+	258	0·3	6
46	213	Mahmudabad, (q)	31. 1. 1964	23·8	1.800	2.072	1.250	7·2	14·4+	331	2·9	58
47	51	Dastgardan, (q)	27. 10. 1966	23·8	935	—	604	8·5	6·12 •	141	2·4	48
48	100	Manzuriyeh, (q)	8. 12. 1963	—	740	—	467	7·0	6·4+	147	1·3	26
49	42	Deh Khan 1, (q)	25. 10. 1966	19·0	780	—	542	8·0	5·2 •	120	1·0	20
	43	Deh Khan 2, (q)	25. 10. 1966	—	786	—	550	8·5	5·2 •	120	1·4	28
	41	Mahmadabad, (q)	25. 10. 1966	20·6	737	—	536	8·5	4·45 •	102	1·9	36
50	35	Del-e-Kuh, (q)	25. 10. 1966	21·8	854	—	549	9·0	4·95 •	114	2·2	44
51	40	Pashneh Darun, (q)	25. 10. 1966	—	737	—	569	9·5	5·85 •	135	2·2	44

Mg		Alkalinity (CO_3)		Cl		SO_4		Cation sum	Anion sum	mval — %	Soda	
mval	mg/l	mval	mg/l	mval	mg/l	mval	mg/l	mval	mval	Na/Ca/Mg—Alk/Cl/SO_4	mval	% of Alk.
0·1	1	3·8	114	3·9	137	2·3+	110	9·3 *	10·0 *	85/15/ 0 — 40/40/20	2·2	60 ▲
0·4	5	3·9	117	4·4	154	2·5+	120	9·8 *	10·8 *	83/13/ 4 — 40/45/15	2·2	60 ▲
0·3	3	3·4	102	5·3	186	1·9+	91	10·9 *	10·6 *	83/15/ 2 — 30/50/20	1·4	40
0·2	2	3·4	136	5·8	203	4·6+	221	11·9 *	13·8 *	84/15/ 1 — 25/45/30	1·0	30
1·7	20	3·8	114	33·1	1.158	16·1+	773	53·0 *	—	94/ 3/ 3 — 5/65/30	0·3	10
0·1	1	3·1	93	2·7	95	0·1+	5	5·7 *	5·9 *	75/25/ 0 — 55/45/ 0	1·6	50 ▲
0·0	—	3·7	111	3·6	126	0·4+	20	8·4 *	7·7 *	80/20/ 0 — 45/45/10	1·9	50 ▲
0·4	5	4·4	176	33·3	1.166	17·8 ·	854	54·2 *	50·6 +	90/ 9/ 1 — 10/60/30	—	—
0·6	7	4·2	126	28·6	1.001	13·8+	648	46·0 *	46·4 *	94/ 5/ 1 — 10/60/30	1·6	40
1·8	22	3·8	114	13·6	476	7·9 ·	379	23·5 +	25·3 +	85/ 7/ 8 — 15/60/25	0·3	10
1·0	12	4·0	120	5·8	203	1·3+	62	11·7 *	11·1 *	70/20/10 — 35/50/15	0·7	20
1·5	18	4·0	120	6·4	224	1·3+	62	11·4 *	11·7 *	65/20/15 — 35/55/10	0·1	5
0·8	9	3·7	111	3·7	130	1·6+	77	8·8 *	9·0 *	75/15/10 — 40/40/20	1·5	40
1·7	20	4·0	120	24·0	854	17·2 ·	826	43·2 +	45·2 +	90/ 5/ 5 — 10/50/40	0·3	7
4·0	48	5·0	150	26·0	926	21·7 ·	1.042	49·6 +	52·7 +	90/ 3/ 7 — 10/50/40	—	—
2·8	34	4·5	135	22·0	784	15·31 ·	735	37·5 +	41·81+	88/ 5/ 7 — 10/50/40	—	—
2·2	26	3·6	108	11·0	392	7·46 ·	358	20·8 +	22·06+	75/15/10 — 15/50/35	—	—
2·9	35	3·0	90·0	9·75	347·0	6·61 ·	317	18·45+	19·36+	75/10/15 — 15/50/35	—	—
0·4	5	3·7	111	4·5	157	1·2+	58	9·2 *	—	90/ 5/ 5 — 40/50/10	2·8	75 ▲
0·8	10	2·7	81	4·4	154	0·1+	5	7·2 *	—	80/10/10 — 40/59/ 1	1·3	50 ▲
0·1	1	5·4	162	8·0	280	2·3+	110	15·7 *	—	96/ 3/ 1 — 35/50/15	4·7	90 ▲
0·0	0	3·6	108	6·2	217	2·4+	115	11·5 *	12·2 *	97/ 3/ 0 — 30/50/20	3·3	90 ▲
1·2	15	2·1	63	11·5	403	7·9+	380	18·5 *	21·5 *	80/15/ 5 — 10/55/35	—	—
2·0	24	2·6	78	4·0	142	3·56 ·	171	9·72+	10·16+	55/25/20 — 25/40/35	—	—
0·5	6	3·1	93	3·8	133	1·3+	62	—	8·2 *	78/15/ 7 — 40/45/15	1·3	40
2·6	31	2·4	72	3·75	133·5	3·43 ·	165	8·8 +	9·58+	60/10/30 — 25/40/35	—	—
2·6	31	2·65	79·5	3·75	133·5	3·28 ·	157	9·20+	9·68+	55/15/30 — 25/40/35	—	—
2·4	29	2·75	82·5	3·50	125	3·35 ·	161	8·75+	9·60+	50/20/30 — 25/35/40	—	—
1·7	20	2·50	75·0	3·75	133·5	3·34 ·	160	8·85+	9·59+	55/25/20 — 25/40/35	—	—
1·4	17	2·25	67·5	3·50	125	3·75 ·	180	9·45+	9·50+	60/25/15 — 25/35/40	—	—

No. in the map	Sampling No.	Locality	Date	Temperature °C	Conductivity		Salinity mg/l	pH	Na		Ca	
					original	deluted			mval	mg/l	mval	mg/l
5. Derenjal Mountains												
52	211	Cheshmeh Kharmayu, (s)	28. 1. 1964	—	3.800	5.181	3.025	7·4	45·0 •	1.035	1·4	28
	215	Chah-e-Baba Ali, (well)	31. 1. 1964	—	3.650	4.710	2.899	7·5	45·6 •	1.049	1·4	28
	149	Cheshmeh Shorm 1, (s)	7. 1. 1964	14·6	3.700	*4.300*	2.817	7·4	44·2+	1.017	1·4	28
53	150	Cheshmeh Shorm 2, (s)	7. 1. 1964	20·0	3.935	5.135	3.178	7·6	49·5 •	1.140	1·1	22
54	68a	Derenjal, (s) (before rainfall)	28. 11. 1963	—	2.026	*2.300*	1.566	7·5	24·5+	564	1·3	26
	68b	Derenjal, (s) (after rainfall)	8. 12. 1963	20·8	1.783	2.260	1.191	7·5	18·4 •	437	1·0	20
55	67	Chah-e-Shur, (well)	27. 11. 1963	—	2.100	2.825	1.423	6·5	20·0 •	460	2·4	48
56	226	Saltstream, SE-corner of the mountains	6. 2. 1964	8·6	30.000	47.100	24.900	7·5	365·0 •	8.400	10·6	212
57a	143	Cheshmeh Chekab, (s)	4. 1. 1964	13·4	1.060	—	587	7·8	9·2 •	212	0·9	18
57b	148	Chah-e-Gerdu, (well)	4. 1. 1964	6·8	3.050	*3.300*	2.173	—	34·1+	784	1·1	22
6. Pirhajat Mountains												
	a. Pirhajat — west											
58	216	Cheshmeh Gowmar, (s)	5. 2. 1964	24·5	9.250	11.780	7.609	7·2	108·0 •	2.793	9·0	180
59	221	Chesmeh Talkhab, (s)	5. 2. 1964	23·2	5.650	8.000	4.571	7·4	61·5 •	1.415	4·8	96
60	180	Abdolabad, (s)	25. 1. 1964	23·4	1.940	2.450	1.312	7·6	19·2 •	442	1·3	26
61	197	Pirhajat, main spring	25. 1. 1964	25·5	1.450	1.774	987	7·3	15·1 •	347	1·4	28
	191	Pirhajat — Mesra'ah, (s)	25. 1. 1964	25·2	1.500	1.884	1.027	7·3	15·7 •	361	1·6	32
	199	Pirhajat — Mesra'ah Mill-spring	25. 1. 1964	25·2	1.400	1.700	1.026	7·5	14·9 •	343	1·9	38
62	182	Bistun 1, (s)	23. 1. 1964	22·4	996	—	698	7·3	11·2 •	258	1·3	26
	186	Bistun, (q)	23. 1. 1964	10·2	926	—	664	7·6	11·0 •	253	1·1	22
	188	Bistun 2, (s)	23. 1. 1964	21·8	845	—	642	7·5	10·9 •	250	1·3	26
	201	Spring south of Bistun	23. 1. 1964	—	810	—	518	7·4	6·3 •	145	1·4	28
	b. Pirhajat — east											
63	202	Cheshmeh Dahaneh Mambar, (s)	26. 1. 1964	22·5	3.950	5.135	3.047	7·6	48·1 •	1.106	0·8	16
64	151	Kalshaneh, (s)	6. 1. 1964	22·2	1.240	1.500	753	7·5	11·4 •	262	1·4	28
65	131	Spring west of Chah-e-Sorb	23. 12. 1963	—	1.977	*2.400*	1.380	7·2	21·8+	501	0·7	14
	130	Well west of Chah-e-Sorb	23. 12. 1963	—	2.856	*4.000*	1.774	7·2	27·9+	644	1·2	24

Mg		Alkalinity (CO_3)		Cl		SO_4		Cation sum	Anion sum	mval — %	Soda	
mval	mg/l	mval	mg/l	mval	mg/l	mval	mg/l	mval	mval	Na/Ca/Mg—Alk/Cl/SO_4	mval	% of Alk.
0·8	10	6·0	180	17·7	620	24·0 ·	1.152	47·2 +	47·7 +	95/ 3/ 2 — 10/40/50	3·8	65 ▲
0·4	5	6·0	180	17·0	595	21·7 ·	1.042	47·4 +	44·7 +	96/ 3/ 1 — 10/40/50	4·2	70 ▲
0·7	9	6·3	189	26·6	931	13·4+	643	46·3 *	—	95/ 3/ 2 — 15/55/30	4·2	65 ▲
0·8	10	6·7	201	28·8	1.008	16·6 ·	797	51·5 *	52·1 +	95/ 3/ 2 — 15/55/30	4·8	70 ▲
0·3	4	5·8	174	13·6	476	6·7+	322	28·0 *	24·2 *	94/ 5/ 1 — 25/50/25	4·2	75 ▲
0·2	2	5·2	156	10·6	371	4·5 ·	206	19·6 +	20·3 +	94/ 5/ 1 — 25/50/25	4·0	80 ▲
1·0	12	2·6	78	11·2	392	11·1 ·	433	23·4 +	24·9 +	85/10/ 5 — 10/45/45	—	—
6·0	72	5·6	168	300·0	10.500	115·4 ·	5.550	382·0 +	441·0 +	95/ 3/ 2 — 0/75/25	—	—
0·8	10	3·2	96	4·4	154	4·1 ·	197	10·9 +	11·7 +	85/10/ 5 — 25/40/35	1·5	50 ▲
0·1	1	7·1	213	15·4	539	12·8+	614	—	35·3 *	97/ 3/ 0 — 20/45/35	5·9	85 ▲
4·0	48	4·0	120	93·4	3.270	24·8 ·	1.200	121+	122+	90/ 7/ 3 — 5/75/20	—	—
3·0	36	4·0	120	51·4	1.800	23·0 ·	1.104	69·3 +	78·4 +	90/ 7/ 3 — 5/75/20	—	—
0·8	10	4·4	132	13·2	462	4·9 ·	240	21·3 +	22·5 +	85/10/ 5 — 20/60/20	2·3	50 ▲
0·9	11	4·4	126	10·5	368	2·4 ·	107	17·4 +	17·1 +	85/10/ 5 — 25/60/15	2·1	50 ▲
0·7	9	3·8	114	10·6	371	2·9 ·	140	18·0 +	17·3 +	85/10/ 5 — 25/60/15	1·5	40
0·5	6	3·9	117	10·5	368	3·2 ·	154	17·3 +	17·6 +	85/10/ 5 — 25/60/15	1·5	35
0·9	11	4·2	126	5·7	200	1·6 ·	77	13·4 +	10·5 +	85/10/ 5 — 30/50/20	2·0	50 ▲
0·8	10	3·8	114	5·5	193	1·5 ·	72	12·9 +	10·8 +	85/10/ 5 — 30/50/20	1·9	50 ▲
0·7	9	3·9	117	5·2	183	1.2 ·	58	12·9 +	10·3 +	85/10/ 5 — 30/50/20	1·9	50 ▲
1·0	12	4·1	123	4·5	157	1.1 ·	53	8·7 +	9·7 +	75/15/10 — 40/45/15	1·7	40
0·4	5	10·4	312	28·1	984	13·0 ·	624	49·3 +	51·5 +	97/ 2/ 1 — 20/55/25	9·2	88 ▲
0·7	9	3·8	114	7·4	259	2·2 ·	106	13·5 +	13·4 +	85/10/ 5 — 30/55/15	1·7	45
0·7	9	6·0	180	11·1	388	6·1	288	24·0 *	22·4 *	95/ 3/ 2 — 20/55/25	4·6	75 ▲
0·5	6	6·0	180	16·4	574	7·2	346	30·4 *	28·8 *	95/ 3/ 2 — 20/55/25	4·3	70 ▲

No. in the map	Sampling No.	Locality	Date	Temperature °C	Conductivity		Salinity mg/l	PH	Na		Ca	
					original	deluted			mval	mg/l	mval	mg/l
66	—	Chah-e-Sorb, shaft 2	10. 1. 1964	21·6	3.150	4.435	2.096	7·4	30·0 •	690	3·6	72
	—	Chah-e-Sorb, drinking water	5. 1. 1964	—	1.100	*1.200*	667	7·5	10·0+	230	1·4	28
7. Shirgesht Region												
67	138	Abbasabad, (q)	28. 11. 1963	12·8	6.553	*8.000*	5.393	6·5	80·5+	1.852	5·1	102
68	63	Shirgesht, (s)	26. 11. 1963	22·6	2.428	3.500	1.869	6·5	28·1 •	646	2·8	56
	74	Qanat east Shirgesht	29. 11. 1963	—	1.883	*2.050*	1.255	7·0	17·3+	398	0·6	12
	136	Well east Shirgesht	26. 12. 1963	—	1.148	1.200	742	7·0	9·4+	216	1·3	26
69	49	Kal-e-Gaz, saltstream	26. 10. 1966	21·4	22.480	37.400	20.014	9·0	285 •	6.555	23·2	464
71	52	Deh Now, (q)	25. 11. 1963	21·4	525	—	386	7	5·0+	115	1·3	26
72	00	Deh Mohammad, (q)	23. 11. 1963	21·8	515	—	387	7	4·7+	108	1·4	28
	39	Amirabad, (q)	23. 11. 1963	21·2	550	—	424	7	5·5 •	127	0·8	16
73	28	Malvand, (q)	22. 11. 1963	22·6	367	—	245	7	2·8+	67	1·0	20
8. Shotori Range												
74	62	Sardar Valley hot spring at Tang-e-Abbasi	29. 10. 1966	33·8	966	—	726	9·0	6·8 •	156	3·4	68
75	68	Sardar River at Tang-e-Abbasi	29. 10. 1966	20·4	710	—	503	9·0	3·41 •	78	3·4	68
	75	Sardar Valley, sidestream near Niaz	31. 10. 1966	17·6	836	—	622	9·0	4·9 •	113	2·1	42
9. Rain and Sang-ab												
76	77	Rain, 0—12 h	3. 12. 1963	—	268	—	167	6·0	1·9+	44	0·6	12
	79	Rain, 12—24 h	3. 12. 1963	—	71	—	91	5·5	1·2+	28	0·3	6
	80	heavy rain, 24—36 h	4. 12. 1963	—	18	—	24	5·0	0·2 •	5	0·08	2
	69	Sang-ab I, Kuh-e-Talkhow	29. 11. 1963	8·6	486	—	321	7·0	3·3+	76	1·8	36
77	72	Sang-ab II, Kuh-e-Talkhow	29. 11. 1963	7·6	430	—	274	7·0	2·4+	55	1·7	34
	73	Sang-ab III, Kuh-e-Talkhow	29. 11. 1963	—	422	—	270	7·0	2·9+	68	1·2	24
	75	Sang-ab IV, Kuh-e-Talkhow	29. 11. 1963	—	494	—	303	7·0	3·0+	69	1·6	32
	94	Sang-ab V, SW Malvand (after rain)	6. 12. 1963	—	25	—	102	6·5	0·6+	14	0·7	15

Mg		Alkalinity (CO_3)		Cl		SO_4		Cation sum	Anion sum	mval — %	Soda	
mval	mg/l	mval	mg/l	mval	mg/l	mval	mg/l	mval	mval	Na/Ca/Mg—Alk/Cl/SO_4	mval	% of Alk.
1·4	17	2·7	81	25·7	900	6·9 ·	366	35·0 +	35·3 +	85/10/ 5 — 5/75/20	—	—
0·2	2	3·5	105	5·9	206	2·0+	96	11·1 *	11·8 *	85/10/ 5 — 30/50/20	1·9	55 ▲
2·4	29	3·8	114	57·0	2.000	27·0+	1.296	88·0 *	87·8 *	91/ 6/ 3 — 5/65/30	—	—
0·6	7	3·8	114	19·5	662	8·0 ·	384	30·6 +	31·3 +	91/ 7/ 2 — 10/65/25	0·4	10
3·3	40	5·1	153	14·8	518	2·8+	134	21·2 *	22·7 *	82/ 3/15 — 25/65/10	1·2	20
2·7	33	4·4	132	7·5	263	1·5+	72	—	13·4 *	70/10/20 — 35/55/10	0·4	10
28·8	346	3·3	99	263·—	9.363	66·4 ·	3.187	337·0 +	332·7 +	85/ 7/ 8 — 10/70/20	—	—
0·2	3	3·4	102	2·6	91	1·0+	48	6·5 *	7·0 *	75/20/ 5 — 50/35/15	1·9	35
0·2	2	3·6	108	3·2	112	0·3	7	6·3 *	7·1 *	74/22/ 4 — 51/45/ 4	2·0	60 ▲
1·0	12	2·6	78	3·4	119	1·5 ·	72	7·3 +	7·5 +	75/10/15 — 35/45/20	0·8	30
0·4	5	3·0	90	1·8	63	tr.	—	4·2 *	4·8 *	67/23/10 — 62/38/ 0	1·6	50 ▲
1·4	17	2·2	66·0	4·75	169	5·21 ·	250	11·6 +	12·16+	58/30/12 — 20/35/45	—	—
1·7	20	2·85	85·5	2·75	98	3·18 ·	153	8·5 +	8·78+	40/40/20 — 30/30/40	—	—
3·3	40	3·20	96·0	3·0	107	4·67 ·	224	10·3 +	10·87+	50/20/30 — 30/30/40	—	—
0·6	7	1·6	48	1·5	53	0·0	—	—	3·1	60/20/20 — 55/45/ 0	0·4	25
0·2	2	1·0	30	0·7	25	0·0	—	—	1·7	70/20/10 — 60/40/ 0	0·5	50 ▲
0·0	—	0·3	10	0·2	7	0·0	—	0·3	0·5	85/15/ 0 — 60/40/ 0	0·2	65 ▲
0·1	1	2·9	87	1·8	63	1·2+	58	5·2 *	5·9 *	60/35/ 5 — 55/35/10	1·0	35
0·2	2	2·0	60	1·6	56	1·4+	67	4·3 *	5·0 *	60/35/ 5 — 45/35/20	0·1	5
0·6	7	2·1	63	1·7	60	1·0+	48	4·7 *	4·8 *	60/25/15 — 45/35/20	0·3	15
0·8	10	2·1	63	2·6	91	0·9+	38	5·4 *	5·6 *	55/30/15 — 35/45/20	—	—
0·1	1	1·8	54	0·5	18	0·0	—	1·5 *	1·9 *	40/50/10 — 80/20/ 0	1·0	55 ▲

Salt streams and rivers — not considered for the purpose of this paper, but included in Plate I — undergo a considerable concentration due to evaporation and reach salinities of 400—1500 mval/l (approximately three times the concentration of sea-water) *).

It has already been mentioned that the discharge of natural springs is generally much lower than that of qanats; conversely, the concentration of springs is usually higher than that of qanats rising from the same area. Springs are also much more influenced by precipitation than qanats, even if the change of water flow in the former is invisible and not measurable. We analysed the same small spring (Pl. I, 5., No. 68 a and b) a few days before and after a rainfall of 10—15 *mm.* and found a dilution of about one fifth of its original salinity, whereas the qanat water of a near-by village did not change at all. Repeated analyses from the same locality made at different times showed greater differences in the results for springs than for qanats (see Plate I). Even apart from this fact, the concentration of springs varies on a very broad scale, depending in a higher degree on the local geological situation, than that of qanats (cf. Chapter IV).

With regard to ionic composition all the springs and qanats of the Tabas—Shirgesht—Ozbak-kuh region belong to a mixed chloride-sulphate type. All transitions from about 75 mval% chloride to the same amount of sulphate occur; if the fraction of the respective anion exceeded 50% of the anion sum we denoted the water as a chloride or a sulphate type, respectively.

Carbonate is always present, but in very small amounts; alkalinity values (including also other weak acids) exceeding 10 mval/l are very rare. Carbonate thus never constitutes the prevalent anion in waters of high concentration. This is a remarkable fact in comparison with the salt waters of other closed basins, and even with waters of other parts of the Iranian highlands (LÖFFLER, 1961). As we have seen, a small fraction of alkali carbonate is found in rain-water and sometimes in sang-ab; it is also present in most qanats of low salinity. For this reason, we considered only those waters to be genuine soda springs which had an excess alkalinity of 100% or more over their content of alkaline earths. The distribution of soda springs is dealt with in Chapter IV, 2 d.

The great variety in the chemical composition of springs and qanats in the report area, shown in Plates I and II, may have two different causes:

a) purely chemical processes, depending on increasing concentration only, or

b) the availability of soluble substances as the water makes its way from the atmosphere through rock and soil to the spring.

For the purpose of our paper it is essential to distinguish between the effects of these two factors.

Fig. 7 represents the relative cationic composition of the waters analysed, showing the three anionic types in triangular coordinate diagrams. The corner of each plot stands for 100% Na, Ca, Mg, respectively and the base-line opposite each corner for 0% of the respective cation; the 50% line is indicated. The samples are also grouped according to their concentration, the scale being different for the three different anionic types, thus allowing for the greater variation with chloride waters than with sulphate and intermediate waters. The diagrams show very clearly the relative increase of sodium with increasing concentration (indicated by an arrow) as far as chloride and intermediate waters are concerned; the same trend can be observed, though less obviously, with waters of the sulphate type. Samples containing soda (indicated by a

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*) The average ionic composition of our concentrated springs, however, was 95 Na/3 Ca/2 Mg — 0 CO_3/75 Cl/25 SO_4 mval% against 80 Na/3 Ca/17 Mg — 0 CO_3/90 Cl/10 SO_4 mval% for average sea-water.

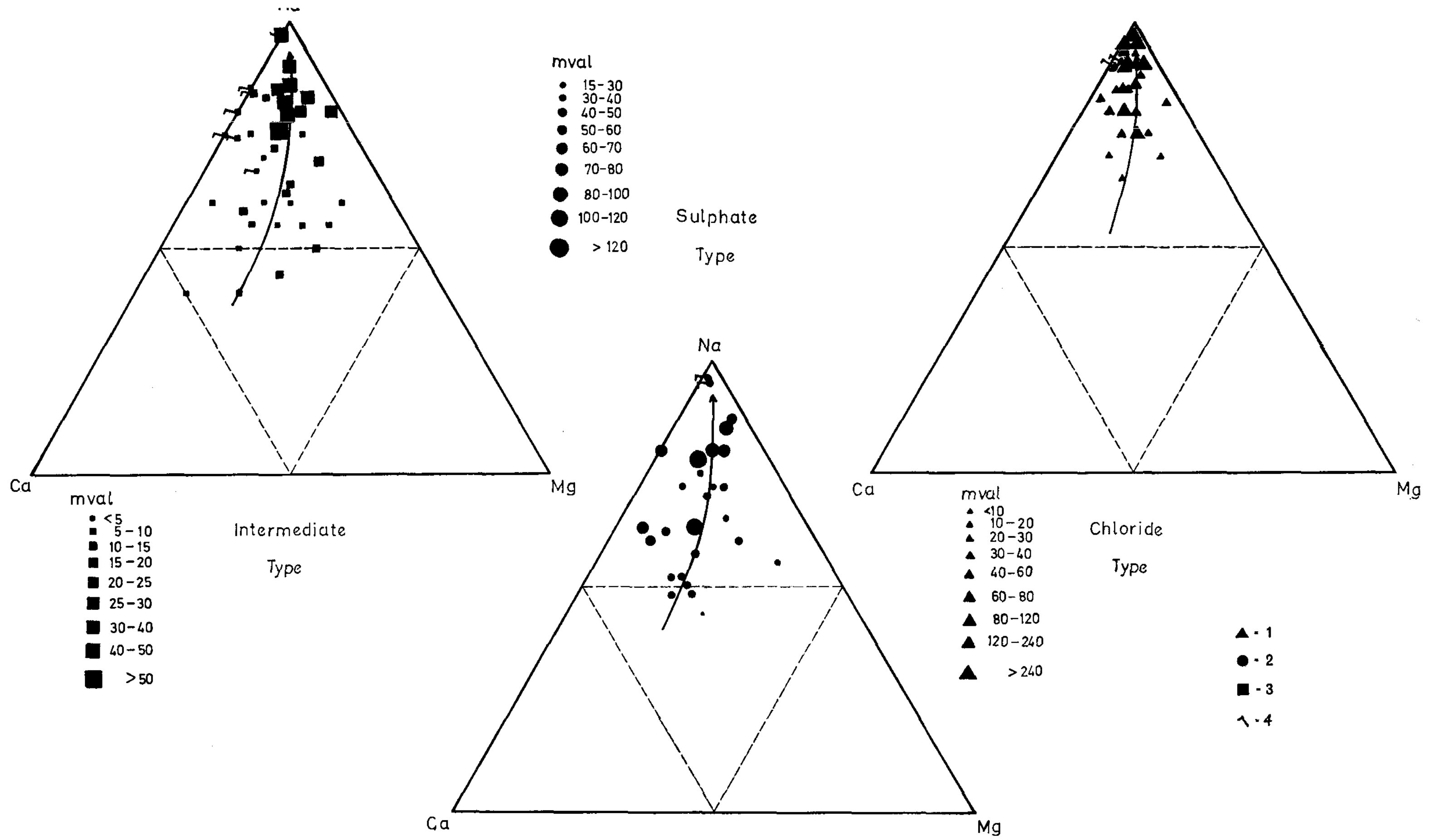

Fig. 7: Triangular coordinate diagrams of the cationic composition of waters in the report area. Samples grouped according to their concentration, the scale being different for the three anionic types. 1 = chloride, 2 = sulphate, 3 = intermediate type, 4 = waters containing soda. Arrows indicate the trend of increasing concentration.

Kationenzusammensetzung der Gewässer im Untersuchungsgebiet, dargestellt in Dreieckskoordinaten-Diagrammen. Die Proben sind in je 9 Konzentrationsstufen zusammengefaßt, der Konzentrationsbereich ist für 3 Anionen-Typen verschieden. 1 = Chlorid-, 2 = Sulfat-, 3 = Intermediärtypus; 4 = Gewässer mit Sodagehalt; Pfeile zeigen die Tendenz bei zunehmender Konzentration an.

tick) attain a high percentage of sodium at a lower concentration than those without soda, somewhat disturbing the general aspect of Na-increase with rising salinity. We found no difference in this trend between various localities within the area, although the mean concentration differs a great deal between different aquifers (cf. Chapter IV).

The general trend proceeds to an end-point of about 95 Na/3—5 Ca/tr.—2 Mg mval%. It is a striking fact that the final ratio of sodium is much higher in our samples than even in sea-water: the increase goes on at the cost of magnesium, which almost disappears in the end. This lack of magnesium is particularly important as inland salt waters are known to contain generally more magnesium than sea-water. The big Iranian salt lakes, for example, show a great amount of magnesium: Lake Resajeh (Urmia) 30, Lake Hamun 30, Lake Famur 40 mval% (according to LÖFFLER, 1961); the Caspian has about 30 mval% Mg.

On the other hand, ENGELHARDT (1960) analysed interstitial water of various geological formations and found in Triassic dolomite 70/25/5, in Cretaceous sandstone 75/20/5, in Liassic sandstone 85/10/5 mval% for Na, Ca, Mg, respectively, a ratio to which the cationic composition of springs and qanats in the report area has a closer resemblance than to surface salt water in Iran, in spite of the fact that those formation waters are about 100 times more concentrated. If one considers chiefly the cationic composition, this would suggest that the salt content of the springs and qanats is influenced more by chemical processes taking place within the rocks than by those which determine concentrating surface waters.

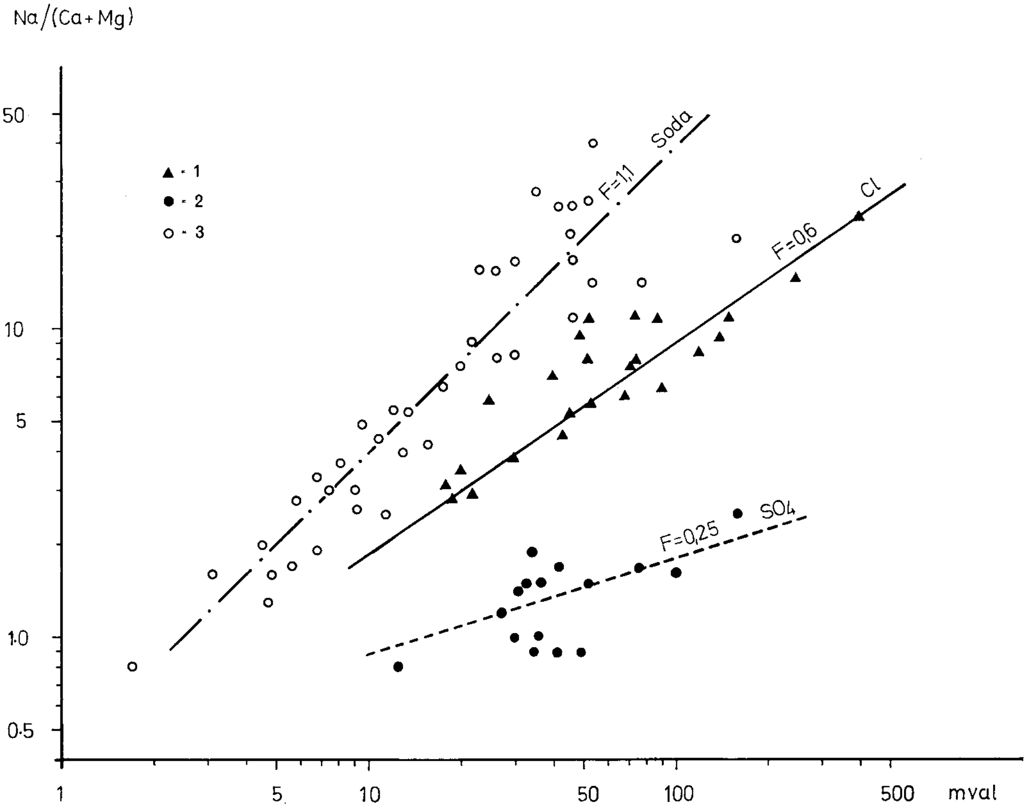

Fig. 8: The relative increase of sodium with rising concentration in waters of the report area. 1 = chloride type; 2 = sulphate type; 3 = waters containing soda.

Relative Natrium-Zunahme mit steigender Konzentration in Gewässern des Untersuchungsgebietes. 1 = Chlorid-, 2 = Sulfattypus; 3 = Gewässer mit Sodagehalt.

Although the trend of sodium increase with rising salinity is general, the intensity of the process is not the same with different anionic types of water. To demonstrate this fact the ratio alkali: alkaline earths is plotted against concentration (as mvalsum/litre) in Fig. 8. The steepest relative sodium increase is found in springs containing soda; the average increase factor, calculated from all available data is 1.1. Next follow the chloride springs with a factor of 0.6, and in waters where the prevalent anion is sulphate the relative Na-ratio increases only at the rate of 0.25. The deviation of the individual values from the calculated average is, however, considerable in each group.

The same graphic representation as in Fig. 7 is used in Fig. 9 for the relative anionic composition. Here, however, the trend of change with rising concentration (again indicated by arrows) is not uniform as it is with the cations: two distinct ways leading to typical chloride or sulphate waters, respectively are clearly apparent, in spite of the existence of intermediate types. In general, springs containing soda belong to the intermediate type, because of their comparatively high ratio of alkalinity, and do not exceed a salinity of 40 mval/l. There exist, however, quite a few chloride waters which show a surplus of alkalinity over alkaline earths, and this type may reach a salinity of 50—80 mval/l. In sulphate waters no soda occurs, except for a few springs with an SO_4-ratio of only 50% and a low salinity. The distribution of waters of the chloride and sulphate type within the report area is correlated to geological features (cf. Chapter IV).

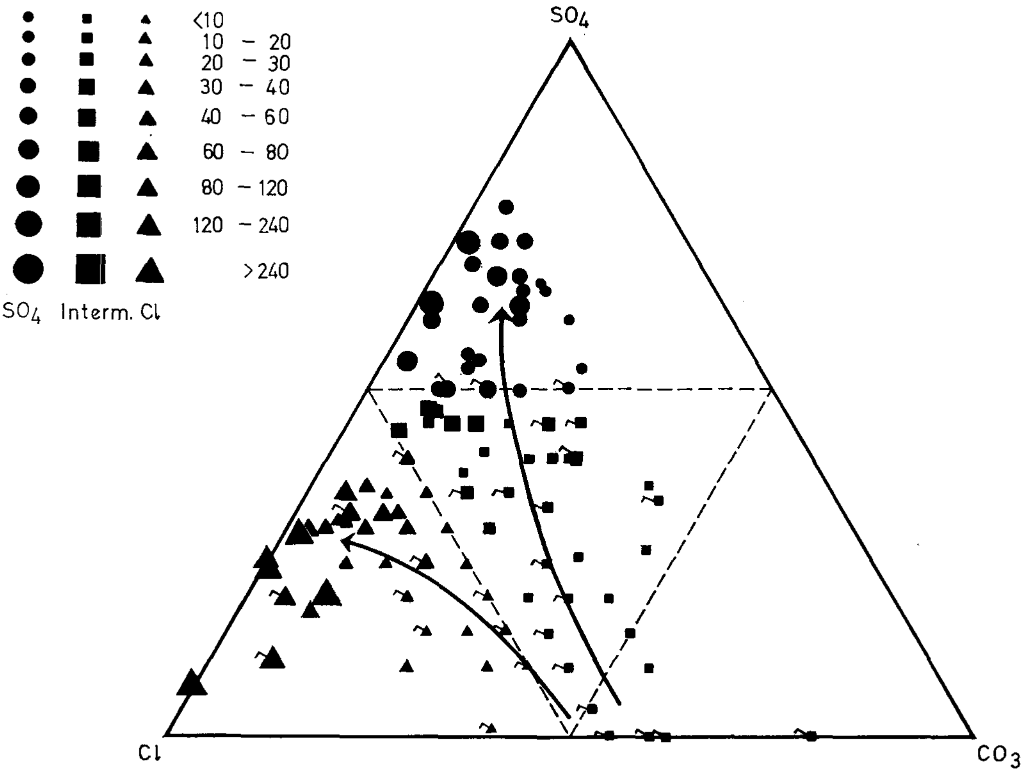

Fig. 9: Triangular coordinate diagram of the anionic composition of waters in the report area, arranged on the same scale for the three types. Symbols as in Fig. 7.

Anionenzusammensetzung der Gewässer im Untersuchungsgebiet, dargestellt im Dreieckskoordinaten-Diagramm auf einheitlicher Skala für alle drei Anionentypen. Zeichen wie in Fig. 7.

The relative decrease of carbonate with rising concentration, however, is general. Considering what we found about the chemical composition of precipitation water, one cannot expect even the qanats with a very low salinity (5—8 mval/l) to have much more than 50% CO_3, and since alkalinity does not rise with concentration (cf. Plate I) the relative decrease is very rapid. For the chloride type the end-point seems to be at a relative anionic composition of 0 CO_3/70—75 Cl/25—30 SO_4 mval%, which corresponds well to other Iranian endorheic waters (Lake Resajeh 0/60/40, Lake Hamun 0/68/32, Caspian 1/70/29 mval% for CO_3, Cl, SO_4, respectively). Waters resembling the sulphate type in the report area with an average anionic composition of 5/25/70 mval% are reported elsewhere chiefly from Tibet (Hutchinson, 1937 b).

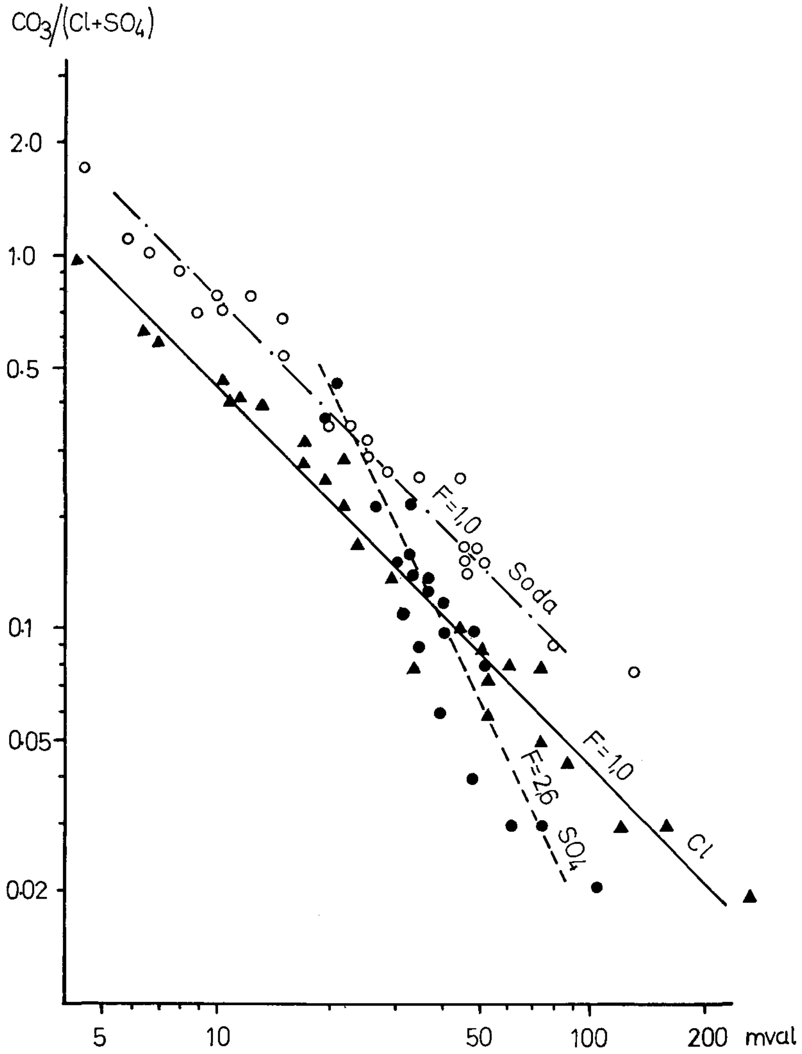

Fig. 10: The relative decrease of carbonate with rising concentration in waters of the report area. Symbols as in Fig. 8.

Relative Karbonatabnahme mit steigender Konzentration in Gewässern des Untersuchungsgebietes. Zeichen wie in Fig. 8.

There is no correlation to the anionic composition of ENGELHARDT' interstitial formation waters, all of which have 99—100% Cl. According to the solubility of various salts in water (Fig. 6) the general trend of changes in relative ionic composition with rising concentration would be from carbonate to sulphate to chloride, and from calcium to magnesium to sodium. The interstitial formation waters (with salinities between 2000 and 6000 mval/l) represent the final stage of this trend. The most concentrated springs in the report area (120—260 mval/l) reach this stage on the cationic, but not on the anionic side. A hint as to how the process continues is, however, provided by a salt river of the area (Plate I, 1 a, Nos. 8 and 12), where the anionic composition attains a ratio of 0.2 CO_3/93 Cl/7 SO_4 *(at a salinity of 1450 mval/l).*

The relative decrease of carbonate for chloride and sulphate springs and for springs containing soda is shown in Fig. 10 in an analoguous presentation to Fig. 8: the ratio $CO_3/(Cl+SO_4)$ is plotted against the mval-sum. The decrease is most pronounced in sulphate waters, the average decrease factor being 2.6. Both chloride and soda springs show the same decrease with an average factor of 1.0; the ratio $CO_3/(Cl+SO_4)$, however, is about twice as high in springs containing soda.

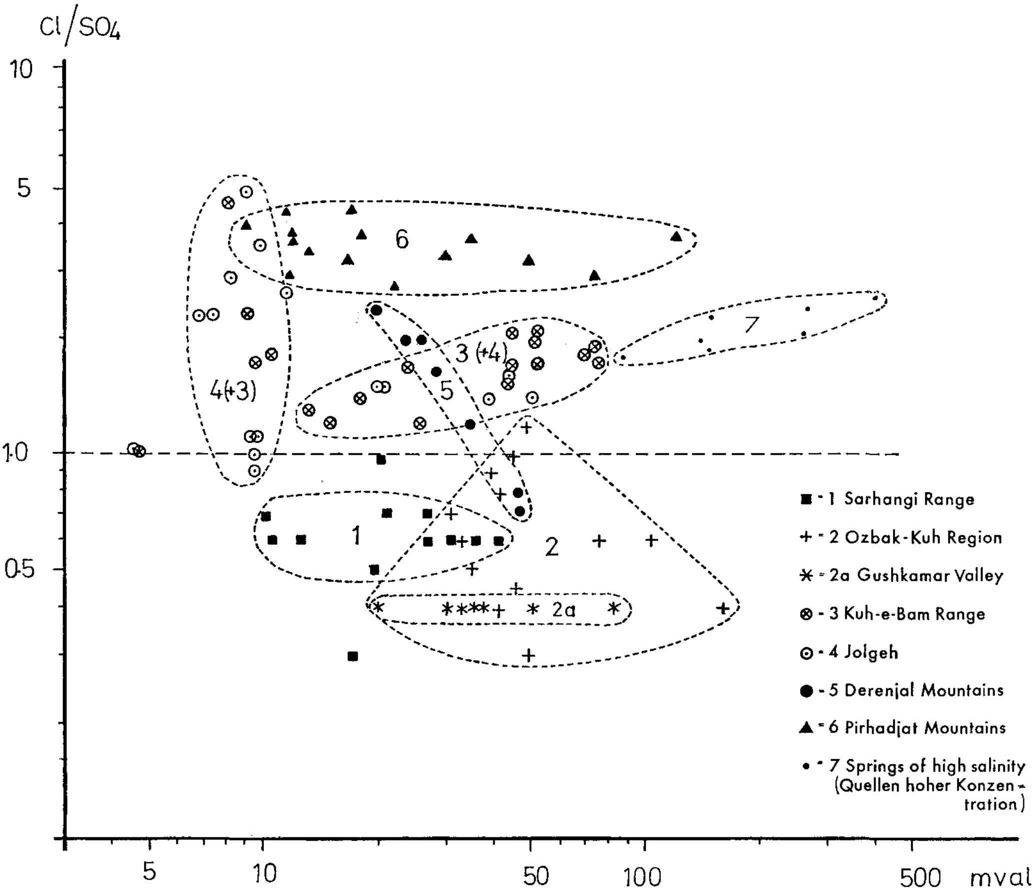

Fig. 11: Correlation between the ratio chloride to sulphate (Cl: SO_4), concentration (mval/l) and geographical location of springs and qanats in the report area. For explanation see text.

Zusammenhang zwischen dem Chlorid-Sulfat-Verhältnis (Cl: SO_4), der Konzentration (mval/l) und der geographischen Lage von Quellen und Qanaten im Untersuchungsgebiet. Die Zahlen beziehen sich auf Gruppen in Pl. I. Erklärung im Text.

Finally, we found no correlation between concentration and the ratio chloride: sulphate (Fig. 11); taken as a whole, the individual values form a cloud without any distinct general trend. Another fact is, however, noticeable: the different geographical groups in which we arranged the chemical data in Plate I can be detected more or less clearly in this presentation. In other words, springs of the various mountain ranges show characteristic Cl/SO_4-ratios as well as characteristic ranges of salinity.

The best-defined group comprises the springs of the westernmost mountain range of Pirhajat (Pl. I, Group 6), all of which have a Cl/SO_4-ratio of ~3.0—4.0 in spite of a wide range of salinity.

Most of the springs of the Sarhangi Mountains (Pl. I, Group 1) also have a characteristic Cl/SO_4-ratio of ~0.6—0.7 and a salinity ranging from ~10—50 mval/l; there are, however, exceptions due to local edaphic conditions (cf. Chapter IV, 1 and 2 a). The springs of the Ozbak-kuh Mountains (Group 2) show considerable diversity, but nearly all of them have a Cl/SO_4-ratio lower than 1.0; within this group the springs of the Gushkamar Valley (cf. Chapter IV, 2 a) are strikingly uniform.

Group 4 includes qanats of the settlement of Jolgeh and of its aquifer (cf. Chapter IV, 1). This group is characterized by a low salinity and a variable Cl/SO_4-ratio ranging from ~1.0—5.0. Several springs and short qanats of the Kuh-e-Bam Ridge (Group 3) coincide with Group 4.

In the group of Kuh-e-Bam (Pl. I, Group 3) comprising springs and qanats of ~10—80 mval/l salinity there is a slight increase of the Cl/SO_4-ratio with rising concentration (factor ~0.15). The same trend can be seen with salt springs of high concentration originating on geological faults; all of them lie in a close group on the plot, independent of their geographical location. The only group where the Cl/SO_4-ratio decreases with rising salinity is that of the Derenjal Mountains (Pl. I, Group 5); local conditions (Gypsum beds) probably affect the two most concentrated springs of this group. The most obvious feature common to all springs of this group, however, is their soda content (cf. Chapter IV, 2 d).

The bearing of geology on waters of the report area will be discussed in detail in the following chapter.

IV. Hydrogeology

In the preceding chapter we have tried to point out that concentration as such has a specific influence on the chemical composition of natural waters in the report area. But in addition, the geological pattern of the area is of great importance for the composition of natural waters — as the diagram in Fig. 11 suggests.

To show this influence we have plotted the ionic composition of as many waters as technically possible on a simplified geological map (Plate II). For this graphic presentation we used the ionic diagrams introduced into limno-chemistry by MAUCHA (1932), though slightly modified for our special purpose. Since we analysed three major cationic and three major anionic constituents only, we constructed a polygon of six equal sectors representing the three cations on the right, and the three anions on the left side. The length of each sector is proportional to the equivalent percentage of the respective ion. This diagram gives at a glance an impression of the relative ionic composition of the water in question. Fig. 12 explains the basic idea of these diagrams.

The salinity (concentration) given in millival/litre (mval/l) is indicated with each diagram. To show this more clearly we have divided the waters into six groups according to their salinity. Group 1 (under 10 mval/l) comprises good drinking waters, Group 2 (10—15 mval/l) waters of medium quality. At a salinity of about 15 mval/l the general biological aspect of the waters changes from that of a fresh water to that of a salt water. Waters belonging to Group 3 (15—30 mval/l) are still used for man, animals and fields, while waters of Group 4 (30—60 mval/l) are very poor waters used — with a few exceptions — for animals and for watering date-palms only. Waters of Group 5 (60—120 mval/l) are, in general, salt waters unusable for any purpose. Finally, Group 6 (over 120 mval/l) comprises waters which have a salinity up to 400 mval/l.

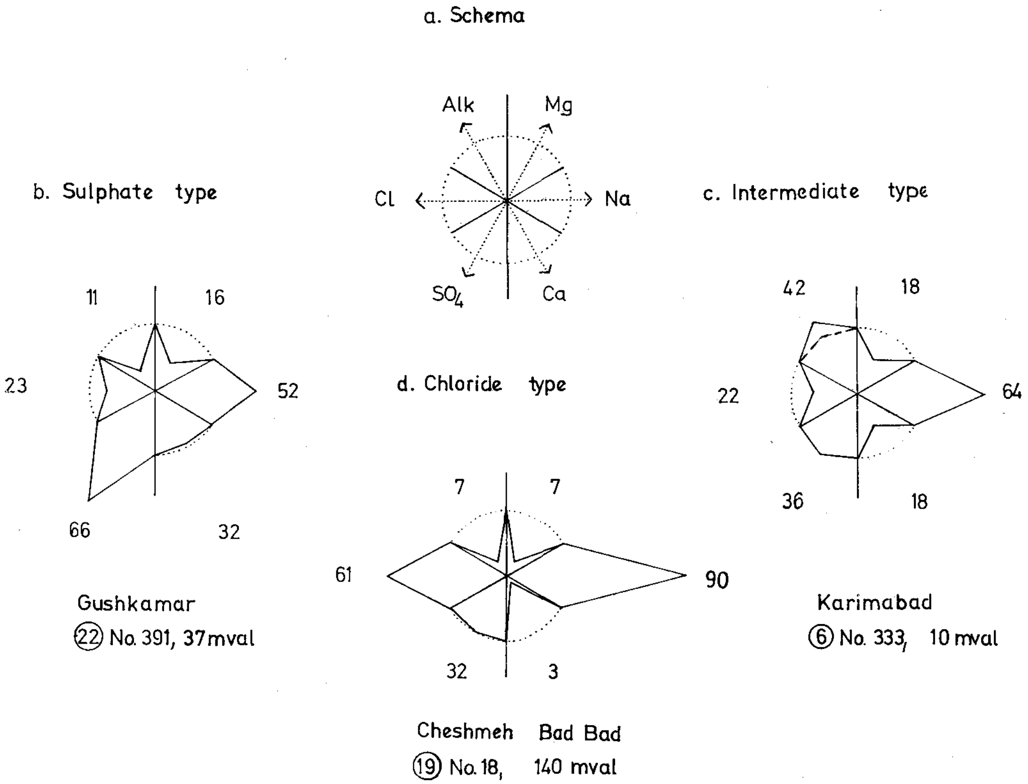

Fig. 12: Asteroid diagrams (modified after Maucha 1932) representing major ionic composition in equivalent-%.
a: Order of ions; the radius of the circle represents within each sector 33 mval-% of the respective ion.
b, c, d: examples of the main types of anionic composition, occuring in the report area; the respective percentage is plotted on the line bisecting each field, values above 33% lying outside, those below 33% lying within the circle; the broken line in the alkalinity sector in fig. c indicates the amount of soda [Alk. — (Ca+Mg)].
Numbers in circle refer to numbers of samples shown in the map (Plate II).

Sterndiagramme (verändert nach Maucha 1932) zur Darstellung des Verhältnisses der Hauptionen in Aequivalent-%.
a: Anordnung der Ionenfelder; der Radius des Kreises gibt in jedem Sektor 33% des betreffenden Ions an.
b, c, d: Beispiele der Haupttypen von Anionen-Zusammensetzung, die im Untersuchungsgebiet auftreten; auf der Mittellinie jedes Feldes sind die betreffenden Aequivalent-% vom Kreismittelpunkt aus aufgetragen, Werte über 33% liegen außerhalb, solche unter 33% innerhalb des Kreises; die gestrichelte Linie im Alkalinität-Sektor Fig. c gibt die Menge Soda an [Alk — (Ca+Mg)].
Die Nummern im Kreis entsprechen der Proben-Numerierung in der Karte (Plate II).

As we have no reliable figures concerning the quantity of water discharged from qanats and springs, we have shown on the map the size of watered and cultivated areas around the villages, corresponding approximately to the amount of water available and usable for agriculture (waters of Groups 1—3).

For hydrogeological purposes we classify the waters of the report area as follows:

1. Waters of Low Salinity (below 15 mval/l)

2. Waters of Higher Salinity
   (a) Sulphate Waters
   (b) Intermediate Sulphate-Chloride Waters
   (c) Chloride Waters
   (d) Waters Containing Soda

1. Waters of Low Salinity

The larger areas of cultivated land lie around the Shotori Range, on both sides of Kuh-e-Bam, at Pirhajat and in Jolgeh. Compared with these, all other parts of the area are very poor in water and especially poor in water of low salinity.

This is due to geological reasons because thick masses of dolomite and limestone occur in the Shotori—Kuh-e-Bam Range and in the southern part of the Pirhajat Mountains. In such limestone and dolomite masses rain-water can percolate quickly enough not to run off on the surface of the rocks. The water is stored there in fissures and internal cavities and may be transported over long distances within the limestone and dolomite bodies (e.g. along faults) until it either emerges into the open or discharges into the gravel fans of the dasht. Consequently, springs may occur at the foot of mountains built up of limestone or dolomite yielding a considerable amount of water. However, the bulk of this water feeds aquifers in the gravel fans of the dasht.

This is the case all around the Shotori Range. The qanats north and south of Tabas, those of Boshruyeh and of the villages at the northern end of the Shotori Range get the water from the Permo-Triassic Tabas Group (well-bedded limestone and dolomite) and from the Upper Jurassic Esfandiar Limestone (massive algal limestone), which, taken together, make up a large part of that range. Virtually, also the bulk of the water which supplies the villages of Jolgeh comes from the Shotori Range (cf. below).

Tabas itself is supplied with water by the Sardar River, which rises in the Shotori Range. Unfortunately, we have no analyses of waters discharged by qanats of the Tabas Basin, nor any from the Boshruyeh region; but the analysis of the Sardar water (No. [75])[1]), that of a hot spring located in the Sardar Valley, and those of waters of qanats situated at the northern end of the range (Nos. [71], [72], [73], [40]) are sufficient to characterize the waters which come from the large water storage of the Shotori Range.

The water of the Shotori Range has a low salinity, the concentration being hardly more than that of sang-ab (region of Deh Mohammad, Nos. [71], [72], [73]). The ionic composition of these waters is also very similar to that of sang-ab or rain-water. The carbonate rocks have no influence on the quality of the water. The water of the Sardar River (No. [75]) is somewhat altered by sulphate (possibly originating from Upper Jurassic marls), that of Esfaq (No. [40]) by chloride (possibly from Neogene evaporites).

At the northern end of the Shotori Range (region of Deh Mohammad) the north-northwest striking longitudinal faults of the range come up to the dasht. There water emerging from that fault system feeds a large aquifer, which extends northwards to the Great Kavir. This aquifer supplies about fifty villages with water, including the agglomeration of settlements called Jolgeh. The Shotori Range is thus the main intake area of the whole Tabas—Shirgesht—Ozbak-kuh region although it is situated in the very south, where precipitation is the lowest of the whole area.

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[1]) Numbers in angular paranthesis refer to numbers of samples shown in the map (Plate II).

To a minor extent, the Kuh-e-Bam Ridge, which consists of Esfandiar Limestone, serves as feeder for several qanats on both sides of the ridge, located at Deh Now-Bam (No. [28]) and in the Neygenan region (Nos. [37], [35], [36]). The qanats originating close to the ridge produce water of high quality (Eshqabad, No. [37] and Bam, No. [28]; see also Plate I/3 c, sample No. 129).

As for the Pirhajat Mountains, the geological conditions are similar to those of the Shotori Range. The mountains continuing southward beyond our report area consist of dolomite and limestone, chiefly of the Permo-Triassic Tabas Group. The springs of Pirhajat and Bistun (Nos. [61], [62]), and likewise the small spring of Abdulabad (No. [60]) and that of Kalshaneh (No. [64]) on the eastern side of the mountains are situated at big fault zones, which cut into the mountains either south-southwestward (longitudinal faults) or south-southeastward (transversal faults). It is obvious that the intake rocks of the water discharged by these springs are the masses of dolomite and limestone exposed in the south, and that the water is carried northward along the fault zones just mentioned. (Cf. also Plate I/6 a, sample Nos. 182, 188, 201.)

The water of the springs mentioned above is somewhat different from that of the Shotori Range: the concentration is higher (10—22 mval/l), and so is the ratio of Na and Cl. This is very probably due to the Liassic sandstone and shale, which covers the Permo-Triassic rocks in the Pirhajat Mountains (cf. Chapter IV, 2 c). The vicinity of the Great Kavir may also play an important rôle. Nearly all these waters contain a relatively high amount of soda ($NaHCO_3$); this we shall discuss later (Chapter IV, 2 d).

Wherever we found water of low salinity in the Derenjal and Ozbak-kuh Mountains the intake rock of these small springs is dolomite or limestone. This is the case with Cheshmeh Senjedu (No. [17]) and Cheshmeh Mohammad Beik (No. [18]) located northeast of the Ozbak-kuh mine, where the mountains consist of Devonian dolomite and limestone, and equally with Cheshmeh Chekab (No. [57 a]), in the Derenjal Mountains, where a dolomite body of the Cambrian Kalshaneh Formation is the intake rock. The discharge of these three springs is too small to support settlements.

Most of the water stored in limestone and dolomite masses is discharged into the gravel fans of the dasht. The dasht cover can be divided into three formations (Ruttner et al., 1968, p. 104):

1) the oldest gravel fans, terraces at the foot of the mountains
2) fossil gravel fans of the actual dasht
3) recent gravel fans.

Of these only the recent gravel fans are active at present. They are partly flooded after heavy winter and spring rains and gather the gravels of the dry river beds which join the dasht as they leave the mountains. Towards the kavir basins the recent gravel fans interfinger with kavir deposits. Close to the kavir the recent gravel fans consists of silt, sand and fine, well-rounded gravel, increasingly mixed with salty clay lower down. The recent gravel fans serve as the main aquifers of the dasht.

The fossil gravel fans, on the other hand, are very distinctly separated from the kavir: they do not interfinger with kavir sediments, but dip below them and are definitely older than the recent salt clay of the kavir surface (H. Bobek, 1955, 1959, 1961 a). These old gravel fans are mostly poor in ground-water.

The big aquifer mentioned above, which is fed chiefly by water from the Shotori Range, is bound to a large recent gravel fan, which occupies central parts of the dasht between the Derenjal Mountains and the Kuh-e-Bam Range. Between the Deh Mohammad region and Jolgeh all qanats of the villages are dug in that gravel fan (cf. Plate II).

At the head of this aquifer the water of Malvand (No. [73]) comes close to rainwater in its chemical constitution. This represents approximately the chemical constitution of the water discharged from the Shotori Range into the gravel fan. On its underground way downward to the north the water changes its constitution: the salinity increases slightly (from 4.5 to nearly 10 mval/l) and so do the sodium and the chloride content at the costs of the other constituents (Nos. [72], [71], [51], [50], [49], [48], [47]).

However, this is true for the axial part of the aquifer only. Marginal parts of the aquifer are affected by water of higher salinity. At the western side of the aquifer this water comes from the Paleozoic Derenjal Mountains (qanats of Mahmudabad, No. [46] and Vakilabad, No. [45]); at its eastern side the aquifer is altered by water coming from Jurassic sandstones and shales exposed in the region northwest of Kuh-e-Bam (Deh-e-Luk, No. [42], Deh-e-Alkhani, No. [43]). In all these cases the increase in salinity corresponds in the main to an increased content of Na, SO_4 and Cl ions.

The highest salinity (44.2 mval/l) in the Jolgeh region was found in the water of a qanat supplying a village situated very close to the kavir (Chah-e-Kavir, No. [41]); but even there the water is altered by a lateral inflow from the east rather than by salt water from the kavir, judging by the ratio of ions in the water (cf. the diagrams Nos. [42] and [43]).

Jolgeh is located at the lower end of the recent gravel fan just above the area where it interfingers with kavir deposits. There the material of the fan has become very fine-grained and contains a large amount of clay. This material dams back the groundwater, and an underground reservoir is formed, which is exploited by the numerous qanats of Jolgeh. Higher up — south of Jolgeh — sand dunes may store some rainwater and add this to the ground-water; the qanats of a few small villages are arranged round the dunes (Nos. [48], [49], [50], [51]). To this group belongs also No. [44]; this qanat is 9 *km.* long and nearly reaches the sand dunes. Altogether, the aquifer is about 50 *km.* long (distance Malvand—Jolgeh).

On a smaller scale, we found a similar ground-water flow on the dasht east of Kuh-e-Bam (Neygenan region), and here again the water of Eshqabad (No. [37], salinity 5.8 mval/l) resembles the water of rock pools, whereas 10 *km.* further down to the east qanats at and near Neygenan discharge waters of twice the salinity (No. [35]; 9.7 mval/l, No. [36]: 12.8 mval/l) and with an increased ratio of sodium and sulphate. There Neogene evaporites may affect the water.

Crystalline rocks, too, yield water of relatively low salinity, but the discharge of springs and the influx into the gravel fans is so poor that only a few tiny settlements exist in and around those parts of the Sarhangi—Zeber Kuh Range which consist of crystalline rocks. Examples of such waters are the short qanats of the one-family settlements of Chah Paliz (No. [5]) and Karimabad (No. [6]). They are characterized by a salinity somewhat above 10 mval/l and by the main constituents Na, CO_3 and SO_4 (cf. Chapter IV, d). The chloride ratio is relatively low (around 20%).

2. Waters of Higher Salinity

(a) Sulphate Waters

All waters containing a ratio of more than 50% SO_4 ions are clearly bound to special geological conditions in our report area. This is true especially of the Ozbak-kuh Mountains, where most of the springs (or short qanats) discharge sulphate water (Nos. [13], [15], [16], [20], [21], [22], [23][1]); see also Plate I/2 b, sample Nos. 119, 126, 362, 160; 2 c, sample No. 67; 2 d, sample Nos. 28, 388, 393, 399, 402). The discharge of all those springs is small, at the best sufficient to supply a few poor mountain villages.

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[1] Numbers in angular paranthesis refer to numbers of samples shown in the map (Plate II).

The sulphate content is derived from Lower Devonian Red Beds, named Padeha Formation, and especially from a gypsum bed of 50 metres on top of that formation. This bed is thickest in the middle part of the Ozbak-kuh Mountains (Gushkamar Valley), which explains the high and uniform SO_4 ratio of the waters in this part of the area (cf. Chapter III, 2 b and Fig. 11).

With one exception (No. [23]), the salinity of those waters is not less than 30 mval/l and rarely exceeds 60 mval/l. These waters are therefore just at the borderline of what can be used as drinking water for man and beast. The few springs with a salinity higher than 60 mval/l ([20], [21]; Plate I/2 c, sample No. 67) are situated at local gypsum outcrops or bound to a fault; they have an extremely small discharge *). All sulphate waters contain a certain amount of Mg (mostly 10—20% of the cations), which, however, is nearly always below the Ca-ratio.

This type of sulphate water is bound to Paleozoic rocks. We found it also in the southernmost part of the Sarhangi—Zeber Kuh Range (No. [7]). There, a narrow strip of Paleozoic is faulted between crystalline rocks forming the northwestern continuation of the Ozbak-kuh Mountains.

We found no sulphate waters of this type in the Paleozoic Derenjal Mountains, which form the southwestern continuation of the Ozbak-kuh Range. The reason for this is the general lack of evaporites in the Padeha Formation in this area. In the northern part of the mountains, however, some gypsum, though poorly developed, exists, and there, in fact, we found a sulphate ratio of 50% in the water of Cheshmeh Kharmayu (No. [52]).

A second group of sulphate waters occurs in the northern part of the Sarhangi—Zeber Kuh Range. Waters there have a low salinity (below 30 mval/l), a sulphate ratio of 50—60% and a Mg-ratio above 20% (20—35%), the latter being higher than the Ca-ratio (Nos. [1], [2], [3]). The qanat of Narm (No. [1]) supplies a large village, and other similar villages lie farther east.

The relation to the geological situation is less clear here than in the Ozbak-kuh Mountains: the relatively greater discharge and the low salinity of the waters are probably due to Infra-Cambrian dolomite bodies, which form the neighbouring mountains. The magnesium and sulphate content may be derived from evaporites of the Neogene Upper Red Formation, which crops out north of the Sarhangi—Zeber Kuh Range.

(b) Intermediate Sulphate-Chloride Waters

In addition to the sulphate waters proper we found an intermediate type of waters, which in their anionic composition show an SO_4-ratio of 30—45% and a Cl-ratio not exceeding 50%. This type, for chemical reasons, occurs in waters of low concentration; the waters have a high CO_3-ratio (cf. Chapter III). With higher concentration the same type can result from sulphate and chloride waters becoming mixed, or — again for chemical reasons — from sulphate waters becoming more concentrated due to a very small discharge.

There are, however, waters of this type, the constitution of which is definitely related to geological conditions. This is true particularly in the Kuh-e-Bam Range for waters whose catchment area consists of Upper Jurassic marls — partly interbedded with limestone — and Red Beds (Baghamshah Formation, Ghal 'eh Dokhtar Formation, Garedu Red Beds). These beds contain a small amount of evaporites and produce a very specific type of water in the springs (Nos. [31], [32], [33], [34]) the ratio $CO_3 : Cl : SO_4$ is about equal (sulphate, for the most part, prevailing slightly),

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*) Waters of high concentration of the chloride type occur also in the Ozbak-kuh Region; they are dealt with in Chapter IV, 2 c.

sodium predominates absolutely over calcium and magnesium, and the salinity is relatively low, ranging between 15 and 30 mval/l. There is generally also a certain amount of soda. The qanat of Abkhorak (No. [29]) yields water of the same type and is thus quite different from the near-by qanat of Bam (No. [28]).

From the geological point of view, the occurrence of this sulphate — chloride — carbonate water in the Kuh-e-Bam Range is interesting in so far as there are also waters of extremely low salinity delivered from the Upper Jurassic Esfandiar Limestone of the Kuh-e-Bam ridge proper (cf. Chapter IV, 1). The occurrence of two entirely different types of water in the Ku-e-Bam Range reflects excellently the peculiar coexistence of different interfingering facies types of the Upper Jurassic in that range.

The poor waters of the Paleozoic of the Derenjal Mountains belong to the same sulphate-chloride type (Nos. [54], [57 b]). There the salinity rises to 50 mval/l; the water of Cheshmeh Chekab, (No. [57 a]), on the other hand, trickling from fissures of a dolomite body in the Cambrian Kalshaneh Formation, has a salinity of no more than 11.3 mval/l. The Cl-ratio of Cheshmeh Shorm (No. [53]; salinity 51.8 mval/l) is somewhat above 50%.

The intermediate waters of the Paleozoic Derenjal Mountains differ distinctly from the sulphate waters of the Paleozoic Ozbak-kuh Mountains; the reason for this is, as pointed out above (Chapter IV, 2 a), the unequal distribution of evaporites in the Lower Devonian Padeha Formation. On the other hand, the intermediate waters of the Paleozoic Derenjal Mountains are very similar to those of the Jurassic Kuh-e-Bam Range. There is a supply of SO_4 ions from the underground in both areas; but this supply is low compared with that of the Ozbak-kuh Mountains.

All the waters of the Derenjal Mountains are characterized by a uniformly high content of soda (Nos. [52], [53], [54], [57 a], [57 b]; Plate I/5, sample Nos. 215, 149). This soda content can be noticed also in those parts of the big aquifer of Jolgeh which are affected by the Derenjal waters (Nos. [45], [46]; Plate I/4, sample No. 173). Similarly, the intermediate sulphate-chloride waters of the Kuh-e-Bam Range contain a considerable amount of soda (cf. Chapter IV, 2 d).

Sulphate-chloride waters occasionally occurring in other regions result from mixing and have no direct relation to special geological patterns. The water of Cheshmeh Tohu (No. [4]) south of Kuh-e-Sarhangi may be a mixture of water coming from crystalline rocks and sulphate waters like those found in the northern part of the Sarhangi—Zeber Kuh Range. Cheshmeh Kerkesu (No. [12]) and Cheshmeh Shir (No. [24]) of the Ozbak-kuh Mountains yield sulphate water mixed with chloride water possibly circulating in fault zones, or derived from Neogene evaporites.

(c) Chloride Waters

Waters with a preponderance of chloride (more than 50%) in their anionic composition are distributed all over the area. There is a general trend towards a relative increase of sodium, and eventually also an increase of the Cl-ratio as the concentration rises (cf. Chapter III, 2 b). Accordingly, all waters of a salinity exceeding 120 mval/l are chloride waters. With these we shall deal at the end of this chapter.

Apart from them, we found chloride waters particularly in the regions built up of Jurassic sandstones, though these waters also contain a considerable amount of sulphate.

The hilly region between the Kuh-e-Bam Range and the Ozbak-kuh Mountains consists of slightly metamorphosed sandstones and shales of the (?) Upper Jurassic. Water samples taken from this region show a strikingly uniform composition: around 60% Cl, somewhat over 30% SO_4 and, on the cation side, a predominance of Na at a salinity of a little more than 50 mval/l (Nos. [26], [27]). This water supplies two poor settlements (Abid, Khadrin). It penetrates into the dasht and affects marginal parts of the large aquifer of Jolgeh (Nos. [43], [42], [41]), as pointed out above (Chapter IV, 1).

South of Deh Now-Bam the small spring Cheshmeh Khormayu (No. [30]) has a similar constitution, but a higher salinity (nearly 80 mval/l). This spring has its source in Liassic sandstones and shales.

All the waters of the Pirhajat Mountains are chloride waters. Here thick Liassic shales and sandstones (Shemshak Formation) cover Permo-Triassic dolomite. Small springs coming directly from these shales and sandstones (Nos. [63], [65]) are characterized by almost identical diagrams (20 Alk/55 Cl/25 SO_4 and 95% Na, or more), though they differ in their salinity (ranging from 23 mval/l to 50 mval/l). But also the waters discharged from the Permo-Triassic dolomite show a very similar relative ionic composition (Nos. [60], [61], [62], [64]), whereas the salinity range varies between 11 and 21 mval/l. The chloride-sulphate water of the Liassic Shemshak Formation has apparently affected the water stored in the underlying masses of dolomite. This would also explain the higher salinity of this water compared with that of the Shotori Range.

Another source of chloride waters are the Neogene evaporites. These evaporites are exposed at the foot of the mountains and appear also in many places of the plain below the dasht cover. Very probably, they form a flat and shallow sheet below the gravel fans over large areas of the dasht. These evaporites are possibly the remnants of an old (Pliocene ?) kavir.

Genuine Red Beds comparable to the Upper Red Formation of northern Central Iran (Miocene) crop out to an appreciable extent only in the extreme south (near Tabas) and in the extreme north (north and east of Ozbak-kuh) of our report area. They may have affected the water in the northern part of the Sarhangi—Zeber Kuh Range (cf. Chapter IV, 2 a).

Unfortunately we have no analyses of these Neogene evaporites. They are obviously very rich in NaCl, for wherever water comes into contact with them it turns into a chloride water of high salinity.

This is the case with two rich springs at the northwestern foot of the Pirhajat Mountains: Cheshmeh Gowmar (No. [58]) and Cheshmeh Talkhab (No. [59]). The water of both springs undoubtedly comes from the Permo-Triassic dolomite below the Liassic sandstones and shales. Like other waters of the Pirhajat Mountains it contains 20% SO_4, but the salinity is high (120 mval/l and 70 mval/l, respectively) and its relative Cl-content amounts to 75%. Cheshmeh Gowmar springs from the soil at the foot of the mountains and flows for a while over an old gravel fan before it cascades down to the level of the recent dasht. Its water may be mixed with water circulating in border faults (see below), but Neogene evaporites crop out close to both springs.

In and close to Shirgesht the water is also affected by Neogene evaporites, though Jurassic marls and Red Beds, too, may play a considerable part, judging from the high SO_4-ratio (25—30%, Nos. [67], [68]). The same is true of the qanat waters near Esfak (Nos. [38], [39]).

In the region West of Ozbak-kuh Garqab (No. [10]; 59 mval/l, 7 Alk/62 Cl/31 SO_4) and Chah-e-Tom (No. [9]; 69 mval/l, 9 Alk/73 Cl/18 SO_4) are chloride waters strongly influenced by Neogene evaporites. Chah-e-Tom is situated at the western edge of Kuh-e-Sefid, very close to the kavir.

Springs discharging chloride water of extremely high salinity (above 120 mval/l) are related to the structural pattern of the area: they are situated at big faults or fault zones and are obviously fed by water of high concentration circulating in these faults. Frequently, these faults are border faults of mountain ranges continuing into the kavir. The quantity of water discharged by such springs is mostly very small.

Cheshmeh Gerdab west of the Ozbak-kuh mine (No. [11], 140 mval/l) is a "mineral spring" — if one can use the term in this area — producing gas bubbles and forming a small pool in the plain. Cheshmeh Bad Bad ('bad wind spring') is situated at a fault zone in the Ozbak-kuh Mountains (No. [19]. 140 mval/l). The water of this chloride spring contains no less than 32% SO_4 and is probably mixed with sulphate water of the neighbourhood.

A typical 'border-fault spring' is the salt spring near Huk (No. [14]) located at the eastern edge of the Ozbak-kuh Mountains. The fault is a very strong one; the water of this spring has a salinity of 265 mval/l and contains 32% SO_4, resembling closely in this respect Cheshmeh Bad Bad. Probably the springs Cheshmeh Kerkesu (No. [12]) and Cheshmeh-e-Sangiche (No. [8]) belong to the same type of border-fault springs though their salinity is lower (48 and 88 mval/l, respectively). Another spring of this type is Cheshmeh Estalkhaq (No. [25]) in the southern part of the Ozbak-kuh Mountains (30% SO_4). In all these springs the relative content of Cl varies between 60 and 80%, that of Na between 75 and 95%.

Finally, the salt streams carry chloride water of high salinity. To demonstrate the effect of evaporation we have put two of them on our map. One of them is a tiny streamlet at the southeastern corner of the Derenjal Mountains (No. [56]), the other a stream in a valley southwest of Shirgesht (No. [69]). They are very similar in their composition: 95 and 87% Na, 75 and 70% Cl, and still 25 and 20% SO_4, respectively, with a salinity of 400 and 335 mval/l, respectively. This is the highest concentration we ever found in our report area.

We regret very much not to be able to offer an analysis of salt water from the kavir west and east of our report area. As an indication of the probable constitution of the final stage reached by the salt waters of the region we present an analysis of a sample taken from the salt river of Doruneh, which flows into the Great Kavir north of Sefid Kuh. This water has a salinity of 1450 mval/l and an ionic composition of 95 Na/0 Ca/5 Mg—0.2 Alk/93 Cl/7 SO_4. Fifty kilometers higher up, the water of the same river had a salinity of 250 mval/l, and an ionic composition of 95 Na/0 Ca/5 Mg—1 Alk/75 Cl/24 SO_4, roughly corresponding to the chemical constitution of the two salt streams in the report area mentioned above.

This may suggest the development the water undergoes as concentration proceeds. The final product is a solution of NaCl containing a small amount of CO_3, Mg and SO_4. Very probably, this is also the composition of the kavir salt *). Dust of this salt dissolved in rain-water provides the starting-point of the whole cycle (cf. Chapter III).

(d) Waters Containing Soda

In nearly half of the analysed samples from springs and qanats in the report area (cf. Plate I) we found an excess of alkalinity over alkaline earths (Ca+Mg) indicating the presence of alkali carbonate or hydrocarbonate, or that of an alkali salt of some other weak acid (e.g. SiO_2); this is what we comprise under the term "soda content".

It has already been mentioned (Chapter III, 2 a, b) that rain-water of this desert area carries a relatively high proportion of such alkali salts, obviously derived from salt dust brought into the atmosphere by rising air currents over the Great Kavir. Where this precipitation water percolates directly into fissures and cavities of limestone and dolomite its soda content can still be detected in springs and qanats of aquifers fed from these rocks.

This is the case in the upper part of the Jolgeh aquifer (Nos. [71], [72], [73]; Pl. I, 7/39) and equally with No. [48] in the middle part of this aquifer, and even with several qanats in the central portion of the settlement of Jolgeh (No. [44]; Pl. I, 4/174); it also applies to short qanats rising from the Kuh-e-Bam ridge to the east (Nos. [35], [37];

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*) According to B. Asklund (1927), a sample of a white salt crust collected by Sven Hedin in the Great Kavir at a place called Dagh-daghu (about 160 kilometers west of our report area) had the following composition: 97.75% NaCl, 0.05% KCl, 0.15% MgCl, 1.56% $CaSO_4$.

Pl. I, 3 c/106, 107, 129). The same is true of the southernmost springs and qanats in the Pirhajat Mountains (Nos. [62], [61]; Pl. I, 6 a/201, 182, 188, 191, 199 on the west side and No. [64] on the east side), although the soda content is apparently slightly enriched in this group owing to geological conditions (see below). All these waters are characterized by a low salinity (<15 mval/l), an alkalinity of 3—4 mval/l and a very small SO_4-ratio (~ 15 mval%).

As soon as rain-water comes into contact with sulphates of alkaline earths (gypsum or $MgSO_4$) the soda content disappears. This is apparent already from the change of ionic composition in sang-ab compared with rain-water (cf. Chapter III, 2 a). Moreover, it explains the lack of soda in several qanats of low concentration fed from the Jolgeh aquifer (Nos. [46], [47]) or from the sand dunes (Nos. [49], [50], [51]). Nos. [28] and [29] in the Kuh-e-Bam ridge and No. [17] in the Ozbak-kuh Mountains are further examples of the same phenomenon. All these waters have alkalinities below 3 mval/l and a SO_4-ratio of ~ 30 mval%, the salinities being below 15 mval/l.

Apart from the soda content in waters of low salinity, where it is apparently derived from the atmosphere, there are also edaphic sources of alkali carbonate or silicate in several parts of the area, causing an increased alkalinity of 5—7 mval/l in all the springs of a whole mountain range (Derenjal Mountains); in some cases, under special local conditions and at various locations (Nos. [34], [63]; Pl. I, 1 b/120), alkalinity even rises to 8—11 mval/l. However, it never reaches an amount high enough for CO_3 to become the prevalent anion in springs of higher salinity (>15 mval/l); hence soda always remains a small fraction of the whole salt content, even if it amounts to 80% of alkalinity (e.g. No. [63]).

The geological provenance of the soda content is most obvious in the Derenjal Mountains (Pl. I, Group 5), where practically all springs show a high proportion of soda, except for a shaft in the dasht east of the range and a salt stream of high salinity rising from a fault. In spite of an SO_4-ratio of 25—50 mval% alkalinity ranges from 5—7 mval/l, more than half of it invariably being sodium alkalinity. This suggests that sodium sulphate, as well as soda, is leached out of the Cambrian Kalshaneh Formation (the dolomite of it providing the main intake rocks of the whole range). The influence of the Derenjal Mountains is also responsible for the soda content of qanats west of Jolgeh (No. [45]; Pl. I, 4/173 — cf. IV, 2 b).

To a minor extent, the Kuh-e-Bam Range shows a similar phenomenon: all the waters in its southern part, as well as those on the northeastern slope, contain a certain amount of soda, probably derived from Jurassic marls or interbedded evaporites. Only the qanats of Deh Now-Bam (No. [28]) and Abkhorak (No. [29]) on the western slope, rising from Esfandiar Limestone proper, have no soda content.

In the Pirhajat Mountains springs have an alkalinity of 4—6 mval/l only; nevertheless nearly all of them contain soda, probably derived from Liassic sandstones and shales. The ratio of sulphate and alkaline earths is always very low and does not interfere with the existence of soda. The exceptionally high alkalinity in Cheshmeh Dahoneh Mambar (No. [63]) may be due to the influence of Neogene evaporites in the vicinity of the spring.

Finally, the crystalline rocks of the Sarhangi Range produce a distinctly higher alkalinity in springs than limestone and dolomite. Since however, the sulphate rate in these rocks is also high, only a few springs of low salinity (Nos. [4], [5]) contain a considerable percentage of soda; for the most part, only a small amount of soda remains in spite of a high alkalinity (Pl. I, 1 b/120), or else, there is no soda at all because of a high ratio of sulphate of alkaline earths (Pl. I, 1 b/114).

Summarizing what we found about the soda content in the waters of the report area, we must confess that the results are not entirely satisfactory. Although it is apparent that alkali salts of weak acids are bound to geological features, the correlation to particular formations is not as clear as with the rest of the ionic composition. It is probably evaporites — old, as well as recent ones — that it comes from. This, together with the soda content of rain-water, suggests that "soda" (including alkali silicate) is a circulating substance, possibly derived primarily from crystalline rocks. In the report area sulphates of alkaline earths prevent sodium carbonate from concentrating to a high salinity. Soda, available in the kavir salts, does obviously not originate in salt rivers of the report area (Pl. I, 1 a), but somewhere else, where waters of a different constitution flow into the salt marshes.

VI. Deutsche Kurzfassung

Die vorliegende Arbeit entstand als Nebenprodukt geologischer und limnologischer Arbeiten in den Gebirgsketten, welche die große zentralpersische Salzwüste im Osten begrenzen. Die geologischen Aufnahmsarbeiten gehörten zu dem Arbeitsprogramm des neugegründeten Geologischen Dienstes von Iran und wurden unter der Leitung von J. Stöcklin und A. W. Ruttner in den Jahren 1963 bis 1966 durchgeführt. Die geologischen Ergebnisse dieser Feldarbeiten sind entweder schon publiziert oder werden in Kürze in Druck erscheinen (J. Stöcklin et al., 1965; A. Ruttner et al., 1968; A. Ruttner et al., in Druck).

Das gesamte, in dieser Zeit kartierte Gebiet war vor Beginn dieser Arbeiten in geologischer Hinsicht fast völliges Neuland; es ist in nord—südlicher Richtung etwa 200 *km* lang und 50—80 *km* breit. Zentrum des Gebietes ist die kleine Oasen-Stadt Tabas; sie liegt 400 *km* südwestlich von Meshed, bzw. 380 *km* nördlich von Kerman im südlichen Teil der Provinz Khorasan.

Während der eine von uns (A. W. Ruttner) gemeinsam mit jungen iranischen Kollegen den nördlichen Teil des Gebietes geologisch kartierte, hatte die andere (A. E. Ruttner-Kolisko) Gelegenheit, einige der "fieldparties" als Gast zu begleiten und die Wässer des Gebietes vom limnologischen Standpunkt aus zu untersuchen. Dabei ergaben sich bemerkenswerte Zusammenhänge zwischen dem Chemismus der Wässer und dem geologischen Aufbau. Wir glauben daher unsere Ergebnisse als Beispiel für die Hydrochemie und Hydrogeologie eines ariden Gebietes in einer gesonderten Arbeit veröffentlichen zu sollen. Wir tun dies in englischer Sprache, um diese Ergebnisse unseren Iranischen Kollegen und den mit hydrologischen Fragen befaßten Iranischen Stellen und Organisationen im Detail leichter zugänglich zu machen. Die nun folgende deutsche Kurzfassung enthält jene allgemeinen Ergebnisse, die auch hier in Europa von Interesse sein dürften.

Das Gebiet Tabas—Shirgesht—Ozbak-kuh besteht aus mehreren nord—süd-streichenden Gebirgsketten, welche die Große Persische Salzwüste (die „Große Kavir") von einem kleineren weiter im Osten gelegenen Salzbecken („Kavir—e—Namak") trennt. Die einzelnen Gebirgsketten sind voneinander getrennt durch Ebenen halbwüstenartigen Charakters („Dasht"), die von mächtigen Schuttfächern (Fanglomeraten) gebildet werden.

Die jährliche Niederschlagsmenge beträgt etwa 100 *mm* (Fig. 3). Trotz dieses trockenen Klimas gibt es auf den Ebenen zwischen den Gebirgsketten stellenweise größere Siedlungen (Tafel II). Diese Siedlungen und die dazu gehörenden Gärten und Felder werden im allgemeinen durch ein in Persien schon seit ältester Zeit üblichen Dränage-System, dem sogenanten „Qanat"-System, mit Grundwasser versorgt (Fig. 2). Nur das Städtchen Tabas erhält sein Wasser außerdem noch von einem frei an der

Oberfläche fließenden Wasserlauf, dem Sardar-Fluß. Natürliche Quellen sind für die sehr dünne Besiedlung innerhalb oder am Rande der Gebirgsketten und als Tränke für das Weidevieh (vorwiegend Ziegen) von einiger Bedeutung.

Der größte Teil des Niederschlags fällt in den Monaten Februar, März und April in Form von heftigen Regengüssen; dieses Niederschlagswasser fließt in unzähligen Gerinnen zu den Salzbecken ab, ohne wesentlich in den Untergrund einzudringen. Nur der seltene Schnee und gelegentlicher leichter, aber länger andauernder Regen während der Wintermonate durchfeuchtet den Boden. Es kommt somit nur ein kleiner Teil des an sich schon sehr geringen jährlichen Niederschlages der Vegetation zugute. Die Lufttemperatur schwankt in weiten Grenzen (—10° C bis +50° C); die relative Luftfeuchtigkeit ist sehr niedrig (jährlicher Durchschnitt etwa 40%) und die Verdunstung außerordentlich hoch (Fig. 4).

Das Wasser der kleineren ständigen oberflächlichen Gerinne verschwindet daher schon nach kurzem Lauf, ohne die Salzbecken zu erreichen. In diesen Wässern nimmt die Salzkonzentration talab rasch zu; der Salzgehalt erfährt dabei auch qualitativ eine Änderung. Diese Arbeit befaßt sich in erster Linie mit dem Chemismus der Quellen und Qanate und besonders mit den Beziehungen dieses Chemismus zum geologischen Aufbau des jeweiligen Gebietes.

Zur Charakterisierung der Wässer wurden mittels Feldmethoden der totale Salzgehalt und außerdem die wichtigsten Ionen-Bestandteile bestimmt, nämlich: Natrium, Calcium, Magnesium unter den Kationen und Alkalinität, Chlorid, Sulphat unter den Anionen (Taf. I). Diese Feldbefunde wurden an einigen Wasserproben im Laboratorium überprüft.

Das Wasser der normalen, kurz andauernden Regenfälle hat einen Salzgehalt von ungefähr 2—3 mval/l; dieser Salzgehalt stammt von dem in der Atmosphäre schwebenden Salzstaub und besteht aus Na- (Ca-, Mg-) chlorid, bzw. hydrokarbonat. In kleinen Felswannen sammelt sich gelegentlich Regenwasser, das vorher die umgebenden Felspartien abgespült hat. Dieses "sang-ab" (= „Steinwasser") enthält auch Sulphat und erreicht eine Salinität von 5 mval/l; seine Konzentration dürfte jener des Wassers entsprechen, das in Spalten oder Klüfte des Gesteins eindringt. Wir dürfen daher in Quellen und im Grundwasser unseres Gebietes keine Salzkonzentrationen erwarten, die wesentlich geringer sind als 5 mval/l.

Die Salinität der Quell- und Grundwässer unseres Gebietes schwankt zwischen 5 und 100 mval/l (ausnahmsweise bis zu 265 mval/l). Hinsichtlich ihres Gehaltes an Anionen sind es Chlorid-Sulphat-Wässer. Wir unterscheiden hier Chloridwässer ($Cl > 50\%$ der Anionen), Sulphatwässer ($SO_4 > 50\%$ der Anionen) und einen intermediären Typus, in dem sich Cl- und SO_4-Ionen ungefähr die Waage halten. Der Gehalt an Karbonat überschreitet nie 10 mval/l. Natrium ist immer das vorherrschende Kation (Fig. 7). Einige allgemeine Gesetzmäßigkeiten konnten festgestellt werden:

Es besteht eine ausgesprochene Abhängigkeit zwischen der Gesamt-Konzentration und der Ionen-Zusammensetzung in den untersuchten Wässern. Mit steigender Konzentration nimmt der relative Na-Gehalt zu: in Sulphatwässern mit einer Verhältniszahl von 0,25, in Chloridwässern mit einer Verhältniszahl von 0,6 und in Wässern, welche Soda enthalten mit einer Verhältniszahl von 1,1 (Fig. 8). Auf der Anionenseite führt steigende Konzentration von intermediären Typen entweder zu typischen Chlorid- oder typischen Sulphatwässern (Fig. 9). Allgemein konnte bei steigender Konzentration eine relative Abnahme des Karbonatgehaltes festgestellt werden, u. zw. in Sulphatwässern mit einer Verhältniszahl von 2,6 und in Chloridwässern mit einer Verhältniszahl von 1,0 (Fig. 10). Das Verhältnis $Cl : SO_4$ hat zu der Gesamtkonzentration keine Beziehung, sondern hängt von den besonderen geologischen Verhältnissen der betreffenden Gebiete, bzw. Gebirgsketten ab (Fig. 11).

Den Einfluß des geologischen Baues auf den Chemismus der Quell- und Qanatwässer unseres Gebietes aufzuzeigen, ist das Hauptziel dieser Arbeit. Tafel II ist eine vereinfachte geologische Karte des Gebietes, in welcher Konzentration und Ionen-Zusammensetzung einer Auswahl von den untersuchten Wässern nach der etwas abgewandelten Methode von Maucha (1932) dargestellt sind.

Taf. III gibt einen Überblick über die in unserem Gebiet anstehenden Gesteinsfolgen, die vom Präkambrium bis in das Tertiär reichen und insgesamt eine Mächtigkeit von nahezu 15.000 *m* haben.

Mächtige Kalk- und Dolomitmassen permo-triassischen und oberjurassischen Alters bauen die schroffen und z. T. schwer zugänglichen Bergketten der Shotori Range (Kuh-e-Shotori = ,,Kamel-Berg", 2838 *m*) im südlichste Teil des Gebietes auf. Außerdem sind dort Mergel, Schiefertone, Sandsteine und wenig mächtige Kalke des höheren Paläozoikums, des Lias und des höheren Jura vertreten. Gegen Norden gehen die Riffkalke des Oberjura in mergelige und sandige Gesteine über. Nur im Kuh-e-Bam ist dort noch ein schmales, langgestrecktes Oberjura-Riff entwickelt. Im Südwesten des Gebietes (Pirhajat Mountains) werden permo-triassische Dolomite von Sandsteinen und Schiefertonen des Lias überlagert.

Ganz anders ist der Aufbau der Derenjal Mountains. Hier ist in einer kompliziert gebauten Aufdomung ein vollständiges Profil von Infrakambrium bis zum Oberdevon aufgeschlossen (s. Taf. III). Diese Gesteine kommen weiter im Nordosten in den Ozbak-kuh Mountains wieder zum Vorschein. Sie sind dort äußerst stark miteinander verschuppt. In den Sarhangi—Zeberkuh Mountains endlich sind diese Gesteine zwischen präkambrischem Kristallin zu einem schmalen Streifen zusammengepreßt, der gegen Nordosten aushebt. Dieses präkambrische Kristallin besteht aus Glimmerschiefer (z. T. mit Marmor), Gneis, Amphibolit und Granit. Ihm sind nicht- oder schwach-metamorphe infrakambrische und paläozoische Gesteine aufgelagert.

Die Tektonik des Gebietes ist charakterisiert durch einen Wechsel im Streichen der Strukturelemente von SE—NW im Süden über SSW—NNE im mittleren Teil des Gebietes zu WSW—ENE im Norden. Bruch- und Faltentektonik ist vorherrschend; es wurden aber auch (stellenweise sehr intensive) Verschuppungen und kurze Überschiebungen festgestellt, die im Süden (Shotori Range) gegen Westen, weiter im Norden (Ozbak-kuh Mountains) aber gegen Südosten gerichtet sind. Von besonderer Bedeutung für die Hydrogeologie sind die sogenannten ,,Randstörungen", größere Brüche oder Bruchsysteme, welche die einzelnen Gebirgsgruppen gegen die Ebene begrenzen. Manche dieser Störungen sind sogenannte "strike slip faults", an denen sich seitliche Verschiebungen kleineren oder größeren Ausmaßes vollzogen. Die große Störung, welche die Pirhajat Mountains im Osten begrenzt und diese Gebirgsgruppe von den Derenjal Mountains trennt, ist sicher eine solche strike slip fault mit einem Verschiebungsbetrag von etwa 40—50 *km*.

Sowohl die Lithologie wie die Tektonik sind für die Hydrochemie und Hydrogeologie unseres Gebietes von Bedeutung (s. Tafel II).

Die erwähnten mächtigen Kalk- und Dolomitmassen permo-triassischen und oberjurassischen Alters spielen als Infiltrationsgesteine für Quellen und Grundwasserkörper eine wichtige Rolle. Selbst während und nach den heftigen und kurzen Regengüssen des Frühjahrs wird das Regenwasser in diesen Karbonatgesteinen rasch aufgenommen, bevor es über die Dasht zu den Kavir-Becken abfließen kann. In den Klüften und Hohlräumen dieser Gesteinskörper wird das Wasser über weite Strecken transportiert, bis es entweder in Form von Quellen wieder zutage tritt oder Grundwasserströme in den Schotterfächern der Dasht speist. Dabei sind Brüche oder Bruchsysteme in den Karbonatgesteinen bevorzugte Transportwege für das Wasser.

Solche Karbonatgesteine größerer Mächtigkeit sind vor allem im südlichen Teil unseres Gebietes vorhanden. Dort befinden sich auch sämtliche größere Siedlungen und Kulturgebiete, obwohl die jährliche Niederschlagsmenge im Süden — im Bereich des Beckens von Tabas — geringer sind, als weiter im Norden. Die Kalk- und Dolomitmassen der Shotori Range, des Kuh-e-Bam und der Pirhajat Mountains bilden das Einzugsgebiet für alle jene Quellen und Grundwasserkörper, welche diese Siedlungen mit Wasser versorgen.

Im allgemeinen hat das Wasser aus diesen Karbonatgesteinen eine niedrige Salinität (4,5—8,5 mval/l); die Ionenzusammensetzung dieses Wassers ist ähnlich jener des Regenwassers bzw. jener des Wassers der kleinen Felswannen ("sang ab"). Die Karbonatgesteine selbst haben keinen Einfluß auf den Chemismus des Wassers (vgl. Nr. 76 und 77 mit Nr. 75, aber auch mit Nr. 71, 72 und 37 auf Tafel II). In den Pirhajat Mountains sind die aus den permo-triassischen Dolomiten kommenden, an Brüche gebundenen Quellen (Nr. 60, 61, 62) durch die überlagernden Schiefertone und Sandsteine des Lias beeinflußt (siehe unten).

Grundwasserkörper die von Wasser aus Karbonatgesteinen gespeist werden, sind meist an die jungen Schotterfächer der Dasht gebunden. Im Verlauf dieser Grundwasserströme erhöht sich die Salinität etwas (bis 12 mval/l), ebenso wird der Na-Gehalt und das Verhältnis $SO_4 : Cl$ größer.

Als Beispiel hiefür sei der große Grundwasserstrom angeführt, der sich in einem rezenten Schuttfächer vom Nordende der Shotori Range über eine Entfernung von 50 *km* gegen Norden zum Ostrand der Großen Kavir bewegt. Dieser Grundwasserkörper wird von Wasser aus einem System von longitudinalen, NNW streichenden Brüchen und Störungen der Shotori Range gespeist; Einzugsgebiet ist die ganze fast 80 *km* lange Gebirgskette.

Am Kopf dieses Grundwasserstromes hat das Wasser noch eine Salinität und Ionenzusammensetzung, die sehr ähnlich jener des Regenwassers bzw. jener des "sang ab" ist (Nr. 73, 72 und 71 auf Tafel II); gegen Norden nimmt die Salinität etwas zu, und auch die Ionenzusammensetzung verschiebt sich etwas (Nr. 51, 50, 49 und 48). An seinem unteren Ende verzahnt der Schuttfächer mit dem Salzton der Kavir; hier wird das Grundwasser durch das feinkörnige mit Ton gemischte Material zurückgestaut und durch zahlreiche Qanate gewonnen. Dies ist der Grund für die überraschende Ansammlung von Dörfern genannt "Jolgeh" (= fruchtbare Ebene) unmittelbar am Rande der sonst so lebensfeindlichen Kavir; etwa 15.000 Menschen sollen hier leben. Die Salinität des Wassers ist auch hier noch niedrig (~10 mval/l), soweit es zentrale Teile des Grundwasserstromes betrifft (Nr. 47, 44). Randliche Teile des Grundwasserkörpers sind durch seitlichen Zufluß von Wasser höherer Salinität beeinflußt (Nr. 46, 45, 43, 42, 41).

Der Oberjura-Riffkalk des Kuh-e-Bam ist das Infiltrationsgestein für kleinere Grundwasserströme zu beiden Seiten dieser Gebirgskette. Grundsätzlich herrschen dort ähnliche Verhältnisse, wie in dem eben kurz skizzierten Grundwasserstrom nördlich der Shotori Range (Nr. 37, 36, 35 östlich des Kuh-e-Bam Nr. 28 westlich dieser Gebirgskette). Ein weiterer kleiner Grundwasserstrom fließt vom Nordende der Shotori Range gegen Osten (Nr. 40, 39, 38).

Nur Karbonatgesteine (und gelegentlich Sanddünen) spielen in unserem Gebiet eine Rolle als Infiltrationsgesteine, bzw. -körper für Grundwasserströme oder Quellen. Regenwasser, das auf tonige Gesteine, Mergel, Sandsteine, vulkanische Gesteine fällt, ja auch der Regen, welcher auf die stark vertonten Schotterflächen der Dasht niedergeht, dringt nur in sehr geringem Maße in den Boden ein. Daher sind alle übrigen Teile unseres Gebietes, abgesehen von den eben erwähnten, sehr arm an Wasser, insbesondere arm an Wasser niedriger Salinität.

Wässer niedriger Salinität (10—15 mval/l) wurden in diesen Gebieten nur dort festgestellt, wo entweder Karbonatgesteine den tonig-sandigen Gesteinen zwischengeschaltet sind, wie z. B. in einigen wenigen Fällen innerhalb der Derenjal und Ozbakkuh Mountains (Nr. 57 a, 17, 18 in Tafel II), oder wo kristalline Gesteine in größerem Ausmaß anstehen, wie im südlichen Teil der Sarhangi—Zeberkuh Range (Nr. 5 und 6 in Tafel II). In allen diesen Fällen ist aber die Schüttung äußerst gering. Beide Gruppen von Wässern gehören zu dem intermediären Chlorid-Sulphat Typus.

Die Quellen und kurzen Qanate der paläozoischen Ozbak-kuh Mountains liefern Sulphatwasser mit einer Salinität von 30—60 mval/l und einem Cl : SO_4-Verhältnis von 0,3—1,0. Der Sulphat-Gehalt kommt von Red Beds des Unterdevons (Padeha Formation), vor allem von einer 50 *m* mächtigen Gipsschicht im Hangenden dieser Formation. Beispiele solcher Wässer sind in Tafel II unter Nr. 13, 15, 16, 20, 21, 22 und 23 dargestellt. Auffallend ist, daß in diesen Wässern der prozentuelle Anteil von Ca unter den Kationen nicht überhöht ist, und daß somit ein großer Teil des Sulphates als Natriumsulphat gelöst ist.

Wir fanden keine Sulphatwässer dieses Typus in den paläozoischen Derenjal Mountains, wo diese Gipsschicht nicht oder nur schwach entwickelt ist. Dort gehören die Wässer zu einem intermediären Sulphat-Chlorid Typus (Nr. 52, 54, 57 in Tafel II). Diese Wässer sind durch einen verhältnismäßig hohen Soda-Gehalt charakterisiert.

Zu demselben intermediären Sulphat-Chlorid Typus gehören auch die Wässer der Kuh-e-Bam Range, soferne ihr Einzugsgebiet aus oberjurassischen Mergeln und Red Beds besteht, mit denen die Riffkalke des Kuh-e-Bam seitlich verzahnen (Nr. 31, 32, 33 und 34 in Tafel II). In diesen Wässern ist unter den Anionen der prozentuelle Anteil von CO_3, Cl und SO_4 ungefähr gleich; Na überwiegt über Ca und Mg. Die Salinität dieser Wässer ist verhältnismäßig niedrig (15—30 mval/l).

Eine besondere Wassertype wurde im nördlichen Teil der Sarhangi—Zeberkuh Range gefunden (Nr. 1, 2 und 3 in Tafel II). Diese Wässer sind charakterisiert durch einen Sulphatgehalt von 50—60% der Anionen und durch ein Vorwiegen von Mg über Ca (20—35% der Kationen). Für die relativ geringe Salinität (unter 30 mval/l) und die verhältnismäßig große Schüttung dieser Wässer sind wahrscheinlich infrakambrische Dolomite verantwortlich zu machen, welche die benachbarten Berge aufbauen. Der Mg- und SO_4-Gehalt dürfte von Evaporiten der neogenen "Upper Red Formation" herrühren, die nördlich der Sarhangi—Zeberkuh Range anstehen, oder von Tonschiefern und Sandsteinen präkambrisch-paläozoischen Alters dieser Gebirgsgruppe.

Chloridwässer sehr einheitlicher Zusammensetzung (zirka 60% Cl und 30% SO_4) entspringen den schwach metamorphen Sandsteinen und Tonschiefern (wahrscheinlich oberjurassischen Alters), welche die Hügel zwischen der Kuh-e-Bam Range und den Ozbak-kuh Mountains aufbauen (Nr. 26, 27 in Tafel II). Ebenso sind alle Wässer, die von den liassischen Schiefertonen und Sandsteinen der Pirhajat Mountains kommen, Chloridwässer (Nr. 63, 64, 65 und 66). In ihnen ist das Cl : SO_4-Verhältnis verhältnismäßig konstant (etwa 2 : 1), während die Gesamtkonzentration zwischen weiten Grenzen schwankt. Diese Wässer beeinflussen auch die Wässer niedriger Salinität, welche aus den permo-triassischen Dolomiten dieser Berge kommen.

Eine weitere Ursache für Chloridwässer sind junge (plio-pleistozäne) Evaporite, die offensichtlich sehr reich an NaCl sind und die in manchen Fällen Wässer hoher Salinität (bis zu 120 mval/l) liefern (Nr. 58 und 59 in den Pirhajat Mountains, Nr. 67 und 68 bei Shirgesht und Nr. 9 und 10 westlich von Ozbak-kuh auf Tafel II).

Quellen mit Chloridwasser von einer Salinität bis zu 265 mval/l sind an große Störungen oder Störungszonen gebunden. Diese Störungen sind entweder sogenannte „Randstörungen", oder sie streichen aus den Gebirgsketten in die Kavir hinaus. Die

Quellen werden offensichtlich von hochkonzentriertem Wasser gespeist, das in diesen Störungen zirkuliert. Die Schüttung solcher Quellen ist meist sehr gering. Beispiele dafür sind: Nr. 11 westlich von Ozbak-kuh, Nr. 19 in den Ozbak-kuh Mountains, Nr. 14, 12 und 8 am Ostrand der Ozbak-kuh Mountains und Nr. 25 im südlichen Teil der Ozbak-kuh Mountains. In allen diesen Wässern beträgt der relative Anteil von Cl 60—80% der Anionen und jener von Na 75—95% der Kationen.

Konzentrationen über 265 mval/l wurden nur in frei an der Oberfläche fließenden Gewässern gefunden. Als Beispiel für die Zunahme der Konzentration durch Verdunstung möge hier der Salzfluß von Doruneh dienen, der außerhalb unseres Untersuchungsgebietes von Norden her der Großen Kavir zufließt und westlich des Sefid Kuh in diese mündet. In seinem Oberlauf führt dieser Fluß ein Wasser mit einer Konzentration von 250 mval/l und einer prozentuellen Ionenzusammensetzung von 95 Na/0 Ca/5 Mg—1 Alk/75 Cl/24 SO_4. Bei zunehmender Konzentration werden diese Wässer immer mehr zu NaCl-Lösungen mit geringen Beimengungen von Mg, CO_3 und SO_4 (vgl. auch Fig. 7 und 9). Wahrscheinlich ist dies auch die Zusammensetzung des Kavir-Salzes; eine Analyse einer Salzkruste der Kavir (nach B. Asklund) ist in Kap. IV/2 c angegeben.

Aus den ursprünglich sehr unterschiedlich zusammengesetzten Salzwässern resultieren somit schließlich kontinentale Salzablagerungen, die vorwiegend aus NaCl bestehen. Am Beginn des ganzen Zyklus steht das Regenwasser, dessen geringer Salzgehalt von dem aus diesen Salzablagerungen aufgewirbelten und in der Luft suspendierten Salzstaub herrührt.

Auffallend ist das Fehlen ausgesprochener Sodawässer in unserem Gebiet. Ein geringer Überschuß der Alkalinität über dem den Erdalkalien zukommenden Äquivalent wurde im Regenwasser und in fast der Hälfte der natürlichen Wässer gefunden. Dieser Überschuß der Alkalinität ist wahrscheinlich auf einen Gehalt an Alkali-Karbonat oder -hydrokarbonat zurückzuführen, wenn auch Salze anderer schwacher Säuren, wie z. B. der Kieselsäure, eine Rolle spielen mögen. Wässer höherer Konzentration mit einem Alkalinitäts-Überschuß sind an ganz bestimmte Regionen gebunden, u. zw. an solche, in denen Evaporite und daneben Mergel, Schiefertone, Sandsteine und, in einem Fall, auch kristalline Gesteine vorkommen.

Ebenso wie Sodawässer, fehlen in unserem Gebiet auch ausgesprochene Magnesiumwässer.

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A.W. RUTTNER und A.E.RUTTNER-KOLISKO – PLATE 2

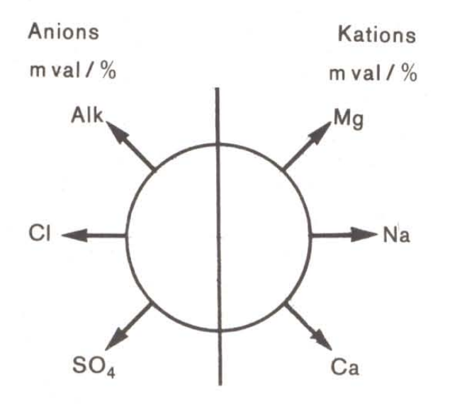
HYDROGEOLOGIC–HYDROCHEMICAL MAP OF THE TABAS-SHIRGESHT-OZBAK-KUH AREA

BY A.W.RUTTNER AND A.E.RUTTNER-KOLISKO

1:200000

HYDROCHEMICAL LEGEND

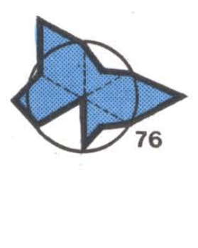
Pattern of the Diagrams:



Ranges of concentration

- < 10 m val / l
- 10 - 15 m val / l
- 15 - 30 m val / l
- 30 - 60 m val / l
- 60 - 120 m val / l
- > 120 m val / l

		Ionic composition in m val% Na Ca Mg Alk Cl SO_4	Soda > 50%	concentration in m val / l
1.	**Sarhangi Range** (and Doruneh)			
1	Narm (q)	55 / 10 / 35 - 10 / 35 / 55		27,0
2	Yakhab (q)	65 / 15 / 20 - 15 / 35 / 50		27,2
3	Yeylaq (s)	60 / 15 / 25 - 20 / 20 / 60		17,1
4	Cheshmeh Tohu (s)	90 / 5 / 5 - 31 / 36 / 33	+ ▲	20,0
5	Chah Paliz (q).	84 / 8 / 8 - 44 / 22 / 34	+ ▲	13,5
6	Karimabad (q)	62 / 20 / 18 - 42 / 22 / 36		10,4
7	Cheshmeh-e-Asbi (s)	57 / 25 / 18 - 19 / 31 / 50		34,0
8	Cheshmeh-e-Sangiche (s)	86 / 7 / 7 - 13 / 55 / 32		88,0
9	Chah Tom (well)	85 / 10 / 5 - 9 / 73 / 18		69,0
2.	**Ozbak-kuh Region**			
10	Garqab (s)	90 / 5 / 5 - 7 / 62 / 31		59,0
11	Gerdab (s)	95 / 2 / 3 - 8 / 81 / 11		140,0
12	Cheshmeh Kerkesu (s)	82 / 10 / 8 - 16 / 45 / 39		48,0
13	Cheshmeh Huk (s)	48 / 30 / 22 - 4 / 20 / 76		48,7
14	Saltspring nr. Huk	75 / 12 / 13 - 1 / 67 / 32		265,0
15	Cheshmeh Taqshiru (s)	48 / 34 / 18 - 8 / 30 / 62		35,4
16	Ma'-dan-e-Bala nr. Qal'-eh (q)	50 / 30 / 20 - 4 / 28 / 68		41,0
17	Cheshmeh Senjedu (s)	44 / 30 / 26 - 19 / 40 / 41		12,6
18	Cheshmeh Mohamad Beik (s)	72 / 17 / 11 - 38 / 36 / 26	+ ▲	13,6
19	Cheshmeh Bad Bad (s)	90 / 3 / 7 - 7 / 61 / 32		140,0
20	Cheshmeh Lokeni (s)	63 / 22 / 15 - 3 / 37 / 60		76,5
21	Cheshmeh Baghal (s)	85 / 5 / 10 - 13 / 25 / 62		83,3
22	Gushkamar 2 (s)	52 / 32 / 16 - 11 / 23 / 66		37,4
23	Cheshmeh Padeha (s)	72 / 14 / 14 - 25 / 22 / 53		20,0
24	Cheshmeh Shir (s)	86 / 7 / 7 - 10 / 43 / 47		40,7
25	Cheshmeh Estalkhaq (s)	80 / 12 / 8 - 3 / 67 / 30		153,0
3.	**Kuh-e-Bam Range**			
26	Abid (q)	85 / 9 / 6 - 6 / 63 / 31		52,0
27	Khadrin (q)	85 / 11 / 4 - 7 / 57 / 36		53,4
28	Bam (q)	50 / 35 / 15 - 46 / 27 / 27		4,7
29	Abkhoraq (q)	75 / 15 / 10 - 15 / 50 / 35		17,9
30	Cheshmeh-e-Khormayu (s)	91 / 4 / 5 - 7 / 61 / 32		79,6
31	Cheshmeh-e-Gholah (s)	69 / 10 / 21 - 29 / 26 / 45		21,5
32	Cheshmeh Neyzar (s)	80 / 10 / 10 - 35 / 40 / 25		15,0
33	Ozbak-kuh II (s)	90 / 5 / 5 - 18 / 44 / 38		27,5
34	Cheshmeh-e-Paderakhti (s)	83 / 5 / 12 - 31 / 29 / 40		29,3
35	Neygenan 1 (q)	85 / 15 / 0 - 40 / 40 / 20	▲	9,7
36	Zardeh (s)	84 / 15 / 1 - 25 / 45 / 30		12,8
37	Eshqabad (q)	75 / 25 / 0 - 55 / 45 / 0	▲	5,8
38	Hosseynabad (q)	90 / 9 / 1 - 10 / 60 / 30		52,4
39	Hajadabad (q)	85 / 7 / 8 - 15 / 60 / 25		24,4
40	Esfaq (q)	70 / 20 / 10 - 35 / 50 / 15		11,4
4.	**Jolgeh**			
41	Chah-e-Kavir (q)	90 / 5 / 5 - 10 / 50 / 40		44,2
42	Deh-e-Luk (q)	88 / 5 / 7 - 10 / 50 / 40		39,6
43	Deh-e-Alkhani (q)	75 / 15 / 10 - 15 / 50 / 35		21,7
44	Hudar (q)	80 / 10 / 10 - 40 / 59 / 1	+ ▲	7,3
45	Vakilabad (q)	97 / 3 / 0 - 30 / 50 / 20	+ ▲	11,8
46	Mahmudabad (q)	80 / 15 / 5 - 10 / 55 / 35		20,0
47	Dastgardan (q)	55 / 25 / 20 - 25 / 40 / 35		9,9
48	Manzuriyeh (q)	78 / 15 / 7 - 40 / 45 / 15		8,2
49	Deh Khan 1 (q)	60 / 10 / 30 - 25 / 40 / 35		9,2
50	Del-e-Kuh (q)	55 / 25 / 20 - 25 / 40 / 35		9,2
51	Pashneh Darun (q)	60 / 25 / 15 - 25 / 35 / 40		9,5
5.	**Derenjal Mountains**			
52	Cheshmeh Kharmayu (s)	95 / 3 / 2 - 10 / 40 / 50	+ ▲	47,4
53	Cheshmeh Shorm 2 (s)	95 / 3 / 2 - 15 / 55 / 30	+ ▲	51,3
54	Derenjal, (before rain, s)	94 / 5 / 1 - 25 / 50 / 25	+ ▲	26,0
55	Chah-e-Shur (well)	85 / 10 / 5 - 10 / 45 / 45		24,2
56	Saltstream, SE-corner of the mountains	95 / 3 / 2 - 0 / 75 / 25		400,0
57a	Cheshmeh Chekab (s)	85 / 10 / 5 - 25 / 40 / 35	▲	11,3
57b	Chah-e-Gerdu (well)	97 / 3 / 0 - 20 / 45 / 35	▲	35,0
6.	**Pirhajat Mountains**			
58	Cheshmeh Gowmar (s)	90 / 7 / 3 - 5 / 75 / 20		120,0
59	Cheshmeh Talkhab (s)	90 / 7 / 3 - 5 / 75 / 20		73,8
60	Abdolabad (s)	85 / 10 / 5 - 20 / 60 / 20	▲	21,8
61	Pirhajat main spring	85 / 10 / 5 - 25 / 60 / 15	▲	17,3
62	Bistun (s)	85 / 10 / 5 - 30 / 50 / 20	▲	11,8
63	Cheshmeh Dahaneh Mambar (s)	97 / 2 / 1 - 20 / 55 / 25	+ ▲	50,4
64	Kalshaneh (s)	85 / 10 / 5 - 30 / 55 / 15		13,4
65	Spring west of Chah-e-Sorb	95 / 3 / 2 - 20 / 55 / 25	▲	23,2
66	Chah-e-Sorb shaft 2	85 / 10 / 5 - 5 / 75 / 20		35,2
7.	**Shirgesht Region**			
67	Abbasabad (q)	91 / 6 / 3 - 5 / 65 / 30		88,0
68	Shirgesht (s)	91 / 7 / 2 - 10 / 65 / 25		31,0
69	Kal-e-Gaz, salt stream	85 / 7 / 8 - 10 / 70 / 20		335,0
71	Deh Now (q)	75 / 20 / 5 - 50 / 35 / 15		6,8
72	Deh Mohammad (q)	74 / 22 / 4 - 51 / 45 / 4	▲	6,7
73	Malvand (q)	67 / 23 / 10 - 62 / 38 / 0	▲	4,5
8.	**Shotori Range**			
74	Sardar Valley, hot spring at Tang-e-Abbasi	58 / 30 / 12 - 20 / 35 / 45		12,0
75	Sardar River at Tang-e-Abbasi	40 / 40 / 20 - 30 / 30 / 40		8,6
9.	**Rain and Sang-ab**			
76	Rain after 12h	60 / 20 / 20 - 55 / 45 / 0		3,1
77	Sang-ab 2	60 / 35 / 5 - 45 / 35 / 20		4,7



HYDROGEOLOGICAL LEGEND

Sand dunes	QUARTERNARY
Evaporite ("kavir")	
Recent / Fossil Gravel fans („dasht")	
Conglomerate	NEOGENE
Evaporite	
Volcanics (andesite, dacite)	PALEOGENE
Conglomerate	
Limestone	CRETACEOUS
Marl	
Reef-	JURASSIC
Bedded	
Red beds	
Sandstone (+shale)	
Marl, shale	
Sandstone + shale (Lias)	
Limestone, dolomite	TRIASSIC–PERMIAN
Limestone, dolomite (Devonian, Carb.)	PALEOZOIC
Evaporite + red beds (L. Devonian)	
Red beds (Cambrian and L. Devonian)	
Sandstone, siltstone	
Shale, marl, limestone	
Dolomite + diabase + marl	
Diabase	
Dolomite, limestone	PRE-CAMBRIAN
Slate, phyllite	
Gneiss, micaschist	
Granite	

Fault

Thrust-fault

Calcite vein

Aquifer of Jolgeh

Irrigated areas

underground channel („qanat")

surface channel

Geology according to:
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J. Eftekhar-nezhad, J. Hajian, A. Hushmand-zadeh,
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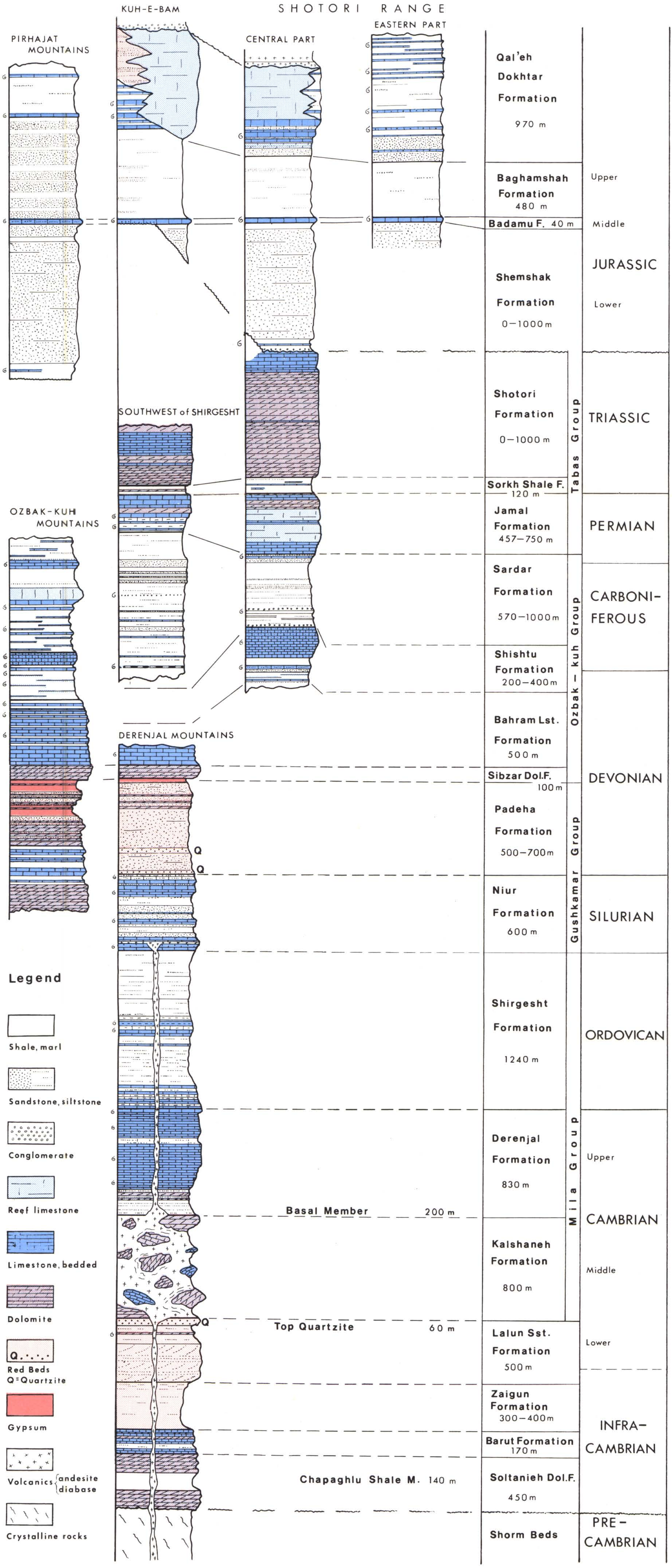
A. W. RUTTNER – Plate III

STRATIGRAPHY OF THE TABAS–SHIRGESHT–OZBAK–KUH AREA



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