THE SUBMARINE SPRINGS OF CHEKKA: EXPLOITATION OF A CONFINED KARSTIC AQUIFER DISCHARGING IN THE SEA

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THE SUBMARINE SPRINGS
OF CHEKKA
EXPLOITATION OF A CONFINED KARSTIC
AQUIFER DISCHARGING IN THE SEA.

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PREFACE

Submarine springs are to most people a curiosity. And yet, with the ever increasing demands on fresh water it would seem that an understanding of their phenomena of flow and a study of their origin should have an unusual appeal if not an important economical value for investors and water development boards. With this thought in mind, the writer with the cooperation of the Underground Water Project personnel and many other people and institutions has undertaken the writing of this paper. It is intended to present to the reader an all-embracing point of view on the submarine springs of the region of Chekka and on the geological, geomorphological and hydrogeological factors that contributed to the development of a karstic confined aquifer discharging in the sea.

The illustrations presented in this paper, are intended to give a full hydrogeological view of the region investigated. It is the writer's opinion that the most important illustration is the "Hydrogeological Map of the Recharge area of the submarine springs". This map should be consulted contantly during the reading of the paper. Other diagrams and figures presented may not be complete but it is thought that they present the necessary requirements to give the reader a clear idea of the subject treated.

Other investigations and observations are currently going on in the region of Chekka to complete the results already acquired. The complexity of flow in underground karstic channels makes it difficult to achieve, theoretically speaking, quick and immediate results. Long duration pumping tests will only prove or disprove the possibility of tapping quantities of water superior to $2m^3$/sec. in Chekka.

ABSTRACT

In the study of the "karst" of Lebanon it was necessary to undertake a serious reconnaissance and an evaluation of the water lost in the sea. The limestone nature of the Lebanese mountain ranges is particularly adapted to massive infiltrations of waters supplied by rainfall and snow melting. These waters are available, in most cases, at altitudes close to base-level i.e. sea level.

Water flow takes place either in a diffuse manner in the limestone mass, or in well delimitated karstic channels, depending on the lithologic nature of the aquifers. In the first case it is practically impossible to trace the phenomena in the sea; but in the second case, the concentration in a few points of very important yields, results in the formation of submarine springs easily recognized at the surface.

Two regions of Lebanon, Tyre in the South and Chekka in the North, were considered in a program of study leading eventually to an exploitation either in the sea, if the salt content was low enough at discharge points, or on the coast, in zones where salt water intrusion did not yet occur.

In priority we have chosen the submarine springs of Chekka.

A preliminary study carried by underwater diving methods (aqua-lung), helped us to describe with precision, the visible summer submarine springs, and to carry on an inventory of all water points on the coast. The results obtained, having proven the existence of very important yields ($6m^3$/sec.) of good waters in the sea (15 gr/l. of Cl), the solution of tapping these waters on the coast was adopted. A Geophysical investigation program made it possible to differentiate the interesting zones from those where underground waters were under the influence of the sea.

At the fall of the first heavy rains of February 1964, the results previously obtained in the summer changed remarkably, yields increased ten fold and salinities decreased tremendously (46 mg/l. of Cl).

The purpose of this paper is to give what we already know about the springs of Chekka, to present a functionning hypothesis of the system of flow based on field observations, and to give an idea on the permissible yields that could be exploited on the coast without inducing salt water intrusion.

This investigation is, economically and socially, of a considerable importance because the submarine springs of Chekka are, by far, the most important springs of Lebanon in the winter, some of the most important in the summer, and are located in a region particularly poor in fresh water supplies.

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CHAPTER I

I.I Purpose and extent of the investigation

Considerable amounts of water (6m3/sec) in the low water period and over 50 m3/sec in the winter spout out in the sea from a number of submarine springs in the Chekka area which lie between 20 and 2000 m off shore. This thesis is a result of three years of observations and studies undertaken on the whole system of submarine springs of Chekka. The importance of these observations and studies will be measured by the extent of their application in other coastal regions elsewhere in the world where the same phenomena occur.
The purpose of this presentation is then two fold: first it is the study of the behaviour of submarine springs; and second, and most important, are the economic possibilities of tapping the equifer on the coast at points where underground flow and pressures are suitable.

1.2 History

Little is known about submarine springs and scientific information is still lacking on their mode of occurence, flow phenomena, and possibility of exploitation.

In the circum-mediterranean countries, submarine springs have been reported off the coasts of Greece, Yugoslavia, Lebanon and Syria since Phoenecian times. De Launay describes in his works "La géologie appliquée à l'Art de l'ingénieur" that in Tyr (South Lebanon) during sieges "it was possible to supply the town with drinkable water due to a spring sxisting in the harbour below the sea level: a bell turned upside down was set on the submarine spring and water used to flow to the surface through a leather tube. "Describing the springs of Ras el Ain near Tyr, De Launay adds: "The Pheenecians had even built nearby a very particular piezometer: A tower was constructed on a point where water would rise and they had succeeded in tapping amounts of that water spouting from the limestone to a reservoir where it was redistributed under pressure to supply the town." Romans later on reconstituted the same hydraulic system of the Phoenicians. The first descriptions of the submarine springs located off the Syrian-Lebanese coast was given by a French scientific mission in 1929. This mission made a survey of the Syrian Lebanese coast from Tyr to Lattaquieh and described the springs off Tyr, Djounié, Chekka, Tripoli and the island of Rouad.

Shortly after World War II, several attempts to tap springs in Yugoslavia and Greece were unseccessful. The springs of Chekka were described by diving observations and temparatures were recorded.

As to their origin, it was suggested by Dr. Louis Dubertret the French geologist that "infiltration through the limestone masses of Lebanon causes water to flow in under ground channels to the sea where though fissures it spouts to the surface."

The Underground Water Survey Project a Lebanese - U.N. Special Fund project - was established in 1963. Its role is to promote the study, exploration and exploitation of underground water. It was in the summer of 1963 that the first serious studies were undertaken by diving off the coast of Chekka on the submarine springs. Results have proved rewarding.

1-3- Economical aspects of the investigation

The most important aspect of this investigation is centered around the "economics" side of it i.e. whether the water produced would be economical to pump and if so which sector of the economy it could most benefit.

1.3-I Agriculture

The region of Chekka is not an agricultural area. Besides a few seasonal (unirrigated) crops, most of the alluvial deposits and the quaternary "ramleh" remain bare due to the lack of available irrigation water. Most of the area around Chekka is composed of Miocene limestones and Senonian chalks. Their soils are heavily loaded with calcium and are unsuitable for such crops as bananas, oranges, lemons, etc... The only possible propect for the area is vegetable cultivation. Unfortunately due to intensively heavy dust fall from the stacks of the neighbouring cement plants over the whole area, the danger of poor crops will remain a constant factor. Between Chekka and Tripoli the narrow coastal area is mainly rocky and unsuitable for any kind of agriculture.

One possibility of a market for the water as far as irrigation is concerned would be pumping it to the Koura plateau which is in need of tremendous supplies. But here too, the problems are enormous:

a) The Koura plateau is mostly covered by olive groves and owners are reticent to adopt any ather kind of cropping.

b(If the irrigated olive tree is adopted which furnishes big olives of table quality a new kind of agriculture should be adopted along with different needs.

At any rate the problem will undoubtly necessitate tremendous changes on the plateau which the landowners are not yet prepared to accept.

1-3.2 Industry

If agriculture cannot absorb the quantities of water available, then industry (which is already important in the area of Chekka) could and must absorb at least part of the water.

Industries requiring big amounts of water (such as paper factories, etc..) should , it is suggested, consider Chekka as an ideal place as far as water supplies are concerned.

Facilities should then be offered by the Government to induce the establishment of new factories in the vicinity of chekka based on this new abundant supply of water.

1.3.3- Domestic supplies of Potable water and alimentation of population agglomerations.

Another important market for the Chekka water would be the alimentation of big centres of population such as the cities of Beirut, Tripoli, etc.. The present consumption of Beirut (which is mostly insured by Jeita and partly by Ain el Delbe) is about 32 million gallons per day and will, in the next decade, almost double. Several attempts to increase the water supplies in the Jurassic and Cenomanian limestones in the vicinity of Beirut have proven the existence of limited reserves insufficient to cope with the city's growing consumption.

The supply of potable water from Chekka by pipelines is feasibly economical. Cities like Oran in Algeria and Casablanca in Morocco and Bari in Italy are supplied by pipelines from sources 200 kms 100 kms and 280 kms away respectively.

There is no doubt that the Chekka waters could, even if the prospects for agriculture are poor, be used for several others purposes mainly industry and alimentation of population agglomerations.

1.4 - Methods and equipment used for the investigation.

The reconnaissance program carried on the submarine springs of Chekka was possible only by the use of the aqua-lung diving apparatus. The crew composed of Mr. Lampietti, the writer and another diver from Batroun was operating in diving shifts, each one going down for a certain time. This was necessary to avoid decompression troubles.

All springs were studied at bottom and areas of flow were measured with an iron rod 1m. in length. Special waterproof plastic paper and special pencils were used for data recording at bottom. Inoxydable chains and drive-pipe samples were also used for sample collection.

Samples were collected by use of a perforated pipe driven at bottom and attached to a plastic hose operated on the small boat, by a happy hand pump.

All underwater photographs (see photos No2) were taken by using a waterproof french-built CALYPSO camera. Flow velocities were measured by current meters connected by a conductor cable to the boat. They were recorded as Turns per Second for the various points of measurement(See Photos No 2 and 3) The velocities were calculated using the average T P S and the mean calibration formula.

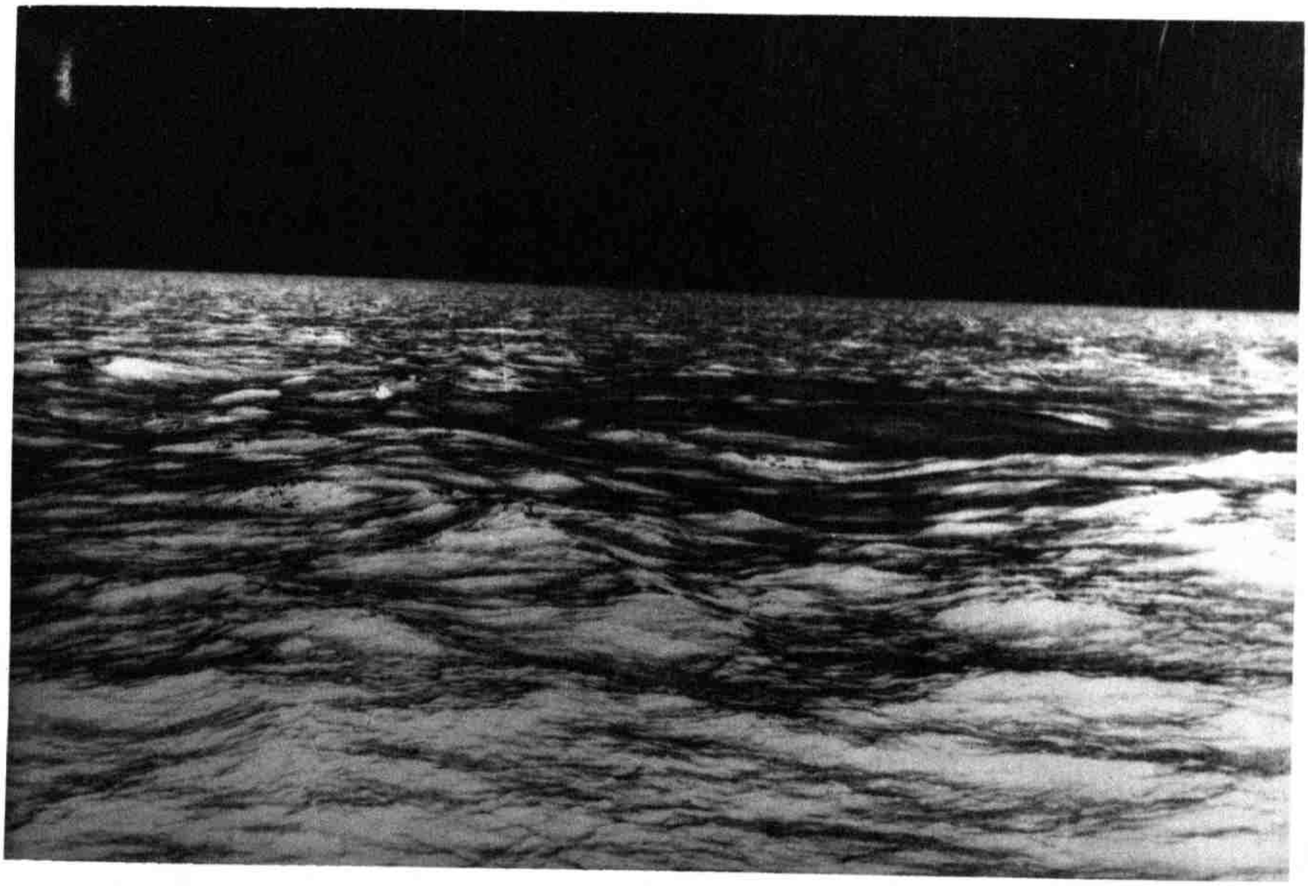


Photo I. Surface view of Chekka II (S2)

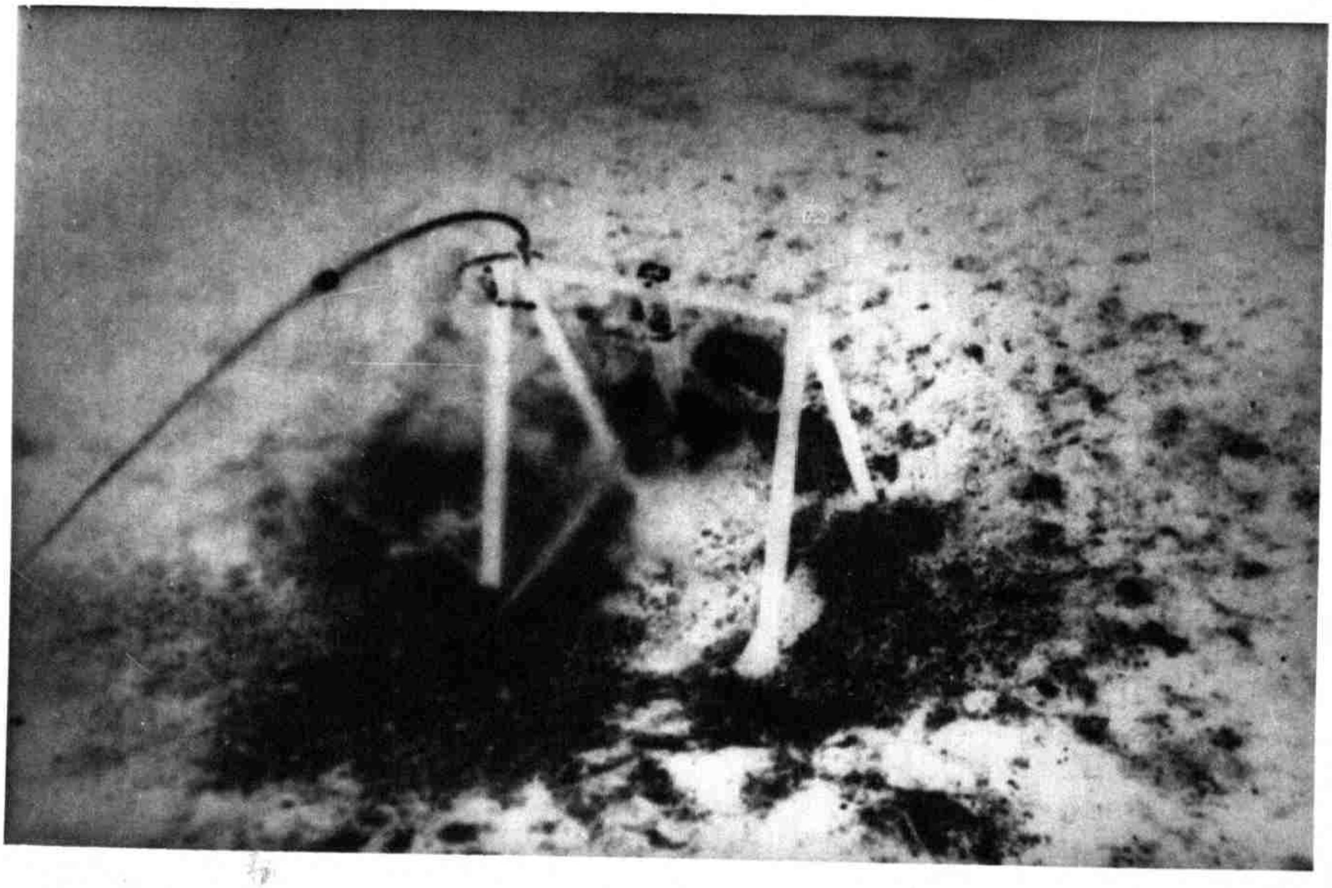


Photo 2- Current meter disposition at bottom of the sea and at the springs discharge points. Notice blurred visibility, suspended sand and algal stains. (Courtesy F. Lampietti).

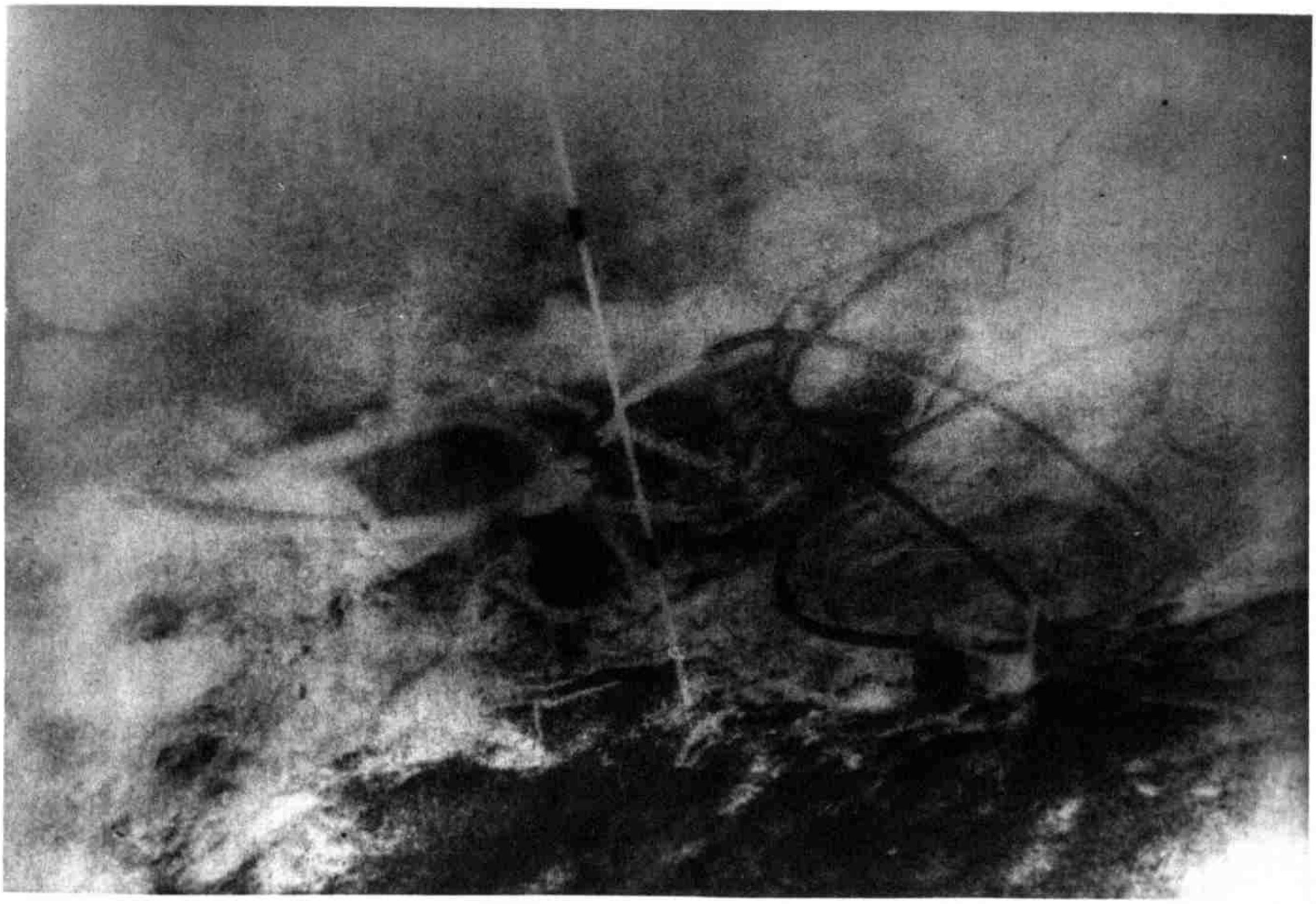


Photo 3- Sample collecting drive pipe with plastic tube and funnel. Suspended sand and blurred visibility. (Courtesy F. Lampietti).

Depths were recorded by a french-built CALYPSO "Profondimetre" or depth recorder.

The Diving apparatus and the necessary equipment were made by the "Spirotechnique" using the Cousteau system.

1.5- Description of the phenomena and main problems of the investigation.

Before the adoption of a method of tapping and exploiting the submarine springs it was necessary to obtain the biggest amount of information on their exact locations the shape of their openings, their depths, yields and salinities. it was also necessary to undertake on the adjoining coast a complete investigation of existing water points with hydrostatic level and salinity measurements. It was hoped that some of the wells along this coastal part had already reached the aquifer supplying the water discharged by the springs.

The Cenomanian-Turonian limestones constituting a recharge area of about 200km^2, are covered in the region of Chekka by the Senonian marls; the submarine springs spout out either in places where the thickness of the marl is small, or along fissures and fractures cutting across the marls.

1.5.1- Description of the submarine springs

The reconnaissance survey carried out in 1963 was made by the Ralph M. Parsons Co. in association with Ocean Science and Engineering Company represented by Mr. Francois Lampietti, and the UN Special Fund represented by the writer. The field investigations were carried out during the period of August 1963. Diving with aqua-lung apparatus was an essential feature of this reconnaissance both for investigation of the springs and the emplacement of various sampling and measuring equipment on bottom. During the period of investigation the weather was uniformly dry and hot. Working conditions were generally satisfactory although spray often proved a handicap to the operation and to the cleaning of the instruments. In general, water visibility was poor never exceeding 15 meters vertically; this was due to the high content of small suspended impurities in the sea water.

In February 1964 very important winter springs appeared on the coast and in the sea. The whole system of spring corresponds to three zones oriented in a NW-SE direction not far from Chekka (see location map No, 1)

a- The first zone is very near the coast (45 to 60 m) and includes Chekka I spring.

b- The second zone includes several springs (including Chekka 2 and 3) located in a circle of 300 m. diameter.

c - The third Zone corresponds to the biggest spring discharging only in the winter(but sometimes in the summer according to local fishermen).

Hence the system includes intermittent winter springs and permanent summer springs.

1.5.1.1 Summer springs (permanent)

Six submarine springs were located by their extension at the surface of the sea at distances from the coast varying between 50 and 600 meters. The springs are detectable by the presence of "slicks"(pathches of water without ripples on the sea surface). These slicks (see photo No. I) are generally porportional to the area of the spring on the sea floor and the intensity of its flow.

Chekka No. I(S1)

This is the closest spring to the coast and it was the first to be investigated. Chekka I occurs in the"Ramleh" (caleareous cemented Quaternary sandstones) and comprised a group of seeps localized in an oval depression about 20 by 10 meters in area oriented in an EW direction. The depth varies between 5 and 9 meters from E to W across the depression. The walls of the depression consist of "Ramleh" sandstone and are steep on all but the eastern side, which slopes more gently to the white gravel bottom at a depth of nine meters.

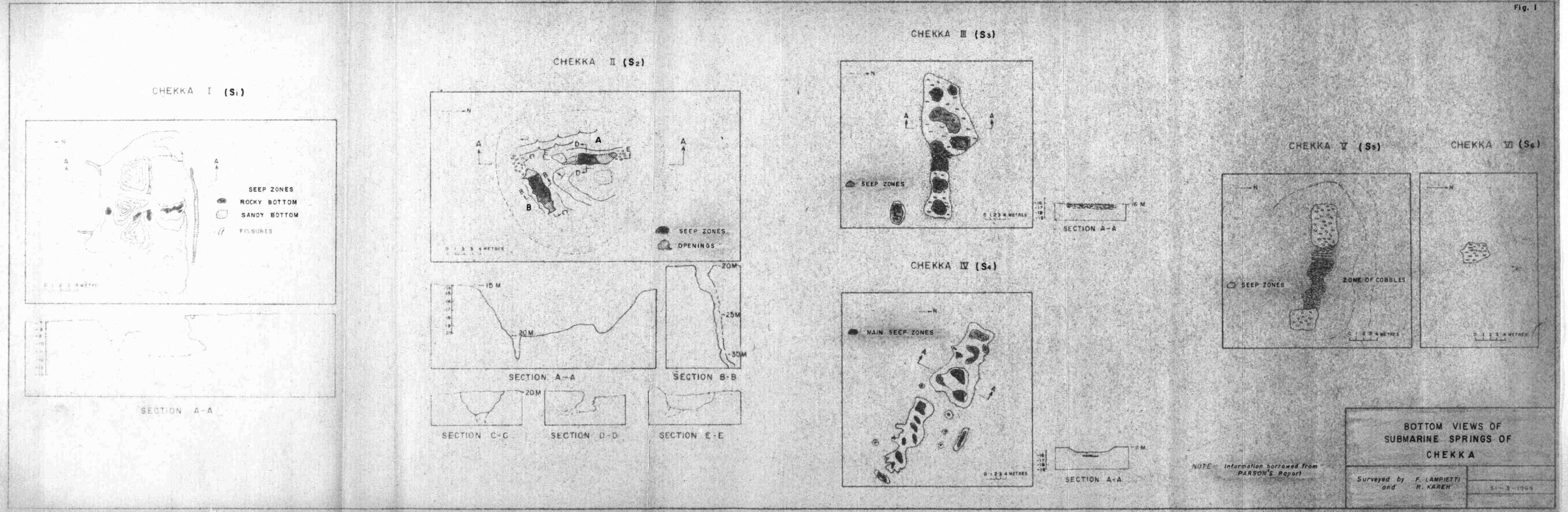
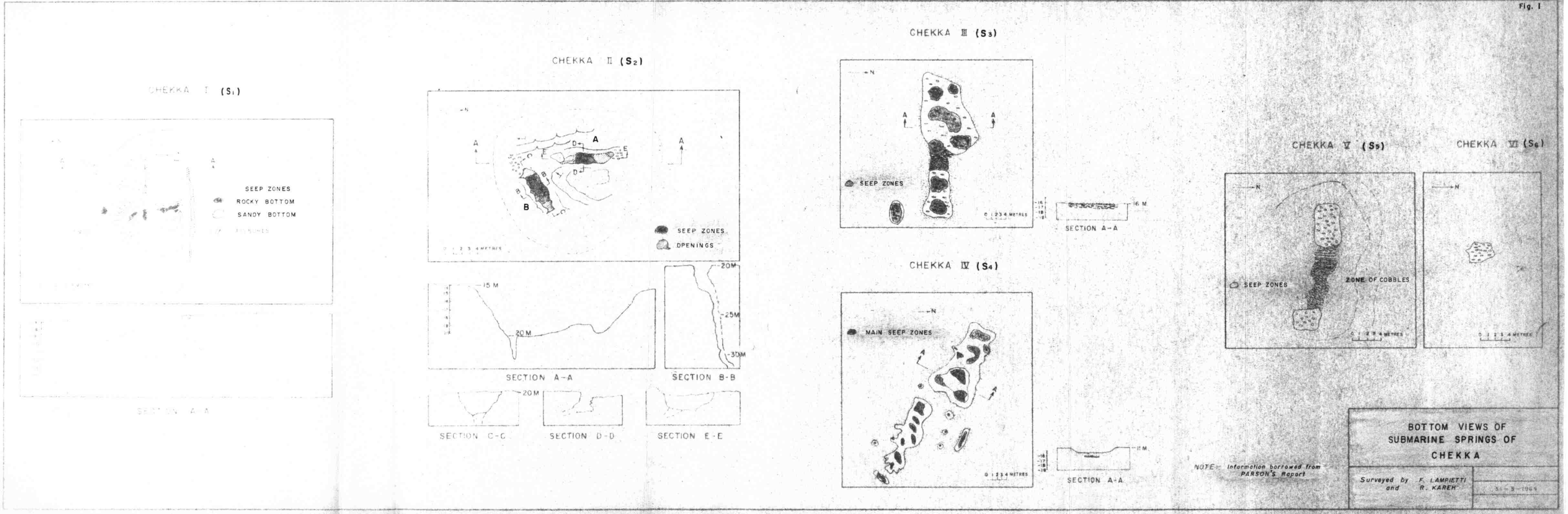


Fig. 1
CHEKKA I (S1)
SEEP ZONES
ROCKY BOTTOM
SANDY BOTTOM
FISSURES
SECTION A-A
CHEKKA II (S2)
SEEP ZONES
OPENINGS
15 M
20M
SECTION A-A
20M
25M
30M
SECTION B-B
20M
SECTION C-C
SECTION D-D
SECTION E-E
CHEKKA III (S3)
SEEP ZONES
16 M
SECTION A-A
CHEKKA IV (S4)
MAIN SEEP ZONES
SECTION A-A
CHEKKA V (S5)
SEEP ZONES
ZONE OF COBBLES
CHEKKA VI (S6)
NOTE: Information borrowed from PARSON'S Report
BOTTOM VIEWS OF
SUBMARINE SPRINGS OF
CHEKKA
Surveyed by F. LAMPIETTI
and R. KAREH

Fig. 1


CHEKKA I (S1)
SEEP ZONES
ROCKY BOTTOM
SANDY BOTTOM
SECTION A-A
CHEKKA II (S2)
N
A
B
C
D
E
SEEP ZONES
OPENINGS
0 1 2 3 4 METRES
15 M
20 M
SECTION A-A
20M
25M
30M
SECTION B-B
20M
SECTION C-C
SECTION D-D
SECTION E-E
CHEKKA III (S3)
N
A
SEEP ZONES
0 1 2 3 4 METRES
16 M
SECTION A-A
CHEKKA IV (S4)
N
MAIN SEEP ZONES
0 1 2 3 4 METRES
11 M
SECTION A-A
CHEKKA V (S5)
N
SEEP ZONES
ZONE OF COBBLES
0 1 2 3 4 METRES
CHEKKA VI (S6)
N
0 1 2 3 4 METRES
NOTE - Information borrowed from PARSON'S Report
BOTTOM VIEWS OF
SUBMARINE SPRINGS OF
CHEKKA
Surveyed by F. LAMPIETTI
and R. KAREH

The remainder of the depression bottom is occupied by sand and large blocks of "Ramleh" that have collapsed from the rim.

When descending to the white gravel bottom, the diver can sense several zones of water colder than the ambient sea water. The sudden presence of water of a different index of refraction prevents him from observing distinct outlines of objects. Indeed these are dominant characteristics of all the springs at Chekka: lower temperatures and different indices of refraction that result in blurred images and murky visibility.

The main spring flow in Chekka I is localized in the white gravel and rises intermittently from various points. In addition a number of small continous seeps occur from a variety of openings in the blocks of "Ramleh" around the white gravel and from fractures on the southern rim of the trough. There is a large abundance of sea-life, fish, sea-urchins and algae in the depression and on the walls except near or in the white gravel. (See Fig. No. I)

The remaining summer springs designated Chekka II(S2), III(S3), IV(S4), V(S5) and VI(S6) in this paper occur in a group distinct from Chekka I. These springs are farther north and at a greater distance from the coast. The bottom surrounding them is uniformly sandy, except for Chekka II which has occasional pathches of sea-grass.

Chekka II (S2)

Of the group mentioned above Chekka II is unique because of its mode of occurance. It is the deepest(about 20 meters) and has the greatest flow. It also has distinct openings in a solid chalky limestone identified as being of Senonian age. On the surface two conspicuous foci of "boiling" are visible in a slick of 15 to 20 m in diameter. These correspond on the sea floor to two openings at the bottom of a steep walled cone in the sand, the rim of which is at a depth of about 15m. The flow does not occupy the entire area of the openings but is as shown on Fig. I (see photo I).

The openings are rectangular in shape about 5m apart. For the purpose of discussion these two openings are designated A and B. Opening B is pinched at the ends and has a water worn fracture several centimeters wide at right angles to its rim. It was proved by lowering steel tubing that reached a depth of 10 m below the rim opening. Each opening bottoms into a shelf two to three meters below. At this level small deeper conduits occur which are not accessible to divers. There appears to be a connection between the two openings, visible from the shelf in opening A. However this could not be determined positively in view of the poor visibility in the spring water. Moreover, dye introduced in opening B failed to come up in opening A.

The four remaining springs share similar features. They all occur as shallow deppressions in the sandy bottom and have a general E-W elongation. They are all characterized by a slow flow of opaque water from numerous openings in cobbles, gravel or sand.

Chekka III (S3)

Chekka III is marked by three slicks on the surface. These correspond on the bottom to three areas of white chalky limestone cobbles with dark algal stains, at a depths of 16 meters. The cobble area is continous but water flows only from certain points. The edges of the spring mark only the rather abrupt transition between cobbles and sand and consequently no structure is apparent. Pointed rods used as sample collectors could not be diven deeper then one meter into the cobbles and it could not be determined whether rock or more cobbles are present below (see Fig. I).

Chekka IV (S4)

Excluding Chekka II, Chekka IV is the largest of the group, It appears as three elongated slicks on the surface but these surprinsingly reflect just one continuous feature on the bottom. (See Fig. I)

The bottom consists of elongated shallow troughs (see Fig. 1) about I meter deeper than the surrounding sand bottom that is at an average depth of IIm.

The characteristic feature of this spring is that its water flows from between a great jumble of heterogenous objects partly covered with sand. These objects include old tires, oil drums, branches, iron bars and other objects that were presumably introduced to plug some of the openings. A number of small circular depressions approximately 1/2 meter in diameter are located adjacent to the main trough. In the center of these depressions, discharge from a cluster of two or three small vents is sufficient to hold the sand in suspension a few centimeters above the bottom, as shown in photographs 2 and 3.

Chekka IV and Chekka III possess very few seeps where upward flow is perceptible i.e. pressure is not sufficient to turn the current meter propeller.

Generally the flow resembles that of a viscous oil ascending under the effects of different specific gravity and viscosity. Introduction of concentrated dye in some of the vents of Chekka IV showed that the flow is laminar for a distance of some 5 to 15 cms above the bottom. Chekka III and IV appear to correspond more closely to the description provided by the French scientific party which visited this and other submarine spring areas briefly in 1929 (see bibliography).

Chekka V and VI (S5 and S6)

Chekka V and VI shown in Fig. I are the least significant of the group. They are hardly visible from the surface and their flow is small. Chekka V is at a depth of 10m and consists of two patches of white cobbles. Chekka VI is a small blanket of cobbles at the same level as the surrounding sandy bottom of 15 meters.

1.5.1.2- Winter springs (Intermittent)

A few days after the first heavy rains of February, the flow of the summer springs increases considerably (five to ten fold) and at the same time other springs appear in the bay of Chekka and on the coast while several wells and water points become artesian : These are:

a- Wells Nos 9, 13, 14, 21, 25 (see location map No. 1) at altitudes of 15, 23, 6, 8, 4, 50 and 22m respectively become all artesian flowing. These wells have all reached the Cenomano-Turonian limestone complex and/or fissures connected with it. (See photo 12)

b- Two dolinas or sink holes located in the quaternary sandstones East of the railroad near the sugar refining plant and at a distance of 200 m from each other.(see location map). These sink holes are in line with Chekka II and occur in a flat surface of the "ramleh" formation in much the same manner as Chekka I. (See photos 8, 9, 10, 11)

Photo 4-Big Spring of Chekka S_{12}
(25/2/64)

Photo 5-Sink-hole "C"(3/2/64)
Notice foci of"boiling".

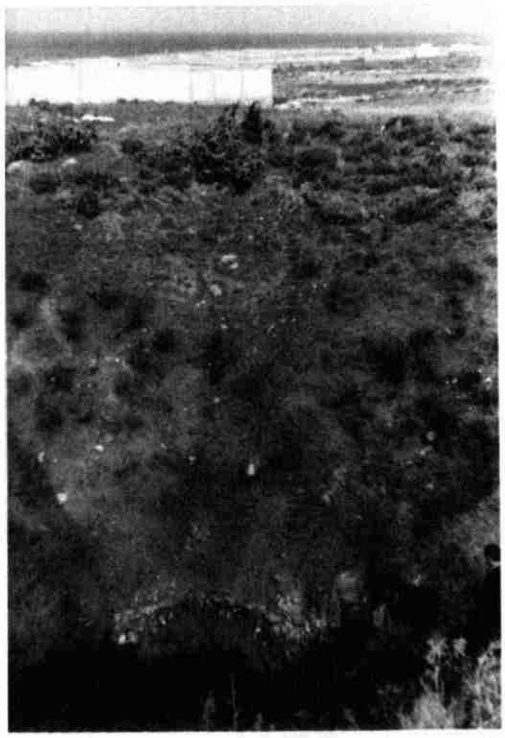
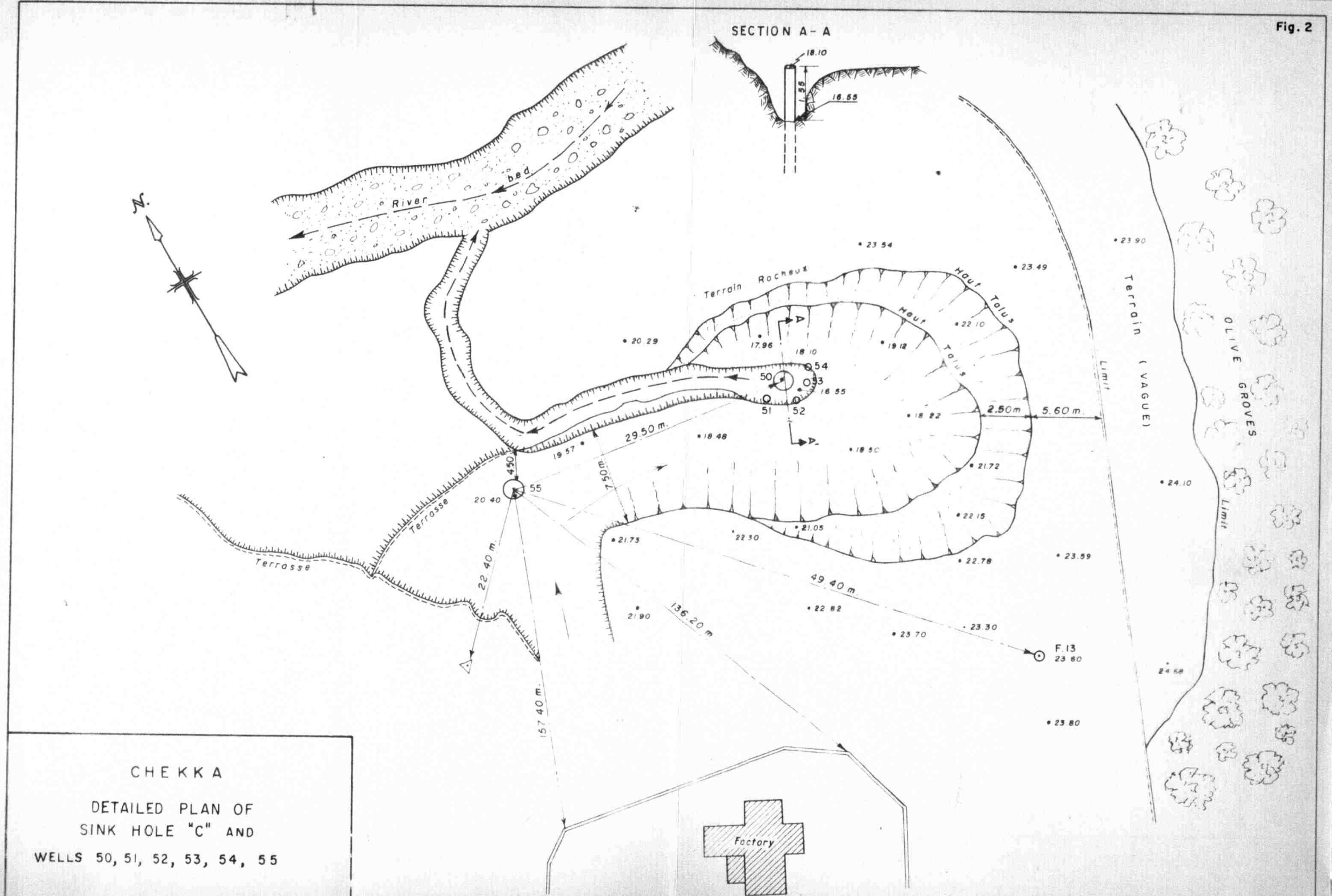


Photo 6-Sink-hole "B" in summer
dry. Depth 15m.

They display in fact the same undercutting of the sides and the same occurence of collapsed blocks in the center. Both of them bottom in roughly circular funnel shaped openings clogged in the summer time by sand and collapsed "ramleh" blocks. The two sink holes which are here designated C and B have diameters of 50 and 30 m respectively and are 22 m and 25 m above sea level; (see fig. 2 and photos 5 and 6). After heavy rains these sink holes fill up rapidly and start flowing abundantly for several days, then progressivly begin to dry up until the next heavy rains. (see photo 6).

c - Several new submarine springs (about 11 were counted in February 1964) which appear in the bay of Chekka and increase the total of springs to 17. It proved very difficult to give an underwater description for them because diving operations in the winter were very limited but their proximity to group 2 of the summer springs is a sign that the bottom is comparable everywhere in that vicinity.

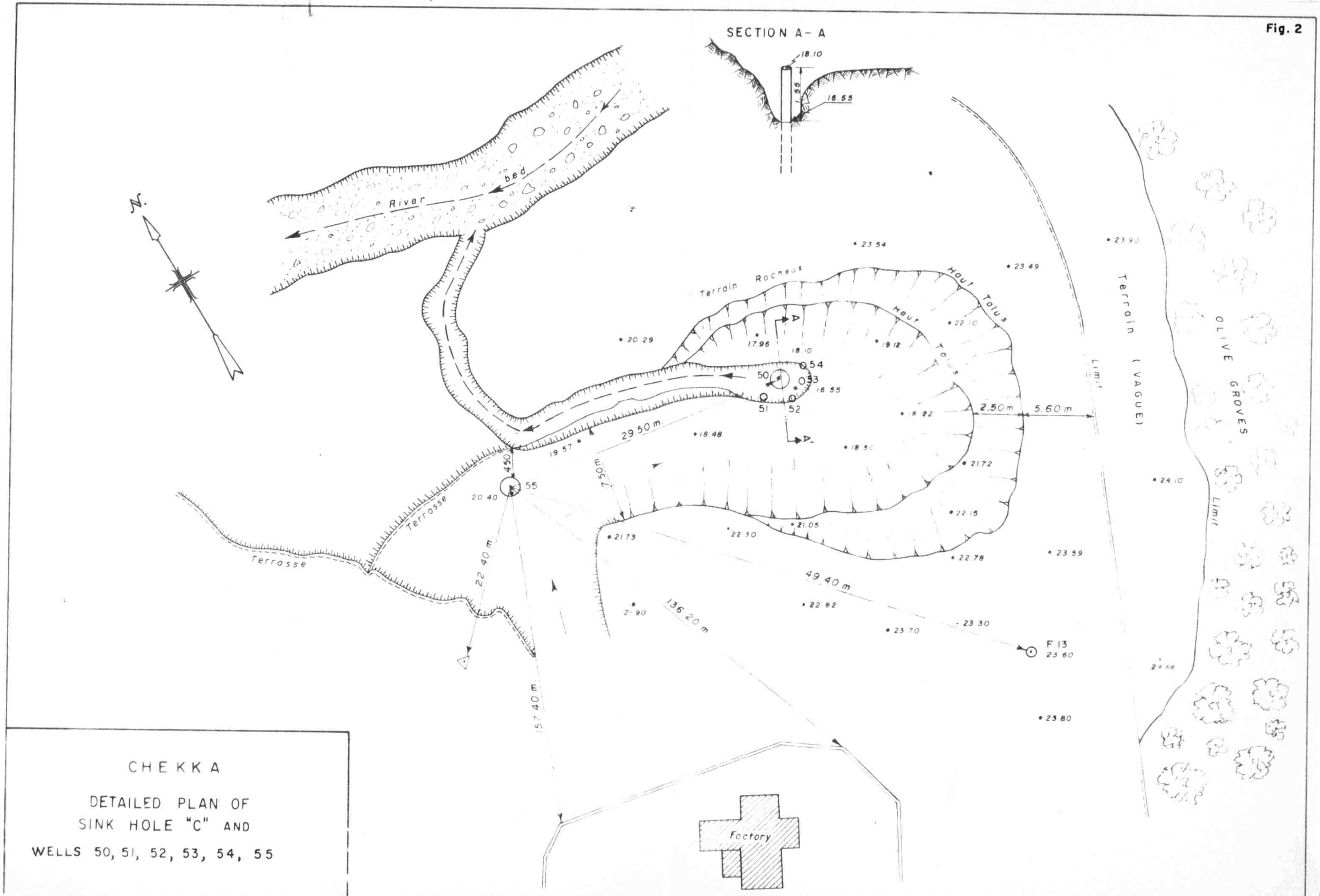
d - Finally the biggest of all winter submarine springs S 12 (see location map No. I and photo No. 4) located about 2 kms off shore in the bay of Chekka. The flow of this springs is so intense that its crossing by a good-size fishing boat is hazardous due to the intense turm oil of the water. The diameter of its slicks is about 300 meters. Diving was impossible in the winter and it could not be located exactly in the summer so that description of the bottom is lacking.



CHEKKA

DETAILED PLAN OF
SINK HOLE "C" AND
WELLS 50, 51, 52, 53, 54, 55

Fig. 2



CHEKKA

DETAILED PLAN OF SINK HOLE "C" AND WELLS 50, 51, 52, 53, 54, 55

Photo 7- Detail of S_{12}
(25/2/64)

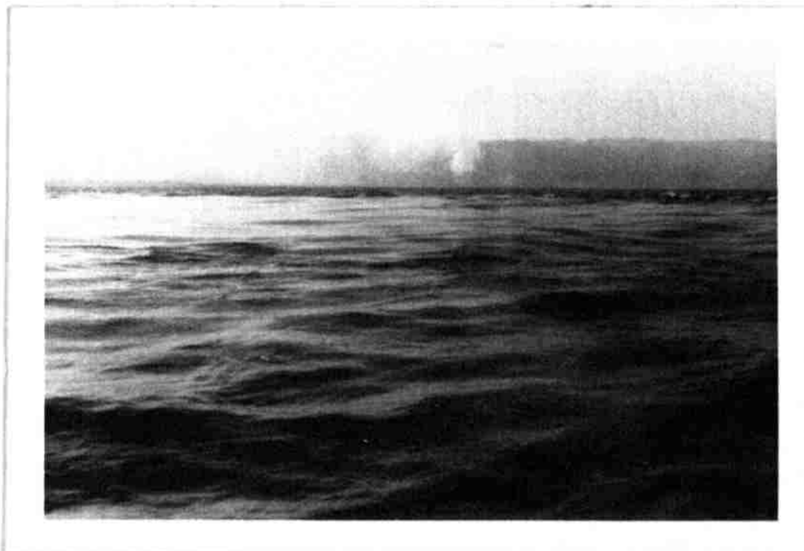


Photo 8- Sink-hole "C" two days after first flow and stop of rainfall. Notice drop in level when compared to photo 5.

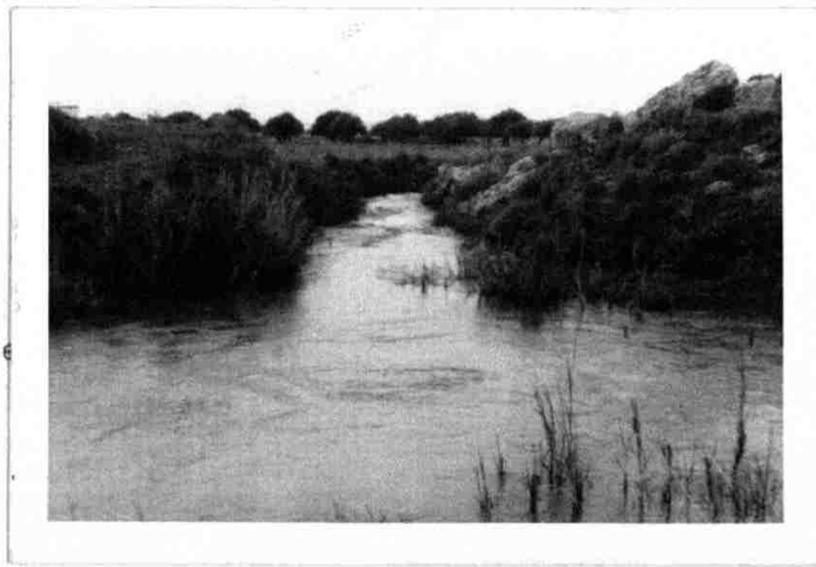


Photo 9- Sink-hole"C" flowing
Approximate yield 2.5m^3/se

On the other hand several depth soundings were taken in the winter and it appears that this spring flows from a funnel shaped depression over 70 meters deep whose edges(i.e. regular sea bottom) are about 46 m deep.

The "big spring"(i.e. S.12) is probably one of the most important submarine springs of the mediterranean basin.

All these water points were located as exactly as possible by intersections from a base-line located on the coast.

In concluding this description of the springs, it can be stated that the whole system of submarine springs and artesian water points on the coast constitutes the natural opening of the same aquifer or the same karstic network. The importance of the phenomena supposes that the recharge area resposible for these underground flows is very important. Finally the presence of blocks of Quaternary "ramleh" in the sink holes and in Chekka 1 indicates rather strongly that at least, a certain number of the springs is of Recent age, posterior to the "ramleh" deposition.

1.5.2 - Description of the phenomena of flow

Observations of hydrostatic levels in water points on the coast during summer and winter periods have shown clearly that one is dealing with a system of springs whose yields vary abruptly from summer to winter.

Photo 10-Sink-hole"B" flowing (3/2/64) Approximate yield 1m^3/sec.

Photo 11-Sink-hole"B" in Winter (3/2/64)

Photo 12-Well 13, near sink-hole"C" becomes artesian as soon as "C".

This sudden variation has been checked by measuring water levels and yields on the different water points located on the coast and at sea.

It is certain that the presence of a thick series of Senonian marls constitutes the essential condition in the formation of a partially fresh water aquifer discharging into the sea; the absence of this "screen" would have certainly provoked a complete intrusion of salt water towards the coast. This ideal situation which limits the possibilities of salt water intrusion and allows its return to the sea (during winter when pressure is great) gives good hopes for the exploitation of sizable quantities of fresh water during the dry season. Two main problems are faced within this investigation:

1 - The determination of the salt-water intrusion limit from the submarine springs.

2- The possibility of exploitation of a good amount of fresh water at points on the coast where flow and pressures are sufficient.

<u>1.6- Acknowledgments.</u>

In the preparation of this paper friendly assistance has been received from many sources. It is not possible them all specifically, but my thanks are none less real. Among those to whom I am most particularly indebted are the Manager of the Project of Underground Water Survey Mr. L. Moullard and my colleagues B. Miatovie, B. Massaad respectively hydrogeologist and Hydraulician of the Project whom I have consulted on various problems in the fields of karst and phenomena of flow in karst; L. Dubertret and G. Ferris for their contribution in the geology and Pumping tests sections; Dr. Ziad Beydoun and Dr. S. Maksoud for their pertinent advise in the fields of geology and hydrogeology; Mr. G. Ferry consultant delegate from the Compagnia Generale di Geophysica; Mr. Francois Lampietti of Ocean Science and Engineering for the field study of the submarine springs of Chekka; the Directorate General of Hydrolectric equipment which made this investigation possible and all the personnel of the Project of Underground Water Survey in Lebanon.

It is a pleasure to acknowledge all this friendly help, but since none of those mentioned has read the paper in its final form. The writer alone must assume the responsibility for any short comings and mistakes.

The illustrations are from many sources all of which are gratefully acknowledged in the credit lines attached to individual figures. However most of them have been done by the writer.

My cordial thanks go to Mr. Raffy Berbarian Chief draftman of the Underground Water Project who did all the final drafting of the map and illustrations.

To Mr. L. Moullard my obligation is unbounded. His supervision was a constant stimulus in my learning of Hydrogeology.

CHAPTER 2

2. Geology of the area

The central part of the Lebanon is a long horst like uplift trending in a SWW-NNE direction; in Northern Lebanon the flanks of this uplift are parallel and delineated in the West by a line of flexures and in the east by the extensive Yammouneh fault. The distance between the flexure line and the fault is about 25 kms.

The topography of this region is tabular with gentle dips to the WNW. The crestal part of the uplift is mainly composed of Jurassic, Lower and Middle Cretaceous sediments. Its core is composed of a very thick, massive dolomite and limestone series of Jurassic age while its cover is the domain of a thick series of Middle Cretaceous limestones. Between the two, clayey and basaltic terrains of Lower Cretaceous age form a neat separation and thus play a major hydrogeological role.

The Mediterranean flank of the Lebanon, in this northern region, is cut by an important WE fault, the Batroun fault which extends to the central part of the uplift and separates two different regions, to the South, Middle Cretaceous limestones dip gently from the flexure to the coast; to the North, these limestones disappear along the flexure. At the foot of the main uplift the topography to a low platform with a Neogene cover whose substratum is formed by the white marly chalks of the Upper Cretaceous. From the Batroun fault to the late Cenozoic-Quaternary basalts of the Tripoli - Homs gap, this platform extends over a length of 45 Kms, and its width varies between 7 and 13 kms.

The coast near Tripoli abounds with information about sea-level fluctuations in Quaternary times; this particular aspect of the Quaternary will be shown to be of the utmost importance in the discussion of the origin of the submarine springs of Chekka.

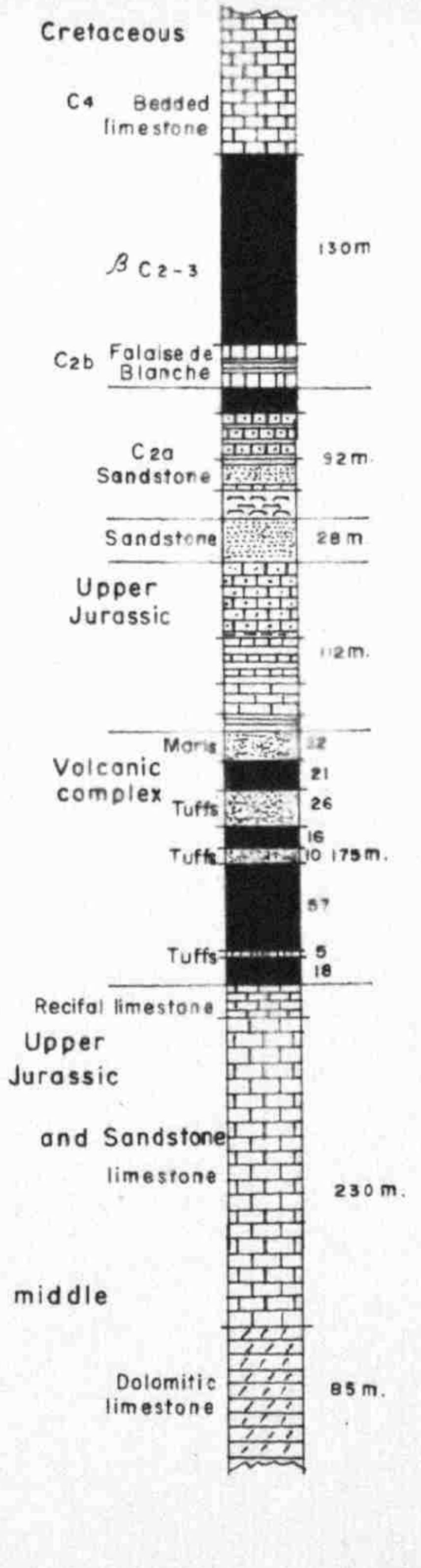
2.I. Lithostratigraphy

In the extensive recharge area of the submarine springs of Chekka, all Mesozoic and Cenezoic rocks are represented beginning with the Jurassic dolomites and limestones. Volcanic rocks are represented by Upper Jurassic and Lower Cretaceous basalts. The sediment succession is without interruption (except for Upper Eocene and Oligocene sediments) up to the Quaternary "ramleh" and Recent alluvial and fluvial deposits.

The stratigraphic succession given in this section is based on Dubertret *et al.* But most of the sections quoted have been revisited and checked by the writer in the field.

2.1.1. The Jurassic Formations

The Jurassic succession is deeply eroded in the Kadisha and Kannoubine valleys where its exposed thickness is about 500m. It is mostly composed of dolomites and grey limestones culminating at the top with grey marls and interstratified basaltic terrains.

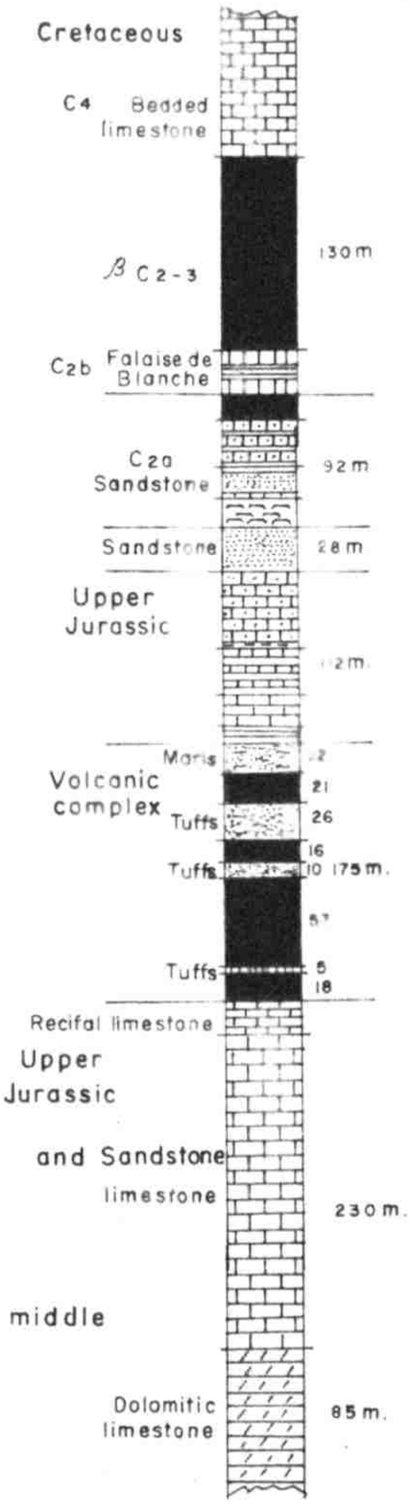


BQAA — KAFRA

Stratigraphic columns of Jurassic and Lower Cretaceous.

SCALE : 1/5000

Revisited by R. KAREH



BQAA – KAFRA

Stratigraphic columns of Jurassic and Lower Cretaceous.

SCALE : 1/5000

Revisited by R. KAREH

The most complete section of the area is in Bkaa Kafra near Hasroun where the following sequence can be seen from the base upwards: (see stratigraphie column Fig. 3)(Dubertret,1955)

a- Lower dolomites and limestones 550m. thick.
 The dolomites are often altered to dolomitic sands and their thickness is about 330 m.
 Upper massive blue-gray limestones interbedded with marly and white reef limestones containing Polyps and Stromatoporids.

b- A volvanic complex about 190m. thick compose of:
 18 meters of basalts at the base.
 5 meters of a dark-brown fossiliferous limestone.
 158 meters of basalts, tuffs and ashes.
 8 meters of brown, clayey marls with fragments of plants and marine fauna.

c- A gray limestone cliff 20m. thick with oyster fragments.

d- Oolitic, yellow-brown limestones about 85m. thick.

The succession is the same as in the type section near Bickfaya. Many fossils are common to both sections except for Cidaris glandaria common in the Bickfaya section but which has not been found in the Kadisha valley (Dubertret, 1955).

The lower dolomites and limestones correspond to a uniform, quiet and rather deep neritie marine environment while the upper formations show a tendency towards emergence.

An erosional surface seems to cut on part of the top Jurassic formation on both sides of the Kadisha valley and the Jurassic succession is complete only near Becharre and Bkaa-Kafra. Prior to the deposition of the Lower Cretaceous sandstones fissure vulcanism disrupted the Jurassic Carbonate sequence and this was later leveled by erosion. The regular distribution of the Lower Cretaceous sandstones all over the Jurassic bears witness to this peneplation.

These indications of emergence, uplift and disturbance at the end of the Jurassic are more conspicuous in Northern than in Central Lebanon.

2.1.2. The Cretaceous Formations

As early as 1833, the Cretaceous deposits of Northern Lebanon had been identified by P.E. Botta, who divided them into three groups:

a- A sandy group with very rare fossils.

b- A marly limestone group with intercalations of flint beds.

c- A white, clayey limestone group.

These divisions correspond, broadly, to the Lower, Middle and Upper Crateceous formations of Lebanon.

2.1.2.1 The Lower Cretaceous succession

These are about 250-300m. thick and include all the arenaceous terrains of the basal Cretaceous which extend upwards to the Upper Aptian. A cliff of gray, reef limestone known as the FALAISE DE BLANCHE (in honor of the french geologist Blanche who first described it) constitutes an excellent regional marker throughout Lebanon and divides the Aptian succession into a lower sandy and marly group and an upper limestone group.

In Northern Lebanon the Aptian was also a period of vulcanicity; its sediments are interstratified with basalts which locally complicate the succession. An excellent section of the Lower Cretaceous is given by L. Dubertret(Dubertret,1951) near Mazraat Beni Saab on the road to Hadath Joubbeh, N. Lebanon. The sequence from the basal Cretaceous to the Albian deposits at this section is as follows:

a- <u>Basal sandstones, 28m</u>.

-2.60m. of gray sandstones with think beds of marls and marly limestones containing caraminifera and oysters.

-25m. of sandstones of ferruginous, quarts sand, ferruginous, loosely cemented and containing small lenses of lignite.

b- <u>Lower Aptian Sandy-Marly group 163m.</u>

- 22m. of yellow and green marls with gastropods and intercalations of thin marly limestone beds.
- 22m. of greenish clayey marls and sands with thin intercalations of oolitic limestone, and with plant fragments, amber and Mollusca shells such as <u>Exogyra SP</u>. and <u>Cardium SP.</u>

- 56m. of yellow oolitic limestones.
- 31m. of oolitic limestones with thin intercalations of clay containing <u>Orbitolina SP</u>
- 32m. of compact basalts and thin beds of limestones and clays with oysters.

c- <u>Upper Aptian limestone-Volcanic group 100-150m.</u>

- 10.5m. of compact, cliff-forming reef limestone the Falaise de Blanche(Dubertret, 1951).
- A volcanic complex of basalts and intercalations of clays limestones and sandstones about 130m. thick. Elsewhere in the area the "volcanic complex" is less well developped and the upper part consists of marly and sandy deposits.

<u>2.1.2.2. The Middle Cretaceous Succession</u>

The Succession is about 1000m. thick and includes the marly sequence of the albian, the limestones of the Cenomanian and Turonian. During the Lower Cretaceous the sea transgressed over Lebanon progressively and deposited neritic sediments in which quartz sand is an important element. By contrast, quartz sand is absent from sediments of the middle Cretaceous and the period is marked by a deepening of the sea. The lower limit of the Middle Crateceous is taken rather arbitrarily and just above the highest occurence of the lower sandstones.

a- <u>Albian Deposits 124m.</u>

The Albian period deposits usually consist of alternations of very fossiliferous limestone and marls easily identified by the presence of the echinoid Heteraster delgadoi, Knemiceras SP. and Engonoceras SP. (Dubertret,1951). The upper limit has not been determined clearly but is arbitrarily delimitated at the occurence of the Radiolites limestone and dolomite beds.

The Albian succession has been identified above the upper Aptian basalts near Beit Mounzer, where the typical Cardium marker bed and the green marls are found. Heteraster delgadoi was not found in this area. Above the Falaise de Blanche, the succession is as follows:

- 45 m. of basalts.
- 41 m. of shales with thin, fossiliferous limestone beds.
- 8m. of stratified basalt.
- 30m. of yellow red marls and clays with pyroclastic elements and thin beds of marly limestones.

b - Cenomanian-Turonian Carbonates 900m.

The Cenomano-Turonian succession is mainly composed of alternations of marly limestones and thinly bedded limestones. The marly limestones are associated with thin flint beds and quarts geodes. Lithologically, the formations of the Cenomanian and the Turonian do not present major differences and hence are not separated.

The regularity of development and the quasi-constant thickness of the Cenomanian Carbonates suggest a rather deeper-water neritic deposition.

The Turonian is recognized by its characteristic ammonites and Hippurites fauna. Turonian limestones are sometimes characterized by their apparent lack of stratification. In the Chekka area the work connected with the submarine springs required detailed mapping of this area with particular attention to the Turonian limestones and the Senonian marls. This was done in 1.10000 scale by the writer (plate I). Mapping showed that the Turonian limestones there occupy the valleys of Nahr el Asfour and its tributaries. These valleys have a characteristic V-shaped profile and are intensely karstified. The Turonian succession has a pot-holes aspect and is spotted by sink holes, dolinas, uvalas giving it the aspect of "small-pox topography" (Cvivic, 1960).

The Turonian-Senonian contact is situated above a brecciated, glauconitic bed containing shark teeth and oysters. In the quarry belonging to the Societe des Ciments du Liban shark teeth can still be found though the glauconitic bed has practically disappeared. It is easily identified by the sharp contast in color between Turonian limestones and the overlying Senonian chalks. The Turonian limestones in the quarry are rather soft and chalky while in the Nahr el Asfour valley they are very hard and compact.

Hippurites and gastropods are seen in the hard limestones near the village of Kefraya.

2.1.2.3- The Upper Cretaceous and Eocene chalky Deposits

The Marly chalks of the upper Cretaceous are not represented in the Lebanon and Anti-Lebanon chains. Their domain is strictly limited to the surrounding low-lands: the coast, the plateaux of S. Lebanon and the Bekaa.

The abrupt change in facies at the limit of the Middle and upper Cretaceous is an indication of a complete change in paleogeographic conditions following probably a short orogenic phase in Turonian time,(the Turonian is not identified in the crestal parts of Mount Lebanon). In the Chekka region the stratigraphic discontinuity as the base of the Senonian could not be followed far, but the conditions of sedimentation change completely and deposition of the globigerinal chalks begins.

The Senonian chalks outcrop near Jbail and Batroun and extend North of the Batroun fault to the raviness South of Fih. On old geologic maps (Zumoffen,1909) the chalks are represented as Senonian; on the more recent map of Lebanon (Dubertret,1955) they are represented as Senonian and basal Eocene.

In the detailed mapping of the Chekka area (plate I) it was not possible to differentiate between the Upper Senonian and the Eocene; they seem to have one basic difference; Senonian flint beds range from 80 to 120 cms. in thickness and are more regular than the Eocene flint beds which are thinner and discontinuous or nodular.

The Senonian and the Eocene were only differentiated on the basis of microfauna(Wetzel, 1945). The succession in the Chekka area from the Upper Turonian is as follows:

- Glauconitic, marly bed with phosphate nodules lying over the Turonian limestone and containing Ostrea vesicularis and shark teeth(collected in Chekka in the cement quarry). This bed is 0.30m. thick.
- alternations of gray, chalky marls and more compact marly limestones with flint beds. 208m. The most important microfossils are:

  Globigerine cretacea(d'ORB.)
  Cibicides floridanus (Cushman)
  Globotruncana cf. rosetta(CARSEY)

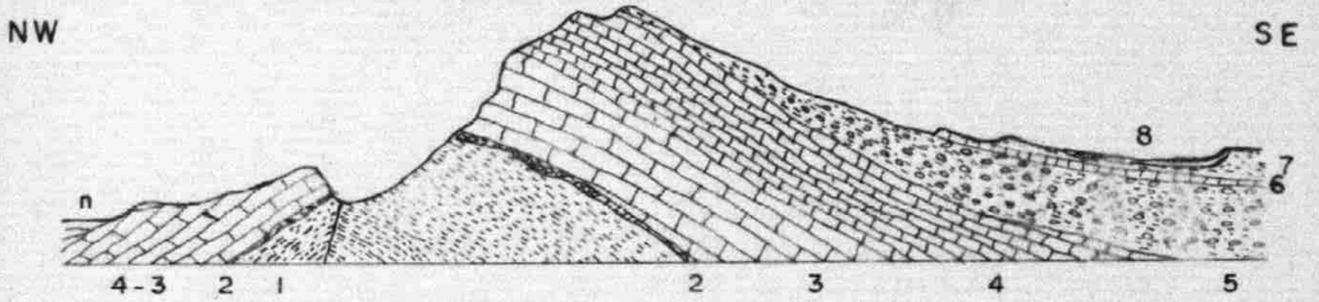
- soft marly chalk; 173m.

The lower Eocene begins with the disappearance of the above-cited microfossils and with the appearance of Globorotalia (Dubertret, 1955). Its succession in El Hery is as follows:

- soft marly clay with numerous thin flint beds; 145m.

  Globorotalia cf. crassaformis(GALLOWAY and WISSLER)

Fig. 4



SECTION OF JEBEL TERBOL, By A. KELLER

Revisited by R. KAREH

Slightly modified

1.— Chalky limestone (Senonian)

2.— Basal conglomerate 3 m.

3.— Limestone

4.— Reef limestone

5.— Ditrital series

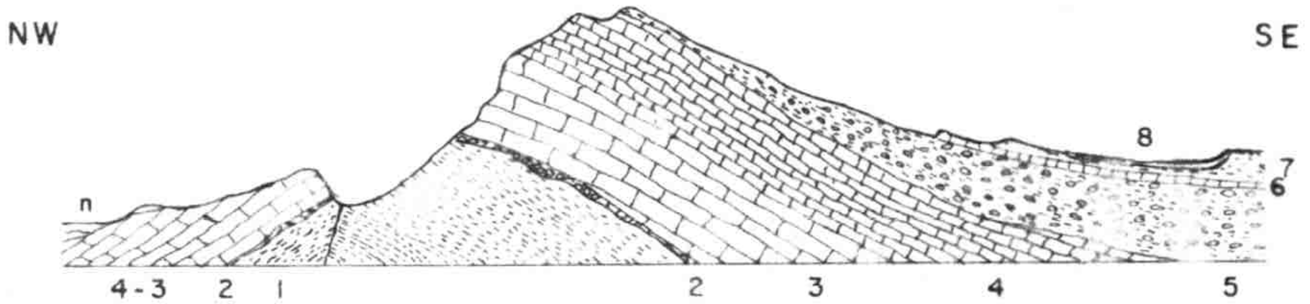
6.— Hard limestone

7.— Chalk with Amussium cristatum

8.— "Ramleh"

n.— Sea-level

Fig. 4



SECTION OF JEBEL TERBOL, By A. KELLER

Revisited by R. KAREH
Slightly modified

1.– Chalky limestone (Senonian)	6.– Hard limestone
2.– Basal conglomerate 3 m.	7.– Chalk with Amussium cristatum
3.– Limestone	8.– "Ramleh"
4.– Reef limestone	n.– Sea-level
5.– Ditrital series	

Overlying this unconformably are the Miocene limestones. The Eocene of Chekka corresponds to the basal Eocene of the Saida region; the upper nummulitic levels have been eroded.

2.I.3. The Neogene Formations

By the Neogene the sea had retreated from the Bekaa and the Damascus plateau; in Vindobonian times, however, it returned to the coastal area of S. Lebanon and the foot of the Lebanon chain where its sediments lie unconformably on a variably eroded substratum. Marine deposits of Neogene age are best developped in Northern Lebanon, between Ras Chekka and the basalt tracts of Halba. The Neogene is divided in two sedimentary cycles separated by an orogenic phase(Dubertret,1946),:

The Miocene cycle

The Pliocene cycle

2.1.3.1. The Miocene Cycle

The succession from older to younger sediments(Keller,1934) is as follows:

a- Vindobonian reef limestones transgressing either on the Eocene or the Senonian marls and chalks.

b- A detrital series Pontian age, composed of conglomerates and terrigenous red marls grading laterally to lacustrian marls.(see Fig. 4).

a- Vindobonian marine sediments

They are about 260-300m. thick and are represented in North Lebanon by the reef limestones of Jebel Kelhate, Jebel Terbol, the Tripoli plateau and the islands off the coast of El Mina. These limestones are characterized by the presence, at their base, of a basal conglomerate and by saccharoidal compact limestones with algae and Lithothamniae. A few beds of marly, sandy limestones with Clypeaster sp. and Ostrea crassissima are interbedded with the saccharoidal limestones.

Close to the mountain range, the basal conglomerate thickens and marly levels increase in the limestones. In Jebel Kelhate the basal conglomerate disappears. The limestones on the Ile des Palmiers contain Heterostegina costata.

b- Pontain lacustrian and torrential deposits

These vary from 200 to 800 m. in thickness and are composed of alternations of white marls, sandy limestones and conglomerates. The Vindobonian limestone deposition is interrupted by an orogenic uplift phase causing the formation of the Zghorta platform, the erosion of the high lands and the filling of lower depressions by continental and marine deposits and especially by torrential, lacustrian and alluvial marly deposits. The flanks of Jebel Terbol were undercut and deposition started at the surface of erosion.

The Pontian conglomerates contain broken fragments of lamellibranchia and gastropods. The lacustrian marls contain the common fresh water form Helix.

2.1.3.2 The Pliocene Cycle

At the end of Moicene times the mountain ranges of Lebanon were uplifted but the Zghorta platform was temporarily submerged to the foot of the Lebanon chain. Marine Pliocene is overlain in several areas by torrential conglomerates of Villefranchian age. Following this, the sea retreated to its actual position. Pliocene deposits occupy the synclinal structure between Jebel Terbol and the mountains. Its only complete section is in Nahr el Arka (Dubertret, 1960)

a- Plaisancian marine deposits

Above the lacustrian marls of Pontian age, lie formations of marly limestones, blue clays and basaltic beds. A white sandy limestone contains Pecten SP. and Cardium SP. The pelecypod Venus is common along with Amussium cristatum.

b- Villefranchian conglomerates

The Villefranchian is composed of conglomerates and yellow sandstones with lenses of tufa containing imprints of leaves.

The interstratified Pliocene basalts die out in the west and south-west are replaced by conglomerates and later by reef limestones. On the flanks of Jebel Terbol, the substratum contains Amussium cristatum. The coast near El Beddaoui spring is formed of blue clays with Amussium cristatum. North of Rachine are found the same Villafranchian conglomerates.

2.1.4. The Quaternary formations

At the end of Pliocene times, a final orogeny gave the Lebanon its present aspect. On the slopes of Jebel Terbol, marine Pliocene deposits were uplifted to 500 m.; along the coast and near the Akkar plain the Pliocene formations are almost vertical.

In Quaternary times these deformations ceased, the land rose slightly and sea-level fluctuated with an amplitude of several meters (WETZEL and HALLER , 1945). When sea-level dropped erosion became more active in the coastal zones but when it rose, alluvial deposits accumulated on beaches and lower river courses.

The extremes of marine fluctuations, especially the maximal phases, had a greater persistence than the intermediary positions thus leaving on the coast excellent markers: erosion levels, and belts of beach pebbles accumulated in bays. The fluctuations reached the altitude of 100m. above the actual sea-level. Stages are recorded at 90 -100m., 65m.,45m, 35m., 15m., and 6m.

The geology of the coastal Quaternary of Lebanon is complicated and difficult to interpret; it gives the Lebanese coast below the 100m. level its particular morphology.

2.2 Tectonics and Summary of Geological History

The stratigraphic column is rich in evidence relating to the structural evolution of the region of Chekka in past geological times. The section of Mazraat Beni Saab gives an excellent account of the dislocations that occured at the end of the Jurassic. The Jurassic succession was faulted, differentially elevated and the sea shot through by volcanics. Erosion peneplained this surface on part of which the Cretaceous basal sands were laid and onto which the Aptian transgressed. Volcanism persisted intermittently till the end of the Lower Cretaceous with a maximum intensity at the end of the Upper Aptian. These phenomena were associated with orogenic disturbances not yet too well explained.

The Tripoli region has a clearly exposed Neogene section. The Burdigalian is not represented but the Vindobonian transgresses, with a basal pebble horizon onto the Lower Eocene and Senonian. During the interval from the Middle Eocene to the Vindobonian the Lebanon chain and the Zghorta platform emerged from the sea and were exposed to erosion. The Zghorta platform is one of the main structural units of this area of Lebanon and occupies the synclinal trough between Jebel Terbol and the Lebanon chain proper. The Vindobonian sea covered all of the Zghorta platform but nowhere does it appear to have attacked the foot of the main uplift: from Batroun to Zghorta, Vindobonian limestones lie exclusively over the Lower Eocene and the Senonian; marly chalky deposits; they approach the main Lebanon up lift but never transgress over the Turonian or the Cenomanian carbonates. Thus before the Vindobonian transgression, the Zghorta platform was mainly a region of Lower Eocene marls with flint beds and Senonian chalks.

At the end of Vindobonian times a general uplift caused folding and emergence of Jebel Terbol and a beginning of erosion. (Dubertret, 1945). In the Synclinal structure of Zghorta the advance of the sea was checked and streams and lakes developed with the Pontian; Nahr Abou Ali and Nahr el Bared valleys were already cut and alluvial deposits accumulated at their mouths in the Zghorta platform.

At the end of the Pontian a new orogeny caused a further uplift of the Lebanese range; the syncline of Zghorta subsided and sank below the sea. To the N.E extensive basaltic flows covered the Tripoli-Homs gap and marked the beginning of the Pliocene. Pliocene deposits lie unconformably on the eroded Miocene formations. In Upper Pliocene times the sea began its final retreat and torrential deposits succeed to marine deposits.

Final uplift and dislocations gave the region its present aspect. The Pliocene was uplifted to 500m. above sea-level and gently folded. In Quaternary times a further regional but slight uplift with an amplitude of about 100m. occured. The present structural characteristics of the region, offer the best contrast in the whole Lebanon between the main horst-like uplift of the Lebanon range and the lower lands (the Zghorta platform).

In the main Lebanon uplift the Jurassic and overlying Lower Cretaceous deposits are,(as in other parts of Lebanon) intensely fractured; the succession culminating at the top with a well developped volcanic series. The Middle Cretaceous cover is less disturbed.

In the Zghorta platform, the most peculiar aspect are the folded structures of Jebel Kelhate and Jebel Terbol, conspicuous from near Jbeil and extending to the basaltic flows of the Akkar plain.

Jebel Terbol trending W-E is not a simple dome and its configuration and asymetry indicates the presence of faulting in depth, beneath the thick sedimentary cover of the platform. As in the other coastal regions of Lebanon and from South to North, the coastal flexure, forming the west flank of the main uplift, is displaced to the east at every major crossfault indicating a more complex attitude than just simple fold flexuring. The zone of flattening out of flexured west of the main uplift is however without complication and a straight forward synclinal area separates the main uplift from the almost parallel fold trend of Jebel Kelhate.

In the region the dip is seawards and despite the axial zone of the Kelhate trend, a hydrostatic head is present due to the higher altitudes of the recharge area.

The summary of the geological history of the region of Chekka and Koura, shows the importance of the hydrogeological research we have undertaken, in that water accumalations are concentrated very close to base-level (i.e. sea-level) and that the supply zone is constituted by the karstified Cenomano-Turonian limestones of the main uplift.

3. Geographical and Geomorphological factors

It is evident that paleogeographical and geomorphological factors have made important contributions to the final development of the karstic system of Chekka. These contributions which started in the Quaternary, would have been more limited but for the prevailing favorable geological conditions, which were thus indirectly responsible for the development of the confined aquifer discharging in the sea through submarine springs.

3.1. Geological Conditions

The presence of a thick series of Senonian marls above the Cenomanian -Turonian limestones constitutes the essential condition in the development of the confined karstic aquifer and the submarine springs of the region of Chekka. The absence of the impermeable Senonian marls would have surely brought about the diffusion and dispersal of the Cenomanian-Turonian waters in the sea, as is the case all along the Lebanese coast between Beirut and Batroun.

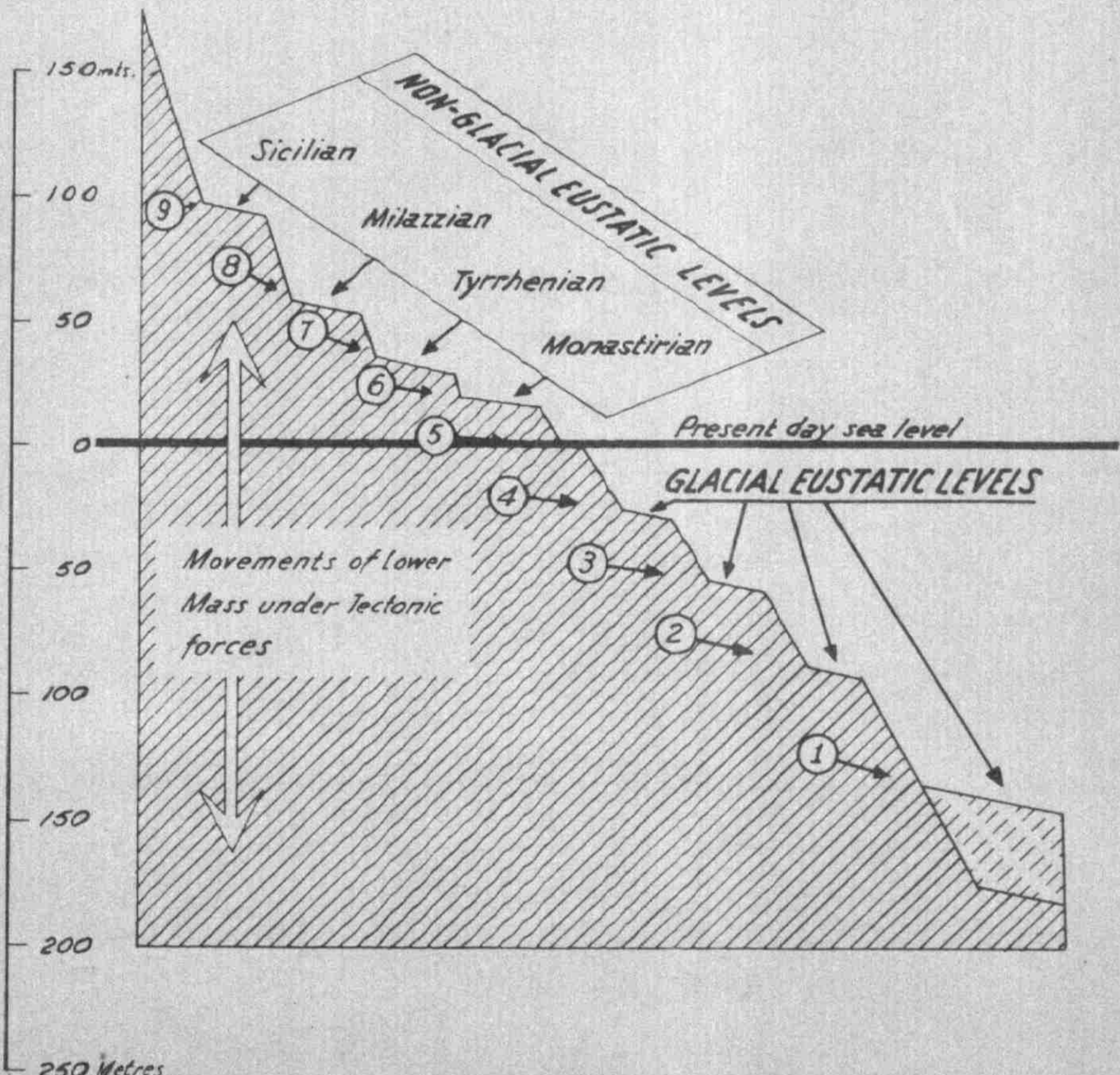
The Cenomanian-Turonian limestones of the submarine springs ' recharge area, are cóvered by Senonian marls only in the Chekka area, in other words at the lowest points of the basin. Hydogeologically, the Senonian marly chalks can be considered as perfectly impervious hence forming an impermeable barrier for all the waters of the Cenomanian-Turonian aquifer.

The importance of the Turonian-Senonian unconformity is here stressed, as it is considered that it originally formed the principal cause for the initial limestone karstification. This paleokarstification, despite its somewhat local extension, was the direct cause, after the deposition of the overlying marls in the subsequent development of a gigantic karstic system in Chekka.

3.2. Origin of the Karstic Phenomena

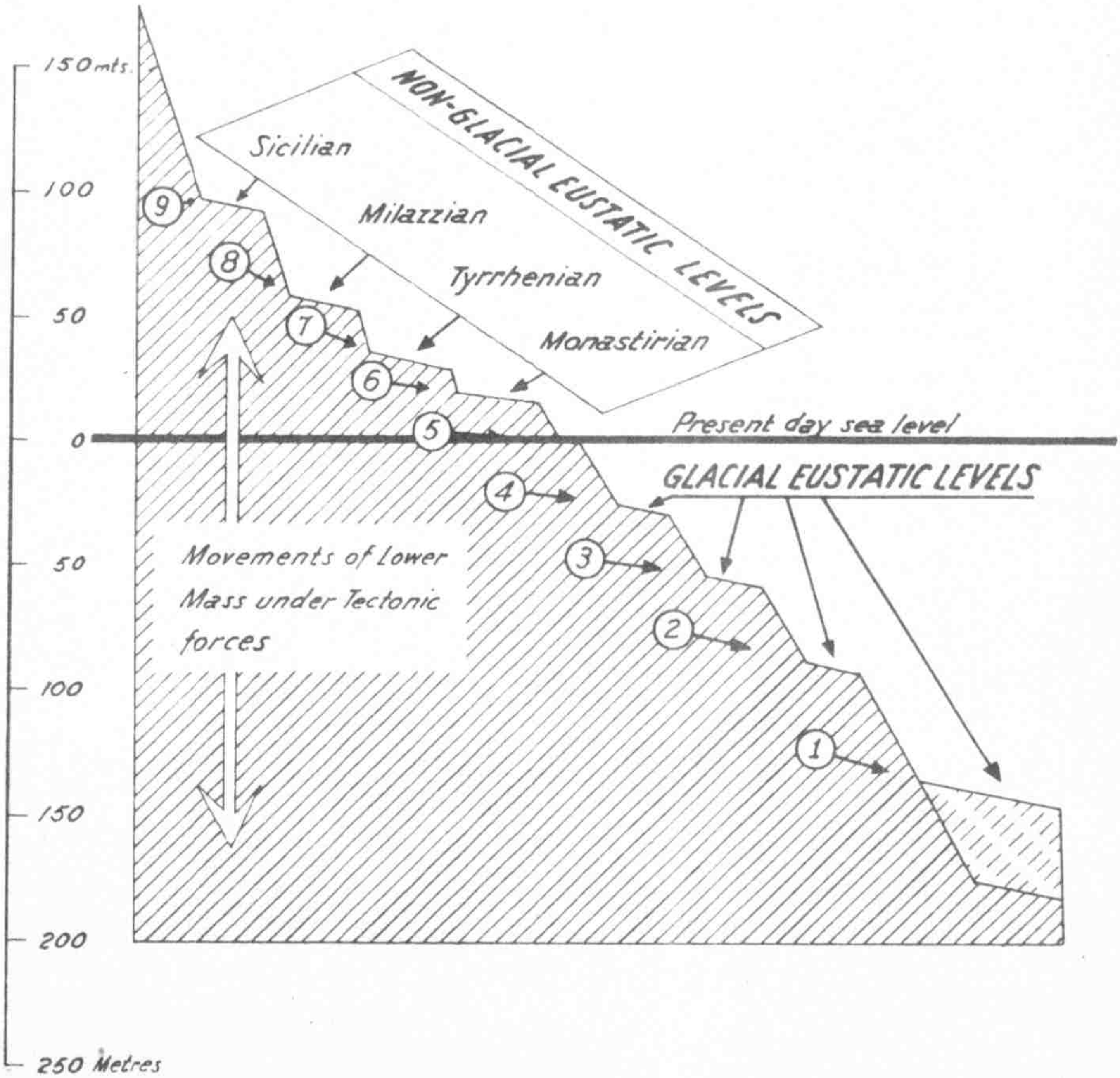
Karstic erosion began in Cenozoic times reaching its peak in the Quaternary when the last tectonic movements created the present tectonic relief of Lebanon. At this stage, karstic evolution in the Chekka region, was conditionned, as in other parts of the Meditteranean coast, by the oscillations of sea-level during glacial and inter-glacial periods (Burdon and Papakis, 1963). These oscillations were frequent in the Quaternary.

Fig. 22



QUATERNARY SEA LEVELS; CIRCLES AND ARROWS SUGGEST POSSIBLE HORIZONS OF QUATERNARY AND PRESENT DAY KARSTIFICATION

AFTER DEPERET (1963)



QUATERNARY SEA LEVELS; CIRCLES AND ARROWS SUGGEST POSSIBLE HORIZONS OF QUATERNARY AND PRESENT DAY KARSTIFICATION

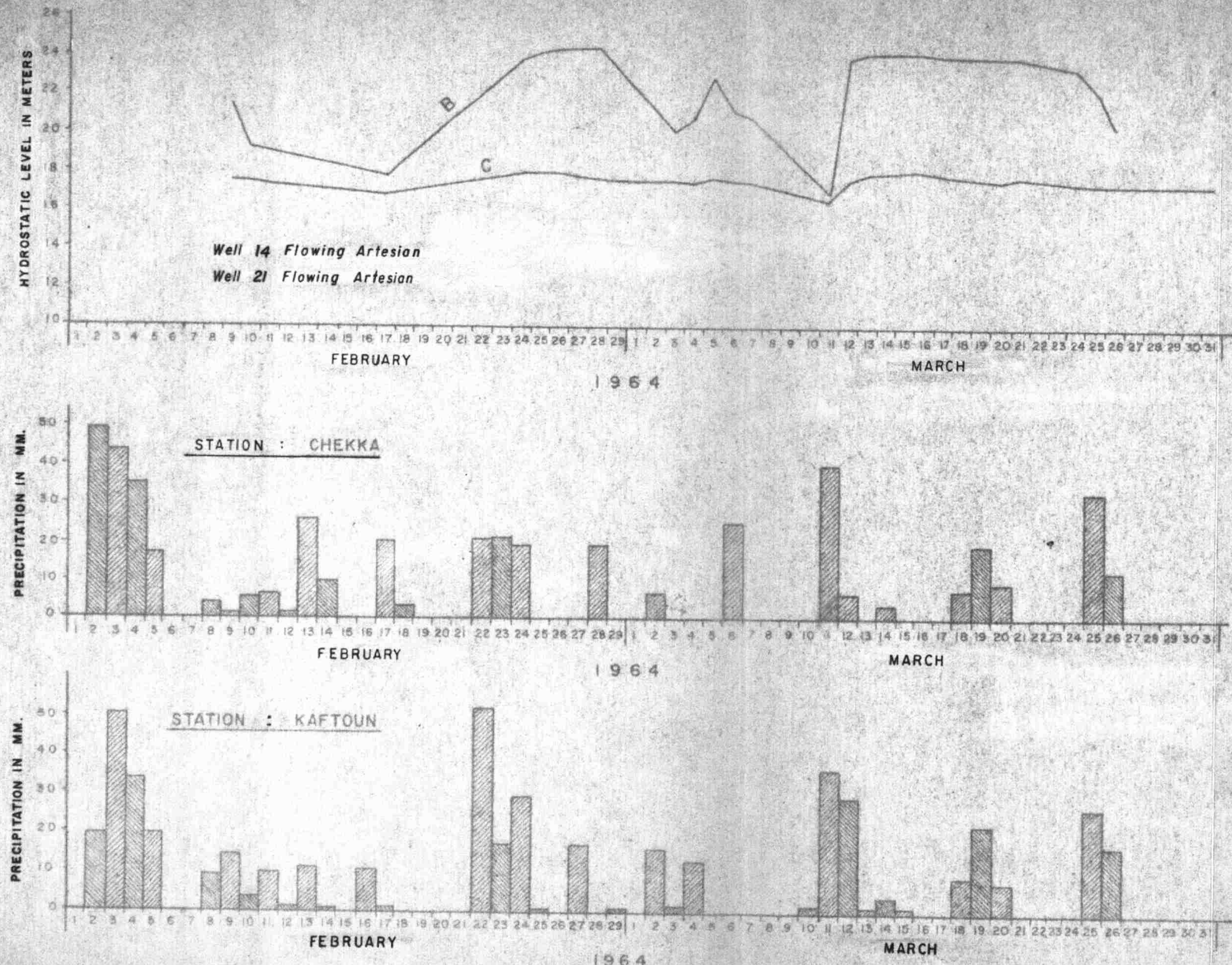
AFTER DEPERET (1963)

Deperet (1963) distinguishes in regions of relative tectonic stability, four eustatic levels above the actual level of the Meditteranean and four levels below, the first group corresponding to epirogenetic movements, the second to glacial and interglacial periods. (See Fig.22)

Near Ras Chekka remnants of incrusted Quaternary beaches were observed, the highest at 100 m. elevation and is composed of gravel and with marine shells and debris. This level corresponds more probably to the oldest inter-glacial eustatic level, the Sicilian (See Fig.22). On the other hand, the different levels of the submarine springs of Chekka, Tyr and the artesian coastal spring of Ras El Ain and Rachidiye, confirm the existence of several glacial eustatic levels. Each one of these levels represented the base of Karstic erosion and the rythmical oscillations of the base of karstification have been of a particular importance in the evolution and depth of extension of the karst.

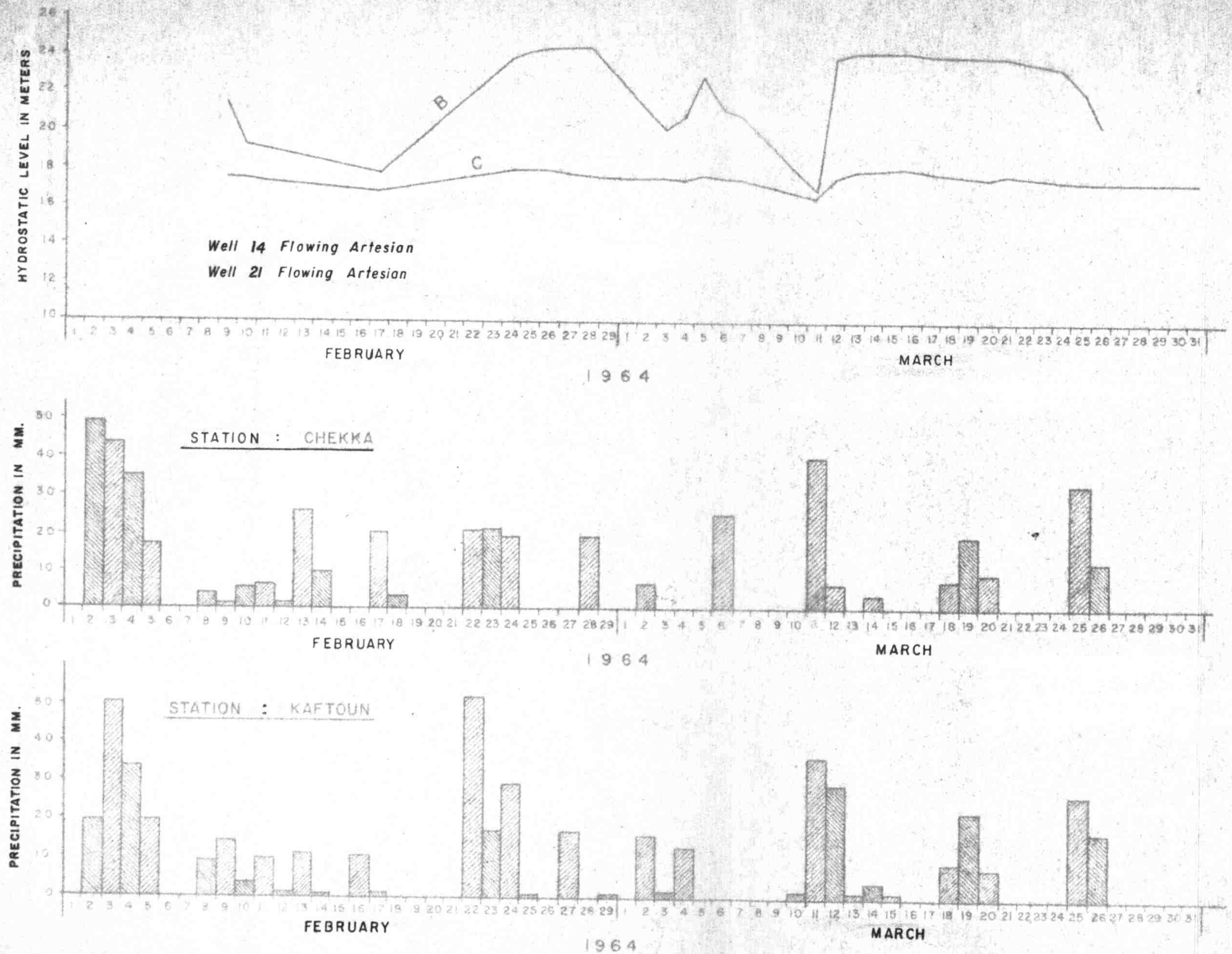
This is fundamental when it comes to explaining the different levels of the discharge points of the aquifer between the submarine springs and sink-holes "C" and "B". There is no doubt that several submarine springs and sink-holes "C" and "B" originated along fissures caused by an anticlinal folding movement involving the Cenomanian-Turonian limestones.

Fig. 20



PIEZOMETRIC LEVEL VARIATIONS IN SINK HOLES B and C COMPARED WITH PRECIPITATION

Fig. 20



PIEZOMETRIC LEVEL VARIATIONS IN SINK HOLES B and C COMPARED WITH PRECIPITATION

8-4-1964

The fissuring along the axis of the anticlinal fold and the oscillations of the Mediterranean sea in Quaternary times were the two essential causes in the formation of the submarine springs and the sink-holes of Chekka. Hence there are no basic differences in the origin of the submarine springs and the sink-holes.

The sink-holes are actually intermittent springs discharging tremendous amounts ($2m^3$/sec.) of water, only a few days in the winter period (around the beginning of February usually). This important winter yield proves that these sink-holes are in communication with the Cenomanian-Turonian aquifer along fissures through the Senonian marls. In the Sicilian stage of sea-level oscillations, when the Mediterranean level was a 100 m. higher than the actual present level, these sink-holes functioned as permanent submarine springs.

CHAPTER 3

4. - Hydrogeology

On the basis of the information obtained on the geological and geomorphological conditions which were favorable for the development of the karstic system of Chekka, we were able to observe the main hydrogeological factors which determined the karstic evolution of the region. All the hydrogeological studies undertaken have given to the problem of water circulation in the karstic medium of Chekka, more concrete results in spite of hypothetical conceptions. The problem of salt water intrusion has been treated theoritically by using the classical Ghyben-Hersberg equation which does not include the dynamic conditions essential in our case. This is why empirical methods of approach (pumping tests) have been used in order to evaluate the importance of the hydrodynamic conditions which determine the relations between fresh and salt water in a typical karstic system.

4.1 - Catchement area and hydrogeological basin

The catchment area of Chekka region covers a square area of 200 km^2 (See Map No. 1). It extends from the coast east to the highest peaks of the Lebanese chain and is limited in the South by Nahr el-Joz and in the North by the Nahr Abou Ali.

This catchment area includes the Cenomanian and Jurassic aquifer.

However, it is thought that the presence of the Lower Cretaceous aquiclude constitutes an obstacle to underground water communication between the two aquifers. The only contribution of the Jurassic to the Cenomanian aquifer is surface run off which re-infiltrates in the limestones of the Cenomanian. The impermeable belt of the Lower Cretaceous formations, by preventing underground water alimentation from the Jurassic to the Cenomanian, reduces the catchment area to a basin of 170 km^2; the area of this basin is insufficient to account for the average yield of the aquifer near Chekka which is about 10 to $15m^3$/sec.

That is why we are convinced that the hydrogeological basin of the Chekka region extends up to the summits of the Lebanese chain and collects all infiltrated waters in the Cenomano-Turonian limestones plus a good quantity of the re-infiltrated surface run off of the Jurassic.

This hydrogeological basin is limited in the east by the summit line of the Lebanese chain, in the North by the Jurassic core of the El Ayoun region, in the west by the contact between Turonian and Tertiary sediments and in the South by the Nahr el Joz river basin (see Map No. 2). Its estimated area is about 900 km^2.

Having determined the hydrogeological basin of Chekka, we consider the submarine springs as being the lowest discharge points of the enormeous Cenomanian-Turonian aquifer which causes other less-important springs such as Rachine, to flow along the impremeable belt of the Senonian marls (see Map 1). The irregularity of Rachine's summer and winter yields (summer: 300 l/sec, winter: $2m^3$/sec) giving an irregularity factor of 7, shows that below the spring, the limestones conceal an important underground flow travelling towards the lowest discharge points of the aquifer i.e. the submarine springs of Chekka.

In a vertical schematic section showing the different hydrodynamic stages of karst, the spring of Rachine belongs to the upper limits of the zone of complete saturation, while the springs of Chekka belong to the zone of deep circulation in which underground flow takes place under the action of artesian or sub-artesian pressures. This accounts for the important yields of the submarine springs.
As an example we will consider the area of the hydrogeological basin as extending over 900 km^2 and the following hydrologic factors:

Precipitation including snow melting	1600 mm
Real evapotranspiration [I]	56 %
Efficient infiltration	32 %
Surface run off	12 %

I) Obtained on basis of calculated data for an area of 2,000 km^2 in Central Lebanon.

We have obtained an average annual yield of 13 to $15m^3$/sec from the Cenomanian-Turonian aquifer. This yield corresponds approximately to the total yields of the submarine springs of Chekka, Rachine and other springs of the Cenomanian-Turonian such as Mar Sarkis spring near Ehden, Syr and Soukkar springs near Syr-Danie, Fneidik spring, etc... This general approximate hydrological balance, checks the theory we have presented in that the hydrogeological basin we have limited justifies the obtained results without too much error.

4.2 - Characteristics of the Aquifer.

The Cenomanian-Turonian limestone aquifer is a typical karstic aquifer in which are developed many karstic forms and the most varied phenomena of underground flow(see Fig. 21). The possibilities of evolution of this karst are unlimited horizontally, at the surface of the ground, as well as vertica-lly in depth within the mass of the limestones. This aquifer consists of very thick (600 m), pure, massive limestones occupying the highest summits of the Lebanon range and extending below sea level. In these massive limestones, impermeable beds are present but are thin and very rare. They are negligible when compared to the limestones thickness and extent; hence they do not stop underground circulation. The substratum (Lower Cretaceous) being at a great depth, hence below the base of karstification, is not reached by erosion.

This karst is known in scientific circles as the Holokarst (Cvivic, 1960) and is comparable to karsts in Yugoslavia, Greece, Jamaica, etc... On the surface of these massive karstic terrains one is stricken by a quasi-total dryness, caused by the numerous karstic forms absorbing almost immediately all surface waters.

The most common karstic forms are the lapiez distributed all over the limestones. A typical example is in the village of Hardine, N-Lebanon; other forms include dolinas dispersed on the plateau North of Ehden. Several sink-holes exist in the Nahr Abou Ali basin around Housba in the region of Bziza and all along the contact between the massive limestones of the Turonian and the Tertiary deposits of the platform of Zghorta. The Bziza sink-hole constitutes the end of a "blind karstic valley"(Cvivic, 1960). Water flowing in the valley has undercut deeply its sides but is lost in the sink-hole where the valley is stopped.

It is normal to suppose that karstification in limestone aquifer is extremely heterogenous and that karstic circulation occurs in the most priviledged zones i.e. karstic channels and conducts often isolated from each other and limited in number (Chekka).

This is why we have obtained in the same aquifer extremely different values of transmissibility.

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This is why we have obtained in the same aquifer extremely different values of transmissibility.

For example in the limestones of Chekka well No. 3(see plate 2) gave a transmissibility of 9.8 x 10-5 and very close to it well 50 gave a transmissibility of 1.3. This proves the existence of an intense underground flow in a generally compact terrain.

4.3- Hydraulic observations

Observations of submarine springs started in the summer of 1963. Regular observations on the coast started in the beginning of 1964; it is only in February 1964 that the artesianism of the wells and the springs(see photos 9,10) already known by the inhabitants of Chekka was noticed and measured for the first time. That is why we were able to point-out, without a risk of error, water-points corresponding to the karstic aquifer located in the limestones.

4.3.1 - Piezometric levels

All the wells that have penetrated the Cenomano-Turonian limestones undergo periodic fluctuations due to the tides. These fluctuations are instantaneous and well pronounced.

Summer 1964

At the end of the dry season, the lowest level was measured in well No. 14(see Table I) at about 300 m from the sea(See plate 2).

Piezometric levels of wells No. 25 and 50 located at about 700 m. from the sea (see plate 2) are higher in the same period and the resulting gradient supposes important losses of head.

Table I

Observation period		Piezometric level in m.		
	Well 14	Well 25	Well 50	Q in m^3/sec
Summer	2.37	6.35	6.5	
	Alt. + 8	Alt.+ 22.10	Alt. + 18	6

Winter 1964

In the beginning of February 1964, wells No. 9, 13, 14 21 and 25 and sink holes "C" and "B"(see table 2) became artesian. It was not possible to measure the head at the surface due to lack of water-proof equipment. It was estimated on wells 13, 21, and 25, the latter being isolated by casing up to the surface. It is about 1m on wells 13 and 25 and 11m on well 21; the distance between wells 13 and 21 is only 650m. This particularly steep gradient is due to the high velocities of underground flow in the winter, resulting in considerably high losses of head.

Table 2

Observation period	Piezometric level in m.			
	Well 13	Well 25	Well 21	Q in m^3/sec
Winter	25	25	15.5	
	Alt.+23.6	Alt.+22.10	Alt.+4.46	60

4.3.2- Yields and velocities

Summer 1963

Yield measurements(Kareh and Lampietti, 1963) on the submarine springs gave a total yield of $6m^3/sec$; spring S2 yielded alone 2.15 m^3/sec. Velocities measured at discharge points vary between 0.05m/sec in S 6 to 0.455m/sec in S 2. (see table 3).

Table 3.

Spring No.	Productive zone m2	Average velocity m/s	yield m^3/sec
I	25	0.0416	0.750
II	A - 3.75 B - 4.50	0.26 0.455	0.975 2.150
III	50	0.039	0.750
IV	60 { $5m^2$ intense; $55m^2$ weak }	0.139	1.200
V	36	Non measurable	0.20
VI	6	0.038	0.10
			6.00

Applying $Vm = \frac{V_I \quad Q_I \; V_2 \; Q_2 \; V_n \; Q_n}{Q_I \quad Q_2 \quad \cdots\cdots\cdots \quad Q_n}$

we find an average velocity of $V_{mI} = \frac{I,463}{6,00} = 0.24$ m/sec

Winter 1963

It was possible to measure the yield of spring S 12 (see photo 4 and plate 2) which constitutes, in this period of the year, the most important submarine discharge point.

It was estimated at $50 m^3/sec$. Sink holes "C" and "B" give a total yield of $4\ m^3/sec$. The total yield from submarine springs could be estimated for comparison's sake, at $60 m^3/sec$, approximately. The average velocity corresponding to this remarkable yield will then be 10 times higher than that corresponding to the summer yield.

$$V_{m2} = \frac{Q_2}{Q_I} V_{mI} = \frac{60}{6} \cdot 0.24\ m/sec = 2.4\ m/sec$$

It should be noted that this considerable increase in yield is felt a few hours after the first heavy rains in the mountain range. (See Fig. 20)

4.3.3 - Fluctuation of the tide.

It was impossible, to determine the storage coefficient S from the pumping tests data.

The purpose of the tide's fluctuations interpretation is the determination of this storage coefficient.

Theory of periodic fluctuations in confined aquifers due to tidal effects.

Sea water rises and falls periodically in concordance with the following equation: (Ferris, 1955).

$$h = h_o \sin\left[2\pi t/t_o\right] \quad (1)$$

ho is the half-amplitude

to is the period

At great distances from the sea, the wave amplitude becomes weaker and weaker.

Considering that dh is negligible in comparison with the aquifer's thickness, the aquifer's level at a point located at a distance x from the sea at a time t is given by the equation: (Ferris, 1955).

$$\frac{\partial^2 h}{\partial x^2} = \frac{S}{T}\frac{\partial h}{\partial t} \quad (2)$$

T and S being the transmissibility and the storage coefficient of an aquifer. From (I)and (2) we get:

$$h = h_o e^{-x\sqrt{\frac{\pi S}{t_o t}}} \sin\left(\frac{2\pi t}{t_o} - x\sqrt{\frac{\pi S}{t_o T}}\right)$$

With time and at a given point located at a distance x from the sea, the variation of the aquifer's level is sinusoidal of a period to dephased of $-x\sqrt{\frac{\pi S}{t_o T}}$ and the half amplitude of the oscillations is reduced to:

$$\lambda = 2\sqrt{\frac{\pi T}{S t_o}} = 3.55\sqrt{\frac{T}{S t_o}}$$

At an instant, the surface of the aquifer has the shape of a damped sinusoid whose wave length is:

$$h_x = h_o e^{-x\sqrt{\frac{\pi S}{t_o T}}}$$

Knowing the values of ho, hx and t from the water-level recorder diagrams and T from pumping tests results, S could be determined with the damped wave equation:

$$\log \frac{ho}{hx} = 0.4383\sqrt{\frac{\pi S}{to\ T}}$$

Measurements recording.

Two pneumatic (Neyrpic, Grenoble) water-level recorders were installed in wells 14 and 3 for a period of 12 days and water-level variations were recorded.

Fig. 5

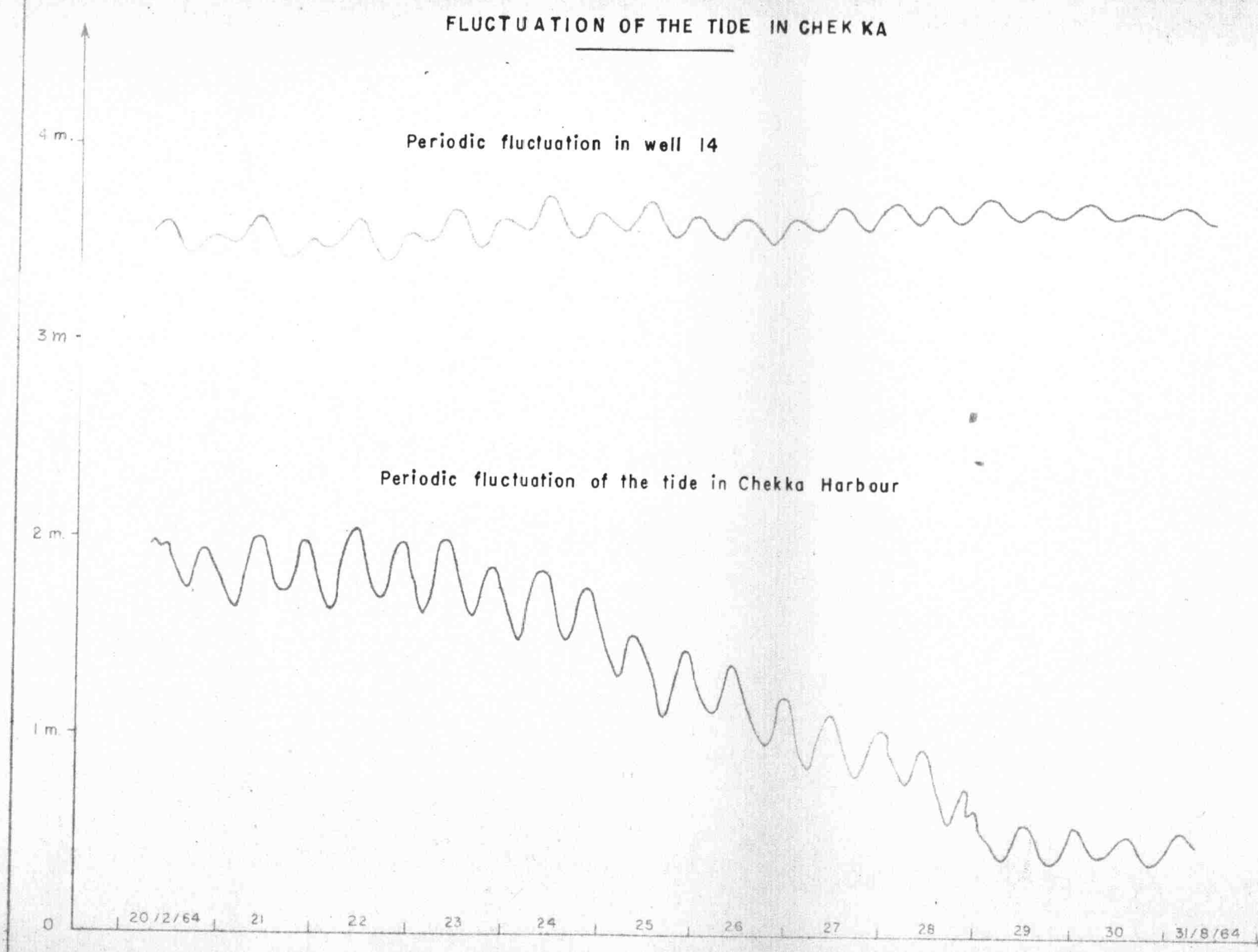
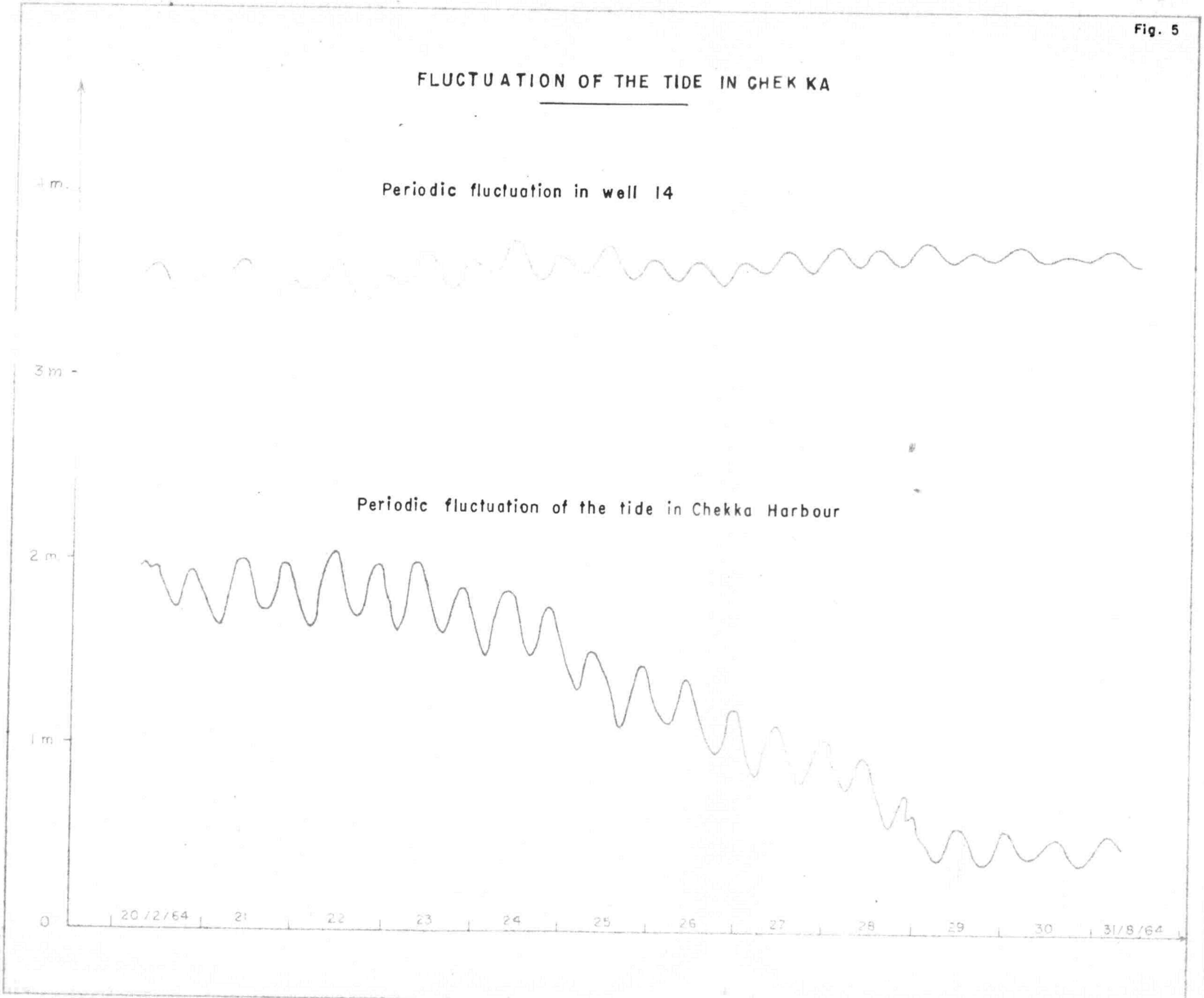

FLUCTUATION OF THE TIDE IN CHEKKA
Periodic fluctuation in well 14
Periodic fluctuation of the tide in Chekka Harbour
4 m.
3 m
2 m.
1 m.
0
20/2/64
21
22
23
24
25
26
27
28
29
30
31/8/64

Fig. 5



FLUCTUATION OF THE TIDE IN CHEKKA
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4 m
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20/2/64
21
22
23
24
25
26
27
28
29
30
31/8/64

Simultaneously, one water-level recorder installed in the port of Chekka, gave the variations of sea-level for the same period. (see Fig. 5).

The diagram sheet of the water-level recorder(in the port) was displaced for an unknown reason and five days of measurements were only used.

Measurements results.

The water level recorder diagrams show clearly the tide's influence on the aquifer. (See Fig. 5).

Two tidal effects, one big and one small, occur in a 24 hour period. The amplitude of the big tide occurs around noon while the small tide's amplitude occurs at midnight.

The tide's maximal amplitudes are:

40 cms in the Chekka port

24 cms in well 14

10 cms in well 3.

The fluctuations of the tide occur over a 12 hour period; $t_0 = 4.3 \times 10^4$ seconds. Wells 14 and 3 are at distances of 300 and 700m. from the sea.

Determination of the storage coefficient S.

A pumping test performed on well No.3 gave a transmissibility of 3.79×10^{-5} $m^2/$ sec.

Well 14.

Applying the damped wave equation we get:

$$\log \frac{40}{24} = 0.4383.\ 300 \sqrt{\frac{\pi S}{4.3\times10^{4}\times3.79\times10^{-5}}}$$

Solving for S. we get:

$$S = 1.5 \times 10^{-6}$$

Well 3

Applying the damped wave equation we get:

$$\log \frac{40}{10} = 0.4383.\ 700 \sqrt{\frac{\pi S}{4.3\times10^{4}\times3.79\times10^{-5}}}$$

Solving for S we get:

$$S = 1.7 \times 10^{-6}$$

we will consider for S a mean value of 1.6×10^{-6}

Determination of the wave's speed of propagation.

We have : $V = 3.55 \sqrt{\frac{T}{Sto}}$

$$V = 3.55 \sqrt{\frac{3.59\times10^{-5}}{1.6\times10^{-6}\times 4.3\times10^{4}}}$$

We get: $V = 0.08$ m/sec.

Conclusion

The values obtained for the aquifer's constants T and S are: $T = 3.79 \times 10^{-5}$ m^2/sec.

$S = 1.6 \times 10^{-6}$

These small values prove definitely that the aquifer is located in a rather compact terrain.

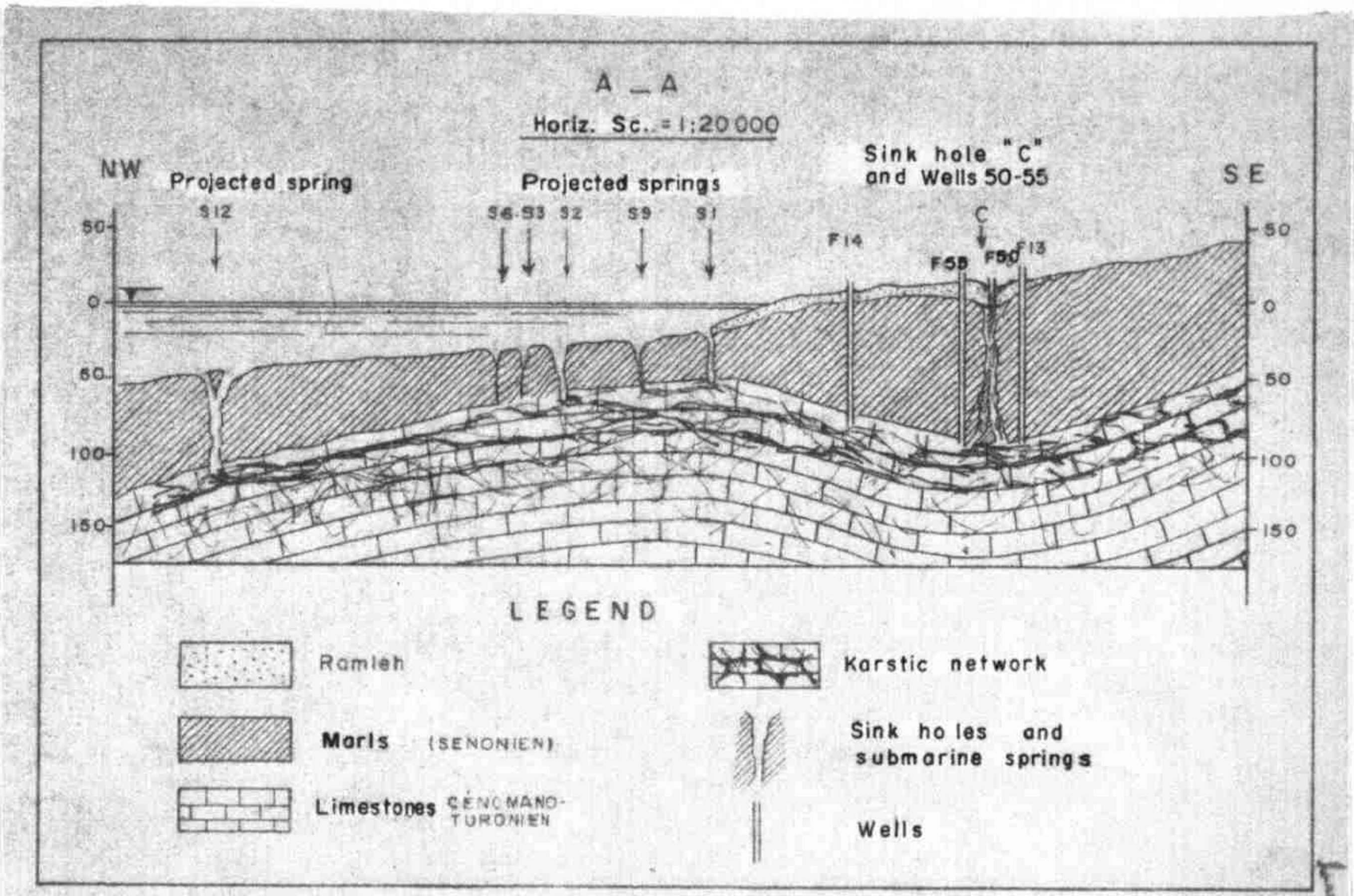


Fig. 21 Hydrogeological Section of the Cenomano-Turonian karstic system of Chekka

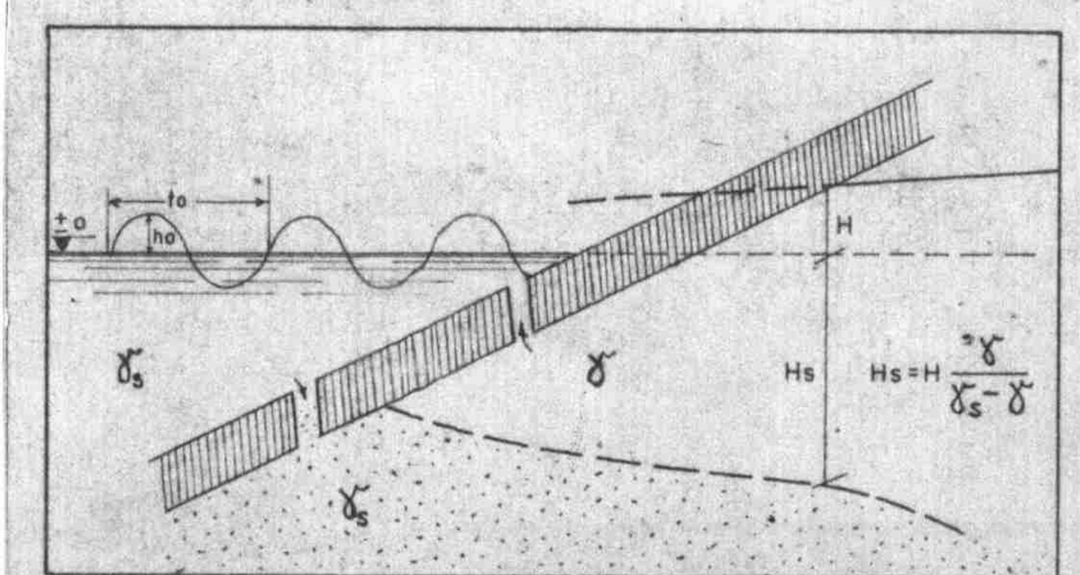
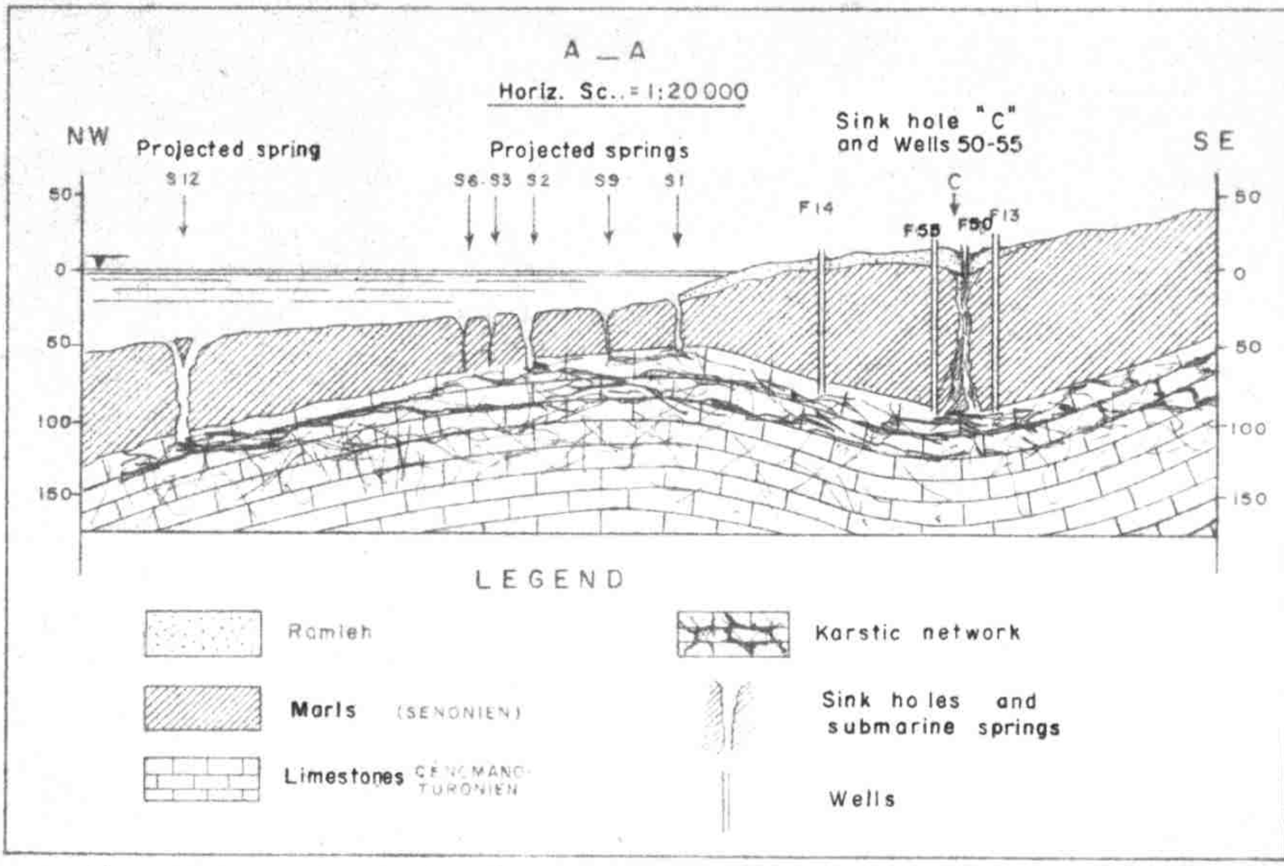


Fig. 14 — Relation between fresh and salt water



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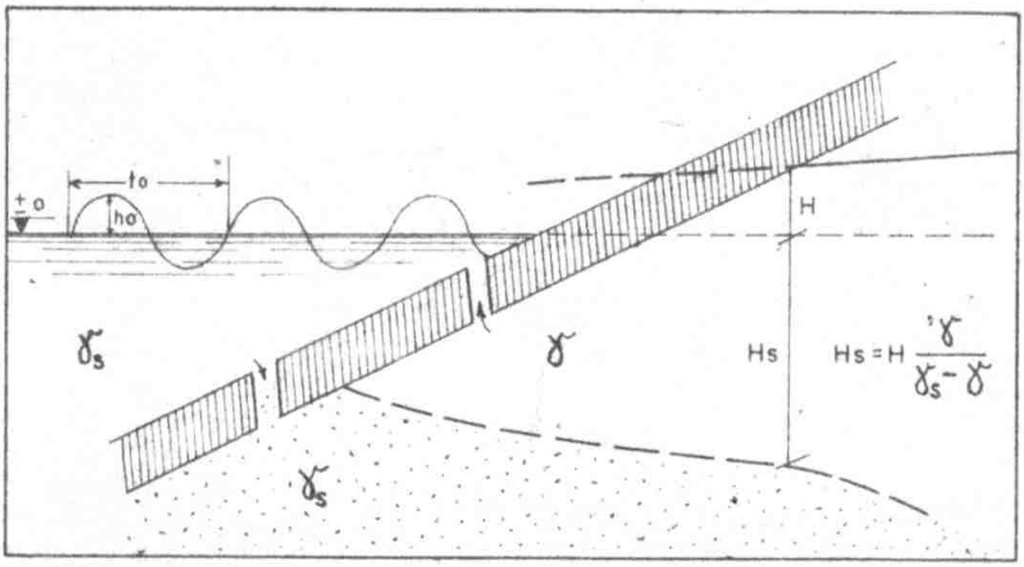


Fig. 14 — Relation between fresh and salt water

Hence the submarine springs' important discharge is only accounted for, by the presence of a well developed karstic system in a compact and/or micro-fissured limestone.

There is no doubt the deep-well exlporation will prove unproductive unless wells fall in well-developed and limited karstic channels.

4.4 - Interpretation of the observations.

All observations lead us theoretically to the consideration of the hydraulic system of Chekka as in aquilibrium between fresh and salt water in a typically karstic system following the general Ghyben-Herxberg (See Fig. 14) equation:

$$\Delta P = (H + H_s)\gamma - H_s \gamma_s \quad \text{or} \quad \Delta P = H.\gamma - H_s(\gamma_s - \gamma)$$

Where ΔP is the pressure variation

H_s is the height of sea-water

H height of fresh water above sea-level

γ specific weight of fresh water

γ_s specific weight of salt water

If $\Delta P > 0$ fresh water leaves the aquifer and is lost in the sea.

if $\Delta P < 0$ salt water penetrates the aquifer (Fi 6.3)

Fresh water yield dimishes with ΔP; Hence for a given H. the discharge will be as small as Hs is big, all factors remaining equal; on the other hand if $\Delta P = 0$ there always exists a certain depth at which the interface(fresh-salt-water contact) is in equilibrium at $H_s = H.\frac{\gamma}{\gamma_s - \gamma}$

Hence Hs is a function of the piezometric level of fresh water and of the difference of fresh and salt water densities. At Chekka where γ_s = 1040 gr/cm^3 and γ = 1000 gr/cm^3, the Ghyben-Herzberg coefficient $\frac{\gamma}{\gamma_s - \gamma}$ equals 25; the depth of the interface below sea-level is 25 times greater than the fresh-water pressure.

S12, which is the most important intermittent spring, is at 45m. below sea-level i.e 25 to 30m. below the permanent submarine springs. Salt-water pressure, in terms of fresh water pressure, at the discharge points in the sea is:

$$H = \frac{\gamma_s . H_s}{\gamma} = 1.04 \times 45 = 46.80 \text{ m.}$$

However in the dry season, when S12 dries and plays the role of a sink-hole absorbing sea-water, the pressure (46,80m) increases to the top of the aquifer i.e. an extra 100m. approximately. This pressure is equal to:

$$H = \frac{1.04 \ . \ 145}{1.00} = 150.80 \text{ m.}$$

But, in the first case, the fresh-water pressure above sea-level should at least equal:

$$H = (\gamma_s - \gamma) H_s = 0.04 \times 45 = 1.80 \text{ m.}$$

and in the second case: H = 0.04. 145 = 5,80 m.

The head at S_{12} in the dry period is hence greater than the head (2.37m) observed in well 14. Hence it is normal that the salt-water wedge advances to well 14, pushing and contaminating fresh water.

The functioning of S_{12} is similar to the phenomena that occur off the yugoslavian and Greek coasts and known as "marine Estavelles": (Burdon, Papakis, 1960)

- When the aquifer's alimentation causes a sufficient head to chase sea-water to spring S_{12} and counterbalances the head of 45 m of salt water, the spring starts flowing and its yield increases rapidly to $50m^3$/sec. approximately.
- When the aquifer's level starts falling, so does the yield of S_{12} and sea-water mixes gradually with fresh-water above the opening of S_{12}.

Salt-water increases more, reducing the yield, intrudes the fissures through the marls and penetrates the aquifer. There is an inversion of the direction of flow and S_{12} acts as a sink-hole.

The rapid fluctuations of yields and piezometric levels prove, with out doubt, that the karstic system occupies a small part of the, otherwise, compact limestones. This system is rather reduced to a certain number of channels whose diameters are insufficient to evacuate rapidly the winter yields.

Let us examine now the values of the summer and winter yields in function of the losses of head occuring on the coast at the same periods.

If the losses of head due to the submarine springs proper are negligible, a loss of head hw between two points 1 and 2 must be expressed by the difference between piezometric levels increased of the term $\frac{v^2}{2g}$ due to flow in karstic channels:

$$h_w = \left(h_1 \frac{v^2}{2g}\right)_{①} - \left(h_2 \frac{v^2}{2g}\right)_{②}$$

However it is impossible to determine the term $\frac{v^2}{2g}$; we will hence examine losses of head on the basis of piezometric levels only. For the determination of these losses of head in winter and summer, we should consider the counter-pressures produced by S_2 and S_{12}.

The loss of head in the aquifer will be:

- 1,57m. in the summer between well No.14 and S_2,(See plate 2) taking of course in account the column of 20m. of sea-water of 1,04 density above S_2.

- At least equal to 13.7m. between well No. 21 and S_{12}(see plate 2) considering that the 50m^3/sec. yielded by S_{12} replace sea-water up to the discharge point and that the counter-pressure of the sea at this period is rather small.

By comparing these results, it is noticed that for yields ten times greater in the winter,(see Table 4), loss of head is only eight times greater than in the summer. This is incompatible with the turbulent regime that probably exists in the karstic channels and one is led to consider that the flow of water through the impermeable marls causes at the springs considerable losses of head.

An attempt to calculate them by taking into account average speeds at discharge points, gave a loss of head 100 times greater in the winter than in the summer.

Table 4

Observation period	Yield in m^3/sec	h in m.	Well
Summer	6	2.37	14
Winter	60	15.50	21

4.5 - Chemical evolution and Quality of Ground Water.

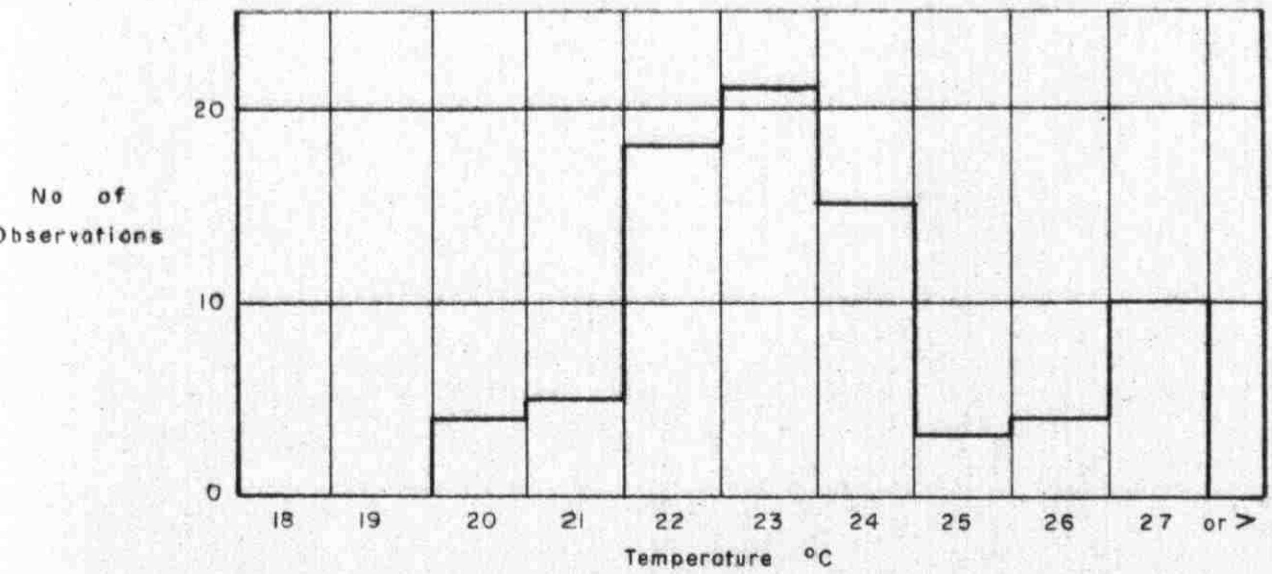
At the same period of yield measurements, in August 1963, several samples were collected from the submarine springs and all water points on the coast.

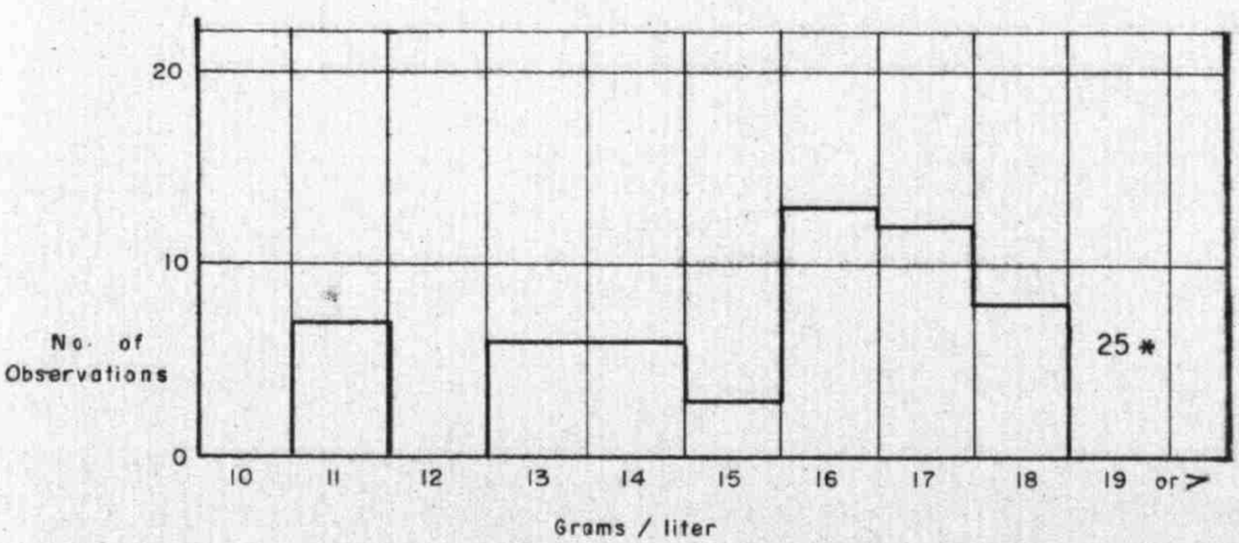
Sea-bottom sampling was done by introducing in the springs (sea-bottom) a perforated 1 1/2" pipe attached to a plastic tube from which water was recuperated by using a small hand pump. (See Photo No. 3).

Complete chemical analyses were done on all samples collected from the submarine springs and water points on the coast except for those which did not penetrate the Cenomano-Turonian aquifer.

More over salinities and tempraretures are presented as histograms for each spring without regard to time,(see fig. 6,7,8,9,10) date or location of the measurements within the area of the spring itself.

Fig. 6

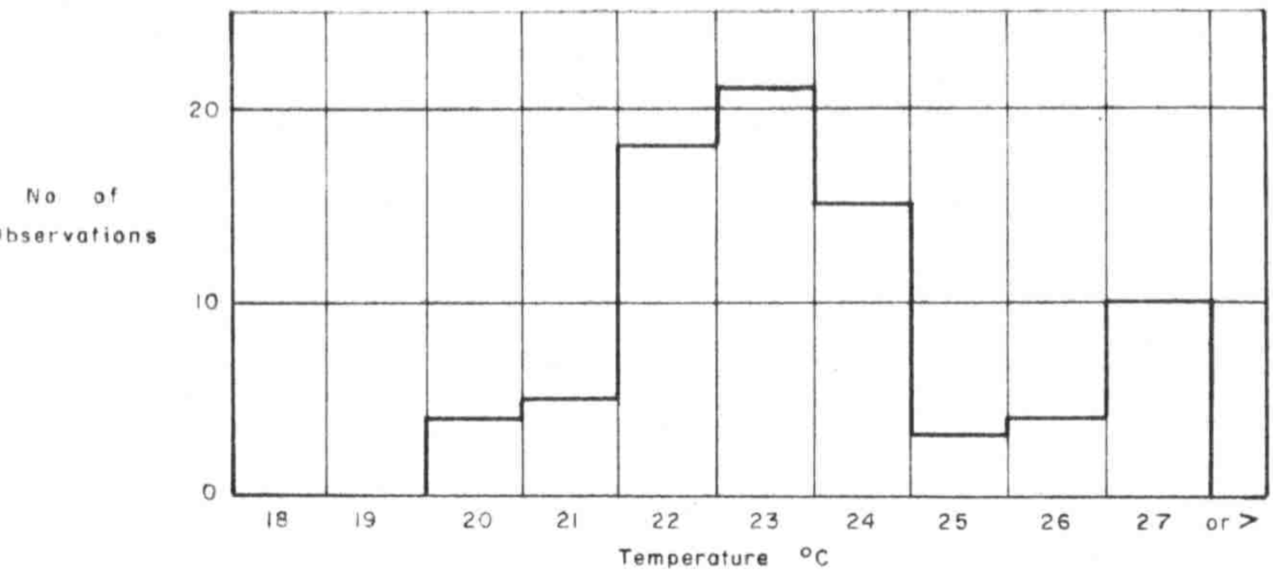


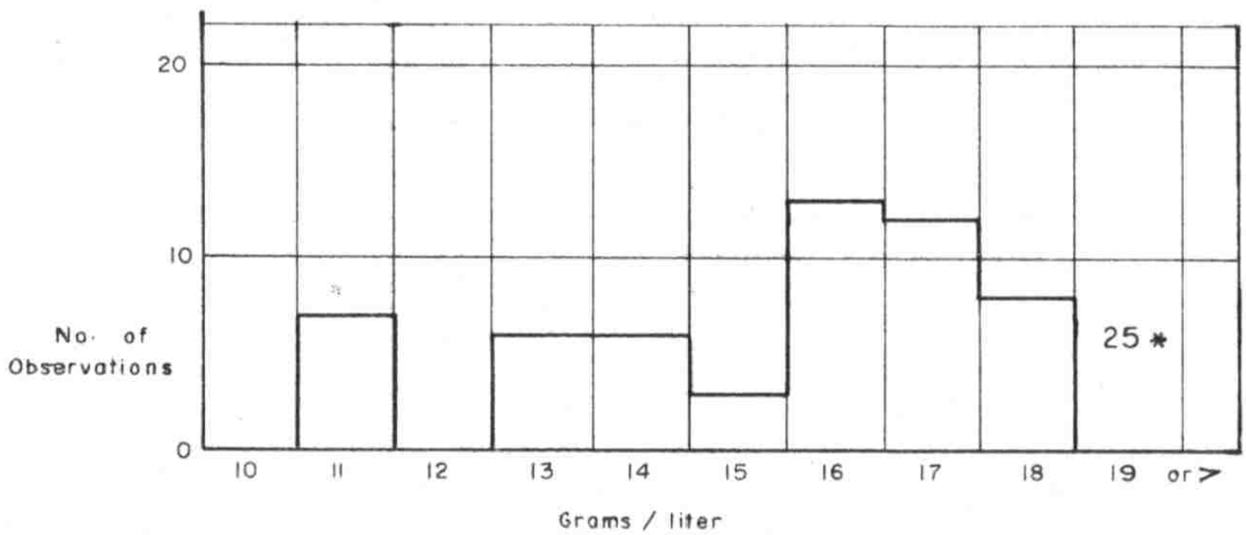


* Includes values from points selected at random on the bottom.

CHEKKA I (S1) TEMPERATURE and SALINITY MEASUREMENTS

Fig. 6

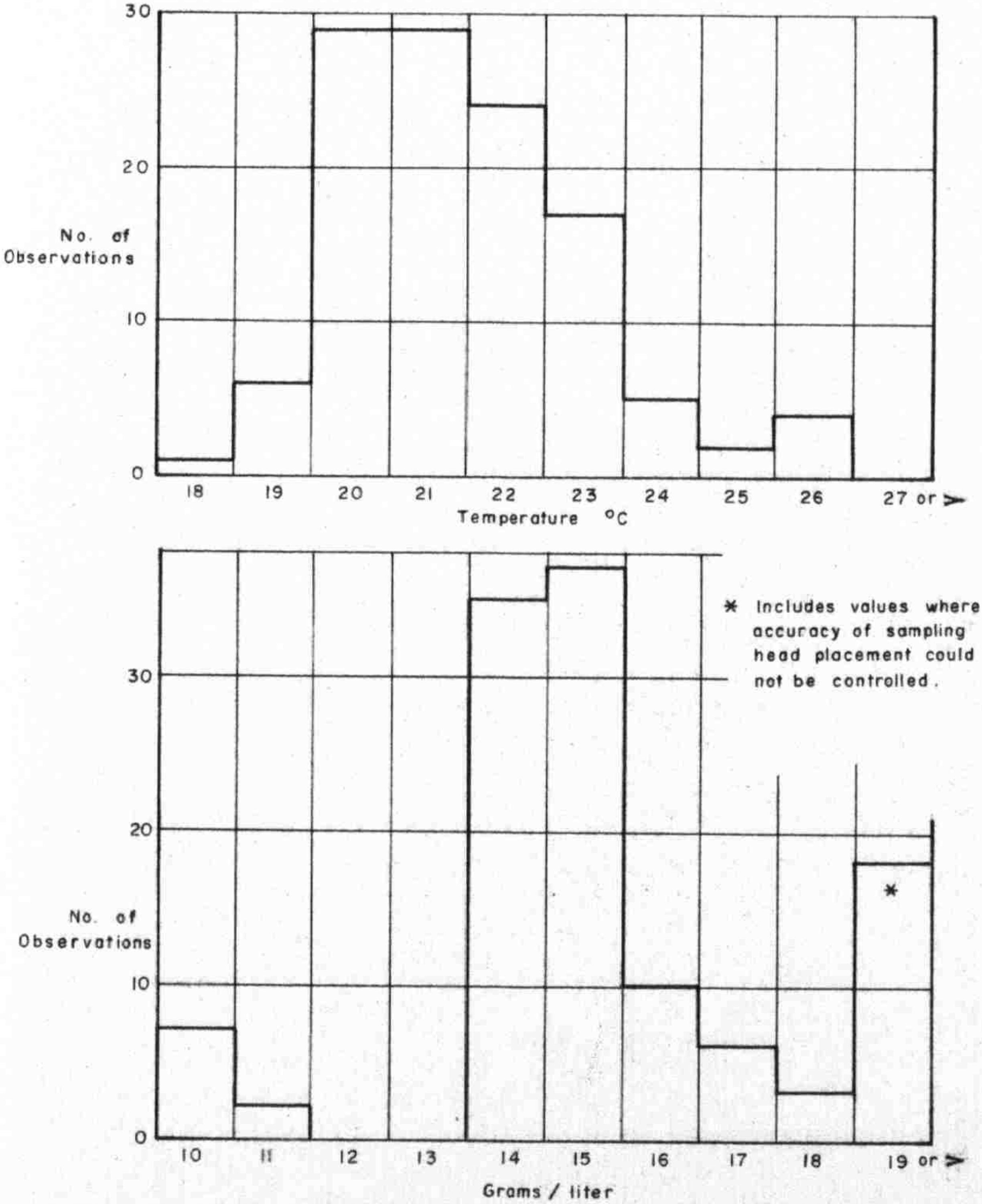




* Includes values from points selected at random on the bottom .

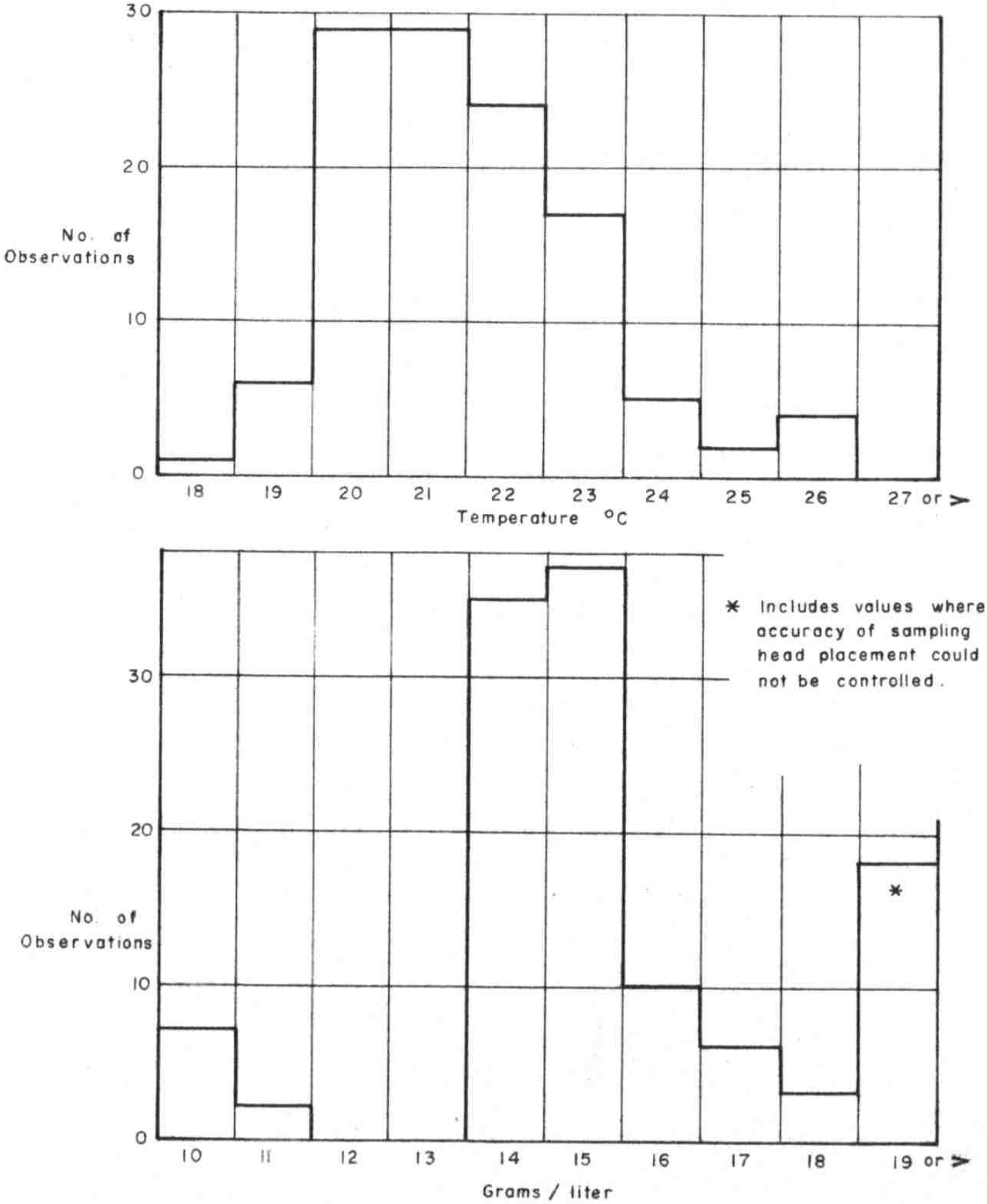
CHEKKA I (SI) TEMPERATURE and SALINITY MEASUREMENTS

Fig. 7

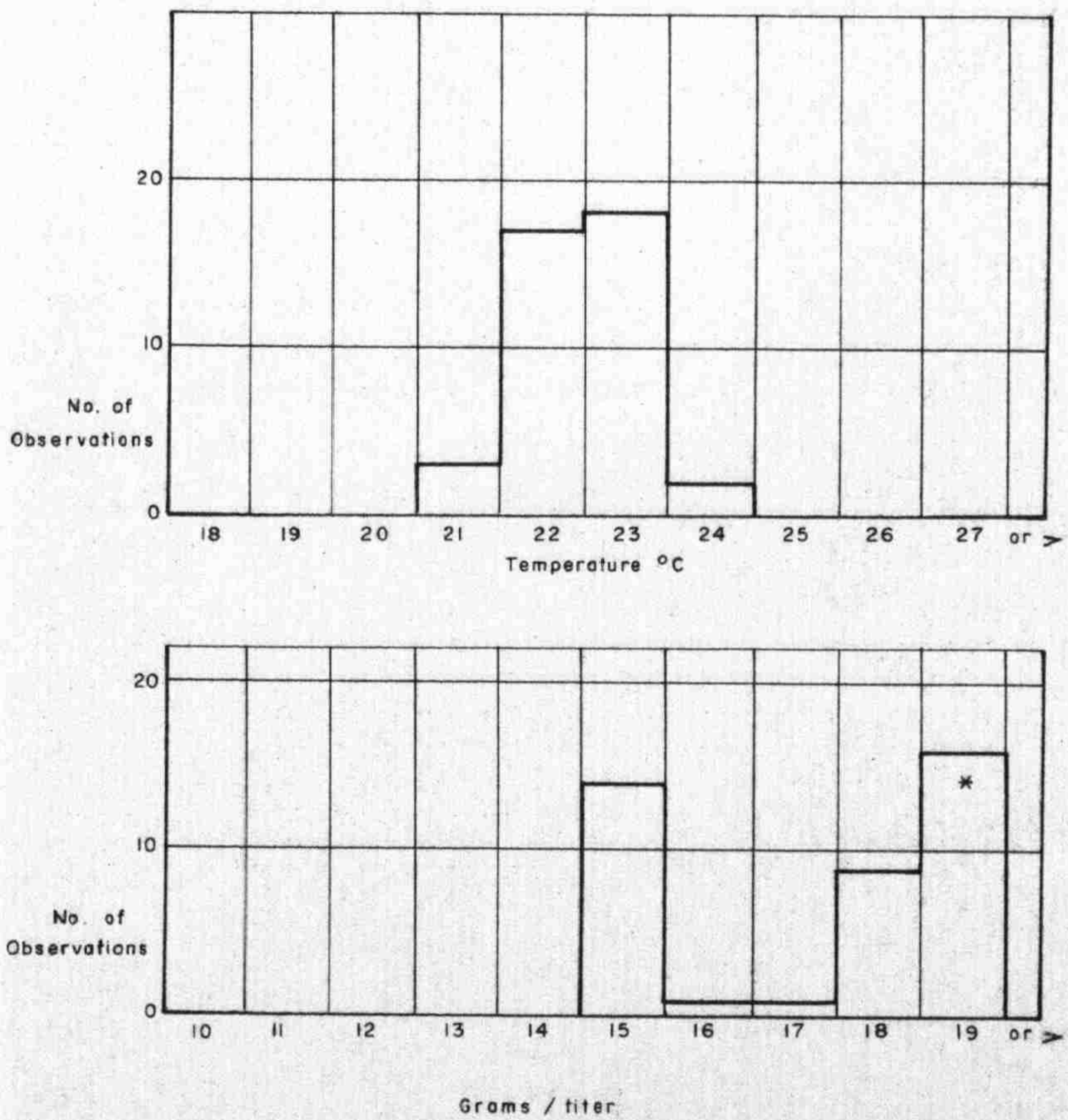


CHEKKA II (S 2) A & B

Fig. 7



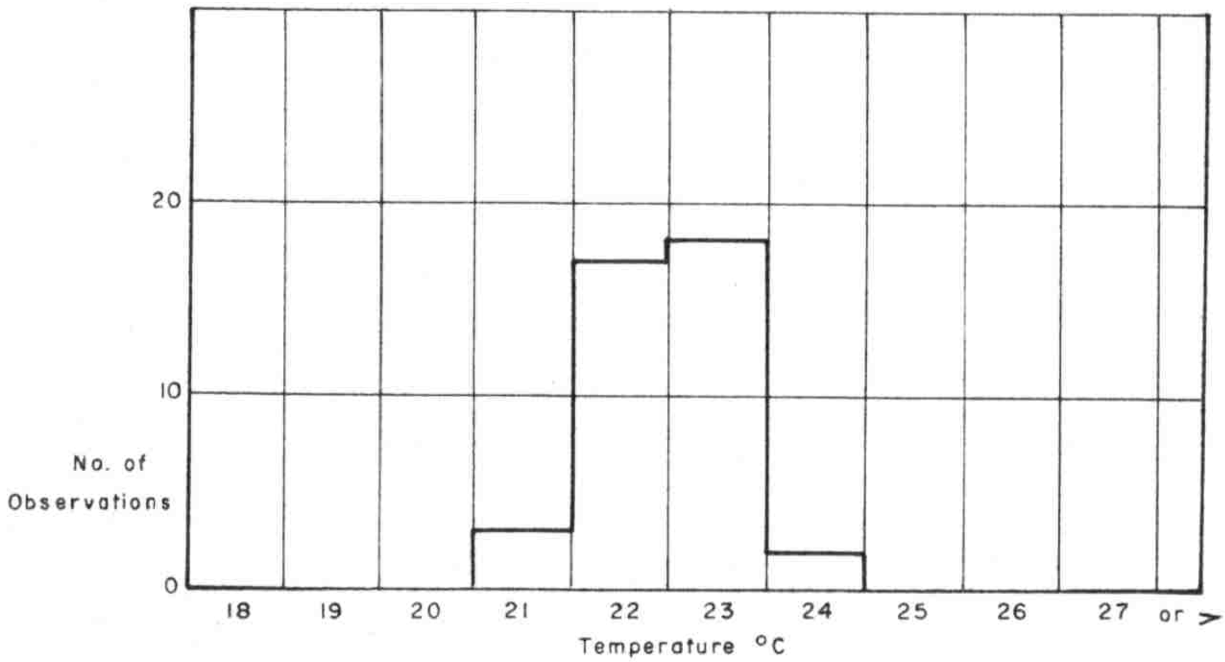
CHEKKA II (S2) A & B

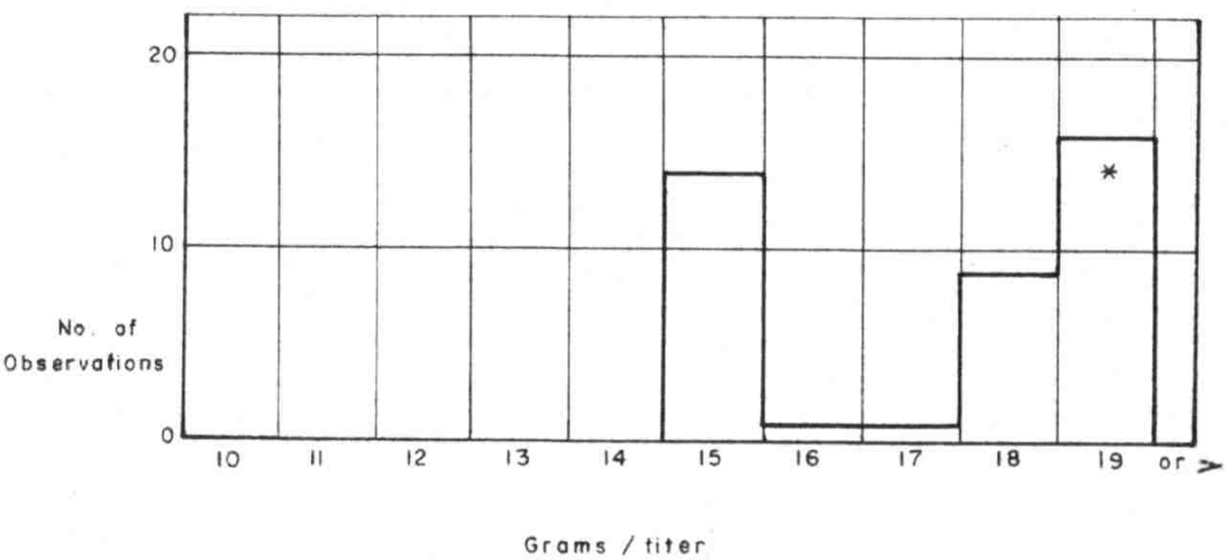


* Includes values from points selected at random on the bottom (not representative).

CHEKKA III (S 3)

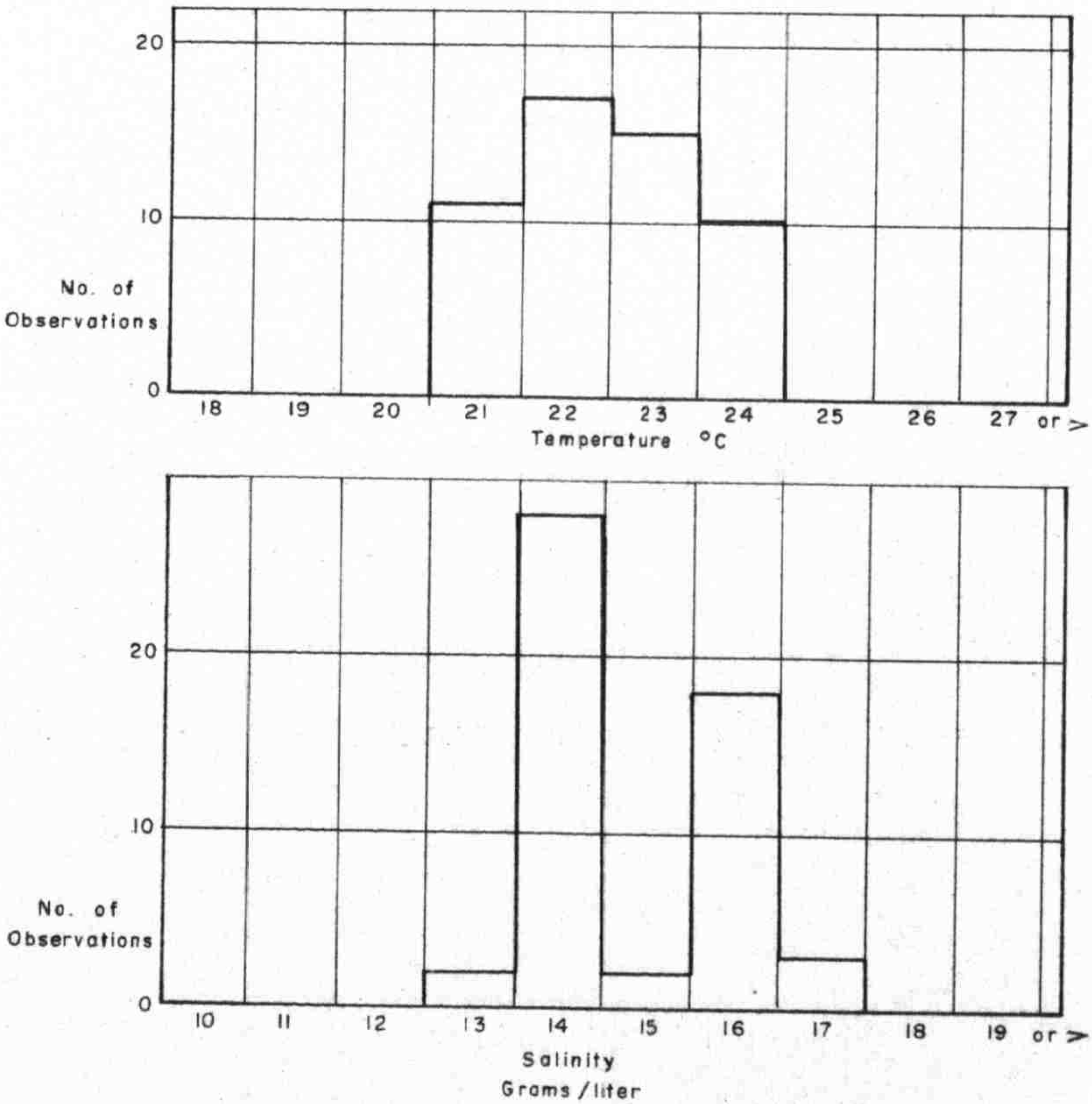
Fig. 8





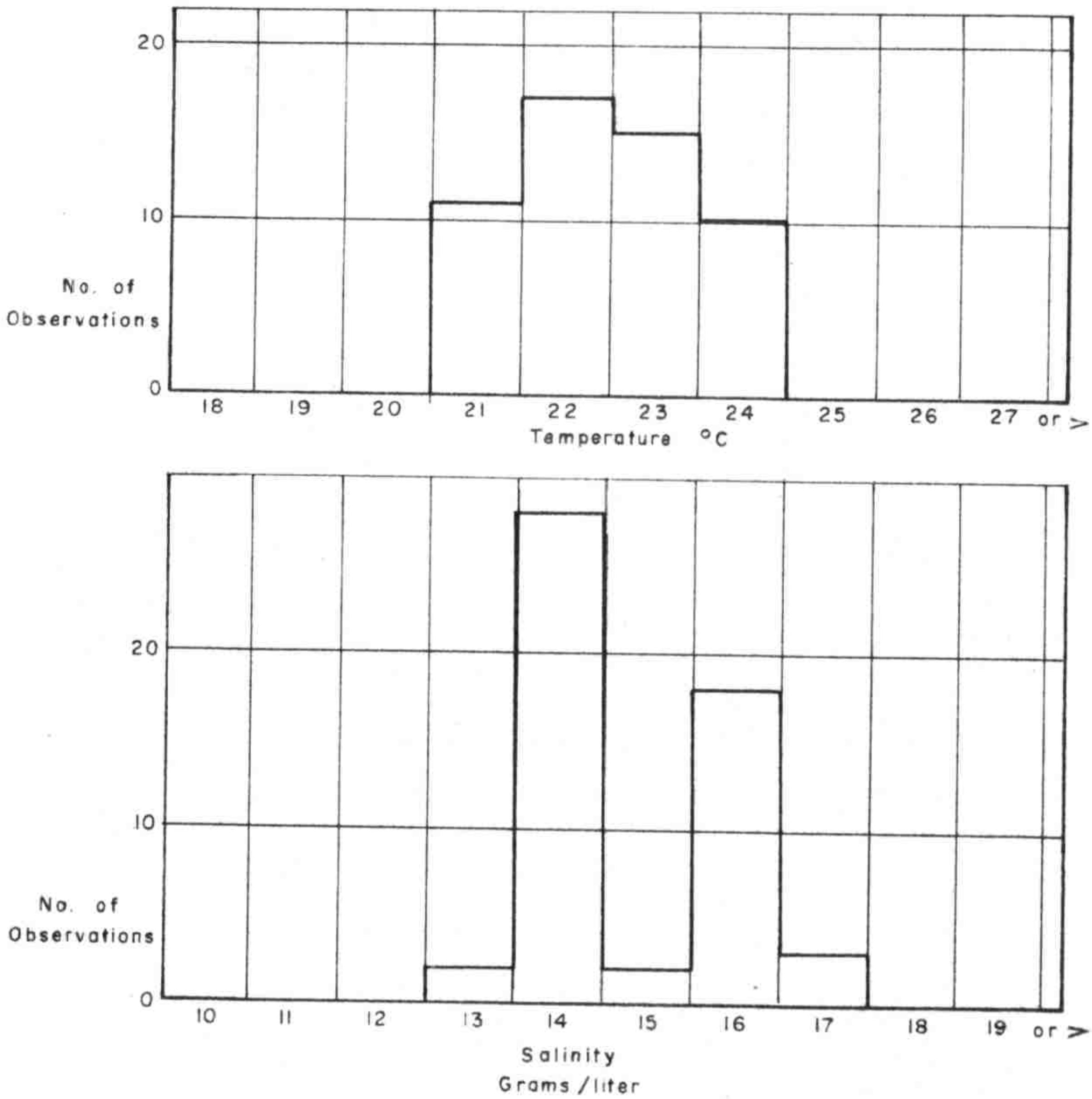
* Includes values from points selected at random on the bottom (not representative).

CHEKKA III (S 3)


20
10
0
No. of
Observations
18
19
20
21
22
23
24
25
26
27 or >
Temperature °C
20
10
0
No. of
Observations
10
11
12
13
14
15
16
17
18
19 or >
Salinity
Grams / liter

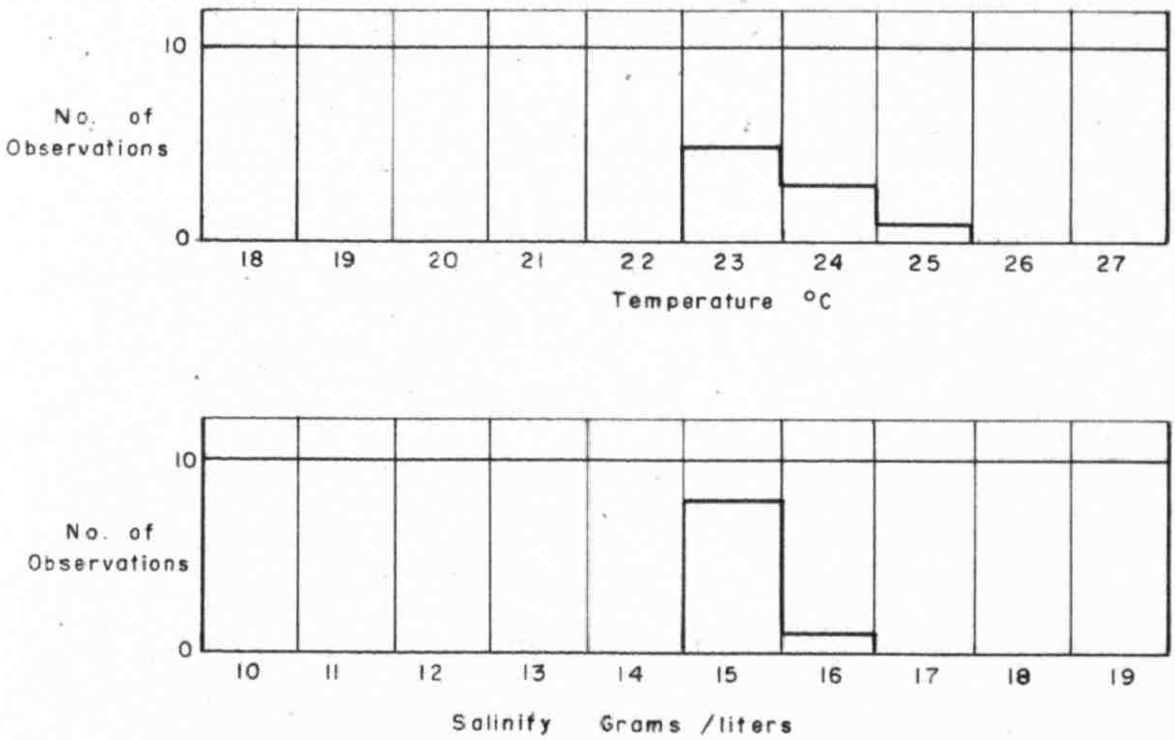
CHEKKA IV (S 4)

Fig. 9

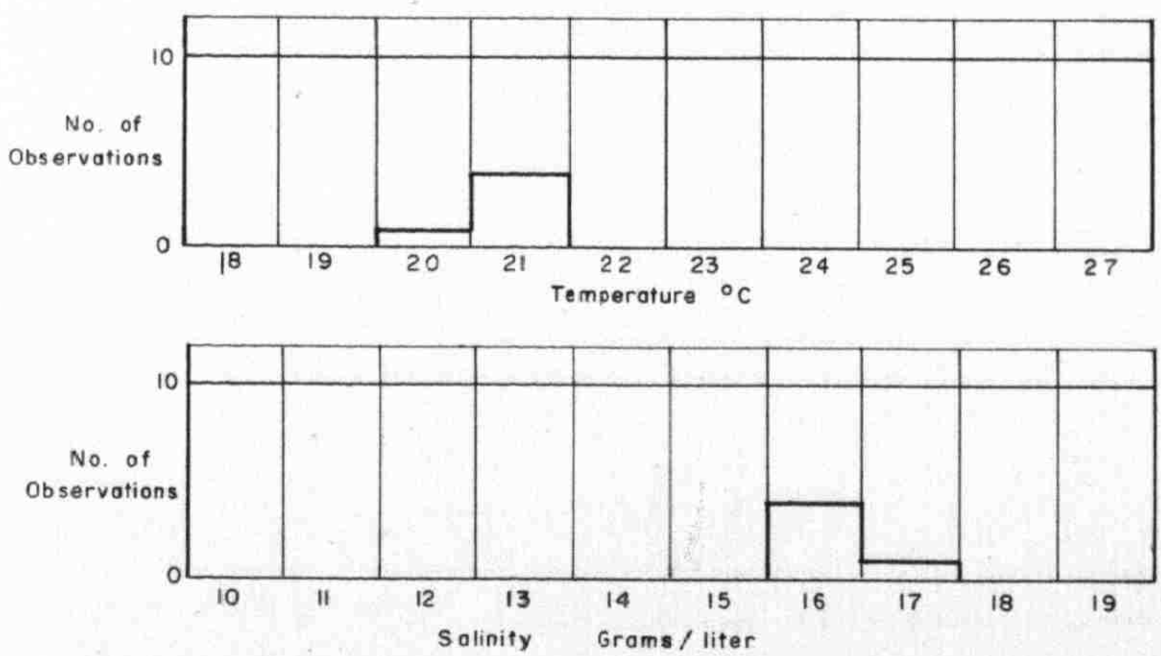


CHEKKA IV (S 4)

Fig. 10

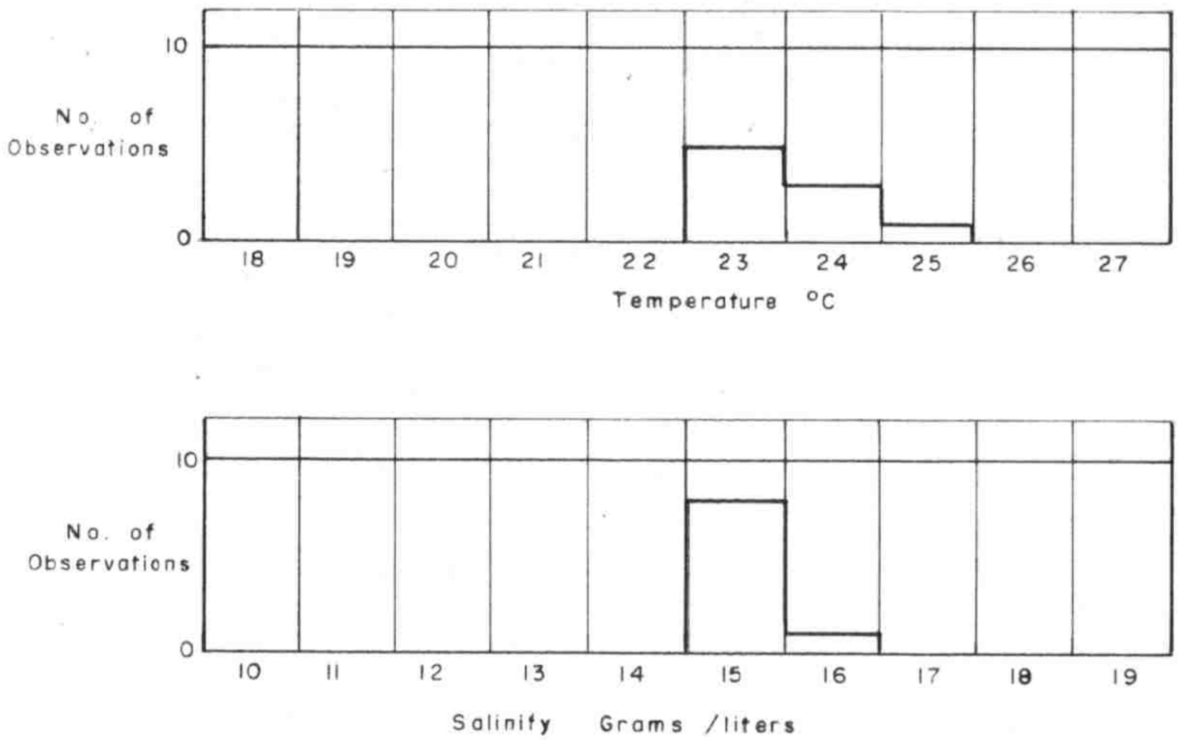


CHEKKA V (S5)

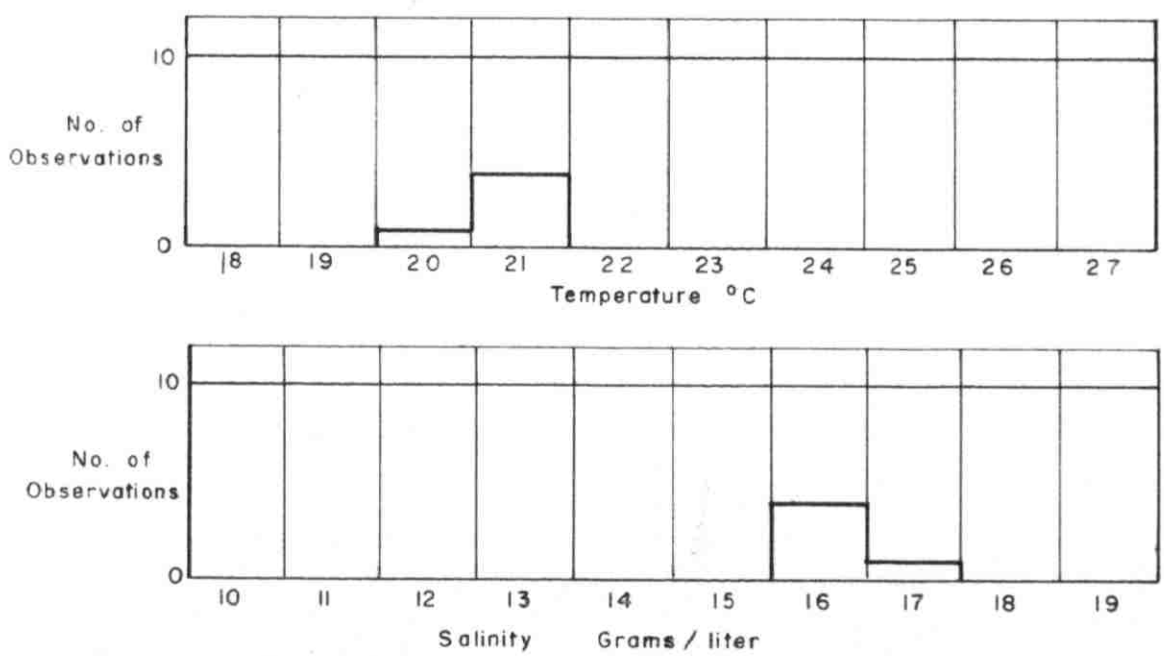


CHEKKA VI (S6)

Fig. 10



CHEKKA V (S5)



CHEKKA VI (S6)

It is felt this gives a better characterisation of each spring. Values of salinity of 19g/l or greater were obtained in a number of instances due to innacurate placement of the sampling heads on bottom or to random sampling of various areas on the bottom. They are not considered significant.

Summer of 1963.

The Cl content of all submarine springs samples is very high and prevents their immediate use. On the coast, among 40 water points, only three communicate with the karstic aquifer; one(well 14) gave highly contaminated water. (see Table 5).

- Well 14	Cl:	3777 mg/l.
- Well 9		43 mg/l.
- Well 21		46 mg/l.

Average Cl content.

Submarine springs	S_2, S_3, S_5	15000 mg/l.
	S_1, S_4, S_6	1600 mg/l.
Sea water	37000 mg/liter.	

Winter 1964

After the first heavy rains, all waters in the Cenomano-Turonian aquifer become remarkably sweet, even those collected at the discharge points in the sea.(See Table 5)

Well 14	CL: 32 mg/l.
Well 9	16 mg/l.
Well 21	14 mg/l.

TABLE 5

CHEMICAL ANALYSES

	S_1		S_2		S_3		C		9		I4		2I	
	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER
H.L..	-	-	-	-	-	-	Dry	24,6I	6,I8	I4,98	2,I9	9	-	I4,46
Ca	258		400	56	232			62	48	58	I34	68	58	58
Mg	709		I332	I3	650			7	I9	8	260	7	I8	II
Na	4800		7200	I4	3280			I0	20	I0	I660	I5	30	I0
Cl	I0508	48	I9397	28	9343			I4	43	I6	3777	32	46	I4
SO^4	I8I9		2523	I0	I2I0			4,8	I9	3,8	442	I9	84	3,9
CO^3	I0		I0	3,0	5			3,0	5	7	3,0	3,0	3,0	8
CO^3H	I98		I74	207	I88			2I4	22I	20I	236	I95	242	2I4
NO^3	0,I		0,I	7	0,I			6	0,8	2,3	0,4	5,0	0,6	3,5
R.Sec	I8926		35I92	320	I6966			I56	220	I76	6840	I56	250	I22
Dh	360		653,3	I9,4	328,9			I8,6	20,0	I8,I	I42,2	20,I	22,2	I9,0
Ph	7,5		7,8	7,6	7,9			7,6	7,9	8,I	7,6	2,5	7,8	8,0

TABLE 5

CHEMICAL ANALYSES

	S_1		S_2		S_3		C		9		14		21	
	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER
H.L.	-	-	-	-	-	-	Dry	24,61	6,18	14,98	2,19	9	-	14,45
Ca	258		400	56	232			62	48	58	134	68	58	58
Mg	709		1332	13	650			7	19	8	260	7	18	11
Na	4800		7200	14	3280			10	20	10	1660	11	36	10
Cl	12508	40	15187	28	9343			14	43	16	3777	32	46	14
SO^4	1819		2321	10	1210			4,8	19	3,8	442	19	84	3,9
CO^3	10		10	3,0	5			3,0	5	7	3,0	3,0	3,0	8
CO^3H	198		[illegible]	207	186			214	221	201	236	195	242	214
NO^3	[illegible]		[illegible]	7	0,1			6	0,8	2,3	0,4	5,0	0,6	3,5
R.Sec	16420		[illegible]	[illegible]	[illegible]			156	220	176	6840	156	250	122
Dh	160		[illegible]	18,4	328,9			18,6	20,0	18,1	142,2	20,1	22,2	19,0
Ph	[illegible]		[illegible]	[illegible]	7,9			7,6	7,9	8,1	7,6	2,5	7,8	8,0

Submarine springs S_1 CL: 48 mg/l.

S_2 26 mg/l.

Sink holes "C" and "B" : 14 mg/l.

Only two submarine springs were sampled. Bad weather conditions in the winter season prevented diving on other springs.

Cl concentrations obtained from summer and winter samples show the complete change occuring in the type of flow as soon as yields reach a sufficient value.

4.5.1 Graphical representation of analyses

Chemical analyses of the submarine springs and wells samples have been represented on logarithmic and lozenge diagrams.

Logarithmic diagrams have been chosen to help determine the origin of the waters while the lozenge diagrams were chosen to study their evolution.

Logarithmic diagrams.(Schoeller)

The diagrams which correspond to the waters sampled in the summer from the submarine springs and well 14 show a perfect similarity indicating without any possible doubt, the marine origin of the salimity measured in well 14. (see Fig 11).

On the other hand, all winter samples as good as the summer samples of wells 9 and 21, are similar; we conclude,

Fig. II

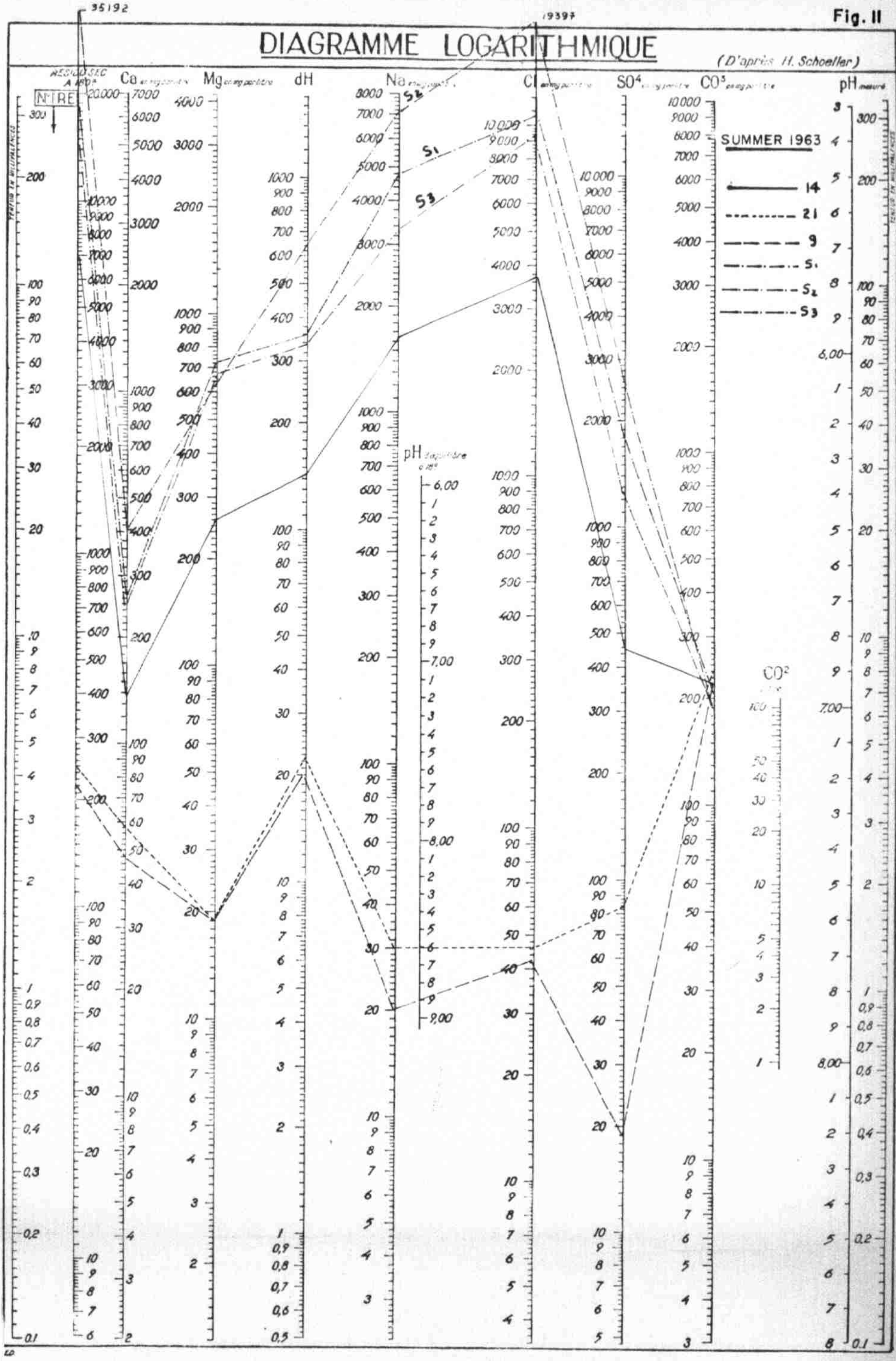


DIAGRAMME LOGARITHMIQUE
(D'après H. Schoeller)
35192
19397
N° RE
Ca
Mg
dH
Na
Cl
SO4
CO3
pH
SUMMER 1963
14
21
9
S1
S2
S3
CO2

Fig. II

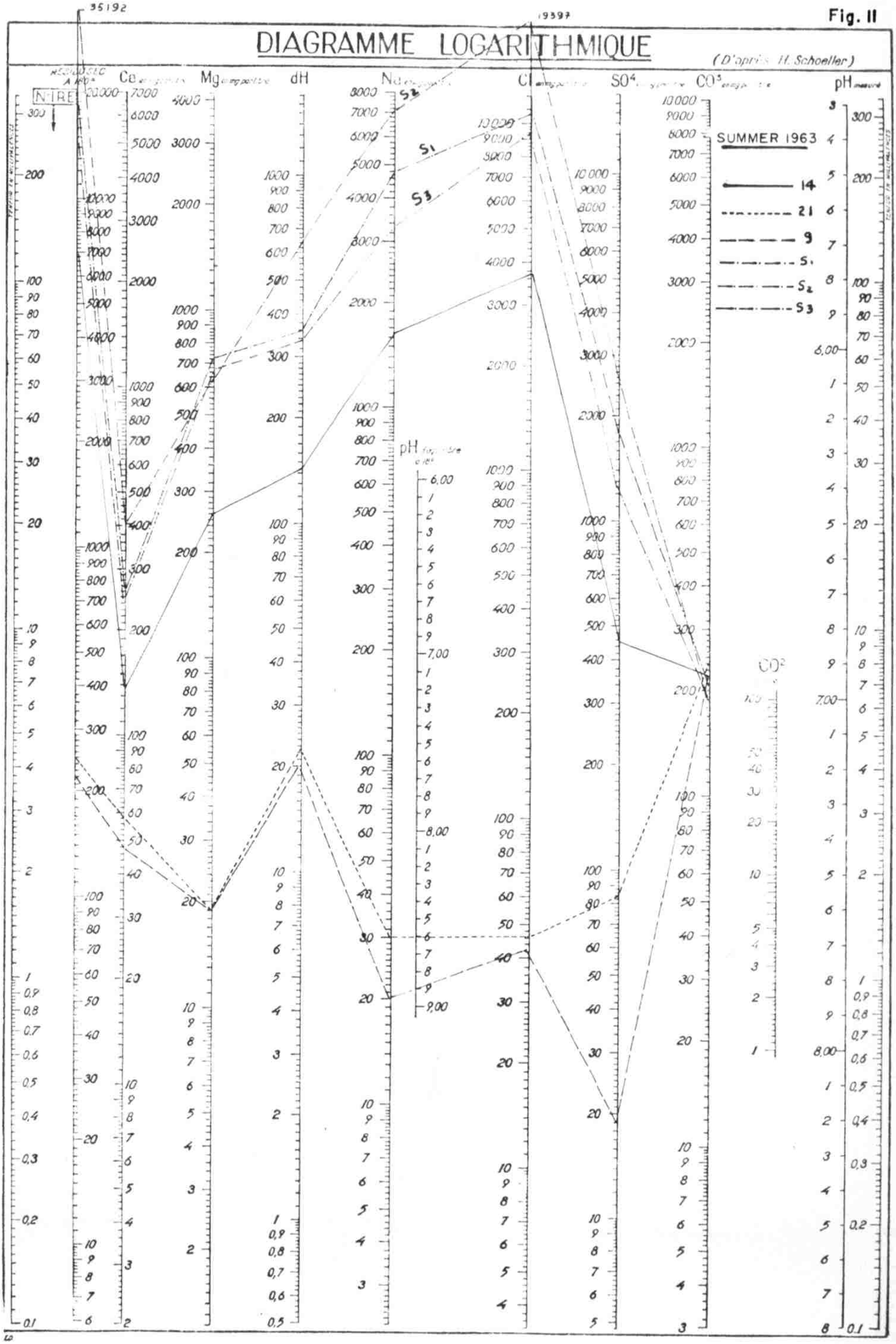


DIAGRAMME LOGARITHMIQUE
(D'après H. Schoeller)
N·IRE
Ca
Mg
dH
Na
Cl
SO4
CO3
pH
pH
CO2
SUMMER 1963
14
21
9
S1
S2
S3
35192
19397

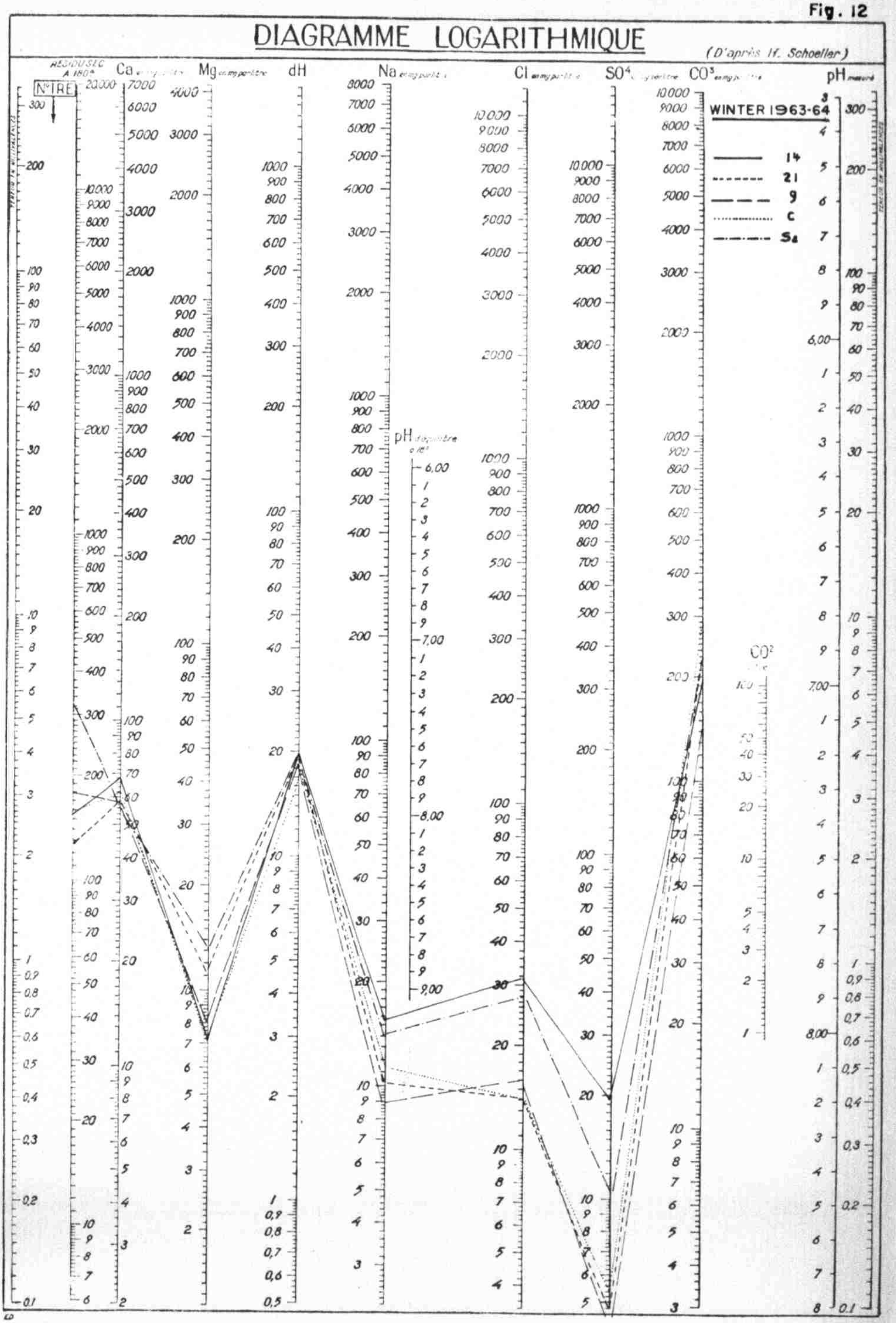


DIAGRAMME LOGARITHMIQUE
(D'après H. Schoeller)
RESIDU SEC A 180°
N°TRE
Ca
Mg
dH
Na
Cl
SO4
CO3
pH mesuré
pH d'équilibre
CO2
WINTER 1963-64
14
21
9
C
S4

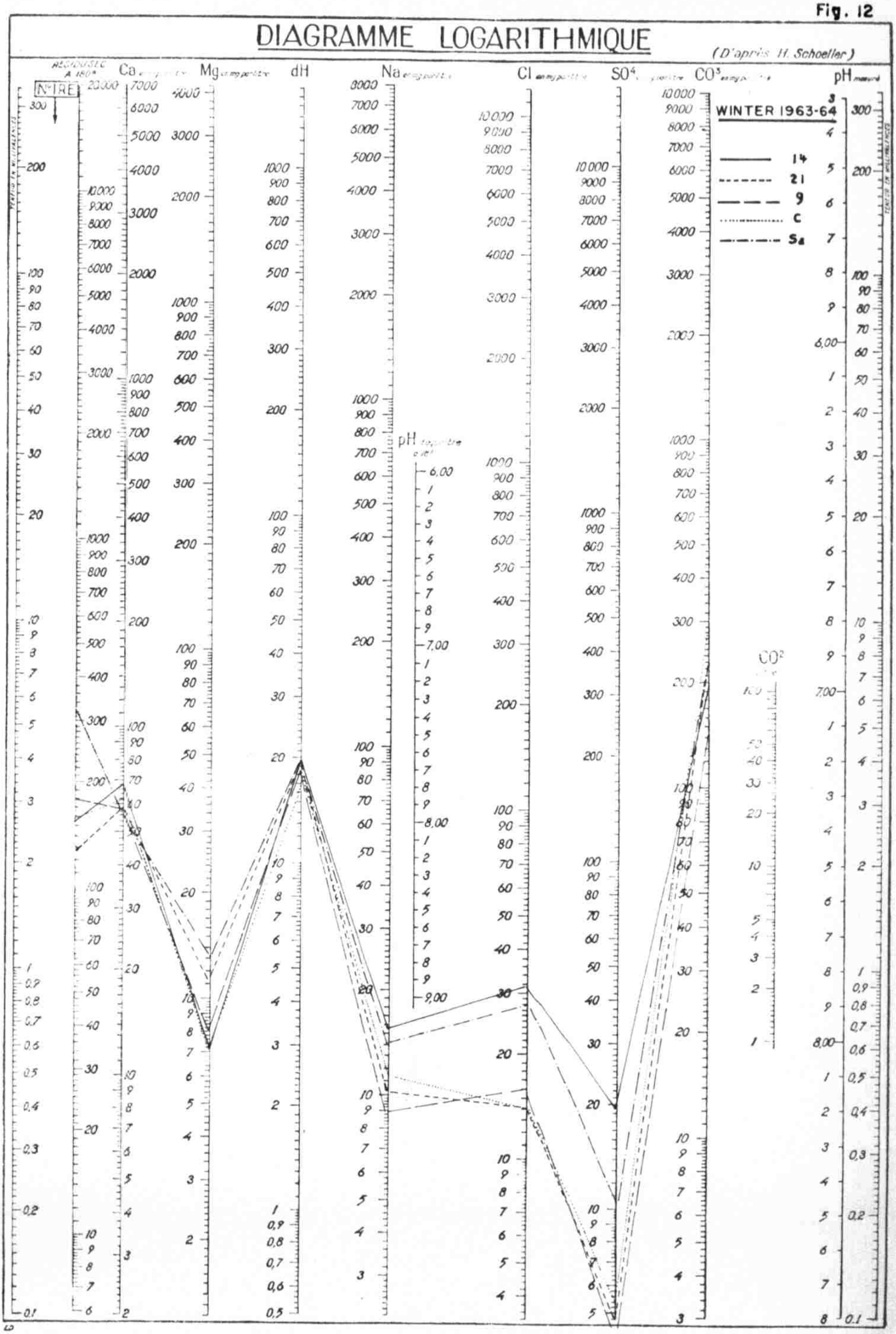


DIAGRAMME LOGARITHMIQUE
(D'après H. Schoeller)
N°IRE
Ca
Mg
dH
Na
Cl
SO4
CO3
pH
CO2
WINTER 1963-64
14
21
9
C
S4

that during summer and despite an intense exploitation, wells 9 and 21 are fed by Cenomano-Turonian waters free of salt contamination. (See Fig. 12).

Lozenge Diagrams

The difficulty of collecting regular winter samples from the submarine springs is a major obstacle in the study of the evolution of the waters from summer to winter and inversely.

However we notice that representative points of the springs and well 14 waters, move in the direction of pure salt water while those of wells 9 and 21, even though they indicate a small increase in Cl ions, move toward a zone showing an increase of Ca without an increase of Na; hence variations in salinities are not caused by the influence of sea-water (See Fig. 13)

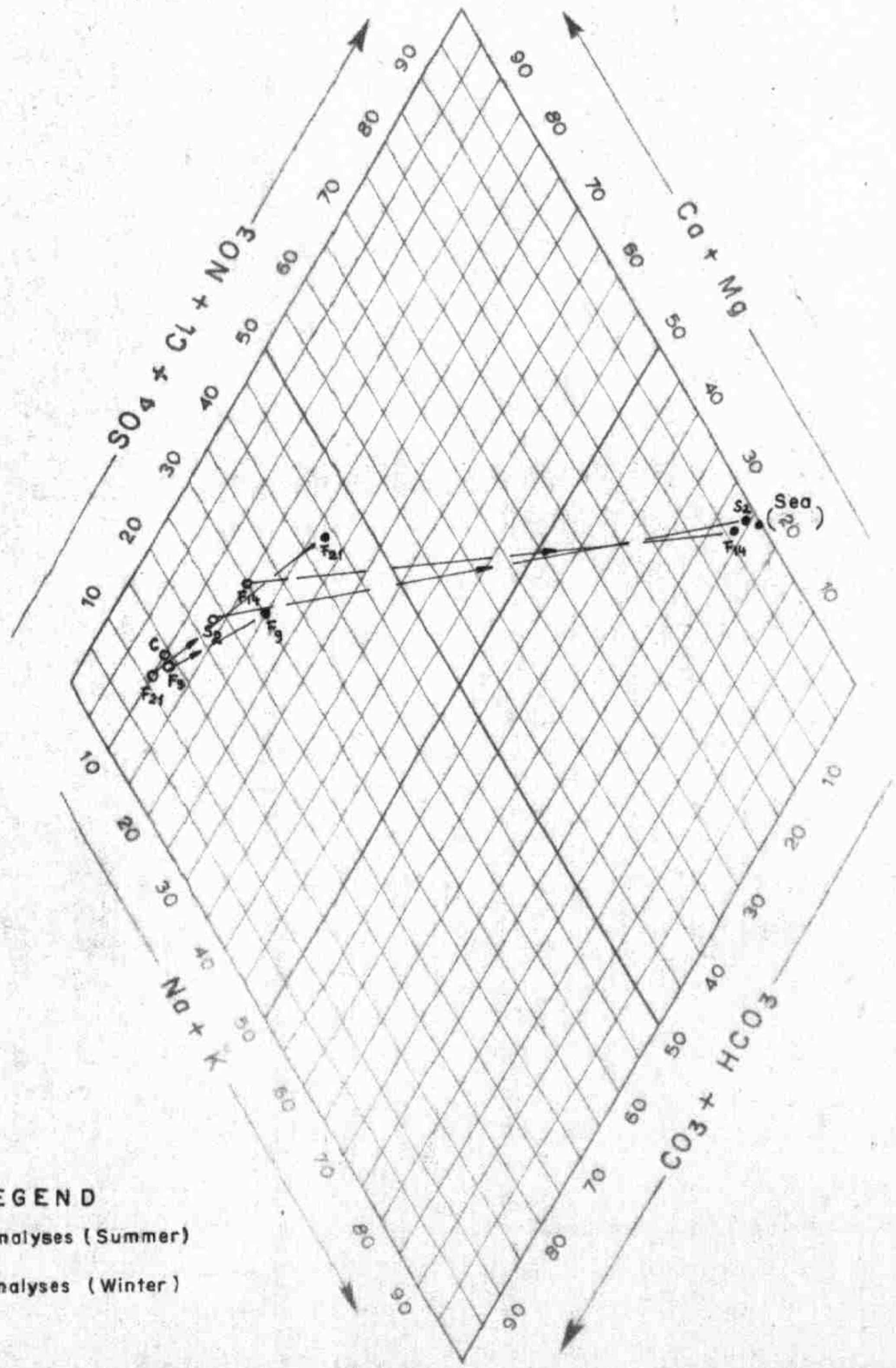
4.5.2 Conclusion

In the summer when the karstic aquifer yield decreases, salt-water intrusion occurs in certain parts of the coast especially in the area of well 14. However, in the areas of sink holes "C" and "B" wells 9,21 and 25 which correspond to zones of intense underground flow, no influence of salt-water is recorded despite heavy pumping.

Hence there are good possibilities that pumping could be developed well over the $1m^3$/sec.

Fig. 13

LOZENGE DIAGRAM



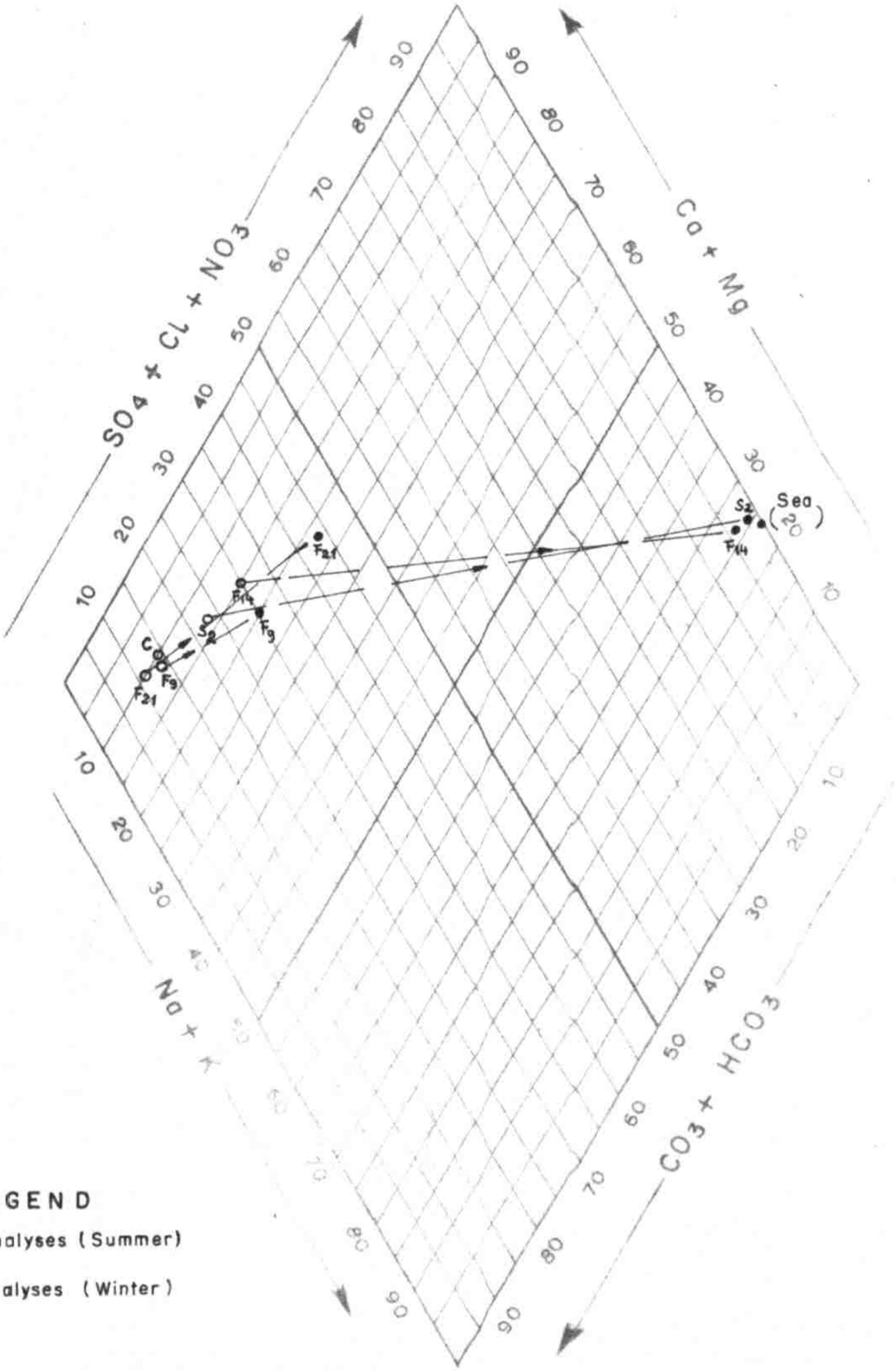
LEGEND

● Full Analyses (Summer)

○ Full Analyses (Winter)

Fig. 13

LOZENGE DIAGRAM



LEGEND

● Full Analyses (Summer)

o Full Analyses (Winter)

yield obtained in 1965; we are hopeful that (even though an intense exploitation would provoke some advance in the salt-water wedge) the considerable increase in the winter yields will immediately reestablish an equilibrium by pushing back the salt water in the sea.

At the present time it is certain that the minimum summer yield of the submarine springs is about $4m^3$/sec. of sweet water and that in the coastal areas (sink holes, wells 9 and 21) where no influence of salt-water exists, the hydrostatic level stabilizes, at the end of the dry season at 3 above sea-level. These figures are undoubtedly very encouraging. An eventual exploitation of the aquifer should be considered on the coast and not in the sea, in a region where the mixing of sweet and saline waters did not yet occur.

4.6- Conclusions

The results of the hydrogeological investigation were essential in the determination of the main characteristics of the karstic aquifer and related phenomena of flow. The practical aspects of the problem(i.e. the eventual exploitation and the prevention of salt water intrusion) will be definitely determined by the summer tests of 1966. These will be of a particular interest to the Government and to investors in general.

However, we know at the present time that the potential of the Cenomanian-Turonian aquifer of Chekka, must draw the attention of the Government always in need of new sources of water. Already we are sure of the following results:

- The karstic system of the Cenomanian-Turonian limestones draining a catchment area of 950 km^2, is discharging in the sea, through the submarine springs of Chekka. Hydrogeologically, the springs of Rachine, Mar Sarkis, Kadisha and all the springs of the Cenomanian of the basin, are a part of this system.
- Circulation in this karstic system is characterized by:
  - a- A turbulent regime in general, taking place in individual, well developed channels.
  - b- Great variations in flow velocities.
  - c- A small volume of useful void space.

Salt water intrusion occurs through some of the intermittent submarine springs which act in the dry season as sink holes. This phenomena depends on the seasonal fluctuations of pressures in the karstic groundwater body.

5.- Pumping tests and miscellaneous investigations

In the course of the investigation of the submarine springs of Chekka, several methods of exploration were initiated on the coast. These include geophysical investigation, drilling of reconnaissance wells and a series of seasonal pumping tests at different yields.

5.-1. Geophysical Investigations

The main problem faced in geophysical exploration was the explanation of the origin and formation of the submarine springs. The Project of Underground Water Survey of Lebanon had previously made an inventory of all water points on the coast. Unfortunately they were not very helpful due to the rather imprecise stratigraphical informations collected from well owners. In most cases, no records, or well logs were available. A well drilled by the Point IV program gave information only on the Senonian marls which it had penetrated. Other wells, drilled by private concerns, have, however, penetrated the Cenomanian-Turonian limestones. Only those have been taken in consideration at the time of the geophysical investigation.

The most interesting wells are those, whose depths are over 50m. wells 3 and 14 (See plate No. 2) at depths of 80 and 125m. have reached the Turonian. Wells 14,6 and 13 have probably penetrated the limestones but it is not known at which depth. Well 13 has been drilled by the Point IV program and stopped at the Senonian-Turonian contact.

One of the main purposes of the geophysical investigation was the study of the alimentation of the submarine springs which is the determining factor in the adoption of an economical solution of exploitation on the coast before the intrusion of saline waters. Two particular problems had to be solved:

- The determination of the Senonian-Turonian contact and the discovery of any evidence of tectonical accidents.
- The determination of the zones of salt water intrusion.
- The determination of the preferential zones of fresh-water flow.

Method used

The marls which contain clay elements are in general well differentiated electrically from the limestones which are poor conductors when compact. In fact, a formation's resistivity varies inversely to its clay content, clay being a very good conductor. On the other hand, the variation in a winter's content in salts, does not affect but one geophysical parameter: resistivity. Hence the electric method is best suited for the solution of the different aspects of the Chekka problem.

About 200 soundings were executed in the **vicinity of Chekka El Jadide** and electrodes were spaced, in general, about 1000 m. apart. A few lines were spaced 2000 m. apart in an E-W direction. (See Plate 3)

5.1.1- Results of the Investigations

For this paragraph Plate No. 4, entitled "Map of the top of the Turonian Limestones of Chekka" should be consulted.

Study of the top of the Turonian limestones.

The electric soundings No. 95,100,102,107 and 104 were executed on outcrops of Turonian limestones. They show that the limestones's resistivity is, in general, superior to 100 Ohm/m. and reaches, in some cases(sounding 107) 1000 Ohm/m. On the other hand, sounding 104 has a smaller resistivity(about 40 Ohm/m.) indicating probably a presence of salt water in the limestones. This salt-water intrusion is noticeable in sounding 104 where the conductor begins at about 150m.

The Senonian chalky marls are generally, very good conductors and tend to be more compact in the south(40 to 50 Ohm/m) than in the north (15 to 25 Ohm/m.) close to the sea, resistivity decreases.

The Quaternary sandstones are, in general, resistant ranging from 100 to several hundreds Ohm/m., while the alluvial materials are in general good conductors.

From the results, we have established the following resistivity scale:

- Alluvium and sands .... 10-100 Ohm/m.
- Quaternary sandstones(Ramleh)......100 to several Hundreds
- Senonian marls.................... 10 to 100
- Limestones saturated with salt water.. 10 to 50
- Compact, dry limestones with or without fresh water.......................... 50 to more than 1000

Due to the big differences in resistivity values, distinction between marls and limestones was, in some cases, very difficult, particularly in the zones where the limestones are saturated with salt water.

5.1.2 - Interpretation of the Results

Results are reported on Plate No. 4, along with the most important wells and the location of soundings with an estimation of the limestones depth at each sounding. Contour intervals of the top of the limestones have been drawn.

North of F, curves have been drawn in dashed lines because they do not correspond to the top of the limestones but to a certain horizon in them. Dashed lines near the coast indicate doubts the top of the limestones because of divergent interpretation hypotheses.

Plate I shows, that in the southern part the limestones sink regularly towards the northwest with a rather small dip (8 to 10^{o}) comparable to dips taken on Turonian outcrops. In the vicinity of wells 13 - 10 - 9 and 14, the limestones are almost horizontal and seen to rise near the coast starting hence an anticlinal movement.

The presence of the submarine springs could be explained by an anticlinal structure located near sounding 32 - 48 - 57,.

They could be situated on the axis of the structure where the Senonian marly cover is thin. The fault F passing north of spring No. 6 would cause an interruption of resurgence in the sea.

5.1.3 - Resistivity Map AB = 1000 m.

On plate 3, equiresistivity curves have been drawn for AB = 1000m.

This map shows resistivity variations in a terrain of uniform thickness about 200.250 meters.

Due to the fact that the marls' thickness, except in the north, does not exceed a 100 meters, this map gives an idea on the superficial part of the Turonian limestones, giving thus information about the karstic zone that could contain fresh water. It is hoped that this map would furnish qualitative informations about the nature and the saturation of the upper part of the limestones.

Hence north of F, there is evidence of a conductor zone where the marl series is probably thicker and limestones intruded by salt water. Salt water intrusion along the coast, clearly appears on the map, especially around soundings No. 98 - 96. Zones of high resistivities (over 200 Ohm/m) correspond, probably, to compact, unsaturated limestones. In general, intersting locations for exploration wells should fall in the zones of average resistivities (between 50 and 100 Ohm/m.)

As mentioned earlier in this paper we are dealing exclusively with a karstic system where flow occurs in well developed channels, but it is also known that there is no geophysical method that could locate these channels individually with precision except in exceptional cases where depth is very small.

At any rate, resistivity increases around soundings 58 - 34 - 33 - 32. This was considered as a preferential zone of flow where a well was executed close to sounding 35.

5.1.4- Conclusions

The Electrical resistivity method showed:(see plates 3 and 4)

1- That in the southern part of the Chekka region, the resistant substratum that was identified as being a limestone of Turonian age, sinks gradually in a northwest direction with a 10^{o} dip.

2- In the vicinity of wells 13-9-14, interpretations is particularly tricky. It seems that the limestones are horizontal with a crest line around soundings 44 - 35 - 30.

3- In the springs vicinity it was supposed that the limestones would correspond to the conductor zone visible in soundings 32 - 48 - 57.

If this is exact there would be a beginning of an anticlinal structure whose axis is in the line with the springs position.

4- A fault F is responsible for the down-throw of the Northern part of the Chekka area.

5- The springs could be explained by the presence of an anticlinal structure, along whose axis the marls thin out and fissure during orogeny.

6- Salt-water intrusion is in evidence, north of F and all along the coast with a maximum intensity near soundings 96 - 98.

Electric prospection should, we think, be complemented by seismic refraction along the coast, and by electric logging of the wells thus giving more information about the origin of the springs and the exact resistivities of the different formations.

5.2 - Exploration wells.

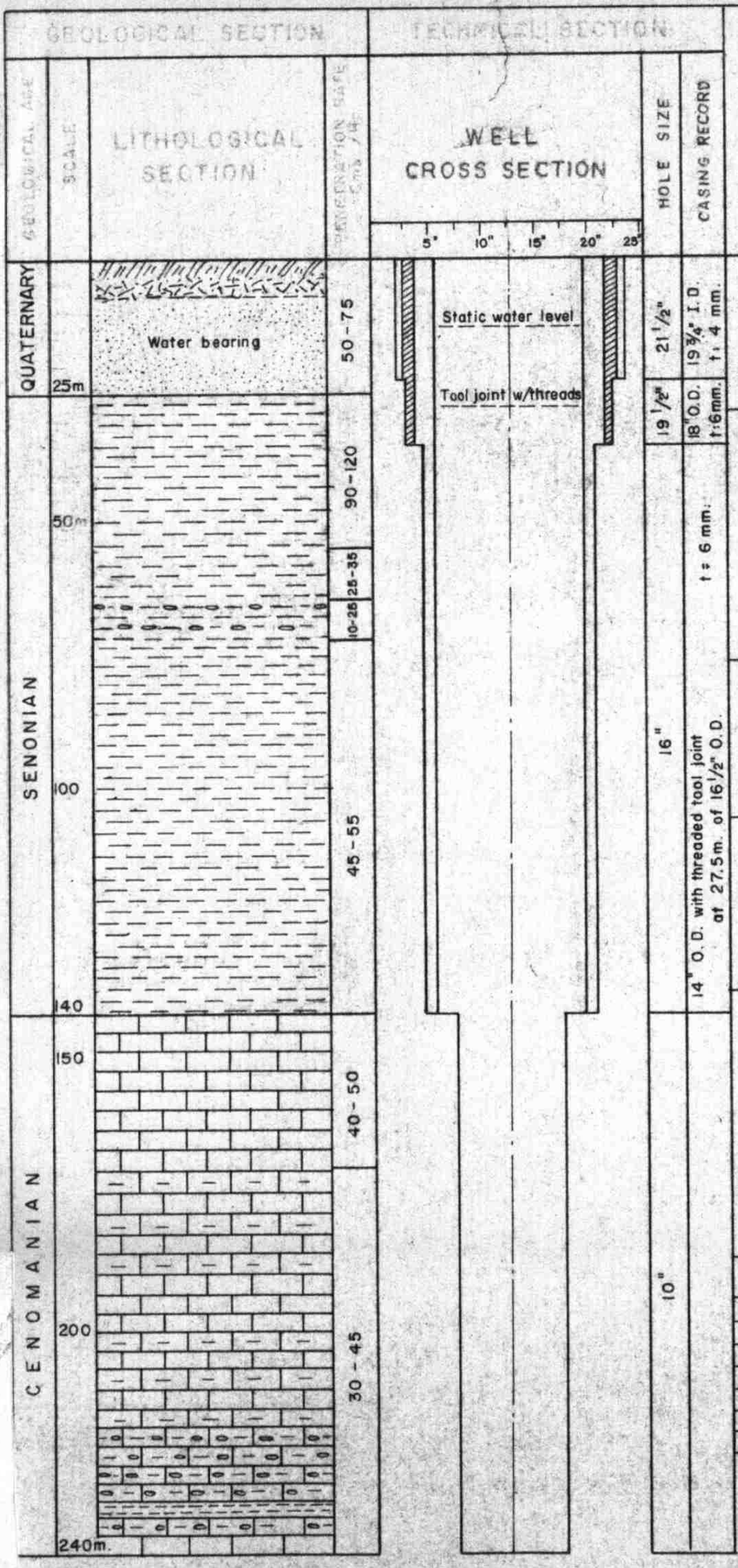
One major reconnaissance well of 240 meters total depth (well 55) was drilled in the preferential zone of flow determined by geophysical investigation. This zone is located near sink hole "C" close to electric sounding No. 35.(See Fig.2)

This well penetrated 25 meters of coarse saccharoidal, quaternary sandstone or "ramleh" containing infiltration water. The thickness of the Senonian marls was determined to be 115 meters and Cenomanion limestones started at 140m. depth.

GEOLOGICAL AND TECHNICAL WELL CROSS SECTION

N° 55/4

Fig. 15



REMARKS

GENERAL DATA

Land owner : Abdullah Tamer
Enterprise : Ibrahim Azam
Drilling system : Percussion

SITUATION

Region : CHEKKA
Coordinates :
X : 151.450
Y : 266.500
Elevation : 20.4 m.

EXECUTION

Spudded in : 11/7/64
Drilling executed : 28/10/64

GROUND WATER

Top water bearing formation 69.5 m.
Static water level : 13.10 m. on 30/10/64

TESTS

Pumping test :
None

Bailing tests

N°	Depth	Flowrate	Drawdown
1	24 m.	1.2 l/sec	164 cm.
2	131	2.5	70
3	153	2.25	38
4	197	2.5	75
5	201	2.5	80
6	229	2.5	76
7	240	2.5	76

N. B. _ Original static water level maintained in few seconds. Test duration ranges from 30-120 mins.

Static water level stabilized at 13.10m. but a pumping test proved unsuccessful. The well, yet close to sink-hole "C" in contact with the main underground channel, penetrated a very compact zone in the Cenomanian limestones. Following this failure, five wells 20" in diameter and 20m. in depth (see fig. 2) were drilled in sink-hole "C". As expected water appeared at 4 and proved the theory that the sink-holes were in connection with the main aquifer(or channel) through a big fissure in the Senonian marls. (See photos 15, 16, 17, 18)

Drilling was stopped in order to start the pumping tests necessary to determine our permissible yields and, most important, the dangers of salt water intrusion in case of intense pumping.

Several piezometric wells should be drilled in the future between the pumping wells and the coast to determine the velocity of sea-water intrusion towards the coast. This program is expected to start in the summer of 1966.

Conclusion

From the drilling program we conclude that we are dealing in the Chekka area with two different cases:

a- A very compact zone without water

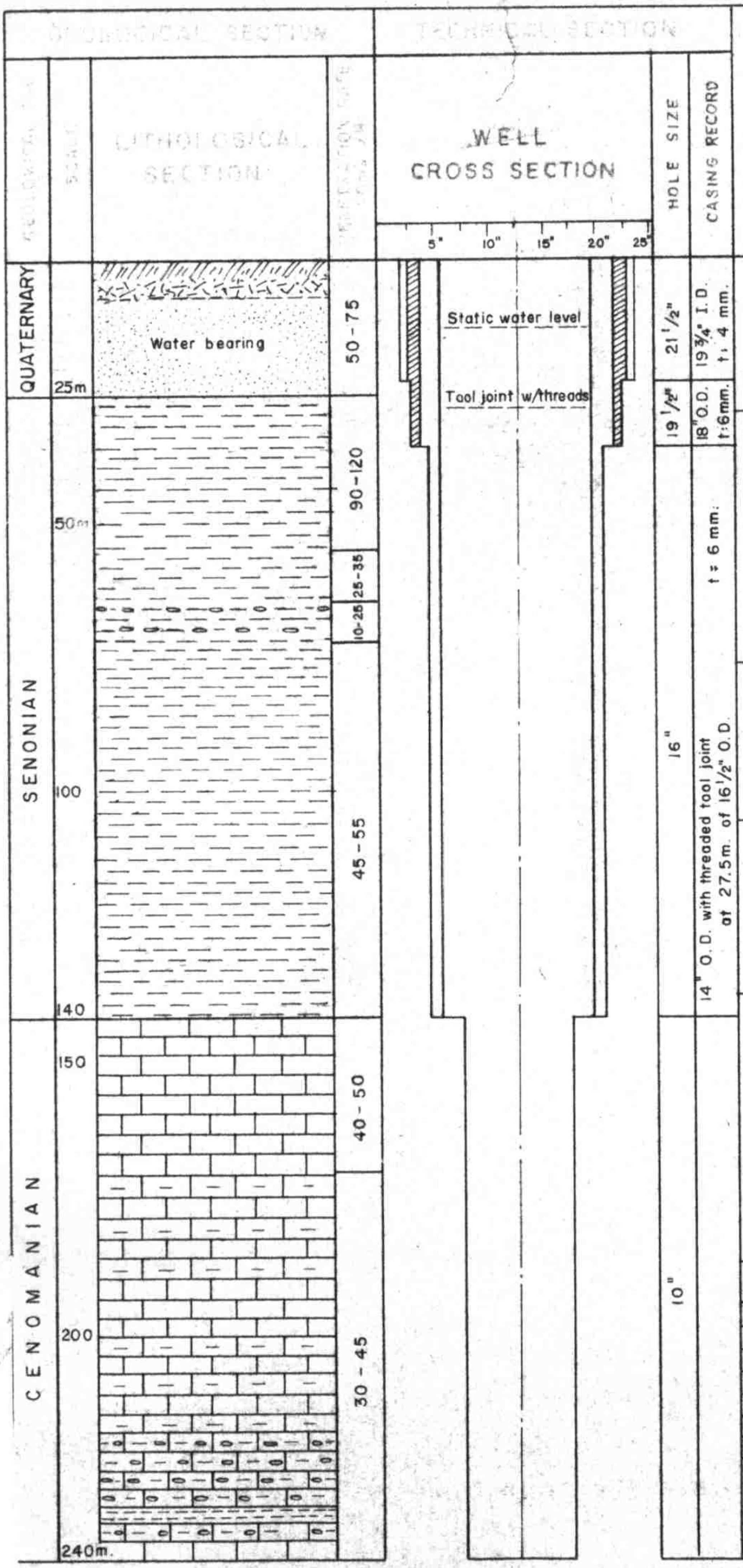
b- well developed underground channels with intense flow.

5.3.- Pumping Tests.

GEOLOGICAL AND TECHNICAL WELL CROSS SECTION

N° 55/4

Fig. 15



REMARKS

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7	240	2.5	76

N. B. _ Original static water level maintained in few seconds. Test duration ranges from 30-120 mins.

Photo 16- Close view of wells
50, 51, 52.
Artesian flow in
Sink-hole "C".

Photo 17-Flow from Sink-hole
"C" showing evacuation
Channel.

Photo 18- Flow at rim of
Sink-hole "C"
indicated by man's hand.

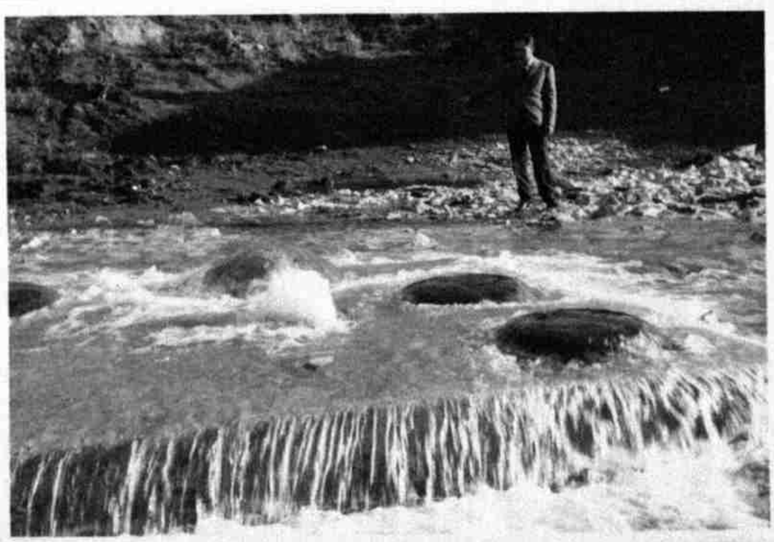

Photo 16- Close view of wells
50, 51, 52.
Artesian flow in
Sink-hole "C".

Photo 17-Flow from Sink-hole
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Channel.

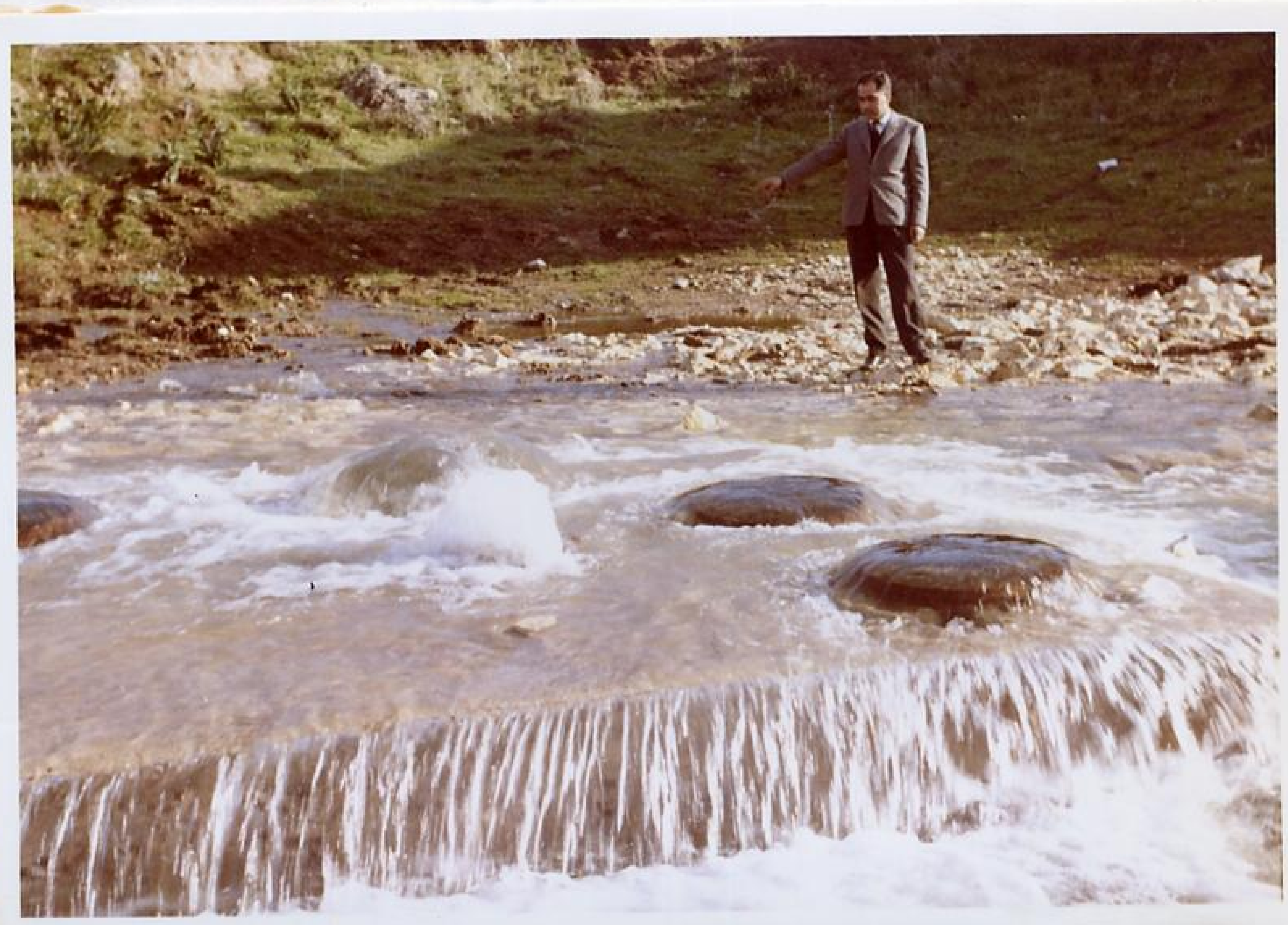


Photo 18- Flow at rim of
Sink-hole "C"
indicated by man's hand.

5.3.1- Generalities

The purpose of the pumping tests is to determine the characteristics of the terrain and to confirm the hypotheses advanced in the different chapters of this paper.

We had previously reached qualitative results concerning the phenomena of flow of undergroundwater. It is possible now to determine quantitatively the several proposed theories.

In order to obtain quantitative results, several pumping tests were performed giving positive results:

a- The first tests confirmed the presence of a superficial aquifer with compact characteristics.

b- The second tests confirmed the existence of an extremely well developed karstic system.

c- The final tests confirmed the possibility of an exploitation of the aquifer at big yields.

Nonetheless there remains a very difficult problem to solve theoretically: It is the problem of salt water intrusion. We think that the only solution to this particular aspect, capable of giving positive results, is the use of the most practical experimental method which is the increase of exploitation yields.

5.3.2 - Test confirming the presence of a superficial aquifer with compact characteristics.

a - Pumping test executed on well No. 3- (See plate No. 2)

Well No. 3 is located in the Turonian limestones near the plaster factory in Chekka. Its characteristics are:

Total depth about 60 meters

Hydrostatic level 32.55 meters

A pumping test executed for a period of 48 hours gave the following results:

Aquifer constant T (transmissibility) = 3.79×10^{-5} m^2/sec.

maximum yield : 1.52 l/sec.

Drawdown : 10 meters.

By taking into consideration the enormous drawdown of 10m. for a small yield such as 1.52 l/sec, and a very low transmissibility, it is easy to conclude to the presence of a compact limestone. The small yield is probably due to micro-fissures.

b - Bailing tests executed on well 50

Seven bailing tests were executed in the well at different levels. As shown in Fig. 15 a maximum flow of 2.5 l/sec. resulted in 76 cms. of drawdown. This clearly proves that in the course of drilling from 0 to 240m, we were dealing with a compact terrain.

5.3.3- Tests confirming the existence of an extremely well developed karstic system.

a - Pumping test executed on well 50

A 100 l/sec. pump was used to perform the test at 15m depth. In well 50 it was shown that we were dealing with a confined aquifer, located in a compact terrain, (where a well defined karstic system had developed) whose discharge points were the submarine springs in the sea and the intermittent sink holes on the coast. Sink hole "C" in particular as an equilibrium chimney yielding, after heavy rains, $2m^3$ per sec.

Results.

As a result of the hypotheses advanced it is considered that the karstic system of Chekka is similar to flow in pipes operating under well-known conditions.

In periods of heavy rainfall, the water level in well 55 is higher than the level of discharge of sink hole C. The difference in elevation between the two levels and the important yield of the sink-hole indicate the theoretical drawdown in water level that could be obtained if a pumping test is performed on well 50 located in sink hole "C". This prevision was confirmed by an instantaneous stabilization of drawdown at 12.5 cms form the initial water level at a pumping rate of 104 l/sec. (See Fig. 17)

On the other hand it is impossible to undertake a quantitative study of the aquifer constants i.e. transmissibility T and storage coefficient S because we are in presence of an equilibrium regime, absolute proof of the existence of a karstic system. Hence we will deal only with loss of head.

Fig. 17

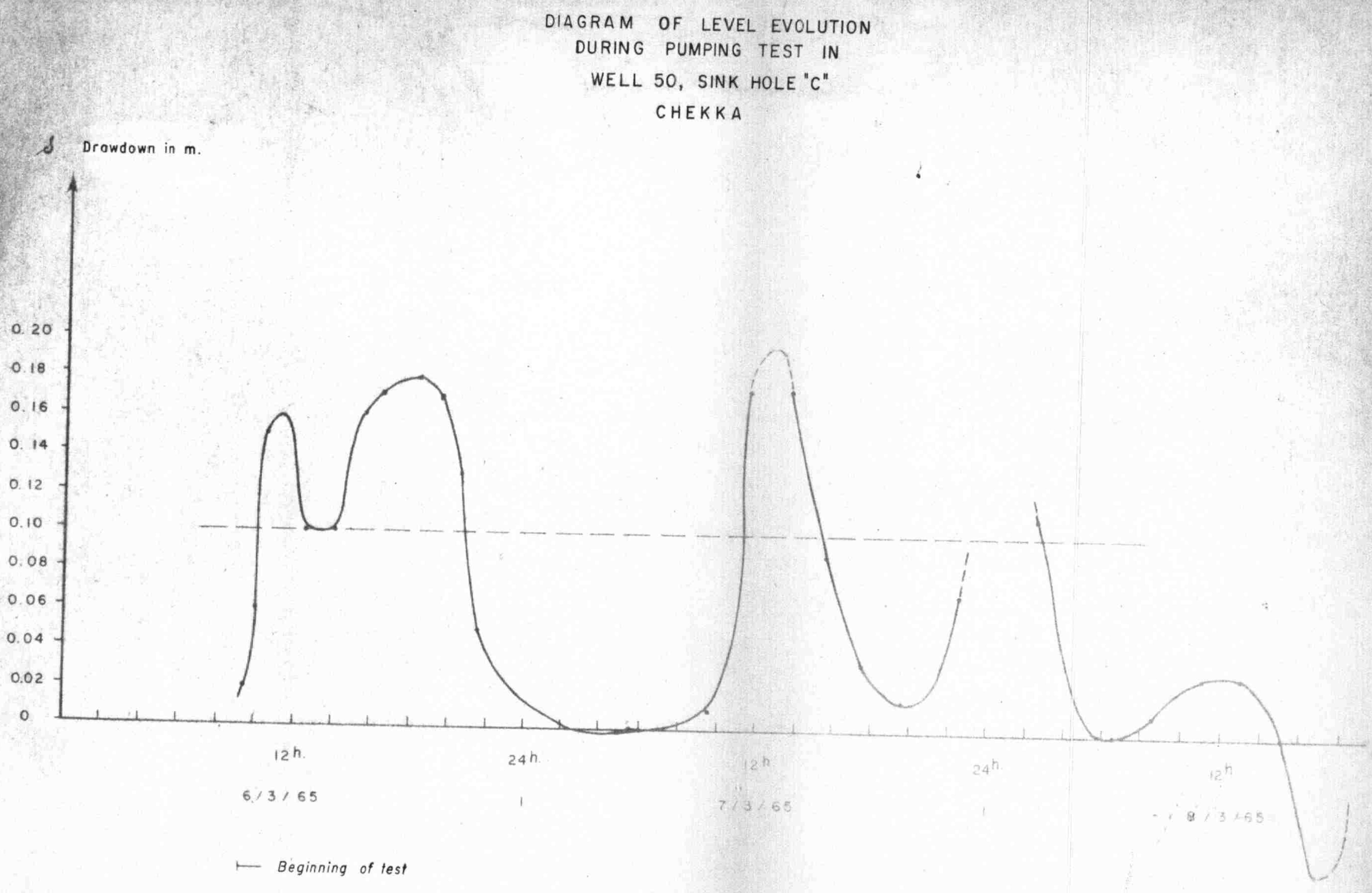


DIAGRAM OF LEVEL EVOLUTION
DURING PUMPING TEST IN
WELL 50, SINK HOLE "C"
CHEKKA
Drawdown in m.
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
12h.
24h.
12h
24h.
12h
6/3/65
7/3/65
8/3/65
Beginning of test

Fig. 17

DIAGRAM OF LEVEL EVOLUTION
DURING PUMPING TEST IN
WELL 50, SINK HOLE "C"
CHEKKA

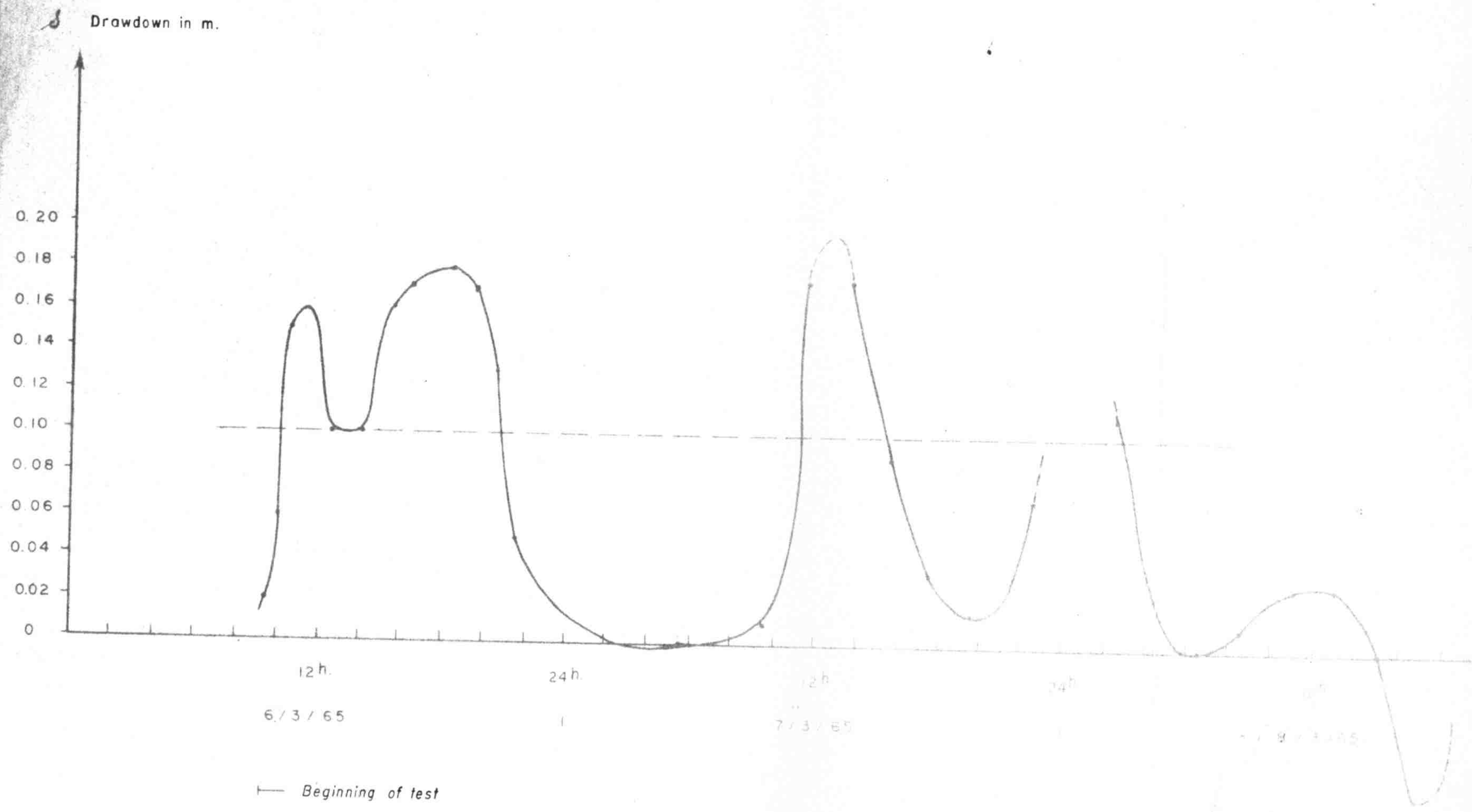
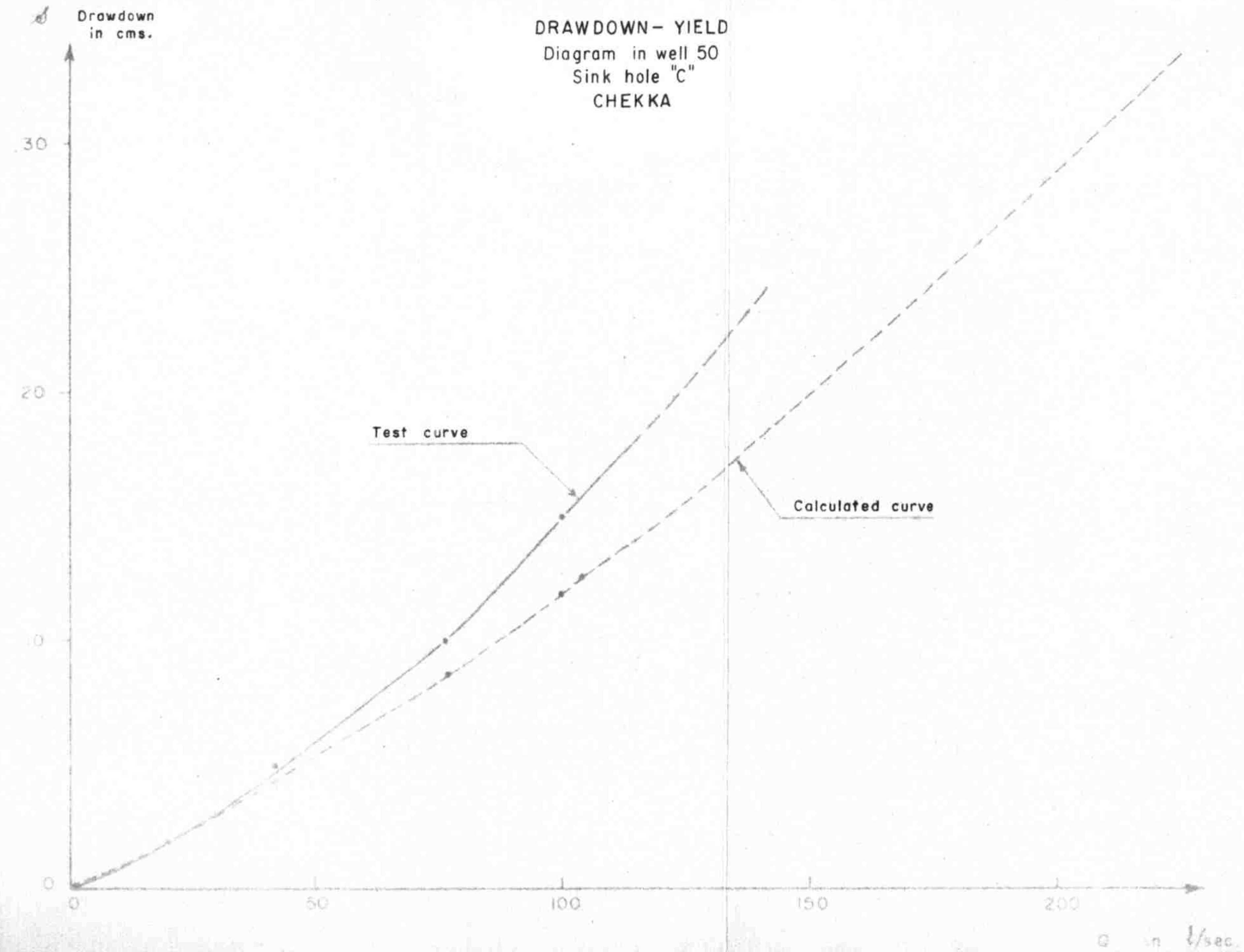
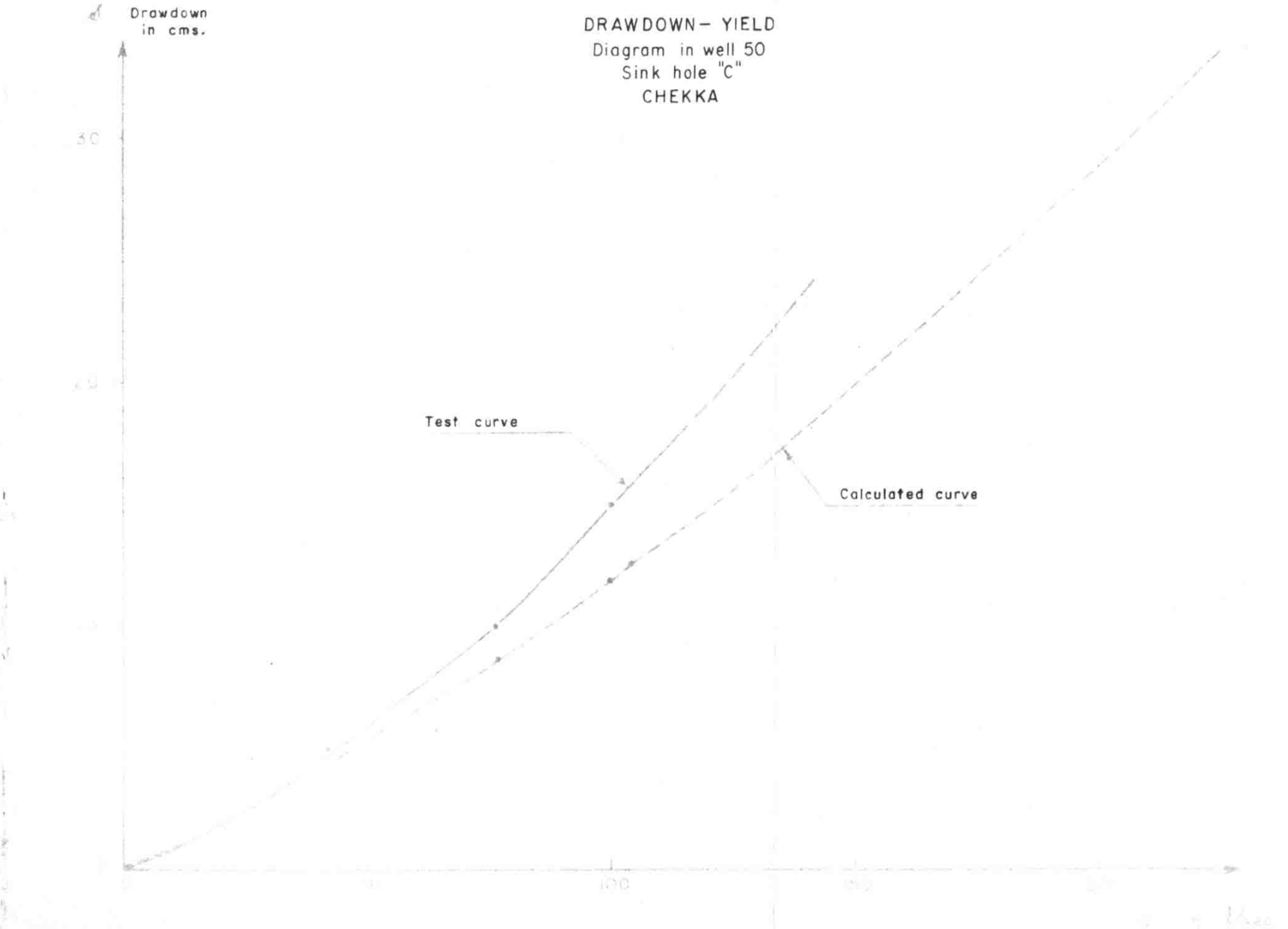


Fig. 18



Drawdown in cms.
DRAWDOWN- YIELD
Diagram in well 50
Sink hole "C"
CHEKKA
30
20
0
0
50
100
150
200
Test curve
Calculated curve
Q in l/sec.

Fig. 18


Drawdown
in cms.
DRAWDOWN – YIELD
Diagram in well 50
Sink hole "C"
CHEKKA
Test curve
Calculated curve

Accordingly several stabilizations were realized and a diagram "Drawdown". Yield was obtained (See fig. 18)

Equation of the Diagram

We will consider in general the presence of loss of head in the well. The diagram's equation is in the form of

$$S = aQ^2 + bQ$$

S represents drawdown in cms.

Q represents yield in 1/sec.

N.B.- It should be noted that the tide's influence in the Chekka area, is instantaneous. Hence, as soon as the water level stabilizes all variations are due to the tide. That is why a very short time of stabilization will be considered.
For the determination of the equation we will take into account the first two stabilizations:

a- The first one obtained during development of the well:

$Q = 104$ 1/sec. and $S = 12.5$ cms.

b- The second one obtained at the beginning of the test:

$Q = 20$ 1/sec. and $S = 20$ cms.

Developing, we find

$a = 2.42 \times 10^{-4}$

$b = 9.51 \times 10^{-2}$

Hence: $S = 2.42 \times 10^{-4} \times Q^2 + 9.51 \times 10^{-2} \times Q$

The coefficient $a = 2.42 \times 10^{-4}$ is small; losses of head are practically negligible compared to the term bQ.

Fig. 19

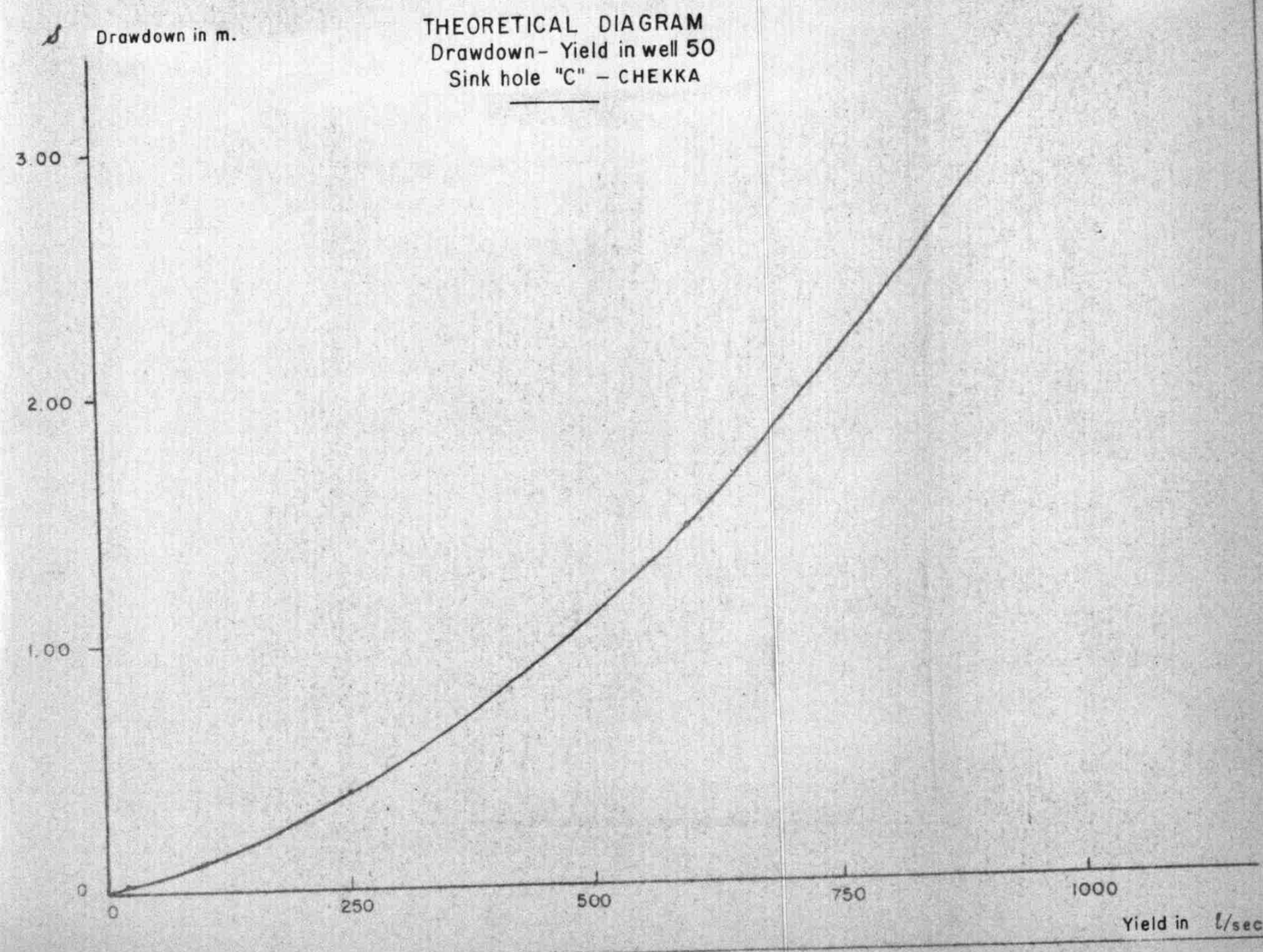
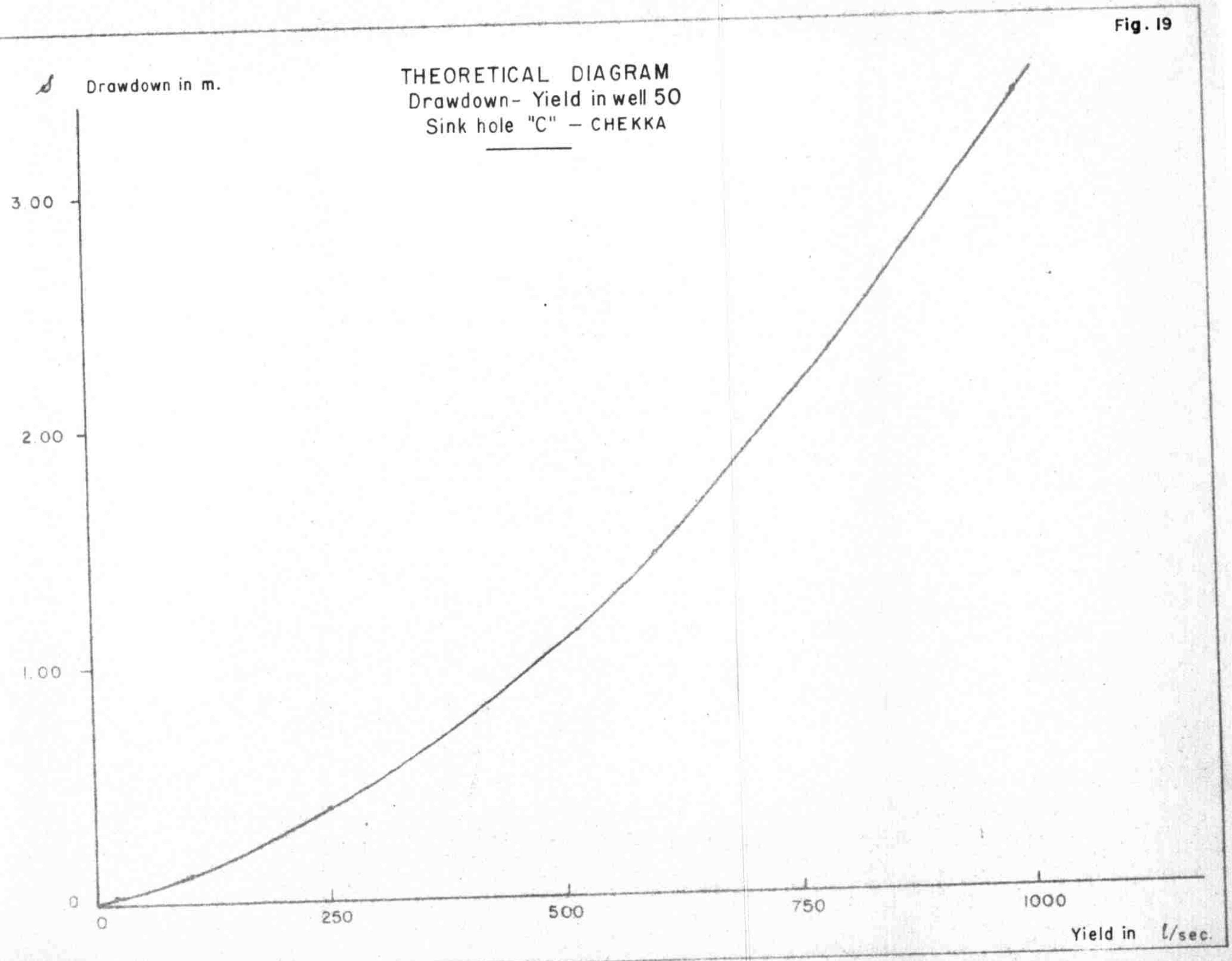

THEORETICAL DIAGRAM
Drawdown- Yield in well 50
Sink hole "C" - CHEKKA
s Drawdown in m.
3.00
2.00
1.00
0
0
250
500
750
1000
Yield in l/sec.

Fig. 19



THEORETICAL DIAGRAM
Drawdown- Yield in well 50
Sink hole "C" – CHEKKA
s Drawdown in m.
3.00
2.00
1.00
0
0
250
500
750
1000
Yield in l/sec.

Hence, when we are dealing with small yields we practically have a straight line.

But for important yileds the term aQ^2 ceases to be negligible; losses of head increase rapidly and, as an example we find that : (See Fig. 19)

for $Q = 250$ l/sec $S = 39$ cms.

$Q = 1000$ l/sec. $S = 337$ cms.

Other example give:

$S = 8,75$ cms for $Q = 77$ l/sec.

$S = 12$ cms for $Q = 104$ l/sec.

First interpretation

Losses of head increasing proportionally to yields, it is preferable to limit the latter by increasing the number of wells. Four wells of 250 l/sec. each, will give a drawdown of 0.40 cms x 4 = 1,60m. Considering that the influence of one well on the other can never be superior to the drawdown at each individual well, we will then always deal with a laminar regime.

Fig. 5 including measurements taken during the test and the evolution diagram of the water level, shows variations due to the tide's influence.

Remarks

It is noticeable that in Fig. 5 the sinusoid of the tide's evolution is displaced on the drawdown axis by about 10 cms; this is due to the pumping of a 100 l/sec.

The value of 11.93 cms calculated for 100 l/sec is more exact that the value of 15 cms measured during the test. At any rate, a theoretical diagram of evolution of drawdown in function of obtained yield is given in Fig. 19.

b - Pumping tests executed on wells 51/, 52/ 53/ and 54/(Fig 2)
Hydrostatic level on the 21/4/65 : 11 meters

Well No.	Drawdown	Yield
51	0.09 meters	35.7 l/sec.
52	0.11 meters	32 l/sec.
53	0.04 meters	35.7 l/sec.
54	0.04 meters	35.7 l/sec.

These results show that by using the approximate formula of Thiem for the calculation of Transmissibility we get:

$$T = 1.3 \frac{Q}{S} = 1.3 \frac{0.104}{0.12} = 1.13 \; m^2/sec.$$

This high value of T shows clearly the presence of a well developed karstic system.

5.3.4 - Tests confirming the possibility of the exlpoitation of important yields from the aquifer

Four pumps of 250 l/sec. each were installed(See photos 13,14) on wells No. 51, 52, 53 and 54 (See Fig. 2)

Pumping test performed in Nov. 1965

Hydrostatic level was at 14 meters. Out of the four pumped wells only two(No. 52,53) gave excellent results. The drawdown was: 1.20m. The two other wells(no.51 and 54) gave only 100 l/sec. each. (Figs. 17, 18, 19).

Photo 13-Discharge of two pumps capacity 3ool/sec in wells 50,51(Oct.1965)

Photo 14-Pumping installation in Sink-hole "C" on wells 50 - 51 - 52 - 53.

Photo 15-Artesian flow in Sink-hole "C". Concrete slab with wells 50, 51, 52, 53.

Photo 13-Discharge of two pumps capacity 300l/sec in wells 50,51(Oct.1965)

Photo 14-Pumping installation in Sink-hole "C" on wells 50 - 51 - 52 - 53.

Photo 15-Artesian flow in Sink-hole "C". Concrete slab with wells 50, 51, 52, 53.

Photo 13-Discharge of two pumps capacity 3ool/sec in wells 50,51(Oct.1965)

Photo 14-Pumping installation in Sink-hole "C" on wells 50 - 51 - 52 - 53.

Photo 15-Artesian flow in Sink-hole "C". Concrete slab with wells 50, 51, 52, 53.

Pumping test performed in March 1966

Hydrostatic level was at 2.40 meters. The four pumped wells operated at full capacity of the pump i.e. 250 l/sec. per pump, the resulting drawdown being 3.5m. (Figs. 18,19).

The differences in yields and hydrostatic levels obtained from both tests show clearly that when the hydrostatic level drops to 14 meters, sink hole "C" behaves as a funnel - shaped crevasse whose base opens on the surface and whose sides are completely impervious.

This was proved by an acid job performed on well No. 54 which, yet it resulted in lateral fissuration, did not increase the yield of the well once water level dropped to 14 meters. This proves definitely that the movement of water is vertical i.e. from the Cenomanian aquifer to the surface, and that lateral alimentation exists in the vicinity of sink hole "C" outside whose limits all strata are impermeable.

5.4 - Conclusion

Geophysical drilling and pumping tests programs complement each other by furnishing the following results:

- The aquifer located in the Cenomanian-Turonian limestone of the Chekka area possesses compact characteristics : $T = 3.79 \times 10^{-5}\ m^2/sec.$
- Sink holes "C" and "B" and the submarine springs constitutes the only discharge points of the karstic system in the sea and on the coast.

We are sure that at least 4 m^3/sec. can be exploited from sink hole "C". One difficult problem will then arise: the problem of salt water intrusion which we think will develop between 1 and 2 m^3/sec.

The only way to find it out is to perform tests at increasing yields of 1, 2, 3, 4 m^3/sec. These will start in October 1966.

6.- General Conclusions

The results obtained from the investigation of the submarine springs of Chekka and their catchment area, show that the karstic system represents hydraulically and hydrogeologically an **extremely complex** aquifer whose lowest discharging points are the submarine springs.

In this system, the srping of Rachine, represents only, an overflow of the karstic underground water body of Chekka.

The first estimates of the hydrologic factors, concerning the hydrologic basin of the submarine springs, (Infiltration = 30%, evapotranspiration 56%, surface run-off 14%) have shown that the average yield of the submarine springs is about 10 to 15 m^3/sec.

It is certain that this yield must be accounted for by a hydrogeological basin of 900 km^2 approximately.

Keeping in mind that the springs of Chekka drain such an extensive and important aquifer, we are sure that the most intensive underground flow occurs in the lowest points of the basin, thus in the vicinity of Chekka, where the karstic collectors(sink-holes, channels, springs) are the best developed.

6.1- Solution adopted for the exlpoitation of the aquifer

The proposed solution is based on three essential factors:

a- The piezometric level (6.5 cm) in sink hole "C" at the end of the dry season indicates that the fresh water pressure at this point is largely superior to the sea water head.

b- Sink-hole "C" being in relation with the karstic aquifer through the marls, it is certain that we are in the most fissured part of the system.

c- The altitude of sink hole "C" being 18m., the manometric head of discharge, during pumping, would only be about 13 or 14 m, which is perfectly reasonable economically.

Before the complete equipment of sink-hole "C" for a final exploitation, four wells, 20" in diameter have been drilled in the sink hole and stopped at - 2m. These wells were tested at 100 l/sec. and gave the same results obtained during pumping of well 50.

The first results allow us to hope for a drawdown of 1.60 m. for a total output of 1 m^3/sec. Pumping tests totalling 2 m^3/sec. will begin at the end of September 1966 and their main purpose is to indicate the possible evolution of salinities at important yields.

We hope that during the tests, the head stabilizing at 4.5 m., will remain important enough to compensate the head of the sea water. In case that results prove to be positive, a first quantity of 1 m^3/sec. would be immediately available for consumption.

6.2 - Civil Engineering Project on sink-hole "C".

On sink-hole "C", a funnel-shaped structure of reinforced concrete will be built mainly to support the pumping station planned by the Government. This Project is under study and the major part of the plans is already finished.

The Lebanese governement is very hopeful that in the next few years, an eventual exploitation of the Chekka waters, would induce in the area an industrialization movement to which tremendous amounts of fresh water could be supplied thus solving one of the main problems of modern industries, always in need of bigger amounts of water.

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MAP I

HYDROGEOLOGICAL MAP
OF THE RECHARGE AREA OF THE SUBMARINE SPRINGS OF CHEKKA

1/2

SCALE : 1/50 000

Geology after L. DUBERTRET
Hydrogeology by R. KAREH

LEGEND

GEOLOGY :

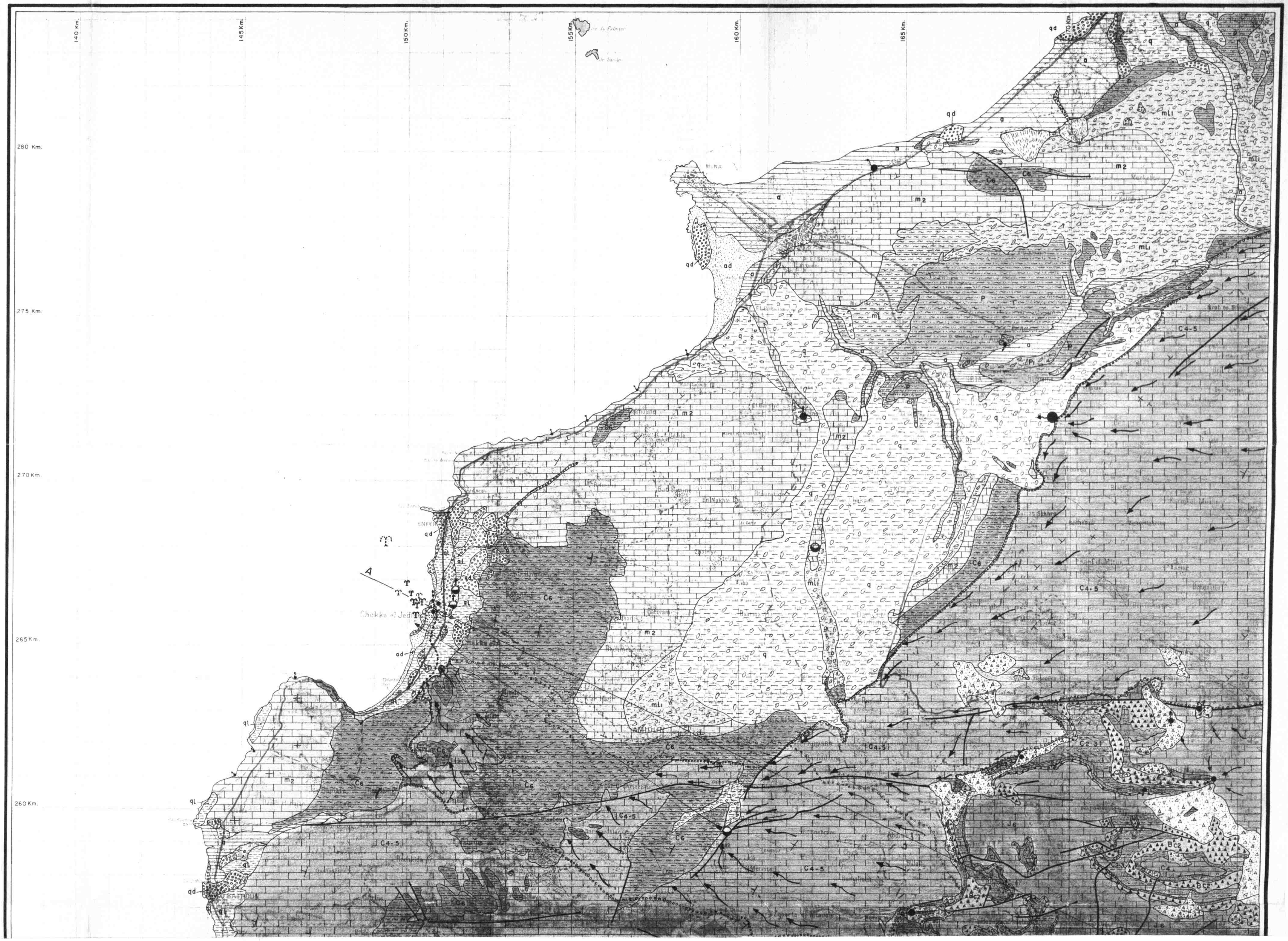
- Talus
- a — Recent alluvial deposits
- Dejection cones
- q — Fluvial conglomerates
- ad. — Sand dunes
- qd — Quaternary sandstones
- ql — Red soils
- P — Pliocene sandy marls
- P1 — Pliocene conglomerates
- mli — Miocene conglomerates
- ml — Miocene lacustrian marls
- m2 — Miocene limestones
- C6 — Senonian white marls.
- C4-C5 — Cenomano-Turonian limestones karstified.
- C2-C3 — Albian-Aptian sandstones, marls, clays and marly limestones.
- Bc2 — Albian basalts, Albian and Aptian
- C1 — Lower cretaceous sandstones
- Bj6 — Jurassic basalts.
- J6 — Jurassic limestones, karstified
- Geological contour
- Fault
- Strike and dip
- Horizontal beds
- Vertical beds

HYDROLOGY :

- Limit of catchment area
- Limit of hydrogeological basin
- Direction of flow of surface waters
- A–B Hydrogeological section

WATER POINTS :

- Permanent karstic spring dry-season yield: 500 ℓ/sec.
- Permanent karstic spring dry-season yield: 100 to 500 ℓ/sec.
- Permanent karstic spring dry-season yield: 50 to 100 ℓ/sec.
- Permanent karstic spring dry season yield: 10 to 50 ℓ/sec.
- Permanent karstic spring dry-season yield: 0 to 10 ℓ/sec.
- Sink hole
- Intermittent submarine spring
- Permanent submarine spring
- Intermittent spring [illegible]



- Miocene lacustrian marls
- Miocene limestones
- Senonian white marls.
- Cenomano – Turonian limestones karstified.
- Albian - Aptian sandstones, marls, clays and marly limestones
- Albian basalts, Albian and Aptian
- Lower cretaceous sandstones
- Jurassic basalts
- Jurassic limestones, karstified
- Geological contour
- Fault
- Strike and dip
- Horizontal beds
- Vertical beds

HYDROLOGY:

- Limit of catchment area
- Limit of hydrogeological basin
- Direction of flow of surface waters
- Hydrogeological section

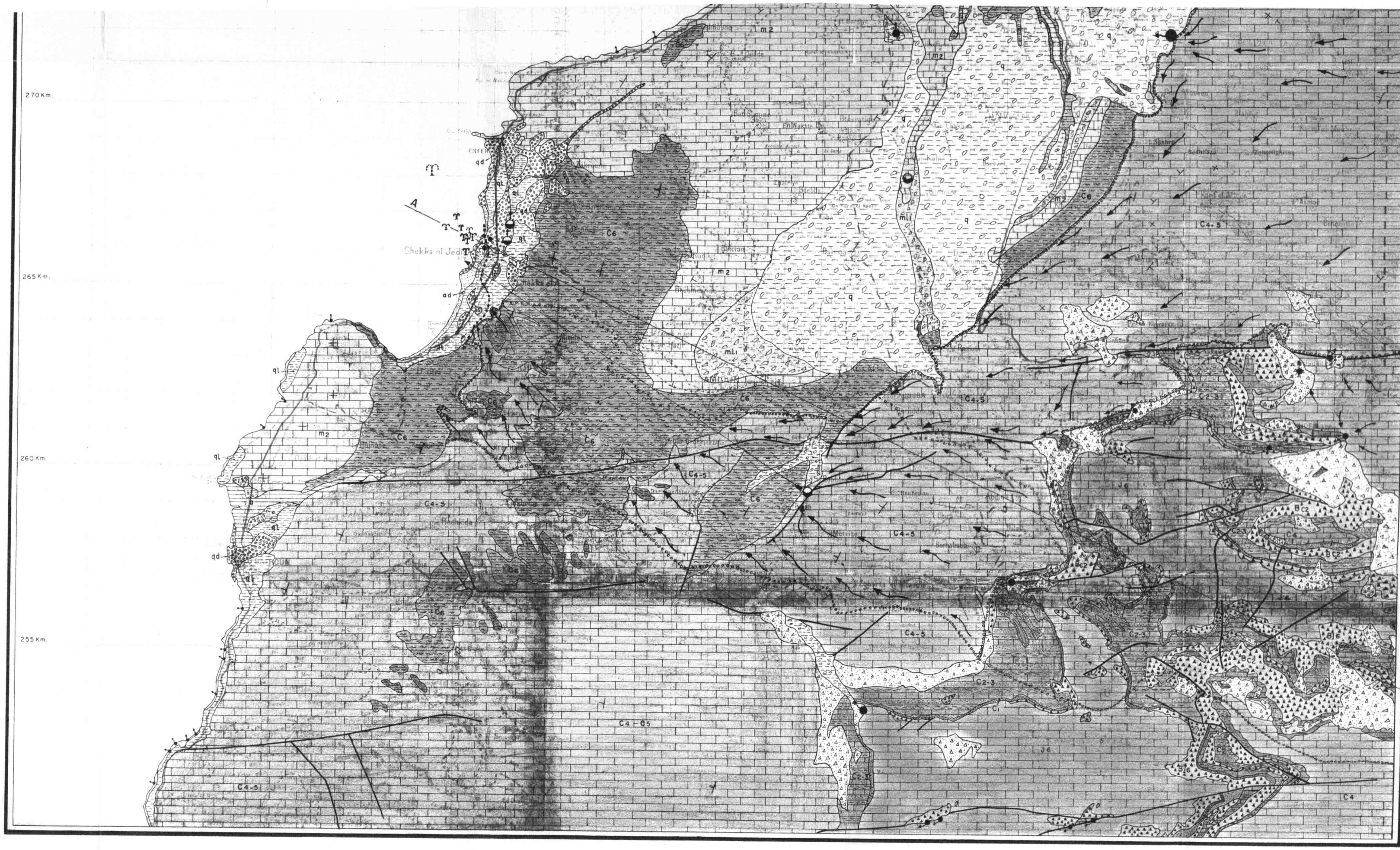
WATER POINTS:

- Permanent karstic spring dry-season yield: 500 ℓ/sec.
- Permanent karstic spring dry-season yield: 100 to 500 ℓ/sec
- Permanent karstic spring dry-season yield: 50 to 100 ℓ/sec.
- Permanent karstic spring dry season yield: 10 to 50 ℓ/sec.
- Permanent karstic spring dry-season yield: 0 to 10 ℓ/sec.
- Sink hole
- Intermittent submarine spring
- Permanent submarine spring
- Intermittent spring (Sink holes "C" and "B" of Chekka
- Wells penetrating the Turonian

UNDERGROUND WATER:

- Direction of flow of underground waters
- Supposed communication between Bziza sink-hole and submarine springs of Chekka
- Salt water intrusion in Cenomanian aquifer of Chekka at the end of the dry season and at sea level

2/2



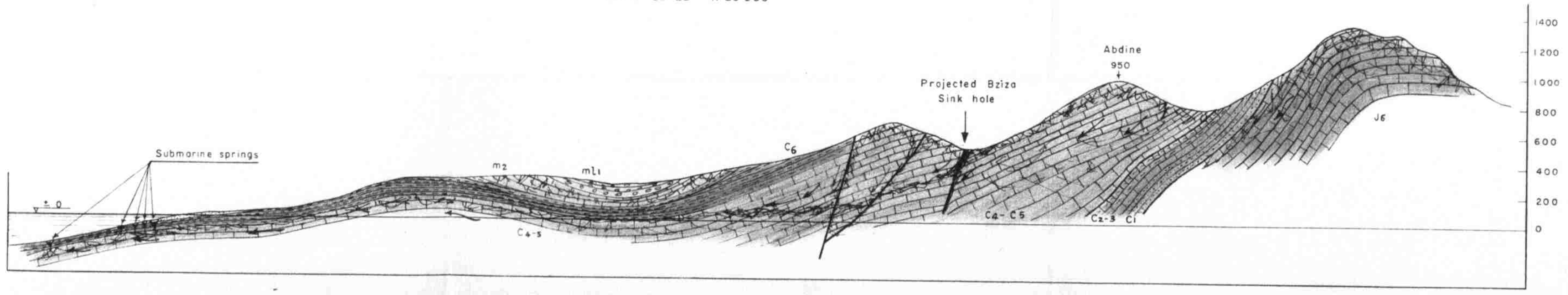
MAP I

LEGEND
OF HYDROLOGICAL SECTION

- Red soils
- Quaternary
- Miocene conglomerates
- Miocene limestone karstified
- Senonian with marls
- Cenomano - Turonian limestone karstified
- Albian - Aptian sandstones, marl, clays and marly limestones
- Lower cretaceous sandstones
- Jurassic limestones karstified
- Fault
- Direction of flow of underground waters
- Submarine spring

HYDROGEOLOGICAL SECTION A - B

HORIZ. SCALE 1/50 000
VERT. SCALE 1/20 000



MAP 2

1/2

RÉPUBLIQUE LIBANAISE
MINISTÈRE DES TRAVAUX PUBLICS

CARTE GÉOLOGIQUE DU LIBAN

dressée par

M. Louis DUBERTRET, Ingénieur civil des Mines,
Docteur-Ingénieur, Docteur ès-Sciences

1955

Stratigraphie établie par :
MM. L. DUBERTRET, A. KELLER et H. VAUTRIN

Contours géologiques d'après les Cartes géologiques dressées avec la collaboration de :
MM. A. KELLER et H. VAUTRIN (levés de reconnaissance au 200.000e).
A. BIREMBAUT (pour la feuille de Saïda).
F. HEYBROEK (pour la feuille de Djezzine).
J. CANAPLE, A. COMBAZ, A. HOSSIN, G. MANDERSCHEID (pour les feuilles de Tyr-Nabtiyé, Naqoura, Bennt Jbaïl).
G. RENOUARD (pour le Nord de l'Anti-Liban).

Fond de carte extrait de la Carte routière et touristique du Liban, avec autorisation de la Société d'Encouragement au Tourisme à Beyrouth (Liban)

Signes conventionnels

- Contour géologique
- Faille apparente
- Faille cachée
- Axes anticlinaux
- Direction et pendage
- Couches horizontales
- Couches verticales
- Axes synclinaux

Terrains figurés

ROCHES ÉRUPTIVES

Basaltes

- Basaltes du Jurassique terminal et du Crétacé inférieur
- Basaltes miocènes, pliocènes et quaternaires
- Coulées basaltiques subactuelles
- Cônes de scorie
- Cinérites

SÉDIMENTS

Secondaire

Jurassique

- j1 marnes vertes et dolomies noires LIAS (?)
- j2-3 dolomies noires (j2) et calcaires ocres (j3) BAJOCIEN
- j4-7 calcaires massifs gris-clair (j4) BATHONIEN-CALLOVIEN et Jurassique terminal détritique ou récifal (j5-7) OXFORDIEN-PORTLANDIEN

Crétacé

- c1 grès de base
- c2 alternances de terrains argilo-sableux et de bancs calcaires APTIEN
- c3 alternances de marnes vertes et de bancs calcaires ALBIEN
- c4-5 calcaires régulièrement lités, clairs CÉNOMANIEN-TURONIEN
- c5 calcaires et marno-calcaires à lits de silex TURONIEN
- c6 marnes et marno-calcaires blancs SÉNONIEN et BASE de l'ÉOCÈNE

Tertiaire

Nummulitique

- e marnes blanches et calcaires sub-récifaux EOCÈNE (e1-3) - OLIGOCÈNE (e4)

Néogène

Faciès marin

- m2 conglomérats marneux et calcaires récifaux MIOCÈNE (Vindobonien)
- p argiles bleues, marnes sableuses et calcaires PLIOCÈNE (Plaisancien)

Faciès continental

- nl marnes et marno-calcaires lacustres MIOCÈNE (nl) et PLIOCÈNE (pl)
- ncg poudingues grossiers torrentiels MIOCÈNE et PLIOCÈNE

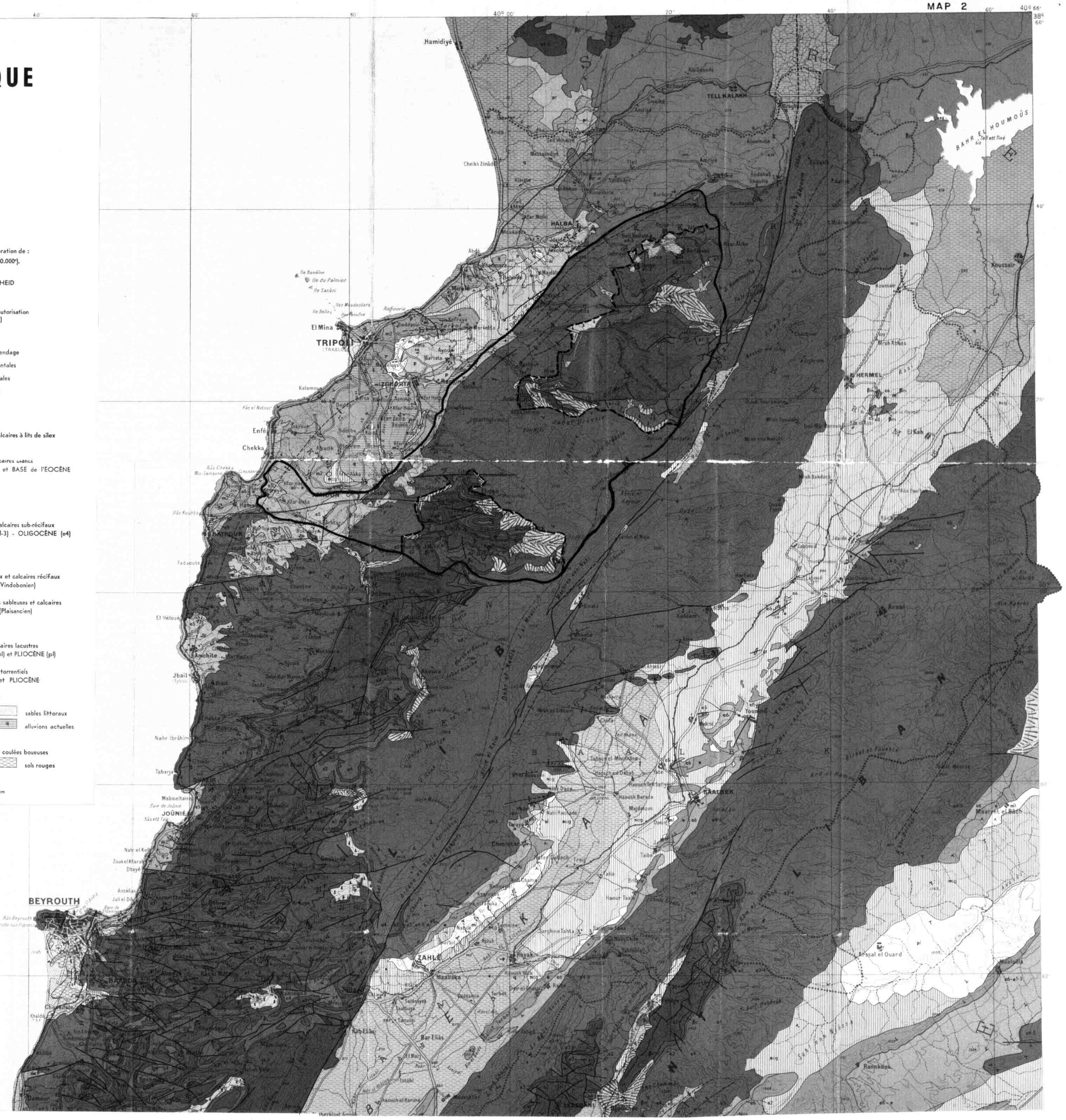
Quaternaire

- grès littoraux
- sables littoraux
- alluvions anciennes
- alluvions actuelles
- décollements
- cailloutis de pentes et coulées boueuses
- terres arables
- sols rouges

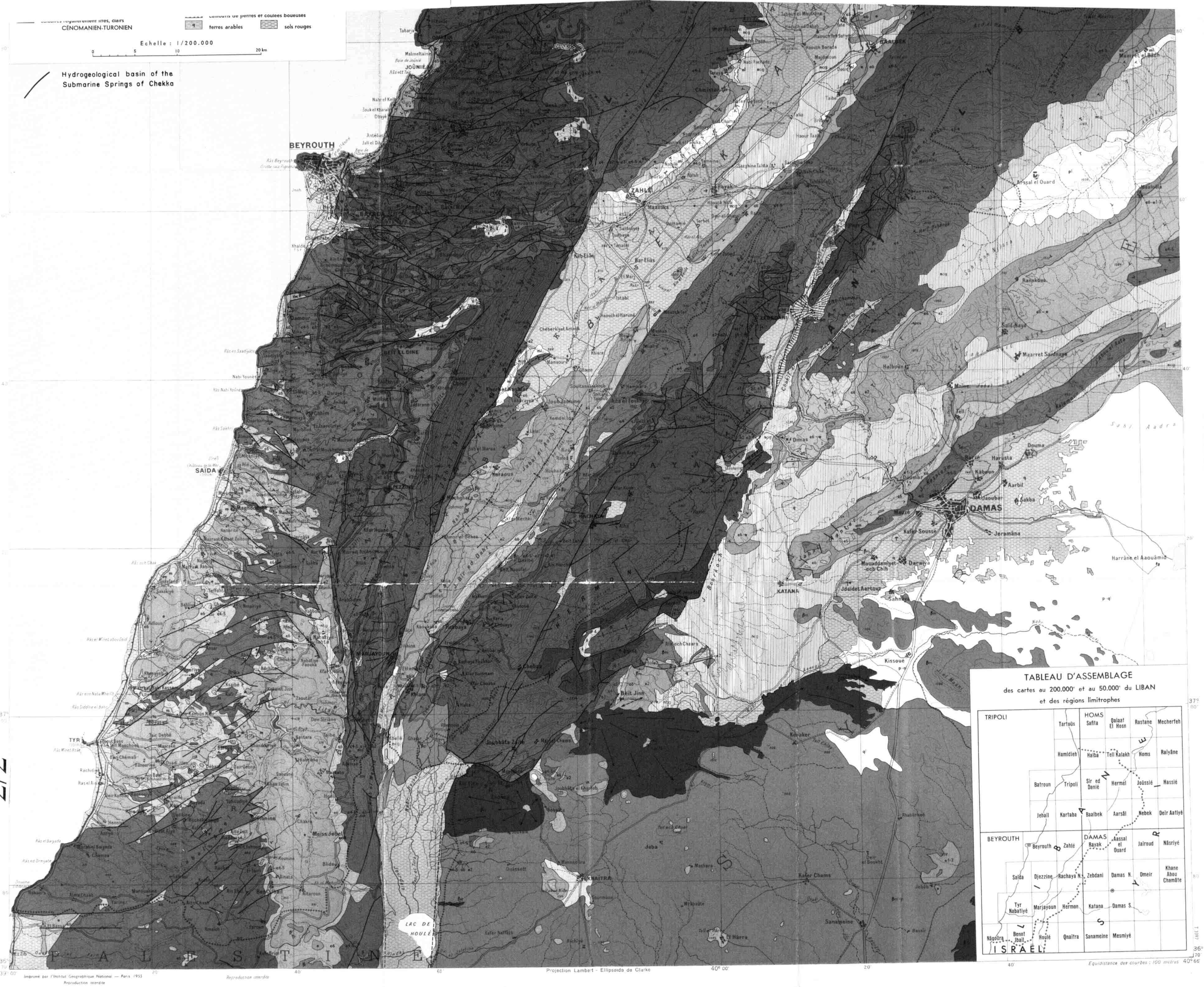
Echelle : 1/200.000

0 5 10 20 km

Hydrogeological basin of the Submarine Springs of Chekka



2/2


CÉNOMANIEN-TURONIEN
terres arables
sols rouges
Echelle : 1/200.000
Hydrogeological basin of the Submarine Springs of Chekka
BEYROUTH
ZAHLÉ
SAIDA
TYR
DAMAS
PALESTINE
TABLEAU D'ASSEMBLAGE
des cartes au 200.000e et au 50.000e du LIBAN
et des régions limitrophes
ISRAËL
Projection Lambert - Ellipsoïde de Clarke

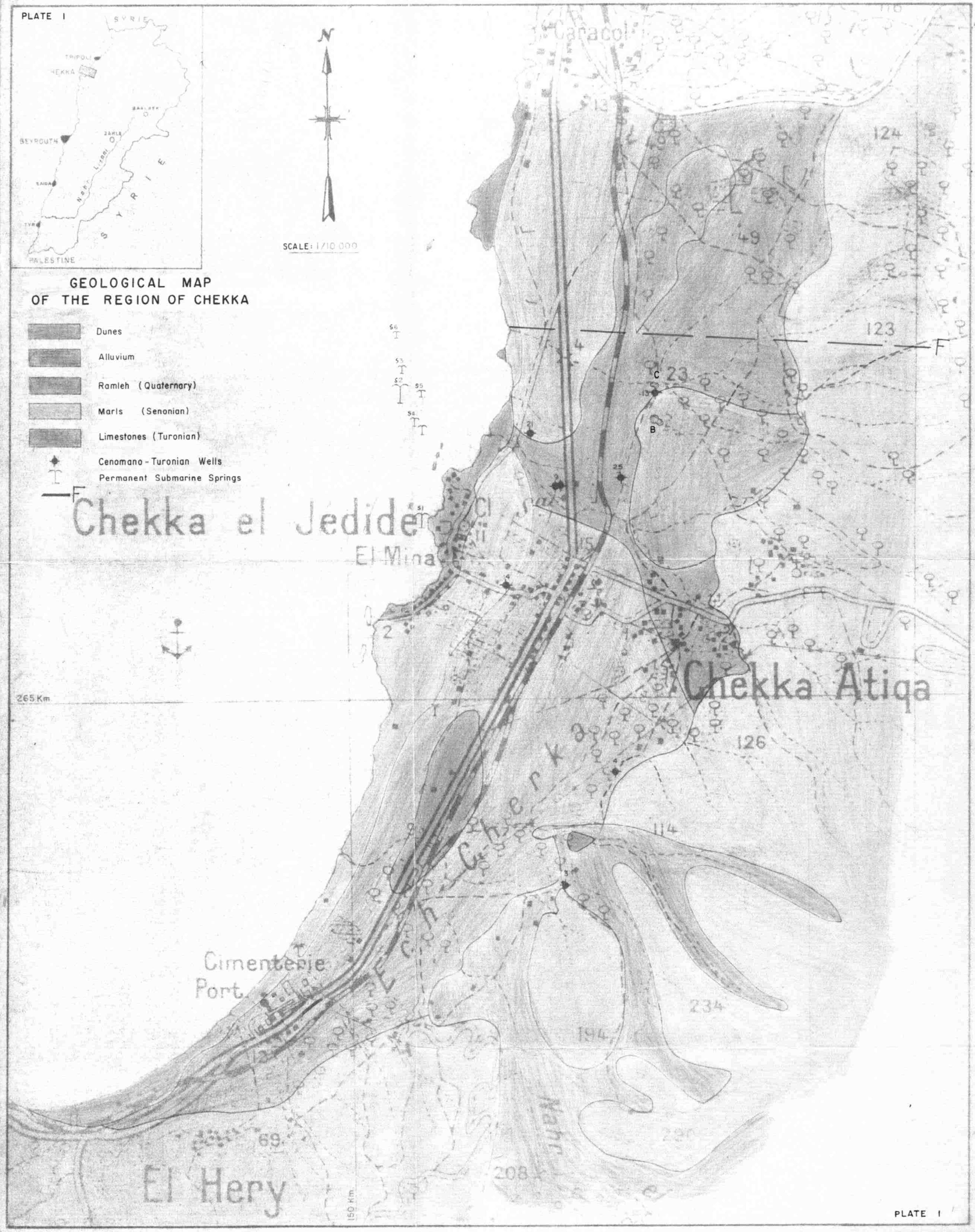


PLATE I
SYRIE
TRIPOLI
CHEKKA
BAALBEK
BEYROUTH
ZAHLE
Nahr Litani
SAIDA
TYR
SYRIE
PALESTINE
N
SCALE: 1/10.000
GEOLOGICAL MAP
OF THE REGION OF CHEKKA
Dunes
Alluvium
Ramleh (Quaternary)
Marls (Senonian)
Limestones (Turonian)
Cenomano - Turonian Wells
Permanent Submarine Springs
F
Caracol
124
123
49
23
C
B
F
Chekka el Jedide
El Mina
Chekka Atiqa
126
114
265 Km
Cimenterie
Port
234
194
Nahr
290
69
208
El Hery
150 Km
PLATE I

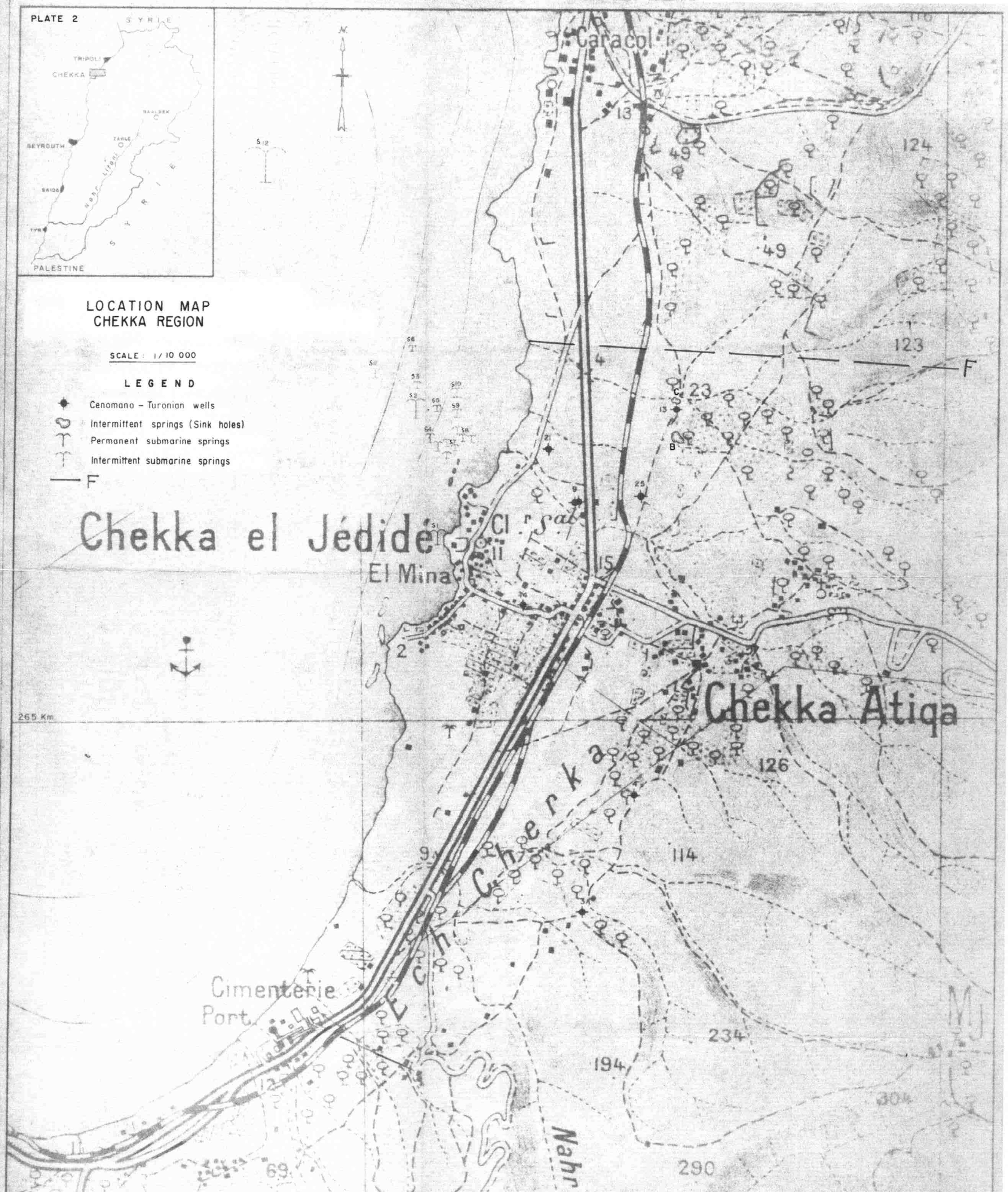
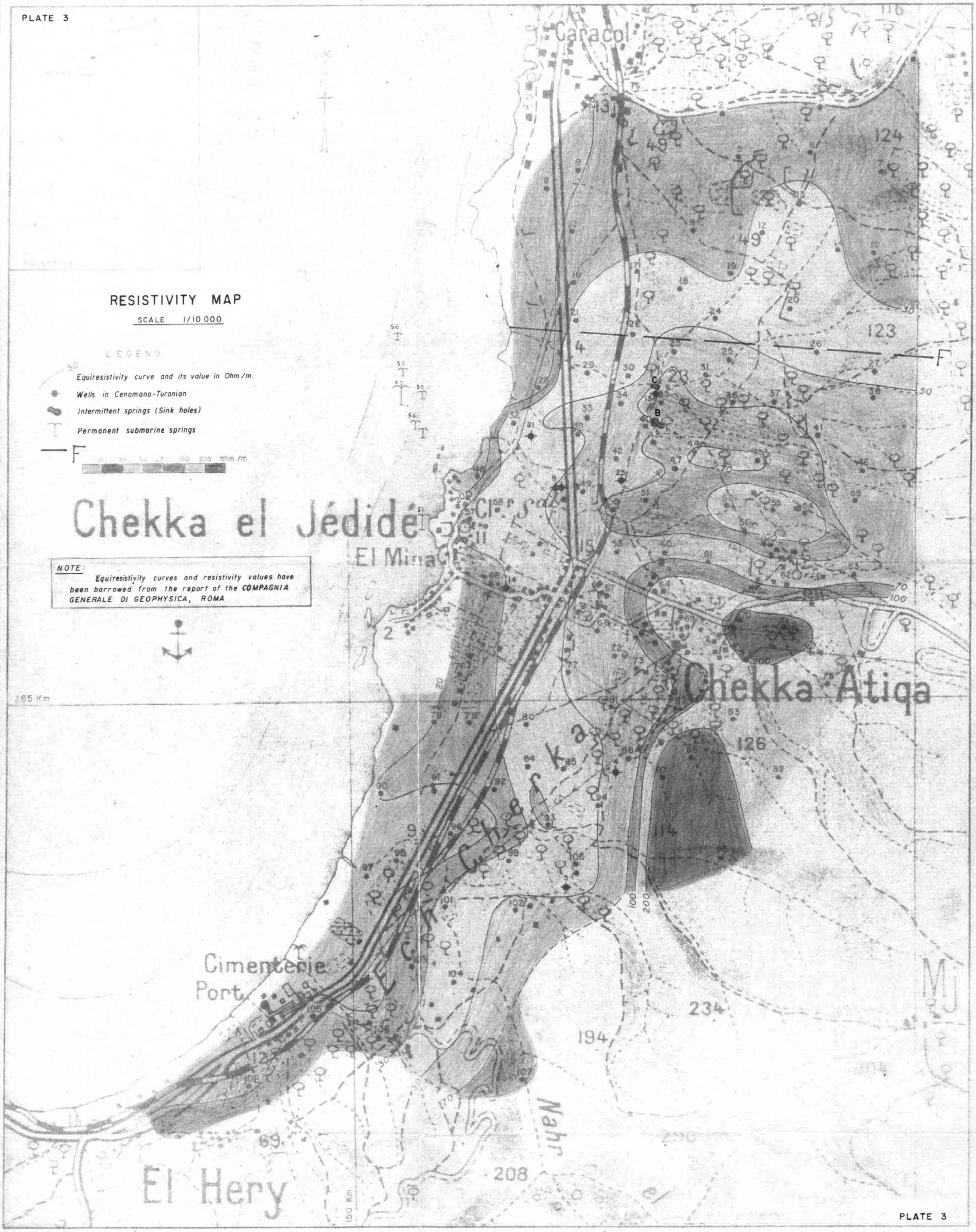


PLATE 2
SYRIE
TRIPOLI
CHEKKA
BAALBEK
ZAHLE
BEYROUTH
SAIDA
TYR
PALESTINE
Nahr Litani
LOCATION MAP
CHEKKA REGION
SCALE: 1/10 000
LEGEND
Cenomano - Turonian wells
Intermittent springs (Sink holes)
Permanent submarine springs
Intermittent submarine springs
F
N.
Caracol
Chekka el Jédidé
El Mina
Chekka Atiqa
Cimenterie
Port
El Hery
Nahr el
265 Km
150 Km
PLATE 2


RESISTIVITY MAP
SCALE 1/10 000
LEGEND
Equiresistivity curve and its value in Ohm/m.
Wells in Cenomano-Turonian
Intermittent springs (Sink holes)
Permanent submarine springs
F
Ohm/m.
NOTE: Equiresistivity curves and resistivity values have been borrowed from the report of the COMPAGNIA GENERALE DI GEOPHYSICA, ROMA
Chekka el Jédidé
El Mina
Chekka Atiqa
Caracol
Cimenterie
Port
El Hery
Nahr
65 Km
150 Km
124
123
126
114
234
194
208
49
4
15
2

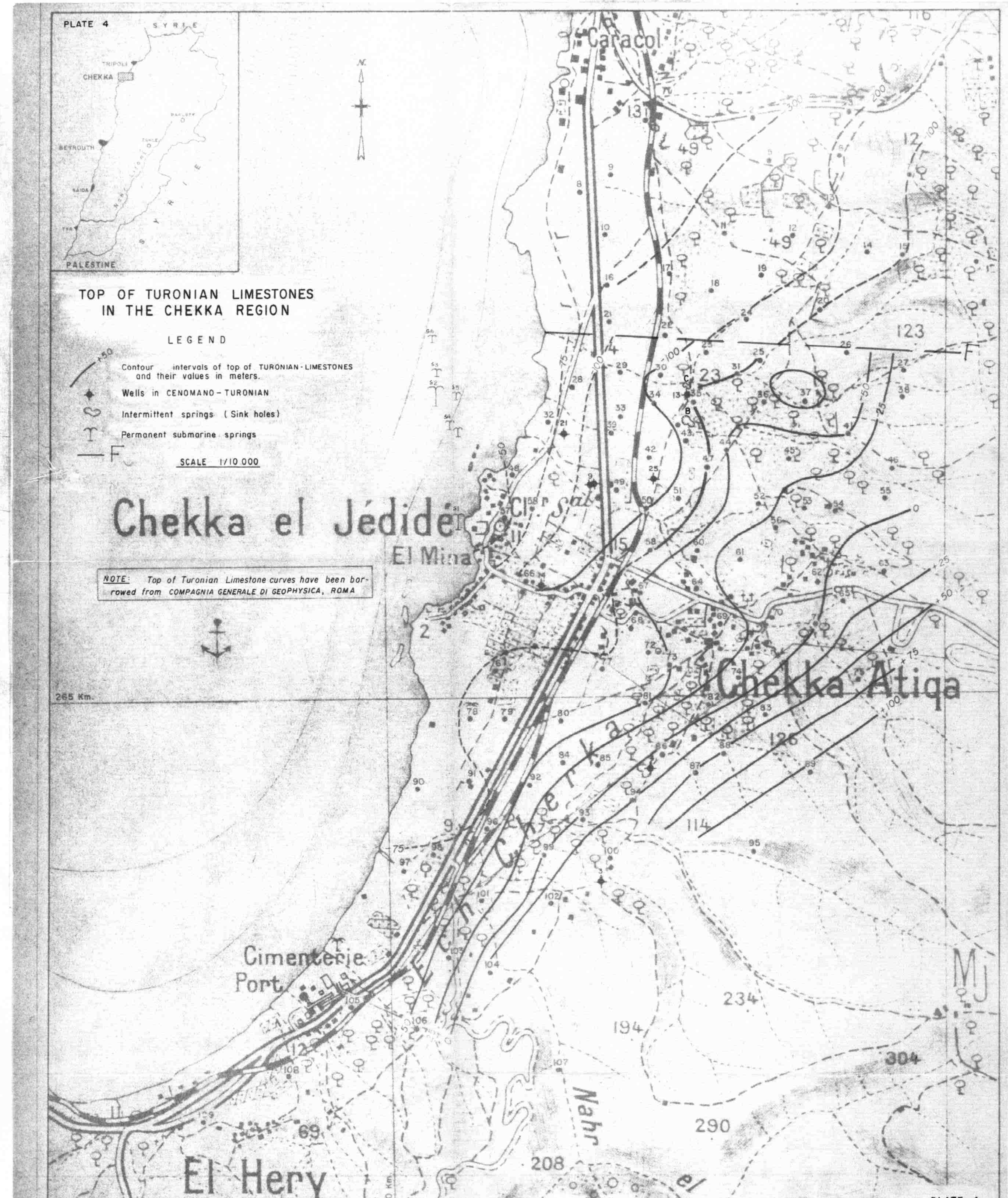


PLATE 4
SYRIE
TRIPOLI
CHEKKA
BAALBEK
BEYROUTH
ZAHLE
SAIDA
TYR
SYRIE
PALESTINE
N.
TOP OF TURONIAN LIMESTONES
IN THE CHEKKA REGION
LEGEND
Contour intervals of top of TURONIAN-LIMESTONES and their values in meters.
Wells in CENOMANO-TURONIAN
Intermittent springs (Sink holes)
Permanent submarine springs
F
SCALE 1/10 000
Caracol
Chekka el Jédidé
El Mina
NOTE: Top of Turonian Limestone curves have been borrowed from COMPAGNIA GENERALE DI GEOPHYSICA, ROMA
265 Km.
Chekka Atiqa
Cimenterie
Port
El Hery
Nahr el
150 Km.
PLATE 4