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Irrigation as a soil and relief-forming factor in the Lower Mesopotamian Plain

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Summary

The foundation of the present physiography of the Lower Mesopotamian Plain is formed by the levee-basin pattern of the meandering twin-rivers Euphrates and Tigris. Owing to the deposition of soil sediment by irrigation water the original physiography of the Plain has undergone a change. The present physiography in which, to a certain extent, the original geomorphological pattern still finds reflection, is dealt with in paragraph 2.

In order to understand the important influence of irrigation on soil and relief conditions in the Plain to its widest extent, the historical background of irrigation has been discussed in paragraph 3.

Thus the gradual development of the successive irrigation systems — seen in the light of the civilization of the time — has been strongly stressed in order that might be reflected more into detail on the part irrigation systems play as a relief and soil-forming factor (paragraph 4).

1. Introduction

Being one of the most extensive river-plains in the world the Lower Mesopotamian Plain occupies an area of approximately 600 × 200 km in the central and southern part of the Republic of Iraq. Built up from soil sediments by the twin-rivers Euphrates and Tigris during the quaternary period it consists of alluvial soils which are too young to show profile development. The Mesopotamian soils are characterized, however, by their stratification and their great diversity in physico-chemical properties over rather short horizontal and vertical distances.

Although of a rather flat topography the Plain shows an important mezo-relief which relates to the deposition system of both the meandering Twin-Rivers and the centuries long irrigation. The variations in soil-physical and soil-chemical properties may be often related with differences occurring in this relief.

The alluvial Plain comprising approximately two thirds of the arable land of Iraq, is threaded with ancient and recent meanders of the Twin-Rivers and criss-crossed by numerous irrigation canals partly of great age and fallen into disuse.

In order to understand the intricate soil pattern and the great diversity in soil conditions, the complex of interacting factors which is active in soil formation and in relief evolution has to be ravelled. These factors are:

a. Free river action,
b. Irrigation practices.

Free river action, as anywhere in the world, has caused the formation of a river-plain with levees and basins threaded with meanders. Irrigation practices in the present and past are responsible for the steady evolution of the relief. They have caused a gradual change in the original physiography of the Plain. Their influence on both soil formation and soil conditions may be perceived best by a soil classification which is based on the actual physiography of the Plain.

2. Brief physiographical description of the Lower Mesopotamian Plain

The Lower Mesopotamian Plain forms part of an extensive geosyncline which has been filled up to considerable depth with marine and fluviatile sediment.

The marine (shelf) sediments are of mesozoic and cenozoic age. They form the deeper strata of the Plain and consist mainly of lime-stone, shale and gypsum deposits. For the greater part these shelf sediments have been covered by fluviatile deposits from the Twin-Rivers during the Pleistocene. This sedimentation process is still continuing at the present time. Only the coastal region which forms the southernmost part of the Mesopotamian Plain is covered by marine sediment.

The Plain is bordered by a higher-lying desert in the west and by an alluvial fan region in the east. The latter consists of material eroded from the Iranian hills and mountains (BURINGH, 1960).

Half-way in Iraq both Euphrates and Tigris flow through narrow valleys 3—10 km in width, which are flanked on either side by terraces lying 10—20 m higher. Since these terraces have never been inundated by floods after their formation, they have developped into deserts. During Abbasid and probably already in Sassanian times the lowest Tigris terrace was converted into arable land by means of the Nahrwan irrigation system which received water from the Adhaim river (BURINGH, 1960). Many "tells" (mound shaped remnants of ancient settlements) are found here.

The small valleys of the Euphrates and Tigris rivers start at places where a rather abrupt decrease in the slope gradient of the river beds occurs, viz. at Hit and near Samarrah respectively. Initially separated and of modest width the valleys gradually widen and join whilst showing the unmistakable features of the meandering river landscape. After this junction the river-plain fans out broadly as far as the Persian Gulf approximately 650 km to the south.

As a result of the at least 6000 year-old irrigation practices the characteristic levee-basin pattern which accompanies the meandering rivers has been superimposed on by another sedimentation pattern which has made the original relief features fade to a certain extent and replaced them by a good deal of the relief elements we know to day. Striking relief elements in the present landscape are the huge silt ridges which border ancient irrigation canals ("arqub", see page 188).

Differences in landscape relating to a rather abrupt decrease in slope gradient of the Euphrates and Tigris riverbeds at Latifiyah and Kut respectively, justify a sub-division of the river-plain. In comparison with the flood-plain (north of the villages mentioned above) the southernly situated delta-plain shows more silted, ancient river courses and branches. This has to be attributed to the presence of smaller and lower levees which are only slightly higher than the adjacent basins. Moreover the basins in the delta-plain are less extensive and in many cases submerged or marshy as compared with the flood-plain whilst the ground water too is found at a higher level (BURINGH, 1957, 1958, 1960; SCHILSTRA, 1959).

The delta-plain changes into a highly marshy region towards the south near Nassiriyah and Amarrah. The rivers split up in many branches which dwindle continuously while proceeding southward. A few main streams reach the southern border of the marsh region only (SCHILSTRA, 1959). Levees are small and low here giving flood-waters an easy chance to inundate. Ancient, silted riverbeds are rare and mainly to be found in the Euphrates marshland.

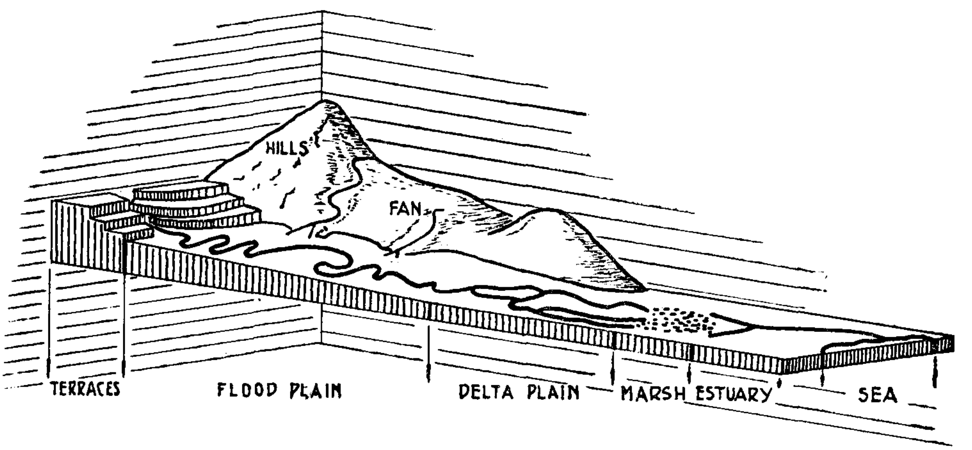
The marshlands are difficult of access and serve as a refuge for tribes wishing to avoid contact with the civilized world (BEEK, 1960). Most of the river water is lost in the marsh land (VAUMAS, 1955). Although sedimentation takes place continuously yet a complete silting up of the marsh land does not occur which points to subsidization of the Plain. Nevertheless the marsh land has been converted into suitable land for rice cultivation at its northern fringes.

For the greater part deprived of their sedimentation load and water the Twin-Rivers are confluent at Quarnah whereafter they flow as Shatt al Arab to the Persian Gulf. River levees have been weakly developped. An intricate creek system branches off from the main river and extends into the tidal mud flats which lie about 1 metre above sea-level. The tidal action of the sea is observable in the Shatt al Arab as far as Quarnah. The river water is fresh save near the river bottom where it is brackish (BURINGH, 1960). Nearly all soils of the Lower Mesopotamian Plain are saline or saline-alkali (DELVER, 1962).

Aeolian soil material blown out of the adjacent Al Jezirah, Northern and Southern Deserts is found locally in the Plain, often accumulated in the form of sand dunes (mostly barkhans) but also mixed with fluviatile deposits. In some areas river sediment has been subject to wind erosion and new aeolian deposits have been formed. Sometimes these deposits appear in the form of barkhan dunes consisting of clayey soil material of sand grain size (pseudo-sand; see BURINGH and EDELMAN, 1955).

The geographical distribution of the physiographic units mentioned above within the Lower Mesopotamian Plain is shown in FIG. 1.

FIG. 1. Block diagram of the physiographic units of the Lower Mesopotamian Plain (after BURINGH, 1960)



3. Historical backgrounds of irrigation

For a period of approximately 6000 years the successive civilizations of Mesopotamia founded their existence on irrigated agriculture. It goes without saying that

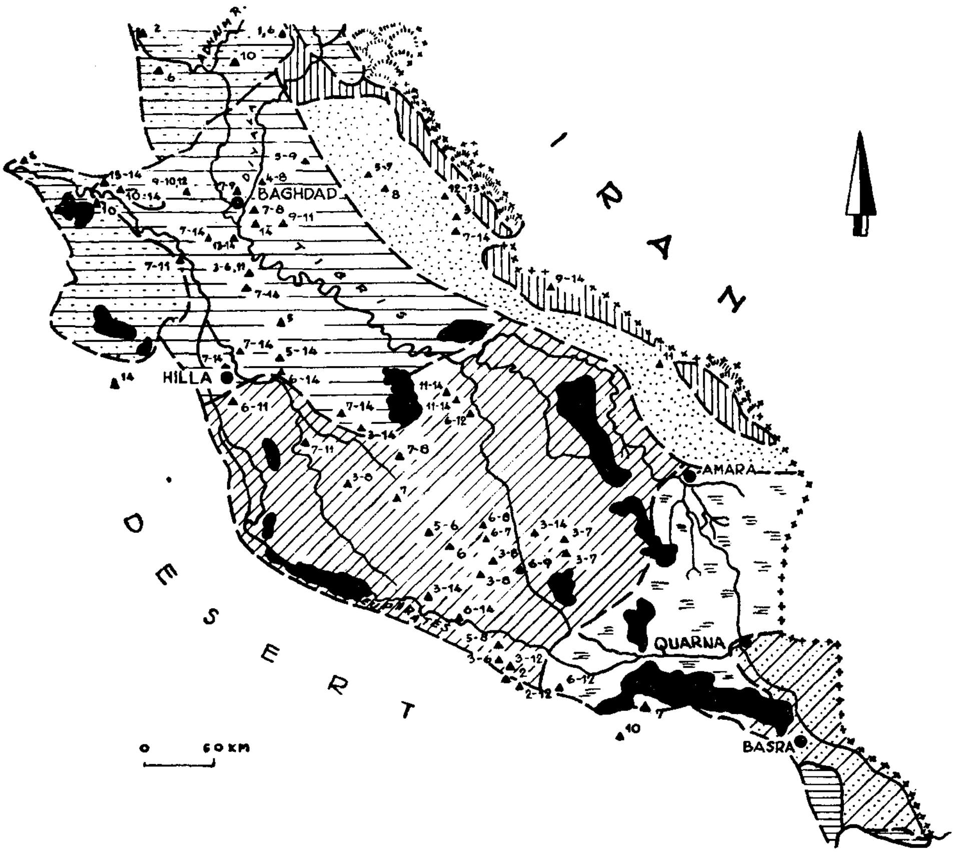
irrigation of even primitively cultivated land has to meet special requirements which presuppose a good deal of agricultural experience. It will be evident that the Lower Mesopotamian Plain with its hot and arid climate and its regularly occurring, disastrous floods was not considered as ideal for rural settlement by pre-historic men.
As revealed by recent archeological discoveries the earliest practice of land-use was applied in Northern Iraq since living conditions were far more favourable there (BEEK, 1955, 1960). In this area the most radical revolution in the history of mankind took place, viz. the change from man as food gatherer to man as food producer (BURINGH, 1960). Thanks to discoveries at Jarmo and Karim Sjachir the period this change took place in could be dated back as far as 6000 B.C. (BEEK, 1960).
This revolution was possible owing to the favourable combination of climatic and pedological conditions prevailing in the northern part of Mesopotamia. Several ancient sites in Northern Iraq indicate pre-historical settlement of a rural population. Irrigation dates back already to these pre-historic times when small earth dams were built in mountain streams to divert water to adjacent grazing land (BURINGH, 1960). The ancient settlements of Hassuna and Samarrah go back to 5200—5000 B.C. (BEEK, 1960). Especially the habitation of the Samarrah area shows very interesting aspects.
In order to be protected against Tigris-floods the Samarrah settlers choose as dwelling place one of the high-lying river terraces. The climatic conditions being considerably worse than in the more northern situated areas, rain-fed agriculture appeared to be impossible. Lacking skill and means to bring the indespensable water to the terrace the small strips of valley-bottom soils on either side of the Tigris were cultivated. Here the regularly occurring floods during the spring effected soil moistening.
The settlement of a rural community in an area with such unfavourable climatic and topographical conditions must have had a very special reason which might be explained as follows. Food production in pre-historic times was attuned completely to taking advantage of the most favourable environmental conditions. The way of land-use resulting from this attitude reflects very clearly the lack of technical capabilities of pre-historic men. The required acreage of land to serve food production must have been excessively large per capitum since great parts of the country did not meet the extravagant demands of the settlers. Consequently the agricultural production could not keep pace with the gradual increase in population. A regular migration in southerly direction has been the result. Migration tended to concentrate on the terrace land at the entrance of the Lower Mesopotamian Plain but also on the estuary region in its southermost part.
The oldest information on habitation of the estuary region may be dated back to 5000—4500 B.C. They refer to the ancient mound ("tell") of Eridu which appeared to contain material of a peasant-civilization which preceded the Sumerian one. The discoveries of Eridu appeared to represent the same culture as those of Tell Halaf in Syria (BEEK, 1960).
As to the terrace settlers of Samarrah they might be considered as advanced posts of the Northern Mesopotamian civilization stationed in the border area of the latter. Both their way of settlement and land-use point in this direction.
As for the settlers of the estuary region these broke off more spectacularly the ties with their country of origin. They left the topographically higher-lying areas and were obliged in joint and well organized efforts to make the fickle and often dangerous river water subservient to agriculture. Although approaching the cultivation of the soils of the Lower Mesopotamian Plain in a different way it is interesting to

observe that the beginning and the end of the Plain were put into use by settlers approximately simultaneously.
The question might be asked why the southernmost part of the Plain was preferred to the central part. The reason is definitely found in the presence of better physiographical conditions in the estuary region as compared with the central area, of course seen in the light of the agro-technical development of the time. Consequently agricultural development took place in the estuary region for approximately 2000 successive years. An initially slow penetration into the delta-plain took place however, during the Obeid and Uruk periods (4500—3200 B.C.).
About 3200 B.C. a general start was made with putting into use the soils of Central Mesopotamia. One reason for the trek to the delta-plain of the Twin-Rivers might be found in the general tendency of the estuary region to subside (LEES and FALCON, 1952), whilst the presence of nomadic tribes penetrating from the western deserts into the flood and delta-plain for finding grazing land, might be another.
First agricultural activities were restricted to the delta-plain only as diversion of the river water is relatively easy here compared with the more northerly lying flood-plain. The marshy region being inaccessible and unsuitable for the cultivation of wheat and barley was not taken into account. The hill shaped remnants of early-dynastic and Sumerian-Akkadian settlements are mainly found in the delta-plain.
The tendendcy to shift the civilization centres towards northerly direction — which entailed of course cultivation of the flood-plain — continued to follow during the successive civilizations. The reason for this might be found in an insufficient agricultural production to feed the growing population in the south, whilst also the political supremacy of the semitic tribes which starts around 2250 B.C. with Sargon of Akkad might play an important part.
According to information obtained from clay-tablets soil salinization caused a considerable decrease in yields whereas the cultivation of barley — the latter being more salt resistant — was extended at the cost of wheat. Mention is made of serious soil salinity at Lagasj (Tello) (BEEK, 1960). Migration from the delta towards the flood-plain did not prove to be the effective measure to escape from soil salinity; this was experienced again in the flood-plain during Babylonian times.
Another reason for partly abandoning the delta-plain was most probably the shifting of riverbeds by which cities were doomed to destruction as civil-technical abilities were not developped enough to prevent or undo this danger. Finally the subsidence of the delta-plain might have been of influence (BURINGH, 1960).
Since the successive irrigation techniques have been developped in physiographically different parts of the Lower Mesopotamian Plain important mutual differences in technical conception occur. Along with these the influence on soil formation, relief evolution and soil salinization varies.
FIGURE 2 shows the position of a number of the ancient centres of civilization within the Lower Mesopotamian Plain. The trend of Mesopotamian civilization to extend its influence and/or to shift its centres — entailing of course the need of irrigating and tilling physiographically different regions — from south to north, may be easily perceived.

4. Irrigation systems and their influence as a relief and soil-forming factor

With respect to effecting irrigation in the various parts of the Lower Mesopotamian Plain different systems may be distinguished. Always having been the life artery of

FIG. 2. Broad physiographic units and their principal ancient sites in the Lower Mesopotamian Plain (After BEEK, 1960, and BURINGH, 1957)



PHYSIOGRAPHIC UNITS

- River terraces
- Flood plain region
- Delta plain region
- Marsh region
- Estuary region
- Coastal plain
- Eastern alluvial border land
- Alluvial fan region
- Hills
- Desert
- ▲10 Ancient site

CIVILIZATION PERIODS

1.	Hassuna	5200—5000 B.C.
2.	Samarra, Halaf Eridu	5000—3800 B.C.
3.	Tell Obeid	4500—3800 B.C.
4.	Uruk	3800—3200 B.C.
5.	Djemdet Nasr	3200—3000 B.C.
6.	Early Dynastic	3000—2500 B.C.
7.	Sumer and Akkad	2500—2000 B.C.
8.	Old Babylonian	2000—1600 B.C.
9.	Kassite and Old Assyrian	1600— 911 B.C.
10.	Assyrian	911— 612 B.C.
11.	New Babylonian	625— 539 B.C.
12.	Persian	539— 331 B.C.
13.	Seleucidian	312— 248 B.C.
14.	Parthenian	248 B.C.—226 A.D.

Mesopotamian Civilization as such, each system has always reflected both the state of technical abilities and the degree of socio-political development of the period it was practised in. Imposing irrigation systems could only be brought about in periods during which populous communities were held together by a strong central government which favoured maintenance and new construction works.

The various irrigation techniques developped in the successive Mesopotamian civilization periods are discussed below. Special attention is paid to the pedological consequences they have had for the areas they have been practised in.

4.1. Irrigation of the valley-bottom soils between the river terraces

As discussed in paragraph 3 the cultivation of the soils of the Lower Mesopotamian Plain took place at the entrance of the Plain between the river terraces firstly. The considerable slope of the river at that place made effective, regulated irrigation of the valley-bottom soils impossible. Barrage building and lift-irrigation not yet belonging to the technical proficiences of the terrace dwellers they had to satisfy themselves with the inundation of the valley-bottom soils by the regularly occurring floods in spring.

It will be evident that this system of agriculture is accompanied by too many caprices for great communities to depend on. Their extent is determined by the intensity and periodicity of flooding, the water-holding capacity of the soils and the fluctuations of and the depth to the ground-water table. Inspired by handed over, ancestral experience — the latter being gained in the mountainous areas of Northern Mesopotamia — primitive water diverting constructions have been erected undoubtedly, but these have never had a permanent character since all progress into this direction has been hampered by the detrimental effect of floods.

Any special influence of the irrigation method pictured above on soil and relief formation — save for that general one of river sedimentation — has not been perceived.

4.2. Irrigation of the estuary region

The inhabitants of the estuary region have availed themselves of the tidal action of the sea in the irrigation of the scarcely sloping soils of this area. During flood-tide the rising river water is made to flow into the numerous ditches dug in the low levees bordering the river and the creeks branching off from it. At ebb-tide the water flows back again. Thus an easy irrigation and subsequent drainage is ensured.

Agriculture has always been practised on the low and therefore easily irrigable levees and on the silt ridges which flank the regularly cleaned out creeks of the mud flats. The latter have always been waste land. Even to day this type of irrigation is followed in the estuary region of Southern Iraq, serving the cultivation of date orchards.

The rise and fall of the river water is mostly perceived in the lower course of the river. As the forcing up influence of the flood-tide becomes less perceptible, i.e. more stream upward, the differences between high and low river levels become smaller. Accordingly, the risk of damage to crop and soil as a result of too vigorous an irrigation and runoff diminishes. It stands to reason that in this respect fruit-trees are more tolerant than small grain or other annual crops. The latter are therefore cultivated on the river-bank soils situated further upstream. At present, for instance,

the farmers of Etchabayah — a village as far away from the Persian Gulf as the northern border of the Hammar Lake — are making use of a difference in lake level of a few centimetres only to irrigate and drain their lands (BURINGH, 1960).
Most probably all the ancient cities the remnants of which have been discovered up till now in the southernmost part of the Lower Mesopotamian Plain, have known the latter type of irrigation.
Since the greater part of their silt load has been deposited already in the river-plain and the marshy region, the Twin-Rivers practically transported fine-sized soil particles only. Consequently the estuary soils do not show a very great textural variety. As to relief forming the flood-pushed irrigation as such has not had special consequences, save for promoting the artificial construction of ridges on either side of the creeks. Otherwise, the normal pattern of far from impressive levees along the main river and the creeks, and extensive low lying mud basins is found.

4.3. Wild irrigation in the river-plain

Abandoning of the estuary region seems to be caused by the general subsidence of that area (LEES and FALCON, 1952). The area considered to be most favourable for new settlement was the delta-plain. The general physiography of this plain was dealt with in paragraph 2. Let it be sufficient to mention here that the landscape of the delta-plain was reminiscent of the estuary region in so far that river levees are small and low, the river basins extensive whilst the often encountered braided stream pattern of flood gullies debouching into the river basins or haurs (marshes) resembled the estuary creek pattern.
The irrigation practice introduced in the delta-plain may be considered as a continuation of the method followed in the transitional zone between estuary and marsh land with this difference that the tidal action of the sea as irrigation and drainage-promoting medium was missing. Supply of irrigation water initially took place during river floods only by way of the existing flood gullies. Excess water could not flow back to the river but collected in the basin depressions and haurs.
The delta basins covering vast and scarcely sloping areas permitted flood waters to stretch out over large areas which therefore became unsuitable for agriculture. This was therefore practised on the higher-situated parts of the basins.
As soon as land emerged seed-beds were prepared. Fortunately a slight fall in water level in the basins caused a relatively large area to fall dry because of the slightly sloping land surface. Thus sowing could keep pace, so to speak, with the fall of the water level in the basins. Agriculture became dependent on the periodicity and extent of the floods, on the rate of emerging, on the water-holding capacity of the soils and on the depth to the ground-water table. Emerging of the basin land, however, took place at too slow a rate to provide enough moist land for an expanding population in the long run.
It is therefore understandable that the basins of the flood-plain were taken into consideration for extending the agricultural lands. As the flood-plain basins were larger they also showed a greater slope in the northsouth direction. This would serve a more readly discharge of flood water and a quicker availability of suitable agricultural land. Flood gullies being rare in the flood-plain because of the presence of higher and larger levees, the supply of irrigation water formed a problem to be tackled. The more detrimental effects of floods because of the higher gradient of the rivers was another.
Problems were solved by making gaps in the river levees at the smallest and lowest

spots (BURINGH, 1957). In doing so a number of meandering river branches threaded the basins, gradually building up their small, sandy to loamy levees on either side. It is evident that this type of basin-flow irrigation could be practised only during a certain part of the year when high water levels prevailed. Also the choice of field crops was limited since crop growth had to take place within the relatively short period that the basin soils remained moist.

Moreover the area suitable for cultivation remained limited too, as only the transitional zone between the higher parts of the basins and the basin depressions could be cultivated. Here the stream velocity of the water has decreased sufficiently for it to fan out over the land, whilst runoff and drainage towards the basin depressions is still possible. Since no actual control measures were taken as to storage of water and its diversion towards special regions this free basin-flow irrigation is referred to as "uncontrolled or wild irrigation". It is still practised in many parts of the world.

As time passed on the wild-irrigation streams became choked by river sediment. They were forced to shift their courses leaving behind a new physiographic element, viz. the wild-irrigation levees. In the lowest-lying parts of the basins the sedimentation load — already deprived of its coarser-sized material — has been deposited in a pattern which reflects the decreasing stream velocity of the spreading water. The success of uncontrolled irrigation depends on many factors which closely relate to topographical conditions. Therefore, this wild irrigation had a very restricted radius of action only. An area intensively irrigated in this way is found near Tuwarij in the Euphrates flood-plain (SCHILSTRA, 1959).

4.4. Controlled irrigation in the Lower Mesopotamian Plain

Along with the increase of population the need for extending the existant agricultural area was growing. The demand for more arable land led to the introduction of a new conception of irrigation which still holds good to day. Wild irrigation was replaced by canal or controlled irrigation. Bij digging canals it became possible to bring water to areas which were deprived of irrigation formerly because of their unfavourable topographical position. The desire to be independent of the water level in the rivers and of all vicissitudes which accompany wild irrigation, storage provisions and flow regulators had to be made by construction of initially primitive dams, sluices and water wheels ("naors"). Hence this irrigation system is referred to as "controlled".

Agricultural activities could be extended now to the higher situated parts of the basins and, later on, even to the levees. The formerly wild-irrigated regions around the basin depressions now formed the fringes of the cultivated area. As soon as controlled irrigation was widely practised a more or less rectangular net-work of criss-crossing canals intersected the entire river plain, dividing it into numerous, relatively small, artificial basins bounded by the banks of the canals.

Besides the intersected basin pattern the so-called fish-bone irrigation-canal pattern is also encountered (ENTE, 1959). This pattern is marked by the presence of one main irrigation canal with many laterals which branch off slantingly. It has been mainly found in the lowest-lying parts of the delta-plain between Euphrates and Tigris. According to ENTE (1959) the fish-bone lay-out represents a more recent technique than the intersected basin lay-out. Although not stating grounds for his opinion ENTE (1959) suggests that the former has served the irrigation of rice fields. If found correct, the fish-bone lay-out cannot be dated back further than the fifth century B.C. since the cultivation of rice has been introduced in the Lower Mesopotamian Plain in that time (GHIRSHMAN, 1954).

Most probably this lay-out has appeared to be less subject to choking up with sediment than the intersected basin lay-out. Since controlled-irrigation canals also tend to become choked with sediment, cleaning out was necessary. Thus huge ridges were formed on either side of the canals in the course of the years. In Arabic these silt-ridges are referred to as "arqub". If in spite of cleaning out the canals were silted up to such an extent as to become useless, re-digging generally parallel with the former ones had to take place. Intensively irrigated areas therefore always show a sequence of arqubs. Controlled irrigation was also practised in the delta-plain but remained somewhat more restricted to the highest parts of the river basins there.

As the canals ended and still end in marshes, the latter silt up gradually and thus, after the introduction of rice as a field crop in the fifth century B.C., were converted into suitable areas for the cultivation of this crop. Although differences occur between delta and flood-plain as to intensity and extent of irrigation, almost all original river-deposited soils have been covered by layers of irrigation sediment in depth varying from 0,5 to 5 metres or even more. In the Lower Diyalah delta-plain archaeological findings dating back as far as 3000 B.C. have been discovered in the deepest irrigation-sedimented strata at a depth of 7 metres below surface. These and other data permit the calculation of the mean annual increase in thickness of the irrigation-sedimented cover at 1½ mm.

Protracted controlled-irrigation has superimposed a secondary meso-relief on the original features of the Lower Mesopotamian Plain. In accordance with the principles which underlie sedimentation, controlled irrigation caused this meso-relief to consist of levees and basins. Irrigation levee soils of medium texture have been formed along the canals.

With increasing distance from them the irrigation deposits become finer-textured whilst wedging out in thickness. The lowest-lying parts of the irrigation basins thus formed, are called irrigation depressions. Since the irrigation basins forming part of the natural river-plain basins gradually became silted up, they might also be referred to as silted basins. FIGURE 3 shows the ancient courses of wild and controlled irrigation streams in the Euphrates flood-plain west and south of Hillah.

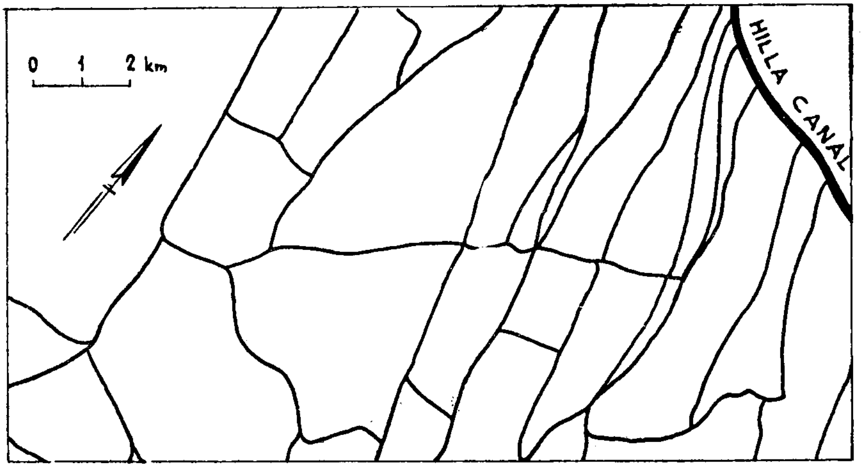
As compared with the pronounced textural varieties which mark the soils deposited by flood water in horizontal direction, the deposits which originate from controlled irrigation show more uniformity. The latter are more or less invariably characterized by their high silt content which mostly ranges from 40 to 60 percent.

The following factors cause sedimentation as a result of controlled irrigation to differ from the deposition system which underlies soil formation in the natural river-plain:

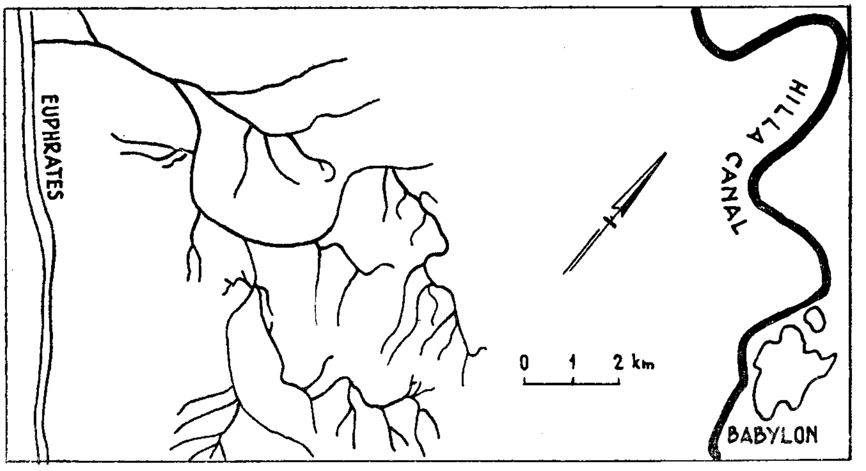
1. The constant, rather high stream velocity of irrigation water which only gives the coarser-sized soil particles a chance to settle on the canal bottoms. Consequently, a rather important part of the sedimentation load has been lost in the irrigation canals whilst the remainder has been relatively enriched with silt.
2. The abrupt inflow into relatively small irrigation basins. The silt load is forced to settle undifferentiated.

Depending on the size of the irrigation basins, their relief and slope as well as the composition of the sedimentation load, the factors mentioned above play a more or

FIG. 3. A: Former system of controlled canal irrigation
B : Ancient natural flow (wild) irrigation system
(After BURINGH, 1957)



A



B

less decisive part in the horizontal distribution of soil textural classes in the irrigated areas. Nearby construction of irrigation canals has strongly limited the formation of interjacent, fine-textured irrigation depressions.

From the above it will appear that the occurrence of fine-textured soils is limited mainly to the central part (irrigation depressions) of large irrigation basins and to the natural basin-depressions. The latter, being unsuitable for agriculture, have been silted up with the finest soil particles which remained suspended in the runoff water from adjacent irrigated fields. Consequently their original character (low-situated and heavy-textured) was not altered to any extent worth mentioning. A striking example

is the Aqarquf depression, an area of approx. 40.000 ha west of Bagdad (SCHILSTRA and ADTHARI, 1957). It stands to reason that the irrigation depressions considerablv outnumber the basin-depressions.
In vertical direction the irrigation-deposited soils show some special morphological features as compared with river-deposited soils

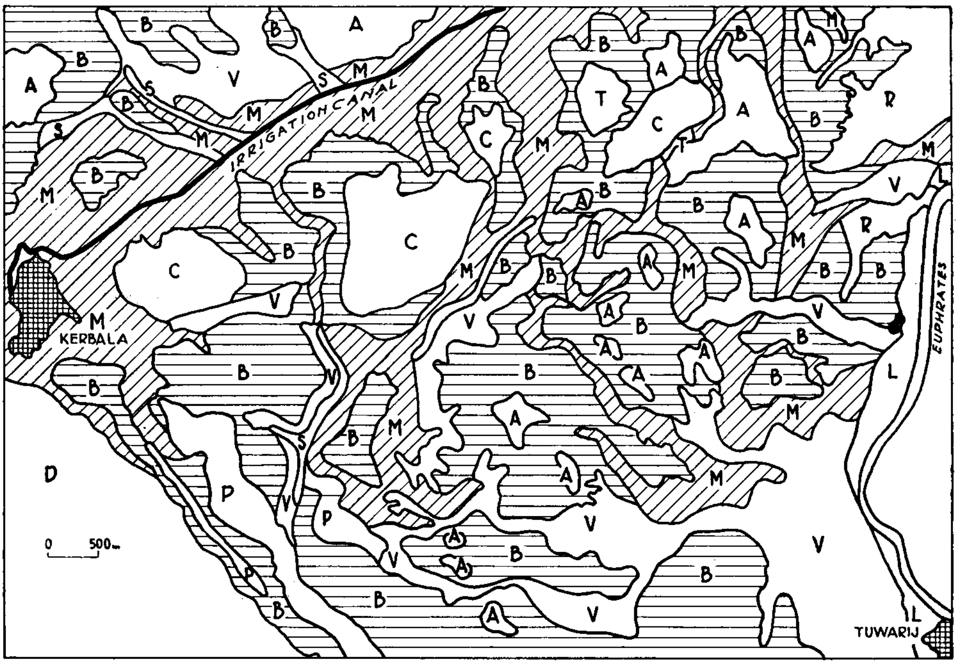
1. A stronger stratification,
2. More abrupt transitions between the deposited layers,
3. The relatively low clay content of the soil layers,
4. The high silt and often fine sand content of the soil layers.

Based on geomorphological differences which are inherent to both the formation of a river-plain by meandering rivers and the practice of irrigation, the Lower Mesopotamian Plain shows the following physiographic sub-units:

A. Relatively high-lying units, consisting of coarse to medium-textured soils
   1. Levees
      a. River-levees
         i. Flanking the Twin-Rivers and their branches.
         ii. Flanking ancient, silted up river courses and irrigation canals.
         iii. Meander belts.
      b. Irrigation-levees
      c. Silt ridges (arqub).
   2. Silted basins
      a. Slightly sloping transitional zone between irrigation-levees and irrigation-depressions.
B. Low-lying units, consisting of moderately fine to fine-textured soils
   1. (somewhat silted) River basin-depressions and haurs
   2. Silted basins
      a. Irrigation-depressions.

This geomorphological classification forms an excellent basis for the mapping of Mesopotamian soils. In FIG. 4 the distribution pattern of soil units is shown for the Euphrates delta-plain between Kerbala and Tuwarij (SCHILSTRA, 1959).
In close relation to the physiographic sub-units these soil units belong to, they show specific soil morphological and often also soil chemical characteristics as illustrated by the soil-sample analyses presented in the TABLE.
Besides its great influence on the morphological and physico-chemical characteristics of Mesopotamian soils, controlled-irrigation has also played an important part in soil salinization. As long as the basin-depressions of the natural river-plain functioned as flood- and irrigation-water collectors, only a relatively small part of the soils of Lower Mesopotamia remained permanently ponded, thanks to unhampered runoff. These permanently ponded parts of the Plain have always shown a high ground-water table due to the combined effect of regular feeding and lack of adequate drainage. Under the prevailing hot and arid conditions this ground water — moreover being saline in itself — has been the source of salinization of the upper soil layers owing to capillary rise and evaporation. The greater part of the Plain, however, must have shown ground-water levels which were deep enough below surface to prevent salinization to occur in the rooting zone of crops.
With the introduction of controlled irrigation the entire river-plain became inter-

FIG. 4. Simplified soil map of the Euphrates-delta plain between Kerbala and Tuwarij showing the distribution of soil units physiographically distinguishable



LEGEND

- L — River-levee soils
- V — Wild-irrigation levee soils
- M — Controlled-irrigation levee soils
- B — Silted basin soils
- A — Irrigation-depression soils
- C — Basin-depression soils (somewhat silted)
- P — Ancient river-course soils; meanderbelt soils
- R — River-crevasse soils
- S — Silt ridges (argub)
- T — Remnants of river terrace (highly gypsiferous)
- D — Desert soils
- ● — Ancient site

TABLE

Depth below surface (cm)	pH (H_2O)	ECe (mmhos/cm)	Textural analysis % S	% Si	% C	class	Gypsum %	Lime %	Sol. Na (me/100 g soil)	Exch. Na (me/100 g soil)
(a) Irrigation-levee soil, very deep phase (SCHILSTRA, 1960)										
0— 10 ..	8,2	1,3	13	67	20	SiL	< 0,3	27,3	0,5	0,6
10— 30 ..	7,9	1,2	14	53	33	SiCL	< 0,3	26,6	0,7	0,2
30— 70 ..	7,8	1,9	24	52	24	SiL	< 0,3	27,0	0,6	0,5
70— 90 ..	7,8	1,7	29	49	22	L	< 0,3	24,1	0,5	0,7
90—130 ..	7,8	2,1	34	48	18	L	< 0,3	23,8	0,4	0,6
130—150 ..	7,8	1,7	26	51	23	SiL	< 0,3	23,9	0,4	0,6
150—170 ..	7,9	1,7	51	34	15	SL	< 0,3	22,4	0,4	0,4
170—250 ..	7,8	1,4	17	61	22	SiL	< 0,3	25,6	0,3	0,5
(b) Basin-depression soil (SCHILSTRA and ADTHARI, 1957)										
0— 30 ..	7,5	43,0	2	45	53	SiC	0,4	24,9	11,3	3,7
30— 60 ..	7,8	15,3	1	37	62	C	< 0,3	24,2	6,4	4,5
60— 80 ..	7,9	17,3	1	39	60	C	< 0,3	24,2	7,6	4,4
80—100 ..	7,9	15,1	2	42	56	SiC	< 0,3	24,7	7,1	4,7
100—120 ..	7,9	18,1	1	39	60	C	< 0,3	24,1	9,5	5,3
120—140 ..	8,0	20,5	1	43	56	SiC	< 0,3	24,9	11,3	5,9

sected with irrigation canals, the latter dividing it into numerous small basins without outlet. The lacking of runoff combined with the liberal use of irrigation water led to a strong percolation. In many cases the natural drainability of the irrigation basin soils has proved to be inadequate to prevent the ground water from rising. Salinization of the upper soil layers became a wide spread phenomenon. At present it is difficult to find non-saline agricultural lands in the Lower Mesopotamian Plain.
It will be evident that the depth to the raised ground-water level (as conditioned by the relief) together with the extent to which capillary rise takes place (as conditioned by soil texture and structure) and the salt concentration of the ground water determine the degree of salt accumulation in the upper soil layers. Consequently there is a wide range in concentration, distribution and even composition of salts in the soils of the various physiographic units.

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