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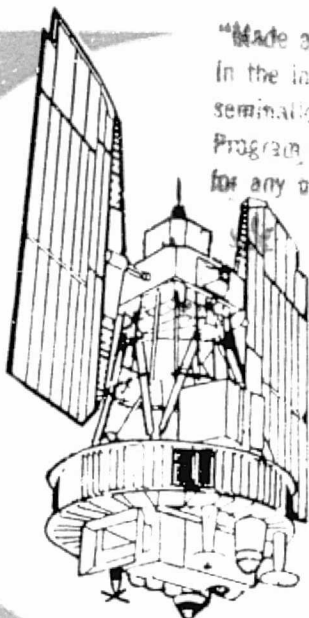
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Part 2

03 GEOLOGIC INTERPRETATION OF LANDSAT SATELLITE IMAGES FOR THE QATTARA DEPRESSION AREA, EGYPT (NASA LANDSAT INVESTIGATION # G2 7930 & # GB 7930)



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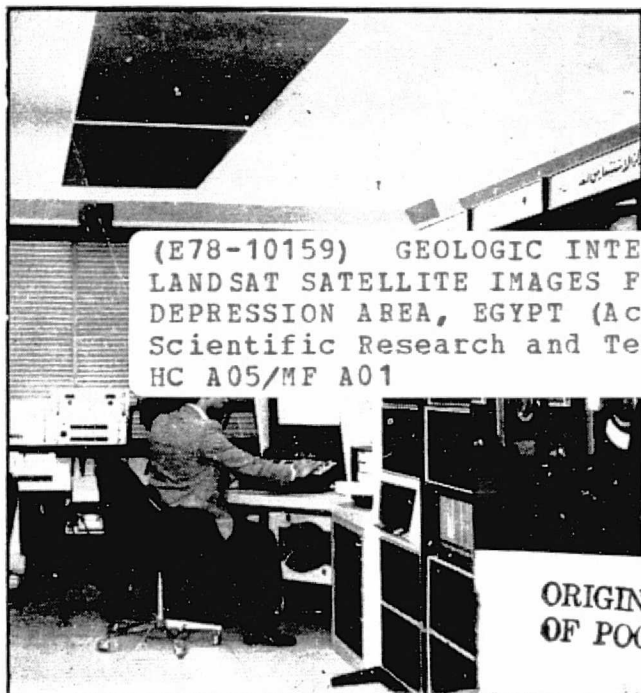
GEOLOGY

GROUNDWATER

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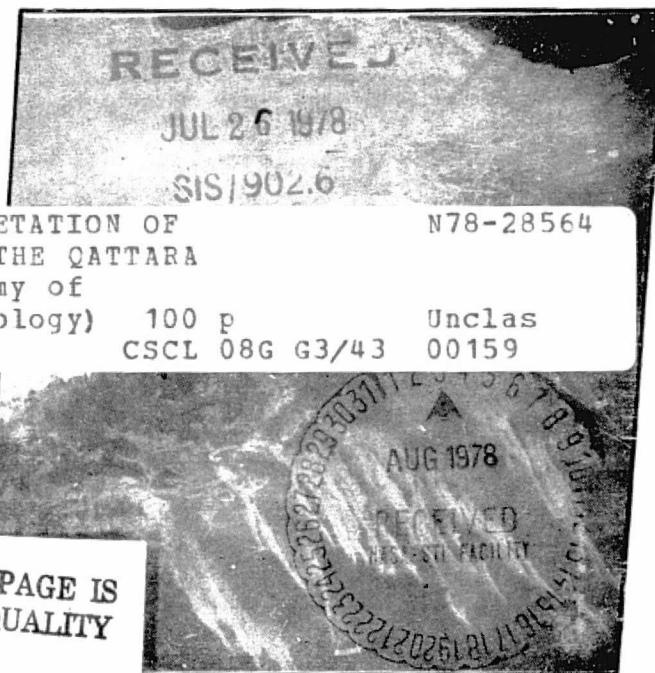


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Geologic Interpretation of Landsat Satellite Images for THE QATTARA DEPRESSION AREA, Egypt

(NASA LANDSAT INVESTIGATION # G 2 7930 & # G B 7930)

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The investigated area is located in the northern part of the Western Desert of Egypt between longitudes 26°00'-29°00'E and latitudes 29°00'-30°30'N, and between longitudes 25°00'-27°00'E and latitudes 28°00'-29°00'N. It covers the Qattara Depression which is a major physiographic feature in the Sahara Desert, as well as other depressions in its environs of smaller surface coverage. Three maps have been constructed for the first time for the Qattara Depression area from LANDSAT satellite images on a scale of 1:500,000, which are the geological, structural lineation and drainage maps. By applying computation techniques lineation density and drainage density maps are worked out for the same area. The groundwater conditions map makes use of the interpretation of the satellite images and the previous observations on the aquifers distributed in the Qattara Depression area and its environs. The present work is supported by considerable field measurements and observations as well as laboratory analyses.

abstract

The investigations carried out give for the first time the regional setting of the geological units; faults, fractures and folds; and drainage lines which help to visualize the environmental impact of the execution of the Qattara Project for electric power generation and to assess the regional questions involved in its implementation. Such questions include locations of intense

structural deformation and weak lines in the earth crust, drainage courses and drainage intersections, the variable character of the rocks encountered during the development of the project and the deposits laid down in the Qattara Depression itself. The latter deposits which are very extensive and saline, together with the drainage and seepage waters, should be considered in the assessment of the character of the waters contained in the depression after passing through the Mediterranean Sea — Qattara Depression canal. The groundwater conditions in the project area and its environs have been elucidated on a regional basis to show the relation between executing a canal along alignment LI and filling the Qattara Depression to an absolute level of —60 m and the utilized waters. Recommendations are proposed in this respect pointing out to the detailed investigations to be carried out.

PART I

Geology

Chapter 1

The investigated area is divided into two units namely that of the Qattara Depression and South Siwa Oasis. The depression itself lies in the northern part of the Western Desert of Egypt several tens of km to the south of the Mediterranean Sea coast (Plate I). It is actually the largest depression in the Sahara Desert covering great territories in northern Africa, and it is really constituted of subsidiary lows forming ultimately a unified complex depression. The maximum depth of the depression reaches 134 m below the Mediterranean Sea level. At -60 m level it covers an area of some 95,000 km² extending roughly ENE-WSW for about 300 km, and attaining variable breadths which increase in a westward direction and reaching a maximum width of roughly 145 km.

drainage

To the north the Qattara Depression is limited by an extensive escarpment named El Diffa Plateau which reaches a maximum height of some $+230$ m. This escarpment makes the northern wall of the depression, which is usually of steep and unstable slopes, though in some localities it has gradational and relatively more stable slopes. El Diffa Plateau slopes in a general manner towards the Mediterranean Sea, both are separated from each other by the Mediterranean coastal zone which is characterized by its gentle topography and low relief. The escarpment of the north wall of the depression is dissected by dense short drainage lines which allow the rain water falling on the southern part of the plateau to

drain southwards into the depression (Plate II). It may be noted in this respect that the trend of the drainage lines in the investigated area is greatly controlled by the fractures and faults (Plate III), while the length of these lines is largely controlled by the slope where short lines are associated usually with steep slopes while long lines are connected with gentle slopes.

To the south the depression slopes northwards in a smooth fashion. A wide plain is located to the south of the depression which is dominated by sand accumulations and sand dune belts extending in a NNW-SSE direction under the influence of the prevailing winds. Eastwards the plain has drainage lines of the dendritic type trending in an E-W direction, while westwards the drainage lines belong to the trellis type and they assume a NW-SE strike. These lines drain eventually into the lowest part of the depression.

The plain bordering the Qattara Depression eastwards is covered by sands and clays of Early Miocene age which are remarkably ferruginated. The sediments are frequently overlain by coarse gravels and pebbles of variable character. The plain in question is interrupted by major sand dune belts extending in a NNW-SSE direction and its drainage lines are poorly developed.

The plateau limiting the Qattara Depression from the west is dissected by relatively dense drainage lines belonging to the dendritic type. These are sloping usually eastwards in a smooth manner towards the depression until they reach its western wall where they become short, dense and steeply sloping into the depression itself. The lines under discussion drain into a wide channel sloping southwards while keeping parallel to the boundary of the depression. Furthermore, short tributaries branch from the previously mentioned channel which drain roughly in an eastward direction into the deepest part of the depression.

The Qattara Depression *sensu strictu* is dissected by drainage lines belonging to the dendritic type. They make sometimes a deltaic form especially in the flattened deep floor of the depression. The drainage lines have their origin normally in the surrounding plateaux and plains. As the former approach the bottom of the depression they join to form a wide channel parallel to the latter's main trend, and then they run with a gentle slope to the southwest where the deepest part of the depression is located.

Shallow saline water ponds are notable in the deep parts of the depression, which are also covered in many localities, by salts and dark encrustations closely resembling the ponds in the satellite images. The floor of the depression is frequently covered by sand, silt and various types of sabkhas. The above mentioned features are brought about by the accumulation of detrital materials carried into the depression by water flowing through the drainage lines

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and by winds, as well as the evaporation of surface waters and leaking subsurface waters during long periods of time.

South Siwa Oasis is covered mainly by sand dunes in its central and western parts. These dunes strike mostly in a NNW-SSE direction and they show notable variation in their density. Each density category has distinctive shape and type of distribution which may be correlatable with the lithology, structure and morphology of the bedrocks. The eastern part of South Siwa Oasis represents a plateau feature which joins southwards the Quss Abu Said Plateau in the vicinity of Farafra Oasis. The drainage lines dissecting the part of the area in question are belonging to the dendritic type and they run E-W and NW-SE.

Statistical analysis of the drainage lines has been carried out for the Qattara Depression and South Siwa Oasis and a drainage density map (Plate V) has been prepared in this respect. It has been found out that the great part of the investigated area is dissected by drainage lines in densities ranging from 0.1001 to 0.4000 km/km² especially in the range of 0.2001 to 0.3000 km/km². Such low density drainage lines are superimposed on rock units of variable lithology though encountered in locations which are not highly disturbed from the tectonic point of view.

The lowest density values of drainage lines, which are ranging from 0.0000 to 0.1000 km/km², are found in the wide plain bordering the Qattara Depression from the south east. The bedrock in this plain belongs to the clay member of the Lower Miocene Gebel El Khashab Formation, however, it is greatly covered with gravels and sand dunes. The plain in question is relatively tectonically quiet.

One of the advantages of the drainage density map (Plate V) is that it points out to the highly disturbed tectonic zones and locations with abrupt unstable slopes where the density of the drainage lines are high.

The highest density values of drainage lines of more than 5.000 km/km² are encountered in two locations on the northern and western rims of the Qattara Depression. The first location has two highly dense centres, one at Minqar Dweis on the eastern side of the northern rim of the depression and the second is situated downwards in the depression itself at Matan Sharib, with the exposed rocks belonging to the Qaret El Himeimat and Jaghbub Formations. The second location is at Qaret El Khadim on the western rim of the depression where the rock cover is soft clay belonging to the Late Eocene Maadi Formation.

High values of drainage density ranging from 0.4001 to 0.5000 km/km² are encountered at the northern escarpment bordering the depression especially at Ras El Qattara. Other locations of comparable density range are distributed in several parts of the investigated area. These locations assume an ESE-WNW, almost E-W, trend which is roughly concomitant with one of the major faults extending through the southern part of the Qattara Depression. Similar drainage density values are met with to the south of the Qattara Depression along important fault lines striking ENE-WSW, one of them is located at El Bahrein and the second some thirty km to the south south east.

Chapter 2

structure

The structural lineaments in the investigated area have been recognized and interpreted as folds and fractures including faults (Plate III) on LANDSAT-1 satellite images. These lineaments have been computed and contoured on a lineation density map (Plate VI). The physiographic features in the area of study including the Qattara and other depressions, as well as El Diffa Plateau and other elevated features, are closely linked with the manifestations of the structural lineaments. The kinds of rock exposures distributed in the area are also connected with the behaviour of these elements.

Several sets of fractures are mapped in the investigated area, and actually they are much more common than hitherto indicated on previous regional maps. The recognized sets possess the following trends : NW-SE and NNW-SSE, ESE-WNW and ENE-WSW, and NNE-SSW and NE-SW.

fractures including faults

The NW-SE set is represented mainly by strike slip faults of right lateral type. These faults are common between the Qattara and Siwa Oasis Depressions, and they, occasionally, traverse the Qattara Depression. A set assuming a trend near to the NNW-SSE is also observed though not as abundant as the previous set and their relation to each other is not so clear.

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A particularly important set in the investigated area is the one assuming an ENE-WSW trend. Important faults are belonging to this set including those bordering the Qattara Depression northwards and some within the depression itself. Other faults are encountered to the south of the depression, one of which is superimposed on the small depressions extending from El Bahrein to Sitra. Another set of especial significance is the ESE-WNW one. This is well illustrated by the very long fault extending from Siwa Oasis Depression westwards to the southern part of the Qattara Depression eastwards (El Shazly, Abdel Hady, El Ghawaby, El Kassas, Khawasik, El Shazly and Sanad, 1975). Smaller faults belonging to this set are distributed in the Qattara Depression reaching to its northern rim, and sometimes these faults are encountered outside the depression proper. The role of this set in the development of the depressions in the northern Western Desert has been also recognized (ibid.). In the present work the combined effect of the ENE-WSW and the ESE-WNW sets of lineaments is well illustrated in the formation of the Qattara Depression.

The NNE-SSW to N-S set of lineaments is less abundant than the previously mentioned ones. Most of the lineaments belonging to this set are encountered on the western side of the Qattara Depression where they take part in the delineation of its western rim, though some of them are distributed near the northern wall of the depression. It has been demonstrated that the faults belonging to the discussed set are strike slip faults occasionally accompanied by left lateral separation.

Two major lineaments and few smaller ones, assuming a NE-SW trend, traverse the northern part of the Qattara Depression. They do not show remarkable dislocation which may lead to the assumption that they are deep seated tension fractures. Most of the lineaments encountered in the investigated area are believed to be belonging to the Alpine diastrophism which reached its peak in the Late Miocene-Early Pliocene times, however, some lineaments may be of older or younger ages.

On the lineation density map (Plate VI) five ranges of density from > 0.4000 down to 0.0000 km/km^2 have been distinguished in the investigated area. The locations of highest density exceeding 0.4000 km/km^2 are encountered at the intersections of lineaments near Ras El Qattara in the vicinity of the northern rim of the Qattara Depression and at the intersections of lineaments near Sitra to the south of the depression. Densities ranging from 0.3001 to 0.4000 km/km^2 are connected with the northern rim of the depression towards its western side and along the ENE-WSW fault extending from El Bahrein to Sitra. Other localities of densities ranging from 0.2001 to 0.3000 km/km^2 are more widely spread in the area of study but they are more abundant in the vicinity of

the western side of the northern rim of the Qattara Depression, in the neighbourhood of its western rim, along fault lines within the depression, and along fault lines of ENE-WSW trend to the south of the depression, and in between the Qattara and Siwa Oasis Depressions. Considerable coverage of El Diffa Plateau and the extensive plain located to the south east of the Qattara Depression are relatively quiet from the tectonic point of view, and the lineament density values encountered there are ranging from 0.0000 to 0.1000 km/km².

folds

Curved lineaments are recognized and interpreted on the satellite images as folds. These are demonstrated to be belonging to two tectonic episodes namely an older late Mesozoic-early Cenozoic Iaramide episode and a younger late Cenozoic Alpine episode. Most of the folds distinguished in the investigated area belong to the latter episode, and the older folds are even modified and refolded by the younger ones.

Bahariya Oasis Anticline : The structure of Bahariya Oasis has been studied previously by El Shazly, Abdel Hady, El Ghawaby and Khawasik (1976). It has been demonstrated that the older folding has an axial trace striking NNE-SSW which has been modified by younger folding to acquire an axial trace striking NNW-SSE. The closure of Bahariya Oasis anticline has been located near Cicely Hill in the presently investigated area where the relics of the Oligocene sediments are bended and they reappear eastwards. Minor crenulations have been noted at the hinge closure of Bahariya Oasis anticline while the spacial distribution of the Oligocene and Eocene sediments has been rearranged under the influence of folding and faulting.

Siwa Oasis Syncline : This structure is located between longitudes 25° E and 27° E, and it traverses Siwa Oasis. The axial trace of this syncline, passing in the vicinity of Ain Tibaghabagh, is trending NNW-SSE and plunging to NNW. The apparent dislocation of the hinge closure of Siwa Oasis syncline from Ain Tibaghabagh to Gebel Khashabi is believed to be mainly due to vertical displacement of the inclined Eocene beds by the great ESE-WNW fault extending from Siwa Oasis to the southern part of the Qattara Depression, which is confirmed by the difference in topography between the southern high terrain and the northern low-lying plain. Naqb Tibaghabagh syncline is superimposed on Siwa Oasis syncline, a feature which may help in the interpretation of the lowest topography exhibited in the southern part of the Qattara Depression.

Qattara Depression Syncline : This is a major open syncline embracing the Qattara Depression. The axial trace of the syncline, which is striking approximately ENE-WSW and slightly plunging to W, is roughly coinciding with the escarpment limiting the depres-

sion northwards. El Diffa Plateau syndical trough is crenulated to form small folds with the same trend as the major syncline though acquiring small angles of dip. The depressed relief of the southern part of the synclinal trough located in the Qattara Depression itself is believed to be due to faulting, however, the superimposition of an intersecting younger synclinal trough should not be excluded for the time being.

The Qattara Depression syncline has its closure eastwards just near the eastern tip of the depression where the Early Miocene Qaret El Himeimat Formation is exposed while the younger Middle to Late Miocene Jaghub and Qaret El Dib Formations are outcropping westwards with the direction of the plunge of the syncline. The exposures of older rocks of the Jaghub and Qaret El Himeimat Formations are expected at the top and the slopes of the Salum escarpment, especially at the closure of the Salum anticline which may be considered as the reversal of the Qattara Depression syncline.

El Qaneitra-Qur Hadid Anticline : This major structure is located to the south of the Qattara Depression syncline. The axial trace of the anticline is striking in an ENE-WSW direction, and its closure is approximately located at Qur El Hadid westwards. Going ENE along the axial trace extensive sediments belonging to Gebel El Khashab Formation are exposed at its core.

Naqb Tibaghbagh Syncline : The major structure flanks El Qaneitra-Qur Hadid anticline from the south. The hinge closure of the discussed syncline is located in the vicinity of Naqb Tibaghbagh and its axial trace is striking in an ENE-WSW direction where a major almost E-W fault is located in the vicinity.

Chapter 3

geological units

A new geological map for the investigated area has been prepared from the LANDSAT satellite images along with the structural lineation and drainage maps. These maps have been augmented by considerable field investigations to prove the identity and characteristics of the geological units in the field and to collect samples from them for lithological, age and chemical studies. The geological (Plate IV), structural lineation (Plate III) and drainage maps (Plate II) cover a larger area than that already investigated in this work, in order to visualize the geology and environment of the areas bordering the Qattara Depression. The description, however, covers only the presently investigated area taking into consideration that the areas bordering Qattara Depression have been described previously by El Shazly, Abdel Hady, El Ghawaby, El Kassas, Khawasik, El Shazly and Sanad (1975), and El Shazly, Abdel Hady, El Ghawaby and Khawasik (1976). The rocks and loose sediments cropping out in the investigated area belong to the Paleocene, Early Eocene, Middle Eocene, Late Eocene, Oligocene, Early Miocene, Middle Miocene, Late Miocene and Quaternary. All the rocks are of sedimentary nature although signs of volcanicity/hydrothermal activity are manifested especially along fault lines. The geological units and structures are considerably more detailed and better delineated as compared to previous regional geological maps compiled by the Survey Department of Egypt in 1928, the Standard Oil

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Company of Egypt in the fifties and the Geological Survey and Mineral Projects Authority in 1971. The drainage lines in the drainage map are more numerous and better defined as compared to the previous regional topographical maps.

The geological units mapped during the present study are described in the following starting with the oldest ones.

Paleocene sediments

These represent the oldest outcropping rocks in the area of investigation. They are exposed in the southern part of the area (Plate IV) where they are represented by grey clay belonging to the upper member of the Lower Esna Formation.

Early Eocene sediments

These are represented by Gebel Serai Formation, which is cropping out to the south east of Siwa Oasis, south east Bahariya Oasis, and south Shoshet El Khadim on Bahariya Oasis-Siwa Oasis road.

Gebel Serai Formation consists of the three following members starting with the oldest : limestone member, chalky limestone member, and crystalline limestone member.

In the field the limestone member and the chalky limestone member could not be separated. However, the satellite image interpretation succeeded to distinguish the localities which are more chalky in general and are identified as the chalky limestone member. The thickness of the two oldest members are estimated to be 36 m, while that of the youngest member is 15 m.

Middle Eocene sediments

The rocks belonging to the Middle Eocene are encountered cropping out in the investigated area in a composite thickness of about 80 m. They are easily correlated to the Middle Eocene rocks cropping out in the adjacent Bahariya Oasis-El Faiyum area. These rocks are classified into two formations, the older is Gebel El Qalamun Formation, and the younger is Gebel Mokattam Formation.

Gebel El Qalamun Formation : The main outcrops belonging to this formation are encountered north of the Bahariya Oasis-Siwa Oasis road especially at its northern part, and they are striking WNW-ESE. The extension of the outcrops is about 190 km and their average width is approximately 30 km. The exposures are wider than the average towards Siwa Oasis and narrower towards Bahariya Oasis.

The bottom of the formation is not cropping out, however, the maximum thickness encountered is estimated to be about 55 m, i.e. 15 m less than the thickness measured at Gebel El Qalamun.

The formation is classified in the field into three members fairly correlated with the three corresponding members in Gebel El Qalamun though with slight lithological variations. These members are as follows starting with the oldest : marl member, limestone member, and crystalline limestone member.

The marl member is correlated with the ferruginous clay member cropping out at Gebel El Qalamun. The maximum thickness encountered in the presently investigated area is about 7 m consisting mainly of reddish marl with interbeds of alternating dark yellow dolomitic limestone and less ferruginous calcareous silt.

The limestone member is lithologically different from the corresponding member in Gebel El Qalamun regarding the absence of chalk in the former, where the maximum thickness is estimated to be 50 m.

The crystalline limestone member is correlated with Samalut crystalline limestone. It consists mainly of chalky crystalline limestone, occasionally dolomitic. Its maximum thickness is about 7 m which is less than that attained at Gebel El Qalamun.

Gebel Mokattam Formation : This formation is cropping out to the east of Siwa Oasis, and in various parts on the midway between Siwa Oasis and Bahariya Oasis. Its maximum thickness is 50 m which is less than that encountered in the adjacent Bahariya Oasis-El Faiyum area by 45 m.

There is no apparent lithological distinction between the exposures belonging to this formation in the present area and the adjacent one. It consists mainly of alternating members of marl and nummulitic limestone, with the latter usually attaining greater thickness. The two members of Gebel Mokattam Formation have been distinguished through the LANDSAT satellite image interpretation (Plate IV).

The sediments belonging to the Late Eocene are represented by one formation which is the Maadi Formation. Its thickness is estimated by 50 m in the present area.

*Late Eocene
sediments*

The bottom of this formation consists mainly of fossiliferous creamy limestone, marl, and partially crystalline limestone, while its top is constituted essentially of sandstone and conglomerate which are more continental regarding their environment of deposition as compared to the marine rocks at the bottom. By satellite image interpretation the formation is broadly classified into two members : the first is encountered south west of the Qattara Depression and consists mainly of limestone, while the more continental upper member has larger exposures which are usually encountered to the south of the depression.

Oligocene sediments

The Oligocene sediments are cropping out in small and low hills belonging to the Bluff Hill Formation with a general NW-SE trend, and attaining a thickness of 25 m. The bottom of the formation consists of slightly calcareous sandy beds while the top is constituted of conglomeratic sandstone which is occasionally calcareous. The clastic ratio increases going higher in the formation. Generally, the Oligocene rocks cropping out in the present area are lithologically consistent with the new Bluff Hill Formation encountered in the adjacent Bahariya Oasis-El Faiyum area. However, the top of the formation at the Qattara Depression area consists of calcareous sandstone whereas at the latter area it is silicified sandstone. Also the carbonate ratio in the bottom rocks of the formation is slightly more in the present area as compared to the case in Bahariya Oasis-El Faiyum area. This indicates that the Oligocene sediments are deposited under relatively more marine environment going to the north west. Furthermore, outcrops simulating Gebel Qatrani Formation have been encountered in a dispersed manner to the south of the Qattara Depression.

Early Miocene sediments

The Miocene sediments cover most of the area of study (Plate IV), and they represent about 45% of the thickness of its composite lithostratigraphic column (Plate VIII). The Miocene sediments are well exposed along the escarpment bordering the Qattara Depression. The vertical and lateral relations of the beds are studied in the field along 150 km of the escarpment.

The Early Miocene sediments are constituted of two formations namely Gebel El Khashab Formation and Qaret El Himeimat Formation. Rocks belonging to Gebel El Khashab Formation are cropping out in small thickness (15 m) at the foot of the escarpment. They could be reached in the field from the low levels of the Qattara Depression at Naqb El Qattara. They consist of white fine-grained equigranular sandstone (Section LXXXII, Plate XII). However, it is found in some other parts to be conglomeratic

calcareous sandstone. Qaret El Himeimat Formation is encountered in a considerable thickness in the escarpment adjacent to the northern boundary of the depression. The lithological units belonging to this formation are described in detail at Hisy El Qattara, Ras El Qattara I, Ras El Qattara II and Naqb El Qattara (Sections LXXIX, LXXX, LXXXI, LXXXII; Plates IX, X, XI and XII respectively). The formation is transitional between the continental environment of Gebel El Khashab Formation and the marine environment of the typical Middle Miocene Jaghbub Formation.

At Hisy El Qattara (Plate IX), it is encountered consisting of a predominant amount of marl, clay, chalky limestone and calcareous sandstone. It is overlain by a thin bed of gypseous limestone belonging to Qaret El Dib Formation. At Ras El Qattara the succession belonging to the formation contains more clay ratio than that encountered at Hisy El Qattara. The maximum thickness of the formation is encountered at Naqb El Qattara overlying Gebel El Khashab formation. The composite thickness of Qaret El Himeimat Formation measured at the escarpment is 180 m.

Jaghbub Formation is cropping out in various parts of El Diffa Plateau (Plate IV). The strata belonging to this formation are described lithologically and their thicknesses are measured in Sections LXXII, LXXIII, LXXIV, LXXV, LXXVI and LXXVII. The composite thickness of the Jaghbub Formation has been estimated at El Diffa Plateau to be 193 m. Lithologically, this formation consists of limestone, chalk, chalky limestone and clayey limestone.

Qaret El Dib Formation is encountered in the field at El Diffa Plateau in patches overlying the Jaghbub Formation. The former consists of gypseous limestone, chalky limestone and clayey limestone. The detailed lithology of the formation can be seen in Sections LXXI, LXXVIII and LXXIX, and its composite thickness is 40 m. It is not settled at present whether Qaret El Dib Formation belongs to the Late Miocene or the late Middle Miocene.

These sediments are particularly important in the investigated area especially Qattara Depression. The geological and environmental units identified in the area are twelve in number. These include alluvial cover derived from Eocene and Miocene rocks, sand dunes and sandy accumulations, sandy and clayey sabkhas, dark and light coloured salty crusts, lakes and ponds, and vegetation (Plate IV). The most abundant salts in the salty crust are rock salt and gypsum (Tables 1, 2).

Middle Miocene sediments

Late/Middle Miocene sediments

Quaternary sediments

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Lithologic Description of Lithostratigraphic Sections

The locations of the following lithostratigraphic sections measured and described in the investigated area are given in Plate VII.

Section LXXI (Qaret El Dib Formation)

Top

9 — Weathered white chalky limestone	3.0 m*
8 — Gypsum embedded in a calcareous medium..	4.0 m
7 — Buff limestone	5.0 m
6 — Fossiliferous limestone	4.0 m
5 — Weathered chalky limestone	unknown
4 — Weathered chalky limestone, clayey in parts	3.0 m
3 — Greyish to white clayey limestone	2.0 m
2 — Weathered chalky limestone	16.0 m
1 — Gypsum in a medium of calcareous material	unknown

Base

Section LXXII (Jaghbub Formation)

Top

6 — Ferruginous slightly calcareous grey clay ..	3.0 m
5 — Clay	10.0 m
4 — Soft chalky limestone	3.0 m
3 — Limy clay	7.0 m
2 — Chalk	20.0 m
1 — White clay, slightly chalky	7.0 m

Base

Section LXXIII (Jaghbub Formation)

Top

5 — Ferruginous fossiliferous chalky limestone..	1.0 m
4 — Compact white chalky limestone	9.0 m
3 — Chalky clayey whitish grey limestone	6.0 m
2 — Sandy chalky limestone	15.0 m
1 — Highly fossiliferous limestone	unknown

Base

Section LXXIV (Jaghbub Formation)

Top

4 — Chalky limestone	2.0 m
3 — Cream dusty limestone	5.0 m
2 — Chalky limestone	12.0 m
1 — Clayey chalky limestone	2.0 m

Base

* Thickness in meters

Section LXXV (Jaghbub Formation)

Top	
6 — Dolomitic white limestone	1.0 m
5 — Chalk	6.0 m
4 — Fossiliferous chalky limestone	1.0 m
3 — Chalk	7.0 m
2 — Dolomitic or clayey limestone	1.0 m
1 — Ferruginous reddish white limestone	6.0 m
Base	

Section LXXVI (Jaghbub Formation)

Top	
6 — White chalky fossiliferous limestone	3.0 m
5 — Red sandy limestone	5.0 m
4 — Red ferruginous limestone	1.0 m
3 — Reddish limestone	8.0 m
2 — White to pale yellow limestone, chalky in parts	2.0 m
1 — Weathered white chalky limestone	4.0 m
Base	

Section LXXVII (Jaghbub Formation)

Top	
4 — Soft clayey limestone	25.0 m
3 — Hard partially crystalline buff limestone	3.0 m
2 — Dark greenish clayey limestone, soft and voidal	5.0 m
1 — Weathered buff to pale yellow chalky limestone	3.0 m
Base	

Section LXXVIII (Jaghbub Formation 1-4, Qaret El Dib Formation 5)

Top	
5 — Gypseous limestone, gypsum is predominant in some locations	0.3 m
4 — Pale yellow chalky limestone, of moderate hardness	2.0 m
3 — Hard dark yellow sandy clay	2.0 m
2 — Slightly calcareous sandy clay	0.5 m
1 — Grey greenish clay with manganese minerals	4.0 m
Base	

Section LXXIX (Plate IX)

Top	
12 — Gypseous limestone	0.5 m
11 — Fine-grained friable, weakly cemented calcareous sandstone	4.0 m
10 — Ferruginous, fine-grained sandstone	4.0 m

9 — Dark grey clay, with salt and gypsum filling fracture planes	1.0 m
8 — Sandy calcareous clay	5.0 m
7 — Grey fine-grained sandstone	0.3 m
6 — Gypseous creamy limestone	0.3 m
5 — Chalky limestone, soft, pale yellow and creamy	10.0 m
4 — Clayey soft limestone, buff in colour	5.0 m
3 — Dark green clay	3.0 m
2 — Weathered marl, white to grey	6.0 m
1 — Dark green marl	15.0 m

Base

Section LXXX (Plate X)

Top

10 — Limestone	1.0 m
9 — White chalky limestone	10.0 m
8 — Fossiliferous yellow limestone	1.0 m
7 — White chalky limestone	1.0 m
6 — Greenish marl	8.0 m
5 — Ferruginous, reddish sandy limestone	2.0 m
4 — Chalky limestone	4.0 m
3 — Grey clay	4.0 m
2 — Sandy dolomitic limestone	2.5 m
1 — Greenish grey clay	20.0 m

Base

Section LXXXI (Plate XI)

Top

10 — Fossiliferous limestone, buff in colour	2.0 m
9 — Ferruginous reddish sandy limestone	2.0 m
8 — Greenish grey shale	2.0 m
7 — Ferruginous, red sandy limestone	0.5 m
6 — Greenish grey clay	5.0 m
5 — Calcareous silt	1.0 m
4 — Reddish limestone	1.0 m
3 — White to pale yellow limestone	5.0 m
2 — Grey clay	4.0 m
1 — Ferruginous marl	1.0 m

Base

Section LXXXII (Plate XII)

Top

30 — Fossiliferous yellow limestone	0.5 m
29 — Yellowish to greenish marl	15.0 m
28 — Yellowish to greenish dolomitic limestone, fossiliferous in some horizons	6.0 m
27 — Grey shale, slightly ferruginous on joint planes	15.0 m

26 — White, fine-grained friable sandstone, uncemented or weakly cemented by a calcareous cement	5.0 m
25 — Greenish sandy clay	1.0 m
24 — Alternating yellow dolomitic limestone and weakly cemented calcareous sandstone . . .	5.0 m
23 — Green shale	2.0 m
22 — Alternation of yellowish dolomitic limestone and ferruginous friable calcareous fine-grained equigranular sandstone	4.0 m
21 — Green sandy shale, with hematitic spots on fractures	0.5 m
20 — Ferruginous, weakly cemented, calcareous sandstone	2.0 m
19 — Yellowish and greenish dolomitic limestone..	1.0 m
18 — Greenish marl	2.0 m
17 — Greenish shale with ferruginous spots on fracture planes	4.0 m
16 — Ferruginous, weakly cemented calcareous sandstone	1.0 m
15 — Green shale	3.0 m
14 — Grey clay	1.0 m
13 — Reddish sandy marl	1.0 m
12 — Clay	3.0 m
11 — Flesh-coloured dolomitic limestone	0.5 m
10 — Yellowish green marl with black knobs of iron and manganese oxides	6.0 m
9 — Dark grey shale	4.0 m
8 — White to pale yellow hard, fine-grained, equigranular sandstone, calcareous in parts	3.0 m
7 — Dolomitic limestone, fossiliferous, reddish to pale yellow	3.0 m
6 — Grey sandy marl	7.0 m
5 — Grey shale, slightly calcareous in parts ..	1.0 m
4 — Sandy marl, creamy	1.0 m
3 — Dark green shale	1.0 m
2 — Dark yellow fossiliferous limestone	6.0 m
1 — White, fine-grained, equigranular sandstone	16.0 m

Base

Section LXXXIII (Qaret El Himeimat Formation)

Top

3 — Reddish ferruginous calcareous silt	0.2 m
2 — Dark conglomeratic sandstone	1.0 m
1 — Reddish slightly calcareous, ferruginous, sandy clay	0.2 m

Base

Section LXXXV (Gebel El Qalamun Formation)

Top

- 2 — Buff dark yellowish limestone, hard, unfossiliferous 1.5 m
- 1 — Pale yellow bedded sandstone, fine- to medium-grained, hard 4.0 m

Base

Section LXXXVI (Gebel El Qalamun Formation)

Top

- 2 — Crystalline dolomitic limestone, with white alteration 0.5 m
- 1 — Chalky crystalline limestone 2.0 m

Base

Section LXXXVII (Gebel El Qalamun Formation)

Top

- 2 — Pale yellow dolomitic limestone 0.25m
- 1 — Soft yellowish silt 1.0 m

Base

Section LXXXVIII (Gebel El Qalamun Formation)

Top

- 10 — Hard dolomitic creamy limestone 1.0 m
- 9 — Clayey and sandy dolomitic limestone, ferruginous in parts 0.5 m
- 8 — Pale yellow and creamy limestone 0.5 m
- 7 — Green dolomitic limestone 0.5 m
- 6 — Yellow and greyish fine-grained sandstone, equigranular 1.5 m
- 5 — Hard dark yellow limestone alternating with flesh-coloured limestone, salt found on joint planes 0.2 m
- 4 — Soft, fine-grained, equigranular sandstone, limonitic alterations encountered in spots 5.0 m
- 3 — Fossiliferous light flesh-coloured limestone 1.5 m
- 2 — Soft green silt, slightly ferruginous in parts 3.0 m
- 1 — Fine-grained equigranular green ferruginous sandstone 1.5 m

Base

Section LXXXIX (Probably on unconformity over Gebel El Qalamun Formation)

Top

- 5 — Dark yellow calcareous conglomeratic sandstone, sand grains fine to medium, matrix calcareous 0.2 m

- | | |
|--|-------|
| 4 — Conglomerate, fine, medium to coarse grains of quartz embedded in a calcareous matrix, limonite alterations not uncommon | 0.4 m |
| 3 — Hard yellow limestone, containing knobs of manganese and iron oxides | 1.0 m |
| 2 — Unconformity surface of white sandstone found in irregular patches in limestone | 0.4 m |
| 1 — Alternation of dark grey clay and friable fine-grained sandstone | 6.0 m |

Base

Section XC (Plate XIII)

Top

- | | |
|--|-------|
| 21 — Ferruginous sandstone | 0.5 m |
| 20 — Friable, yellow unequigranular sandstone, grains are fine to medium | 1.0 m |
| 19 — Black hard calcareous sandstone | 7.0 m |
| 18 — Greenish marl, soft, sandy in parts | 1.0 m |
| 17 — Greenish sandy clay | 1.5 m |
| 16 — Sandy limestone, hard, yellowish | 1.0 m |
| 15 — Greenish marl | 2.0 m |
| 14 — Friable medium-grained sandstone | 2.0 m |
| 13 — Conglomerate | 0.5 m |
| 12 — Grey clay | 2.0 m |
| 11 — White marl | 8.0 m |
| 10 — Fossiliferous white clayey limestone | 0.5 m |
| 9 — Grey dolomitic limestone | 6.0 m |
| 8 — Clay with molds and casts of gastropods and other fossils | 0.3 m |
| 7 — White dolomite containing microfossils? | 3.0 m |
| 6 — White to greyish marl | 4.0 m |
| 5 — Fossiliferous creamy limestone | 1.0 m |
| 4 — Greenish sandy clay | 1.0 m |
| 3 — Pale yellow limestone | 1.0 m |
| 2 — Slightly ferruginous sandstone | 0.5 m |
| 1 — Sandy, slightly ferruginous pale red limestone | 2.5 m |

Base

Section XCI (Gebel Mokattam Formation)

Nummulitic limestone with occasional thin laminae of clay.

Section XCII (Gebel Mokattam Formation)

Top

- | | |
|------------------------------------|-------|
| 4 — Nummulitic limestone | 0.8 m |
| 3 — Marl | 7.0 m |

2 — Nummulitic limestone	0.2 m
1 — Marl	4.0 m

Base

Section XIII (Lower horizons of Gebel
Mokattam Formation)

Top

5 — Marl	1.0 m
4 — Grey limestone	0.5 m
3 — Yellowish limestone	1.5 m
2 — Marl	2.0 m
1 — Nummulitic limestone	unknown

Base

Description of Lithologically Studied Samples

The locations of the following individual samples, collected from the investigated area for the purpose of lithologic description, are shown in Plate VII.

Sample 701 : White fossiliferous chalky limestone with brownish tarnish (Jaghbub Formation).

Sample 702 : Sand and scattered pebbles of fossiliferous limestone, covering wide plains (Quaternary, bedrock Jaghbub Formation).

Sample 735 : Clayey chalky limestone, in an extensive bed, covering the wadi and giving the ground surface a light appearance (Jaghbub Formation).

Sample 736 : Brownish white limestone, stratigraphically overlying the previous bed. The former bed is covered with growing small natural vegetation (Jaghbub Formation).

Sample 737 : Selected gypsum samples, derived from a horizon corresponding to the upper part of the previous bed. The thickness of the horizon at this locality is 3.0 m (Qaret El Dib Formation).

Sample 738 : Marl, occasionally covered by small recent deltas of clay. These deltas are encircled by Quaternary loose calcareous sediments (Qaret El Himeimat Formation).

Sample 740 : White limestone dissected by recent dry streams forming small clay deltas (Jaghbub Formation).

Sample 741 : Clay from the previous small deltas (Quaternary).

Sample 742 : Hard partially crystalline limestone (Jaghbub Formation).

Sample 759 : Chalky gypseous limestone (Qaret El Dib Formation).

Sample 760 : Quaternary white dust derived from Miocene limestone.

Sample 761 : Gypseous limestone (Qaret El Dib Formation).

Samples 762 & 763 : Gypseous limestones. In some locations they are overlain by clay (Qaret El Dib Formation).

Sample 773 : Gypseous limestone in wide plains (Qaret El Dib Formation).

Sample 832 : Small outcrops of fine-grained calcareous sandstone, buff in colour. The rock is jointed into two main systems S 80° and S86°E 78° (Gebel El Khashab Formation, sandstone member).

Sample 833 : Quaternary friable sandstone containing abundant salty materials. The general appearance of the ground surface is dark.

Sample 834 : Fine gravel, covering the ground surface (Quaternary).

Samples 838 & 839 : Quaternary sands and gravels. Occasional partially crystalline limestone is encountered in small bodies belonging to the Jaghbub Formation.

Sample 840 : Quaternary surficial ill-sorted sand, fine to medium and occasionally coarse. Recent ripple marks are found taking a linear direction of S70°W. Occasionally rock salt and gypsum are encountered.

Sample 842 : Sand dunes of S50°E direction, underlain by fine-grained sand with abundant salt.

Sample 843 : Surficial fine-grained sandstone. The ground surface has a general dark yellow colour.

Sample 845 : Recent equigranular friable fine-grained sandstone covered by sand dunes assuming a NW-SE direction.

Sample 846 : Calcareous sandstone (Gebel El Khashab Formation, sandstone member). Small bodies of anhydrite with rock salt and probably alunite are encountered.

Sample 854 : Limestone in small outcrops (Maadi Formation).

Sample 858 : Petrified wood (Gebel El Khashab Formation).

Sample 859 : Soft weathered limestone, dark in colour containing occasional calcite crystals (Gebel Mokattam Formation ?).

Samples 860 & 861 : Hard ferruginous fine-grained sandstone in small outcrops containing occasional petrified wood (Gebel El Khashab Formation, sandstone member).

Sample 911 : White limestone, slightly chalky (Gebel Serai Formation).

Sample 912 : White limestone (Gebel Serai Formation).

Sample 913 : Yellowish hard limestone, partially crystalline (Gebel Serai Formation, crystalline limestone member).

Sample 914 : Yellowish green marl (Gebel Mokattam Formation, marl member).

Sample 915 : Fossiliferous, yellowish white limestone (Gebel Mokattam Formation, limestone member).

Sample 916 : Pleistocene marl as small pockets in early Middle Eocene rocks. The marl pockets show growing small natural vegetation especially along the drainage lines.

- Sample 917 : Partially crystalline limestone of early Middle Eocene age (Gebel El Qalamun Formation, crystalline limestone member).
- Sample 919 : White limestone of Middle Eocene age.
- Sample 920 : Clayey white limestone of Middle Eocene age.
- Sample 921 : Brownish dolomitic limestone of Middle Eocene age.
- Sample 922 : Fossils collected from Eocene limestone.
- Sample 924 : Fossils collected from Eocene limestone beds.
- Sample 925 : Fossiliferous limestone (Gebel Mokattam Formation).
- Sample 926 : Nummulites collected from light coloured wide plains of Nummulitic limestone of late Middle Eocene age (Gebel Mokattam Formation).
- Sample 927 : Nummulitic limestone of late Middle Eocene age (Gebel Mokattam Formation).
- Sample 928 : Pleistocene salty clay of brownish green colour.
- Sample 929 : Pleistocene calcareous salty silt.
- Sample 930 : Nummulitic limestone of late Middle Eocene (Gebel Mokattam Formation).
- Sample 931 : Recent salts, filling a great depression.
- Sample 932 : Recent sodium chloride crystals in Eocene limestone.
- Sample 933 : Nummulites covered by thin crust of recent salts.
- Sample 934 : Fossiliferous chalky limestone (Gebel El Qalamun Formation, chalky limestone member).
- Sample 939 : Gypsum flakes found in marl beds (Gebel El Qalamun Formation, marl member).
- Sample 940 : Quaternary dust accumulations derived from Eocene limestone.
- Sample 941 : Brownish limestone, covered with recent silt (Gebel El Qalamun Formation).
- Sample 942 : Weathered chalky fossiliferous limestone (Gebel El Qalamun Formation, chalky limestone member).
- Sample 943 : Nummulites attached together by calcareous materials, covering wide ground surface (Gebel Mokattam Formation, nummulitic limestone member).
- Sample 944 : Hard brownish limestone bed, covered in the field by sands and gravels (Gebel El Qalamun Formation).
- Sample 945 : Recent fine-grained well sorted sand, in small pockets along drainage lines covered with growing natural vegetation.

Lithologic Description of Chemically Analyzed Samples

Sample 718 : Thick Quaternary loose calcareous deposits of dust size. (Quaternary, derived from Miocene limestone).

Sample 741 : Grey to green clay, forming small deltas. (Quaternary, bedrock limestone from Jaghbub Formation).

Sample 764 : Red calcareous silt, extensively distributed in wide plains, underlying Qaret El Dib Formation. (Jaghbub Formation).

Sample 779 : Green clay covering wide and extensive plains, occasionally forming small conical hills. Occasional vegetation is grown on these plains. The clay is slightly ferruginous on the fracture planes. This clay bed is overlain by a gypseous limestone bed so that it is correlated with the location of sample 764. (Gebel El Khashab Formation).

Sample 830 : Rock salt, found in salty marshes in Qattara Depression. Sample taken from a location at the foot of Ras El Qattara escarpment. (Quaternary, bedrock Gebel El Khashab Formation, sandstone member).

Sample 831 : White gypsum with sand and rock salt. The general feature of the ground surface is dark, however, white patches are encountered consisting of white salty clay. (Quaternary, bedrock Qaret El Himeimat Formation).

Sample 835 : White rock salt with sand impurities, found in a country of salty sand, of dark general appearance in the field. The ground is hard enough for the passage of field vehicles. (Quaternary, bedrock Gebel El Khashab Formation, sandstone member).

Sample 836 : Rock salt with sand, gypsum, clay and iron oxides. (Quaternary, bedrock Jaghbub Formation).

Sample 837 : White salts, consisting of gypsum and rock salt. (Quaternary, bedrock Gebel El Khashab Formation, sandstone member).

Sample 838 : Calcareous (dolomite and calcite) fine-grained sandstone, containing soluble white salts. (Quaternary, at contact of Gebel El Khashab Formation, sandstone member, and Jaghbub Formation).

Sample 841 : White gypsum and rock salt. (Quaternary).

Sample 844 : Taken from a plateau of colourless rock salt. The rock salt ground is covered with thin film of sand. (Quaternary, bedrock Qaret El Himeimat Formation).

Sample 847 : Anhydrite with rock salt and probably with little alunite found on a line representing a NW-SE fault ? (Gebel El Khashab Formation, sandstone member).

Sample 848 : Sand with carbonates, rock salt, sulphates and clay.
(Quaternary).

Sample 849 : Rock salt with sand. (Quaternary).

Sample 885 : Clay marsh with white disseminated rock salt.
(Quaternary, bedrock Maadi Formation).

Sample 886 : Anhydrite with rock salt and probably with little
alunite, no definite fault detected. (Gebel Mokattam For-
mation).

Sample 909 : Black recent clay containing white rock salt. (Qua-
ternary, bedrock Maadi Formation).

Sample 910 : Fine-grained sand, with clay, rock salt, carbonates,
gypsum, sulphates, etc. Samples taken from the lowest level
in Qattara Depression. (Quaternary, bedrock Gebel El Qalamun
Formation).

TABLE I. CHEMICAL ANALYSIS OF SAMPLES EXCEPT SALT.

Sample No. Chemical constituents (wt. %)	718	741	764	779	831	836	838	847	848	849	885	886	909	910
SiO ₂	4.38	46.57	42.96	45.55	15.54	25.33	50.85	0.15	69.45	28.37	31.52	1.40	33.64	59.96
TiO ₂	0.08	1.55	0.33	1.55	0.08	0.33	0.37	0.03	0.40	0.22	0.95	0.03	0.75	0.31
Al ₂ O ₃	0.40	14.38	1.60	16.11	0.24	2.54	1.15	0.40	2.01	0.89	10.61	0.25	8.24	1.94
Fe ₂ O ₃	0.13	8.76	1.34	8.76	1.09	3.61	0.30	0.03	1.88	1.23	3.18	0.05	3.00	1.77
MnO	0.03	0.09	0.05	0.96	0.03	0.41	0.13	0.01	0.06	0.06	0.04	0.01	0.04	0.06
MgO	18.80	2.35	4.15	2.17	1.32	1.28	8.13	trace	2.93	1.63	3.96	trace	2.09	2.39
CaO	28.70	1.20	18.05	2.05	28.86	5.55	14.23	36.90	5.02	4.53	0.95	36.50	2.59	6.43
Na ₂ O	0.50	1.43	0.46	0.26	0.22	0.61	0.40	trace	0.31	0.42	0.28	trace	0.29	0.54
K ₂ O	0.40	3.55	0.71	2.83	0.19	0.46	0.72	0.30	0.55	0.24	1.10	0.14	1.00	0.35
P ₂ O ₅	0.11	0.18	0.11	0.17	0.07	0.14	0.14	0.02	0.13	0.09	0.17	0.03	0.15	0.11
NaCl	1.05	2.90	0.28	2.77	10.36	44.59	1.70	4.83	3.58	55.08	21.61	7.08	25.91	4.03
SO ₂	2.55	0.18	11.32	0.12	30.57	5.08	0.32	52.80	3.01	2.22	1.06	52.50	1.09	4.38
H ₂ O	1.20	7.80	8.02	6.60	2.65	5.40	0.70	2.30	6.26	1.44	13.14	1.10	10.00	12.90
L.O.I.	41.90	8.80	11.75	10.60	8.09	4.63	20.40	3.20	5.46	3.35	12.72	1.80	12.86	6.46

Chemical Analysis by Dr. M. A. Hathout, Faculty of Education, University of Menoufia.

n.d. : not detected.

TABLE 2. CHEMICAL ANALYSIS OF SALT CRUST.

Sample No. Chemical constituents (wt. %)	830	835	837	841	844
Na+	38.10	33.76	12.76	6.93	38.68
K+	n.d.	n.d.	n.d.	n.d.	n.d.
Ca++	0.73	1.52	18.27	23.24	0.50
Mg++	0.04	0.19	0.16	0.18	0.05
Cl ⁻	58.05	51.08	20.09	10.67	59.06
SO ₄ ⁻	2.80	4.27	45.00	57.65	2.04
SiO ₂	0.19	7.40	1.96	0.29	n.d.
Fe ₂ O ₃	0.09	0.20	0.09	0.09	0.04
H ₂ O	0.50	1.10	1.80	0.80	0.30

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Part II

Groundwater

Chapter 4

groundwater conditions

The Qattara Depression area is located within the arid belt of Egypt. With the exception of the aquifers existing along the Mediterranean Sea coast, which depend for their water supply on local precipitation, other aquifers are recharged from various sources, e.g. sea water intrusion, seepage from the River Nile, recharge from the deep-seated aquifers, etc. The groundwater conditions in the detected aquifers are greatly affected by structural features especially faulting; lithologic nature of the influencing rocks as well as their topographic settings. For these reasons the construction of new geological, structural lineation and drainage maps from LANDSAT satellite images are of prime importance for deciphering groundwater problems on a regional basis in the Qattara Depression area.

According to their position in the stratigraphic column, the groundwater aquifers of interest in the investigated Qattara Depression area include the following :

- Groundwater in Pleistocene detrital limestone, dominating in the coastal strip along the Mediterranean Sea.
- Groundwater in Pliocene reddish brown to creamy limestone, encountered in the synclinal basin between El Sira and Abu Samra monoclines.
- Groundwater in Middle Miocene limestones occurring at El Diffa Plateau and Siwa Oasis.

- Groundwater in Early Miocene sands and sandstones, present between Wadi El Natrun and the Qattara Depression, and along the northern rim of the depression.
- Groundwater in Eocene limestones, encountered at El Arag, El Bahrein, Sitra, etc.
- Groundwater in Late Cretaceous limestones and dolomites, detected in the environs of Siwa Oasis.
- Groundwater in Early Cretaceous — Early Carboniferous sandstones, encountered in the deep wells drilled in the Qattara Depression and in the environs of Siwa Oasis.

*groundwater in
Pleistocene detrital
limestone*

The groundwater in this aquifer depends mainly on local precipitation and exists normally as a thin layer of fresh to brackish water floating on the main saline water body intruded inland from the Mediterranean Sea.

In El Dabaa locality (Plate XIV) and its neighbourhood to the east and to the west, the considered aquifer dominates in the coastal strip where it involves a great portion of the surface bedrock. It exists at altitudes ranging from about sea level up to +110 m, the latter altitude is at Ras El Husan locality. In the subsurface, the aquifer is encountered at depths which may reach 40 m. The detrital limestone, which has an average thickness of about 50 m, exists mostly in the form of successive elongated ridges acting — in the Mediterranean Sea coastal strip — as water shed divides for the surface runoff water.

The limestone in question constitutes a main source of groundwater in the coastal strip, and it exists either in exposed outcrops or it may be overlain by a thin veneer of loamy deposits. Near the shore of the Mediterranean Sea, the limestone is covered by a chain of dune sand accumulations which accelerate the rate of infiltration of the surface runoff into the limestone aquifer. Generally, the limestone is constituted of carbonate grains with dispersed quartz grains and fossil allochems. These constituents are cemented in various degrees by carbonate cement. Locally, the rock is interbedded with sandy loam layers indicating the fluctuation of the climatic conditions during the Pleistocene time. The detrital limestone is cross bedded and jointed, and it possesses variable petrophysical properties which are related to the degree of compaction and the extent of post depositional changes to which it has been exposed.

In El Dabaa locality, as elsewhere along the Mediterranean Sea coast westwards of Alexandria, the limestone wedges out inland. The upper boundary of the limestone is either generally above sea level or hidden below the younger loamy deposits or the eolian sand. The lower boundary, on the other hand, is of irregular nature and extension, and it is marked by a conspicuous unconformity between the limestone and the underlying Pliocene reddish brown or creamy

limestone and/or the Middle Miocene limestone, both of which are water-bearing in the area of investigation.

The groundwater in the discussed aquifer exists under free water table conditions at different depths from the ground surface. In most cases, the water table exists at depths of 10 to 15 m from the surface, but close to the coast line where the ground surface comes near sea level as exemplified by Ras El Dabaa, where the groundwater comes near to the surface. On the other hand, the water table exists at different absolute levels and it ranges usually from +5 m to -3 m with respect to sea level.

The regional movement of groundwater in the considered aquifer is mostly in the northward direction towards the Mediterranean Sea. It has been recorded in the eastern part of El Dabaa locality, that the constructed water table maps (Gindy, 1974; Korany, 1975) show the existence of at least three thin lenticular water layers, and the groundwater movement is both in the northward and southward direction. This phenomenon is mainly attributed to the existence of the previously mentioned elongate ridges which act as water divides.

The limestone possesses different degrees of porosity and permeability. Laboratory measurements of its porosity show that it ranges from 28% to 45% by volume, and its permeability is varying between 140 and 290 g/dft². On the other hand, the field experiments for the determination of the hydraulic constants of the aquifer also revealed variation from one locality to another as given in Table 3.

The groundwater exhibits variable chemical salinity along the vertical water column. Its salinity varies from 400 ppm TDS in the top portion of the fresh water layer to 5,000 ppm TDS near the interface of its lower portion with the main saline water body, below which the salinity increases to 15,000 ppm TDS. The chemical type of the water varies also from the bicarbonate type in the top levels to the chloride type in the deeper levels.

TABLE 3 : HYDRAULIC PARAMETERS AT BURG EL ARAB AND RAS HEKMA LOCALITIES.

Locality	Burg El Arab 1963) (Saad et al., (1953)	Ras El Hekma (Hassan and El Ramly, 1965)
Hydraulic parameters		
Transmissibility		
coefficient	0.35 m ² /min	0.03 m ² /min
Permeability		
coefficient	7 (10) ⁻³ m/min	1.5 (10) ⁻³ m/min
Storativity	5.7 (10) ⁻³	6.3 (10) ⁻⁶

*groundwater in
Pliocene reddish
to creamy limestone*

This aquifer is of secondary importance in the investigated area, as it has so far been found to be restricted to the synclinal basin located between El Sira and Abu Samra minor monoclines. The water exists in a free water table condition, it is almost brackish with a salinity varying between 2,888 and 3,320 ppm TDS, and it belongs chemically to the sodium-chloride type. The Pliocene reddish brown to creamy limestone is medium hard and its thickness as reported in Galal Well is about 38 m.

*groundwater in
Middle Miocene
limestones*

The cavernous sandy limestone, which represents a good part of the Middle Miocene Jaghub Formation, constitutes a water-bearing unit, which is developed into high escarpments and elevated plateaux at a distance of 10 to 35 km from the Mediterranean Sea coast, and extending southwards to the northern rim of the Qattara Depression where it forms the white limestone cap rock. In the northern part along the coast, this limestone is encountered in the subsurface at various depths underneath Pliocene and/or Pleistocene rocks, as well as Holocene deposits. The lower boundary of the limestone is marked by a general slope in the northward direction where it is underlain by the sandy and sandy shale facies of the Early Miocene.

The groundwater in the cavernous sandy limestone exists either under unconfined or perched conditions. The latter is detected at El Qutaf in El Dabaa locality and at Fuka locality further to the west. In the eastern part the free water table condition predominates. The limestone in question is recharged from the direct percolation of the rainfall, from the downward leakage from the Pleistocene detrital limestone and via the Pliocene reddish brown or creamy limestone aquifers, and from sea water with which it comes in contact in the north.

Under the normal free water table condition, the groundwater level shows marked variations with respect to sea level. While it is mostly at about sea level in the coastal strip at El Dabaa, it reaches -10 m in Abu Subeiha to the south west of El Dabaa village. Although the regional movement of the water in the discussed aquifer seems to be in the northward or northwestward direction, as illustrated by Qasaba 1X SI, level -1.8 m, Washaka 1X, SI, level -7 m and Abu Subeiha 1X SI, level -10 m, this is not an indication to the actual direction of the groundwater movement which is not definitely controlled because of the changeable nature of the facies of the limestone, the connection or nonconnection of the movement routes within it, the variation of its upper and lower boundaries, as well as the structural undulations superimposed on it in the whole area. The water obtained from the aquifer under the free water table condition is generally saline reaching to more than 14,500 ppm TDS and possessing a chloride chemical type.

With regard to the perched water condition which occurs in the Middle Miocene strata at El Qutaf located 16 km west south

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west of El Dabaa village and at Ras El Husan situated 22 km south west of the latter, and which is related to either stratigraphic conditions or to structural features, the groundwater level exists at +45 m and +42 m respectively.

The perched groundwater is of good quality as the salinity is generally less than 1,000 ppm TDS and the aquifer is recharged mainly from the surface runoff through percolation from the top.

To the west of the Qattara Depression as well as in Siwa Oasis, the Middle Miocene limestones represent a main aquifer. The Middle Miocene section has a thickness of about 125 m and is differentiated into three horizons, namely an upper limestone water-bearing horizon of 30 m thickness, a middle shale and marl semiconfining horizon of 45 m thickness, and a lower limestone water-bearing horizon of 50 m thickness. The water-bearing limestones are characterized by the occurrence of fissures and channels resulting from solution action.

The groundwater exploited from the Middle Miocene limestones in Siwa Oasis is the only source of water utilized for domestic and cultivation purposes. It is produced mainly through abundant artificial and natural springs dominating Siwa Oasis Depression. The groundwater flows freely to the surface at locations of low altitudes where it recharges the lakes covering an extensive surface of the depression. In elevated locations along the peripheries of the depression, the groundwater exists at shallow depths from the surface.

The water in the Middle Miocene seems to belong to two sources, namely the formation water circulating in the jointed fissured limestone aquifer and the water leaking upwards from deeper aquifers along important deep seated fractures and faults. Pumping tests carried out on the considered aquifer indicate its low though variable transmissivity, which has been found to be 43.3 m² d at Helbako spring and 10 m² d at Tagzarti spring. The wide variations in transmissivity are characteristic features of limestone aquifers, however, it may also reflect in our case the two sources of groundwater recharging the considered aquifer, especially as the movement of water vertically along fractures and faults may vary greatly between the fracture/fault zones and the locations away from them. This phenomenon is well illustrated by the variation in the salinity of groundwater which is 1,440 ppm TDS in Tanaklish spring, 7,830 ppm TDS in Qurishit spring and 25,000 ppm TDS in Maaser spring.

The groundwater in Siwa Oasis is generally brackish and it belongs to the sodium-chloride type. The water accumulating in the lakes spread in the Siwa Oasis Depression is brine and its salinity may reach more than 300,000 ppm TDS. This excessive salinity is mainly attributed to the successive evaporation processes to which the lake water has been subjected.

*groundwater in
Early Miocene sands
and sandstones*

This aquifer dominates in the area to the north and east of the Qattara Depression. The Early Miocene rocks are differentiated into two formations namely Abu Subeiha Formation and Qaret El Himeimat Formation. In the subsurface in the northern part of the investigated area, Abu Subeiha Formation dominates and is formed of sandy shale beds with thin layers of sandstones and sandy limestones of marine to fluviomarine origin. The sand/shale ratio does not exceed 1/5. The top of this formation is encountered at -115 m level in El Dabaa Well where it attains a thickness of 590 m. Qaret El Himeimat Formation dominates southwards in the investigated area and it is either outcropping or hidden in the subsurface. It is constituted of sandstone beds with thin layers of sandy shale, dolomite and limestone interbeds of fluviomarine origin. The sand/shale ratio is 5/1. This formation is encountered in the subsurface at different altitudes with respect to sea level. It exists at +15 m in Alam El Bueib Well, +9 m in Dahab Well and -30 m in El Alamein Wells. Near the approach of the northern rim of the Qattara Depression, the surface of El Himeimat Formation is exposed at an absolute level of about +180 m. The formation under discussion has a maximum thickness of about 957 m reported in El Dabaa Well.

The sandstones and sandy beds of the Early Miocene are developed into an aquifer, the upper boundary of which is either hidden beneath the previous cavernous limestone of the Middle Miocene or it may be exposed, whereas its lower boundary is developed into an irregular surface due to the occurrence of alternating positive and negative structural elements, underlain by the Oligocene marine shale facies termed El Dabaa Formation.

The groundwater in the Early Miocene aquifer, existing almost under unconfined condition, has been tested in considerable number of wells drilled by various petroleum companies. The detected water levels in these wells reveal that the water exists below sea level and that the water movement is controlled by the Qattara Depression. In the northern part, the movement of water is regionally directed from north to south, where the water level exists at -28 m in Dahab 1X SI located to the south west of El Alamein and at -41.8 m in Sanhur 1X SI situated further to the south near the Qattara Depression. In this part, the aquifer is recharged from two sources, namely the Mediterranean Sea water intruded inland to the south, and the water leaking downwards from the overlying cavernous sandy limestone where there is a hydraulic connection. The water in this aquifer discharges naturally into the Qattara Depression which acts in this case as a natural drain.

In the eastern part which is located between Wadi El Natrun and the Qattara Depression, the groundwater in the Early Miocene aquifer shows a regional movement directed from east to west, i.e. towards the Qattara Depression. The water level in this part ranges

between -12 m in Wadi El Natrun, -20.9 m in Zobeida Well No. 1, -27.9 m in Tiba Well No. 2, and about -38 m to -50 m at El Moghra lake and spring. The aquifer here is recharged from the western fringes of the Nile Delta Basin.

This aquifer has been detected in El Arag Depression to the south west of the Qattara Depression, as well as in the southern part of the investigated area between Bahariya Oasis and the Qattara Depression. Groundwater from natural springs in El Arag Depression is produced from the porous and fissured limestones of the Middle Eocene at an absolute level of -50 m. These springs are aligned on fractures and fault lines, thus leading to the visualization of the fractures and faults traversing the Middle Eocene limestones acting as channels of groundwater from the artesian deep seated aquifers. A striking example for this phenomenon is illustrated by the case of the lakes at El Bahrein (level -12 m) Noweimsa (level -19 m) and Sitra (level -17 m) which are located on a major fault line attaining an ENE-WSW direction. This system of faults has been delineated on the structural lineation map (Plate III) constructed from LANDSAT satellite images. The water derived from the Middle Eocene limestones is almost brackish belonging to the chloride-sodium chemical type with a remarkable content of potassium salts.

This aquifer is constituted mainly of limestones with intercalations of dolomites and shales, and attains a thickness of 132 m reported in Siwa Well No. 1. It overlies the artesian sandstone aquifers, and produces groundwater of salinities varying between 246 ppm TDS in Siwa Well No. 1, 186 ppm TDS in El Bahrein Well No. 1 and 129 ppm TDS in Dessouky Well No. 1.

The composite Early Cretaceous - Early Carboniferous succession in Siwa Oasis environs is constituted of sandstones intercalated with sand, shale and carbonate beds. The sandstone water-bearing horizons constitute main aquifers which comprise a portion of the extensive multilayered artesian reservoir dominating southwards. The groundwater from the Early Cretaceous sandstones which are some 450 m thick, is generally fresh to brackish in nature, while that of the Early Carboniferous sandstones which are about 650 m thick is more saline. The TDS values in the groundwater of the Early Cretaceous sandstones are 620 ppm and 240 ppm in Siwa Well No. 1 and El Bahrein Well No. 1 respectively. These values increase with depth; in Siwa Well No. 1 near the base of the Early Cretaceous aquifer at depth of 1,115 to 1,125 m the TDS value reaches 1,564 ppm, rising to 2,985 ppm at the depth of 1,151 to 1,155 m. In the Early Carboniferous aquifer at 1,770 to 1,775 m interval, the TDS value is 3,736 ppm.

The Early Carboniferous aquifer is underlain by a thick sedimentary section of about 1,550 m in Siwa Oasis environs. Such section is constituted of sands and sandstones with shale inter-

*groundwater in
Middle Eocene
limestones*

*groundwater in
Late Cretaceous
limestones and
dolomites*

*groundwater in
Early Cretaceous -
Early Carboniferous
sandstones*

calations and ranges in age from Silurian to Cambrian. The groundwater obtained from the depth 1,865 to 1,870 m is relatively saline and the TDS value is 3,183 ppm.

The movement of groundwater in the investigated area, at least in the Early Cretaceous sandstone aquifer, follows the major trend of the comparable aquifer in Bahariya Oasis further south, which is the SW-NE direction, northward and SE-NW movements are also expected. The static level of groundwater shows declination in the SW-NE direction from +134 m in Bahariya Oasis to +37 m at Abu Senan due north, and to +73 m at Siwa Oasis due north west. The movement of groundwater apparently follows the major NE-SW Bahariya Oasis folding which has been delineated on the LAND-SAT satellite images.

groundwater recharge possibilities

From the previous discussion on the different hydrogeological conditions prevailing at Qattara Depression and its neighbourhood, there exists several possibilities for the recharge of groundwater in the Qattara Depression area which include Cretaceous and older sandstone aquifers, connate water, precipitation water, Nile water and Mediterranean Sea water. The recharge will be discussed in relation to the following geographic units.

South and West of the Qattara Depression : Regarding the piezometric head of the Cretaceous sandstone aquifer in the drilled deep wells in Agila, White Rock, El Bahrein and Siwa, there is an upward deep seated pressure which increases with depth. The static head decreases regionally to the north where it ranges from about +140 m to +75 m in the same direction. The natural springs near the southern limit of the Qattara Depression at El Arag, El Bahrein, Sitra and Noweimsa Lakes are oriented along fault lines as illustrated by the structural lineation map (Plate III). Moreover, the lithologic characteristics of the thick successive beds overlying the Cretaceous and older sandstone aquifers render the upward leakage difficult. So the possibility of the upward leakage of groundwater from the mentioned deep seated aquifers into the Eocene limestones dominating in the southern part of the investigated area at Sitra, El Bahrein and El Arag, and the Miocene limestone dominating in the western part in the environs of Siwa Oasis is attained through channels created by structural disturbances.

On the other hand, there are numerous natural springs distributed in this part along the peripheries of the tableland and at its contact with the depressional slopes. The water flowing from these springs is salty and it belongs to the sodium-chloride type. This may lead to the thought that the groundwater of such springs is derived from the water circulating in the limestone plateau, which is partly formation water diluted with fresh water during pluvial times, however, the orientation, of these springs along fault lines and fissures may give a special role to these lines as channels for bringing water from depth. The possibility of sea water intrusion and

present Nile water infiltration into the southern and western parts of the investigated area is excluded.

From the hydrogeochemical point of view, the water in the Cretaceous and older sandstone aquifers detected in the discussed part is generally fresh where the salinity ranges between 240 ppm TDS in El Bahrein Well and 800 ppm TDS in Siwa Well, while it belongs to the bicarbonate-sodium and chloride-sodium chemical types. Most of the water flowing from the natural springs in this part is highly saline, sometimes exceeding 8,000 ppm, and it belongs to chloride, sulphate-sodium type. Vertical chemical changes and salt concentration in spring water resulting from leaching processes might have taken place, but the effect of fault/fracture systems as well as the lithology of the enclosing rocks should be considered in evaluating the spring recharge.

It may be concluded that the Eocene and Miocene aquifers in the southern and western parts of the Qattara Depression appear to be mainly recharged from the upward leakage of the Cretaceous and older sandstone deep seated water especially along faults and fracture lines. However, additional contribution from Pleistocene and Holocene precipitation should be also considered. For a more precise evaluation of the groundwater in the discussed part a number of shallow bore holes are recommended to be drilled for piezometric observations and for studying the geochemical behaviour of the groundwater and its more specific sources and movements.

East of the Qattara Depression: In the part extending from the Qattara Depression eastwards to Rosetta Nile Branch, there exists natural water basins at Wadi El Natrun and El Moghra Depression. In this wide part, there is a gradual and regional piezometric slope from east to west, i.e. from Rosetta Branch (absolute level about +10 m) to Wadi El Natrun (absolute level approximately -12 m) to El Moghra Depression (absolute level about -38 m) where the groundwater percolates through permeable Neogene-Quaternary sediments.

The hydrochemical properties of the groundwater in the discussed part changes from bicarbonate-calcium type in the shallow aquifer existing in Pleistocene and Holocene gravels to chloride-sodium and sulphate-sodium types in the Miocene aquifer in Wadi El Natrun to chloride-sodium type in the Miocene aquifer in El Moghra.

The deep seated faults in the eastern parts are not very effective where the overlying sedimentary succession is relatively thick and impermeable. Accordingly, the upward leakage from the deep seated aquifers is doubted. It is visualized that the Nile water seeping due west with some contribution from the Neogene connate water and rain water are the sources of water recharge to the east of the Qattara Depression.

North of the Qattara Depression : From the physiographic point of view, the part located between the Mediterranean Sea and the Qattara Depression is occupied by an immense limestone plateau. There is an altitude difference of more than 130 m between the Mediterranean Sea water level and the bottom of the depression. The plateau is built up to a considerable extent of cavernous limestone of Middle Miocene age overlying a thick succession of sandy facies belonging to the Early Miocene. Northwards, this sandy facies changes into clayey facies.

The regional northward dip of the whole succession and the presence of aquicludes of Paleogene sediments underlying the aquifer limit the intrusion of the sea water towards the depression. The main saline water table which is created as a result of the sea water intrusion does not extend beyond 10 to 15 km and even less inlands. This is followed laterally by a deeper water table, the level of which is controlled by the low lying Qattara Depression. To the east of El Dabaa the groundwater level in the Miocene aquifers is ranging between -1.8 m and -50 m. The water flow in this locality is in the southward direction and is not always smooth, but showing some irregularities which are controlled by surface topography, local structure, thickness of the aquifer penetrated and lateral change of facies. In the part to the south of Mersa Matruh, there is also a regional trend of water movement in the southward direction towards the Qattara Depression. The groundwater level exists always above sea level in the area occupied by El Diffa Plateau beyond the coastal plain. It exists at a level varying from $+94$ m in Mersa Matruh Well No. 2, to $+72$ m in Khalda 1 SI, to $+66$ m in NKSH 1 SI. This high absolute level of the groundwater is neither related to the sea water intrusion, nor to the upward leakage from the deep seated aquifers equivalent to the Cretaceous and older sandstone aquifers dominating in the south, due to the great thickness of the overlying succession and its development into impervious media. However, it is visualized to be related in the first place to connate water with contributions of precipitation water.

effect of Qattara Project on groundwater conditions

Pending the execution of detailed research work along the alignment L1 of the proposed canal connecting the Mediterranean Sea at El Sira with the Qattara Depression at Salt Springs or the Western Wadi (Qattara Project Authority, 1976), the following conclusions are reached regarding the effect of this canal on the groundwater conditions in its environs .

The proposed canal will come surely in contact with the Pleistocene detrital limestone aquifer, where the fresh to brackish groundwater is floating on the sea water. If the canal is not lined by an impermeable lining the groundwater will seep from the aquifer into the canal along its northern 10 to 15 km. As the aquifer is the one normally used for agriculture and civil consumption on the Mediterranean Sea coastal strip, the leakage has to be quanti-

tatively estimated by further detailed studies. If the canal is lined even as high as a level of about 150 cm above sea level or in case of application of nuclear explosives whereby a glazed layer is created on the sides of the canal, this will prevent the water seepage from the aquifer into the canal. In the latter case the effect of the nuclear explosives on the quality of the part of the aquifer adjacent to the canal is one of the important problems to be tackled in the detailed investigations to be carried out along the canal alignment. Another problem which should be evaluated at the same time is the probable extension of the small perched aquifer at El Qutaf in El Dabaa locality into the canal site and, accordingly, the possible seepage from the mentioned aquifer into the canal.

The seepage of the saline sea water from the canal into the Middle Miocene cavernous limestone aquifer and the Early Miocene sandstone aquifer will be maintained until an equilibrium is reached. The seepage is expected to cause the rise of the groundwater table in the Miocene aquifers, however, this will not cause any particular damage as these aquifers are not utilized.

The water flowing from the hanging springs along the northern rim of the Qattara Depression which is mostly brackish to salty in nature, will be more saline in general near the canal discharge into the depression. However, as the water flowing from these springs is not utilized this salinization will not represent any damage of particular significance. Furthermore, filling the Qattara Depression with sea water up to the absolute level of -60 m, as expected to occur after the execution of the Qattara Project for electric power generation, does not appear to affect the groundwater conditions in an adverse manner in the northern and eastern parts of the depression. The latter will still act as a natural drain for groundwater reaching El Moghra at a level of about -38 m from the east, and the northern rim of the depression at an absolute level below -50 m from the north. Even if there is any change in the groundwater level after the construction of the canal, the tendency will be towards the rising of the water level in the aquifers.

In the southern and western parts of the Qattara Depression, the pattern of the major faults and fractures there points out to the importance of conducting detailed investigations on the possible interconnection between the southern part of the depression and the utilized aquifers in Siwa Oasis Depression. There are small depressions near to the southern part of the Qattara Depression which include El Arag and others, however, the water in these depressions is not utilized. The long distance which separates the Qattara Depression from Siwa Oasis Depression makes the short term effects of filling the Qattara Depression to the absolute level of -60 m on the groundwater in the Siwa Oasis Depression highly improbable, however, the long term effects represent a subject worth of further detailed studies.

TABLE 4. Results of Chemical Analysis of Water Samples From Several Aquifers.

Aquifer	Locality	T.D.S. ppm	pH	Cations				Anions			
				Na ⁺	K ⁺	Mg ⁺⁺	Ca ⁺⁺	Cl ⁻	SO ₄ ⁻⁻	CO ₃ ⁻⁻	HCO ₃ ⁻
Detrital Limestone (Pleistocene)	El Dabaa	360	8.1	110	11	7	12	23	110	15	174
	Zaweit El Moneim	1,380	6.4	380	18	117	54	265	128	31	406
	Gemeima	4,800	7.5	855	38	276	138	2,085	190	20	179
Cavernous Limestone (Middle Miocene)	NW El Dabaa	16,000	7.7	5,650	430	417	77	9,135	210	406	1,302
	El Qutaf, El Dabaa	400	6.2	41	14	18	28	19	20	14	233
Limestone (Middle Miocene)	Abu Shuruf, Siwa	8,985	7.2	2,500	70	32	28	3,536	2,300	15	94
	Zeitun, Siwa	2,120	6.9	520	31	62	114	785	450	18	126
	Ain Ashtar, Qara	8,148	6.8	1,960	52	336	434	3,067	2,200	18	166
	Ain Qattara, Qara	7,920	6.7	2,090	54	279	374	2,700	2,400	11	193
Sandstone (Early Miocene)	Washaka 1X Water Well	—	—	—	—	—	—	13,000	—	—	—
	Alamein Field Water Well	—	—	—	—	—	—	11,000	—	—	—
	Abu Gharadig	18,120	6.9	5,000	73	598	792	8,566	3,050	11	121
	El Moghra	2,915	6.9	800	24	76	162	1,350	425	11	123
Sandstone (Cenomanian)	Maesra Well 1, Bahariya	166	6.4	28	17	11	10	39	15	—	92
	Bahariya Well 1	240	6.8	62	10	5	340	37	30	9	94
	Siwa Well 1	620	7	213	16	3	9	157	130	22	145
	Ghazalat Well	4,830	6.5	1,550	49	37	123	1,478	1,400	35	303

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منخفض القطارة لتوليد الطاقة الكهربائية ، وتقييم المسائل الإقليمية المرتبطة بذلك التنفيذ . وتتضمن تلك المسائل مواقع الفواقي والتهشم الكبير في القشرة الأرضية وخطوط الضعف التي تعترضها ، ومجاري الصرف والمسيول والتقاءاتها بعضها ببعض ، والخصائص المختلفة للصخور التي سوف تصادفها الأعمال الإنشائية للمشروع ، والتي يلزم تحديدها بوضوح قبل التخطيط الهندسي واعداد التصميمات الهندسية الخاصة بالمشروع . كما تم كذلك تحديد الرواسب المحيطة التي تغطي المنخفض ذاته .

ونظرا لأنه قد تبين من صور القمر الصناعي ان الرواسب المحيطة التي تغطي قاع المنخفض ضخمة جدا ، وان المياه التي تحملها السيول الى المنخفض والتي تتسرب اليه كبيرة الكميات ، فانه يجب اخذ تلك العوامل في الاعتبار في تقييم الخواص الطبيعية والكيميائية للمياه التي ينتظر تجمعها في المنخفض عن طريق القناة الموصلة بينها وبين البحر الأبيض المتوسط .

وقد تم توضيح ظروف المياه الأرضية في منطقة المنخفض وما يتأخمها على اساس اقليمي لبيان العلاقة بين حفر قناة على الخسب ل 1 و ملء منخفض القطارة حتى مستوى مطلق يبلغ ٦٠ مترا وبين المياه المستخدمة في الأغراض الزراعية والمدنية وغيرها في المنطقة المحيطة بالمنخفض . وقد وضعت بناء على ذلك التوصيات الخاصة بما يلزم اجراؤه من ابحاث تفصيلية في مواقع محددة بالمنخفض .

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الملخص

تقع منطقة الدراسة في الجزء الشمالى من الصحراء الغربية
المصرية بين خطى الطول $26^{\circ}00' - 29^{\circ}00'$ شرقاً ، وخطى
العرض $29^{\circ}00' - 30^{\circ}00'$ شمالاً ، وبين خطى الطول
 $25^{\circ}00' - 27^{\circ}00'$ شرقاً ، وخطى العرض $28^{\circ}00' - 29^{\circ}00'$
شمالاً . وتغطى هذه المنطقة منخفض القطارة الذى يعتبر اكبر
منخفضات الصحراء الكبرى واحد معالمها الفسيوجرافية الرئيسية .
كما تغطى كذلك عددا من المنخفضات الاصغر مساحة .

وقد عملت خرائط للمرة الاولى لمنطقة منخفض القطارة
بمقياس رسم 1 : 50.000 باستخدام الصور الالكترونية للقمر
الصناعى « لاندسات » المأخوذة فى اربعة مجالات ضوئية .
وتتضمن هذه خرائط التكاوين الجيولوجية والتراكيب الارضية
والصرف السطحى كما عملت خريطة لكثافة التراكيب الارضية
وخريطة لكثافة الصرف السطحى لنفس المنطقة بتطبيق الحساب
الالكترونى على الخرائط السالفة الذكر . وقد تم كذلك عمل خريطة
تبين ظرووف المياه الارضية فى منطقة منخفض القطارة والمناطق
المتاخمة لها بناء على تفسير صور القمر الصناعى مع البيانات
الخاصة بالطبقات الحاملة للمياه الارضية السائدة فى تلك المناطق .
وقد تم تعزيز العمل البحثى الحالى بقياسات ودراسات حثلية مستفيضة
وتحليل معملي للعينات التى تم جمعها اثناء العمليات الحقلية .

وقد اوضحت الدراسات الحالية للمرة الاولى الوضع الاقليمى
للوحدات الجيولوجية والفوالق والكسور والطيات بالقشرة الارضية ،
وخطوط الصرف مما يساعد على استنباط التأثير البيئى لتنفيذ مشروع

دراسات جيولوجية للصخور الإلكترونية
للقمر الصناعي "لاندسات-1"
لمنطقة منخفض القطارة
بمصر

استاذ دكتور محمد احمد عبد الهادى

استاذ الهندسة المدنية بجامعة ولاية أوكلاهوما بالولايات المتحدة
الأمريكية ومدير مركز الاستشعار من البعد - القاهرة

استاذ دكتور الشاذلى محمد الشاذلى

نائب مدير هيئة الطاقة الذرية ورئيس قسم الجيولوجيا والخامات
الذرية ومدير المجموعة الجيولوجية بمركز الاستشعار من البعد -
القاهرة

دكتور محمد محمد الشاذلى

استاذ مساعد بمعهد الصحراء والباحث بمركز الاستشعار من البعد
القاهرة

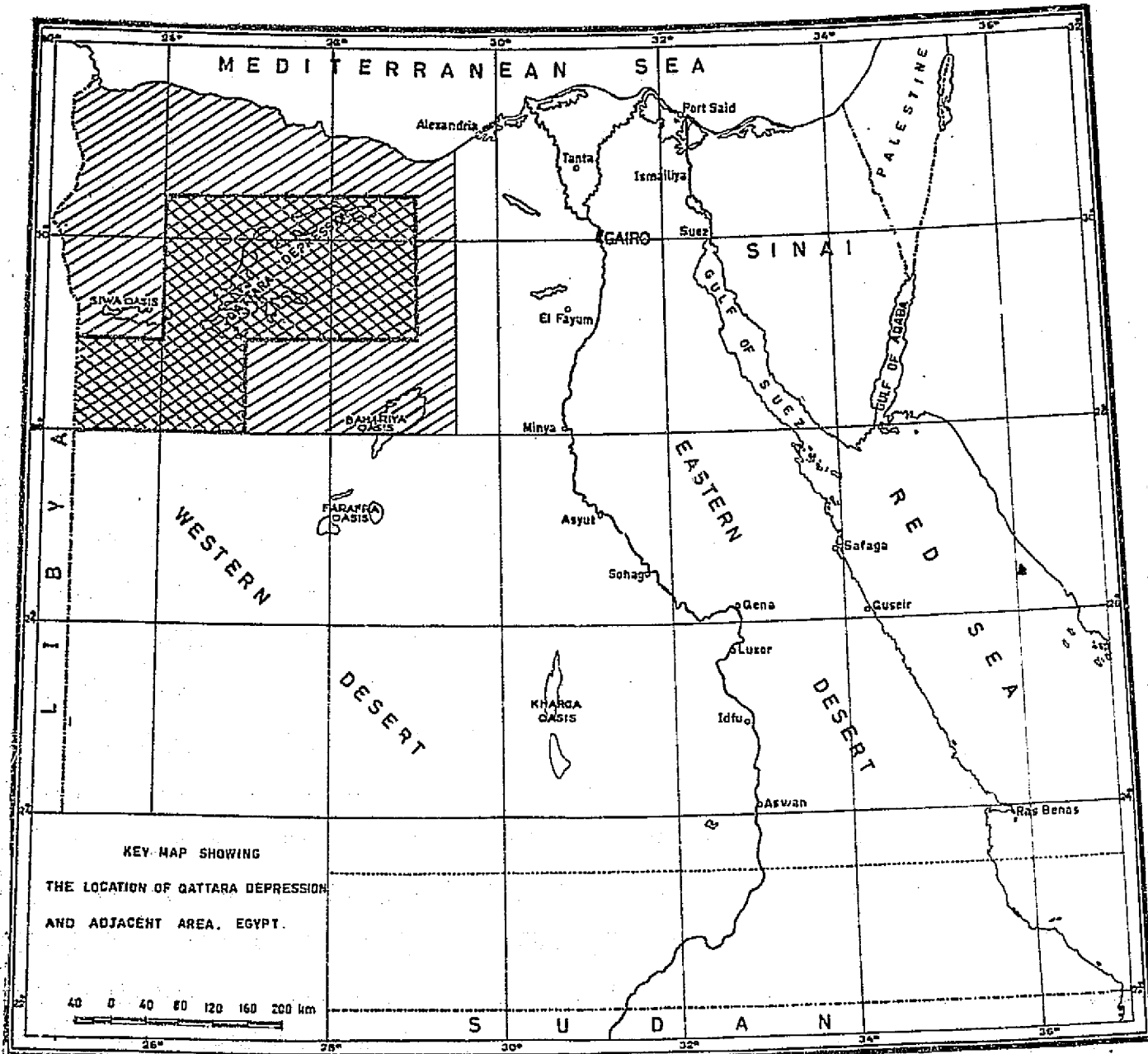
دكتور محمد عبد الرازق الفوايى

ودكتور سمير محمد خواسك

جيولوجيان بقسم الجيولوجيا والخامات الذرية وباحثان بمركز
الاستشعار من البعد - القاهرة

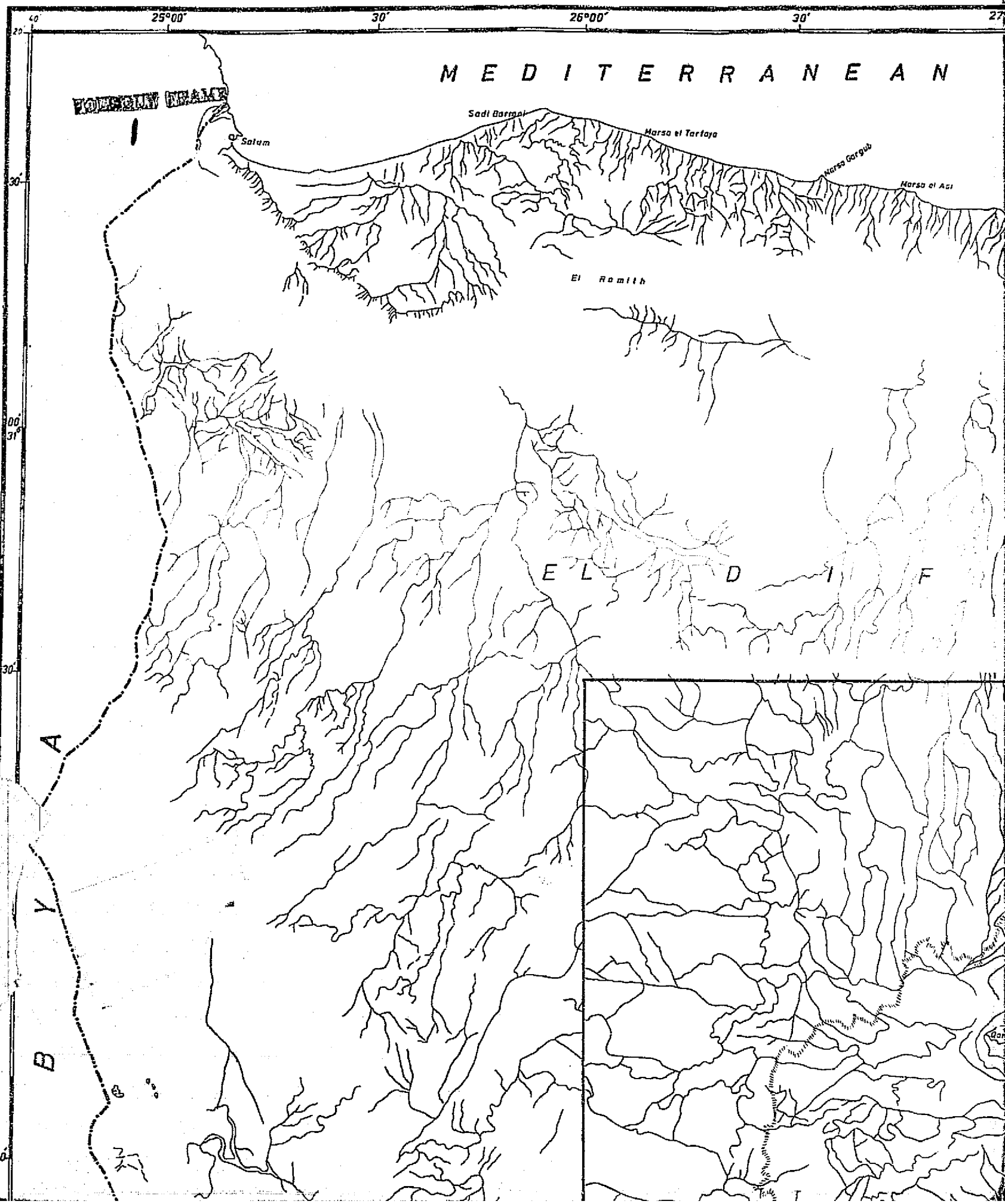
مركز الاستشعار من البعد
أكاديمية البحث العلمى والتكنولوجيا
القاهرة - جمهورية مصر العربية
نوفمبر ١٩٧٦

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OSU-REMOTE SENSING RESEARCH PROJECT
ACADEMY OF SCIENTIFIC RESEARCH AND TECHNOLOGY, CAIRO



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27°00'

30'

28°00'

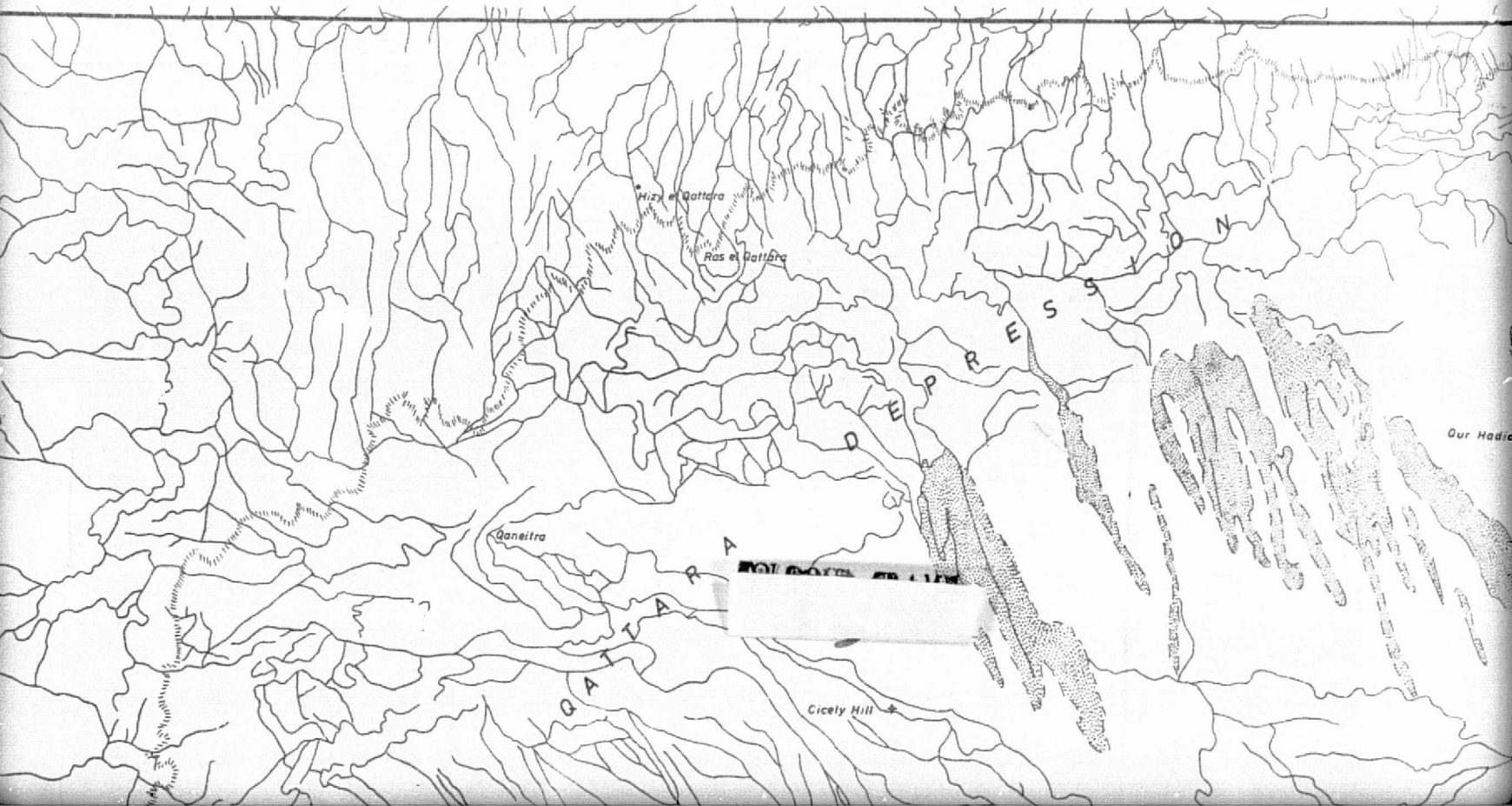
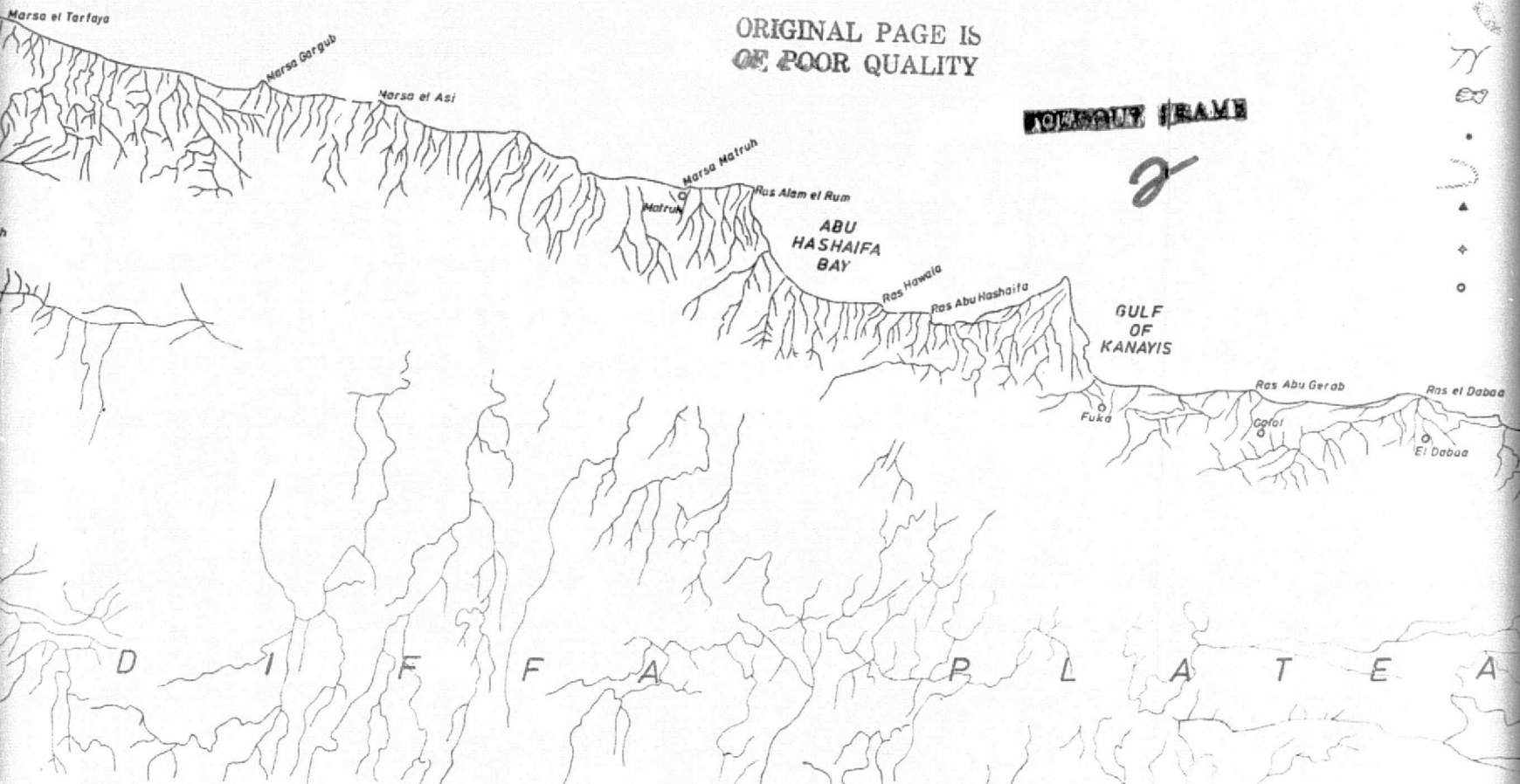
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TOPOGRAPHIC FRAME

2



30°

28°00'

30°

29°00'

30°

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LEGEND



SAND DUNES



SAND DUNE BELTS



DRAINAGE LINES



WATER PONDS



SPRINGS AND WATER WELLS



BOUNDARY OF ESCARPMENTS



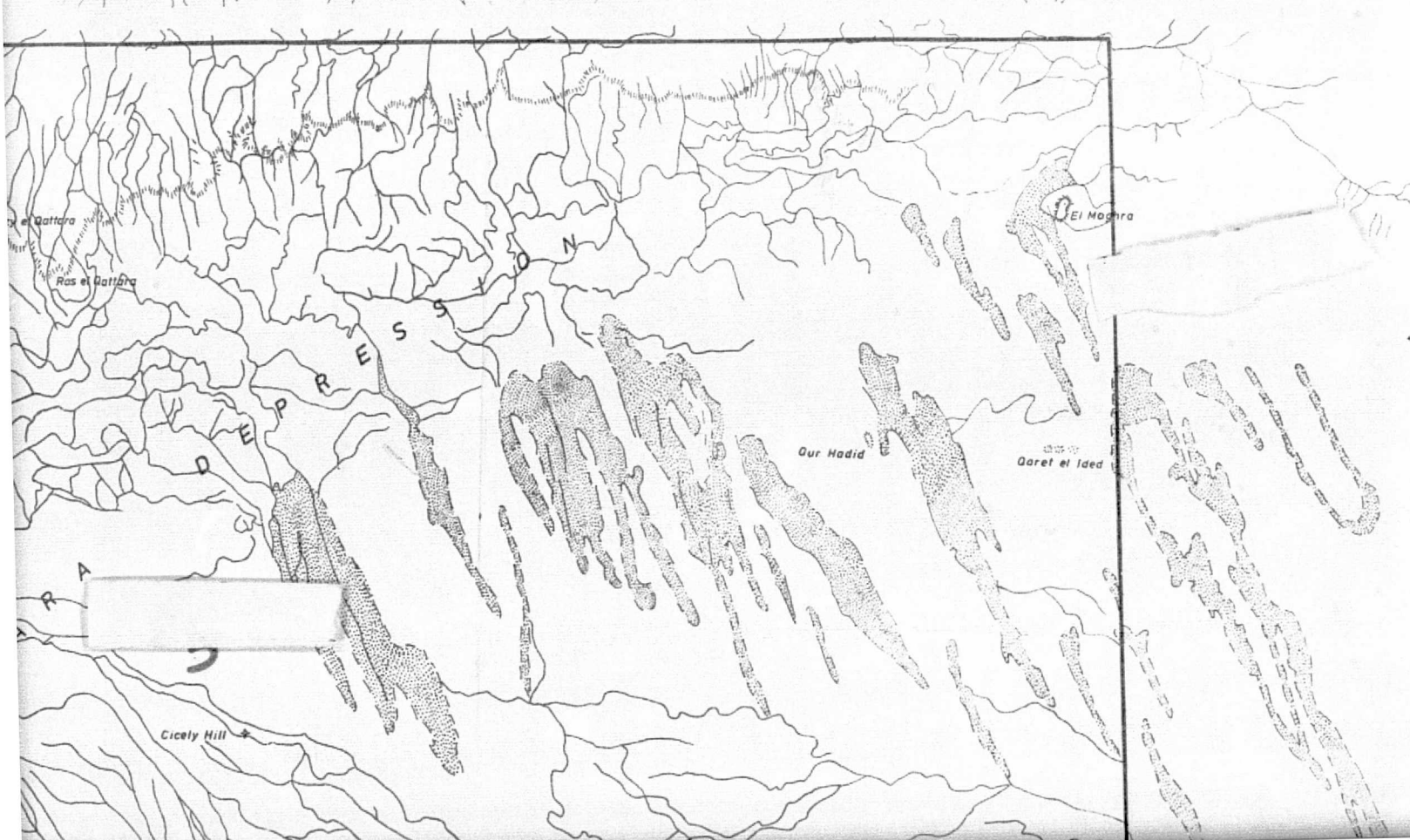
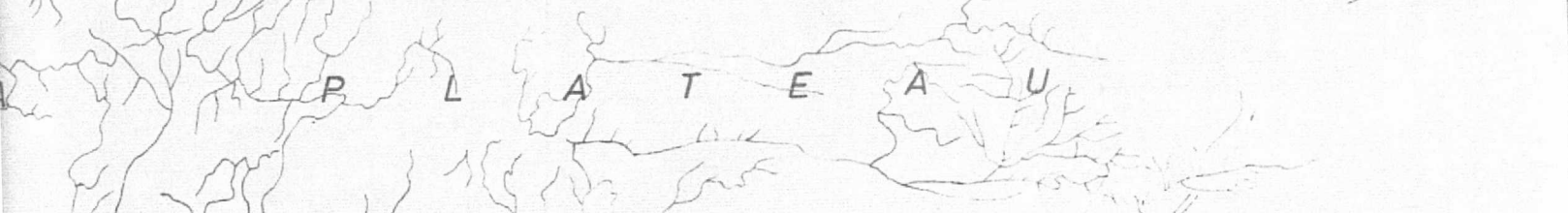
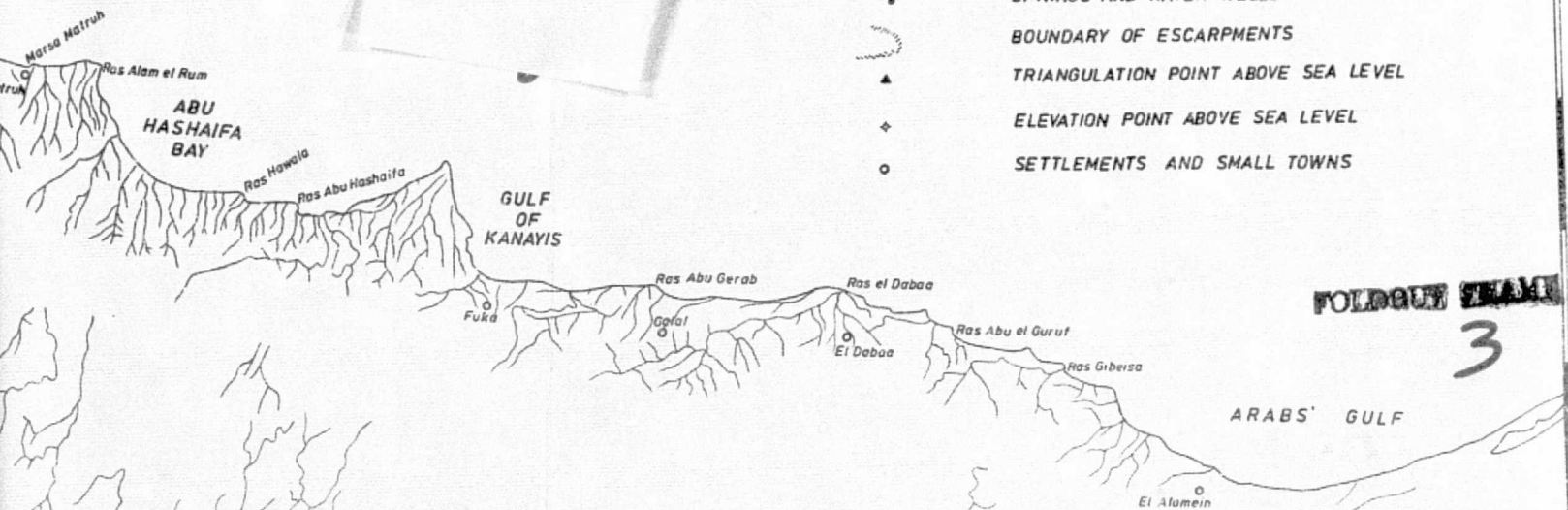
TRIANGULATION POINT ABOVE SEA LEVEL

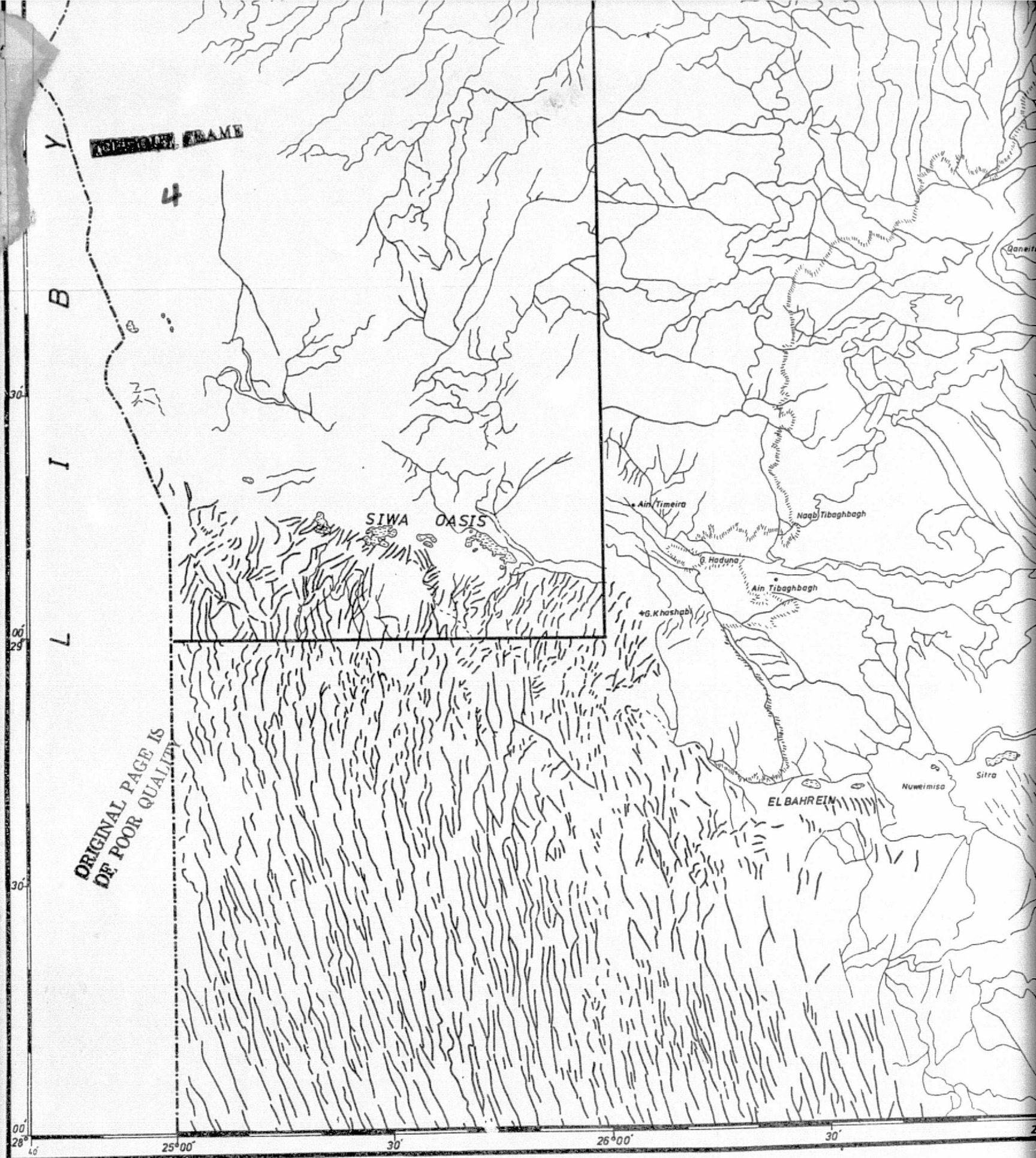


ELEVATION POINT ABOVE SEA LEVEL

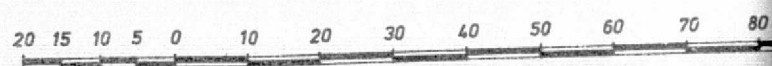


SETTLEMENTS AND SMALL TOWNS

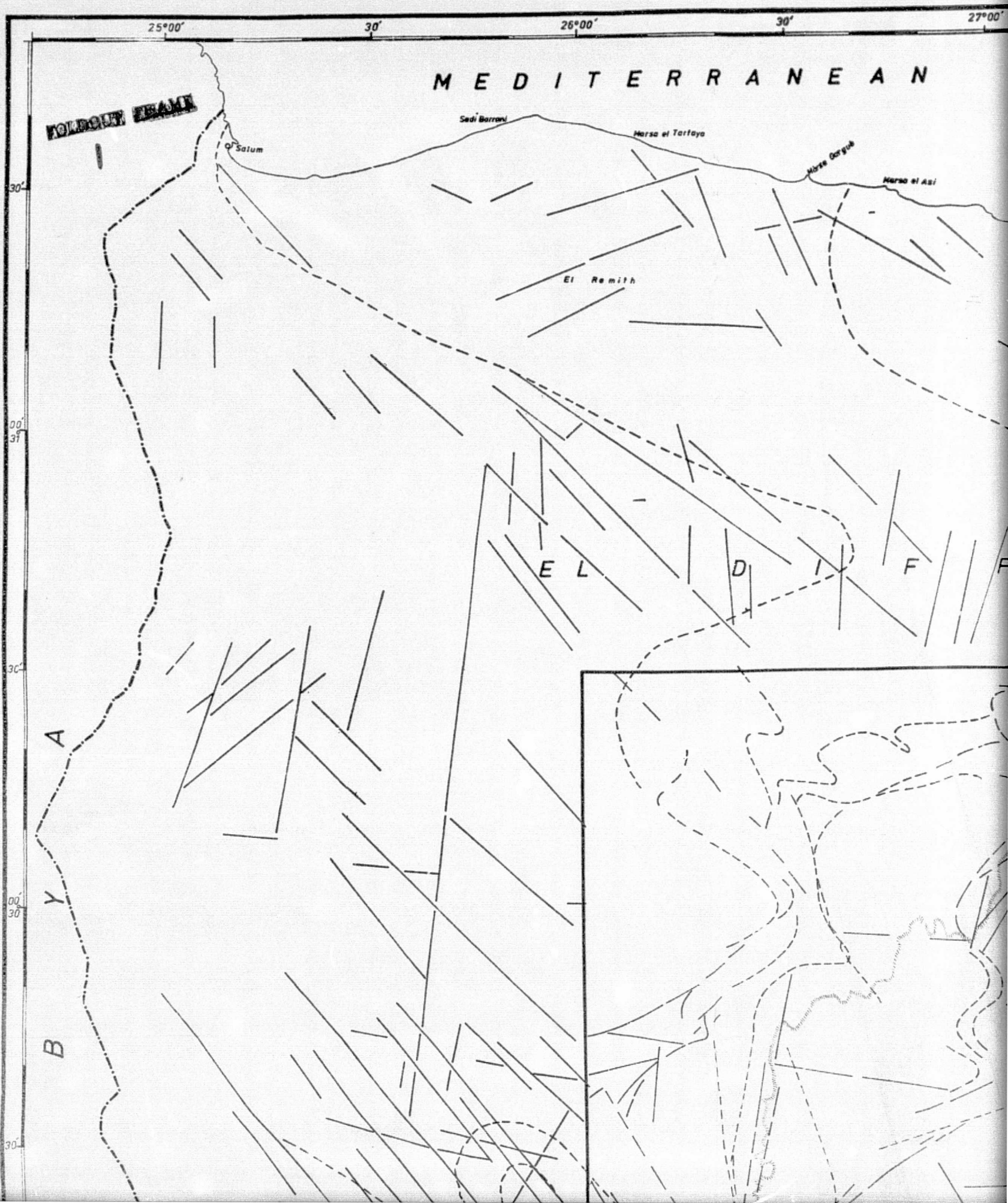




DRAINAGE MAP OF QATTARA DEPRESSION
(FROM LANDSAT - 1 SATELLITE IMAGES)



OSU-REMOTE SENSING RESEARCH PROJECT
ACADEMY OF SCIENTIFIC RESEARCH AND TECHNOLOGY, CAIRO





30'

28°00'

30'

29°00'

30'

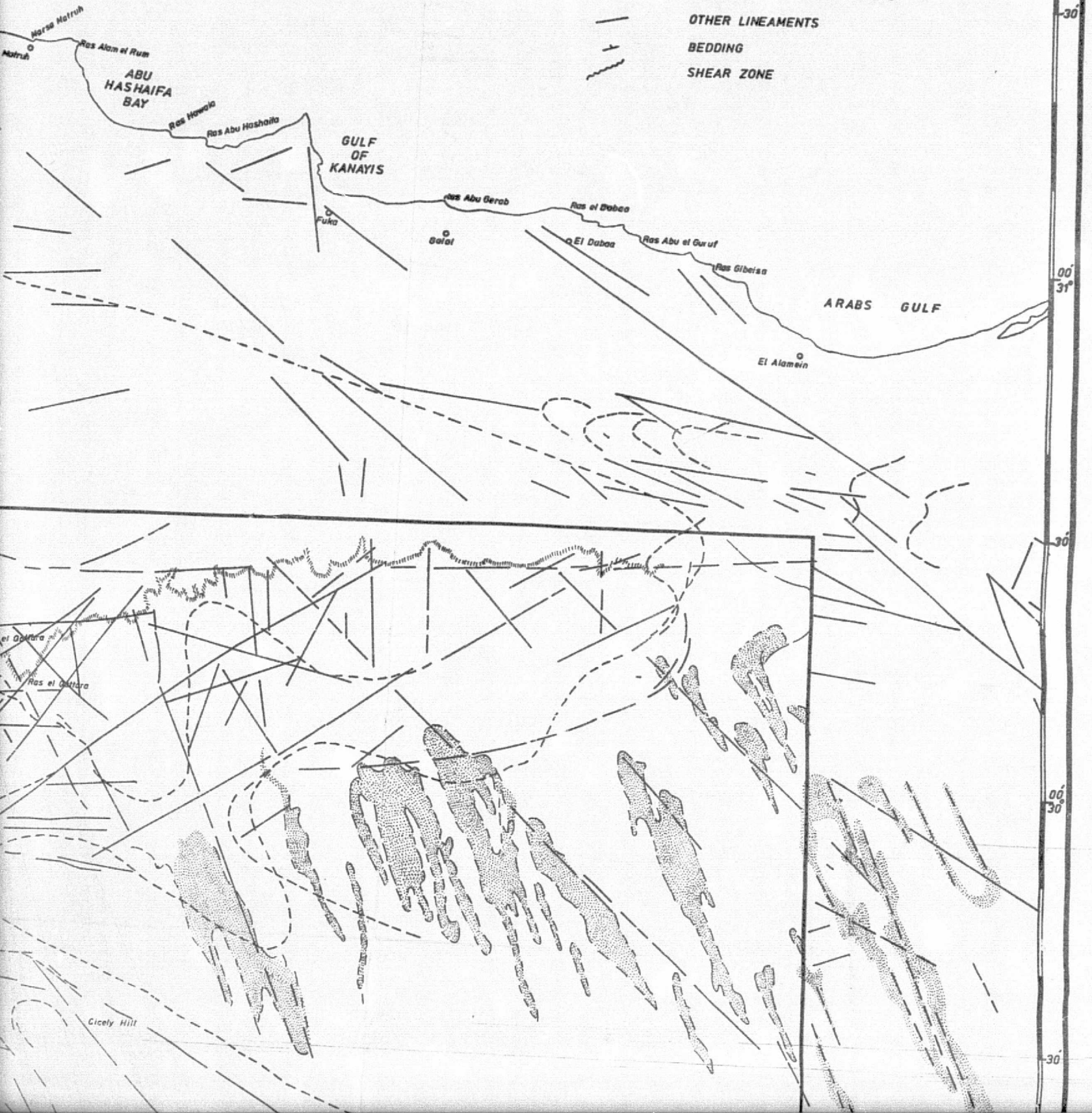
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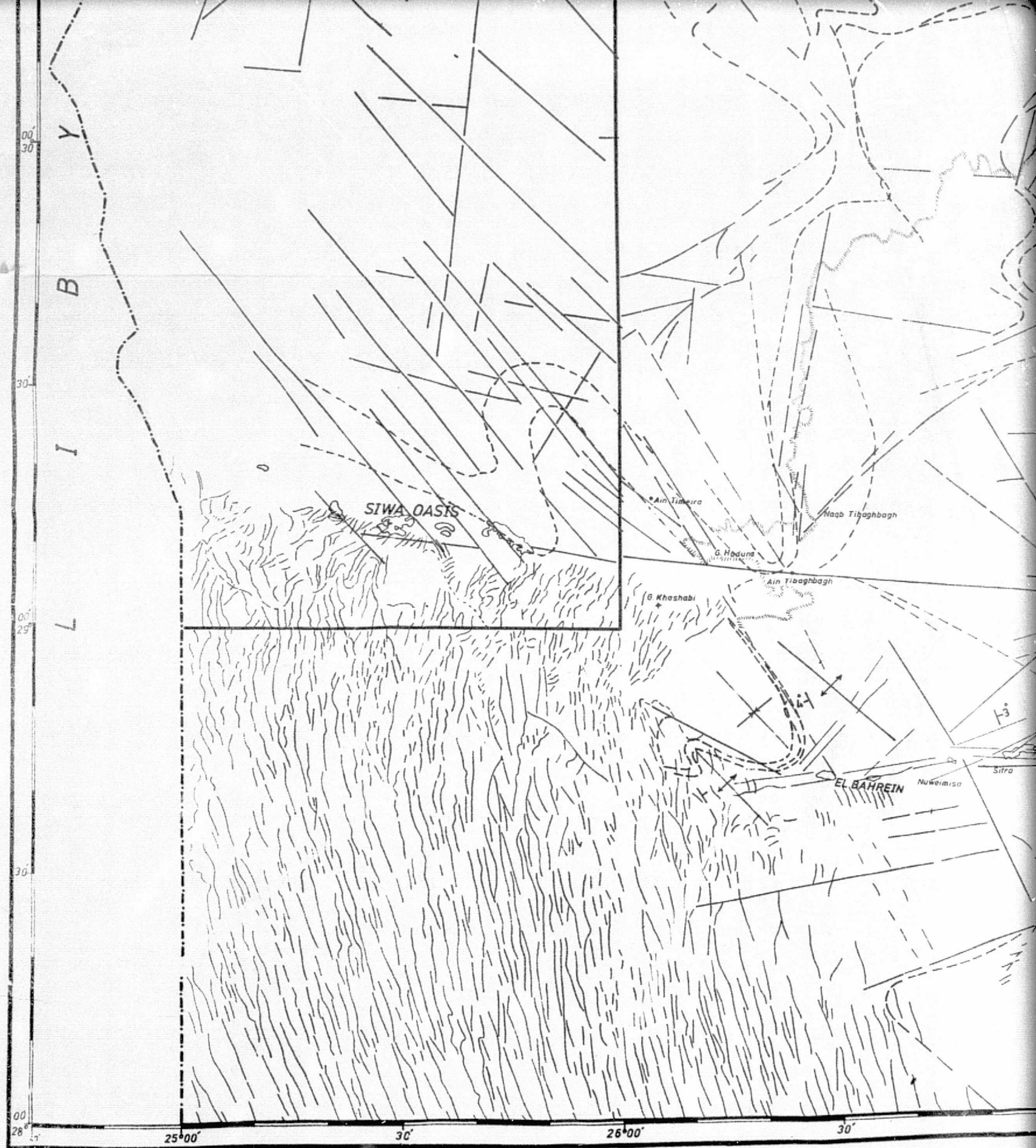
LEGEND

-  SAND DUNE
-  SAND DUNE BELTS
-  FOLD TRACES
-  FRACTURES INCLUDING FAULTS
-  OTHER LINEAMENTS
-  BEDDING
-  SHEAR ZONE

1000 METERS

3

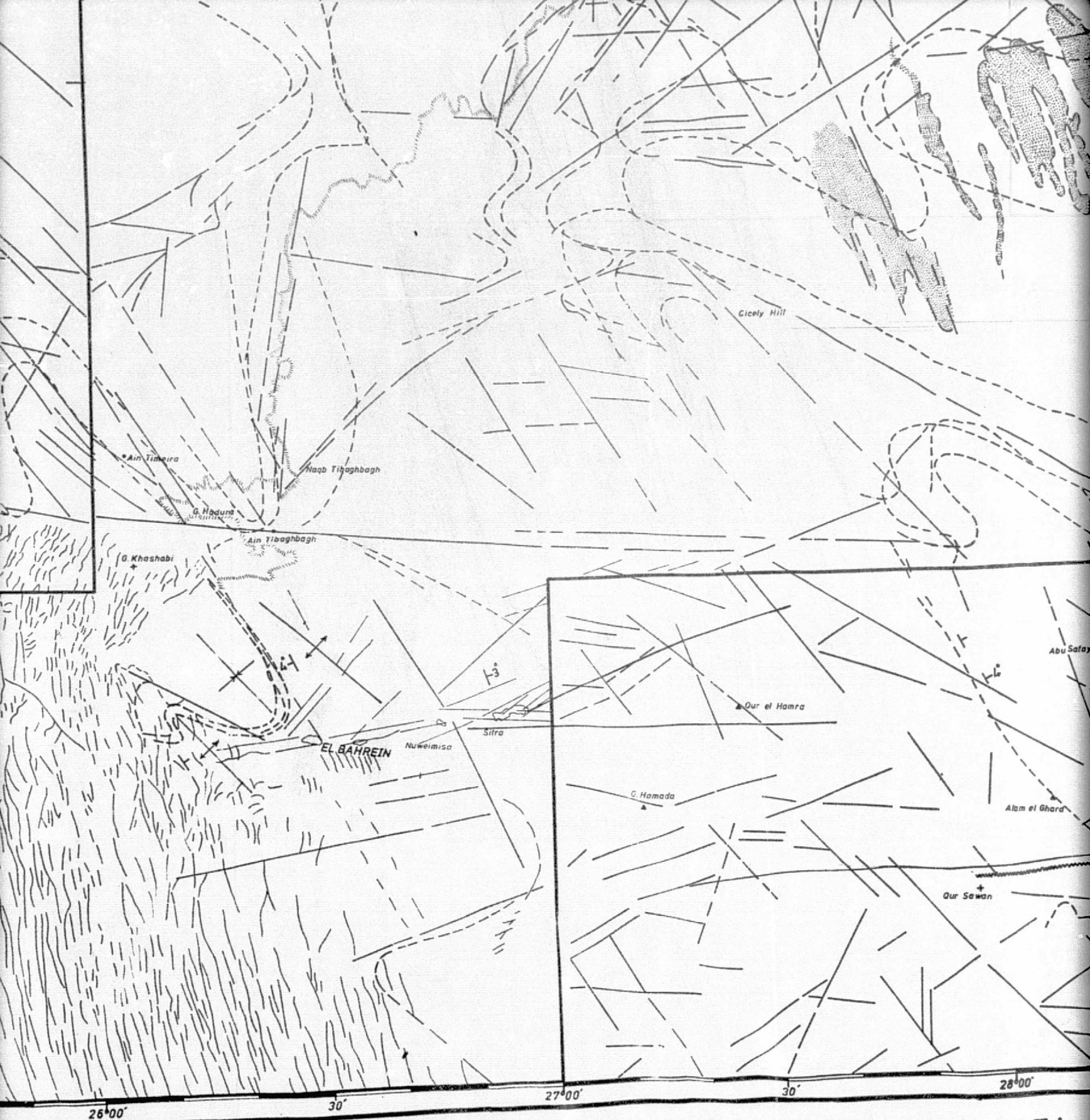




STRUCTURAL LINEATION MAP OF QATTARA L
(FROM LANDSAT - 1 SATELLITE)

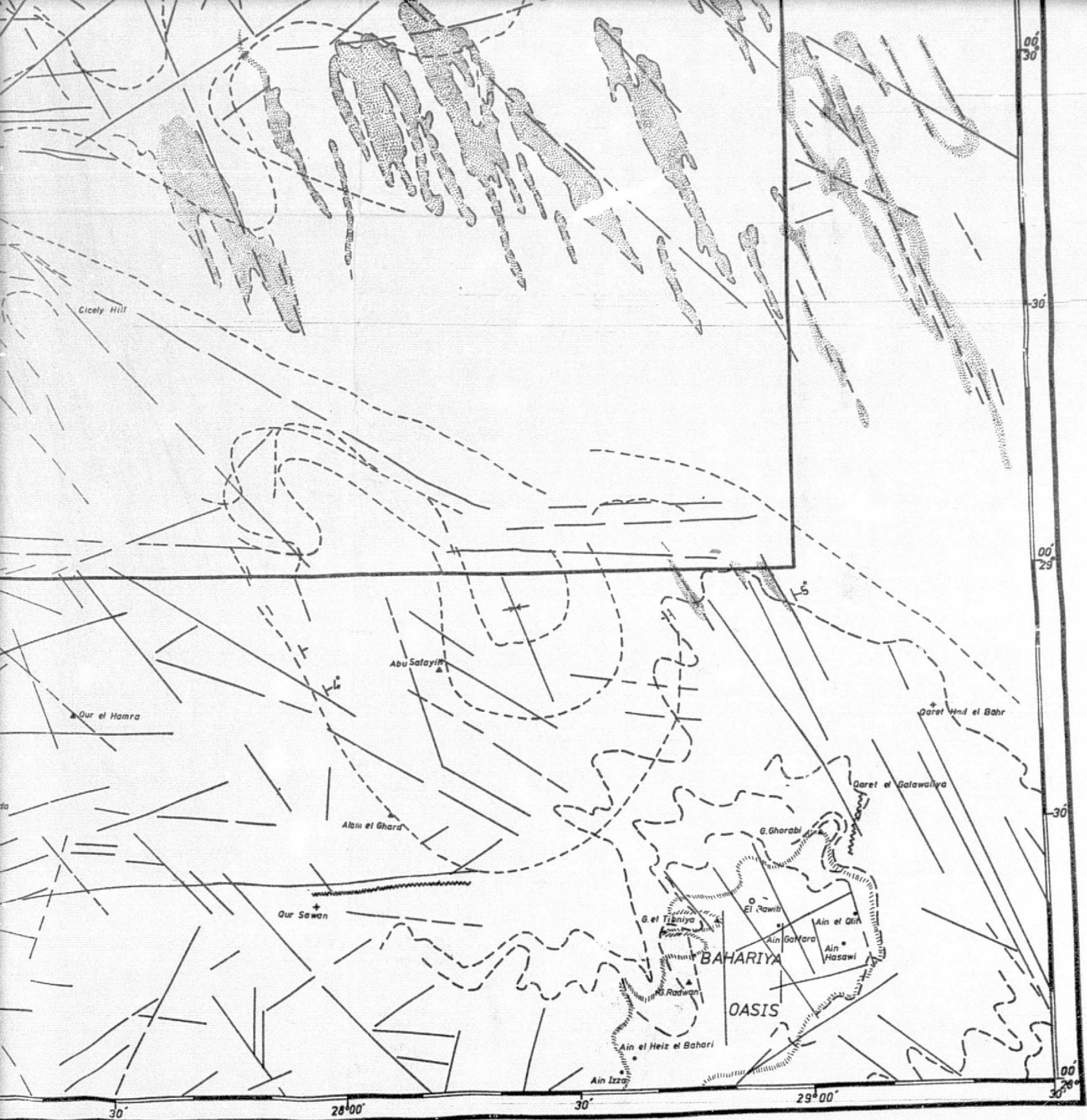
FRAME
4

20 15 10 5 0 10 20 30 40 50 60



AL LINEATION MAP OF QATTARA DEPRESSION AND ADJACENT AREA,
 (FROM LANDSAT - 1 SATELLITE IMAGES)





ON AND ADJACENT AREA, EGYPT

100 Km

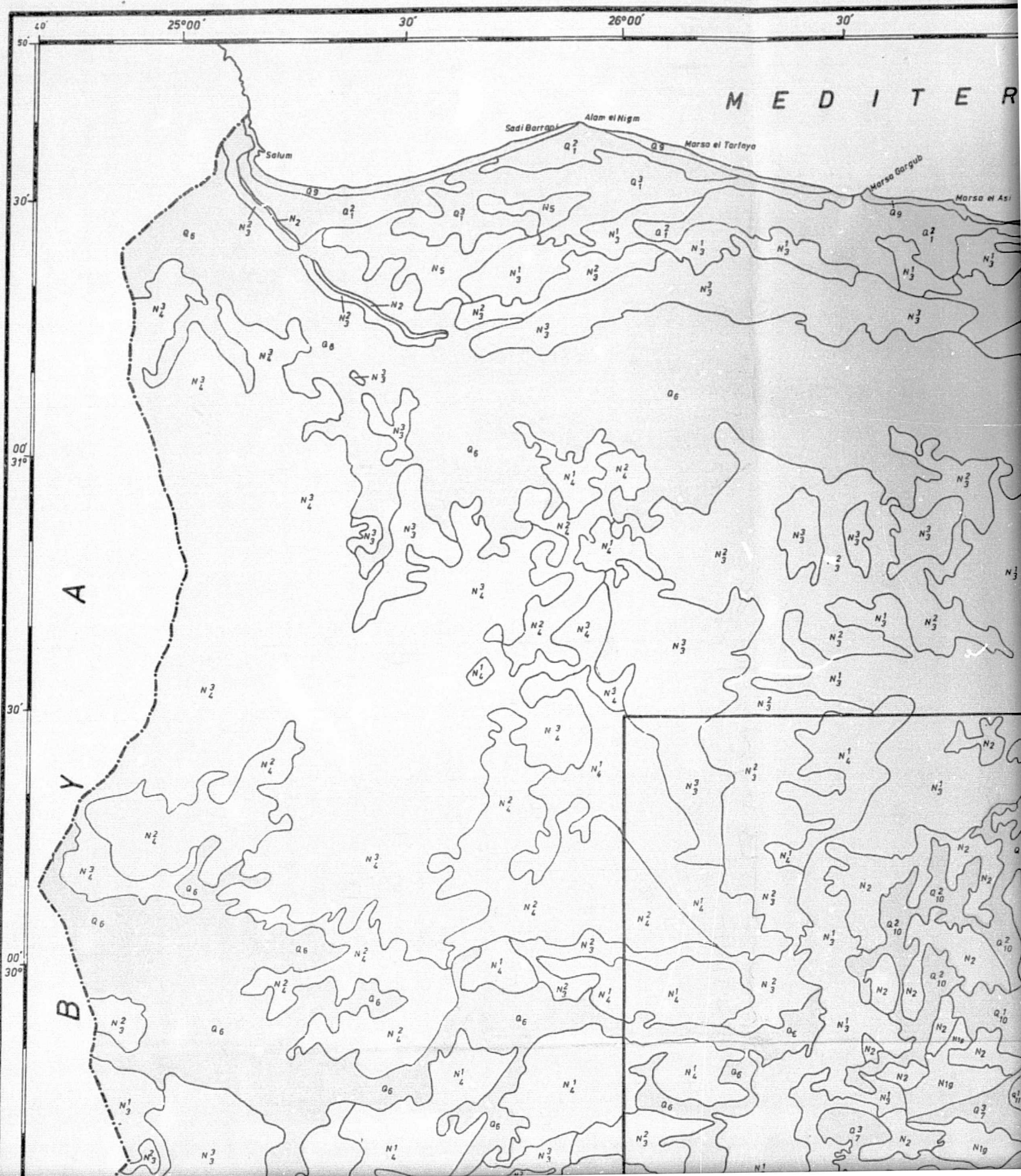
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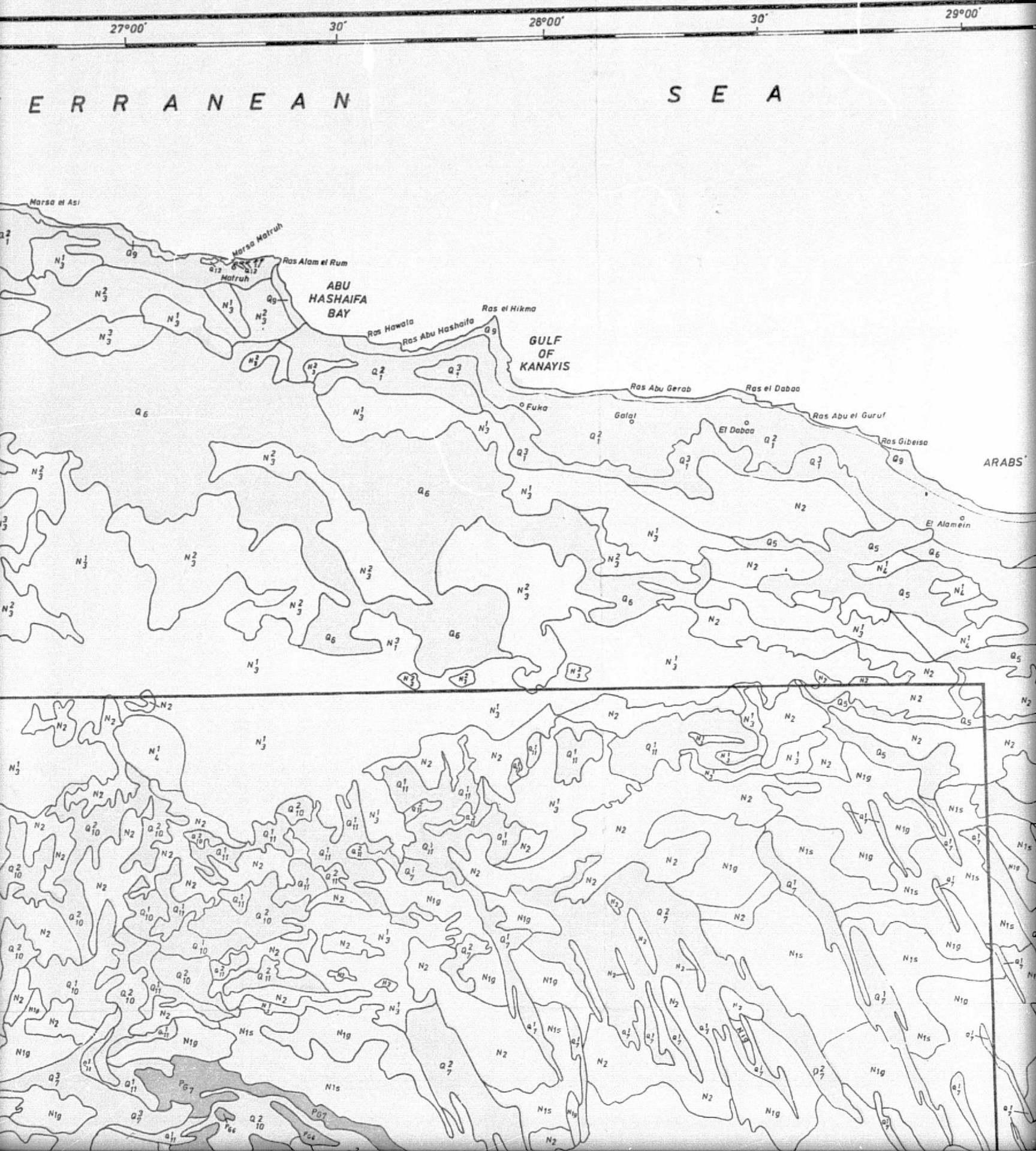
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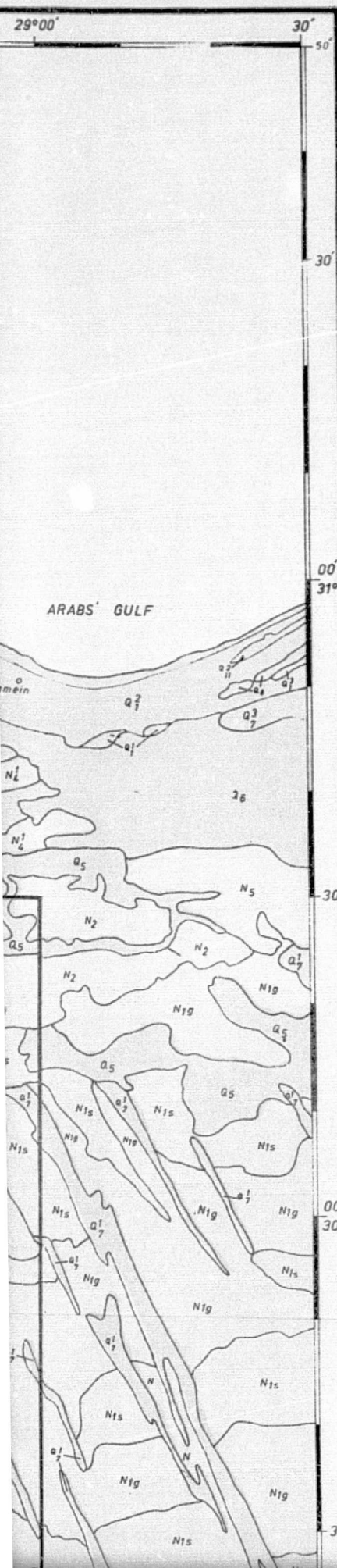
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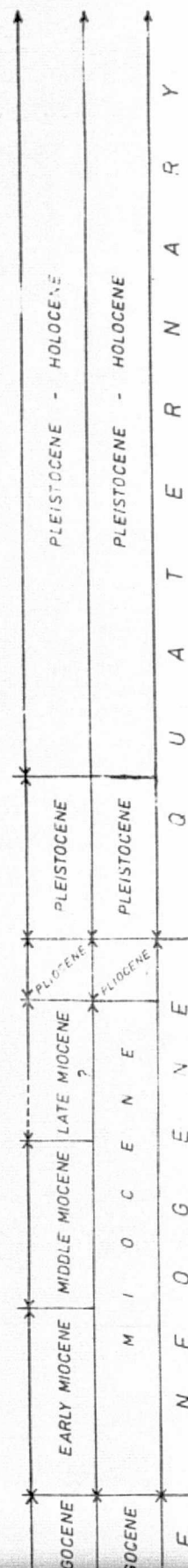


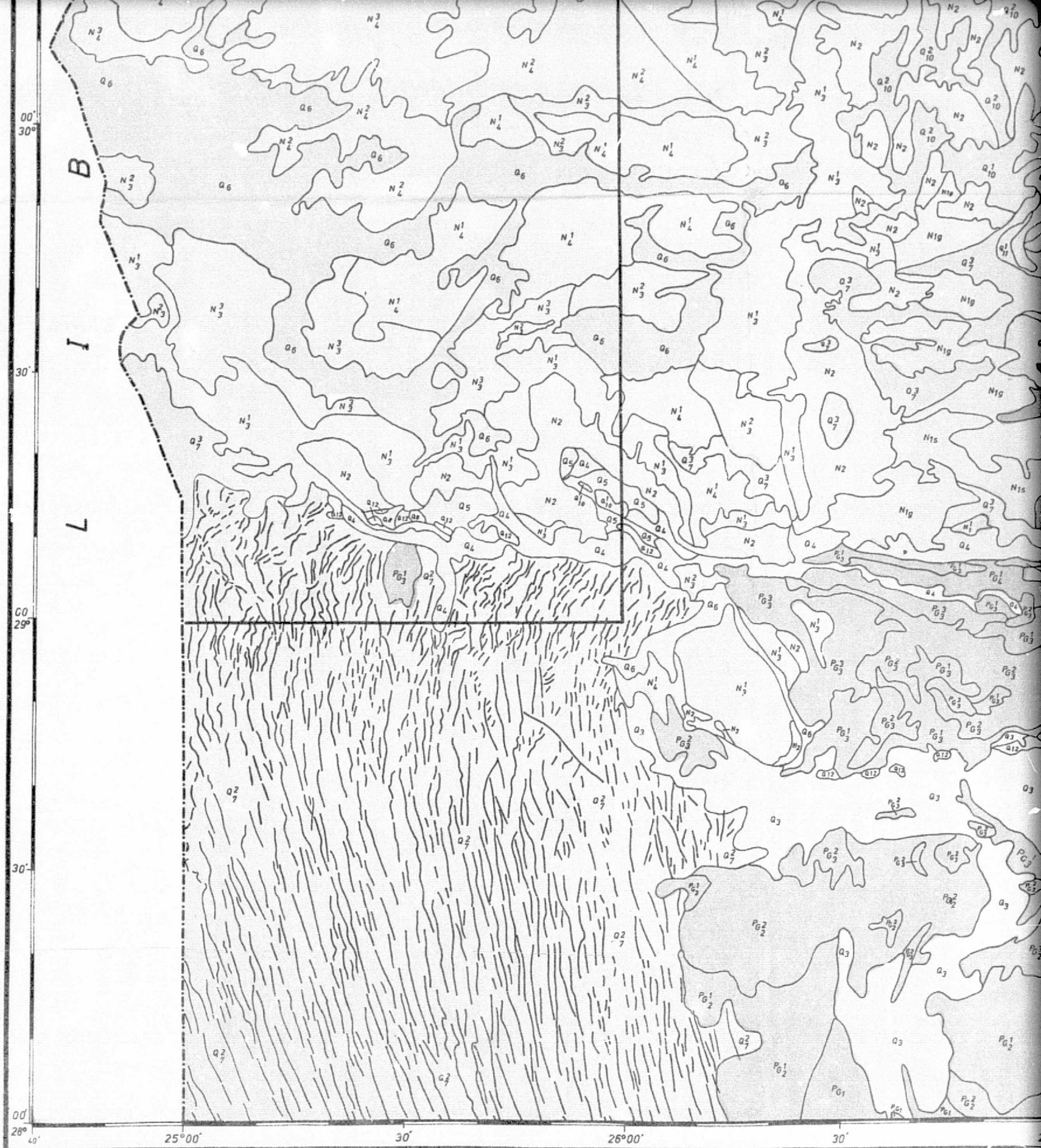


LEGEND

3

Q₁₂	LAKES AND WATER PONDS	a₁₁²	Light colored salty crusts
Q₁₁	SALTY CRUSTS	a₁₁¹	Dark colored salty crust
Q₁₀	SABKHAS	a₁₀²	Clayey sabkhas
		a₁₀¹	Sandy sabkhas
Q₉	BEACH DEPOSITS		
Q₈	NATURAL VEGETATION AND SPORADIC CULTIVATION		
		a₇³	Small sand dunes and sand accumulations
Q₇	SAND DUNES	a₇²	Moderate sand dunes
		a₇¹	Sand dune belts
Q₆	ALLUVIAL DEPOSITS DERIVED FROM MIOCENE AND PLIOCENE ROCKS		
Q₅	" " " " " OLIGOCENE AND EARLY MIOCENE ROCKS		
Q₄	" " " " " MIDDLE AND LATE EOCENE ROCKS		
Q₃	" " " " " PALEOCENE AND EARLY EOCENE ROCKS		
Q₂	" " " " " LATE CRETACEOUS ROCKS		
		a₁³	Detrital limestone member with indurated crust
Q₁	ALEXANDRIA FORMATION	a₁²	Detrital limestone member
		a₁¹	Clay - gypsum member
N₅	ALAM EL KHADIM FORMATION		
		N₅²	Ferruginous clayey limestone member
N₄	QARET EL DIB FORMATION	N₄²	Chalky gypseous limestone member
		N₄¹	Sandy gypseous limestone member
		N₃³	Clayey limestone member
N₃	JAGHBUB FORMATION	N₃²	Sandy limestone member
		N₃¹	Chalky limestone member
N₂	QARET EL HIMEIMAT FORMATION		
N₁	GEBEL EL KHASHAB FORMATION	N_{1g}	Covered with gravel
		N_{1s}	Covered with sand
Pg₇	BLUFF HILL FORMATION		
			GEBEL QATrani VOLCANICS "BASALTS"





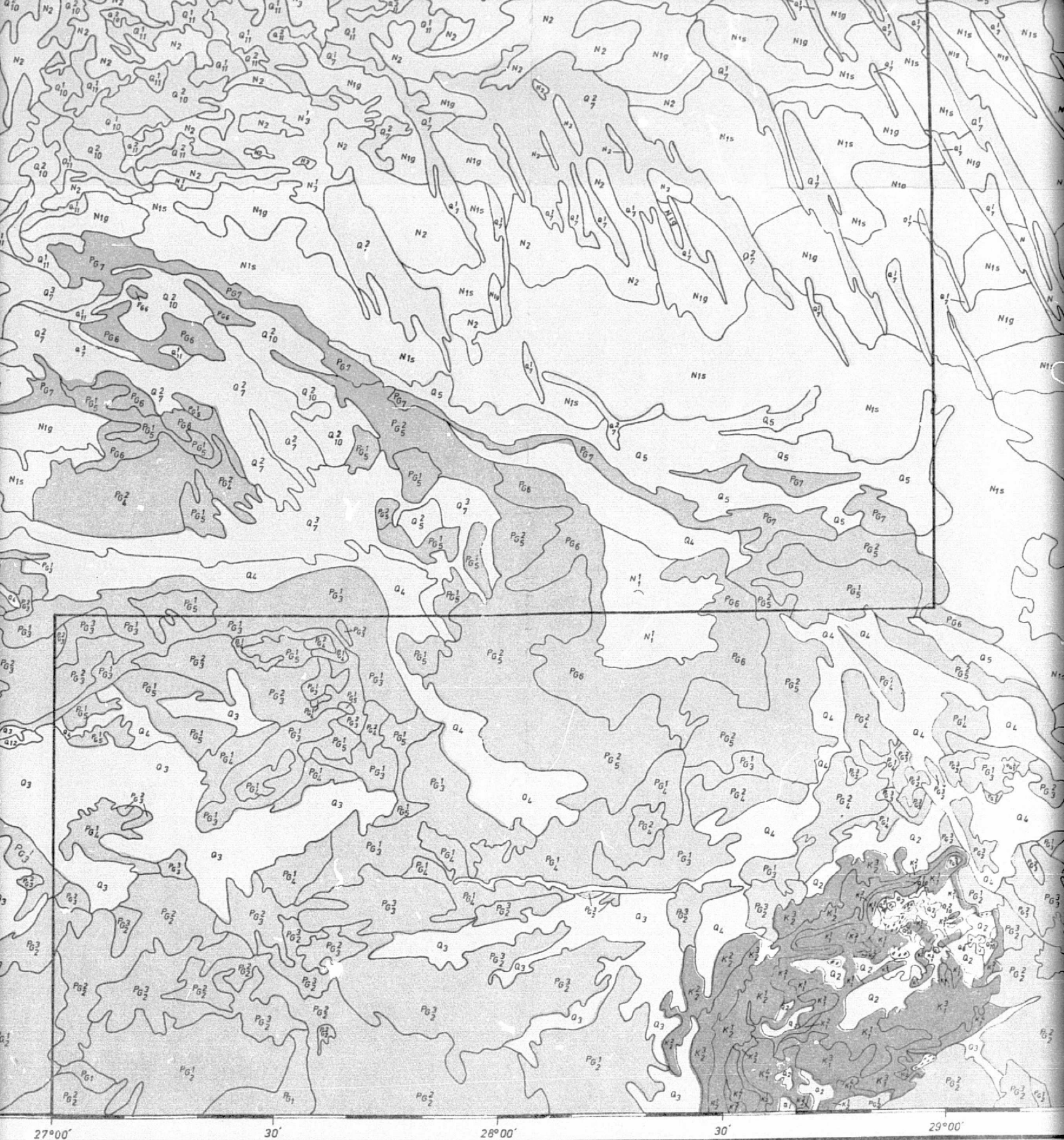
GEOLOGICAL MAP OF QATTARA DEP (FROM LANDSAT - 1 S)

TOPOGRAPHY TEAM

4

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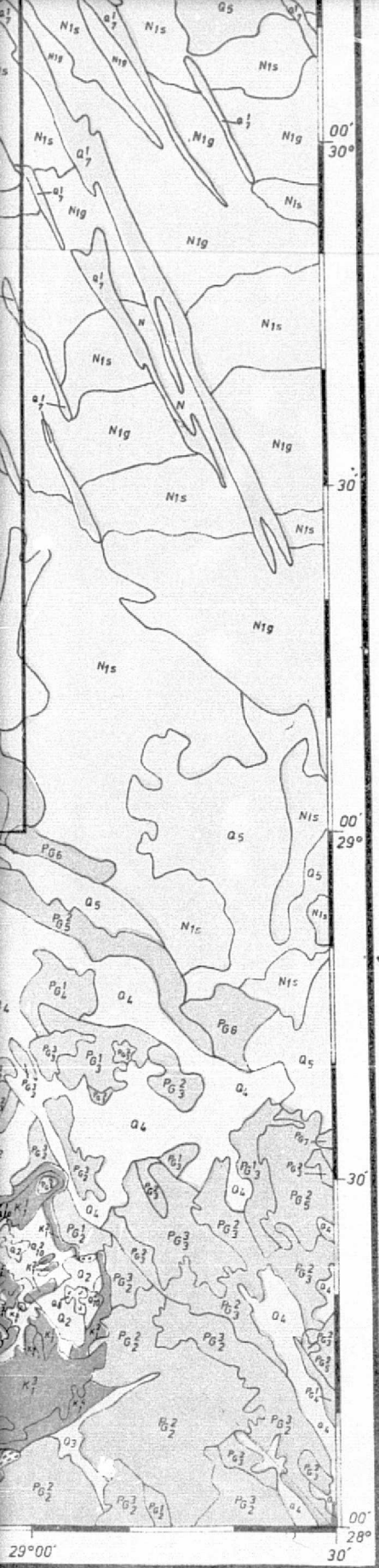


DEPRESSION AND ADJACENT AREAS, EGYPT
 SATELLITE IMAGES)

MOBILITY FRAME 5

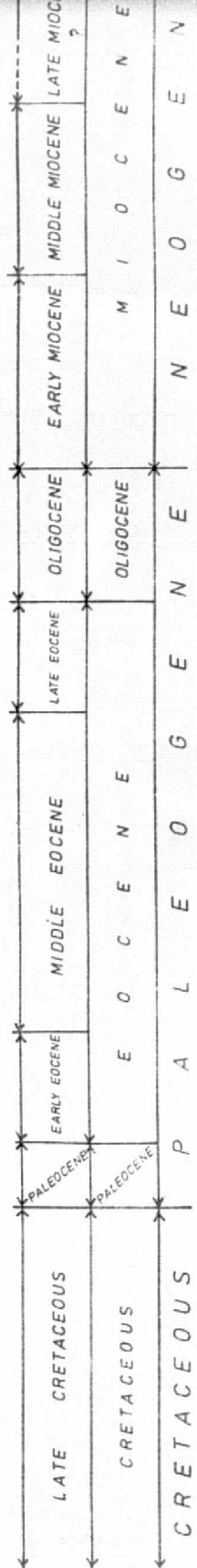
30 40 50 60 70 80 90 100 Km

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N₄	QARET EL DIB FORMATION	N₄²	Chalky gypseous limestone member
		N₄¹	Sandy gypseous limestone member
		N₃³	Clayey limestone member
N₃	JAGHBUB FORMATION	N₃²	Sandy limestone member
		N₃¹	Chalky limestone member
N₂	QARET EL HIMEIMAT FORMATION		
N₁	GEBEL EL KHASHAB FORMATION	N_{1g}	Covered with gravel
		N_{1s}	Covered with sand
			GEBEL QATrani VOLCANICS "BASALTS"
P_{G7}	BLUFF HILL FORMATION		
P_{G6}	GEBEL QATrani FORMATION		
P_{G5}	MAADI FORMATION	P_{G5}²	Sandstone - conglomerate member
		P_{G5}¹	Fossiliferous limestone - marl member
P_{G4}	GEBEL MOKATTAM FORMATION	P_{G4}²	Nummulitic limestone member
		P_{G4}¹	Marl - limestone member
		P_{G4}³	Crystalline limestone member
P_{G3}	GEBEL EL QALAMUN FORMATION	P_{G3}²	Limestone member
		P_{G3}¹	Marl member
		P_{G3}³	Crystalline limestone member
P_{G2}	GEBEL SERAI FORMATION	P_{G2}²	Chalky limestone member
		P_{G2}¹	Limestone member
P_{G1}	LOWER ESNA FORMATION		
		K₂²	Chalk member
K₂	SUDR FORMATION	K₂²	Chalky limestone member
		K₂¹	Dolomitic limestone member
		K₁	Clay member
K₁	BAHARIYA OASIS FORMATION	K₁³	Ferruginous limestone member
		K₁²	Kaolinic member
		K₁¹	Shale member

o Settlements and small towns



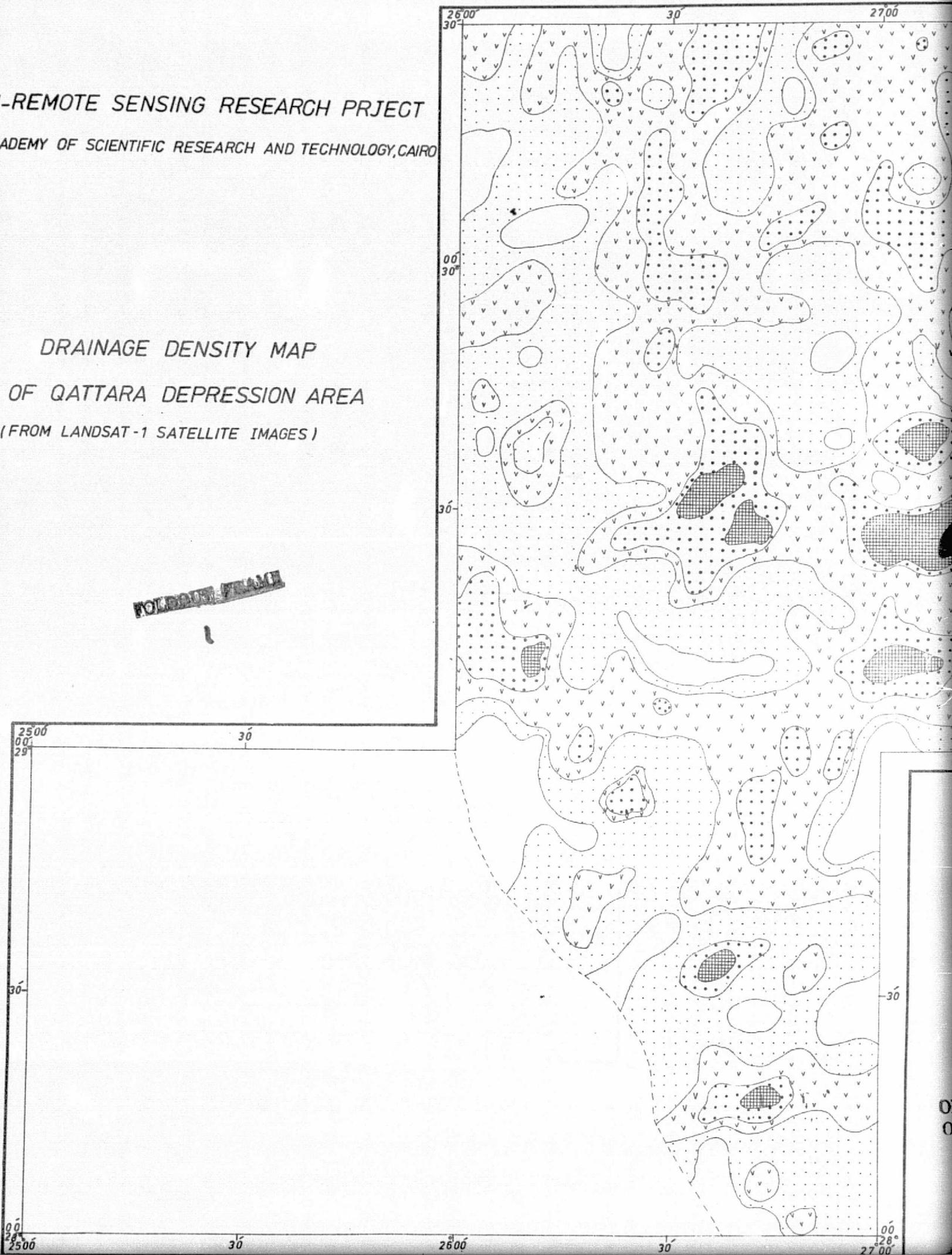
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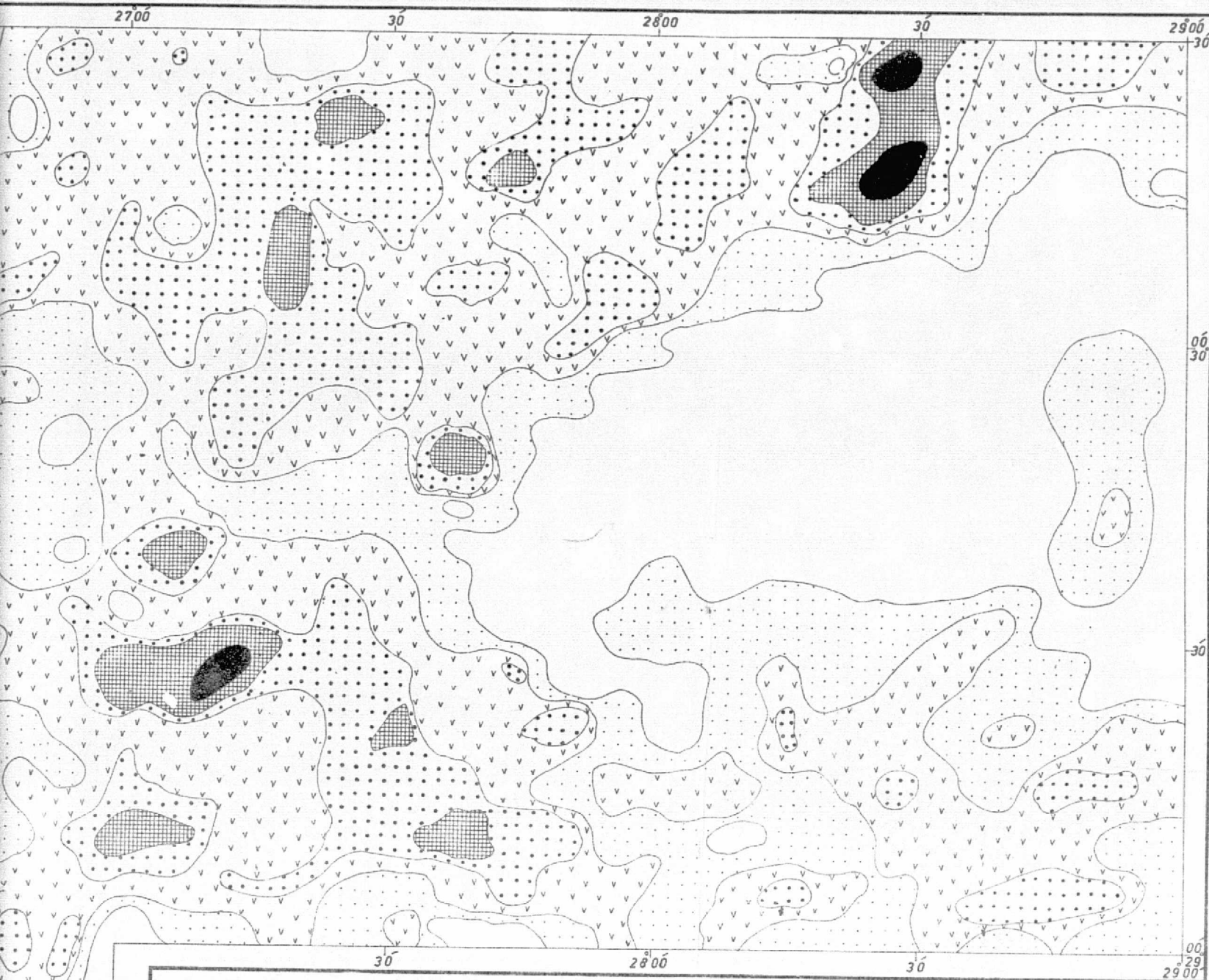
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ACADEMY OF SCIENTIFIC RESEARCH AND TECHNOLOGY, CAIRO

DRAINAGE DENSITY MAP
OF QATTARA DEPRESSION AREA
(FROM LANDSAT-1 SATELLITE IMAGES)

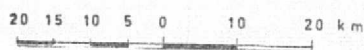
TOPOGRAPHIC MAP





FOLDOUT MAP

2



LEGEND

DENSITY OF THE FIRST ORDER STREAMS
(km / km²)

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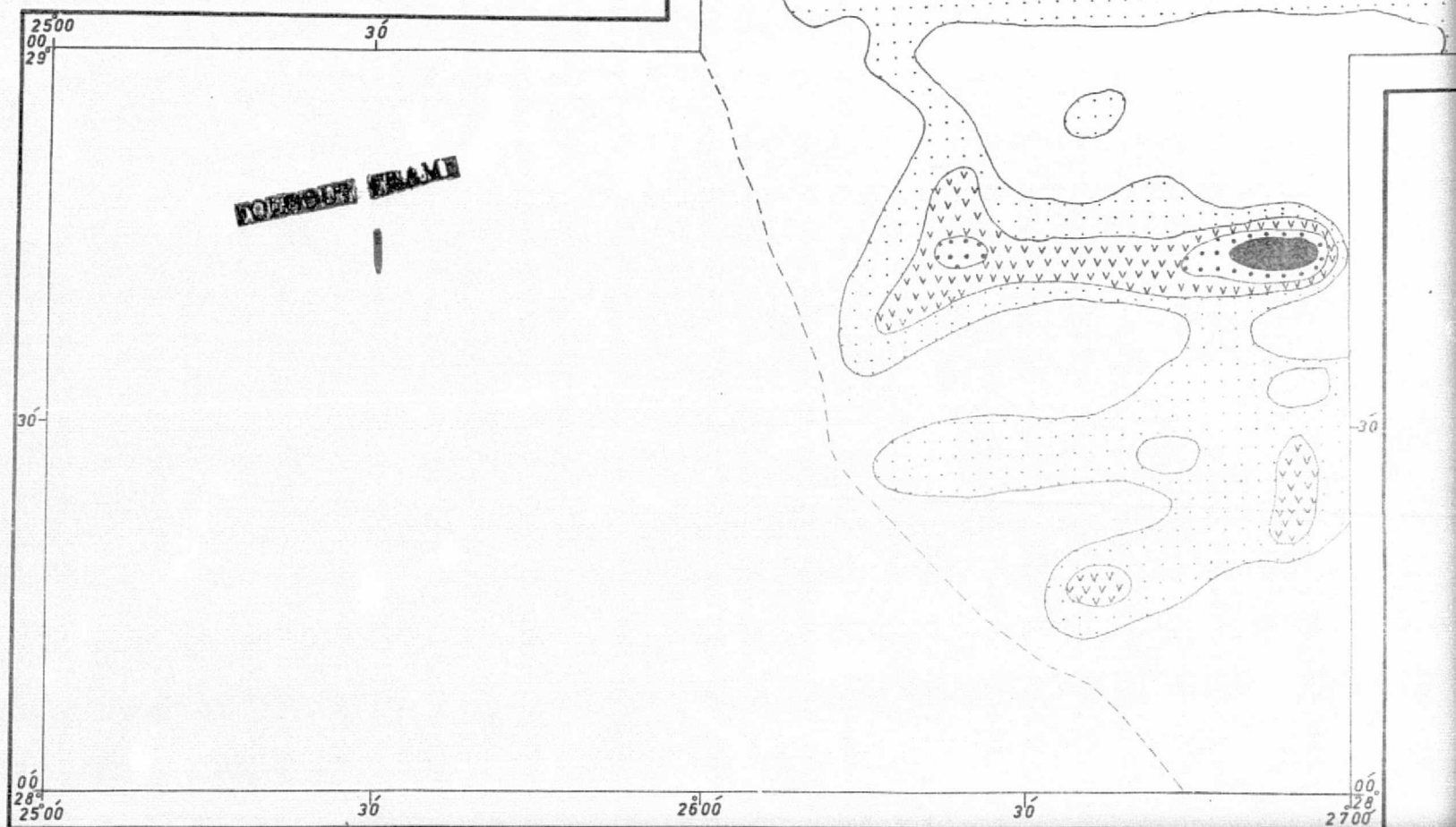
	> 0.5000
	0.4001 - 0.5000
	0.3001 - 0.4000
	0.2001 - 0.3000
	0.1001 - 0.2000
	0.0000 - 0.1000

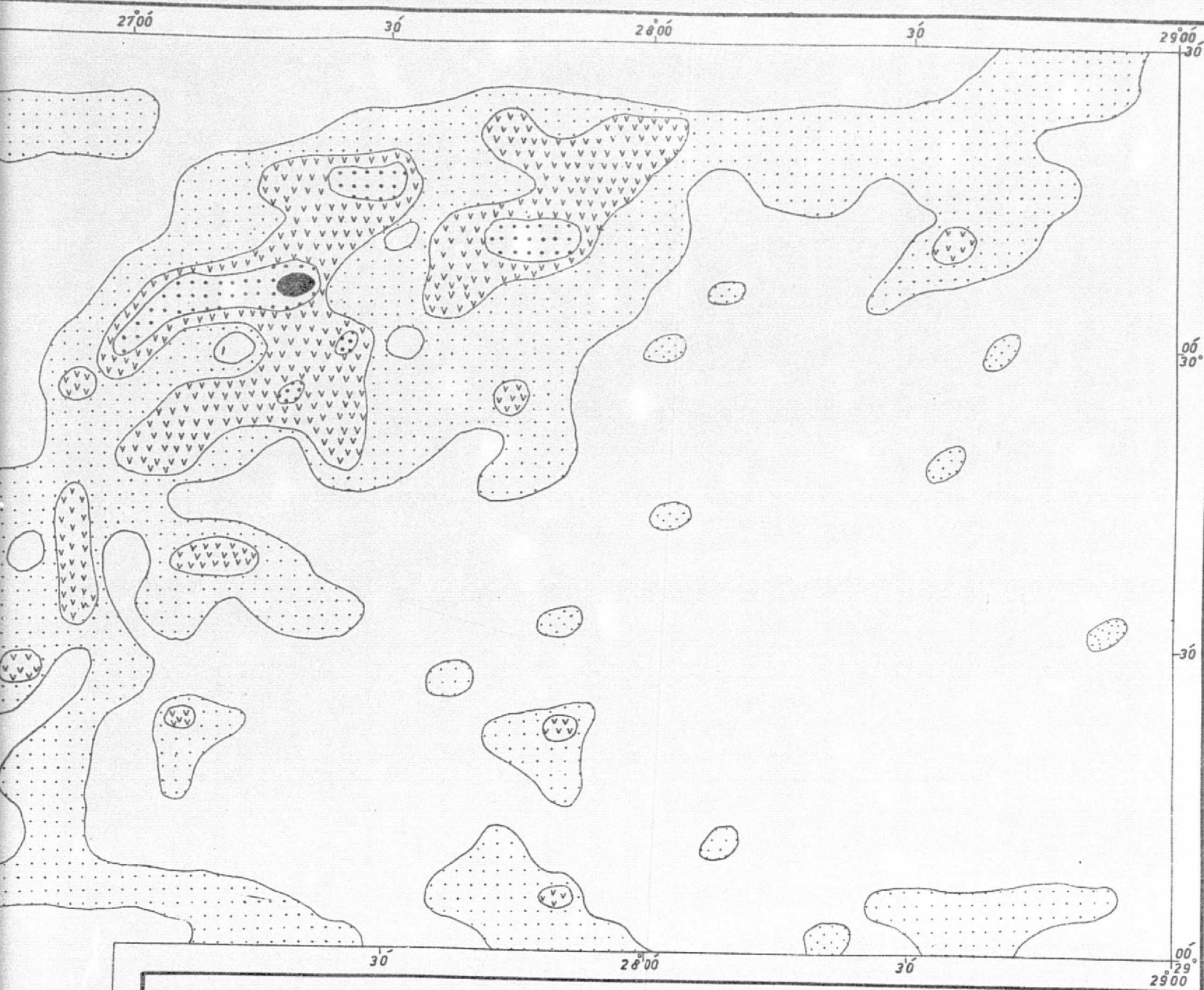
00
28°
27 00'

OSU-REMOTE SENSING RESEARCH PROJECT

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LINEATION DENSITY MAP OF QATTARA DEPRESSION AREA (FROM LANDSAT -1 SATELLITE IMAGES)





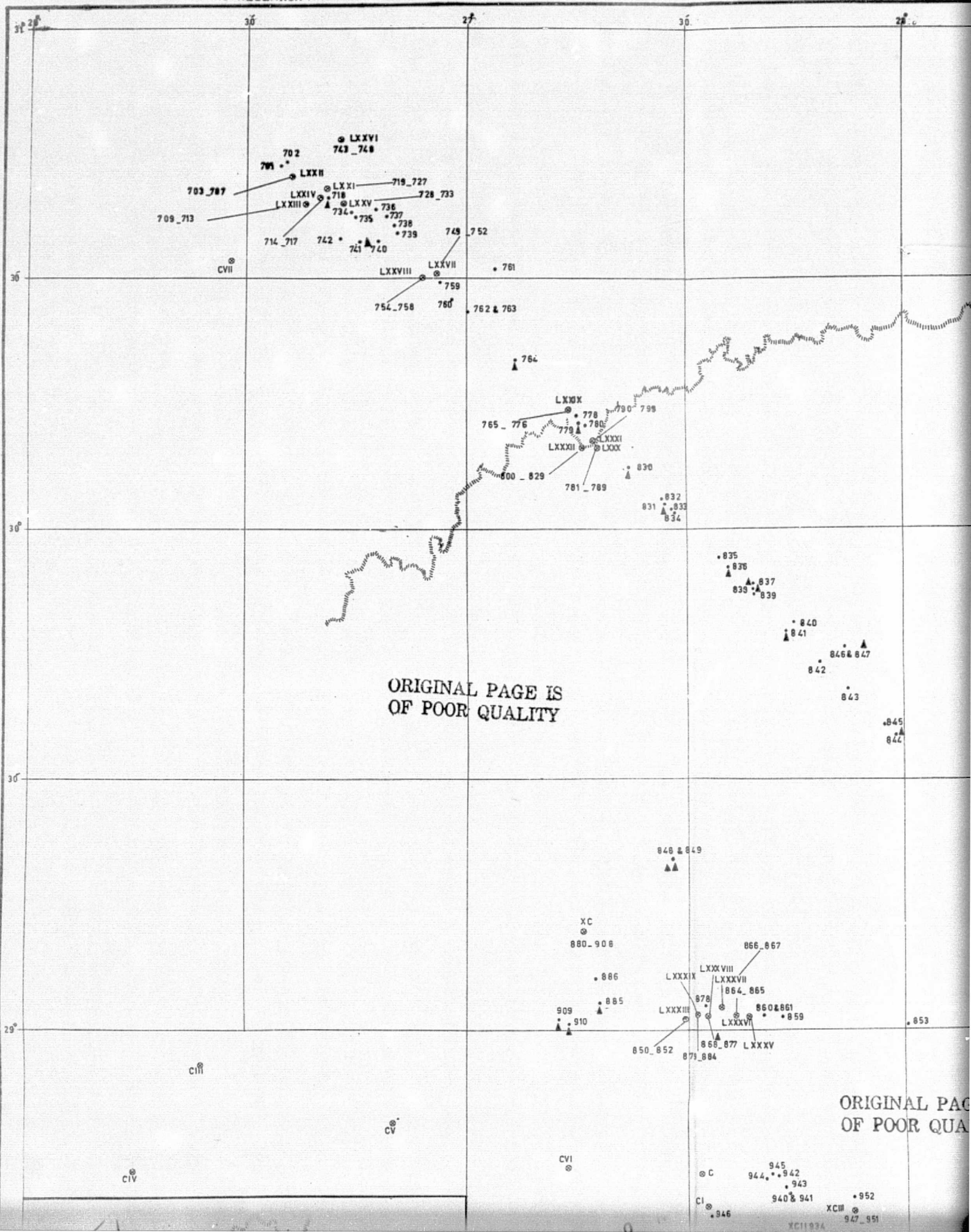
LEGEND

DENSITY OF LINEATIONS
(km / km²)

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	0.3001 - 0.4000
	0.2001 - 0.3000
	0.1001 - 0.2000
	0.0000 - 0.1000

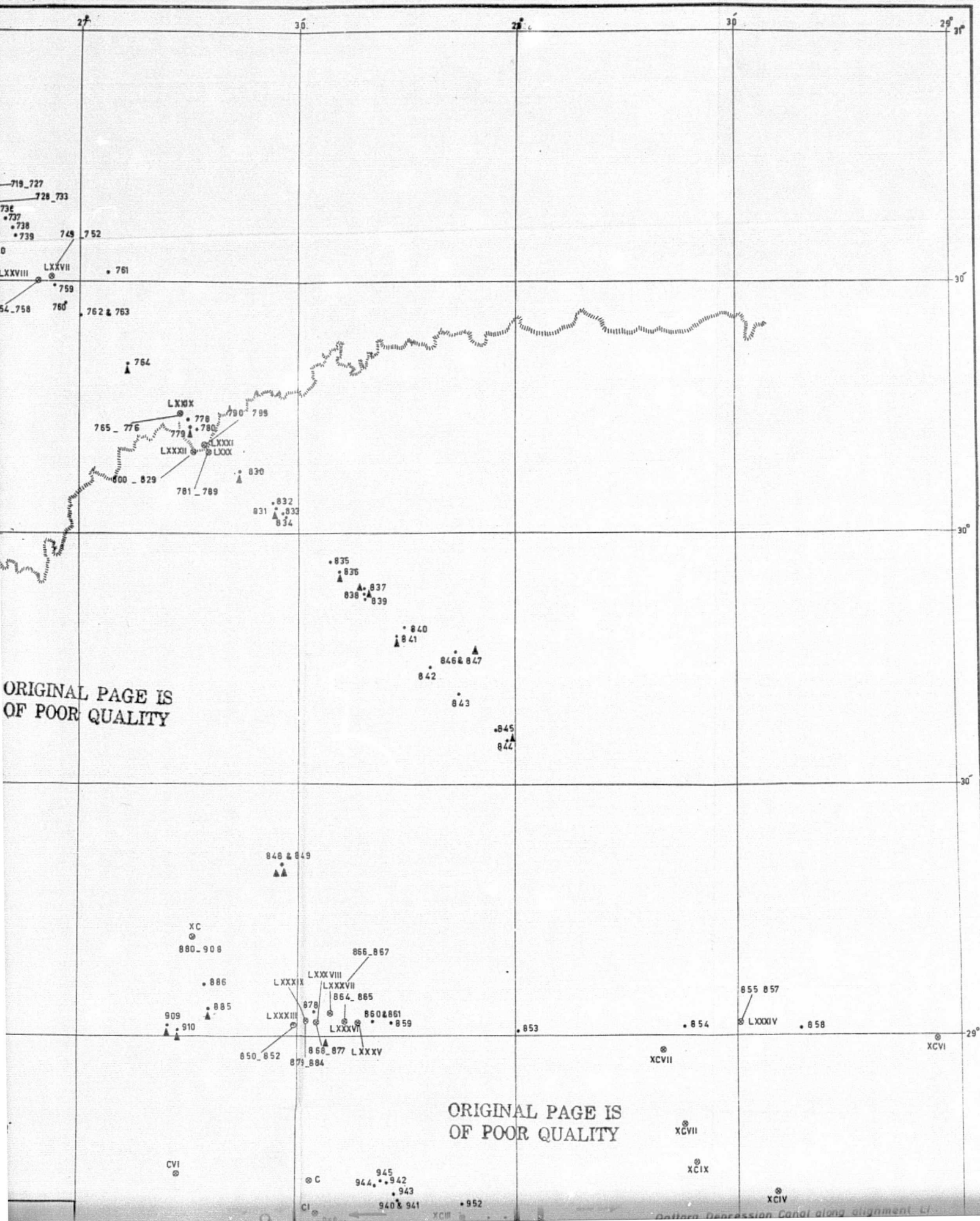
WOLBOMI PLATE
2

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MAP SHOWING LOCATIONS OF
LITHOSTRATIGRAPHIC SECTIONS AND
SAMPLES IN QATTARA DEPRESSION
AND ADJACENT AREAS

20 15 10 5 0 10 20 km

LEGEND

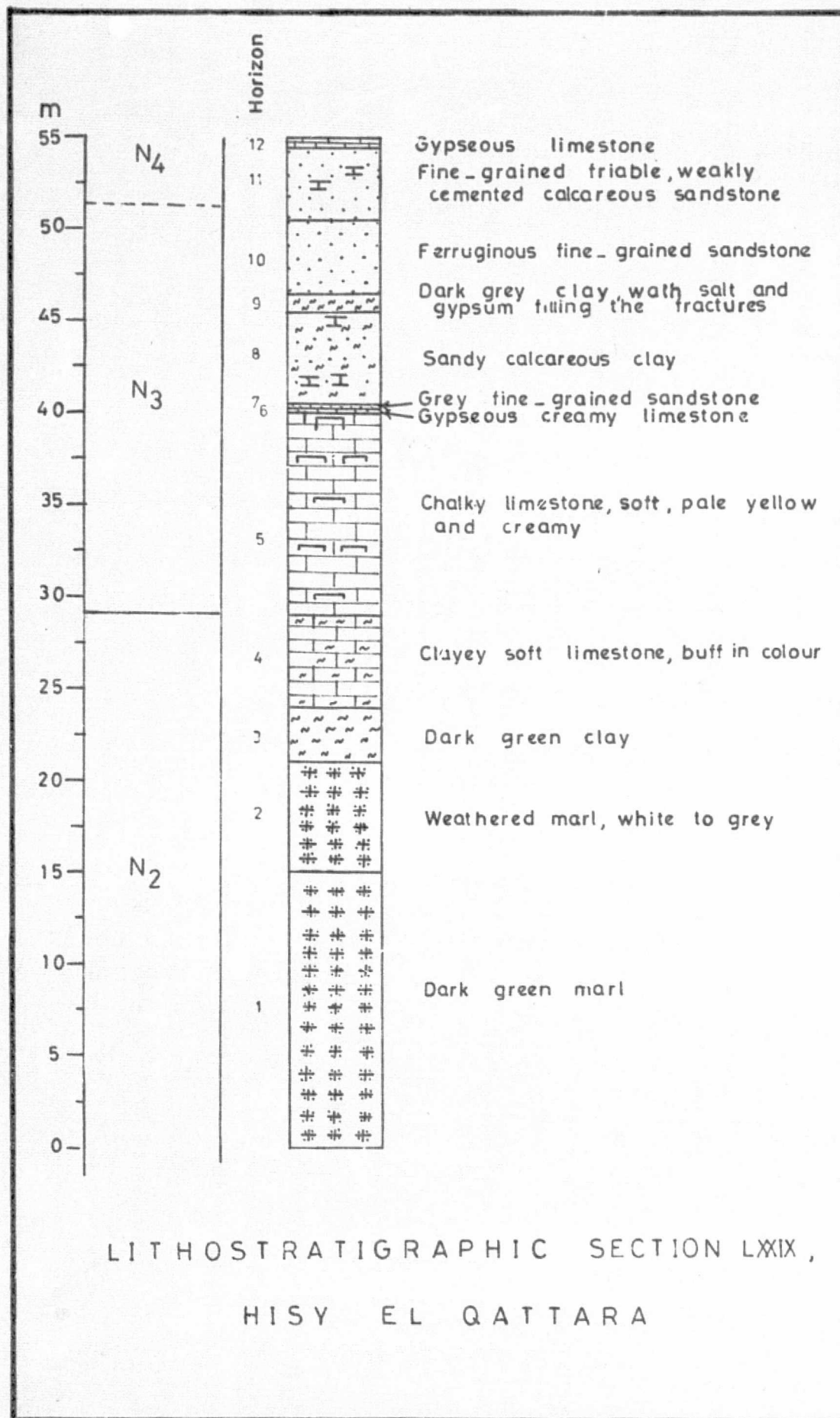
- ⊙ LITHOSTRATIGRAPHIC SECTION
- SAMPLE LITHOLOGICALLY STUDIED
- ▲ SAMPLE CHEMICALLY ANALYZED

3

LITHOSTRATIGRAPHIC OF QATTARA DEPRESSION AREA

m	ROCK UNIT		LITHOLOGY	AGE	LOCALITIES
	FORMATION	MEMBER			
700	N ₄	QARET	limestone	MIDDLE OR LATE EOCENE	Southwest Bir El Gattara, Qaret Tartaia
650		EL DIB FORMATION	gypsiferous limestone Bull. limestone fossiliferous limestone clayey limestone cherty limestone gypsiferous limestone		
600	N ₃	2	clayey limestone	MIOCENE	Qaret Tartaia
550		1	partially crystalline limestone		
500		0	clayey limestone		
450		1	cherty limestone		
400		2	sandy calcareous clay		
350		3	ferruginous calcareous clay		
300		4	clay		
250		5	cherty limestone		
200		6	limy clay		
150		7	chalk		
100		8	white clay		
50		9	cherty clayey whitish grey limestone		
0	N ₂	10	cherty clayey whitish grey limestone	MIOCENE	Southwest Bir El Hilw, Southeast Bir Istadi, Northwest Bir Qasir El Sirr
50		11	sandy cherty limestone		
100		12	fossiliferous limestone		
150		13	cherty fossiliferous limestone		
200		14	sandy limestone		
250		15	ferruginous limestone		
300		16	cherty limestone		
350		17	chalk		
400		18	ferruginous white limestone		
450		19	limestone, cherty or clayey in parts		
500		20	cherty limestone, fossiliferous in parts		
550		21	greenish marl		
600	N ₁	22	ferruginous sandy limestone	MIOCENE	Nash El Gattara, Ras El Gattara and Hiss El Gattara
650		23	cherty limestone		
700		24	greenish grey clay with interbeds of sandy dolomitic limestone		
750		25	fossiliferous limestone		
800		26	greenish grey clay and shale		
850		27	white limestone		
900		28	calcareous grey clay		
950		29	fossiliferous limestone		
1000		30	marl		
1050		31	dolomitic limestone		
1100		32	grey shale, slightly ferruginous on the fringes		
1150		33	alternating ferruginous shale, clay, calcareous sandstone and marl		
1200	N ₀	34	marl and clay	MIOCENE	Naga El Gattara
1250		35	dolomitic limestone		
1300		36	yellowish green marl		
1350		37	dark grey shale		
1400		38	dolomitic limestone		
1450		39	grey sandy marl		
1500		40	grey shale, calcareous in parts		
1550		41	dark yellow fossiliferous limestone		
1600		42	white fine grained equigranular sandstone, occasionally conglomeratic		
1650		43	calcareous ferruginous sandy clay the sand increases upward		
1700		44	calcareous sandstone clay and thin bands of limestone and cherty limestone		
1750		45	fossiliferous creamy limestone		
1800	P ₁	46	marl, partially crystalline limestone, conglomerate and sandstone. The top of the succession is more terrestrial	Eocene	Section AC
1850		47	the formation consists of alternating marl and hummock limestone members, the beds belonging to the latter are of greater thickness		
1900		48	white crystalline limestone		
1950		49	white limestone		
2000		50	reddish marl alternating with less dolomitic limestone and calcareous bit		
2050		51	reddish white crystalline limestone		
2100		52	greyish white limestone and cherty limestone, the former is occasionally nodal		
2150		53	grey clay		
2200		54	grey clay		
2250		55	grey clay		
2300		56	grey clay		
2350		57	grey clay		
2400		58	grey clay		
2450	P ₂	59	grey clay	Paleocene	East of El Hawad, Section LXXVI, Northeast Bay of Gahat, Section LXXVII, Bay Hasanein, West of Bahrein, Section LXXVIII, El Guss, Abu Said
2500		60	grey clay		
2550		61	grey clay		
2600		62	grey clay		
2650		63	grey clay		
2700		64	grey clay		
2750		65	grey clay		
2800		66	grey clay		
2850		67	grey clay		
2900		68	grey clay		
2950		69	grey clay		
3000		70	grey clay		
3050		71	grey clay		

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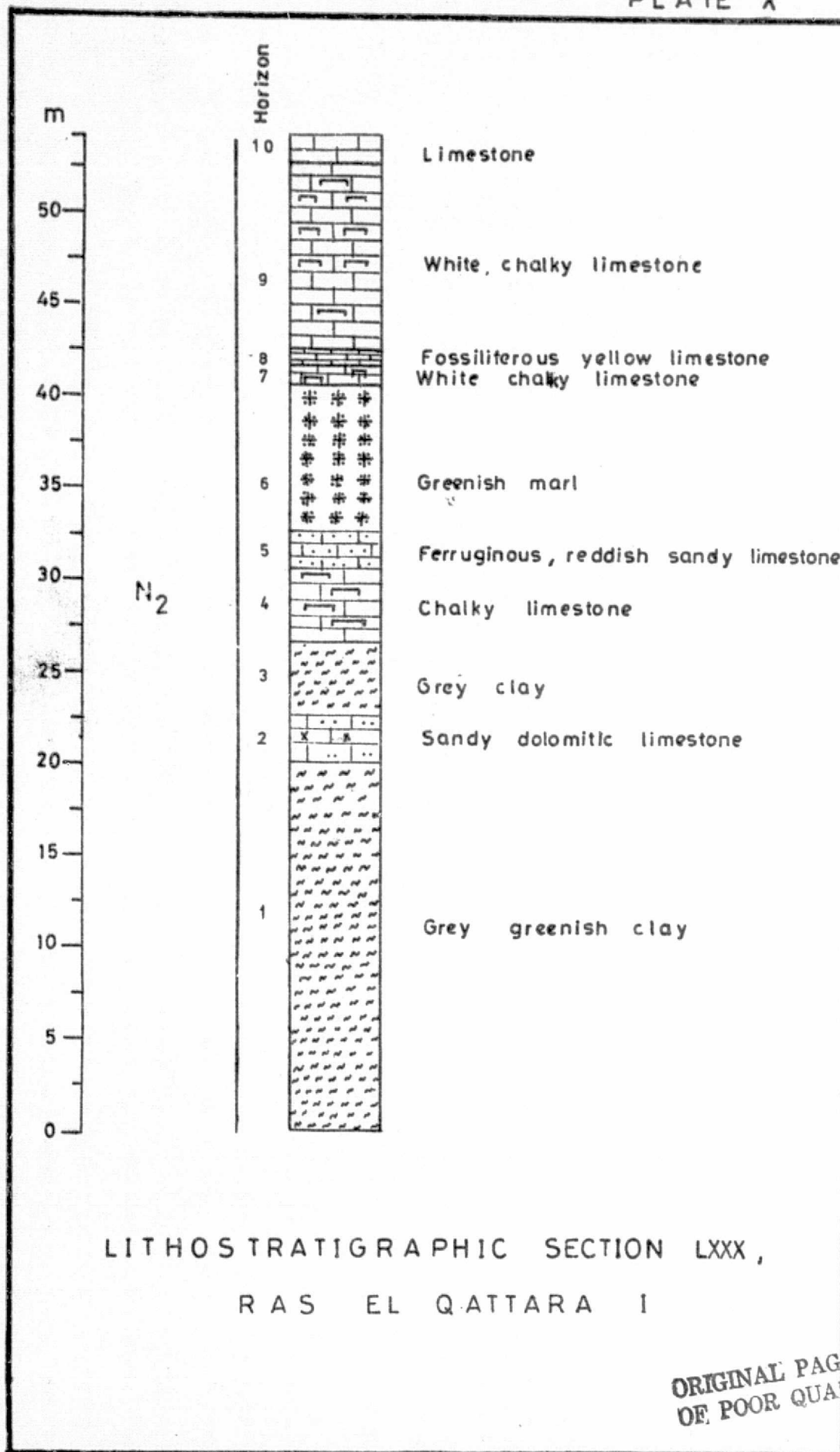
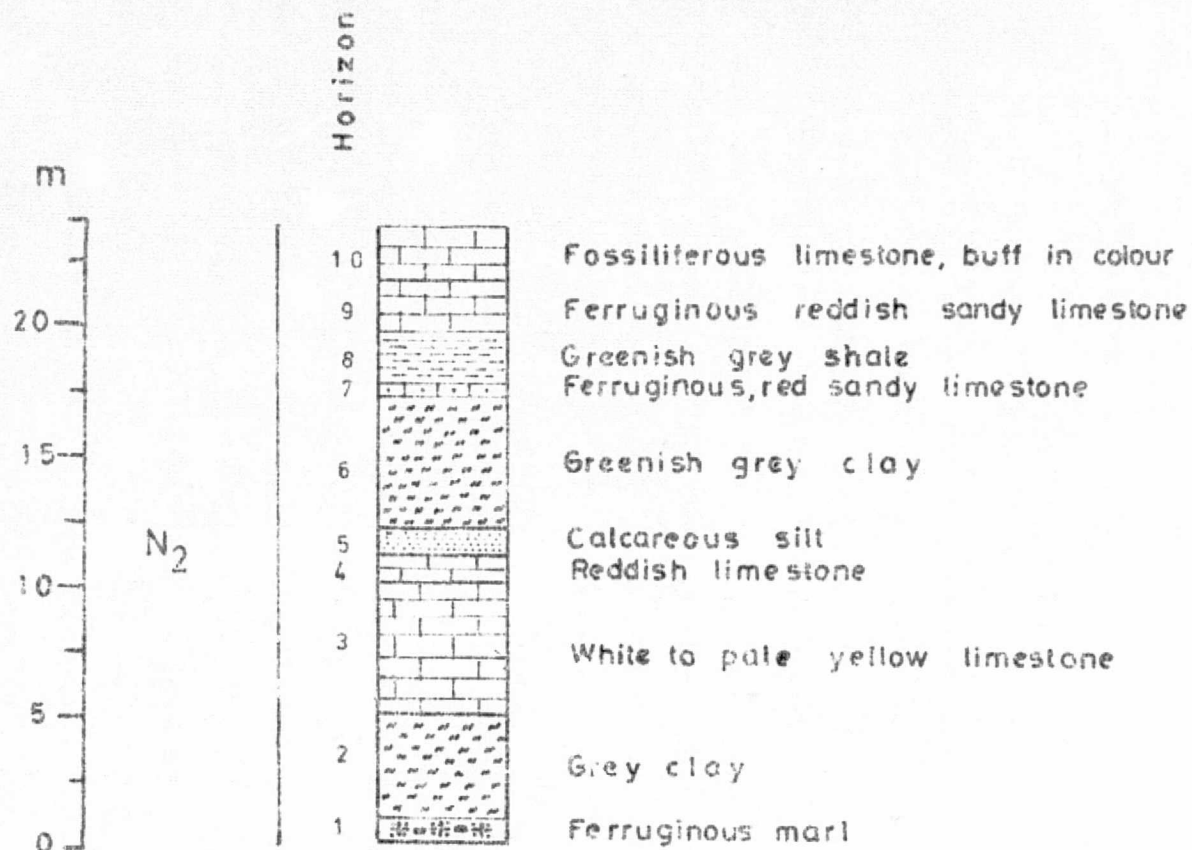


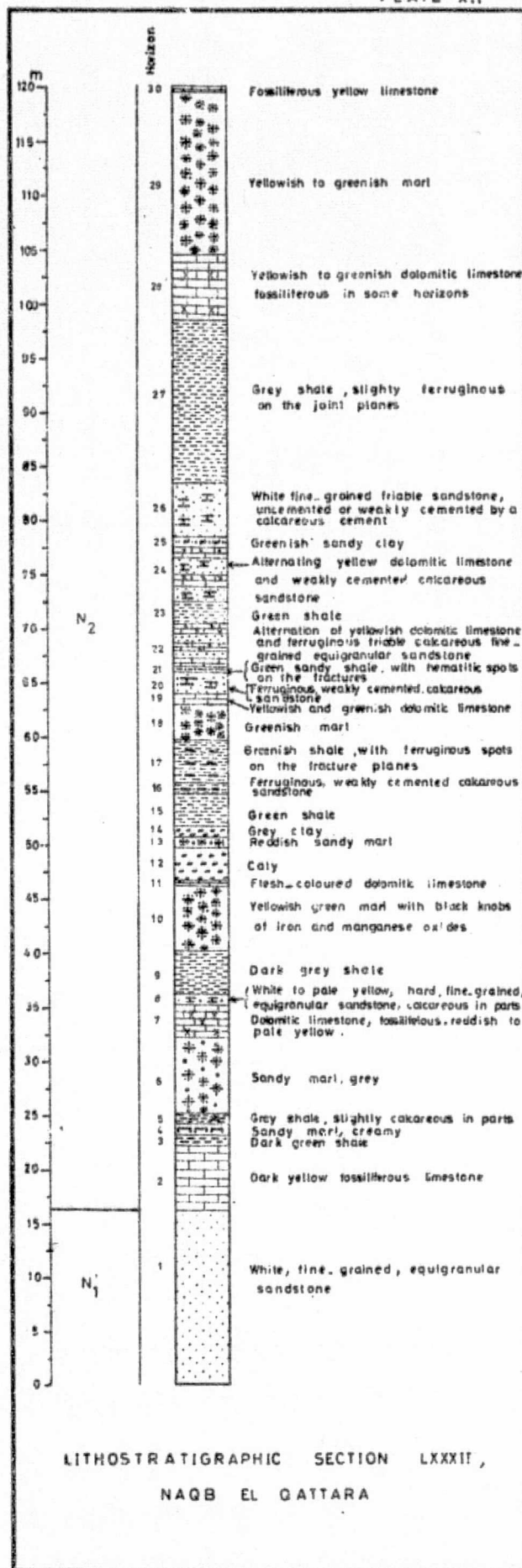
PLATE XI

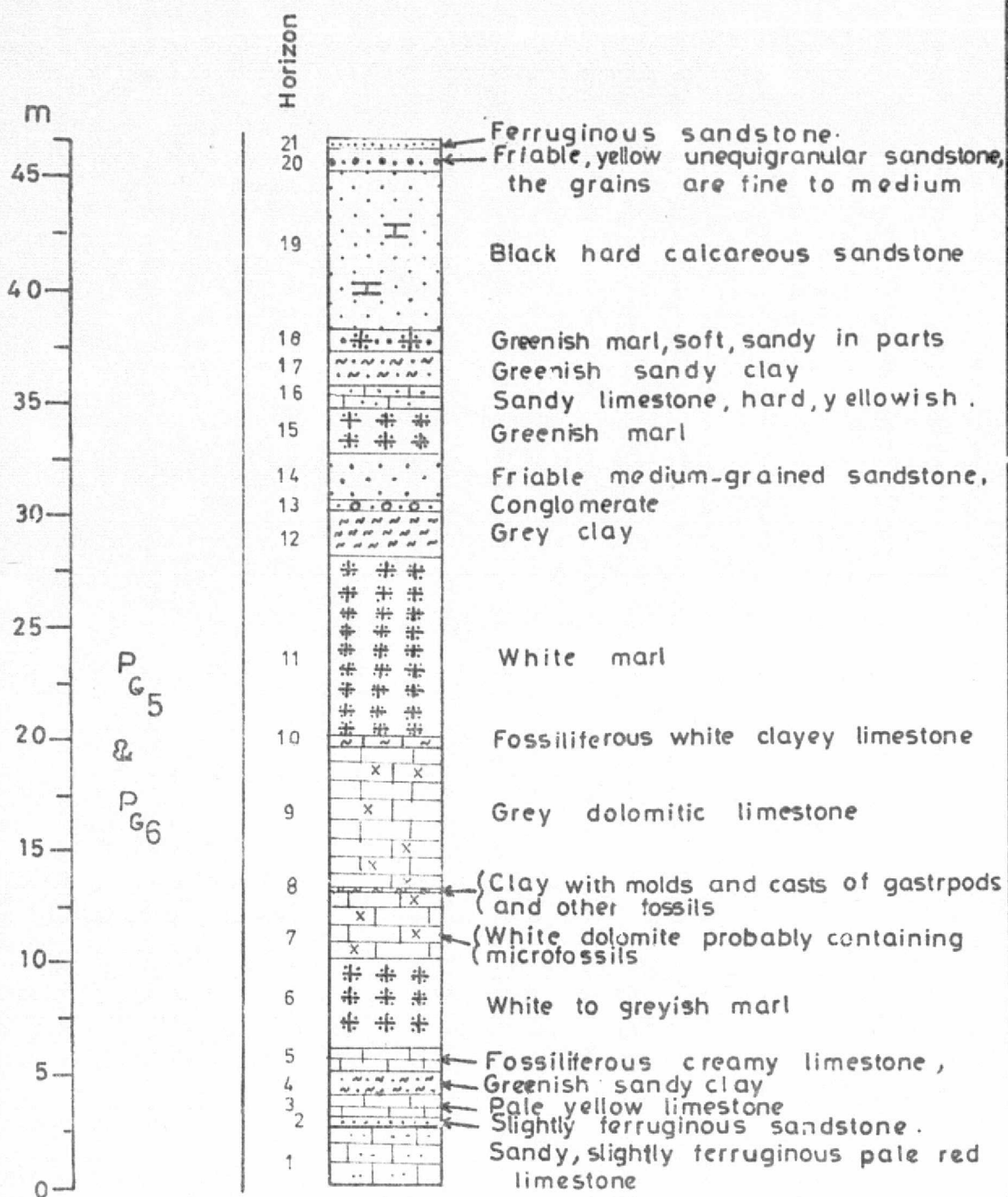


LITHOSTRATIGRAPHIC SECTION LXXI,

RAS EL QATTARA II

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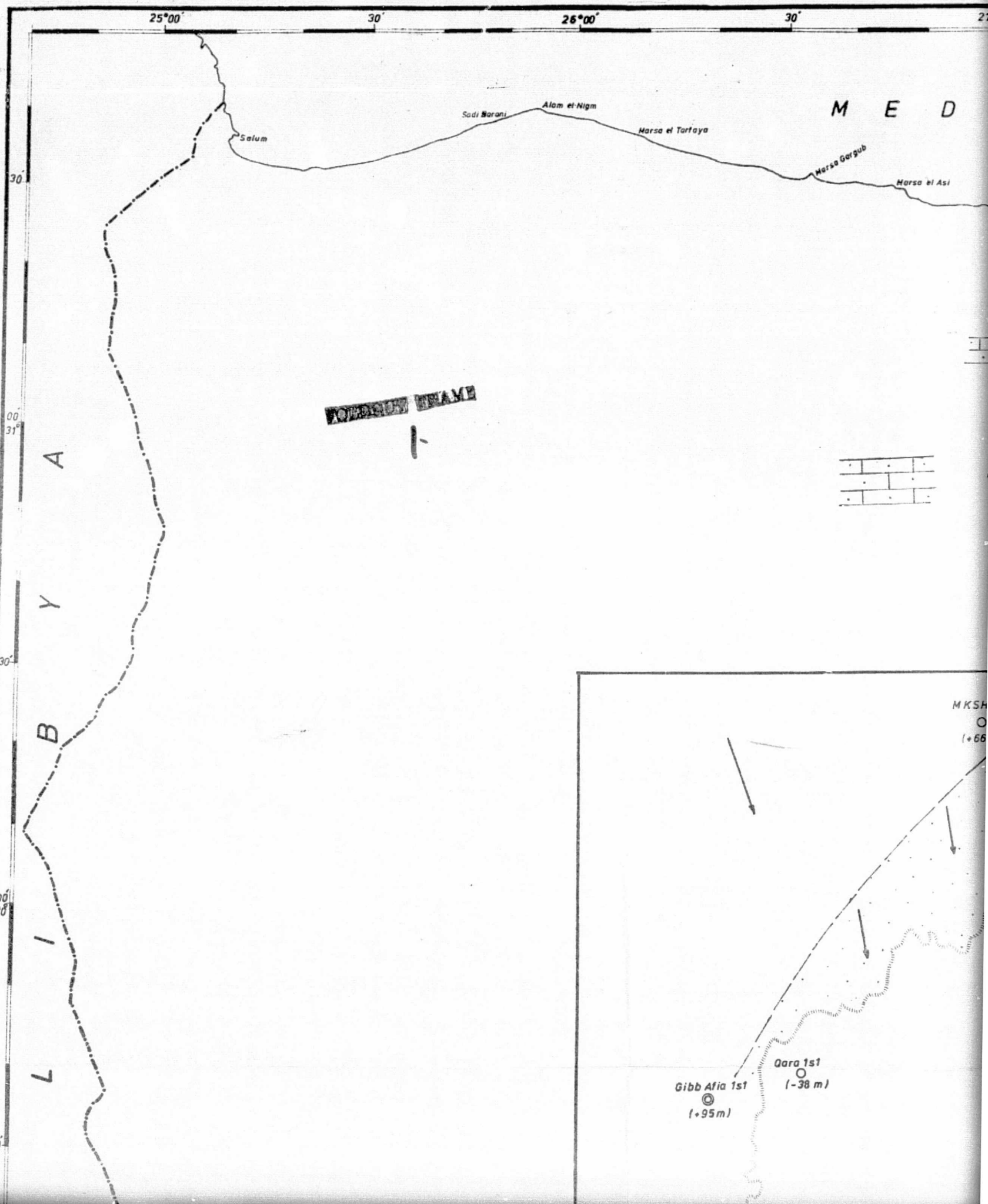


LITHOSTRATIGRAPHIC SECTION XC,

SW CICELY HILL

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OSU-REMOTE SENSING RESEARCH PROJECT
ACADEMY OF SCIENTIFIC RESEARCH AND TECHNOLOGY, CAIRO



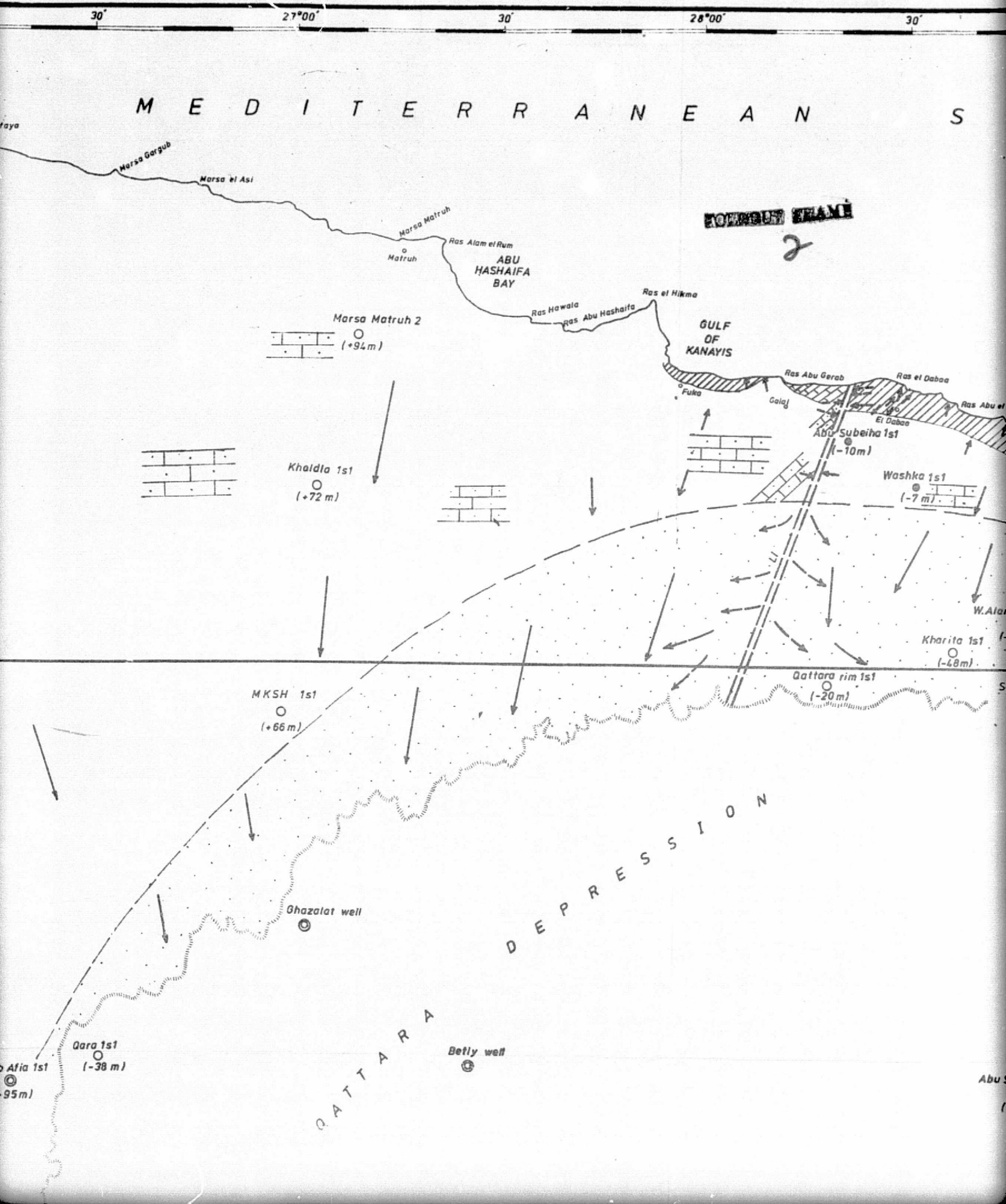


PLATE XIV

FORSDY TRAM

3

LEGEND



Unconfined Groundwater in Pleistocene Detrital Limestone.



Unconfined Groundwater in Pliocene Reddish Brown to Creamy Limestone.



Unconfined Groundwater in Middle Miocene Limestone.



Perched Groundwater in Middle Miocene Limestone.



Unconfined to Subconfined Groundwater in Early Miocene Sands and Sandstone.



Unconfined Groundwater in Middle Eocene Limestone.



Artesian Groundwater in Early Cretaceous Sandstone.



Direction of present water flow.



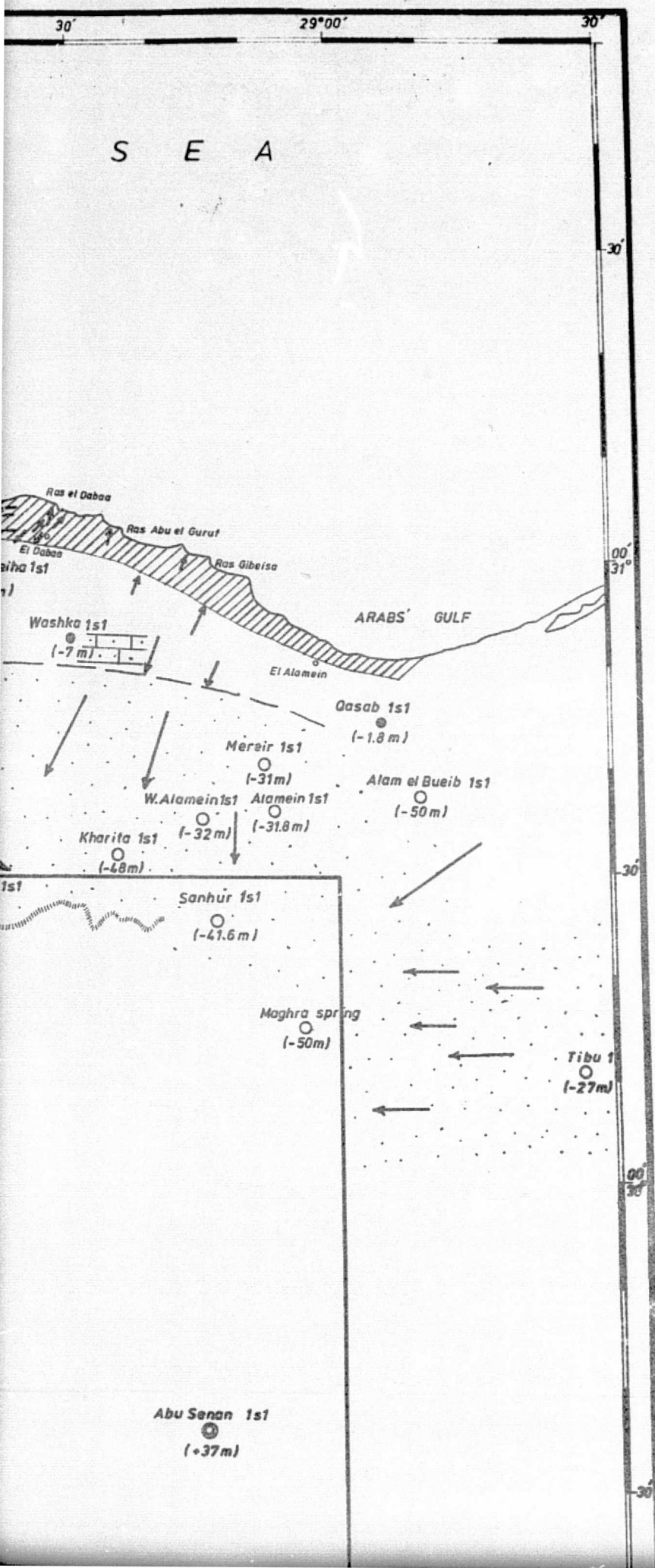
Expected flow due to construction of unlined Mediterranean-Gattara Depression Canal along alignment LI.

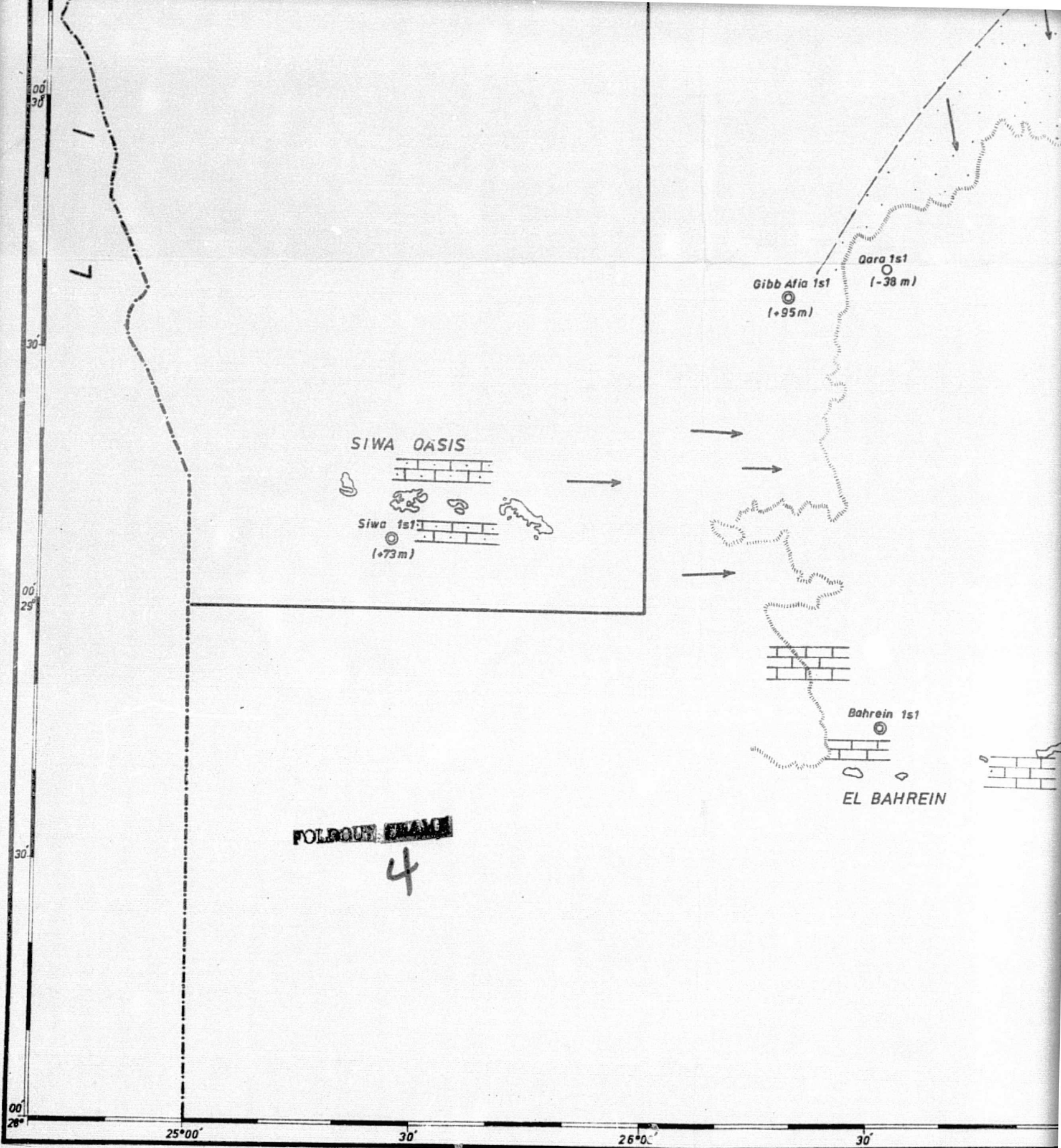


Probable flow of the Early Cretaceous artesian groundwater

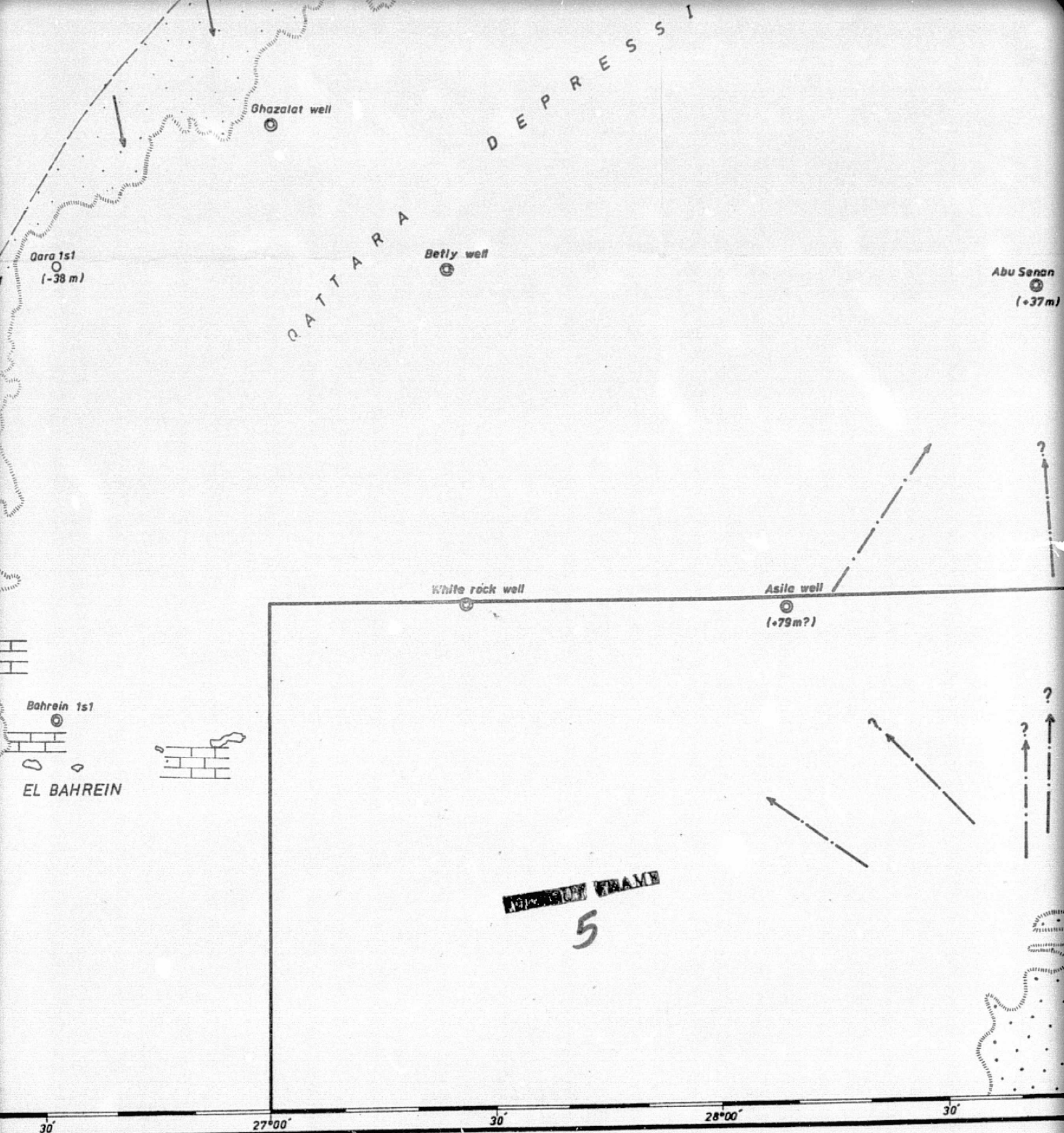


Groundwater level

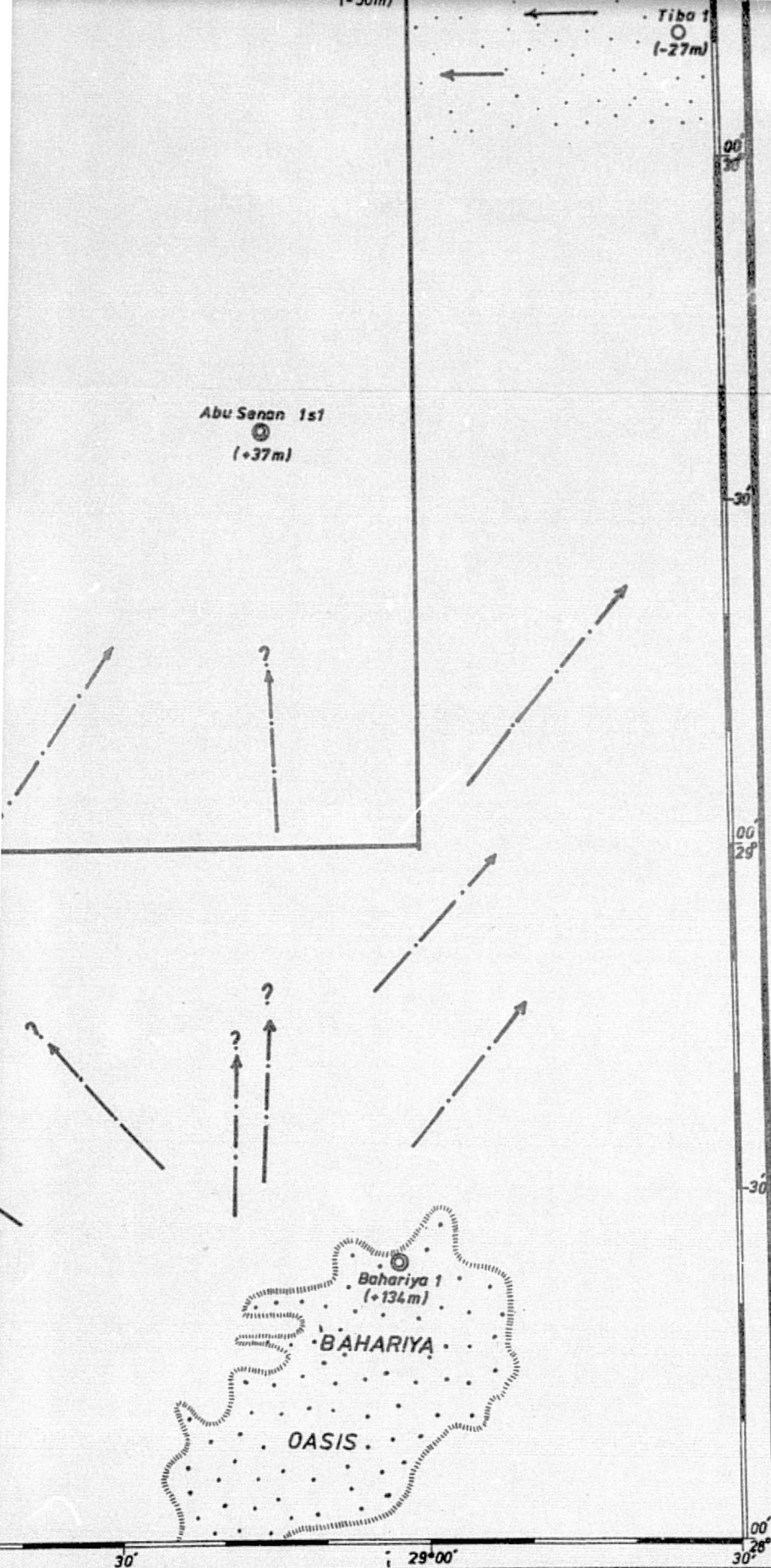




HYDROGEOLOGICAL CONDITIONS MAP OF
(BASED ON LANDSAT-1 SATE



ATIONS MAP OF QATTARA DEPRESSION AND ADJACENT AREAS, EGYPT
 ON LANDSAT-1 SATELLITE IMAGES, AND COMPILATION OF AVAILABLE PREVIOUS WORK)



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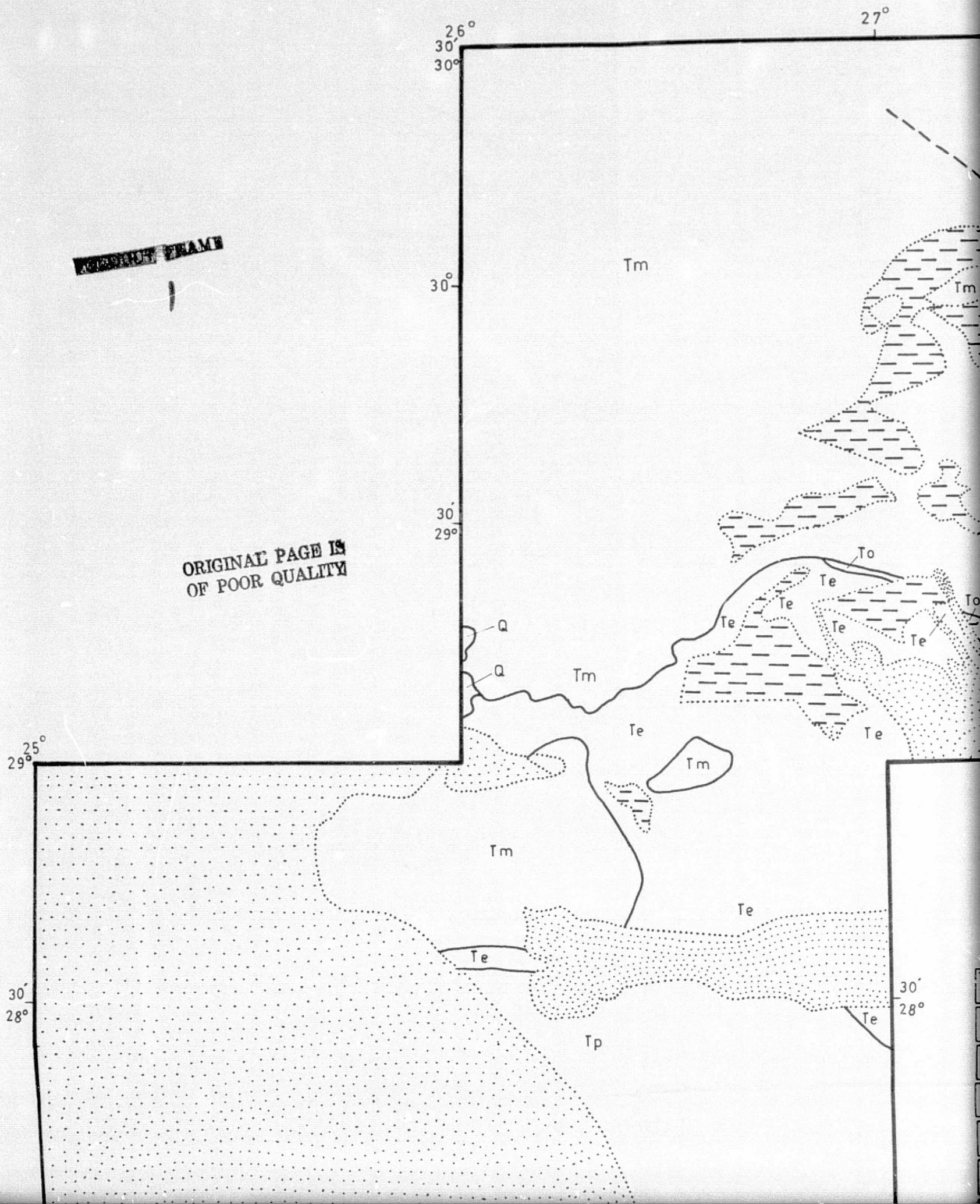
T AREAS, EGYPT.
(US WORK)

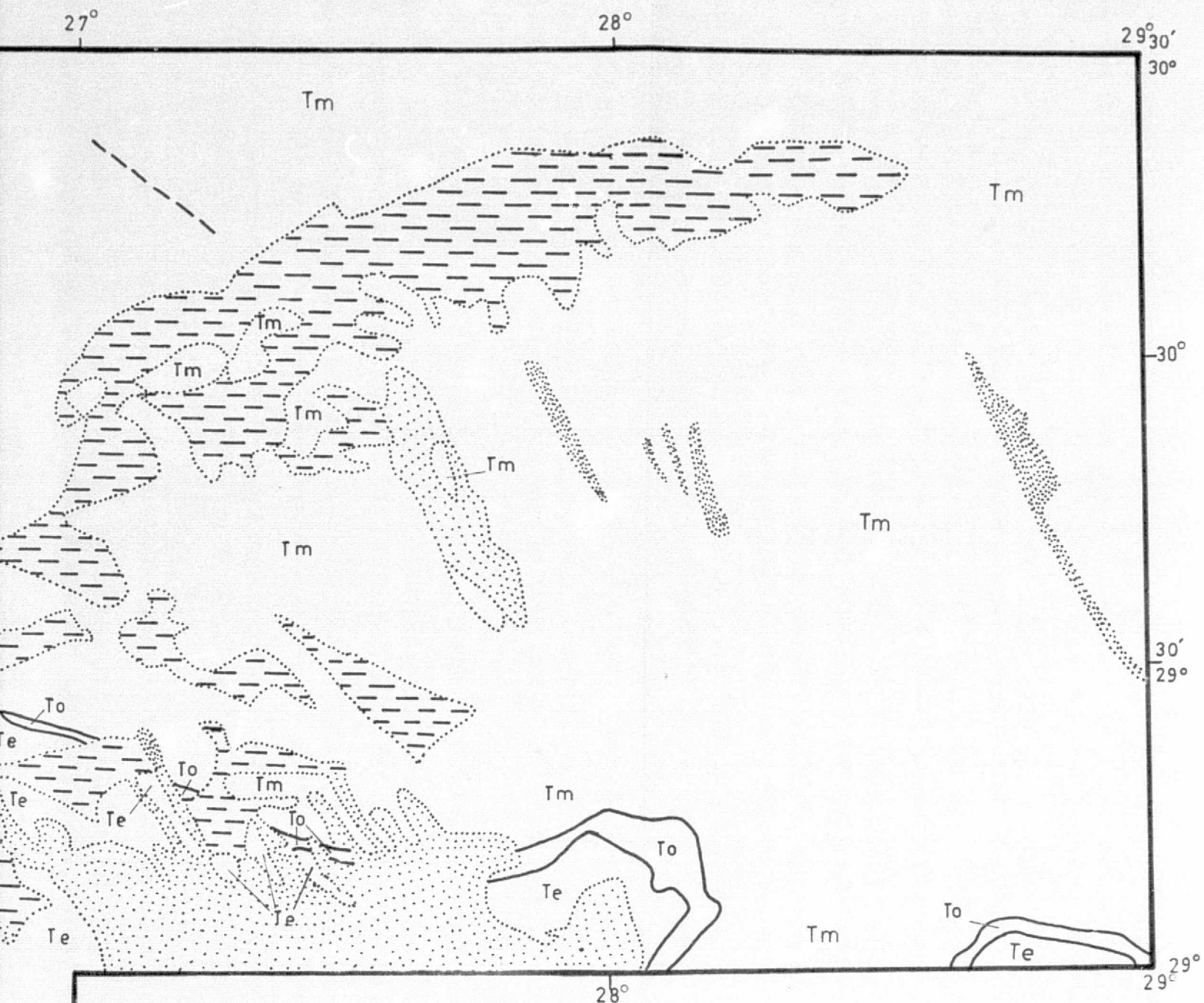
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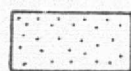
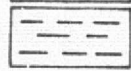
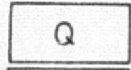
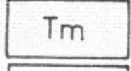
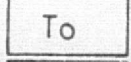
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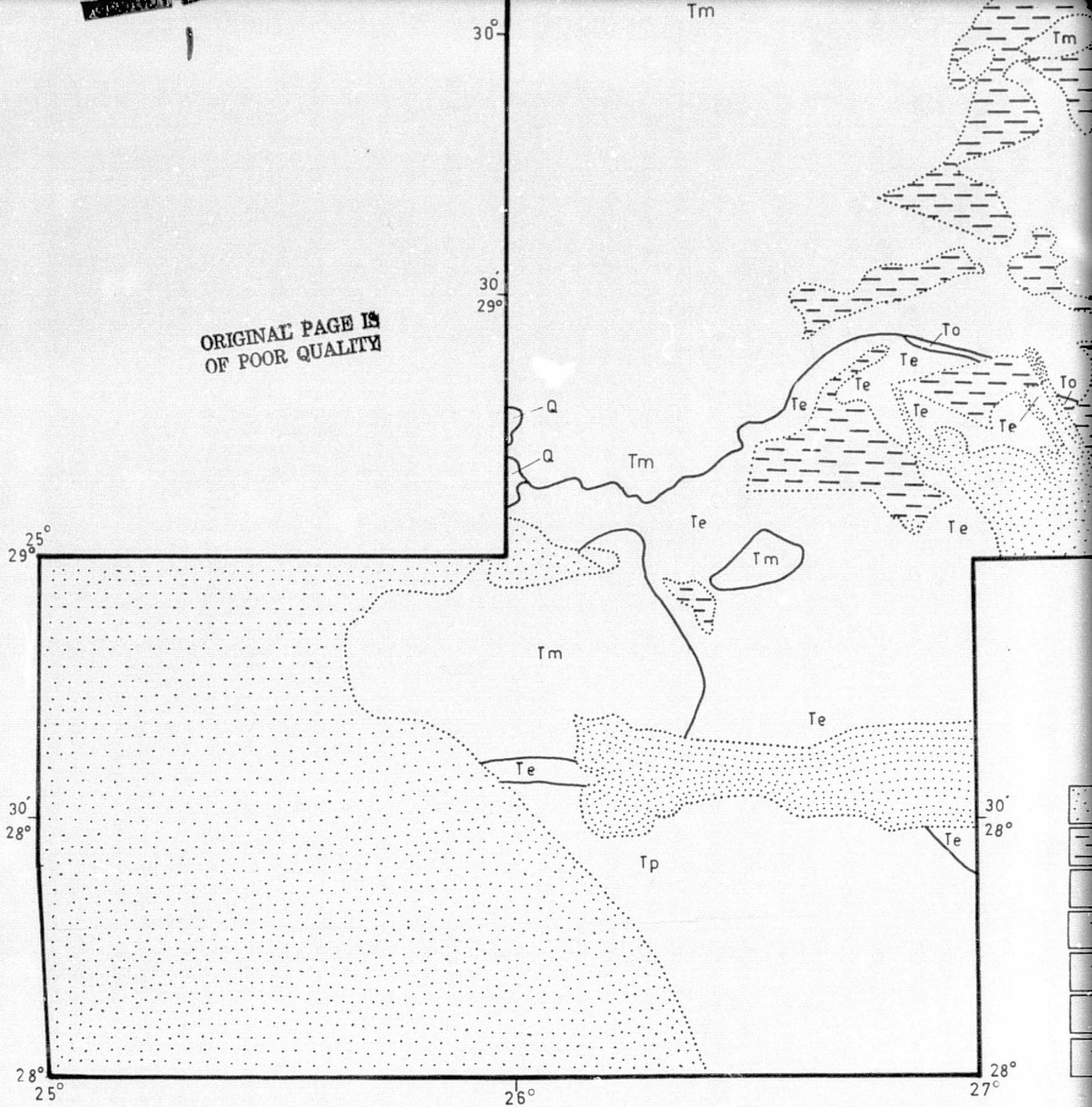
LEGEND

	Sand Dunes
	Sabkha
	Quaternary
	Miocene
	Oligocene

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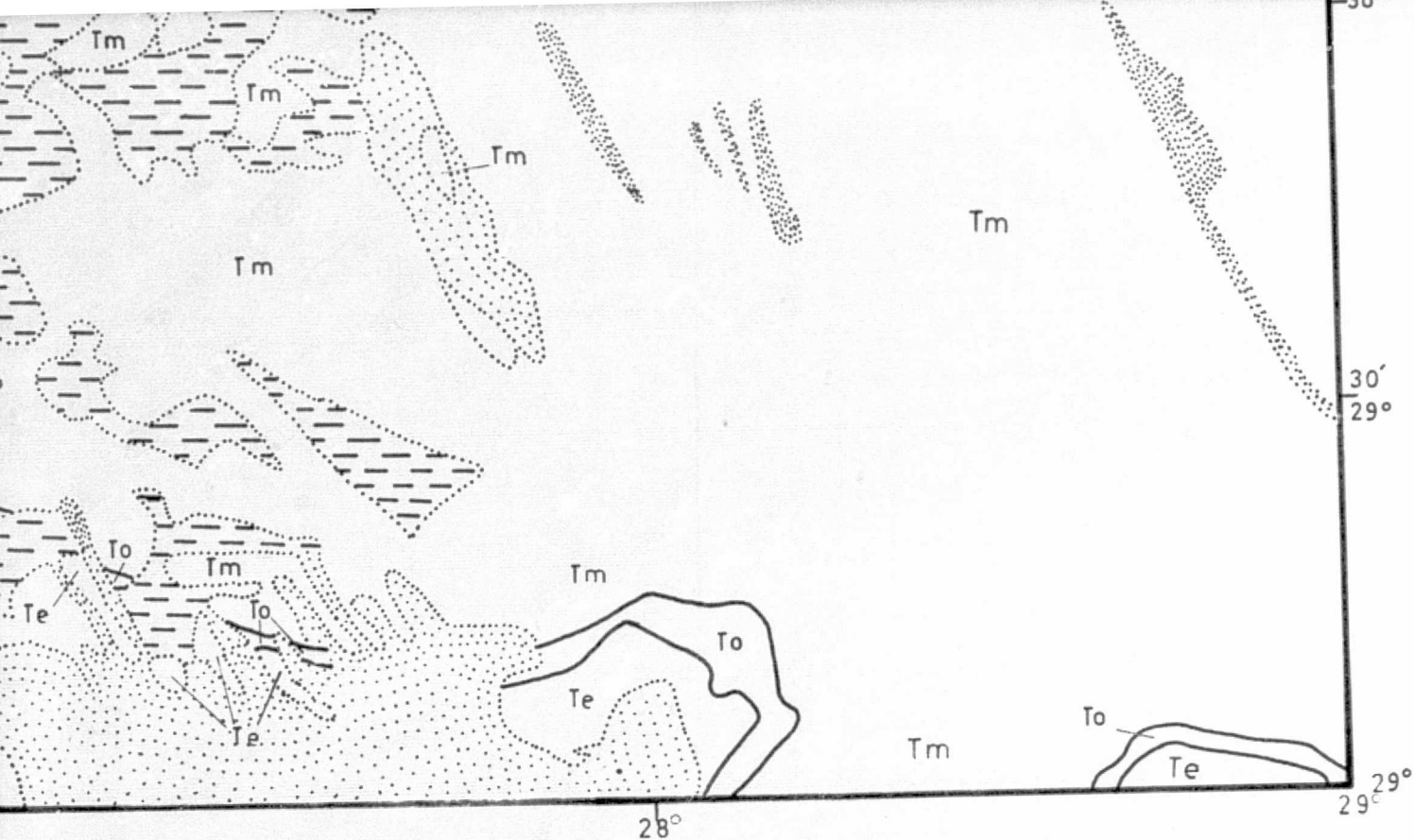
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COMPILED GEOLOGICAL MAP OF THE QAT
(AFTER THE GEOLOGICAL MAP OF

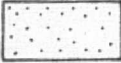
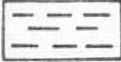
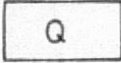
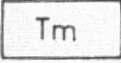
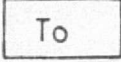
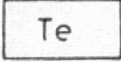
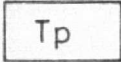
ADDITIONAL FRAME

3



0 10 20 30 40 50 Km

LEGEND

	Sand Dunes
	Sabkha
	Quaternary
	Miocene
	Oligocene
	Eocene
	Paleocene

QATTARA DEPRESSION AREA, EGYPT.

OF EGYPT, 1: 2,000,000, 1971)

NO. 3001 PLATE 2

2

NO. 3001 PLATE 4

4