Institute of Geological Sciences
Hydrogeological Department

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Post-Oligocene sediments, Jalo Region, Sirte Basin, Libya

by

A C Benfield, B.Sc., F.G.S.

Exhibition Road, London
January 1972

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(in folder at back of report)

INTRODUCTION

Investigations by the Hydrogeological Department of the Institute of Geological Sciences (IGS) in 1967 and in 1968 (Wright and Edmunds 1969) revealed the presence of a large body of groundwater of fair to good quality underlying Central Cyrenaica. In 1971 IGS were retained by the Government of Libya to continue hydrogeological investigations in the same area with the object of developing the groundwater resources present. The studies reported upon here commenced in mid-June, 1971.

One of the primary objectives of the present investigations is to determine in some detail the distribution, depth and variability of the aquifers within which the groundwater is contained. It is to this end that the present study is directed. The information obtained will be integrated with hydrochemical data and determinations of the magnitude and variation of the aquifer constants, to permit the assessment of the long-term potential yields of the aquifers and to define overall criteria for the design, construction and operation of the necessary production wells.

Attention is being concentrated on two regions where irrigation projects are being considered. One, to the south, lies between Tazerbo and Sarir, while the other, to the north, comprises the region around Jalo (previously spelt Gialo). The present study is concerned with the latter and for the purpose of this report the region is defined as that lying between latitudes 28° 25' and 29° 20' N, and longitudes 20° 20' and 22° 00' E. (Maps 1 and 2).

PREVIOUS WORK

The Jalo region (Map 1) lies on the northwest margin of the area covered by previous IGS hydrogeological studies in Central Cyrenaica (Wright and Edmunds, 1969) but limited data on the region were acquired for that report. In the case of the lithological and lithofacies studies contained in that report, data were collected from nine control points in the east and south-east of the region (op. cit., Fig. 6). These permitted the drawing of a north-south section through the east of the region (op. cit., Fig. 4, Section IV-IV'). Additional data on the areas immediately to the south and west of the region were utilized in east-west and north-south sections respectively (op. cit., Fig. 4, Section I-I' and V-V'). All the data were integrated to yield a lithofacies map of the post-Eocene formations, (op. cit., Fig. 6). On the lithofacies map, which only covered the south-eastern half of the region, the Jalo region fell within Area IV where an upper series of unconsolidated sands overlie a variable succession of shales, mudstones, limestones, dolomites and sands. The occurrence of gypsum and anhydrite, locally increasing to the east, was noted.

It should be noted that the "upper series of unconsolidated sands" referred to in the post-Eocene lithofacies map includes in the western area (Area IV) sands of Oligocene and Miocene age, as well as Plio-Pleistocene to Recent. This is apparent from the surface geological map (op. cit., Fig. 3) and is alluded to in the text of the report (op. cit., p. 4).

As a result of their hydrological investigations, Wright and Edmunds (1969, p. 6) identified the "upper series of unconsolidated sands" as the principal aquifer of Central Cyrenaica and showed that over much of this area the quality of the groundwater within it was fair to good with specific electrical conductance values of less than 3000 micromhos/cm (Map 1).

AIMS OF PRESENT STUDY

The aims of the present study of the Jalo region were:

1. To collect and synthesize basic geological data on the post-Oligocene succession in the region. At the same time, the opportunity was taken to collect data on the Oligocene sediments in the region but this has not yet been analysed and is not dealt with in this report.

2. To define more closely than hitherto the sequence of lithostratigraphic units within the post-Oligocene sediments. A preliminary assessment showed, for example, that in the north of the region the near-surface sediments divided between an upper unit of generally coarse sands with occasional clay bands and a lower unit of fine sands interbedded with limestones and calcareous clays.

3. To investigate the areal variation within the post-Oligocene lithostratigraphic units of those parameters of particular relevance to the hydrogeological character of the sediments.

BASIC DATA

i) Oil Company Borehole Files

The wildcat and production borehole files of the various oil companies operating in the region constitute the principal source of lithologic and stratigraphic information utilised in this study. For each borehole a number of logs are available which usually include a Lithological Log based on an examination of the borehole cuttings and a variety of electric logs. In some cases an interpretation of the strata penetrated correlated with the Induction Electric Survey (IES), termed an IES/Lithology Log, and a Final Log, which incorporates any palaeontological information and presents a detailed stratigraphy of the borehole, were also made available.

The problems associated with each log and its availability as regards the post-Oligocene strata in the Jalo region are discussed below:

1. Lithological Log: In addition to the usual problem of time lagging samples in rotary drilling, in the Jalo region further problems result from

the extreme rapidity with which the upper unconsolidated strata are penetrated. In many cases the upper 600 ft are drilled in less than one day, and even to depths as great as 1500 ft high drilling rates are maintained. This results in excessively long sample intervals - one to two hundred feet being common - and the production of only a very generalised log. In many instances, no lithological log was compiled for the first few hundred feet but thereafter the log is usually available.

2. IES: Two problems arise as regards the present study. First, as surface casing may be carried to around 500 ft or even deeper to penetrate the unconsolidated near-surface sands, no IES log is available until below this depth. Second, the low salinity of groundwater within the near-surface formations results in a self-potential (SP) log which shows almost no detail in this part of the section. IES logs are always available below the casing.

3. Borehole Compensated Sonic Log (BHS): This log is of course only available below the surface casing and even here problems with excessively large borehole diameter may make the log unusable. However when this does not occur, the log has been found to be of considerable value in distinguishing between sands and limestones in the upper 1500 ft of the succession. Availability of the log is patchy over the Jalo region and appears to depend on the type of oil reservoir being sought at depth.

4. Caliper: This is only available for the post-Eocene sediments in a small number of boreholes where it has proved to be a useful confirmatory log.

5. Gamma Ray (GR): Since this log can be run within a cased hole it has proved most valuable in the interpretation of the near-surface strata. Only where several strings of casing are present and cause excessive diminution of the tool signal is the log unusable. Availability is fortunately quite good, though by no means all boreholes are logged in this way.

6. Neutron Porosity Log: This log is generally run in conjunction with the GR and may in some cases provide a measure of confirmation of the other logs. Rather few boreholes in the Jalo region have been logged in this way in their upper sections.

7. IES/Lithology Log: This interpretative log is often only compiled in rather generalised units in the upper 1500 ft of the borehole. In one case, for example, sands in the upper part of the Miocene from which an adjacent water well was producing, had been identified as limestones. In a number of boreholes, the log was not compiled above the top of the Oligocene at

around 1600 ft below ground level. Consequently for the purposes of the present study, it proved necessary to prepare or revise IES/Lithology Logs of the post-Oligocene strata for a considerable number of boreholes.

8. Final Log: This log is only available for a limited number of boreholes. However, in many cases formation tops are picked on the IES/Lithology Logs and provide a most valuable source of stratigraphic information.

Oil Company water well files were also consulted. However in only a very few cases have lithological logs been compiled for water wells in the region. Where these were available, the information was integrated with that from the associated wildcat borehole.

ii) Coverage over the Jalo region

Data from the records of 105 boreholes were utilised in the present study. Their locations are given on Map 2 which also shows the boundaries of the oil company concessions in the Jalo region.

The density of the coverage of boreholes aimed at in this study of the post-Oligocene sediments was one per five minute rectangle, the map being conveniently divided on this grid. In some cases, the absence of information in adjacent rectangles led to the selection of a borehole record at the edge of an already sampled rectangle. In other cases, although a borehole had been drilled in a rectangle, the record proved to contain no information about the post-Oligocene sediments and it is this that accounts for the apparently unsampled but drilled rectangles.

STRATIGRAPHIC SEQUENCE

The post-Oligocene sediments of the Jalo region divide between the Lower and Middle Miocene, predominantly carbonates and shales with evaporites and with generally only subsidiary sandstones, and the post-Middle-Miocene (possibly Plio-Pleistocene in age), predominantly clastics, which the present study has shown can be subdivided into a lower unit of sandstones, sands and clays with occasional limestones and an upper unit consisting almost entirely of coarse sands. (Table I).

TABLE I

POST-OLIGOCENE SEDIMENTS, JALO AREA, SIRTE BASIN

POST-MIDDLE-MIOCENE	UPPER SANDS	Coarse sands grading to calcareous sandstones in part, with rare thin clayey sands and clays.
	LOWER UNIT	Clayey sandstones and sands, clays, occasional fossiliferous limestones in the north.
LOWER AND MIDDLE MIOCENE		Predominantly limestones and clays, with evaporites. Interbedded sands and sandstones occur to the south-west.

i) Post-Middle-Miocene

Two subdivisions can be distinguished:

a) Upper Sands: coarse to very coarse, sometimes pebbly, quartz sands, subrounded to subangular grains, frequently frosted, generally unconsolidated but grading to sandstones in part, with pronounced calcareous cement, and to sandy calcilutites. Relatively rare, thin interbeds of clay, sometimes associated with thin calcilutites. Occasional sandy clays grading to clayey sandstones. Anhydrite/gypsum reported from a few boreholes.

b) Lower Unit: where thinly developed, this comprises medium grained clayey sandstones and sands and interbedded clays. Where thickly developed, the unit generally comprises fine to medium grained clayey sands and sandstones, sandy clays, clays and fossiliferous marine limestones. In some sections, clays are developed to the virtual exclusion of all other sediment types. Anhydrite is recorded from one borehole.

In the well logs, the Upper Sands are best characterised by the gamma log which generally shows very low values reflecting a low clay content. Higher gamma values indicative of clays are generally restricted to well defined thin horizons. Zones of intermediate values indicative of clayey sands are rare and again generally thin. Thin limestones may be associated with clayey horizons and cause narrow peaks on the BHS logs. These contrast markedly with the generally low interval transit times of the bulk of the Upper Sands which reflect the low degree of consolidation of the unit.

Where the Lower Unit is thin and comprises mainly clayey sands, gamma logs show intermediate values. Where it is thick, rather more variability is seen in both the gamma and BHS logs, reflecting the more heterogeneous nature of the sediments. However, average values are intermediate and clearly lower than in the underlying Lower and Middle Miocene sediments.

The age of the sediments is poorly known. The fauna from the Lower Unit has only yielded a post-Middle-Miocene age. It is possible that the unit is of Upper Miocene, Pliocene or possibly even early Pleistocene age. The Upper Sands are barren but are generally regarded as being of Pleistocene to Recent Age.

As regards depositional environments, the general lithology, the coarseness and the lack of fauna of the Upper Sands suggest deposition in an alluvial plain environment in which fluviatile channel sedimentation was dominant. The interbedded clays could represent limited over-bank deposition while the thin fine-grained limestones suggest deposition in shallow ephemeral lakes. The Lower Unit is clearly marine in part while the sandy lithologies probably point to shoreline deposition (see below).

ii) Lower and Middle Miocene

Lower and Middle Miocene sediments comprise mainly limestones, dolomites and interbedded clays grading to shales. Sandstones, generally fine grained, but reaching coarse to very coarse in places, are less common but may form a significant proportion of the succession in some areas, notably to the south-west (see below).

Gypsum and/or anhydrite occur widely and are associated with both the carbonates and the clays. The evaporites are generally disseminated but may form discrete thin beds at some horizons.

In comparison with the overlying post-Middle-Miocene, logs of the Lower and Middle Miocene show a number of points of contrast. Where the latter comprises a carbonate-clay sequence differences in the resistivity and BHS logs are particularly well marked. However even where the Lower and Middle Miocene presents a sandy facies, significant differences occur. There is an overall increase in gamma values and a general drop in resistivity, while the pattern of the BHS log shows a marked change reflecting the greater degree of consolidation. Such differences permit distinction between the two major parts of the succession even where the Lower Unit of the post-Middle Miocene is absent and the Upper Sands rest directly on the Lower and Middle Miocene.

Evidence of the age of the beds derives from the presence of a marine fauna which includes foraminifera. These have been investigated by oil company palaeontologists who have classified the strata as Lower and Middle Miocene.

The dominance of marine limestones and clays indicates that the bulk of the sediments were deposited in a shallow shelf environment. The presence of evaporites suggests that conditions became lagoonal at times, while the sands were probably laid down in a variety of shoreline environments. The pattern of lithological variation over the area throws further light on the depositional environments and this is discussed below.

REGIONAL VARIATION

Variation in the nature and configuration of the post-Oligocene sediments of the Jalo region is shown in a series of maps. The parameters depicted on the maps were chosen for their significance in terms of the hydrogeology of the area. The maps are supplemented by two cross-sections, one approximately north-south and the other approximately east-west (Map 2. Cross-sections A-A' and B-B' respectively).

i) Post-Middle-Miocene

a) Upper Sands

The configuration of the base of the Upper Sands (Map 3; cross-section B-B') is that of a broad trough elongated in a north-west - south-east direction and deepening to the south-east. Within this trough the base is deepest in a similarly oriented basin in the east where it reaches over 300 feet below sea level. In the west a shallower, elongate but closed basin in which the base is deeper than 200 feet below sea level occupies the greater part of Concession 103. The steepness of the northern margin of the trough suggests that the boundary between the Upper Sands and the sandstones, clays and limestones of the Lower Unit could possibly represent a lateral facies change. Upper Sands are absent in the south-western extremity of the area.

The Upper Sands show little lithological variation. Sands, grading to sandstones in part, comprise the bulk of the sediments (Map 4), and only fall below 85 per cent of the succession in five small, somewhat generalised, areas. Map 4 also shows the location of the few boreholes from which anhydrite has been recorded in the Upper Sands. Apart from being situated in the northern half of the region, the distribution of these sites shows no obvious pattern.

b) Lower Unit

The configuration of the base of the Lower Unit (coincident with that of the post-Middle-Miocene) shows marked changes in elevation (Map 5). Pronounced lows occur to the north-west, to the north-east and to the east in which the base reaches depths in excess of 350 to 400 feet below sea level. An area of intermediate elevation occupies the centre of the region. To the south-west, the base rises sharply and the sediments are absent in the south-west corner of the region, where Lower and Middle Miocene rocks occur at the surface.

Comparison with the map of the configuration of the base of the Upper Sands (Map 3) shows that while a general similarity exists, much of the increase in thickness of the post-Middle-Miocene sediments in the lows is due to the thickening of the Lower Sands and Clays. Only the southern extension of the north-west low into Concession 103 provides an exception to this.

These conclusions are confirmed by the map of the total thickness of the Lower Unit (Map 6) which shows maximum values along the northern and eastern margins of the region. By contrast, over much of the south-central part of the region, the Lower Unit is thin, values of 5 to 10 feet being common. In Concession 103, the Lower Unit is absent in a small area in the north and over much of the concession in the south.

Lithological changes are associated with the increase in thickness of the Lower Unit (Map 7). To the north the total thickness of sands and sandstones increases sharply in contrast to the low and zero thicknesses over the greater part of the south-central part of the region. The change corresponds quite closely with the southern limit of limestone development in the Lower Unit (Map 5) which suggest that the zone of sand deposition could be located along or adjacent to a shoreline trend. Only in the east is the increase in thickness of the Lower Unit unaccompanied by significant sand deposition.

ii) Lower and Middle Miocene

a) Upper 500 feet

In the well records used for the study, no boundaries within the Lower and Middle Miocene were delimited, nor in many cases was even the base of the Miocene defined. Since insufficient time was available to undertake such detailed correlation studies, areal synthesis was restricted to an arbitarily defined unit, the 500 feet of the Lower and Middle Miocene immediately underlying the post-Middle-Miocene, which is referred to in this report as the upper 500 feet. This thickness was selected because at the time of compilation, the maximum depth of groundwater exploration boreholes was planned to be of the order of 1000 feet, which generally corresponds with the elevation of the base of the arbitary unit.

Lithological variation in the upper 500 feet of the Lower and Middle Miocene was assessed using lithofacies analysis. Map 8 gives values for the total thickness of sands and sandstones within the interval and shows that a north-west - south-east line through the centre of the Jalo region separates a mainly sand-free zone to the north-east from a sand rich zone to the south-west. The zero sand isolith defines a number of isolated sandy areas in the east and a major lobe of sand deposition covering the south-west quadrant of the region.

Within the south-western lobe of sand deposition, net sand thicknesses of over 200 feet are recorded at some localities. Generally, however, values vary markedly and show no clear pattern. This probably indicates the development of sand bodies with differing trends at different horizons. In this situation, contouring of the sand isolith for the relatively thick interval under consideration would be of restricted value in a predictive sense and hence was not undertaken.

It should be noted at this point that lithofacies studies of stratigraphically correlated units would most probably resolve the difficulties arising with the arbitarily defined unit and reveal sedimentary patterns of predictive value. The presence of such patterns is in fact hinted at by the disposition of the zero sand isolith (Map 8), which suggests the combined effect of a north-west - south-east longshore trend and a north-easterly directed sand input. Such a pattern compares well with that documented by Selley (1966, 1967, 1969) for the Miocene Marada Formation at outcrop in the Jebel Zelten and Marada regions, immediately to the west of the Jalo region.

Values for the total thickness of carbonates in the upper 500 feet of the Lower and Middle Miocene are shown in Map 9. As in the case of the sand thickness data, there is a significant difference between the north-eastern and south-western halves of the Jalo region. The 200 feet isolith provides a convenient dividing line. To the north-east net carbonate thicknesses are high and exceed 400 feet in places. To the south-west, values are lower but nevertheless are only rarely less than 100 feet. Overall, values vary rapidly over small areas and the plotting of a full range of isoliths has not been attempted.

In the upper 500 feet of the Lower and Middle Miocene, gypsum and/or anhydrite are recorded from all lithologies. Map 10 gives the total thickness of evaporite-bearing strata irrespective of lithology. Yet again there is a clear distinction between the north-east and the south-west of the region, which in this case is marked by the zero isolith. Within the north-easterly evaporite-bearing zone, a wide range of thicknesses is observed, while evaporites appear to be absent in certain areas. Although this variability probably results in part from the effects of superimposition, the difficulties of sampling in these rapidly drilled holes cannot be ignored and may well account for some of the more extreme variations. As with the previous maps, a full range of isoliths has not been plotted.

The final map in this section (Map 11), presents a general synthesis of lithological variation in the upper 500 feet of the Lower and Middle Miocene. The region divides into three. Over the whole of the north-eastern half, the sequence is made up of limestones, dolomites and interbedded clays. To the south-west lies a band of alternating sandstones, limestones and clays. Gypsum and/or anhydrite are widely developed over the whole of the former zone and part of the latter. In the far south-west, limestones decrease in importance and the sequence comprises mainly sandstones and clays.

Comparison of the Lower and Middle Miocene lithofacies pattern for the Jalo region with that of the Marada Formation in the Miocene outcrop area immediately to the west (Selley, 1967, 1969), shows a marked degree of similarity. As a result of detailed sedimentological field investigations, Selley was able to distinguish five facies and relate them to their depositional environments. Four of the facies form laterally interfingering belts parallel to the palaeo-shoreline. Detrital limestones deposited as carbonate sand barrier beaches and offshore bars are succeeded landwards by lagoonal laminated shales. These interdigitate with interlaminated shales and sands deposited on tidal flats fronting a fluviatile coastal plain comprising crossbedded sands and shales. Calcareous channel-sandstones comprising the fifth facies cut through the other facies orthogonally to to their trend and represent estuarine deposition.

The similarity both of broad facies relationships and of sandstone body trends suggest that Lower and Middle Miocene deposition in the Jalo region took place in a similar shoreline complex. Only the trend of the shoreline appears to differ. In the Marada area the trend is east-west (Selley, 1969 p. 447) while in the Jalo area it would seem to be north-west - south-east.

b) Upper 150 feet

Over much of the centre of the Jalo region the Lower Unit of the post-Middle-Miocene is thin and may be absent in places (Map 6). In terms of the hydrogeology of the region this suggests the possibility of a significant degree of hydraulic connection between groundwater in the Upper Sands and that in the Lower and Middle Miocene. Since both the extent of the connection and the chemical quality of groundwater in the lower formation would be affected by the nature of the uppermost strata of the Lower and Middle Miocene, it was decided to investigate these beds in greater detail in the central area of the Jalo region.

Map 12 shows vertical sections of the upper 150 feet of the Lower and Middle Miocene in that area. The general pattern of lithological variation is comparable with that revealed by the lithofacies studies of the upper 500 feet of the formation. Carbonates, chiefly dolomites, predominate in the north-east while clastics increase in importance to the south-west. In detail, however, quite marked deviations from the average pattern can be discerned.

Sections in which carbonates comprise the bulk of the sequence, while most common in the north-east, can also occur in the south (for example, well J2-59) and in the west (Q1a - 103). Although clastics predominate in the south-west, they comprise clays rather than sands. Hydrogeologically this is significant as this region (the southern half of Concession 103) coincides with an area in which the Lower Unit of the post-Middle-Miocene is absent (Map 6). Clays in the upper part of the Lower and Middle Miocene could be expected to reduce the degree of hydraulic connection between the Upper Sands and the underlying strata in the same way the Lower Unit does elsewhere. Sand-rich sequences do occur to the north of Concession 103 and it should be noted that at C1-103 one such sequence is in continuity with the Upper Sands as the Lower Unit is absent.

The sections depicted on Map 12 also indicate the presence of evaporites and the minimum depths below the top of the Lower and Middle Miocene at which they occur. As with the general lithology, the distribution pattern corresponds with the generalised pattern for the upper 500 feet (Map 10). Maximum development occurs in the north-east, while evaporites are absent in the south-east. An additional feature shown by the sections is a general trend of increasing minimum depths of evaporitic sediments below the top of the Lower and Middle Miocene towards the south-west. Exceptions to the trend occur, however, and one of hydrogeological significance is at Q1a-103 where evaporite-bearing Lower and Middle Miocene sediments directly underlie the Upper Sands.

SUMMARY OF CONCLUSIONS

1. Examination of the logs of 105 oil company wildcat and production boreholes in the Jalo region (Maps 1 and 2) shows that the post-Oligocene section comprises two major divisions, the post-Middle-Miocene above, and the Lower and Middle Miocene below. The post-Middle-Miocene divides between the Upper Sands and the Lower Unit below (Table I).

2. The Upper Sands comprise mainly coarse unconsolidated sands grading to calcareous sandstones in part. Thin clayey sands and clays are rare and may be associated with thin fine grained limestones. Anhydrite has been recorded at a few localities. Lithological variation within the unit appears to be slight (Map 4). The Upper Sands were probably deposited in a continental alluvial plain environment. Comparison with Wright and Edmunds (1969) indicates that the Upper Sands constitutes the principal near-surface aquifer of the Jalo region.

3. The base of the Upper Sands (Map 3; Cross-sections A-A', B-B') is deepest in a trough occupying the east of Concession 97 in the east of the Jalo region and in a closed basin centred on Concession 103 in the west. To the north and to the south-west the base rises rapidly.

4. The Lower Unit includes clayey sandstones and sands, and clays. Marine limestones occur in the north of the region. The Lower Unit is thin and may be absent in the centre of the region (Map 6; Cross-sections A-A', B-B') but thickens to the north and east. The total thickness of sands and sandstones within the Lower Unit also increases to the north. Deposition probably took place mainly in the near-shore zone.

5. The base of the post-Middle-Miocene (Map 5) is lowest in the east, north-east and north-west. It rises to the south-west where post-Middle-Miocene sediments are absent.

6. The Lower and Middle Miocene comprises a variety of lithologies. Limestones, dolomites and clays predominate but sands and sandstones increase in importance to the south-west. Gypsum/anhydrite occur widely in association with both the carbonates and the clays.

7. Lithofacies analysis of the upper 500 feet of the Lower and Middle Miocene (Maps 8, 9 and 10) reveals a pattern of north-west - south-east trending facies belts (Map 11). In the north-eastern half of the Jalo region the interval is made up of limestones, dolomites and clays. To the south-west lies a band of sandstones, limestones and clays. Evaporites are widely developed over the whole of the former and part of the latter. In the south-west the interval comprises mainly sandstones and clays.

8. The similarity of the Lower and Middle Miocene facies belts to those

recognised in the Miocene outcrop immediately to the west (Selley, 1966, 1969) and related to deposition in a shoreline complex passing from shallow marine through lagoonal to fluviatile coastal plain suggests that deposition in the Jalo region took place in a similar series of environments. Only in the trend of the shoreline, east-west in the outcrop area, south-east - north-west in the Jalo region, is a difference noted.

9. Detailed investigations of the upper 150 feet of the Lower and Middle Miocene in the central part of the Jalo region (Map 12) shows that while the general pattern of sedimentary variation is comparable with that for the upper 500 feet, local variations may be significant. Thus in the south of Concession 103 where the Lower Unit of the post-Middle-Miocene is absent, clays rather than sands directly underlie the Upper Sands. The detailed study also shows that the depth of evaporite-bearing sediments below the base of the post-Middle-Miocene appears to increase to the south-west (Map 12).

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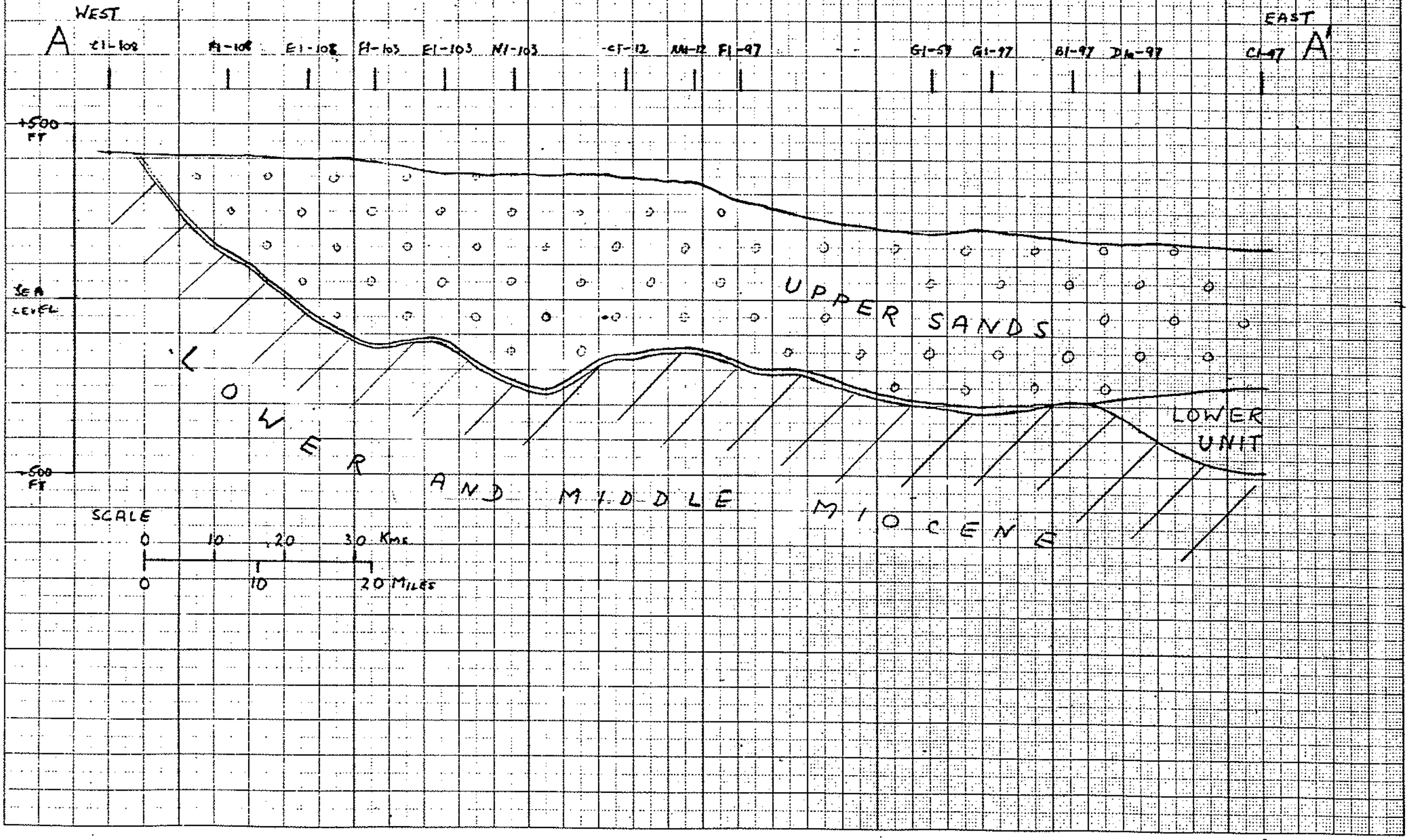
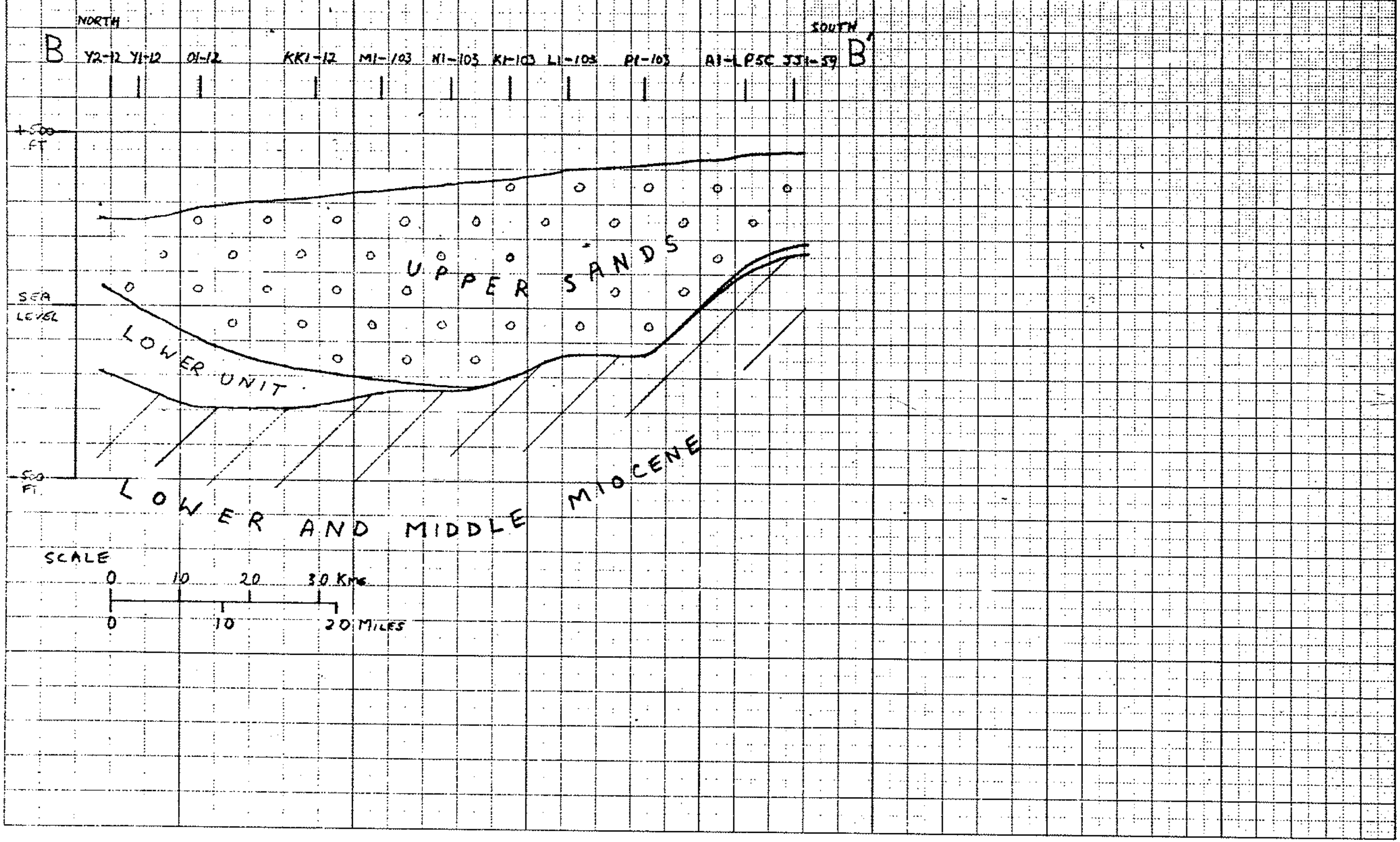
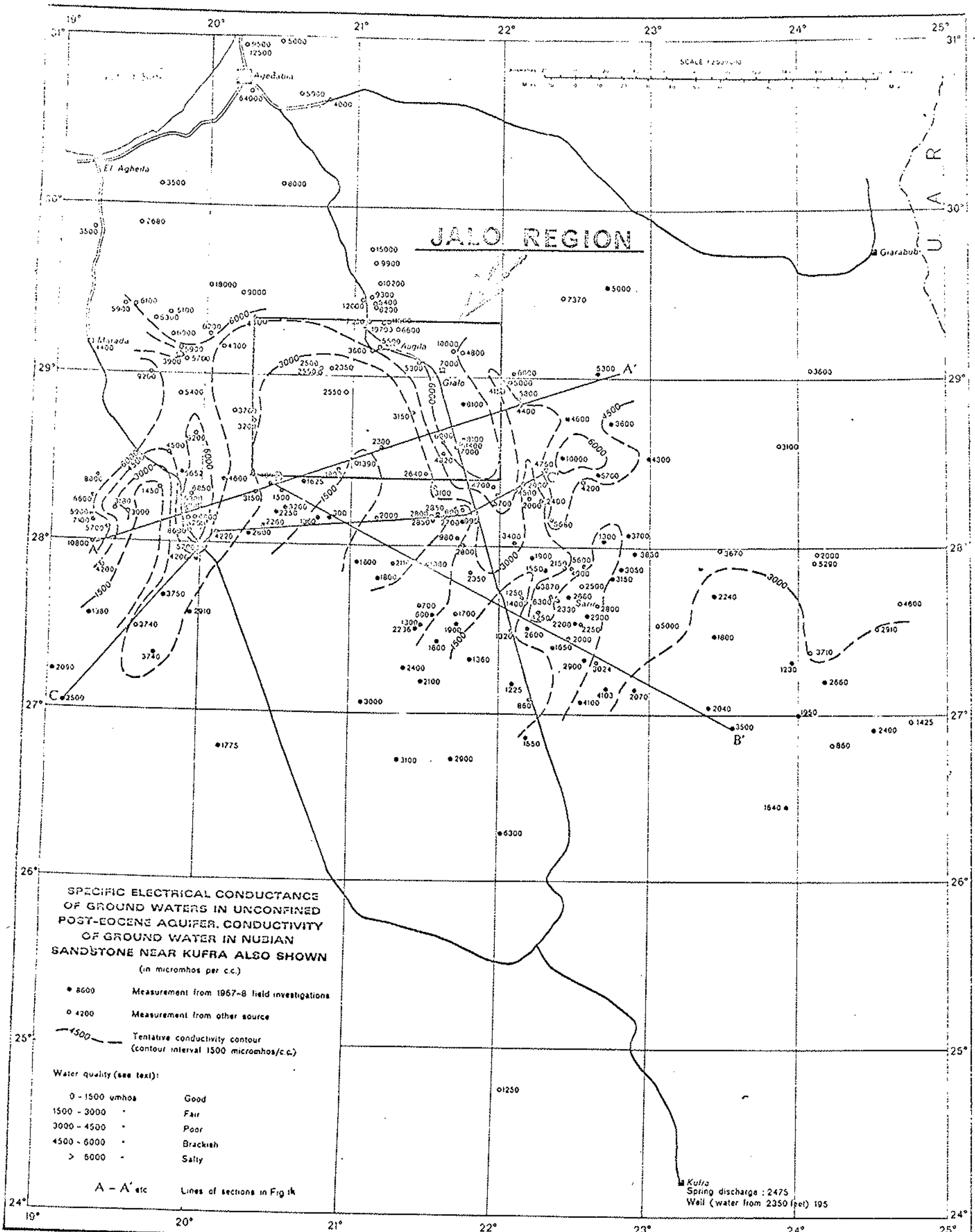
Cross-section A-A'



Cross-section B-B'



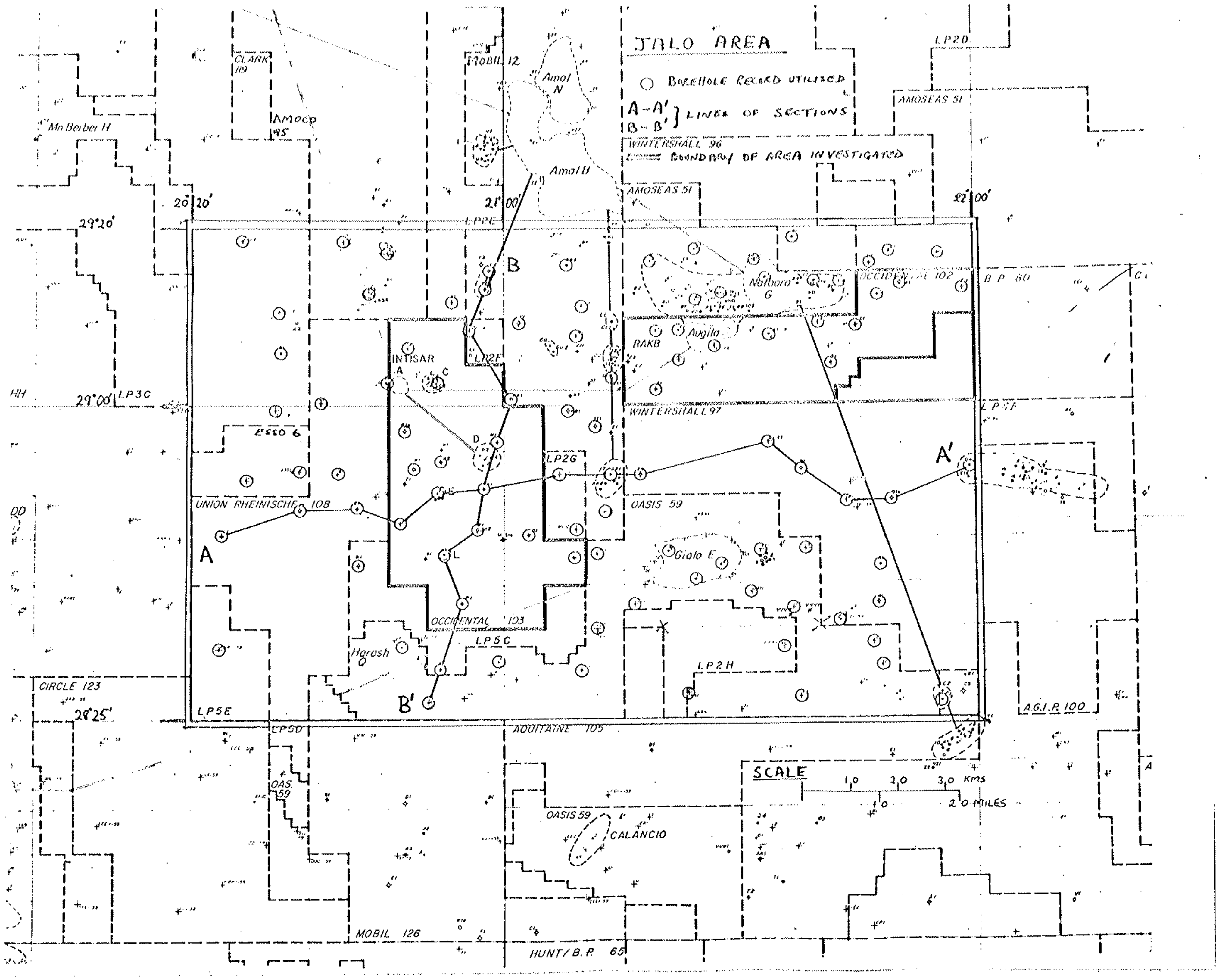
MAP 1



AFTER WRIGHT & EDMONDS (1969)

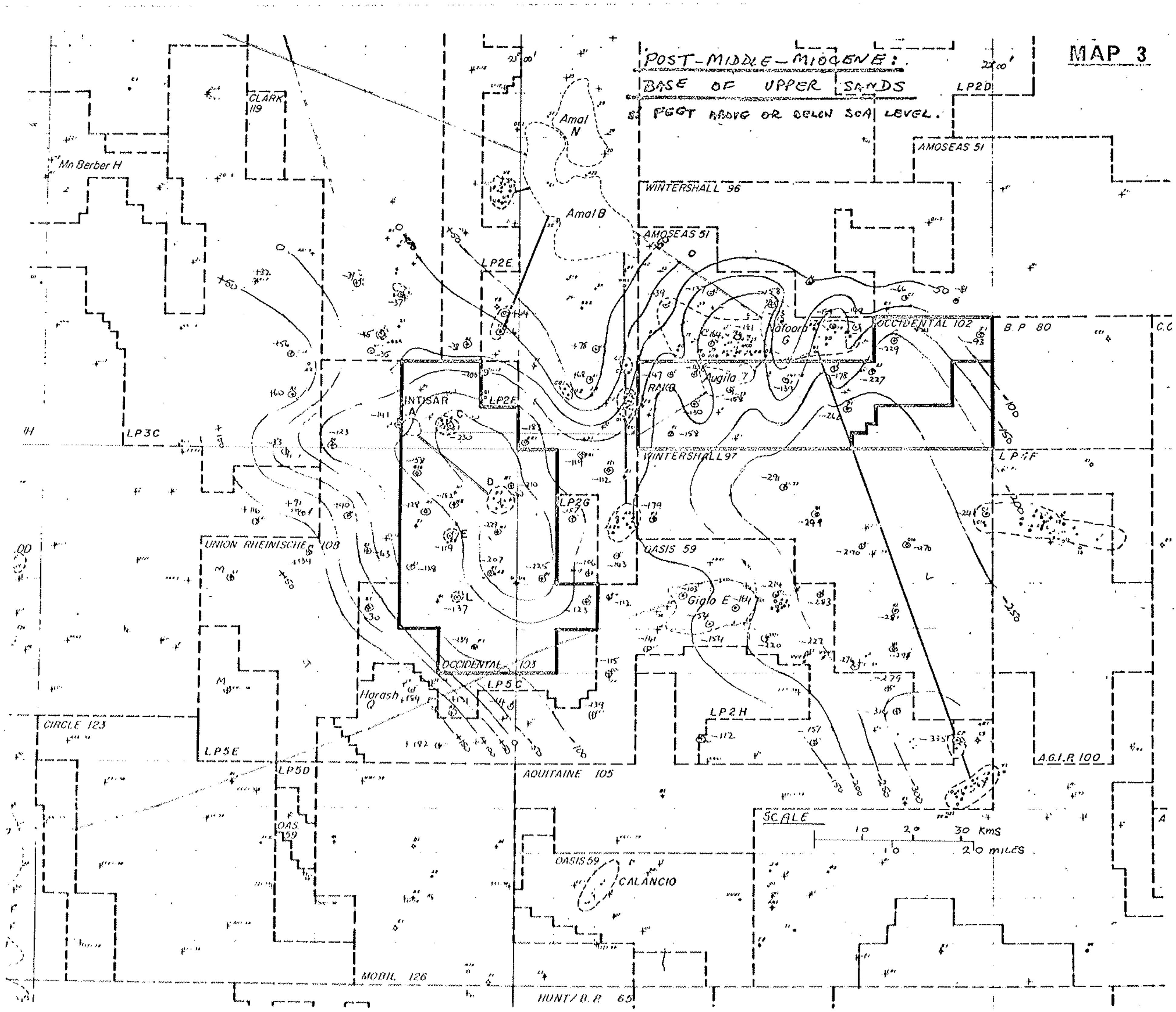
Figure 9

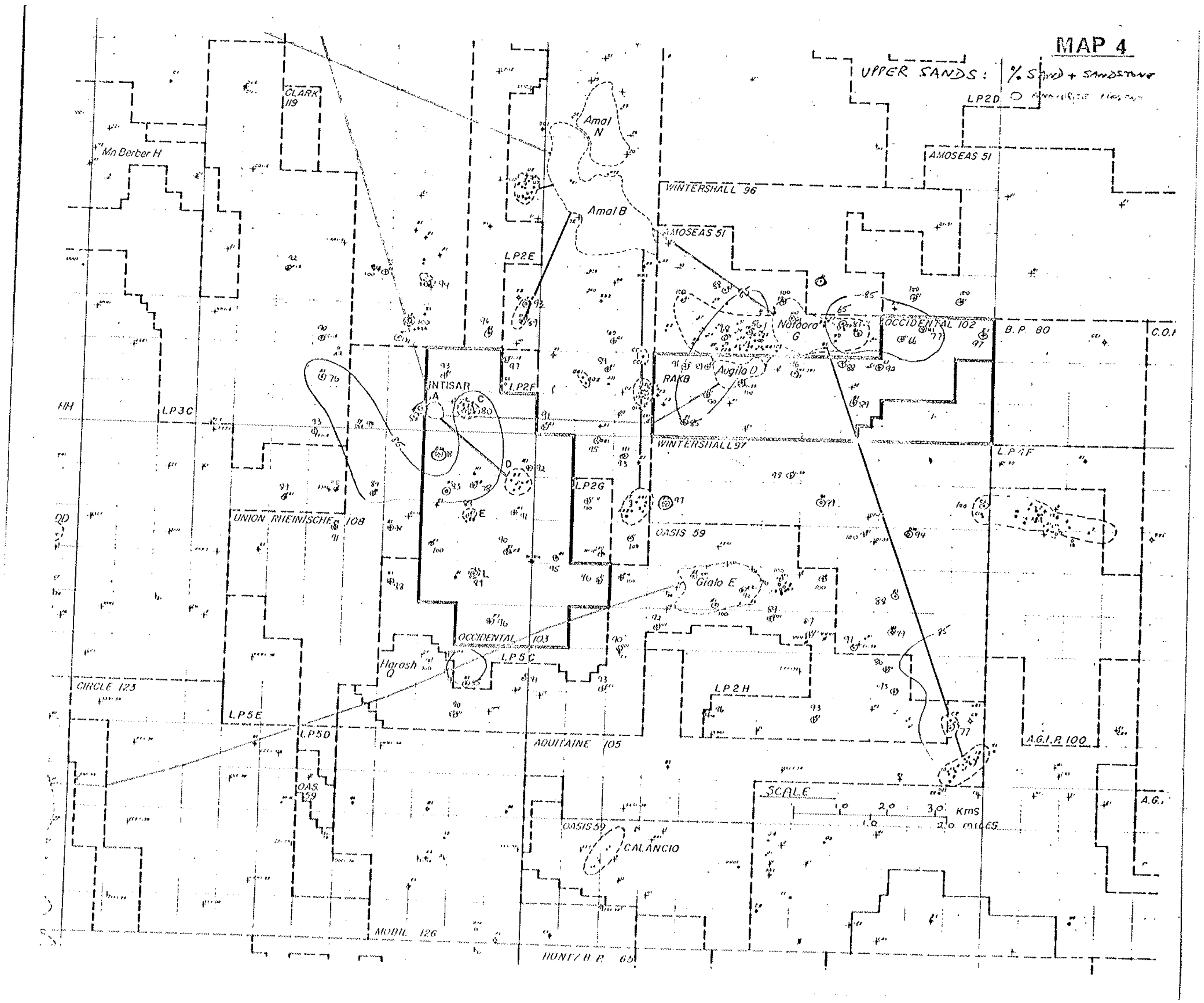
MAP 2



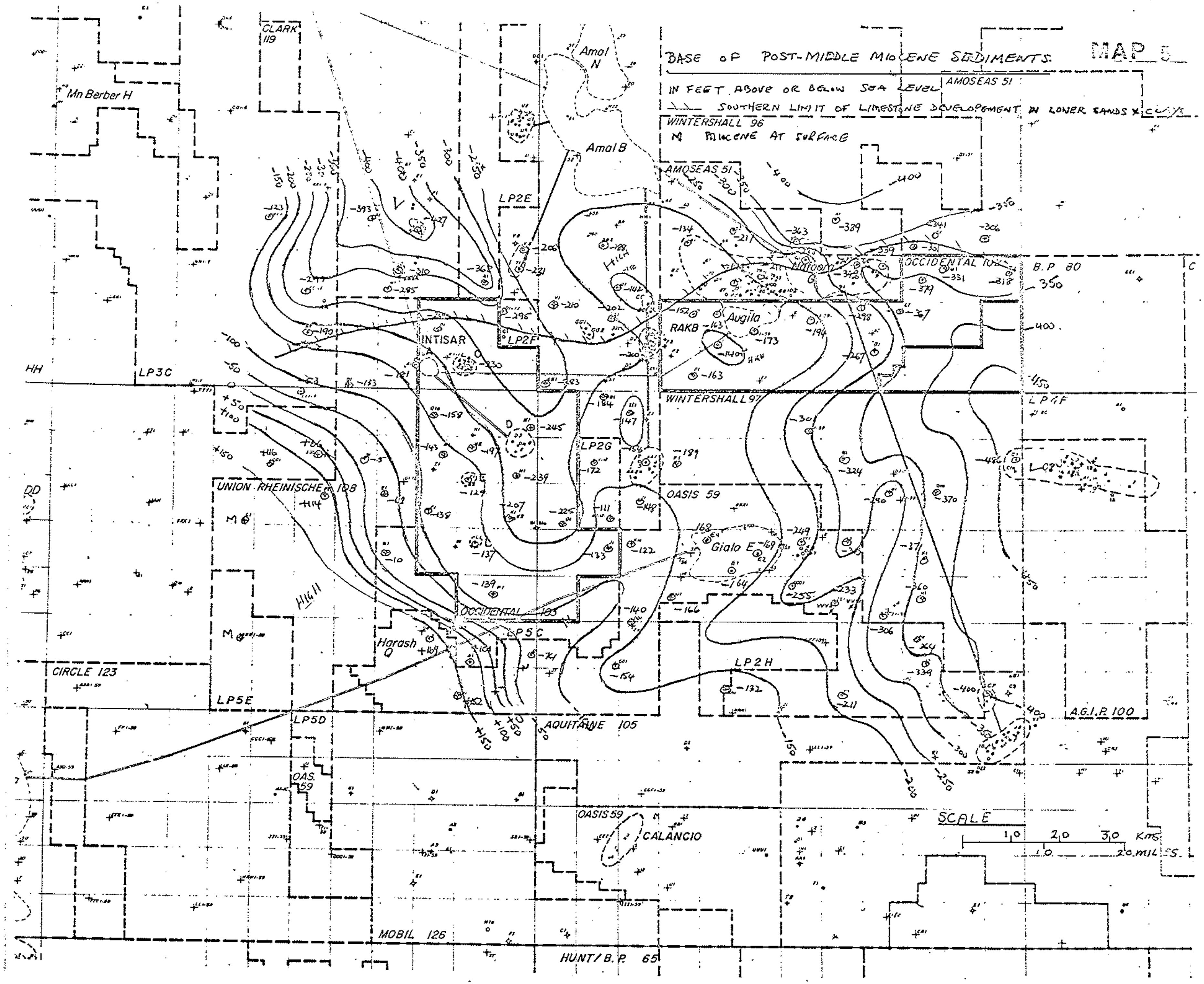
JALO AREA
○ BOREHOLE RECORD UTILISED
A–A' B–B' } LINES OF SECTIONS
BOUNDARY OF AREA INVESTIGATED
SCALE
1.0 2.0 3.0 KMS
1.0 2.0 MILES
INTISAR
UNION RHEINISCHE 108
OCCIDENTAL 103
OASIS 59
WINTERSHALL 97
WINTERSHALL 96
AMOSEAS 51
MOBIL 12
CLARK 119
AMOCO 45
ESSO 6
CIRCLE 123
AQUITAINE 105
MOBIL 126
HUNT/B.P. 65
A.G.I.P. 100
B P 80
CALANCIO
Gialo E
Haroch Q
Augila
Nafoora G
Amal N
Amal B
RAKB
LP2D LP2E LP2F LP2G LP2H LP3C LP5C LP5D LP5E
29°20'
29°00'
28°25'
20°20'
21°00'
22°00'
A A' B B'

MAP 3

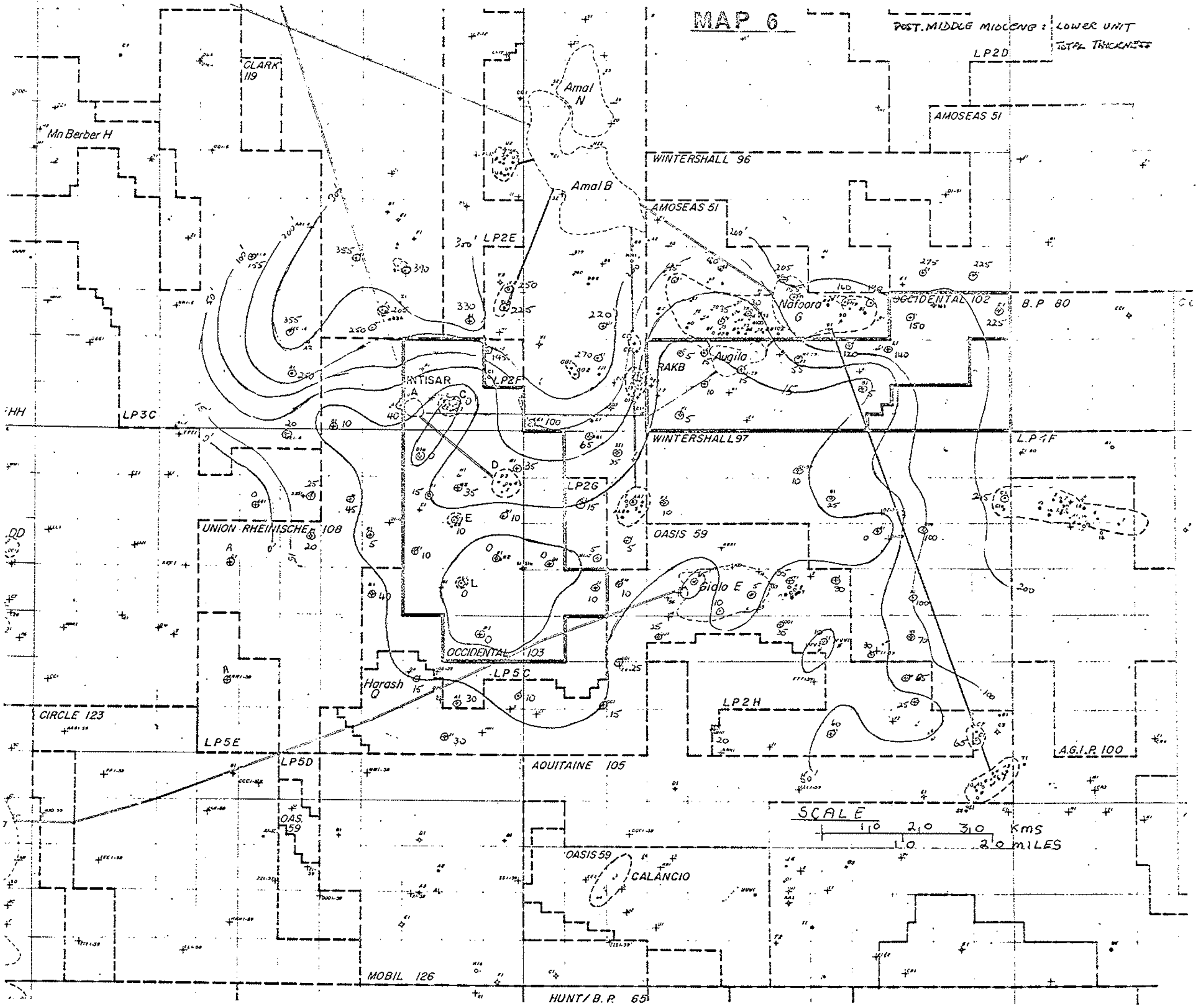

POST-MIDDLE-MIOCENE:
BASE OF UPPER SANDS
FEET ABOVE OR BELOW SEA LEVEL.
CLARK 119
Mn Berber H
Amal N
Amal B
LP2D
AMOSEAS 51
WINTERSHALL 96
LP2E
Nafoora G
OCCIDENTAL 102
B.P. 80
INTISAR A
LP2F
Augila
RAKB
LP3C
WINTERSHALL 97
LP2G
LP4F
UNION RHEINISCHE 108
OASIS 59
Gialo E
OCCIDENTAL 103
Harash Q
LP5C
LP2H
CIRCLE 123
LP5E
LP5D
AQUITAINE 105
A.G.I.P. 100
OAS. 59
OASIS 59
CALANCIO
SCALE
10 20 30 Kms
10 20 miles
MOBIL 126
HUNT/B.P. 65



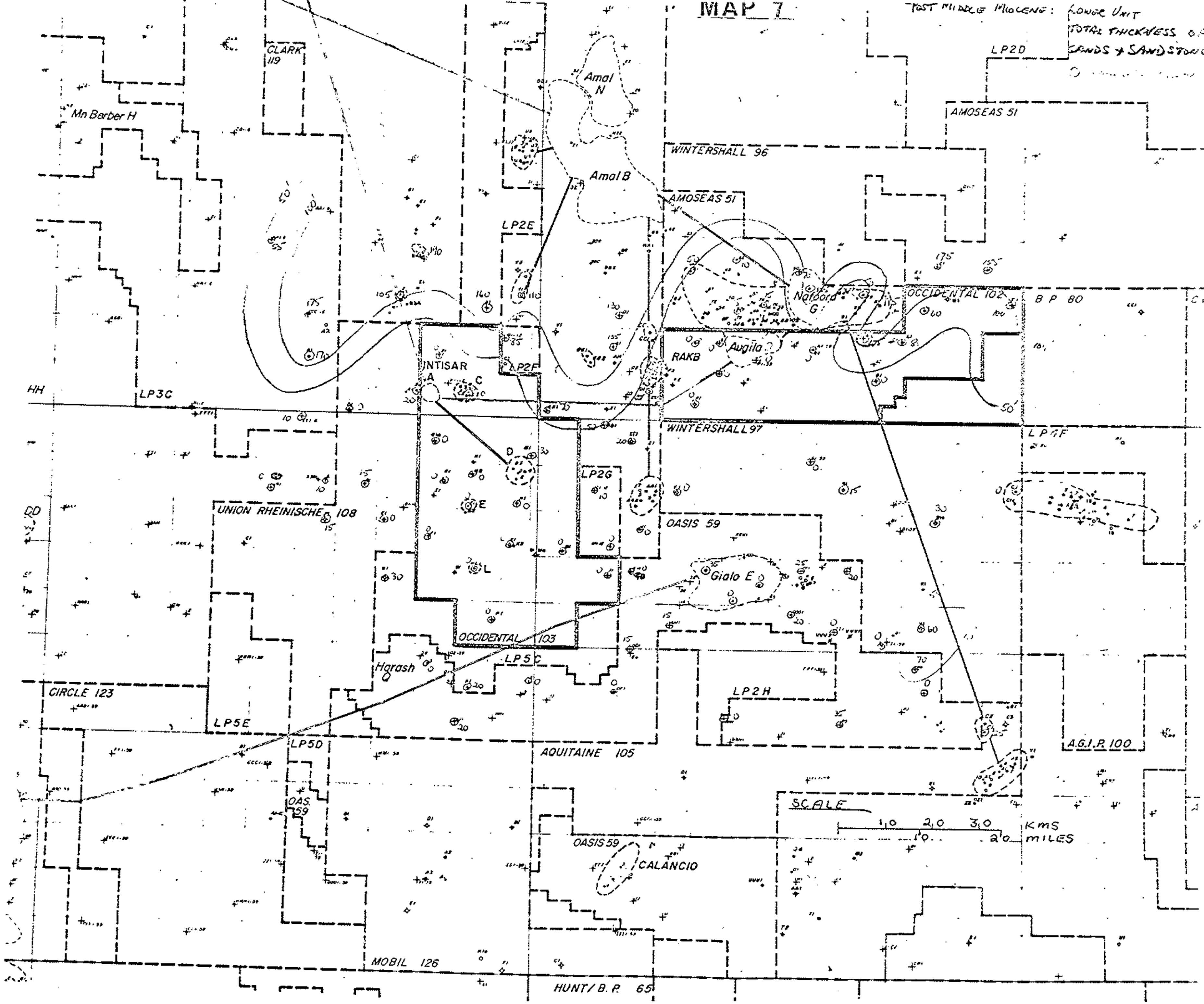
MAP 4
UPPER SANDS: % SAND + SANDSTONE
LP2D
AMOSEAS 51
CLARK 119
Mn Berber H
Amal N
Amal B
WINTERSHALL 96
AMOSEAS 51
LP2E
Nafoora G
OCCIDENTAL 102
B.P. 80
C.O.
INTISAR
LP2F
RAKB
Augila D
LP3C
WINTERSHALL 97
L.P.4F
LP2G
UNION RHEINISCHE 108
OASIS 59
Gialo E
OCCIDENTAL 103
LP5C
Harash Q
CIRCLE 123
LP5E
LP5D
LP2H
A.G.I.P. 100
AQUITAINE 105
OAS 59
SCALE
10 20 30 Kms
10 20 MILES
A.G.
OASIS 59
CALANCIO
MOBIL 126
HUNT/B.P. 65


MAP 5
BASE OF POST-MIDDLE MIOCENE SEDIMENTS
IN FEET ABOVE OR BELOW SEA LEVEL
SOUTHERN LIMIT OF LIMESTONE DEVELOPMENT IN LOWER SANDS X CLAYS
M MIOCENE AT SURFACE
AMOSEAS 51
WINTERSHALL 96
WINTERSHALL 97
OCCIDENTAL 102
OCCIDENTAL 103
B.P 80
LP2E
LP2F
LP2G
LP2H
LP3C
LP4F
LP5C
LP5D
LP5E
CLARK 119
Mn Berber H
Amal N
Amal B
INTISAR
Nafoora
Augila
RAKB
HIGH
OASIS 59
Gialo E
UNION RHEINISCHE 108
Harash
CIRCLE 123
AQUITAINE 105
A.G.I.P. 100
OAS. 59
CALANCIO
MOBIL 126
HUNT/B.P. 65
HH
DD
SCALE
10 20 30 KMS
10 20 MILES

MAP 6

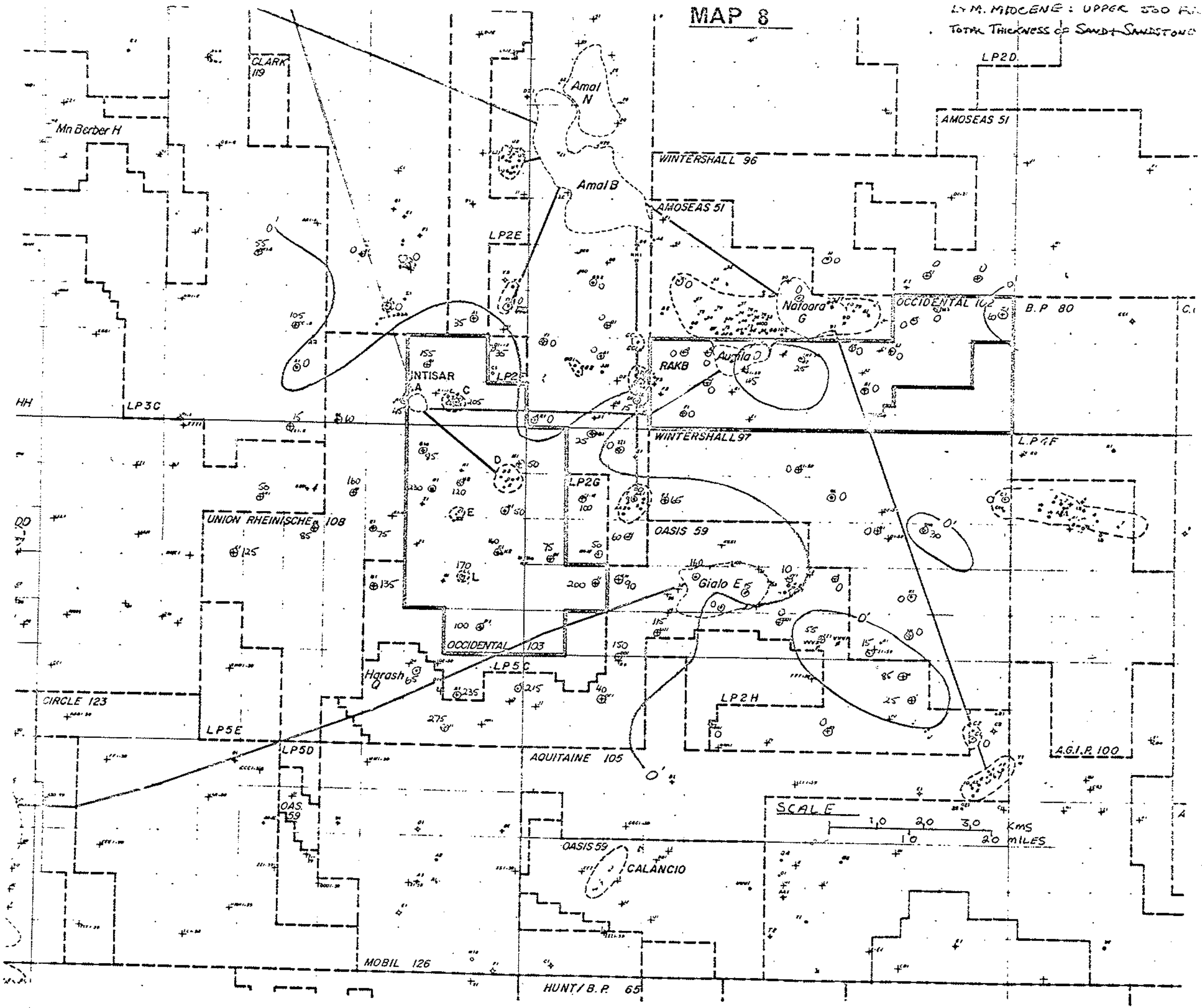

POST. MIDDLE MIOCENE : LOWER UNIT
TOTAL THICKNESS
LP2D
AMOSEAS 51
WINTERSHALL 96
AMOSEAS 51
OCCIDENTAL 102
B.P. 80
Amal N
Amal B
Nafoora G
Augila
RAKB
CLARK 119
Mn Berber H
LP2E
LP2F
LP3C
INTISAR
WINTERSHALL 97
L.P. 1F
LP2G
OASIS 59
UNION RHEINISCHE 108
Gialo E
OCCIDENTAL 103
LP5C
Harash Q
LP2H
CIRCLE 123
LP5E
LP5D
AQUITAINE 105
A.G.I.P. 100
OAS. 59
OASIS 59
CALANCIO
MOBIL 126
HUNT / B.P. 65
SCALE
10 20 30 Kms
10 20 MILES

MAP 7


POST MIDDLE MIOCENE: LOWER UNIT
TOTAL THICKNESS OF
SANDS + SANDSTONES
LP2D
AMOSEAS 51
WINTERSHALL 96
AMOSEAS 51
CLARK 119
Mn Barber H
Amal N
Amal B
LP2E
LP2F
INTISAR
A
C
D
E
L
HH
LP3C
Nafoora G
OCCIDENTAL 102
B P 80
RAKB
Augila
WINTERSHALL 97
LP7F
LP2G
OASIS 59
Gialo E
UNION RHEINISCHE 108
DD
OCCIDENTAL 103
LP5C
Hqrash
LP2H
CIRCLE 123
LP5E
LP5D
AQUITAINE 105
A.G.I.P. 100
OAS. 59
OASIS 59
CALANCIO
SCALE
1.0 2.0 3.0 KMS
1.0 2.0 MILES
MOBIL 126
HUNT/B.P. 65

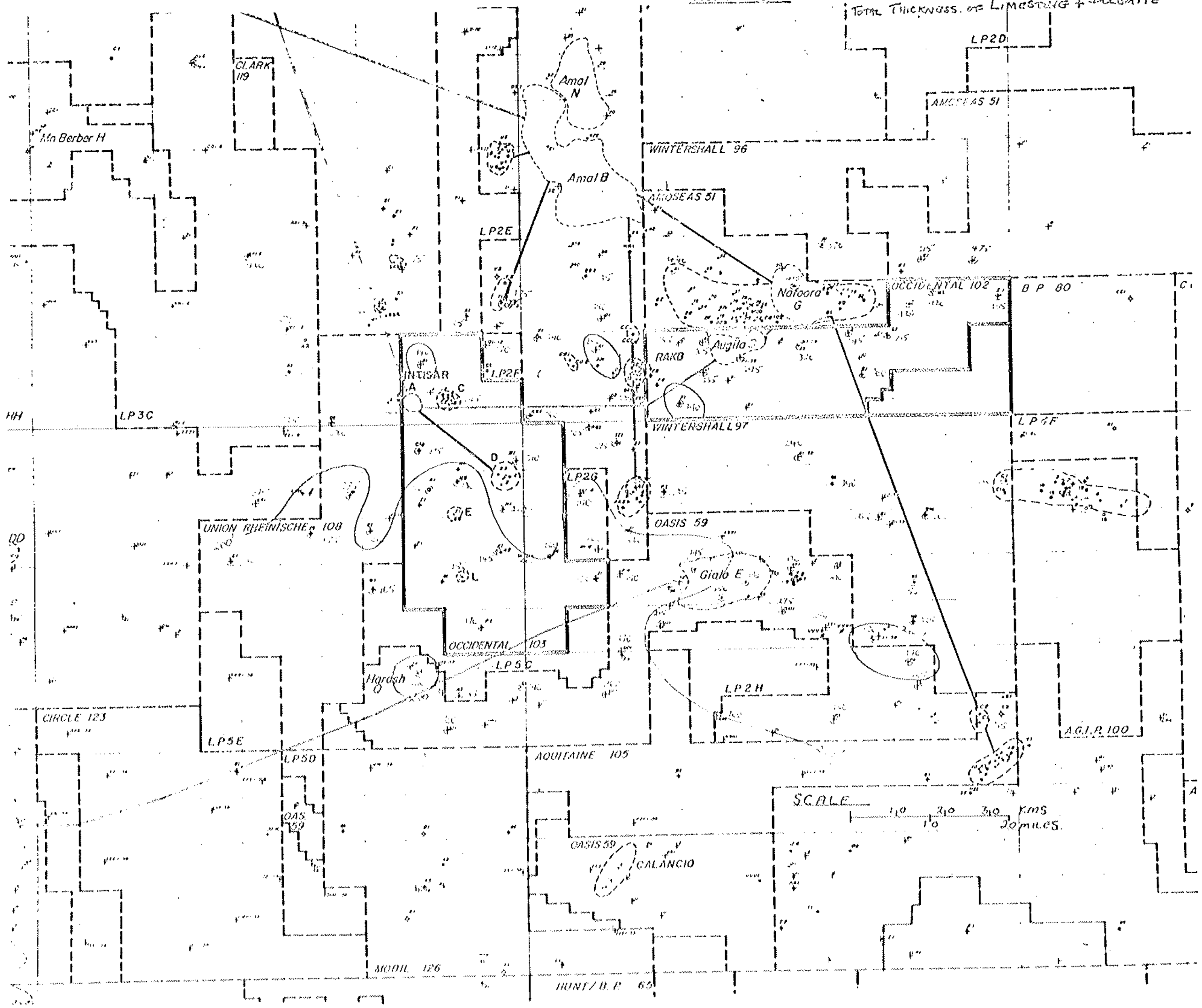
MAP 8

L. M. MIOCENE : UPPER 300 FT.
TOTAL THICKNESS OF SAND + SANDSTONE



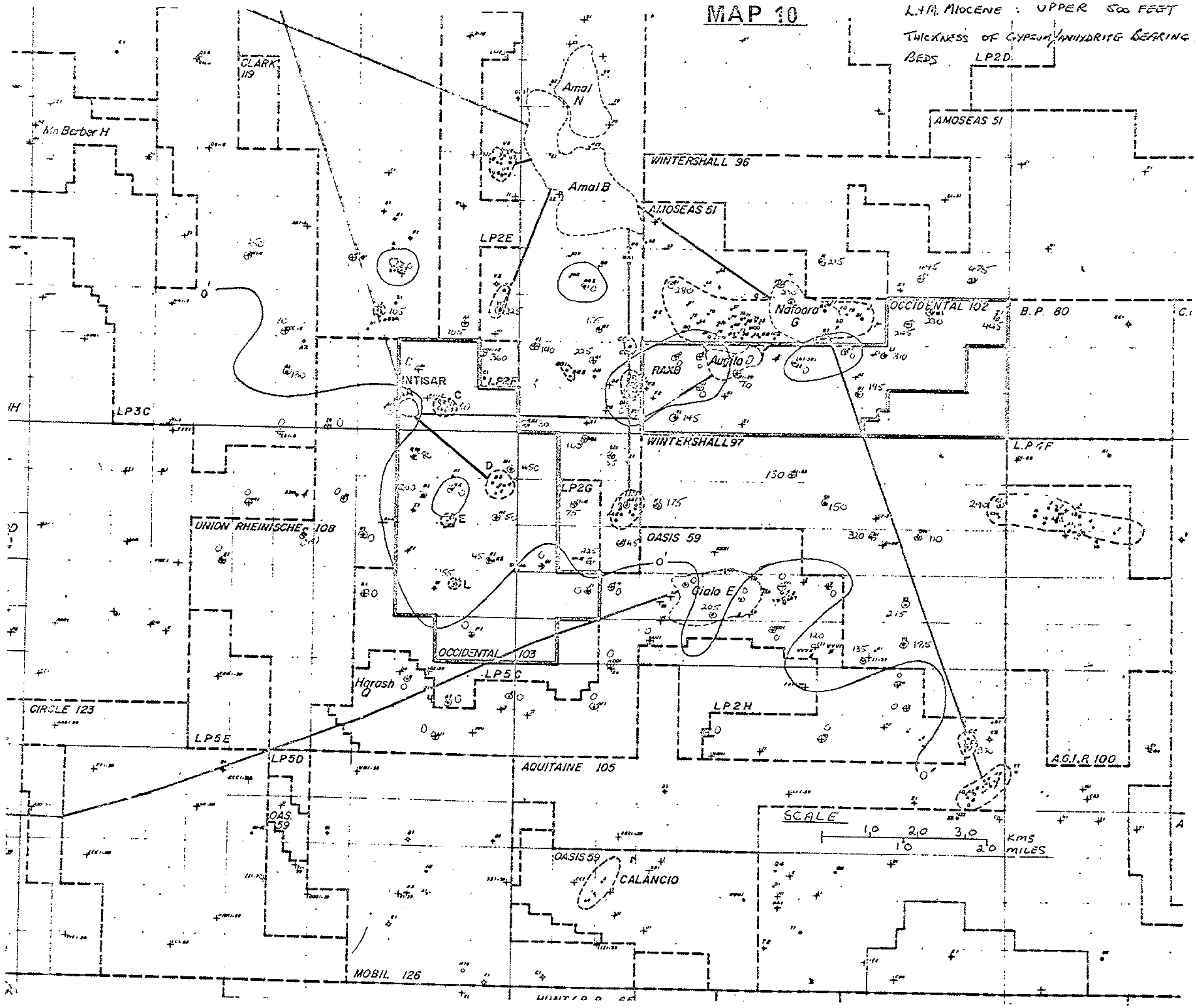
MAP 9

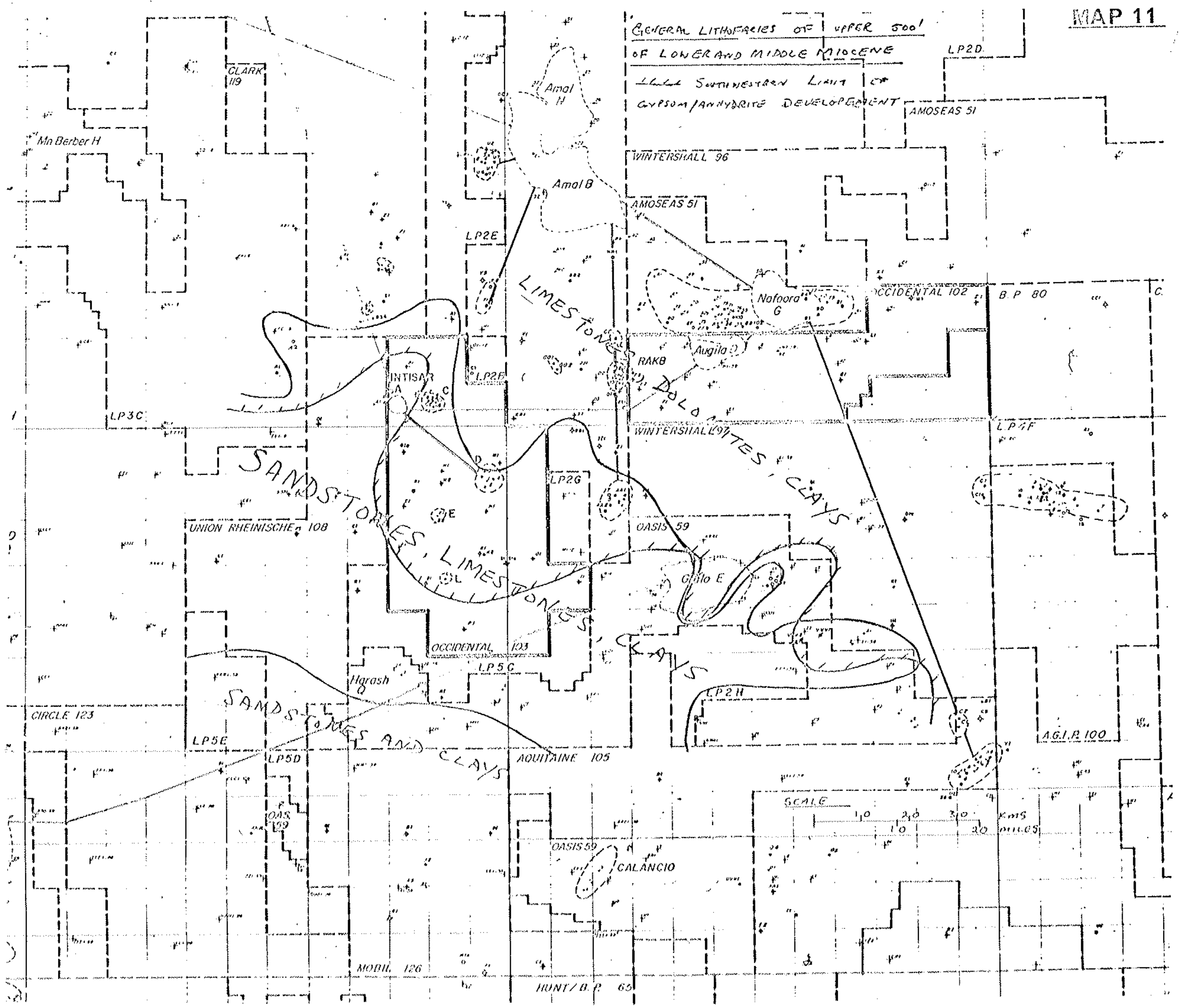
L + M. MIOCENE : UPPER 500 FEET
TOTAL THICKNESS OF LIMESTONE + DOLOMITE



MAP 10

L.+M. MIOCENE : UPPER 500 FEET THICKNESS OF GYPSUM/ANHYDRITE BEARING BEDS




MAP 11
GENERAL LITHOFACIES OF UPPER 500' OF LOWER AND MIDDLE MIOCENE
SOUTHWESTERN LIMIT OF GYPSUM/ANHYDRITE DEVELOPEMENT
CLARK 119
Mn Berber H
Amal H
Amal B
LP2D
AMOSEAS 51
WINTERSHALL 96
LP2E
LIMESTONES, DOLOMITES, CLAYS
Nafoora G
Augila
RAKB
OCCIDENTAL 102
B.P. 80
INTISAR
LP3C
WINTERSHALL 97
LP4F
SANDSTONES, LIMESTONES, CLAYS
LP2G
OASIS 59
UNION RHEINISCHE 108
Gialo E
OCCIDENTAL 103
LP5C
Harash
LP2H
SANDSTONES AND CLAYS
CIRCLE 123
LP5E
LP5D
AQUITAINE 105
A.G.I.P. 100
SCALE
10 20 30 KMS
10 20 MILES
CALANCIO
MOBIL 126
HUNT/B.P. 65

MAP 12 L+M. MIOCENE : LITHOLOGY OF UPPER 150 FEET.