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JALU-TAZERBO PROJECT
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LIBYAN ARAB REPUBLIC
PHASE 1 AREA

Investigations of Clay Beds within the Saturated Zone of the Post-Middle Miocene Calanscio Formation by Gamma Ray Logging

by

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Feb., 1974

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1 Introduction

1.1 General

The Post-Middle Miocene aquifer of the Jalu-Tazerbo Project Phase 1 Area comprises the lower part of the Calanscio Formation. The Formation consists of sands, mainly unconsolidated and dominantly medium in grain with interbeds of clay, sandy in part. Analyses of pumping tests run by IGS at the Phase 1 Exploration/Production borehole sites indicated that these clay interbeds acted as confining beds at least for the length of the tests conducted (5-6 days) (Interim Report, 1973, p 27 *et seq*). It was therefore necessary to investigate these clays in some detail in the proposed Production well field region in an attempt to define their nature, thickness variation, areal distribution and lateral continuity. Such information could then be incorporated in a long-term digital model of the development of the aquifer in the Production Well-field region centred on southern Concession 103.

1.2 Sources of information

The presence of clay beds within the Calanscio Formation was first revealed by the appraisal and synthesis of the information contained in the oil company wildcat well files (Benfield, 1972). In particular, the Schlumberger gamma logs showed occasional peaks indicative of clay interbeds and these were supported by evidence from the company percentage-lithology logs. Much more detailed information was obtained from the running of gamma logs by IGS personnel using a Portalogger instrument in specially selected boreholes. These logs are the basic source of information for this Report.

2 Field investigations and log variability

2.1 Location, numbers and type of boreholes gamma logged by IGS

Gamma ray logs were run by IGS at a total of 17 sites in the general vicinity of the proposed Production Well region (Figure 1, Table 1). At three sites, more than one borehole was logged. At JB site (P1-103), four boreholes were logged, while at both JC (J1-103) and JE (F1-103), two boreholes were logged. A single borehole was logged at each of the remaining sites.

In almost all cases, the borehole logged was one of the water wells drilled to provide water for the drilling of the oil company wildcat well. At JD site (C1-12) and at those sites at which more than one borehole was logged, observation boreholes drilled for the Project were also logged.

2.2 <u>Intervals logged</u>

At each site, a gamma log was run from the bottom of the logged borehole to the surface. In approximately half the boreholes logged, this interval covered the whole of the saturated thickness of the Calanscio Formation (Table 1). However in the remainder, the base of the borehole was some distance above the base of the Calanscio Formation as defined in the oil company wildcat well, and thus no information was obtained for the lower part of the Formation.

At one site (A1-LP3C), the whole of the Calanscio Formation was in the unsaturated zone and at a second (A1-LP5C) only the lowest 24 feet of the Formation was saturated. These have therefore not been utilised in the regional compilations.

2.3 <u>Log variability and the identification of claybeds</u>

The response of gamma ray probes is markedly affected by borehole conditions, such as the borehole diameter, the presence and type of mud in the borehole, the depth of mud invasion and the presence and thickness of casing and gravel pack. Further variation results from differences in instrument scale sensitivity, and in logging procedures such as logging speed and time constant which in turn reflect the essentially statistical nature of the phenomenom of natural gamma radiation. In the proposed

Production Well-field region of the Phase 1 Area, IGS gamma logs were run in boreholes exhibiting a variety of conditions, while logging procedures were varied in order to optimise probe response. As a result, the logs show a considerable degree of variability.

In the face of this variability an empirical approach has been adopted. Statistical variability within an individual log was assessed from the short repeat section run at the beginning of each log. These showed a general repeatability of peak height of the order of less than 1 count per sec with a 10 cps full scale deflection and of peak position of 1-2 feet. Clay beds were identified in the logs where peaks stood out significantly from the general background level of radiation, this generally being by more than 1.5 cps.

2.4 Comparison with Schlumberger gamma logs of oil company wildcat wells.

Comparison of the gamma logs run by IGS with those run by Schlumberger in oil company wildcat wells showed that the IGS logs were capable of much more detailed resolution than those from the wildcat wells. Whilst very prominent clays could in some cases be correlated across the wildcat sites, the bulk of the clays revealed by the IGS logs could not be identified in the wildcat well logs. Clearly this must reflect differences in both hole conditions and logging procedures.

Consequently it has not been possible to integrate the limited information on the occurrence of clay beds obtained from the wildcat well logs with the more detailed data derived from the IGS logs. The following accounts of both within-site and between-site variation are therefore based entirely on the results of the IGS gamma logging programme.

3 Within-site variation of clay beds in the saturated zone of the Calanscio Formation

3.1 General

In order to assess the within-site variability of the clay beds within the

Calanscio Formation, detailed studies have been made of the three sites at which more than one borehole was gamma-logged. Each site is discussed separately below.

3.2 <u>JB Site (P1-103)</u>

At this site IGS gamma-logs were run in four wells (Figs 3 and 4). That of JB-01 covered the whole of the saturated section of the Calanscio Formation, while that of Water Well North omitted only the lowest 26 feet. Partial logs covering approximately the lower half of the saturated section were run in JB-P and JB-02. Clay beds, as evidenced by peaks of increased gamma radiation, occur in all the boreholes and a total of 15 beds have been recognised in the boreholes across the site. The vertical distribution of the beds throughout the saturated zone of the Calanscio Formation is generally uniform, there being no discernible trend towards a concentration of beds at any particular horizon. Bed thicknesses vary from 3 feet to 12 feet. It should be noted however that minor variations in thickness may reflect differences in logging speeds in different boreholes.

A considerable degree of correlation of clay beds can be sustained across the site (Fig 3). Correlation has been effected at two levels. Probable correlations are based on distinctive peak heights and shapes. Possible correlations involve less distinctive peaks and rely to a certain extent on sequential position. Four beds, Beds 3, 4, 5 and 7 show probable correlation across the whole site. However Bed 5 appears to split into two leaves to the northwest. Other beds, such as Beds 2 and 11, show possible correlation in three out of the four boreholes, no data being available from the fourth at the level at which the bed would be expected to occur. In the upper part of the saturated Calanscio Formation, logged in JB-01 and WWN, Bed 13 can be possibly correlated and Bed 15 probably correlated between the two boreholes. It therefore seems clear that some beds have a lateral continuity greater than the extent of the site.

On the other hand, there appears to be evidence that other beds do not extend across the site. Bed 6, though showing possible correlation from JB-02 through JB-P to JB-01, cannot be recognised in WWN. Bed 8 cannot be recognised northwest of JB-01 while Bed 9 appears to occur only in JB-P and JB-01. Bed 10, though showing probable correlation between JB-P and JB-01, does not appear in WWN. Bed 12 appears to be confined to JB-01. Finally Bed 14, a distinctive thick horizon, cannot be traced from WWN to JB-01.

The correlations indicate that the sand beds between the intervening clays vary in thickness and are broadly wedge-shaped (Fig 4). The development of the split in clay Bed 5 suggests that the beds could in fact be lenticular in shape.

The correlations also show that individual clay beds vary in thickness. The feature is particularly marked in Beds 4, 10 and 11.

The clay beds may also possibly vary in clay content as in some cases peak heights appear to differ between boreholes to a greater extent than might be expected from differences in hole conditions. It seems likely that all the clay beds contain some sand as peak heights are almost always appreciably less than those recorded from clays in the underlying Lower and Middle Miocene.

3.3 JC Site (J1-103)

Two boreholes, Water Well South and JC-01A, were logged by IGS at this site (Figs 5 and 6). Despite differences in borehole construction and logging procedures, some clay beds can be correlated between the boreholes. Bed 3 can possibly be correlated, while Beds 4, 5 and 7 can probably be so. However Bed 6 in WWS cannot be recognised in JC-01A, nor does it seem likely that Beds 1 and 2 can be correlated as their gamma peaks present marked differences in height, shape and position. If they did correlate, they would indicate a very pronounced wedge-shape for the overlying sand beds.

3.4 JE Site (F1-103)

IGS gamma-logs were run in two wells on this site, WWSW and JE-01 (Figs 7 and 8). Bed 2 shows a probable correlation and Beds 4 and 5 possible correlations between the two wells. Bed 3 in JE-01 however, appears to be absent in WWSW. The correlations indicate that the clay beds vary in thickness and that the intervening sand beds are broadly wedge-shaped. A marked change in the peak height of Bed 4 between the boreholes probably indicates a change in the clay content.

3.5 Discussion

Synthesis of the information from the three multi-well sites reveals five main points:

a. The clay beds have a limited continuity. At no site could all clay beds be traced between adjacent boreholes.

b. The thickness of individual clay beds varies across the sites.

c. The clay content of some clay beds appears to vary across the sites, probably reflecting differing sand content.

d. The clays vary in position with respect to each other and delimit sand beds which are distinctly wedge-shaped.

e. Splitting of clay beds may occur and may result in the development of lenticular sand beds.

Sedimentologically, the above features combine to present a picture of a thick sand sequence cut by relatively thin clays, individually of limited extent but as lithological units always present. The clays may become sandy and die out laterally or may in fact be cut out by erosion at the base of the sand horizons. Such a sequence corresponds well with that found in fluviatile deposits. In the Calanscio Formation, the presence of coarse grained sand horizons, positively skewed grain size distributions (E P Wright, pers comm) and distinctive cross-plot patterns of skewness, sorting and median size support this environmental interpretation. In such a sedimentary model, the sands represent deposition within or adjacent to channels, while the clays are laid down in overbank locations.

Finally, with regard to the lateral continuity of the clay beds, both the evidence from the sites and the environmental interpretation preclude the possibility of reliably correlating individual clay beds from site to site over distances of several miles. In fluvial sequences, such clays are notably impersistent, their continuity being controlled by such factors as the size and morphology of the depositing system, and the balance between the rate of reworking of the flood plain and the overall rate of deposition. Unfortunately, although some quantitative data on the continuity of clay beds within marine, deltaic and channel sediments have been assembled (Zeito, 1965), such studies do not appear to have extended to river flood plain deposits. However field experience with such formations suggests that the lateral continuity of any clay bed could reasonably be expected to lie in the range 2,000 - 20,000 feet. For example, Allen (1962) reports that in the Lower Old Red Sandstone of Shropshire cyclothems comprising a lower sandstone member overlain by an upper siltstone member and deposited in a floodplain environment, can be generally traced for distances of up to half a mile (approx. 2,500 feet). However, one such cyclothem in which the sandstones are notably calcareous occurs over some seven miles of outcrop (approx. 36,000 feet).

4 Regional occurrence of clay beds in the saturated zone of the Calanscio Formation

4.1 General

Faced with the impossibility of being able to correlate individual clay beds reliably across the region under investigation, it has been necessary to adopt a more general approach. The vertical distribution of clay beds within the whole of the saturated zone of the Calanscio Formation has been investigated from plotted sections for each site at which IGS gamma logs were run. Statistical measures of the frequency and thickness of the beds, necessitated by the fact that only about one half of the boreholes logged penetrated the Formation fully, have been calculated and their regional distribution plotted.

Since pumping drawdowns in the proposed production well region have been estimated at a maximum of 100 feet below static-water level, more specific data on the occurrence of clay beds within this interval has been collected and analysed.

4.2 Occurrence of clay beds throughout the saturated zone of the Calanscio Formation

The positions and thicknesses of all the clay beds recognised in the gamma logs are shown in the vertical sections plotted for each borehole logged (Figs 4, 6, 8, 9, 10, 11, 12 and 13). The sections show that the clay beds occur throughout the region and at all levels within the saturated zone of the Calanscio Formation. There appears to be no regional trend towards the concentration of individual clay beds at any particular horizon.

Statistical data on the frequency and thicknesses of the clay beds are given in Table 2, while the regional distributions of the mean number of clay beds per 100 foot of section logged, the mean bed thickness and the percentage of section logged occupied by clay beds are plotted in Figures 15, 16 and 17. From regional distribution of the mean number of clay beds per 100 feet of section logged (Fig 15), it appears that clay beds are least common in an area covering the centre of Concession 103, and become more common outwards from this area. Mean clay bed thickness is least in a closed area only slightly further to the west (Fig 16) and values increase markedly to the south-east. The total value of clay within the saturated zone of the Calanscio Formation as measured by the percentage of section occupied by clay beds (Fig 17) appears to be lowest in and to the west of west-central Concession 103, that is between F1-103 and B1-108. Values increase in all directions away from this area and approximately double both to the south-east and north-east.

4.3 Occurrence of clay beds within the upper 100 feet of the saturated zone of the Calanscio Formation

Examination of the vertical sections (Figs 4, 6, 8, 9, 10, 11, 12 and 13) again shows no marked concentration of clay beds at any particular horizon in the upper 100 feet of the saturated zone of the Calanscio Formation. Frequency and thickness data for clay beds within this interval are given in Table 3, while the regional distributions of various parameters are given in Figures 18, 19 and 20.

There are fewest clay beds in the upper 100 ft of the saturated zone of the Calanscio Formation in a narrow area extending between N1-103 and K1-103 (Fig 18). Numbers increase quickly to the north-east and east but less rapidly to the west. Mean clay bed thickness (Fig 19) is, however, high in the area of lowest numbers of clay beds and the region of lower values occurs further west. The distribution of values for the total thickness of clay shows the combined effect of these trends. A broad area of lower total thickness extends from the south of Concession 103 north-west into Concession 108. Higher values occur to the west and over a wide region to the north-east, east and south-east.

4.4. Discussion

In the data both from the whole and from the upper 100 feet of the saturated zone of the Calanscio Formation, the area of the fewest clay beds lies a little to the east of that of the thinnest clay beds. The area of the least total clay generally coincides with that of the minimum mean bed thickness indicating that this is a more important factor than the number of clay beds. Regionally, both sets of data show that the fewest clay beds, the thinnest clay beds and the least total clay thicknesses all occur between south-central Concession 103 and northern Concession 108. Away from this area, clays are significantly more important.

5 Possible zone of generally more clayey sediments in the upper part of the saturated zone of the Calanscio Formation

5.1 General

A feature of all the gamma logs run through the Calanscio Formation is a general increase in levels of natural gamma radiation towards the top of the Formation. It is possible that this could represent a general increase in the amount of naturally disseminated clay within the Formation. On this basis the Formation has been divided into a lower zone of less clayey sediments and an upper zone of more clayey sediments. The extent to which the latter occurs within the saturated zone of the Calanscio Formation is discussed below.

It should be noted however that individual clay beds can still be distinguished within the zone of more clayey sediments as their peak heights are correspondly higher than general background levels. This might suggest that in the upper zone some other influence has been superimposed on the general pattern of natural gamma radiation. Such influences could possibly include the effects of excessively high cosmic radiation related to the generally clear atmospheric conditions prevailing in the desert.

5.2 Occurrence of the upper more clayey zone within the saturated zone of the Calanscio Formation

Inspection of the vertical sections (Figs 4, 6, 8, 9, 10, 11, 12 and 13) shows that at eleven of the sites logged, the upper clayey zone extends down into the saturated zone of the Calanscio Formation. At the remaining sites the base of the upper clayey zone occurred above the static water level (Table 4).

The regional distribution of the thicknesses of the upper clayey zone occurring within the saturated zone of the Calanscio Formation is presented in Figure 21. This map shows that in an area over the centre of Concession 103 and extending into northern Concession 108 the clayey zone extends only a very little or often not all into the saturated zone of the Calanscio Formation. To the north-east, east, and south-east, the clayey zone extends to much greater depths within the saturated zone and may occupy the whole of the upper 100 feet of the saturated zone as at KK1-12 and K1-97. It should be noted that the very sharp change between S1-103 and O1-103 would seem to be somewhat anomalous and may reflect some inconsistencies in log-response or interpretation.

6 Hydrogeological implications

6.1 General

The result of the gamma ray logging investigations have significant implications for the interpretation of hydrogeological conditions within the saturated zone of the Calanscio Formation. Those stemming from the studies of the frequency and thickness of individual clay beds are considered first, followed by those related to the possible presence of an upper zone of generally more clayey sediments.

6.2 Significance of the clay beds throughout the saturated zone of the Calanscio Formation

The hydrogeological implications of this section of the studies fall under four headings:

a. Both the vertical sections (Figs 4, 6, 9, 10, 11, 12 and 13) and the statistical data (Table 2) emphasise the multi-layered nature of the whole of the aquifer in the proposed Production Well area. Clay beds occur throughout and show no regional trend to concentration at any particular horizon.

b. The range of mean thickness values for the clay beds, up to 9.3 ft (Table 2) is such that the beds could constitute significant barriers to vertical flow, as was in fact observed during pumping tests. At some sites clay beds are sufficiently numerous and thick (Table 2) so as to form an appreciable proportion of the saturated zone of the Calanscio Formation and thus significantly reduce the volume of productive strata available for development in wells.

c. The within-site variation in the gamma-ray peak heights of some clay beds suggests a variable clay content which probably reflects differing sand admixtures. It can be noted that peak heights of clay beds in the Calanscio Formation on oil company Schlumberger gamma logs are markedly less than those of marine clays in the underlying Lower and Middle Miocene, suggesting that the former are generally more sandy. This could be significant in terms of the vertical permeability of the clay beds.

d. Studies at sites where more than one well has been logged (cf Section 3) indicate that the clay beds bound sand units which are wedged shaped in nature and that the clay beds are variable in thickness. These features may be significant hydrogeologically in that they could affect the interpretation of the pumping tests and relate in particular to possible areal variations in the amount of leakage through overlying clay layers. The within-site variability studies further show that clay beds are laterally impersistent and may occasionally split into two. Together all these factors preclude the reliable correlation of individual clay beds between sites.

There is therefore no direct evidence as to the lateral extent of any individual clay layer. However from the hypothesis suggested by the lithological sequence and the grain-size-frequency data that deposition took place in an alluvial plain environment, it may be inferred that the clay beds generally extend over distances in the range of 2000 feet to 20,000 feet. It should be noted that comparison with at least one alluvial sequence, the Old Red Sandstone of Shropshire, shows agreement with this range.

Under pumping conditions, the amount and extent of the clay beds is significant in that it raises the possibility of the vertical movement of water following a step-wise path around the ends of the clay layers. The quantitative importance of this flow will depend on the cross-sectional area of such conduits and their length in relation to the head differences. From the statistical data on the vertical occurrence of the clay beds (Table 2) and a range of assumed values for their lateral extent, combined with leakage data from the pumping tests it might be possible to calculate a range of magnitudes for these flows. Regional differences in the distribution and character of the clay beds (see below) would necessitate separate consideration of the areas of high and low clay content.

e. The regional studies of the occurrence of clay beds throughout the saturated zone of the Calanscio Formation (Figs 15, 16 and 17) reveal the presence of a region of minimum clay whether measured by numbers of clay beds, mean bed thicknesses or percentage of the section occupied by clay. This region covers the western part of Concession 103 between Q1a-103 and extends west into Concession 108 (Fig 22).

In this region thickness of productive horizons is maximised, while the number and thicknesses of potential barriers to vertical flow are minimised. Since the region also corresponds in a general way with a region of increased saturated thickness, it would seem to constitute an optimum region for any proposed production well field.
To the north-east, east and south-east the clay content increases markedly, and it is conceivable that this could possibly affect the hydrochemical characteristics of groundwaters within the formation in this vicinity.

6.3 Significance of clay beds within the upper 100 feet of the saturated zone of the Calanscio Formation

The particular significance of the clay beds in the upper 100 feet of the aquifer lies in their leakage characteristics and the extent to which they will affect the onset of water table conditions after the commencement of large scale and long term pumping. The points made in the previous section regarding the variability in thickness and in clay content of the clay beds in relation to leakage are equally valid.

With regard to the question of the degree of confinement within the upper 100 feet of the saturated zone of the Calanscio Formation a critical factor is the lateral extent of the individual clay beds, and as discussed above, this unfortunatedly remains unknown. One possible solution to this problem would seem to be to set up a series of conceptual three-dimensional models of the upper 100 feet of the aquifer in which the vertical frequency and the thicknesses of the clay beds correspond with the regional distribution of the data obtained from the gamma logs (Table 3 and Figs 18, 19 and 20) and the lateral extent of the beds is represented by a selection of values taken from the range 2000-20,000 feet suggested by considerations of the depositional environment. Within this framework, using appropriate values for the leakage through the clay beds and consequent head changes, it would as before, appear possible to assess the effects of vertical flow following a stepwise path between clay beds.

Regionally the existance of an area appreciably deficient in clay (Figs 18, 19 and 20), extending north-west from southern Concession 103, is significant. In such an area, barriers to vertical flow are at a minimum, and the onset of water table conditions is likely to take place more rapidly than elsewhere. This area overlaps that of minimum clay within the whole of the saturated zone of the Formation (Fig 23).

6.4 Significance of the possible zone of more clayey sediments within the upper part of the saturated zone of the Calanscio Formation

The presence of this zone, if in fact it represents an actual increase in dispersed clay within the Formation, will decrease permeability values and possibly create an additional confining effect. The regional occurrence of the zone with its greatly increased thickness to the east indicates that its effect will be additional to that of the individual clay layers. Where these are least important to the west, the development of the clayey zone below the static water level is either small or non-existant.

7 References

Allen, J.R.L.	1962	Petrology, origin and deposition of the highest Lower Old Red Sandstone of Shropshire, England. J. Sedim. Petrol., 32, 657-697.
Benfield, A.C.	1972	Post-Oligocene sediments, Jalo Region, Sirte Basin, Libya. Hydrogeological Department, IGS. Unpublished Report No. WD/72/5.
Wright, E.P.	1973	Jalu-Tazerbo Project: Phase 1 - Interim Report. Hydrogeological Department, IGS Unpublished Report No. WD/73/10.

Zeito, G.A. 1965 Interbedding of shale breaks and Reservoir heterogeneities. J. Pet. Technol., 17, 1223-28.

Table 1

Details of intervals gamma-logged by IGS in boreholes penetrating the saturated zone of the Calanscio Formation

Site	Well	Base of Calanscio Fm (Determined from logs of adjacent Wildcat Oil Well) FT WRT SL	Static Water Level FT WRT SL	Interval logged within saturated Calanscio Fm	
				Base FT WRT SL	Top FT WRT SL
P1-103 (JB)	JB-02	-139	-	-139	+25
	JB-P	-139	-	-131	+96
	JB-01	-139	+156	-139	+156
	WWN	-139	+159	-113	+159
J1-103 (JC)	WWS	-123	+140	-78	+140
	JC-01A	-123	+140	-123	+140
F1-103 (JE)	WWSW	-128	+118	-118	+118
	JE-01	-128	+118	-63	+118
G1-103	WWS	C-120	+126	-52	+126
B1-108	WW	+40	+226	+40	+226
D1-108	WW	-123	+68	-114	+68
F1-97	WWN	-179	+115	-163	+115
C1-12 (D)	JD-01	-157	+119	-157	+119
KK1-12	WWE	-183	+91	-167	+91
Q1a-103	WWNW	-158	+95	-108	+95
O1-103	WWE	-225	+137	-78	+137
S1-103 (JA)	WWS	-247	+137	-136	+137
K1-103	WWW	-207	+123	-109	+123
N1-103	WW	-229	+117	-102	+117
F1-108	W9	+134	+253	+134	+253
SSS1-6	WW	+91	+258	+91	+258

Table 1

Details of intervals gamma-logged by IGS in boreholes penetrating the saturated zone of the Calanscio Formation

Site	Well	Base of Calanscio Fm (Determined from logs of adjacent Wildcat Oil Well) FT WRT SL	Static Water Level FT WRT SL	Interval logged within saturated Calanscio Fm	
				Base FT WRT SL	Top FT WRT SL
P1-103 (JB)	JB-02	-139	-	-139	+25
	JB-P	-139	-	-131	+96
	JB-01	-139	+156	-139	+156
	WWN	-139	+159	-113	+159
J1-103 (JC)	WWS	-123	+140	-78	+140
	JC-01A	-123	+140	-123	+140
E1-103 (JE)	WWSW	-128	+118	-118	+118
	JE-01	-128	+118	-63	+118
G1-103	WWS	C-120	+126	-52	+126
[illegible]-108	WW	+40	+226	+40	+226
D1-108	WW	-123	+68	-114	+68
[illegible]-97	WWN	-179	+115	-163	+115
C1-12 (JD)	JD-01	-157	+119	-157	+119
K[illegible]1-12	WWE	-183	+91	-167	+91
Q1a-103	WWNW	-158	+95	-108	+95
[illegible]-103	WWE	-225	+137	-78	+137
S1-103 (JA)	WWS	-247	+137	-136	+137
K[illegible]-103	WWW	-207	+123	-109	+123
N1-103	WW	-229	+117	-102	+117
F[illegible]-108	W9	+134	+253	+134	+253
SSS1-6	WW	+91	+258	+91	+258

Table 2

Frequency and thickness data for clay beds throughout the saturated zone of the Calanscio Formation

Site	Well	Logged Interval Ft	Number of Clay Beds	Mean Number of Clay Beds Per 100ft	Thickness of Clay Beds			Total Thickness of Clay Beds Ft	Clay Beds as Percentage of Section
					Maximum Ft	Minimum Ft	Mean Ft		
P1-103 (JB)	WWN	272	8	3.0	12	2	8.1	65	24
G1-103	WWS	178	5	2.8	10	3	5.8	29	16
B1-108	WW	186	5	2.7	6	3	4.4	22	12
D1-108	WW	182	5	2.8	17	3	6.2	31	17
F1-97	WWN	278	8	2.9	12	4	7.3	58	21
C1-12 (JD)	JD01	276	7	2.5	10	3	6.4	45	16
J1-103 (JC)	WWS	218	6	2.8	10	4	7.7	46	21
KK1-12	WWE	258	11	4.2	13	3	6.5	71	27
Q1a-103	WWNW	203	7	3.5	8	3	4.6	32	16
O1-103	WWE	215	6	2.8	18	6	9.3	56	26
S1-103 (JA)	WWS	273	6	2.2	17	5	7.7	46	17
K1-103	WWW	232	6	2.6	16	4	8.5	51	22
N1-103	WW	219	4	1.9	11	6	8.8	35	16
F1-103 (JE)	JE-01	200	4	2.0	10	2	6.3	25	12
F1-108	W9	119	4	3.4	8	6	6.5	26	22
SS1-6	WW	167	7	4.2	40	2	4.1	29	17

Table 2

Frequency and thickness data for clay beds throughout the saturated zone of the Calanscio Formation

Site	Well	Logged Interval Ft	Number of Clay Beds	Mean Number of Clay Beds Per 100ft	Thickness of Clay Beds			Total Thickness of Clay Beds Ft	Clay Beds as Percentage of Section
					Maximum Ft	Minimum Ft	Mean Ft		
[illegible]1-103 (JB)	WWN	272	8	3.0	12	2	8.1	65	24
[illegible]1-103	WWS	178	5	2.8	10	3	5.8	29	16
B1-108	WW	186	5	2.7	6	3	4.4	22	12
[illegible]1-108	WW	182	5	2.8	17	3	6.2	31	17
[illegible]1-97	WWN	278	8	2.9	12	4	7.3	58	21
C1-12 ([illegible]D)	JD01	276	7	2.5	10	3	6.4	45	16
[illegible]1-103 (JC)	WWS	218	6	2.8	10	4	7.7	46	21
K1-12	WWE	258	11	4.2	13	3	6.5	71	27
Q1a-103	WWNW	203	7	3.5	8	3	4.6	32	16
[illegible]1-103	WWE	215	6	2.8	18	6	9.3	56	26
[illegible]1-103 (JA)	WWS	273	6	2.2	17	5	7.7	46	17
[illegible]1-103	WWW	232	6	2.6	16	4	8.5	51	22
N1-103	WW	219	4	1.9	11	6	8.8	35	16
[illegible]1-103 ([illegible]E)	JE-01	200	4	2.0	10	2	6.3	25	12
F1-108	W9	119	4	3.4	8	6	6.5	26	22
[illegible]S1-6	WW	167	7	4.2	40	2	4.1	29	17

Table 3

Frequency and thickness data for clay beds in the upper 100 feet of the saturated zone of the Calanscio Formation

Site	Well	Number of Beds	Thickness of Clay Beds			Total Thickness of Clay Beds Ft
			Maximum Ft	Minimum Ft	Mean Ft	
P1-103 (JB)	WWN	3	12	2	6.3	19
G1-103	WWS	3	6	3	4.0	12
B1-108	WW	3	5	3	4.0	12
D1-108	WWN	3	4	3	3.7	11
F1-97	JD-01	4	8	5	7.0	28
C1-12 (JD)	WWS	4	10	3	7.0	28
J1-103 (JC)	WWS	4	10	4	6.8	27
KK1-12	WWE	6	13	6	8.3	50
Q1a-103	WWNW	3	8	3	5.0	15
O1-103	WWE	3	18	6	10.7	32
S1-103 (JA)	WWS	3	17	5	9.7	29
K1-103	WWW	2	16	12	14.0	28
N1-103	WW	1	8	8	8.0	8
F1-103 (JE)	JG-01	3	8	2	5.0	15
F1-108	W9	5	8	6	6.8	34
SSS1-6	WW	4	6	4	4.8	19

TABLE 4

Elevation of the base of the upper clayey zone of the Calanscio Formation and its thickness within the saturated zone

Site	Well	Base of Upper Clayey Zone FT WRT SL	Static Water Level FT WRT SL	Thickness of Upper Clayey Zone Below SWL FT
P1-103(JB)	WWN	+136	+159	23
J1-103(JC)	WWS	+127	+140	13
F1-103(JE)	JE 01	+152	+118	0
G1-103	WWS	+165	+126	0
B1-108	WW	+221	+226	5
D1-108	WW	+76	+68	0
F1-97	WWN	+7	+115	108
C1-12(JD)	JD 01	+82	+119	37
KK1-12	WWE	-18	+91	109
Q1a-103	WWNW	+79	+95	16
O1-103	WWE	+43	+137	94
S1-103(JA)	WWS	+134	+137	3
K1-103	WWW	+105	+123	18
N1-103	WW	+118	+117	0
F1-108	W9	-	+253	0
SSS1-6	WW	+256	+258	2
A1LP-5	WW	+242	+155	0

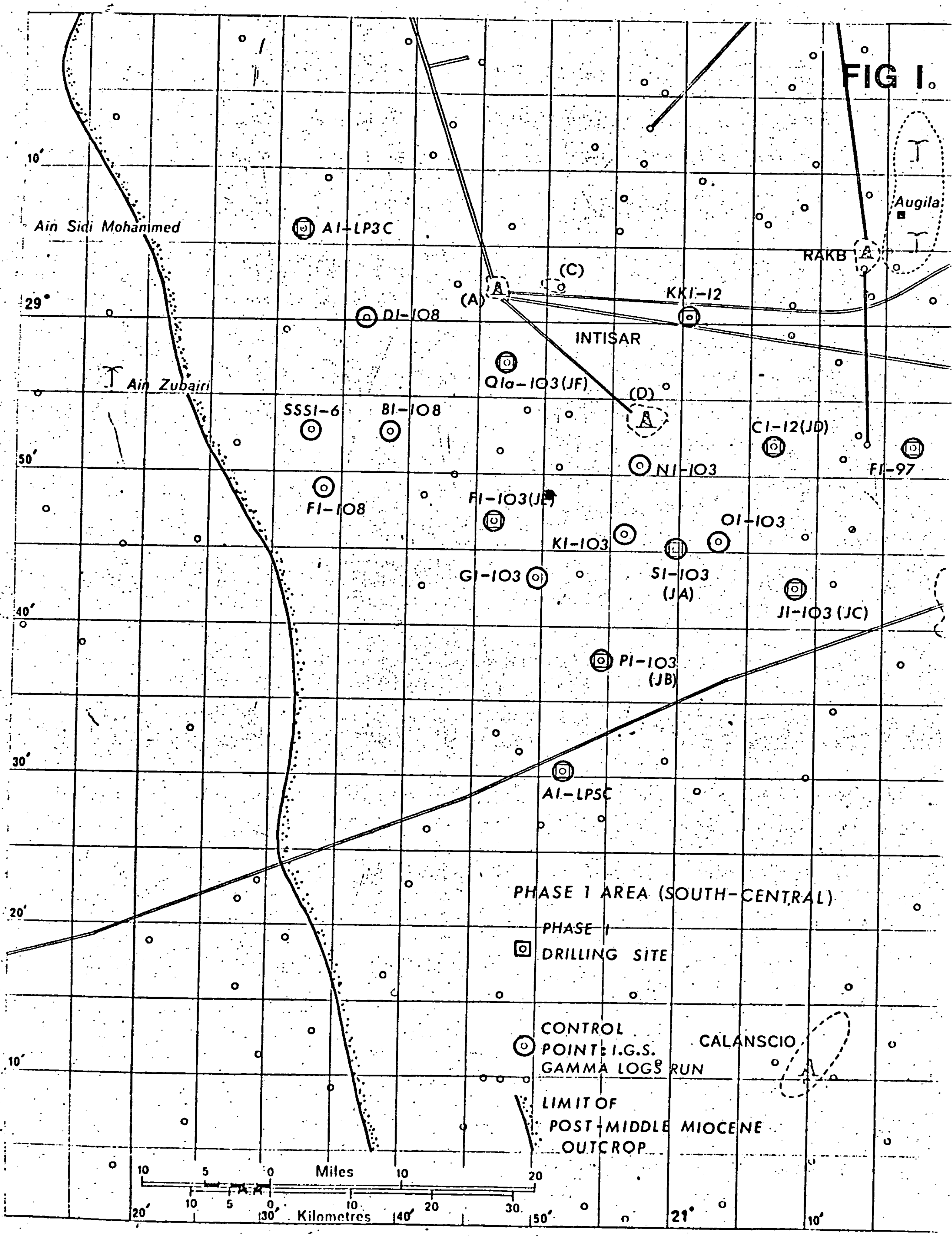

Ain Sidi Mohammed
A1-LP3C
(C)
(A)
KK1-12
RAKB
Augila
29°
10'
D1-108
INTISAR
Q1a-103 (JF)
Ain Zubairi
(D)
SSS1-6
B1-108
C1-12(JD)
50'
N1-103
F1-97
F1-108
F1-103(JE)
O1-103
K1-103
S1-103
(JA)
G1-103
J1-103 (JC)
40'
P1-103
(JB)
30'
A1-LP5C
PHASE 1 AREA (SOUTH-CENTRAL)
20'
PHASE 1
DRILLING SITE
CONTROL
POINT: I.G.S.
GAMMA LOGS RUN
CALANSCIO
10'
LIMIT OF
POST-MIDDLE MIOCENE
OUTCROP
Miles
Kilometres
20'
30'
40'
50'
21°
10'

FIG I.

FIG 2

KEY FOR VERTICAL SECTIONS

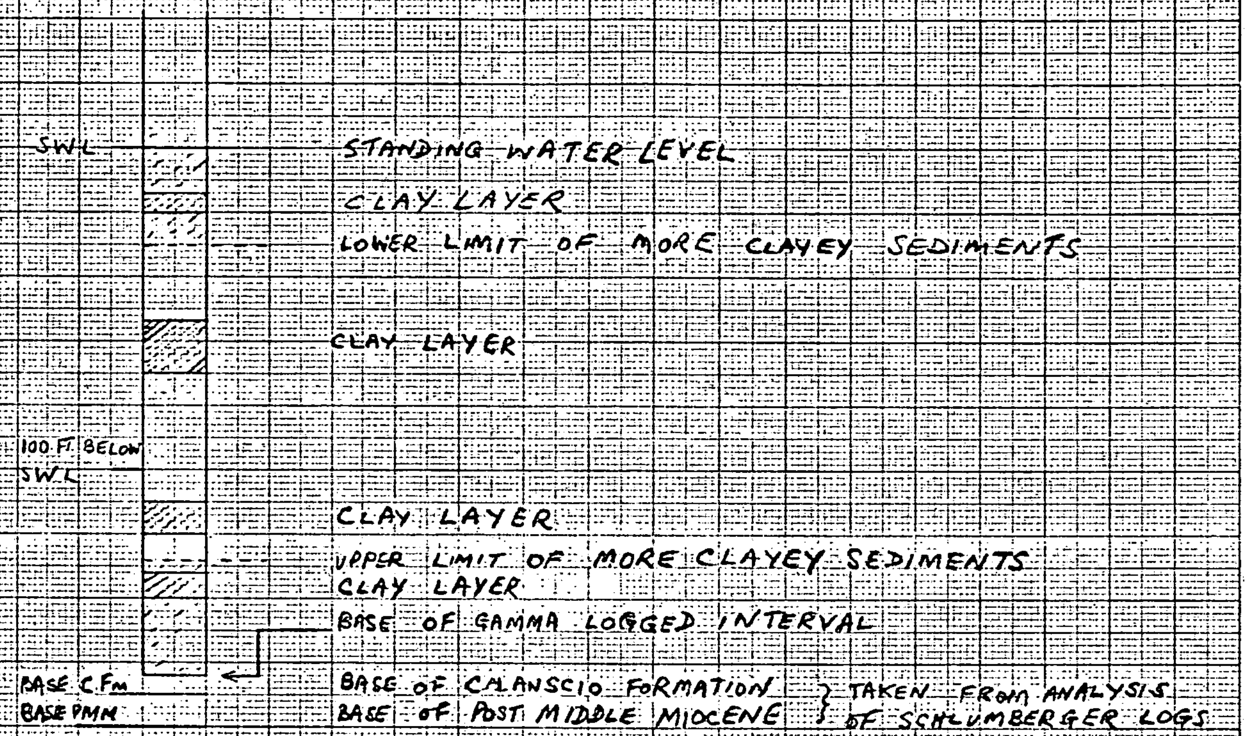
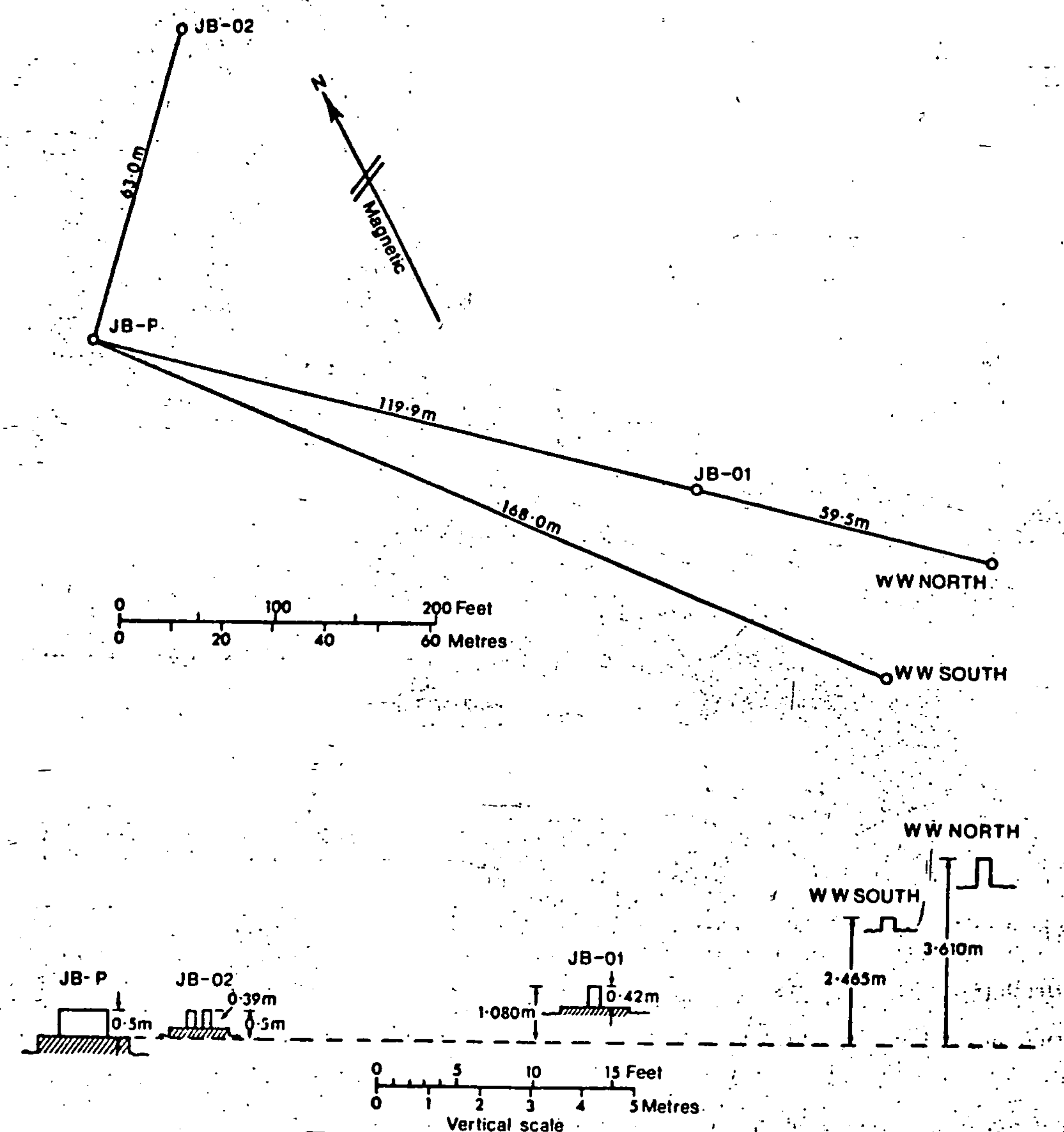
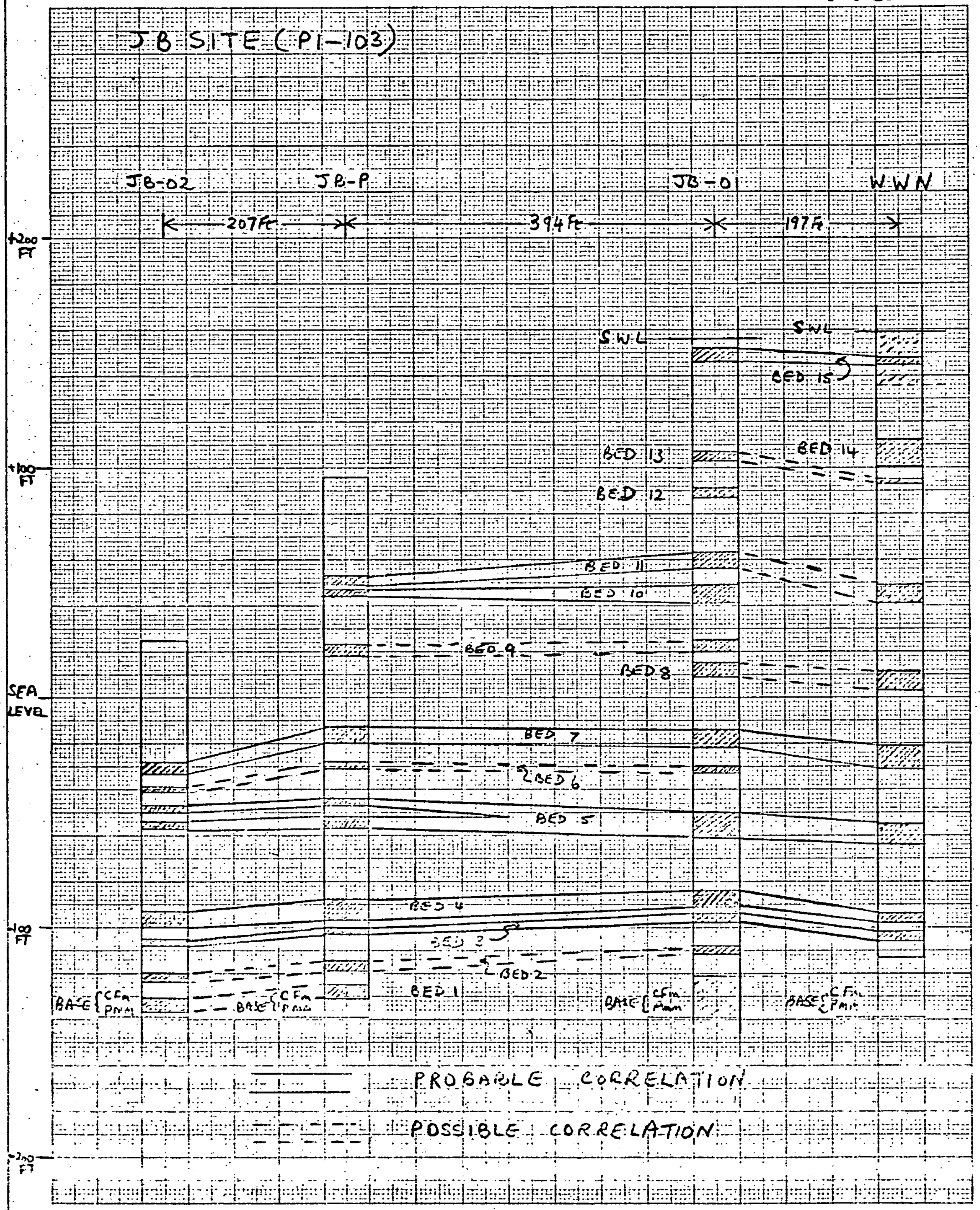


FIG 3



Site JB: Site plan and elevations

FIG 4



JB SITE (PI-103)
JB-02
JB-P
JB-01
WWN
207Ft
394Ft
197Ft
+200 FT
+100 FT
SEA LEVEL
-100 FT
-200 FT
SWL
SWL
BED 15
BED 14
BED 13
BED 12
BED 11
BED 10
BED 9
BED 8
BED 7
BED 6
BED 5
BED 4
BED 3
BED 2
BED 1
BASE {CFm PMm
BASE {CFm PMm
BASE {CFm PMm
BASE {CFm PMm
PROBABLE CORRELATION
POSSIBLE CORRELATION

FIG 5

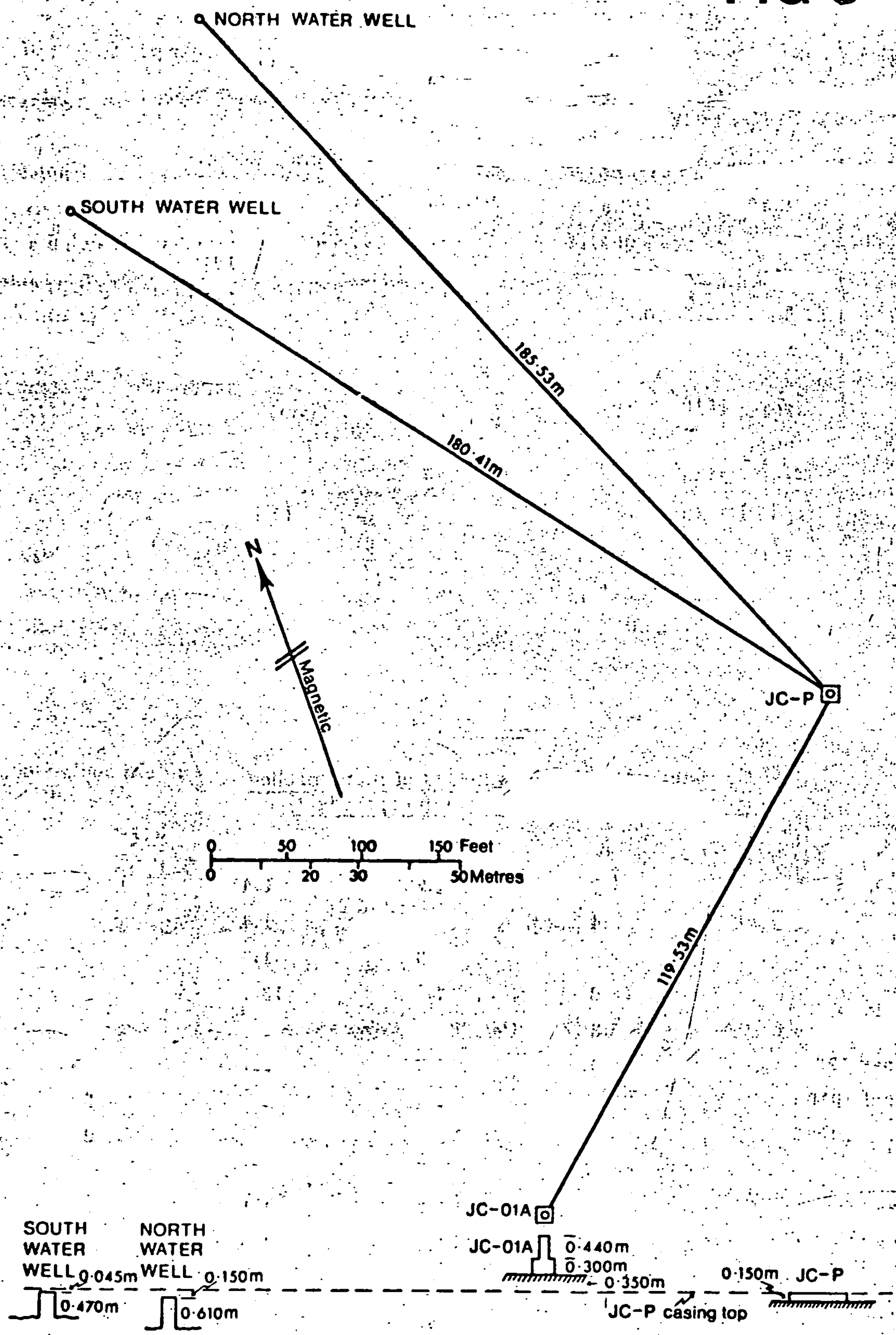
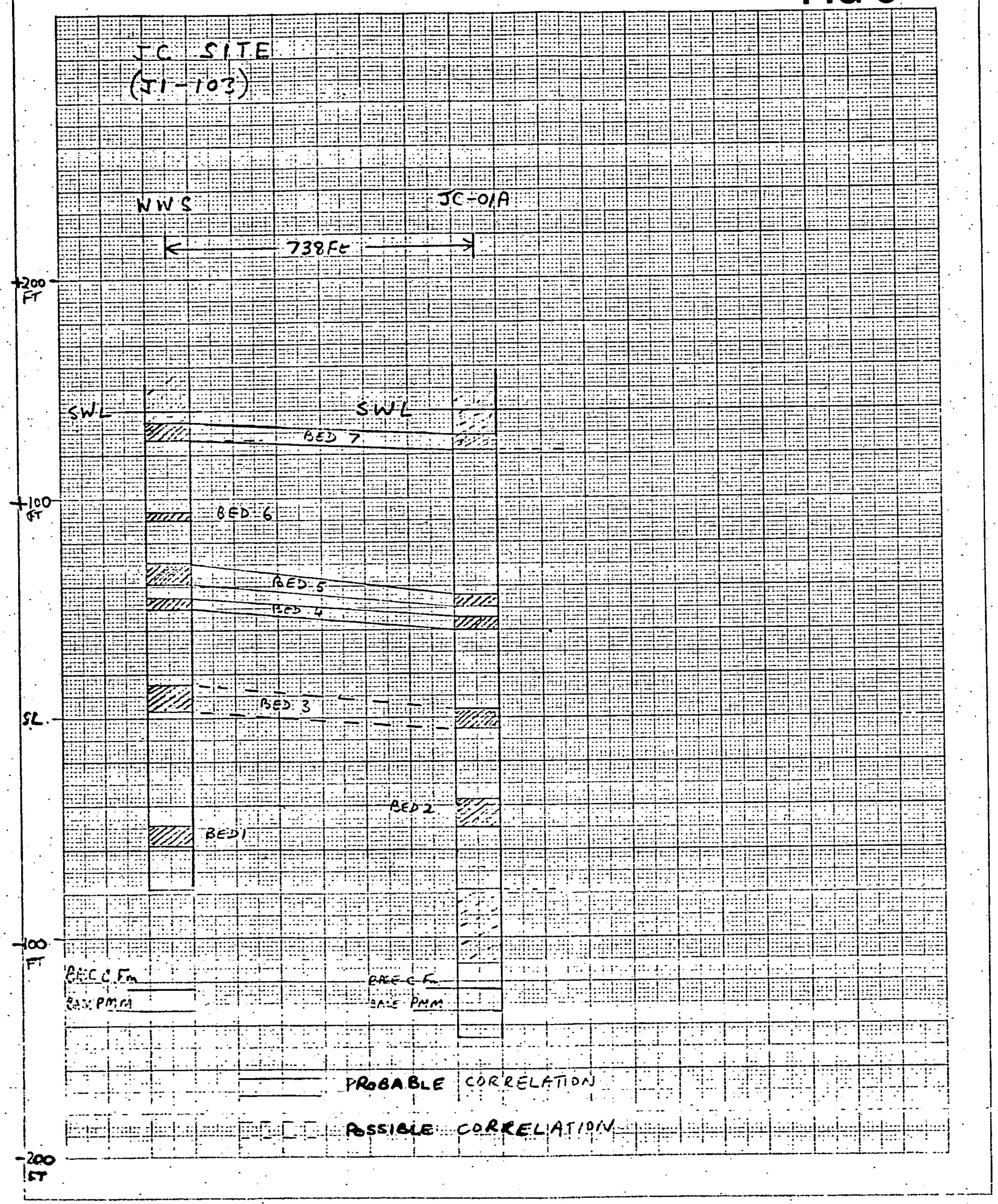


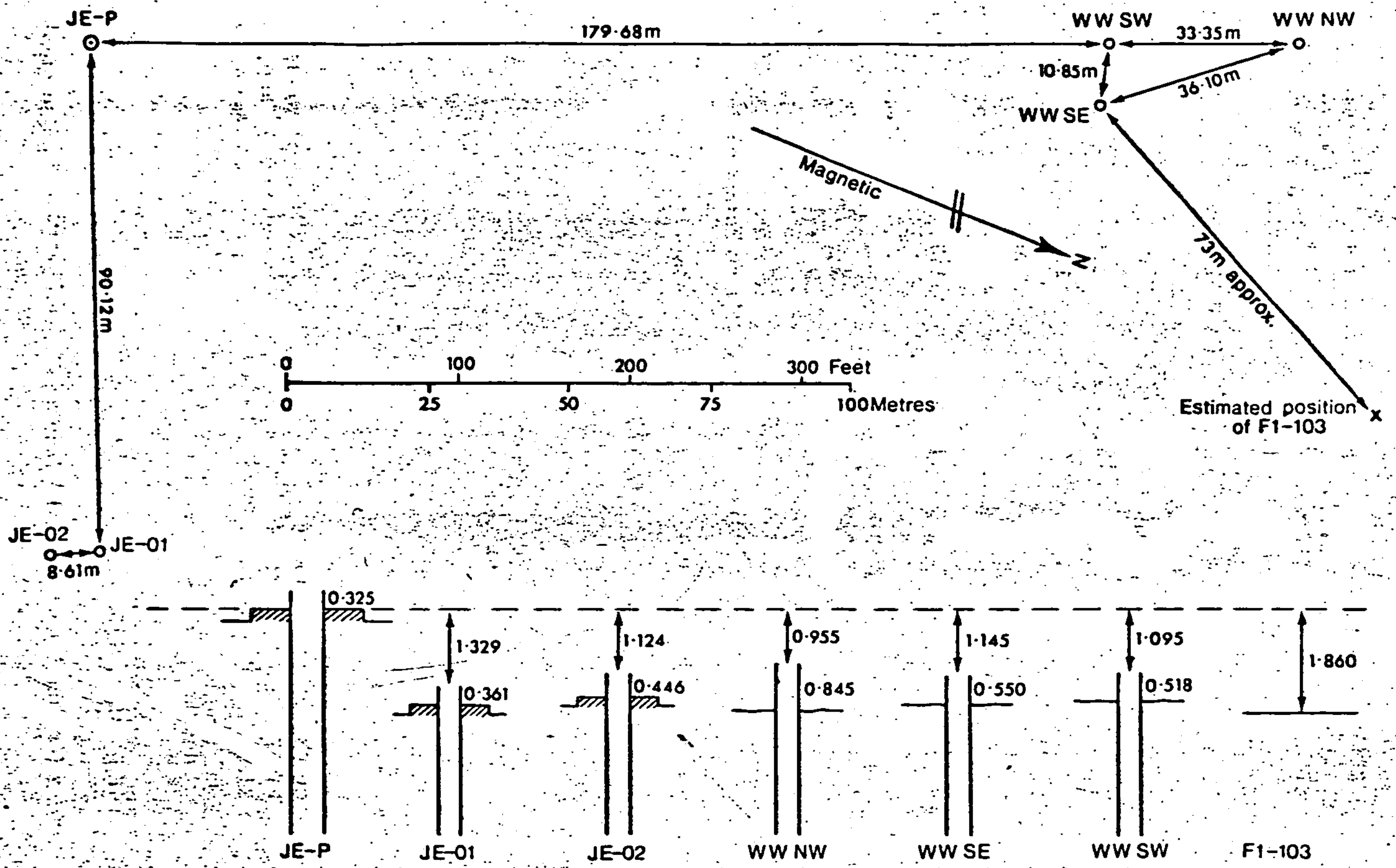
Figure Site JC: Site plan and elevations

FIG 6



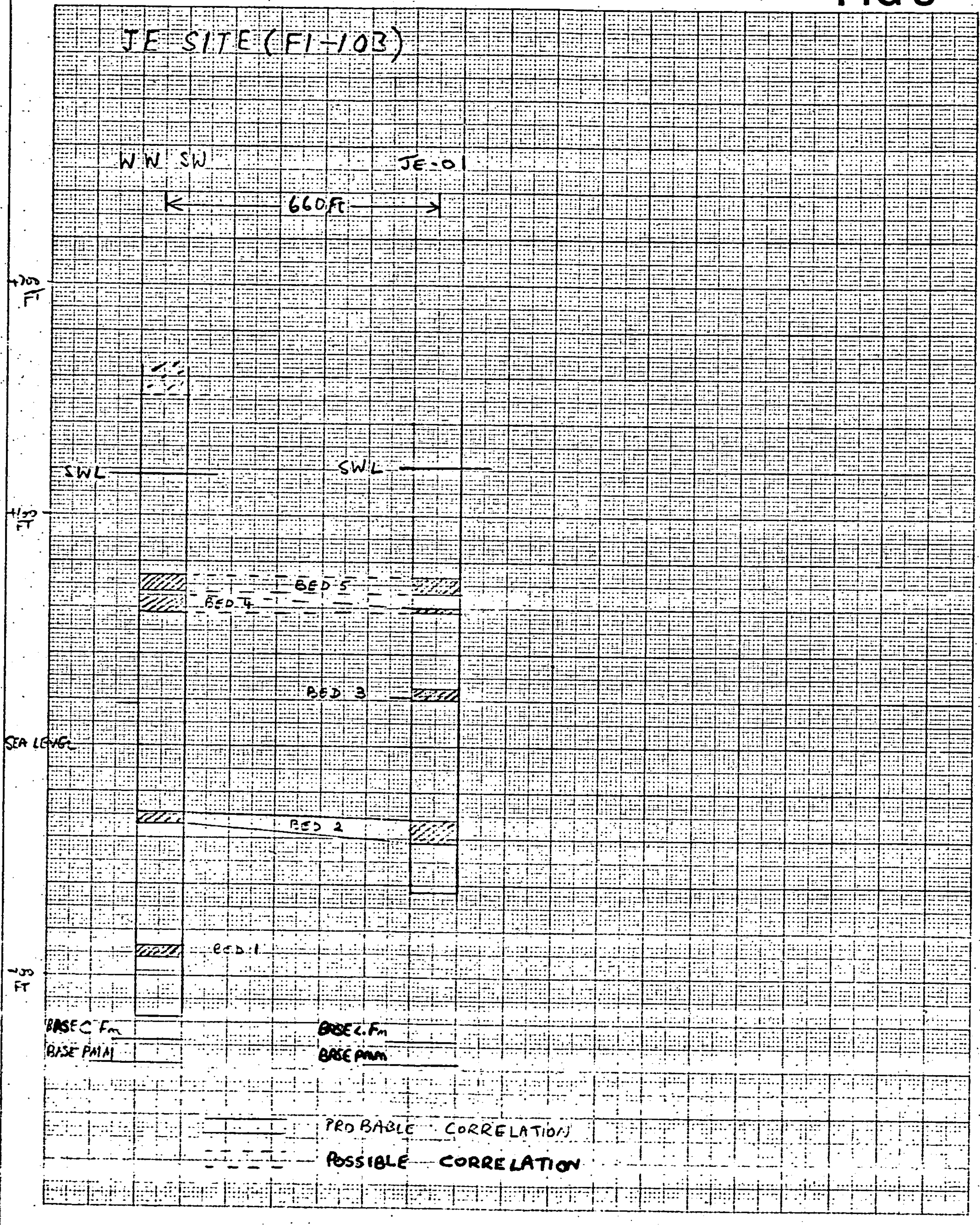
JC SITE
(J1-103)
WWS
JC-01A
738Ft
+200 FT
SWL
SWL
BED 7
+100 FT
BED 6
BED 5
BED 4
BED 3
SL
BED 2
BED 1
-100 FT
BASE C Fm
BASE PMM
BASE C Fm
BASE PMM
PROBABLE CORRELATION
POSSIBLE CORRELATION
-200 FT

FIG 7



Site JE: Site plan and elevations

FIG 8



JE SITE (FI-103)
WW SW
JE-01
660 Ft
+700 FT
SWL
SWL
+100 FT
BED 5
BED 4
BED 3
SEA LEVEL
BED 2
BED 1
BASE C Fm
BASE PMM
BASE C. Fm
BASE PMM
PROBABLE CORRELATION
POSSIBLE CORRELATION

FIG 9

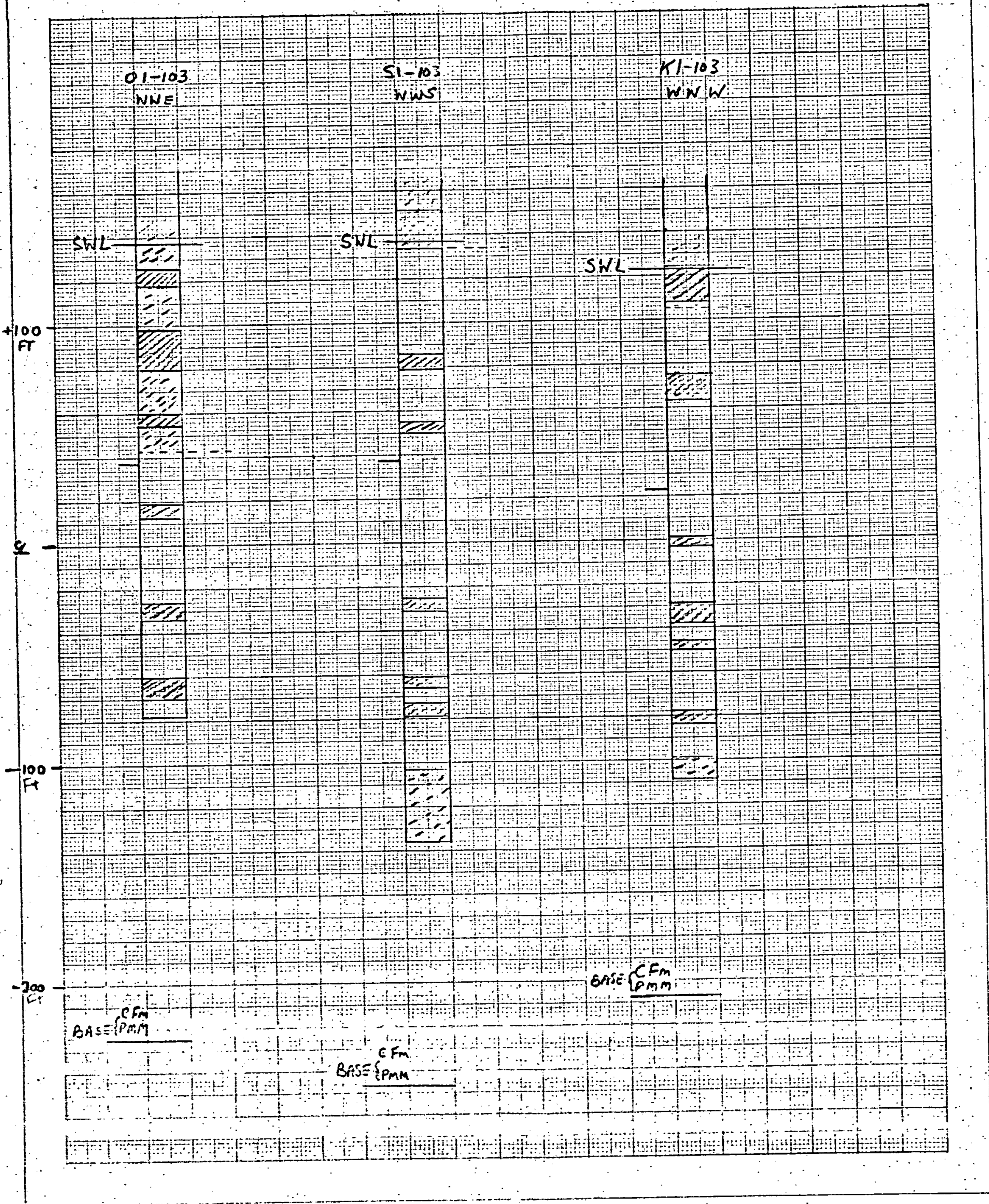
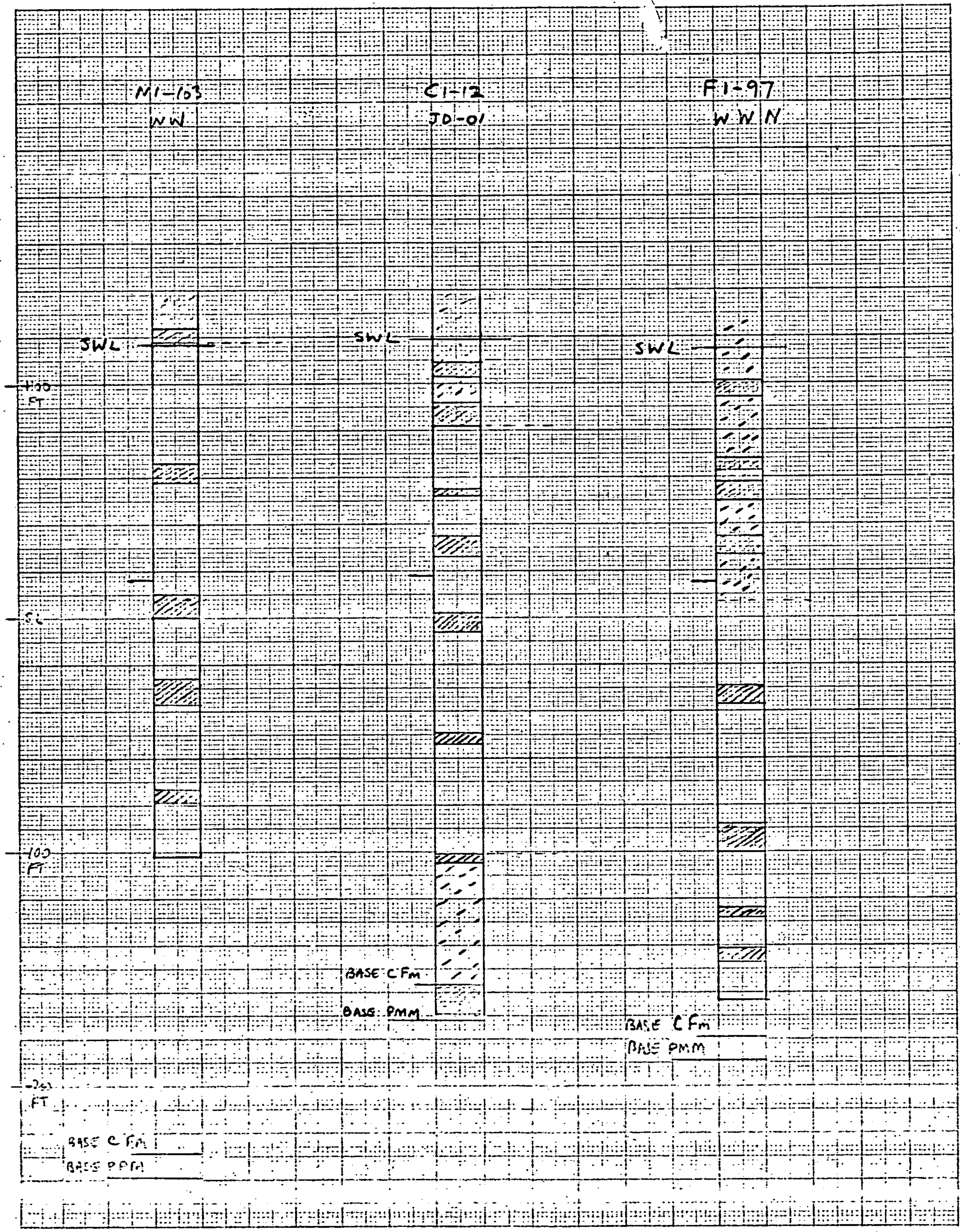
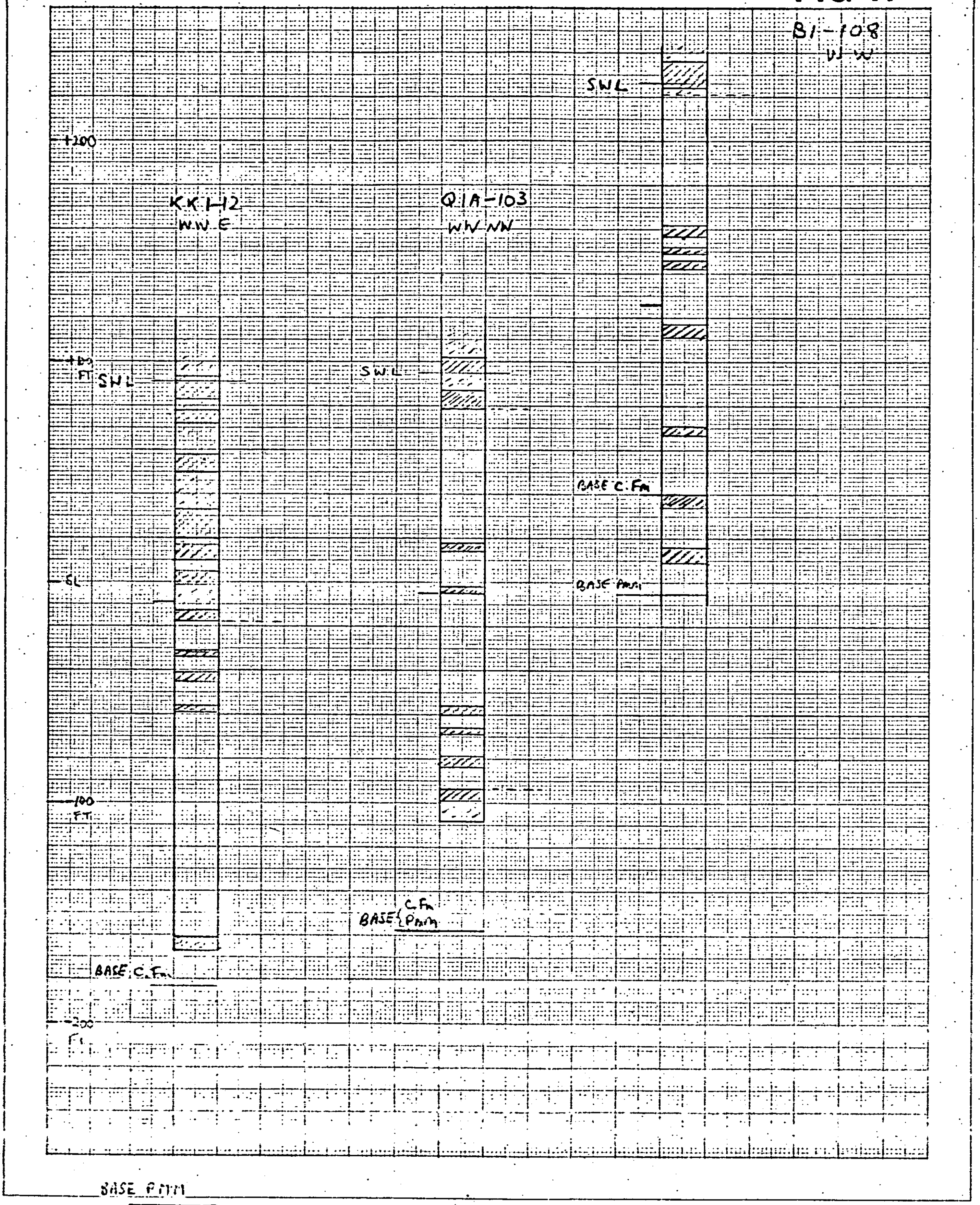

O1-103
NNE
S1-103
WWS
K1-103
WNW
SWL
SWL
SWL
+100
FT
-100
Ft
-200
BASE {CFm
PMM
BASE {CFm
PMM
BASE {CFm
PMM

FIG 10



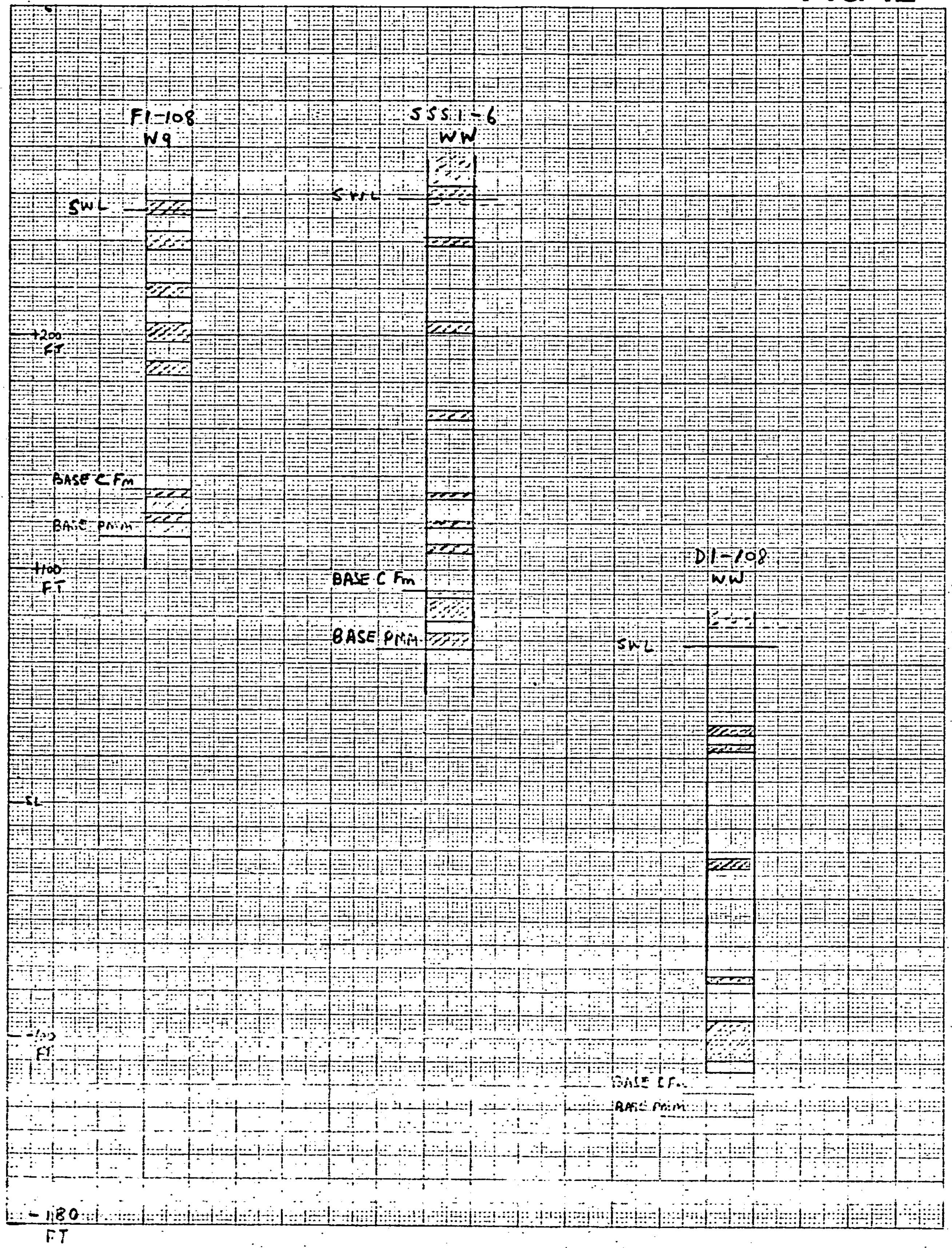
N1-103
WW
C1-12
JD-01
F1-97
WWN
SWL
SWL
SWL
100 FT
100 FT
200 FT
BASE CFm
BASE PMM
BASE CFm
BASE PMM
BASE CFm
BASE PMM

FIG 11



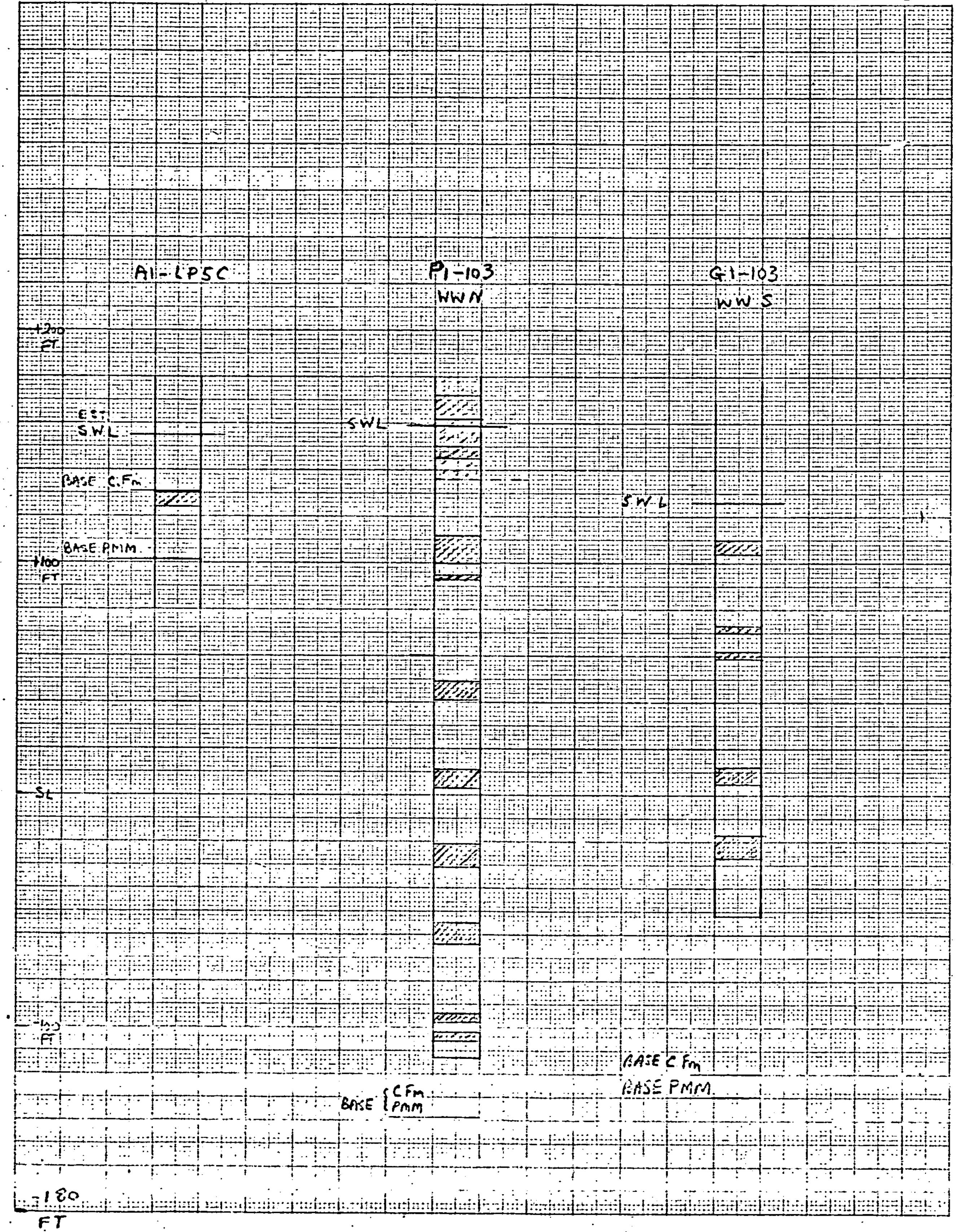
81-108
W W
SWL
+200
KK 1-12
W.W. E
Q1A-103
WW NN
+100 FT
SWL
SWL
BASE C. Fm
SL
BASE Pmm
-100 FT
BASE {C. Fm Pmm
BASE C. Fm
-200 Ft
BASE Pmm

FIG 12



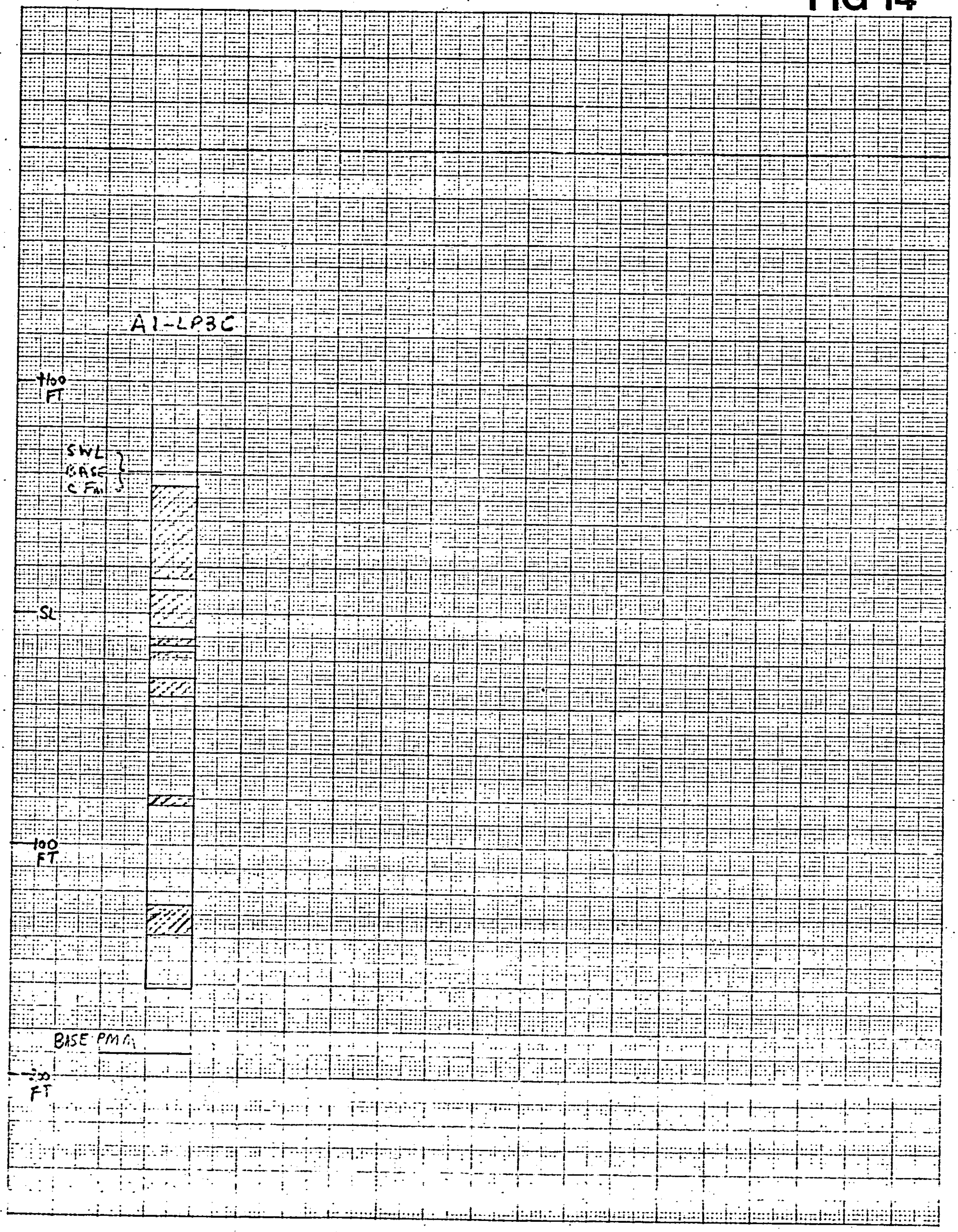
FI-108
W9
SWL
+200 FT
BASE C Fm
BASE PMM
+100 FT
SSS1-6
WW
SWL
BASE C Fm
BASE PMM
D1-108
WW
SWL
SL
-100 FT
BASE C F.
BASE PMM
-180 FT

FIG 13



A1-LP5C
P1-103
WWN
G1-103
WWS
+200 FT
EST. S.W.L
SWL
S.W.L
BASE C.Fm
BASE PMM.
+100 FT
SL
-100 FT
BASE C Fm
BASE PMM
BASE {C Fm / PMM
-180 FT

FIG 14



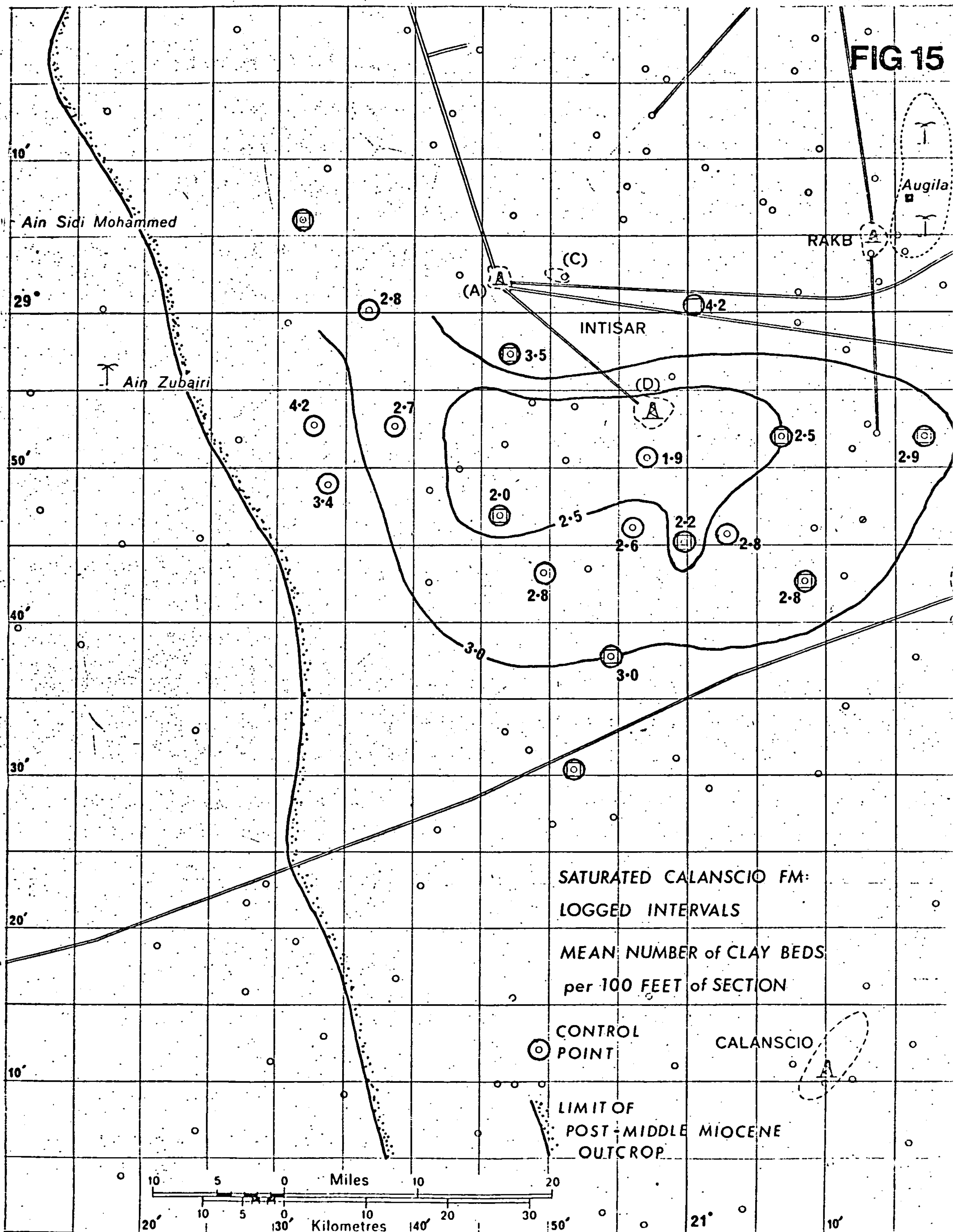


FIG 15
Ain Sidi Mohammed
Ain Zubairi
Augila
RAKB
(A)
(C)
(D)
INTISAR
CALANSCIO
2·8
4·2
3·5
2·7
1·9
2·5
2·9
3·4
2·0
2·6
2·2
2·8
2·8
2·8
3·0
SATURATED CALANSCIO FM:
LOGGED INTERVALS
MEAN NUMBER of CLAY BEDS
per 100 FEET of SECTION
CONTROL POINT
LIMIT OF POST-MIDDLE MIOCENE OUTCROP
Miles
Kilometres
10 5 0 10 20
10 5 0 10 20 30
10′
29°
50′
40′
30′
20′
10′
20′
30′
40′
50′
21°
10′

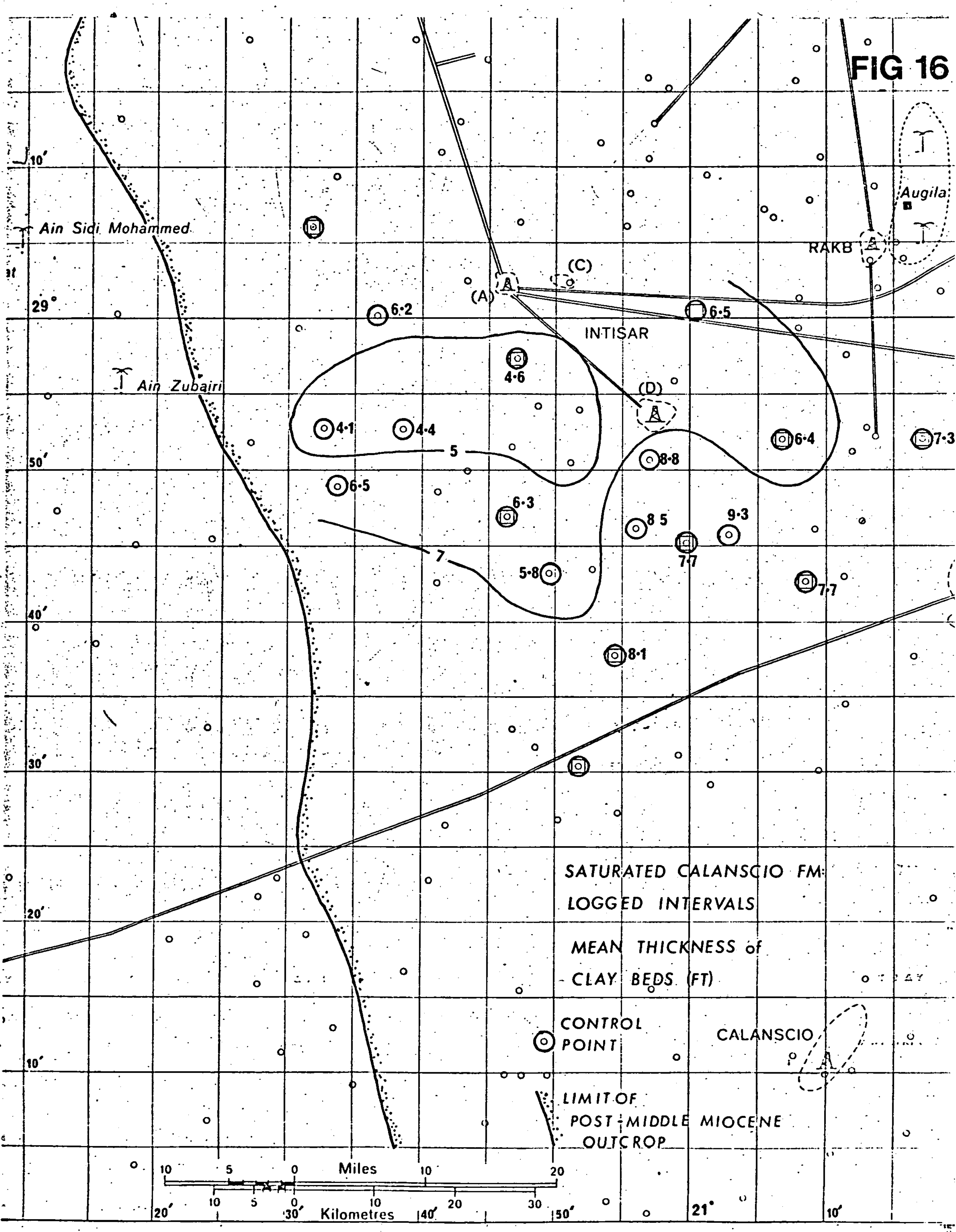
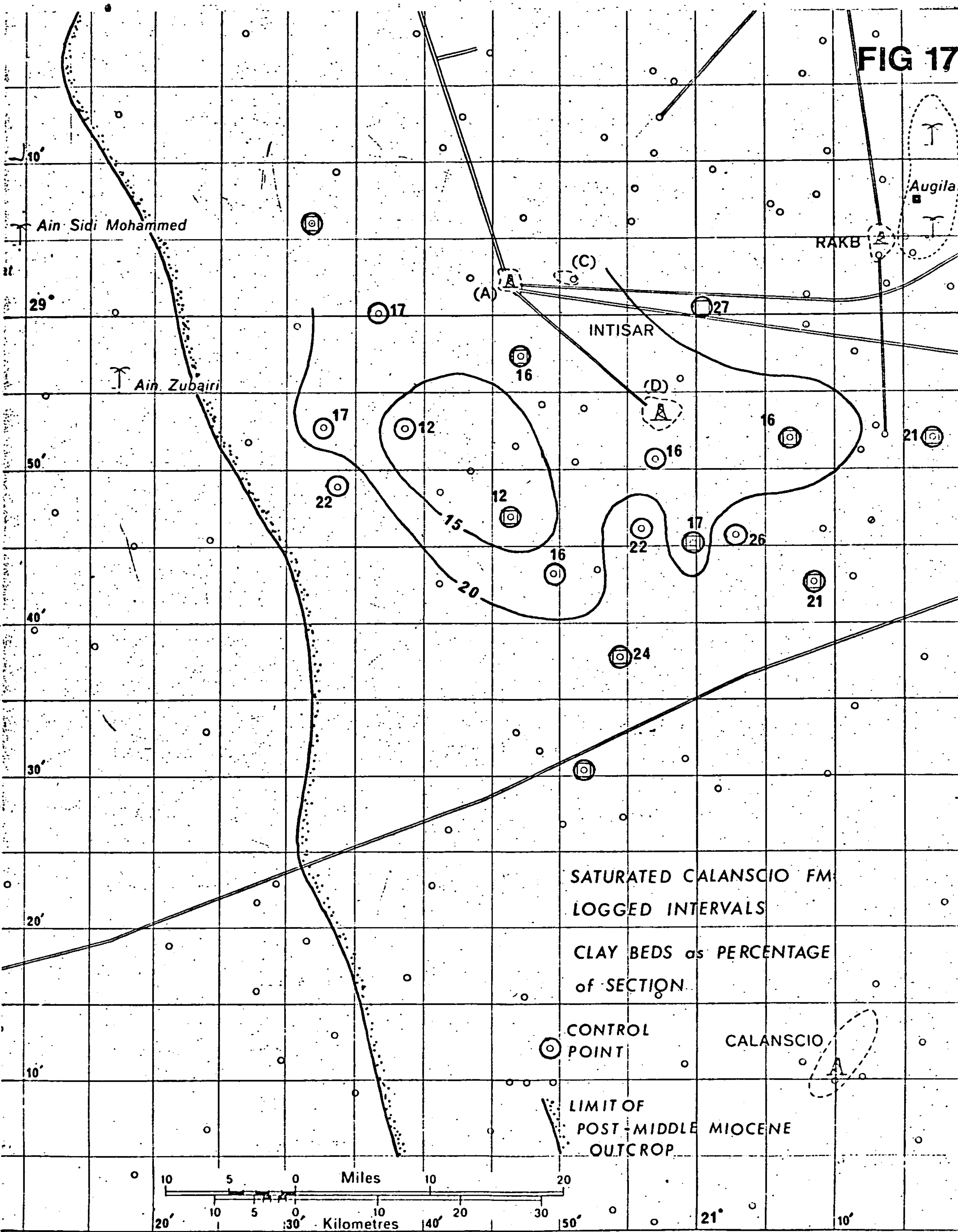

Ain Sidi Mohammed
Ain Zubairi
Augila
RAKB
(A)
(C)
(D)
INTISAR
CALANSCIO
29°
10′
50′
40′
30′
20′
10′
20′
30′
40′
50′
21°
10′
6·2
6·5
4·6
4·1
4·4
5
6·4
7·3
8·8
6·5
6·3
8 5
9·3
7·7
7
5·8
7·7
8·1
SATURATED CALANSCIO FM
LOGGED INTERVALS
MEAN THICKNESS of
CLAY BEDS (FT)
CONTROL
POINT
LIMIT OF
POST-MIDDLE MIOCENE
OUTCROP
10 5 0 Miles 10 20
10 5 0 10 20 30
Kilometres

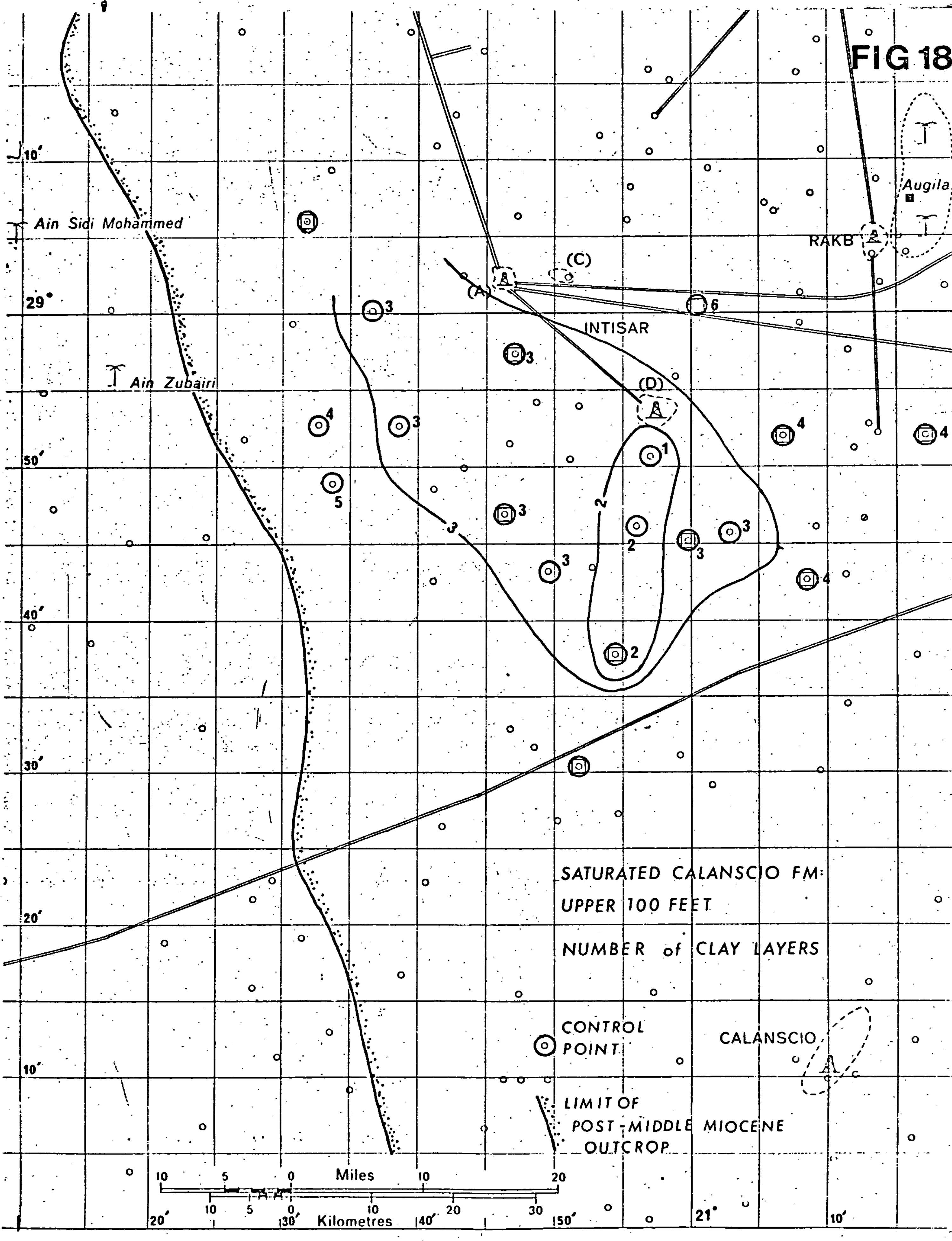
FIG 16

FIG 17



Ain Sidi Mohammed
Ain Zubairi
Augila
RAKB
(A)
(C)
(D)
INTISAR
CALANSCIO
SATURATED CALANSCIO FM
LOGGED INTERVALS
CLAY BEDS as PERCENTAGE of SECTION
CONTROL POINT
LIMIT OF POST-MIDDLE MIOCENE OUTCROP
Miles
Kilometres

FIG 18



Ain Sidi Mohammed
Ain Zubairi
Augila
RAKB
(A)
(C)
(D)
INTISAR
CALANSCIO
10'
29°
50'
40'
30'
20'
10'
SATURATED CALANSCIO FM:
UPPER 100 FEET
NUMBER of CLAY LAYERS
CONTROL POINT
LIMIT OF POST-MIDDLE MIOCENE OUTCROP
Miles
10 5 0 10 20
Kilometres
10 5 0 10 20 30
20' 30' 40' 50' 21° 10'

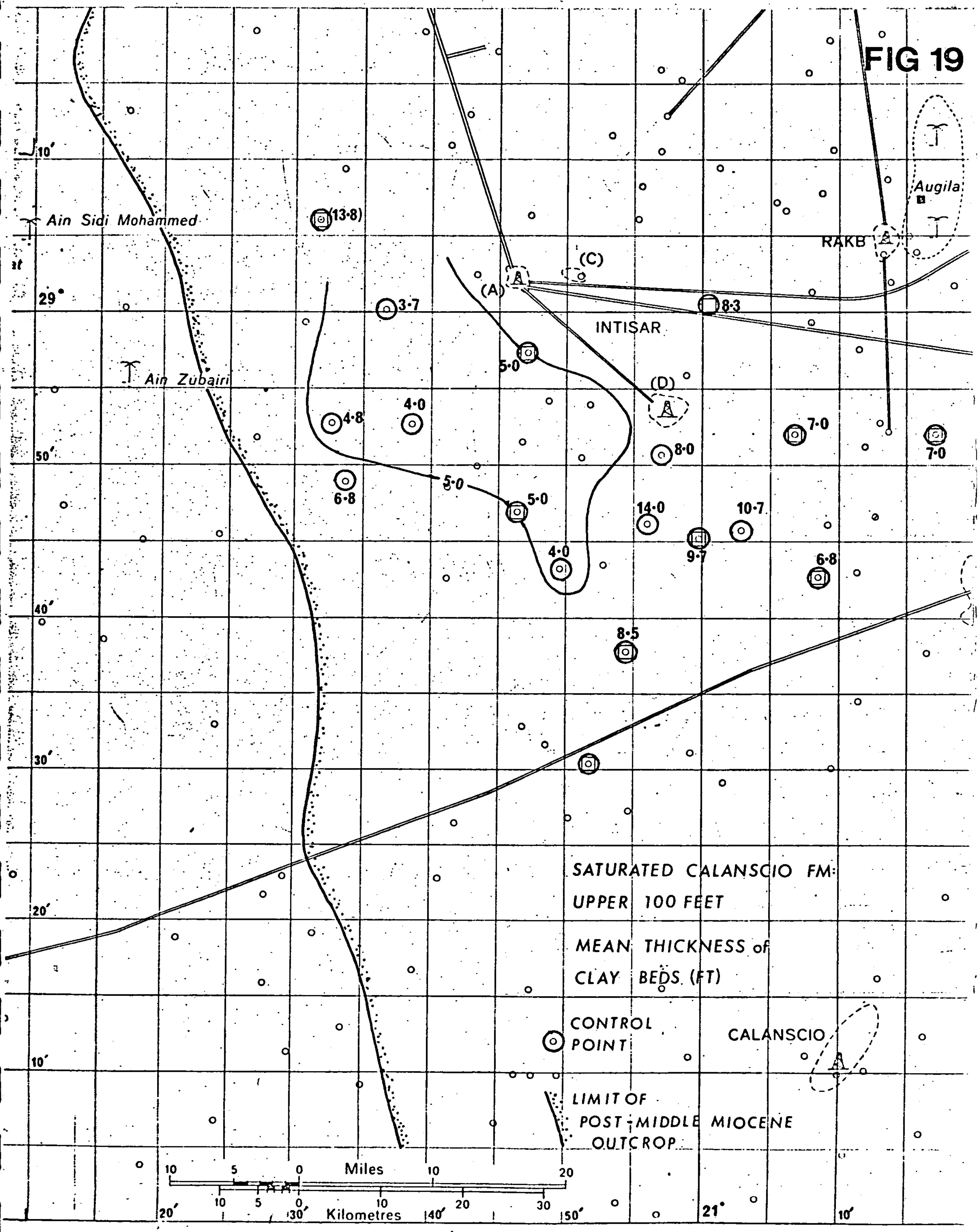


FIG 19
Ain Sidi Mohammed
Ain Zubairi
Augila
RAKB
(A)
(C)
(D)
INTISAR
(13·8)
3·7
5·0
4·8
4·0
6·8
5·0
5·0
4·0
8·3
8·0
7·0
7·0
14·0
9·7
10·7
6·8
8·5
SATURATED CALANSCIO FM:
UPPER 100 FEET
MEAN THICKNESS of
CLAY BEDS (FT)
CONTROL POINT
CALANSCIO
LIMIT OF POST-MIDDLE MIOCENE OUTCROP
10 5 0 Miles 10 20
10 5 0 10 20 30 Kilometres
29°
21°
10′
50′
40′
30′
20′
10′
20′
30′
40′
50′
10′

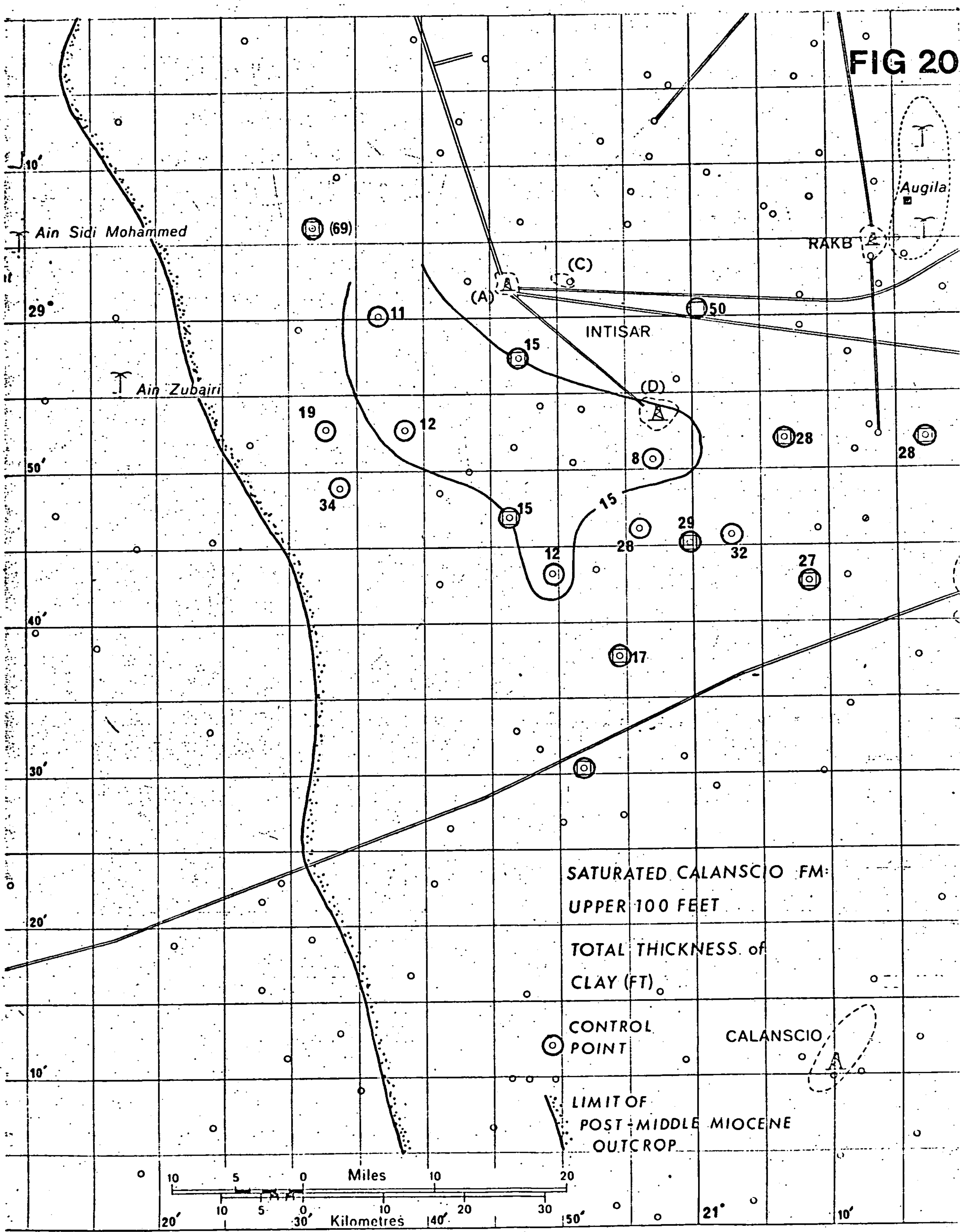
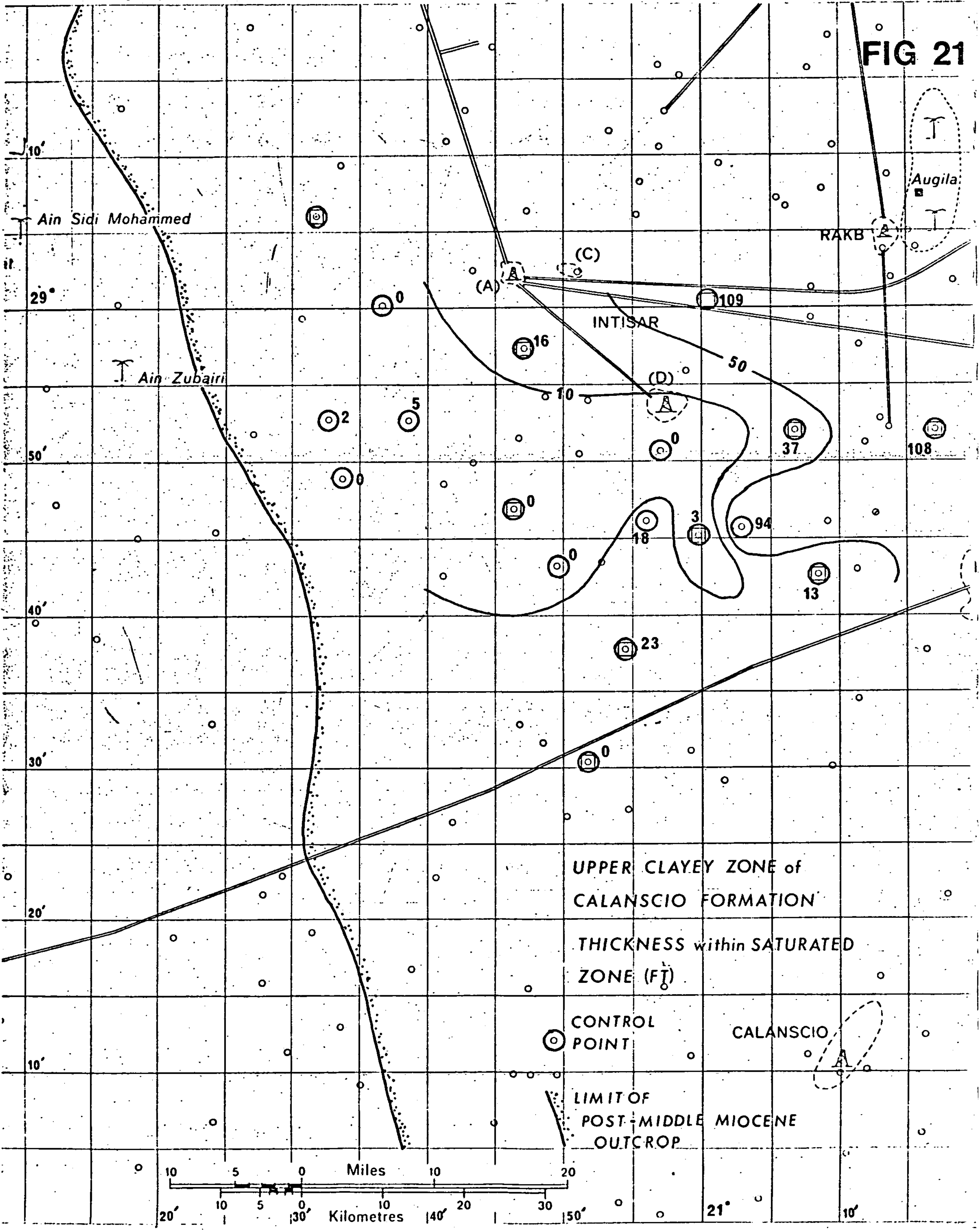


FIG 20
Ain Sidi Mohammed
Ain Zubairi
Augila
RAKB
INTISAR
CALANSCIO
(A)
(C)
(D)
SATURATED CALANSCIO FM: UPPER 100 FEET
TOTAL THICKNESS of CLAY (FT)
CONTROL POINT
LIMIT OF POST-MIDDLE MIOCENE OUTCROP
Miles
Kilometres
29°
21°

FIG 21



Ain Sidi Mohammed
Ain Zubairi
Augila
RAKB
(A)
(C)
(D)
INTISAR
CALANSCIO
109
16
0
2
5
10
50
37
108
3
18
94
13
23
29°
10'
50'
40'
30'
20'
10'
20'
30'
40'
50'
21°
10'
UPPER CLAYEY ZONE of
CALANSCIO FORMATION
THICKNESS within SATURATED
ZONE (FT)
CONTROL
POINT
LIMIT OF
POST-MIDDLE MIOCENE
OUTCROP
10 5 0 Miles 10 20
10 5 0 10 20 30
Kilometres

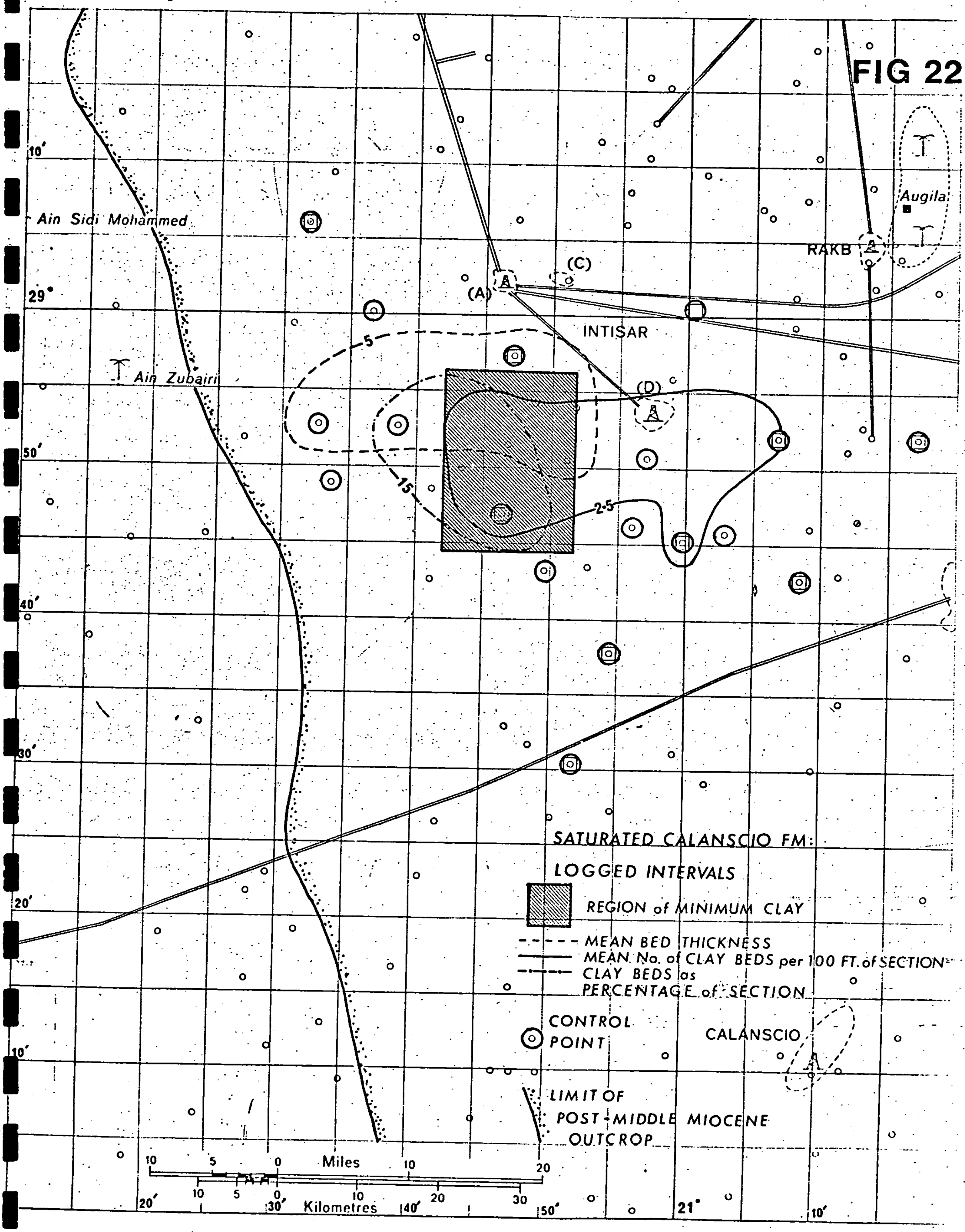


FIG 22
Ain Sidi Mohammed
Ain Zubairi
Augila
RAKB
(A)
(C)
(D)
INTISAR
5
15
2·5
29°
10'
50'
40'
30'
20'
10'
20'
30'
40'
50'
21°
10'
SATURATED CALANSCIO FM:
LOGGED INTERVALS
REGION of MINIMUM CLAY
MEAN BED THICKNESS
MEAN No. of CLAY BEDS per 100 FT. of SECTION
CLAY BEDS as PERCENTAGE of SECTION
CONTROL POINT
CALANSCIO
LIMIT OF POST-MIDDLE MIOCENE OUTCROP
10 5 0 Miles 10 20
10 5 0 10 20 30
Kilometres

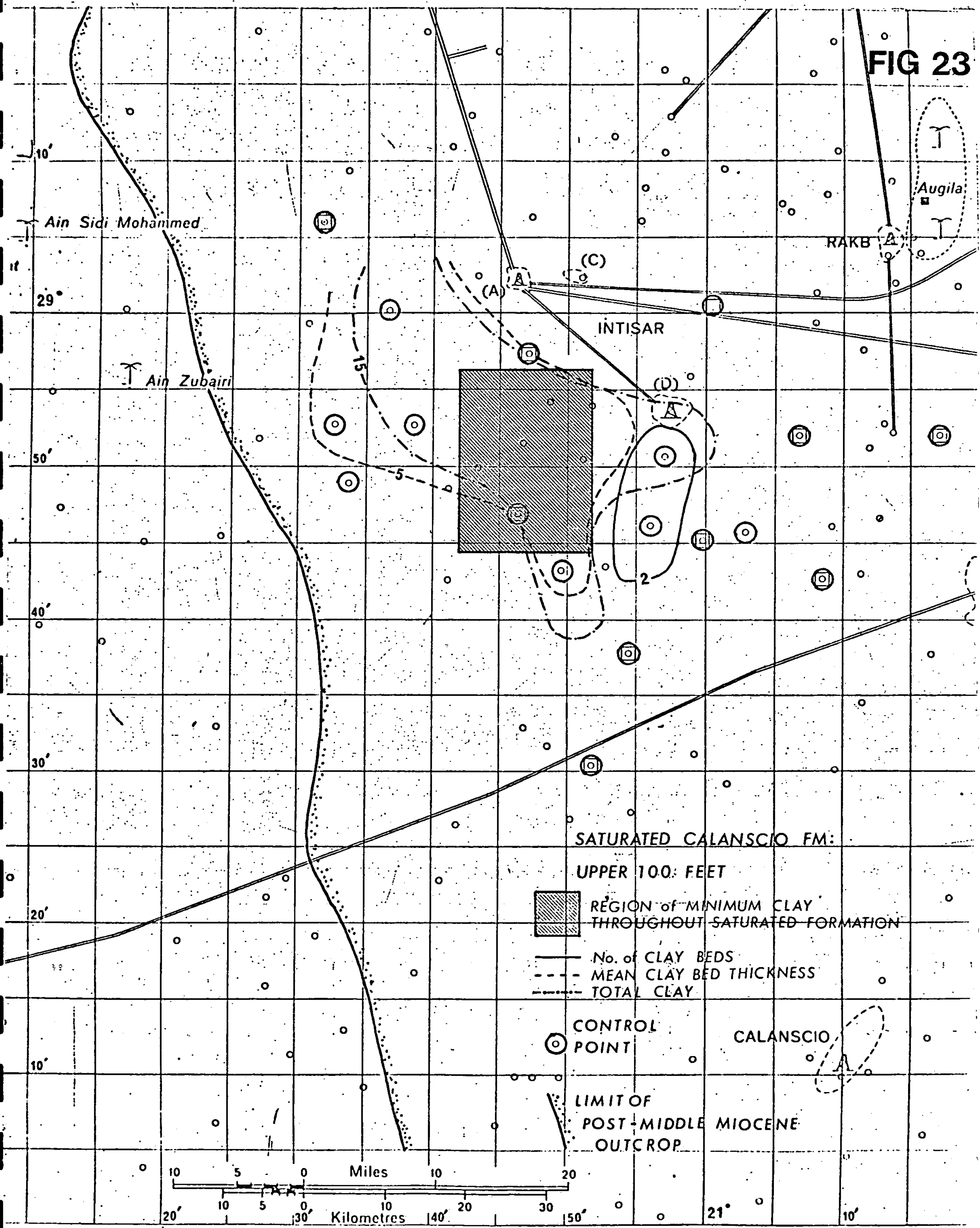


FIG 23
Augila
RAKB
Ain Sidi Mohammed
(C)
(A)
INTISAR
Ain Zubairi
(D)
15
5
2
SATURATED CALANSCIO FM:
UPPER 100 FEET
REGION of MINIMUM CLAY THROUGHOUT SATURATED FORMATION
No. of CLAY BEDS
MEAN CLAY BED THICKNESS
TOTAL CLAY
CONTROL POINT
CALANSCIO
LIMIT OF POST-MIDDLE MIOCENE OUTCROP
Miles
Kilometres
29°
21°