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K. S. McLaehlan

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A geographical study of the coastal zone
between Homs and Misurata, Tripolitania
A Geography of Economic Growth

K. S. McLachlan

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Thesis submitted for the degree of Ph.D.
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Durham

September 1961

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(i)
TERMS OF REFERENCE

The writer began study of the agrarian geography of Misuratio, Tripolitania, United Kingdom of Libya in September 1958. Considerable freedom of choice of subject matter was permitted by the supervising body, the Department of Geography, Durham Colleges in the University of Durham. The scope of the examination to be presented in this thesis was defined in consultation with the writer's academic supervisor after the first field tour in Libya.

The title of the thesis to be produced at the end of the period of study was to be 'A geographical study of the coastal zone between Homs and Misurata, Tripolitania'. Further definition of reference was introduced after the second field tour in Misuratio when it became apparent that information gathered by field survey allowed specialisation in aspects of economic and social geography.

During the writer's period of higher study, there was opportunity for two field tours in Libya, from September 1st, 1958 to May 8th, 1959 and from March 1st to May 1st, 1960. For much of this time, the writer was engaged in field work in the Misuratio study area covering the following major heads:-

1. Land Ownership and Associated Factors.
2. Economic Growth and its Social Implications.
3. Land Use and Farm Management.
4. The Farm Economy.

The writer was able to utilise techniques of land use mapping, questionnaire survey and verbal questioning of subjects. Further

coverage of the preceding topics was undertaken:-

1. In discussion with Libyan and alien officials concerned with the development activities in Tripolitania.
2. In accumulation of a library of books and documents relevant to Libya and its problems.

The aim of the writer was to analyse trends in the development of indigenous and Italian society in the oases and the oasis periphery regions in relation to economic growth in national and, more pertinently, local terms. Work of this kind brought the writer in close contact with the farming community, the peoples of the village, the local notables and to some extent with the semi-nomadic groups of the area.

LANGUAGE

A working knowledge of Italian and French proved useful; even in the most isolated encampments, one or more of the groups were able to speak Italian, French or English. The writer's understanding of Arabic was limited to formal phrases and local terms relevant to farming and the farm. Where possible interpreters were recruited to facilitate the work during questionnaire visits by the writer.

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to the Department of Geography, Durham Colleges in the University of Durham, and particularly to Professor W.B. Fisher and Mr. H. Bowen-Jones, as well as to officials of the Government of Libya, F.A.O., U.S.O.M., L.A.R.C. and the many individuals who assisted him in the accomplishment of this work. A special acknowledgment is

made to the officers and men of the 6th and 2nd Royal Tank Regiments, who made possible the completion of field work in Libya.

GLOSSARY OF TERMS

A full glossary of all non-English language terms used in this thesis is included in Appendix 7.

CURRENCY

The unit of currency in all provinces of Libya is the Libyan pound which is exchangeable at par with the pound sterling. Each Libyan pound unit is divided into piastres and milliemes.

100 piastres = £L1
1000 milliemes = £L1

USE OF MEASURES

At the present time there are many different systems of measurements in general use in Tripolitania. On the one hand, the metric system has been adopted by the government offices and the Italian section of the community. On the other hand, Arabs in rural areas use local measures especially for areas and weights. Where possible, use has been made of the metric system; other terms are explained in the text.

REFERENCES

Reference to written works made in the text of the thesis is indicated where appropriate in the following form - (84). Text reference numbers are explained in Appendix 6.

MAPS

All geographical locations mentioned in the text of the

thesis are taken from ~~Instituto~~ Istituto Geografico-Militare 1:100,000, 1937, reprinted December 1953 (Sheets 1476 & 1477) and 512 Fd. Survey Coy., R.E., 1:200,000 December 1942, reprinted November 1945 (Sheets 1, 2, 3). References of locations mentioned in the text are included in Appendix 8.

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INTRODUCTION

The area of Misuratio

The eastern coastal oases of Tripolitania, situated on a detached segment of the Jefara lowland comprise the unitary region of Misuratio (Vide Figures 1 and 3). Misuratio is separated from the Tripolitanian Jefara by the eastern limb of the Jebel Tarkuna and Msellata, and is bordered on the south by the foot hills of the Jebel system. Further small scale diversification of relief is occasioned by the presence of well-developed areas of littoral dunes (Vide Figure 2).

The dominant climatic theme throughout the oasis and oasis periphery is aridity; in Misuratio we shall be examining an environment exhibiting greater or lesser degrees of aridity. Nonetheless, regional variations in climatic effect are appreciable and are significant in terms of human occupation (Vide Figure 4).

Brief outline of the theme

(1) In Section One of the thesis, we shall develop a description of the physical characteristics of Misuratio and indicate that the environment places sharp limitations upon opportunities for human advancement. It will be shown that climatic restrictions upon the agricultural potential are most marked. Precipitation on the area is small in quantity and unreliable in nature. The character of the physical environment tended to align the Arab economy towards a predominantly pastoral and semi-nomadic life. This type of occupation offered the least

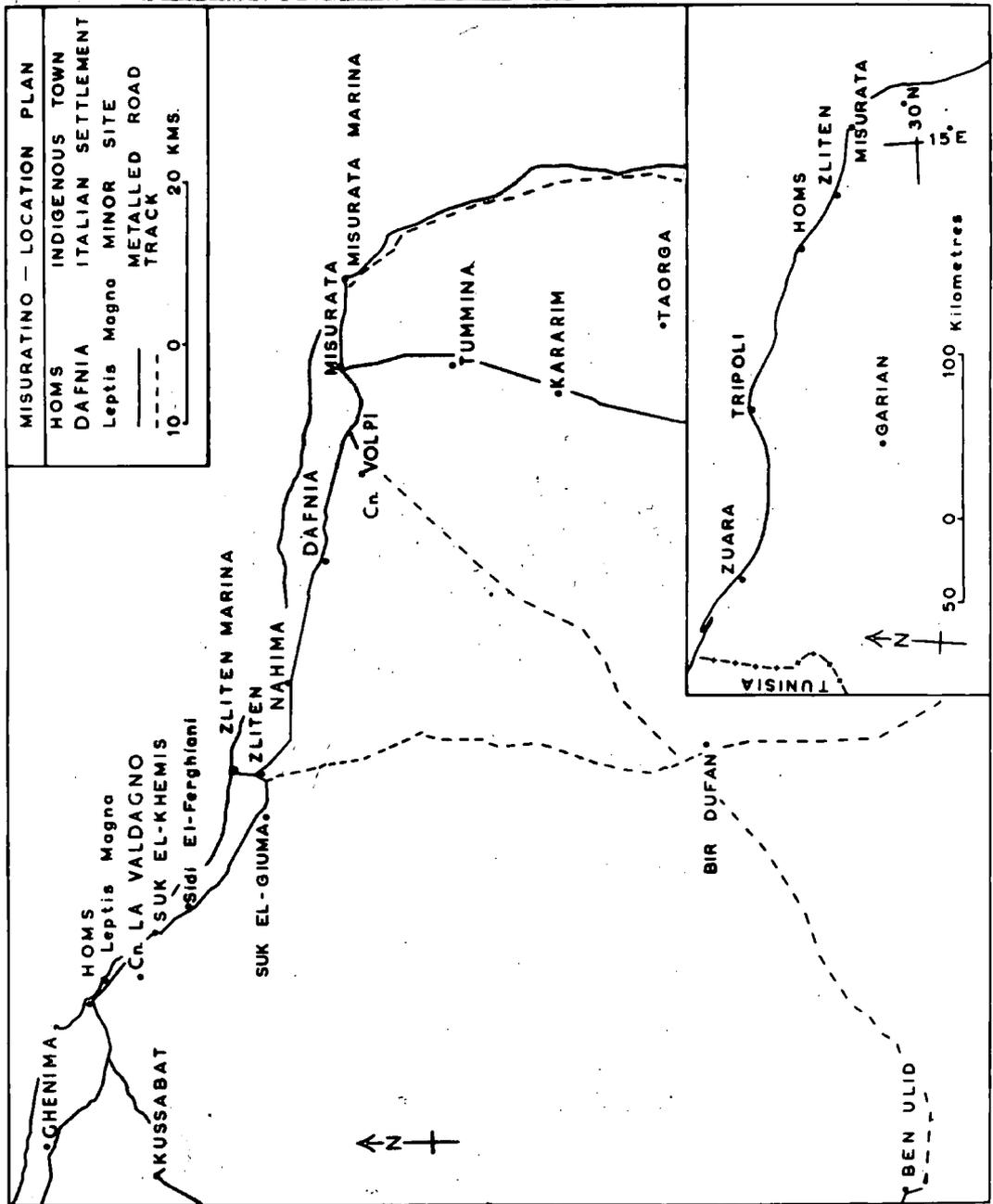


Figure 1

line of resistance to, and was in keeping with the cultural predilection of the Arab groups which occupied Tripolitania in the post-Hilalian era.

(ii) In Chapter Two (Influences of Geology and Geomorphology), we shall examine the balance of water supply in Misuratio in relation to the growing appreciation and exploitation of sub-surface water supplies. It will be indicated that there is a close correlation between the capitalisation of water reserves and the stage of growth of the individual farm operators in Misuratio. As a preface to later discussion of social and economic growth in the oases based on exploitation of water resources, analysis of the costs and the potential importance of different sources of supply and water extraction will be undertaken.

(iii) Under the head of Section Two, we shall discuss further elements of the quasi-constant factors bearing upon economic and social geography in Misuratio, particularly the formalisms and practices influencing agrarian land holding. It will be demonstrated that the pattern of land holding reflects changing appreciation of land use. And we shall suggest that a multi-phase mechanism may be discerned in features of land holding which offers evidence of the rate and direction of social and economic growth in the Misuratio study area.

(iv) Chapter Three will describe the social structure of the cabile and their origins. A brief history of the evolution of the present population patterns will be introduced at this juncture. It will be shown that in the centuries following

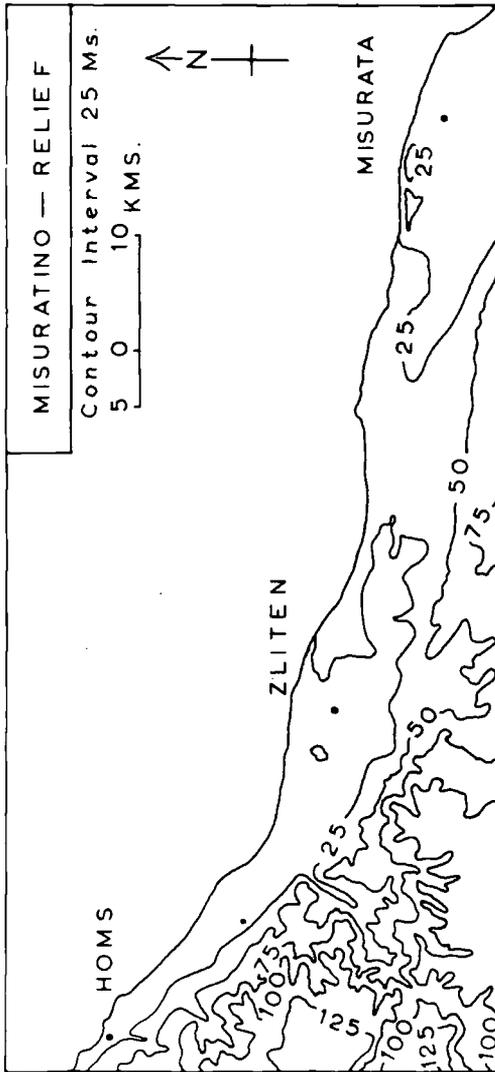


Figure 2

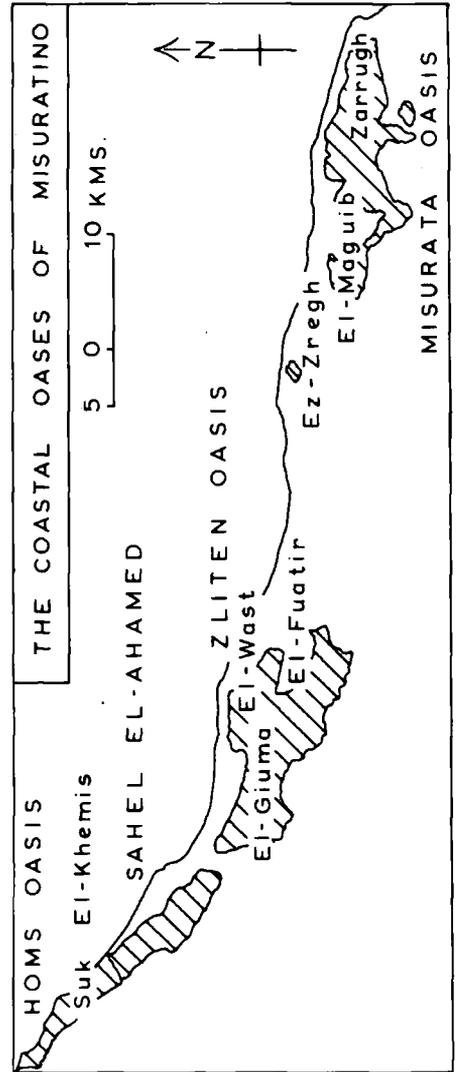


Figure 3

the Hilalian invasions, little change took place in the tribal structure. Different ruling powers occupied Tripoli and parts of the littoral, but the effect upon the indigenous peoples was insignificant.

We shall suggest that the structure of traditional Arab society in Misuratio began to change towards the close of the Nineteenth Century. It will be pointed out that the essentially communal nature of the cabila was weakening under pressure from individuals and family groups within the tribe. Men were seeking gain for their own ends outside the confines of the cabila unit. This trend will be illustrated by analysis of the growth of fixed capital installations in the sedentary zone of occupation. The culmination of the process of internal change will be traced in the transfer of lands from communal to private ownership.

(v) The theme in Section Two will be enlarged in Chapter Four (Elements of social structure in Misuratio in relation to modern economic growth) into a discussion of the impact of the Italian occupation. We shall show that the initial changes generated within traditional society gathered momentum under planned de-tribalisation by the Italian administration. The causes and the systems employed in the de-tribalisation process will be examined at some length with special reference to the varying attitudes of the colonial power towards its Libyan possessions.

In summary of this section, we shall advance the hypothesis that indigenous contact with modern ideas and technology induced

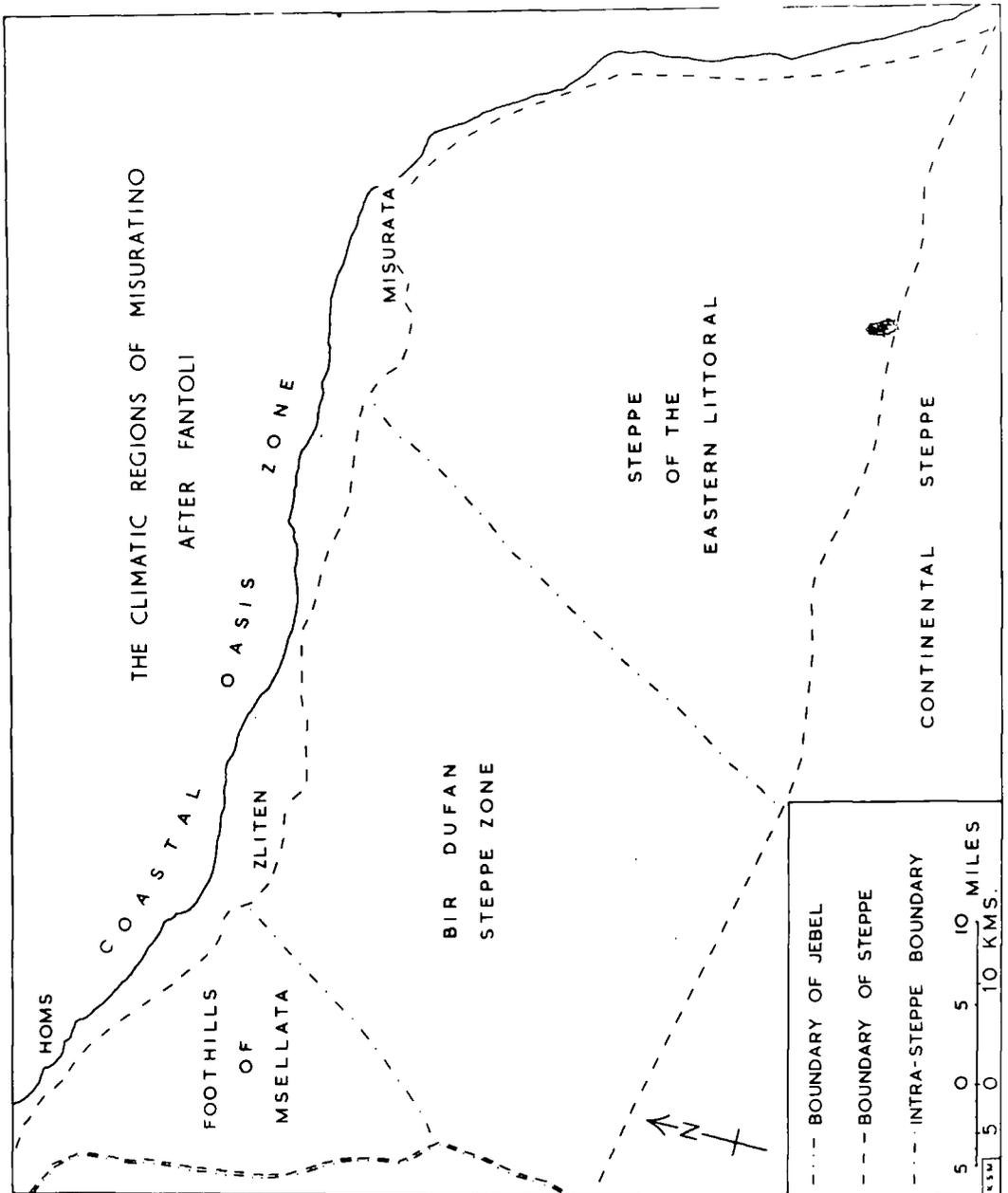


Figure 4

a chain reaction of minor but important economic developments in the towns and oases. The thesis will demonstrate that the increasing interaction of communities has now reached the stage where indigenous society may be more correctly described as transitional than as traditional.

(vi) The main body of the thesis is contained in Section Three, where the elements of transition apparent in indigenous society will be developed largely within the context of the agrarian structure of rural society. Arab agriculture and Italian agriculture will be considered under separate heads.

The form of Section Three arises from the framework provided by description and analysis of:-

- (a) the results of the Questionnaire Survey of Misuratio.
- (b) the results of the land use survey of Misuratio.

Using evidence drawn from these sources, it will be suggested that the farming economy in Misuratio exhibits an over-all tendency for growth stimulated by an amalgam of the following factors:-

- (1) a quickening in the rate of sedentarisation of indigenous peoples in the littoral oases.
- (2) a general change of land holding from common to private ownership.
- (3) a transition from non-differentiation of land use categories to appreciation of varying land qualities. Relatedly, varietal specialisation in cropping replaces cereal monoculture.
- (4) a trend towards capitalisation of water resources.

It will be suggested further that there is a well marked operation of a phase by phase mechanism of growth in the oasis

economy. Evidence will be discussed to indicate that the phase mechanism works within the following limits:-

- (1) Phase I - Traditional economy based on semi-nomadism or full nomadism. Aligned to steppe, pastoral occupation.
- (2) Phase II - Traditional economy aligned towards pastoralism but exhibiting greater dependence upon dry-land, oasis cultivation.
- (3) Phase III- Traditional, self-sufficient but peasant economy based on irrigated oasis possessions.
- (4) Phase IV - Transitional farming founded upon irrigated cropping for market production.
- (5) Phase V - Modern Arab farming utilising up-to-date equipment and rational cropping practice.

With the help of material accumulated during the Questionnaire Survey and the land use survey of Misuratino, it will be shown how the growth mechanism operates in the oases in relation to capitalisation of water resources.

Throughout the thesis, we shall demonstrate that the geographical method may be brought to bear successfully upon the complex problems of social and economic growth.

S E C T I O N O N E

THE PATTERN OF HYDRO-AGRICULTURAL DEVELOPMENT

Chapter One - Climatic Influences in Misuratio

- (i) General Description and Introduction.
- (ii) Meteorological Elements Influencing Climate in Misuratio.
- (iii) Thermal Conditions in Misuratio.
- (iv) Frost Conditions.
- (v) Precipitation in Misuratio - Distribution.
- (vi) Precipitation in Misuratio - Variability.
- (vii) Drought Effects in Misuratio.
- (viii) Aridity.
- (ix) Relative Humidity.
- (x) The Incidence and Effects of Dew in Misuratio.
- (xi) The Incidence of Fogs and Mists in Misuratio.
- (xii) The Incidence of Winds in Misuratio.
- (xiii) Climatic Influences - Summary.

CHAPTER ONE - Climatic Influences in Misuratio

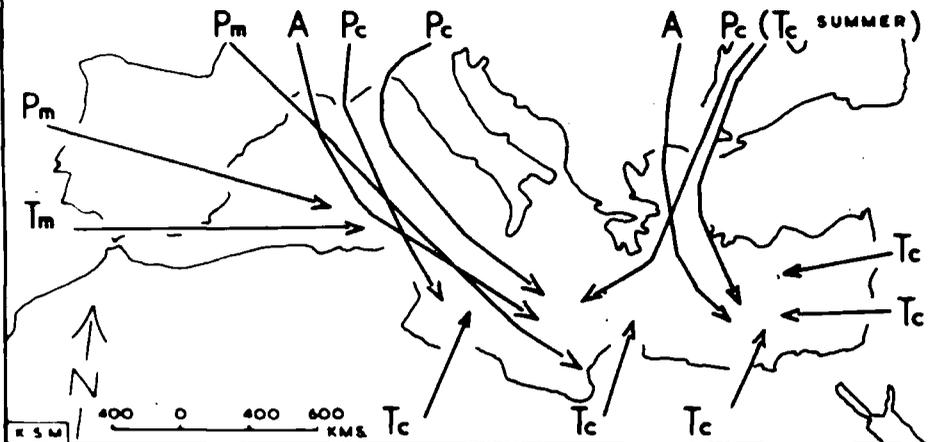
(1) General Description and Introduction.

Considered in general terms, Misuratio and the adjacent steppe lands may be described climatically as an area experiencing a mild, relatively wet winter, followed by a warmer and increasingly dry spring and early summer. Summers in the area are intensely dry and hot. In spite of the overall homogeneity of climatic phenomena throughout the region, there are differences to be observed both between one locality and another and between one year and another in the same area.

The oases of Misuratio are situated on a Quaternary lowland which is drained to the Mediterranean coast by small wadi systems such as the Zennad at Homs and the Lebid at Suk El-Gioma (Vide Figure 25). Small scale diversification of relief within this lowland is caused by the presence of coastal dunes and minor sand sea developments in the north and by the Jebel foothills and their outliers in the south. These elements of relief are responsible for local variations in climate both in respect to thermal and precipitation conditions. Msellata, the easterly limb of the Jebel, extends to the coast in the west of Misuratio and constitutes a marked physical feature which has a formative influence upon the character of temperature and rainfall in Misuratio. Msellata projects in a narrow Cretaceous bluff to the coast and creates a barrier to the prevailing westerly winds, a factor which is reflected in the fact that the coastal strip from Homs to Dafnia exhibits a declining rainfall from west to east. Eastwards from Dafnia,

MAIN TRACKS ALONG WHICH AIR MASSES ENTERING THE MEDITERRANEAN

— AFTER — AVIATION METEOROLOGY CASTEL BENITO TO CAIRO — (MET. OFFICE)

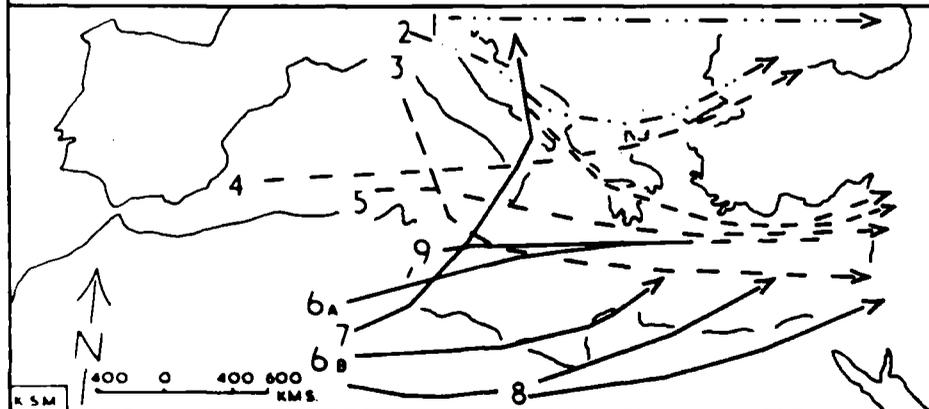


KEY

P _m	POLAR MARITIME
P _c	POLAR CONTINENTAL
T _c	TROPICAL CONTINENTAL
T _m	TROPICAL MARITIME
A	ARCTIC

MAIN TRACKS OF DEPRESSIONS EFFECTING LIBYA

— AFTER — AVIATION METEOROLOGY CASTEL BENITO TO CAIRO — (MET. OFFICE)



---	MEDITERRANEAN DEPRESSIONS MOVING TO THE BLACK SEA
---	MEDITERRANEAN DEPRESSIONS MOVING TO THE LEVANT
—	MEDITERRANEAN DEPRESSIONS MOVING TO THE NORTH WEST & WEST ASSOCIATED WITH GIBLI DEPRESSIONS

Above Figure 5
Below Figure 6

the coast becomes more exposed to the winds and the influence of Maellata becomes insignificant.

The northern boundary of the area is the Mediterranean sea coast. The sea provides a surface, which, compared to the land is relatively warm in winter especially at night, and relatively cold in summer especially during the day. It also provides a supply of atmospheric moisture throughout the year. At the same time Misurata is fully exposed to all meteorological conditions moving in a southerly direction.

(11) Meteorological Elements Influencing Climate in Misurata.

Of the major meteorological elements affecting the structure of climate in Misurata, the maritime influence from the west is confined mainly to the winter months when migration south of the main world atmospheric belts takes place. The Sahara itself is governed by the Horse Latitude High, an influence which spreads to include virtually all the Mediterranean littoral in summer. Interaction between the western maritime influences from the Mediterranean Gate into Libya and the Saharan High pressure system is the fundamental factor behind climatic conditions experienced in the Jefara of Tripolitania.

The main tracks along which the various air masses enter the Eastern Mediterranean, and the sources of the constituent bodies of air which are associated with them are shown on FIGURE 5. Figure 6 on the other hand, shows the trajectories of cyclones which affect the Mediterranean in general and Libya in particular.

In general, during winter, Mediterranean depressions are secondary to major depressions which have their tracks lying over North Europe. As may be seen from Figure 6, some depressions enter the Mediterranean Basin from the west through the Bay of Biscay and the Straits of Gibraltar, while there are other tracks lying across the Iberian Peninsula and Northern Morocco. Principle tracks of the depressions which generally bring rain in winter are those marked on Figure 6 as 2, 5, 6 and 9. Most rainfall in winter can be accounted to the influence of disturbance movements along track 6 B. These enter the Mediterranean from the Atlantic Ocean via Morocco, and swing south of the High Atlas before skirting the shores of Sirtica and passing north of the Jebel Akhdar in Cyrenaica. During the winter season, winds associated with track 6 A usually bring rain along the coast of Tripolitania, although only to half the extent of winds associated with track 6 B. Track 6 A emerges into the Mediterranean Basin through the Gulf of Gabes. Thence it crosses the sea in a direction running approximately NNE, with associated westerly winds along the Tripolitanian littoral. Depressions travelling along tracks 2, 5 and 9 according to recorded data have associated westerly winds in winter, although they are responsible only for a quarter as much of the winter rainfall as these on track 6 B. (1)

Spring rainfall in Misuratio is generally the product of westerly winds associated with depressions resulting from the interaction of the air masses indicated in Figure 5 and following

the lines of movement shown in Figure 6. Air masses following track 3 are usually minor depressions with a circuitous route running south from the Italian Peninsula and swinging eastwards off Tunisia. They pass along the North African shores before joining with air masses following track 6 B in eastern Sirtica.

Depressions which form to the south of the High Atlas, such as those following track 8, tend to be very weak until they are sufficiently easterly to affect the air system over the Mediterranean. Spring rain during track 8 depression conditions is associated with relatively strong north-easterly winds.

Cyclonic rainfall in the autumn months is associated primely with winds of track 6 B. Track 6 A depressions are responsible for about a quarter of the total precipitation at this time of year. Occasional falls from winds associated with tracks 2 and 15 are also experienced in the autumn months. Track 15 is not shown in Figure 6 for cartographical reasons.

The incidence of rainfall along the coastal lowlands of Misuratio is closely associated with the operation of depressions along track 6. Conditions of temperature, cloud cover and relative humidity shown in Figure 18 illustrate the climatic situation in Misuratio during the passage of a depression along track 6.

For the purposes of defining and physically delimiting the climatic conditions in Misuratio, varying periods of observations between 1913 and 1958 have been used. Data covering most aspects of climate are available, but recordings

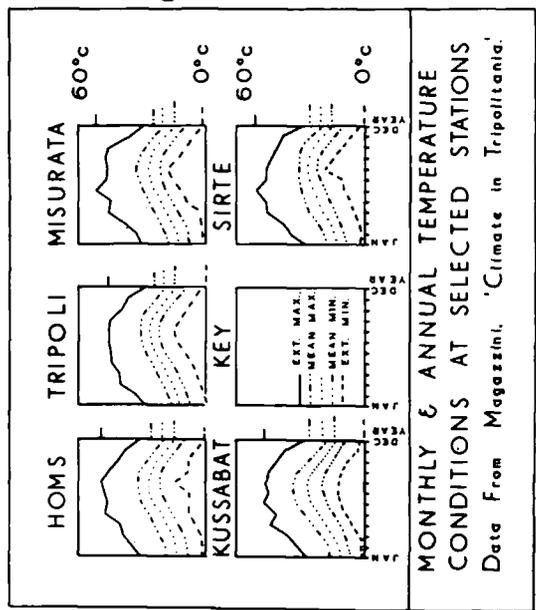


Figure 7

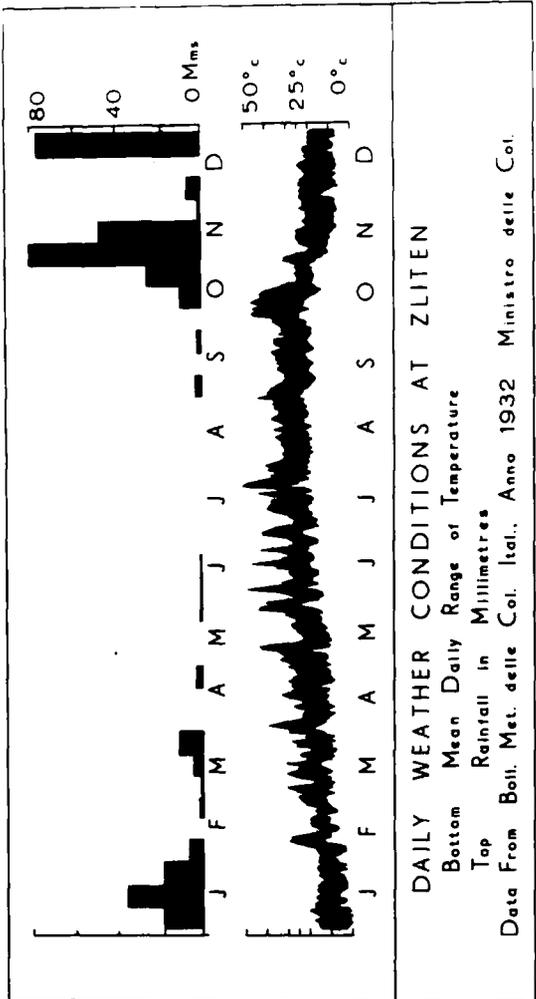


Figure 8

tend to be incomplete from month to month in any one year. The number of consecutive years of recordings is so low as to make most average estimates rather suspect. The climatic figures for the war years 1941, 1942, 1943 are either inadequately covered, or are totally absent from all published works and official records. When scarcity of material precludes the use of a standard period for different stations under review, the actual years involved will be mentioned.

Following the advice of the Controller of the Meteorological Section Tripolitania, records of the period 1927-35 have been used when consideration of daily readings has been necessary. The Controller suggests that the figures covering this period are more reliable than later data since full-time staff was employed at that time. Later periods of observations were kept by local officials, whose work was less accurate.

In any treatment of the Libyan environment, it cannot be over-stressed that any quantitative values presented and any conclusions drawn are strictly applicable only to those years on which the calculations are based.

(iii) Thermal Conditions in Misuratio.

Consideration of temperature conditions over an area of this size will show considerable differences not only between the major zones of the littoral oasis strip and the inner steppe, but also between points relatively close to each other. An over-all picture of the thermal conditions in Misuratio compared with those in adjacent provinces may be gained from Figure 7.

TABLE 1

MEAN MONTHLY TEMPERATURES AT SELECTED STATIONS IN °C.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HOMS	13.2	14.0	15.6	18.5	29.5	24.3	26.2	26.9	25.8	23.5	19.0	14.7
MISURATA	12.5	13.5	15.6	18.3	29.7	24.1	26.2	27.0	25.9	23.2	18.9	14.1
TUMMINA	12.5	13.4	15.6	18.4	21.0	24.5	26.5	27.2	26.1	23.1	18.6	14.1

The period of recordings at Homs was for 19 years, at Misurata for 18 years, and at Tummina for 24 years. Source: Boll. Met. Della Col. It.

In the lowland area itself, differences in temperature occur resulting from the interaction of various climatic elements, especially distance from the sea, local relief conditions and variations in the constituent materials of the ground surface. The influence of the underlying rocks is of importance here. In the Homs region, there are rapid local transitions from sands to hard rock surfaces. In the region of Zliten, marine dunes and rough gravel deposits are found in alternation. In the area surrounding Misurata, there are appreciable changes over short distances from marine sands to sebkha to tinn (Vide Chapter 2). Throughout the whole area numerous bordering limestone hills, stretches of wadi detritus and littoral marine dunes are to be found.

Although there are no figures to substantiate the point, lower night and higher day temperatures might be expected on the dunes and sandy areas relative to the temperatures on the areas of compact alluvium and the sebkha.

Variations in temperature from place to place resulting from proximity to the sea can best be illustrated by a comparison between Misurata Gitta and Homs on the littoral, and Tummina, which is some fifteen kilometres south of Misurata.

Conditions at Tummina are somewhat more extreme than those at the two coastal stations (Vide Table 1). During the months from April to September, Tummina returns mean daily temperature figures which are 0.1°C to 0.4°C lower for each month, than the stations at the coast. The maximum variation occurs in June, when the latter rains (Vide p. 20) persist along the littoral, (1.4 mms. at Misurata, 1.3 mms. at Homs) but fail to penetrate as far south as Tummina.

In fact, the onset of summer Saharan conditions is delayed considerably by the moderating influence of the Mediterranean at the coastal sites. Tummina returns high summer temperatures, and shows all the characteristics of a semi-desert site some three or four weeks earlier than Misurata.

Comparison of the mean daily range at Misurata and Tummina illustrates the tendency for the littoral steppe to suffer more extremes of temperature throughout the year. Here again, the quasi-continental conditions at Tummina are most marked in June. As for extreme temperatures, at Tummina, these have varied between 51.2°C and 0.2°C in the eighteen year period with which we are dealing (Vide Table 2). This variation is more akin to

conditions at an inland station such as Ben Ulid (56.8° to 1.0°C), than to conditions at the coast. Coastal conditions are more truly represented by the values for Homs, which is fully exposed to the influence of the Mediterranean Sea. Mean temperatures here tend to be lower than at Misurata for the months of July and September, due in part to the greater frequency of sea breezes during the summer.

TABLE 2

MEAN DAILY RANGE OF TEMPERATURE AT SELECTED STATIONS IN °C.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HOMS	10.3	10.8	11.4	12.0	11.6	11.9	11.1	10.6	10.8	10.8	10.6	10.2
MISURATA	10.1	11.0	11.7	11.7	11.0	11.3	11.1	10.4	10.5	11.1	10.4	10.0
TUMMINA	10.7	11.3	11.1	12.2	11.9	14.8	12.2	11.6	11.2	11.4	11.1	11.0
BEN ULID	11.4	12.0	13.6	15.5	16.8	17.1	16.7	15.9	14.3	12.4	12.2	11.7

The period of recordings at Homs was for 19 years, at Misurata for 18 years, at Tummina for 24 years, and at Ben Ulid for 20 years. Source: Boll. Met. Della Col. It.

The fall of temperature with increasing altitude of the recording station is amply shown by the comparison of figures for the lowland town of Homs (thirteen metres above sea-level), and El-Kussabat (345 metres above sea-level), in Msellata. El-Kussabat is not included in the physiographic region of Misuratino as previously defined. However, it is the only hill station on the periphery of the lowland for which reliable data are available.

TABLE 3

MEAN MONTHLY TEMPERATURES AT HOMS AND EL-KUSSABAT
IN DEGREES CENTIGRADE

<u>STATION</u>	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EL-KUSSABAT	11.0	12.0	14.9	17.7	21.0	24.7	26.3	26.7	25.4	22.1	17.5	12.7
HOMS CITTA	13.2	14.0	15.6	18.5	20.5	24.3	26.2	26.9	25.8	23.5	19.0	14.7

The period of recordings at El-Kussabat is for 18 years and at Homs Citta for 19 years. Source: Boll. Met. Della Col. It. and Ser. Met. Trip.

At the latter station, the mean annual temperature was 19.3°C for an eighteen year period, while at Homs, for a comparable period, the mean annual temperature was 20.2°C. In Table 3, the mean monthly temperatures indicate that this orthodox relationship between relief and mean average temperature holds true for nine months of the year; from January to April, and from August to December. The difference between the two points is at a maximum in winter.

In summer, in fact, a temporary reversal of the situation occurs due mainly to the moderating effect of the coastal location of Homs, and also in small part to the more southerly position of El-Kussabat. The maximum difference between the two during this reversal is in May and totals only 0.5°C. It might be suggested in this connection that for a longer period of recordings, August in El-Kussabat would prove to be hotter than Homs (Cf. Tarhuna). These relationships are further

reinforced by the mean maximum temperatures for El-Kussabat, which for all months show a lower figure than for Homs. From May to September, however, the mean maximum at Homs is significantly below that at El-Kussabat, again mainly as a result of the maritime influence at Homs.

Perhaps the most marked feature of thermal conditions in the Libyan regime is the large daily range of temperature at any given station. Along the extreme littoral of Misurata, the daily range of temperature is moderated by the cooling influence of the Mediterranean during the day, and the relative warmth of the sea during the night. In 1933, for example, the mean annual daily range of temperature recorded at Ben Ulid between the hours of 08.00 and 14.00 hours G.M.T. was 7.4°C . For the same period at Homs, the mean annual range between the two readings was 2.5°C and at Misurata Marina 5.0°C .

Figure 19 shows the maximum and minimum daily ranges recorded in each month of the year 1932 at three selected stations. At each of these stations the daily range of temperature tends to be greater in summer than in winter. The range of temperature in Libya is to be accounted to the high temperatures during the day rather than the low night temperatures. A further influence in this respect is the cloud cover in the winter months, which tends to modify both the day and night temperatures by limiting insolation during the day and acting as an insulator during the night.

Mean daily ranges of temperature at the coastal stations for the years 1930-34 inclusive averaged between 11.0° to 15.0°C

at Homs, and 9.0° to 14.0°C at Misurata. The month of August regularly shows the highest mean daily range. Further inland at Ben Ulid, the mean daily range for each month during this four year period averaged between 10.0° and 19.0°C; i.e. twice the mean daily variation experienced at coastal stations. These average daily variations are appreciable, and illustrate adequately the tendency for means to increase inland. They fail, however, to bring out the essential factor in the climatic scene, which is the crucial effect of frequent extremes of temperature occurring within a short time period.

An example of the tremendous diurnal range of temperature can be seen in the figures for Ben Ulid for 1932. A range of 23.1°C was recorded on March 2nd, 24.8°C on April 17th, and 25.7°C on May 7th. The following table illustrates the movement of temperature from early morning to late evening on these dates.

TABLE 4

DAILY VARIATIONS IN TEMPERATURE AT BEN ULID 1932

Date	0700 hrs.	0900 hrs.	1500 hrs.
2 III 32	12.1°C	16.5°C	29.7°C
17 IV 32	17.5°C	18.3°C	37.5°C
7 V 32	24.8°C	33.5°C	40.5°C

Although these variations at Ben Ulid are most spectacular, and illustrate well the exceedingly erratic temperature conditions in the semi-desert interior, the impact of the extremes is almost negligible amongst people with a pastoral economy. In the coastal oases and the peripheral steppe zone, less marked variations in temperature have an immediate impact

upon the sedentary cultivators. Heavy dews following cloudless nights have a certain beneficial effect in adding slightly to plant and soil moisture. On the other hand, high day temperatures and low night temperatures cause intense damage to the maturing wheat and barley, especially at the 'milk' phase of ear growth. Likewise, extreme variations in temperature during the flowering phase in the indigenous and Italian orchards can cause serious losses in quality and quantity of fruits and olives. This is especially so if the night temperatures approximate to freezing point.

Indigenous farm areas are well-adapted to this thermal regime. A dense cover of date palms exists even where date yields are insignificant. Cultivation is carried on in restricted areas, and a high proportion of the land in the oases is in constant use. Fallow land is invariably left with a weed covering after harvesting. These agricultural practices give an insulating effect in the suaní, especially on still nights when radiation is most intense.

Italian agricultural land is characterised by widely spaced trees and dispersed cultivated strips scattered over large areas. Clean weeding is a common practice in the concession plantations. The result of this European approach to land use in Misuratino is that these areas tend to suffer badly from the effects of the diurnal range of temperature. This is true of other climatic elements studied in this chapter.

TABLE 5

DAILY TEMPERATURE RECORDS AT HOMS DURING THE APPROACH,
PASSAGE AND DEPARTURE OF A GIBLI WIND-IN DEGREES CENTIGRADE

20 VII 32			21 VII 32			22 VII 32		
HOURS			HOURS			HOURS		
0700	0900	1500	0700	0900	1500	0700	0900	1500
35.5	33.0	32.0	36.0	37.1	28.5	25.3	25.5	27.5

SOURCE: Boll. Met. Della Cel. It. Anno 1932.

The Ghibli is an exceedingly hot and dry wind coming from the desert south. It develops in association with passing low pressure systems which generate local but strong winds inland⁽¹⁾. Ghibli bring high temperatures and considerable diurnal ranges of temperature to both steppe and coastal areas alike. The figures in Table 5 give some indication of the rapid increase in temperature with the onset of a Ghibli wind. Appreciable damage to crops may be caused by the high temperatures and the low relative humidity occasioned by the onset of a Ghibli, especially if it occurs at a critical stage in the growing season and is of prolonged duration.

(iv) Frost Conditions

The relative frequency or absence of low temperatures and associated ground frost is of great importance in the spring months. At this time, both the olive and the almond are most vulnerable to frosts, even if they last for only a brief period and are localised to hollows and shallow depressions. As yet, there are no figures available to show the frequency of frosts

in Misuratio, although it is common knowledge and is borne out by personal observation, that frosts do occur along the whole length of Misuratio. The highest incidence of frosts, as noted from farmers' statements, probably falls in January. Frosts have been observed as late as May in the foothills of Msellata. In the oases, it is likely that frosts are far less frequent than at sites further inland.

Similarly, the inverse relationship of hill-foot and hill-top sites will probably hold true for the incidence of frosts as it does for the run of mean minimum temperatures. On the higher slopes, frosts will be the result of the low temperatures of the free air rather than of the ponding-up of cold air draining into a wadi-hollow or lowland basin.

There are no figures available which show clearly the relationship between conditions at any pair of hill-top and hill-foot sites throughout the area. Nevertheless, there is strong evidence to suggest that hill-top and higher slope locations have a higher mean minimum temperature than sites with a hill-foot or wadi side location. Gravity flow of air away from the higher sites to receiving areas below appears to take place especially in the evening. This basic factor in the thermal conditions on and around these upland areas is emphasised by the fact that the extreme mean minimum and maximum temperatures tend to show greatest divergencies at the lower sites.

An example of the divergence is brought out by a comparison of Homs Valdagno (49.0° to 1.0° C) and Homs Citta (49.0° to

0.2°C). These more equable conditions on the hill slopes have their effect in the siting of farmhouses in the Msellata zone. In this zone, there is a marked tendency for settlement to be scattered along the hill slopes surrounding the agricultural land.

(v) Precipitation in Misuratio - Distribution.

It is difficult to talk of averages when dealing with the rainfall of Libya. This is mainly a result of the tremendous variability of rainfall from year to year, and partly a result of the fact that records of rainfall are incomplete and are available for only a short period. From the Carta Pluviometrica of 1956 by Magazzini, the general trends can be traced with reasonable accuracy. (Vide Figure 12). Figure 13 A allows some comparison between stations in Misuratio and stations in other contiguous physiographic regions of Libya.

Of outstanding significance is the rain-shadow effect of the Msellata hills. Ghanima on the west-facing flanks of Msellata returns an average annual rainfall of 330 mms. Homs on the east flank returns an average of 271 mms. The rain-shadow effect is at a maximum in the Sahel El-Ahamed district, where declining precipitation is reinforced by the declination of the coast towards the south. Areas on the steppe periphery of Zliten Oasis are estimated by Magazzini to receive a rainfall of less than 200 mms. This total is comparable with the arid southern Sahel of Tunisia and the Tummina-Taorga district south of Misurata.

This paucity of rainfall is reflected in the poverty of the palm gardens of the western extremity of Zliten Oasis. Here, the spacing between palm trees increases and the productivity decreases with movement east. The full implications to the agricultural community of this slight but significant decrease in rainfall will be considered more comprehensively later in this thesis.

About the environs of eastern Zliten, as the coast becomes more exposed to the rain bearing winds, the decline of rainfall with the increasing distance from Msellata becomes less marked. From Dafnia to Misurata, the rainfall progressively increases with the relative exposure to the winds blowing from the westerly quarter over the Mediterranean. The southerly swing of the coast throughout the length of Misurata appears to have little effect upon the amount or periodicity of rainfall.

The alignment of the coast is generally E.S.E. In the southern quadrants of depressions moving parallel to, but off the coast, maritime air tends to veer to a predominating N-W direction (Vide Figure 13 B). The most satisfactory explanation that may be advanced at the moment, is that where this angle of incidence of winds and coast occurs, even if acute, then there is rainfall. Where the angle disappears and winds and coast are parallel, rain does not fall. Further to the east, Sirte receives rainfall comparable to Misurata, whilst the surrounding areas do not. From this evidence, it may be

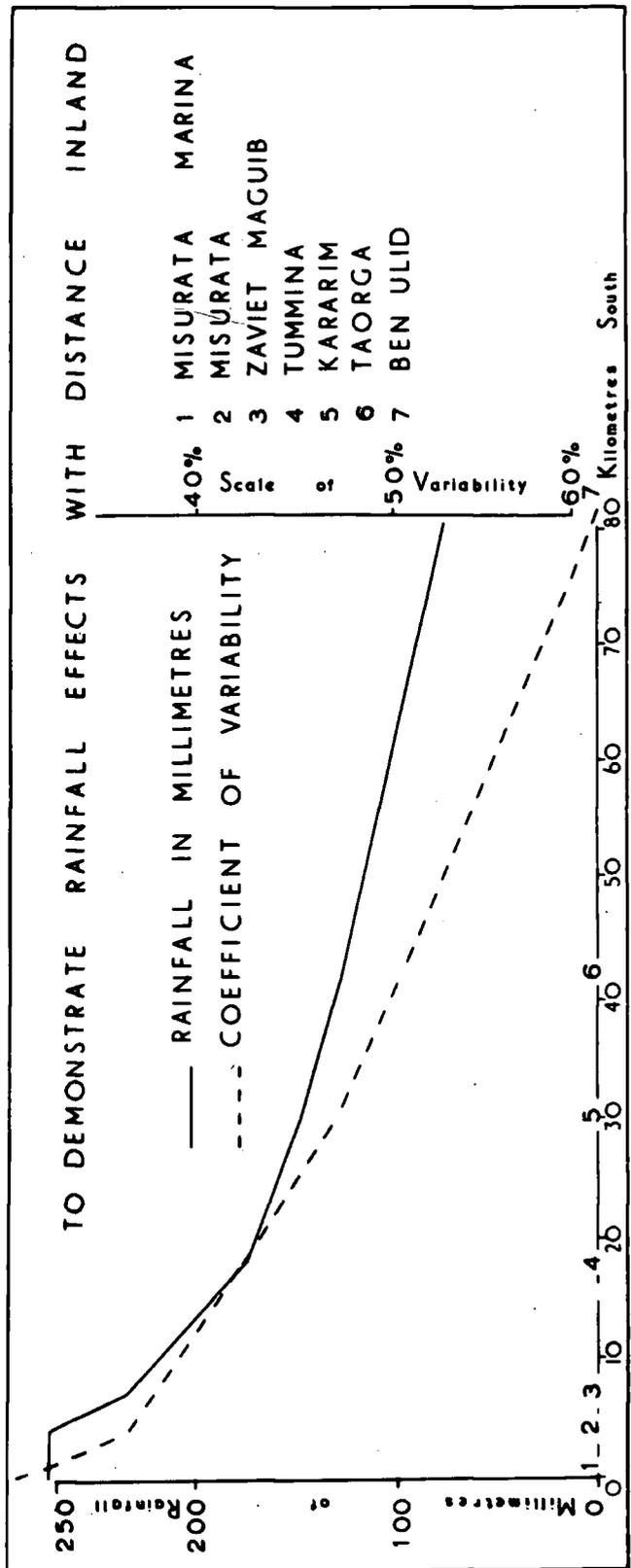


Figure 9

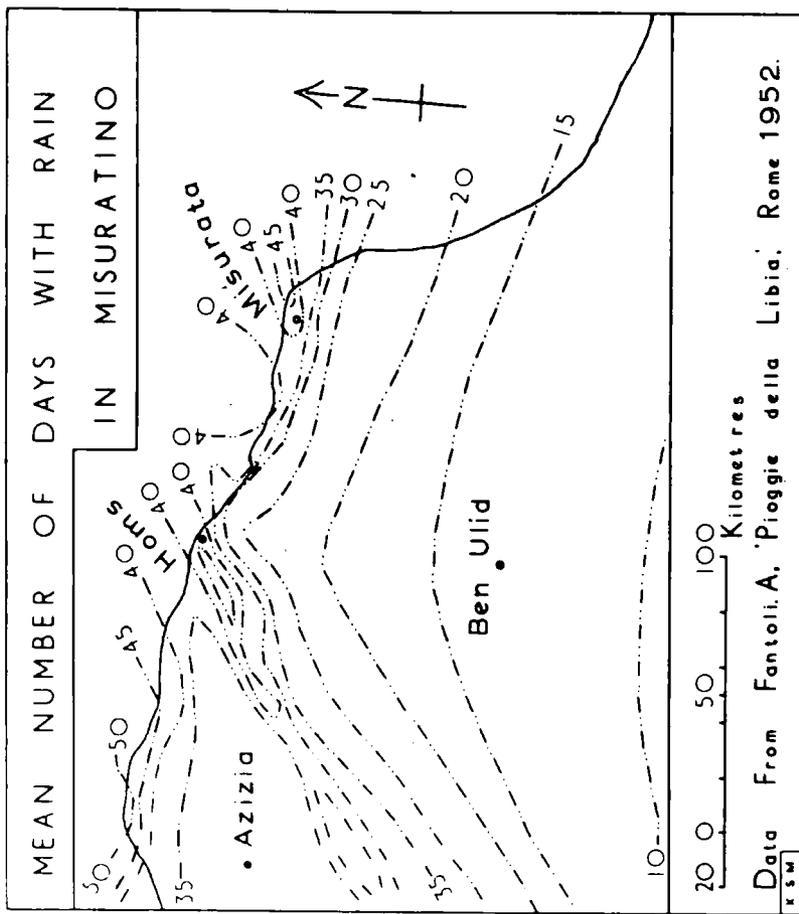


Figure 11

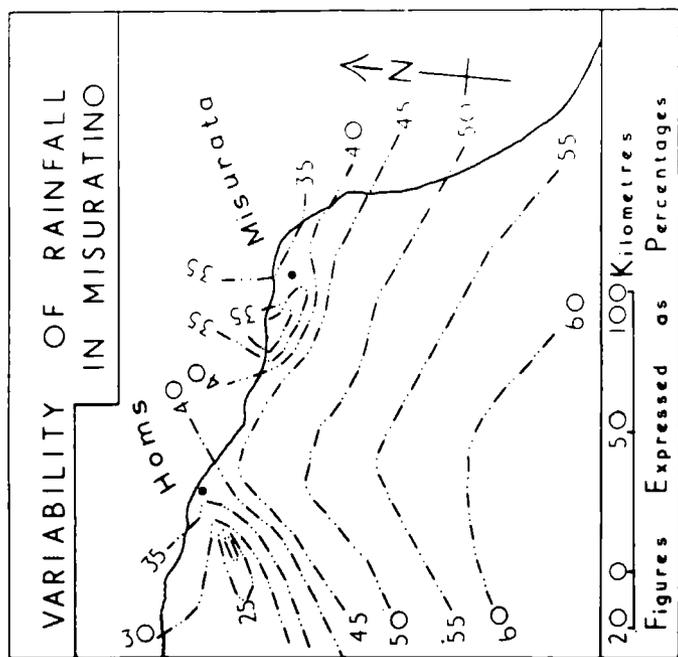


Figure 10

deduced that exposure to the operation of this mechanism is the key factor in the geographical distribution of rainfall in Misuratino.

Precipitation declines rapidly inland from the Mediterranean coast and the rate of this decline is shown by the graphs of Figure 9. Along the immediate littoral, including the first four kilometres inland, there is only a slight decline. This is followed in the littoral steppe zone by a rapid fall in the annual average rainfall, e.g. from 250.2 mms. at Misurata to 175.5 mms. at Tummina. Thereafter, the fall in precipitation with progression southwards tends to be less marked. At this stage it is worthy of note, that the characteristics of the pre-desert steppe as represented by the Faerga to Ben Ulid section of Figure 9, are more the product of the steep gradient of variability than the rate of declining rainfall.

(vi) Precipitation in Misuratino - Variability.

Intense variability of rainfall is a fundamental factor throughout the whole of Libya. In Misuratino, the reliability of rainfall is poor, and the best that can be said, is that some areas within the zone are more reliably watered than others. Figure 10 shows the percentage variability of rainfall for all stations in the area. Sahel El-Ahamed shows the greatest degree of variability for a coastal station, e.g. Zliten returns a figure of 44%, which is directly comparable with that returned by Tummina. In fact, the rain-shadow zone

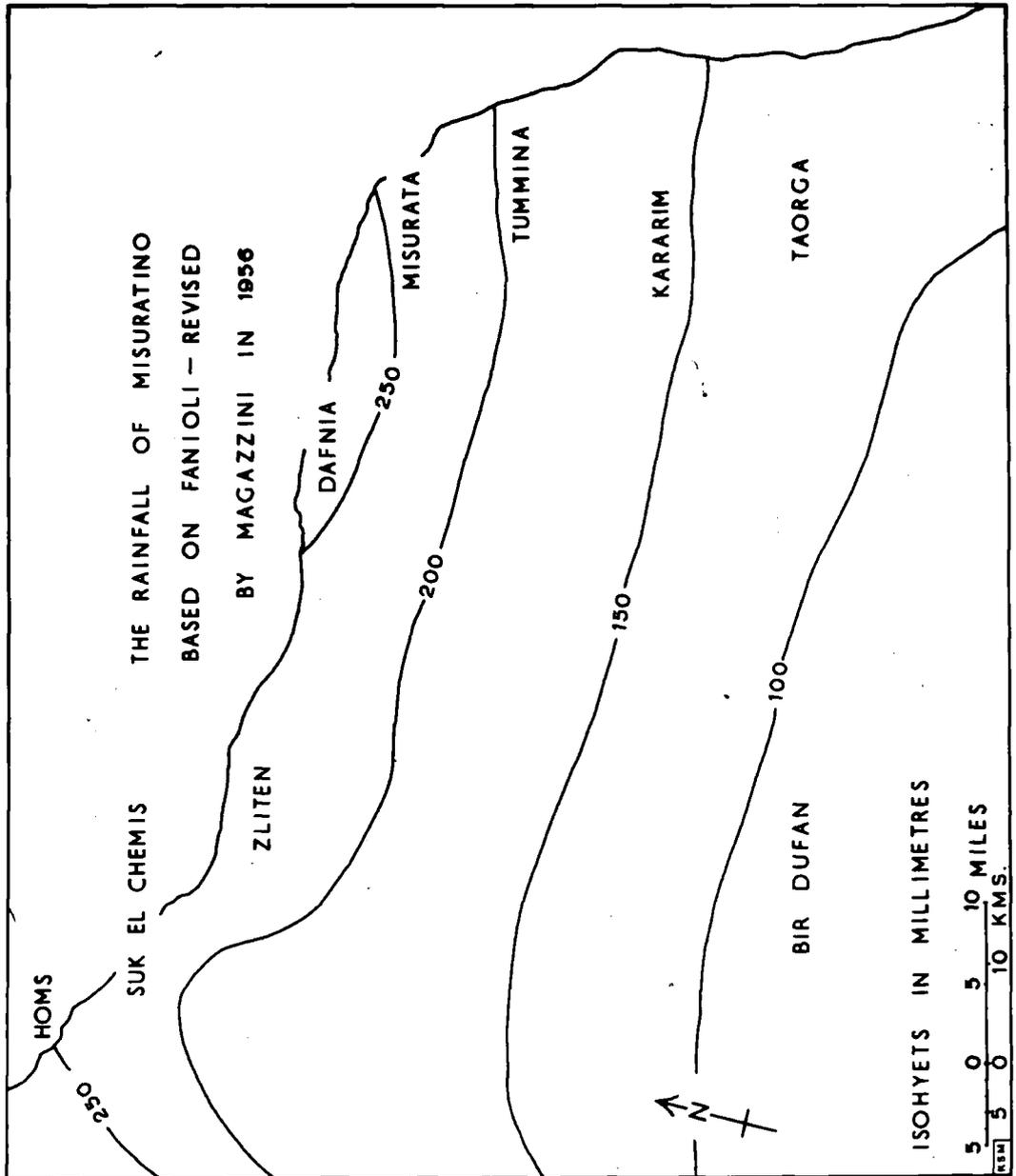


Figure 12

of western Misuratio has less reliable rainfall than the eastern area. In this latter zone, especially in the Dafnia-Bir Gzir area, the greater reliability of rainfall is the result of local relief effect by the dunose sand seas along the littoral of Dafnia. Altitudes of 40-50 metres are sufficient to give localised orographic rainfall in this coastal zone, where spring and winter winds have an unhindered fetch over the Mediterranean.

Figure 11, showing the mean number of days with rain, gives further evidence of rainfall distribution on lines that have been suggested.

The gradient of variability falls steeply inland, as may be seen from Figure 9. Even on the coast, the unreliability of rainfall is such that irrigation is necessary everywhere if the quality and quantity of the harvests are not to fluctuate violently. In this context it must be pointed out that stabilisation of crop yields is as great a problem in Libya as the development of new lands. In spite of the fluctuations in annual precipitation, irrigation water from the shallow phreatic water table has enabled the growth of reasonably secure settlement in the narrow and discontinuous oases of the littoral. Where irrigation water is not available, shifting cultivation is paramount.

(vii) Brought Effects in Misuratio.

Prolonged periods without rain are frequent in Misuratio. At Homs, a maximum of 216 consecutive rainless days were

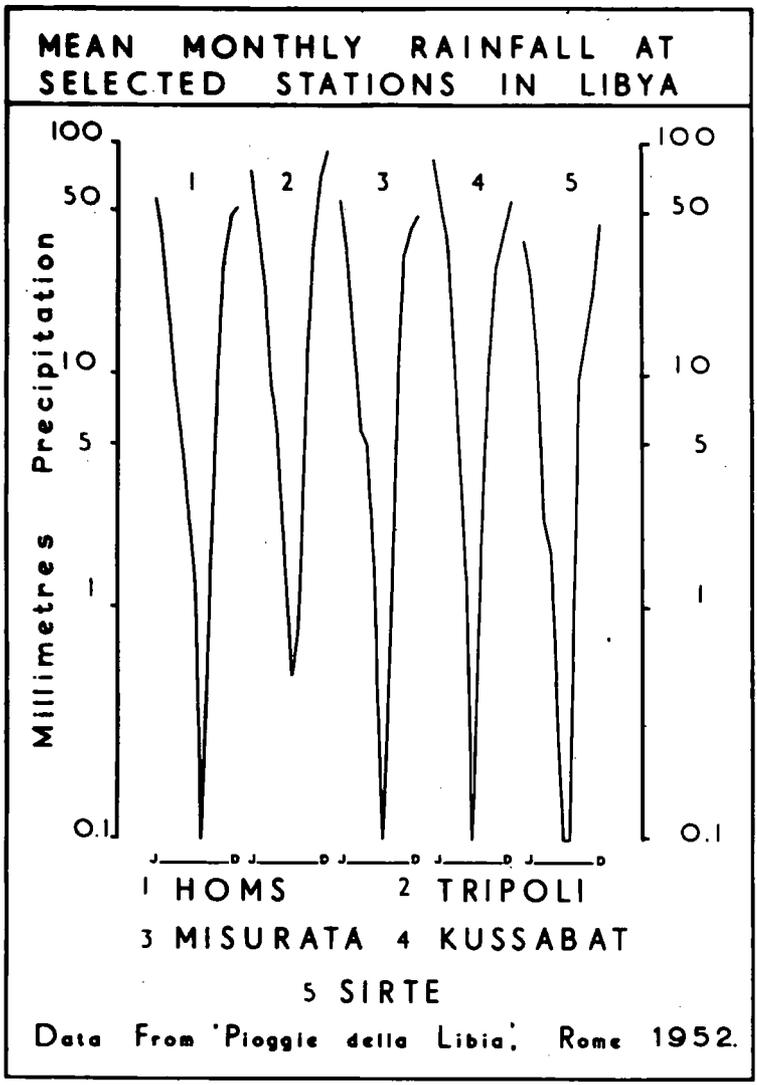


Figure 13 A

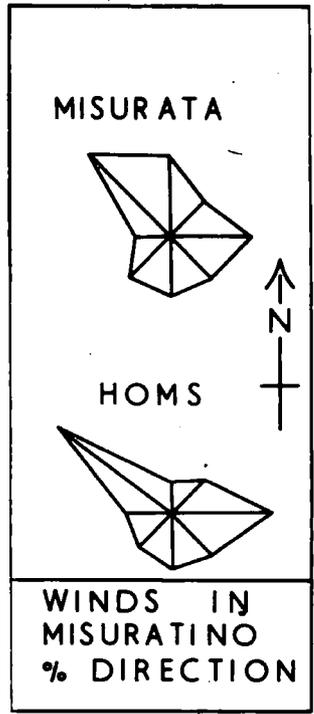


Figure 13 B

recorded in 1928. In any year, an average of five to six rainless periods each with more than fifteen days without rain may be expected⁽²⁾. Local effects of rainless periods have little immediate impact, since adaptation to the scarcity of water for human and agricultural needs is well developed.

Nevertheless, a high incidence of rainless periods has a cumulative effect over a single year, especially if the long, dry periods are experienced in the normally wet months of the year. At Homs, in the maritime zone, one year in five has a high incidence of rainless periods sufficient to give drought conditions (Vide Figure 11).

More precise analysis of the years 1918-1922, 1926-1940 at Homs Citta and the years 1927, 1929-1941, 1944-1949 at Misurata Citta is shown in the following table. 1955-56 and 1960 were poor years for rainfall, and crops and animals suffered accordingly. Figures 14 and 15 show the distribution of rainfall in the former period.

TABLE 6

FAILURE OF RAINFALL-PERCENTAGE ANOMALY

Station	More than 50%	50-25%	25%-0%
Homs Citta	1	3	6
Misurata Citta	2	4	5

Where two consecutive years or more show markedly less than average rainfall, disruption of the local economy is most evident. Agriculture with average conditions is a marginal

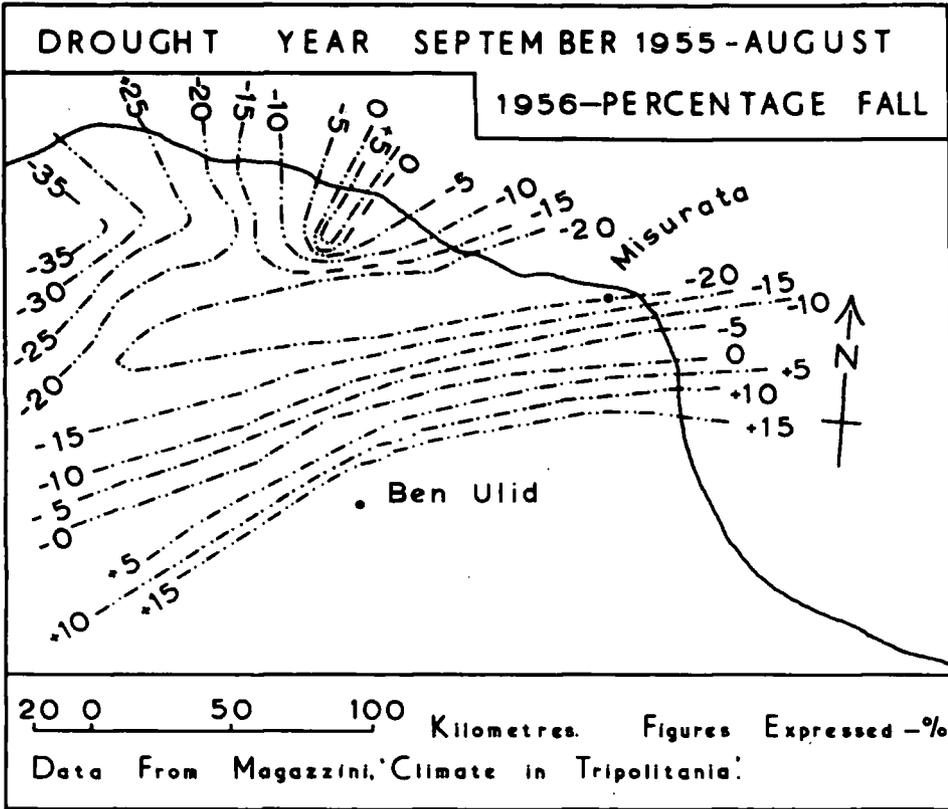


Figure 14

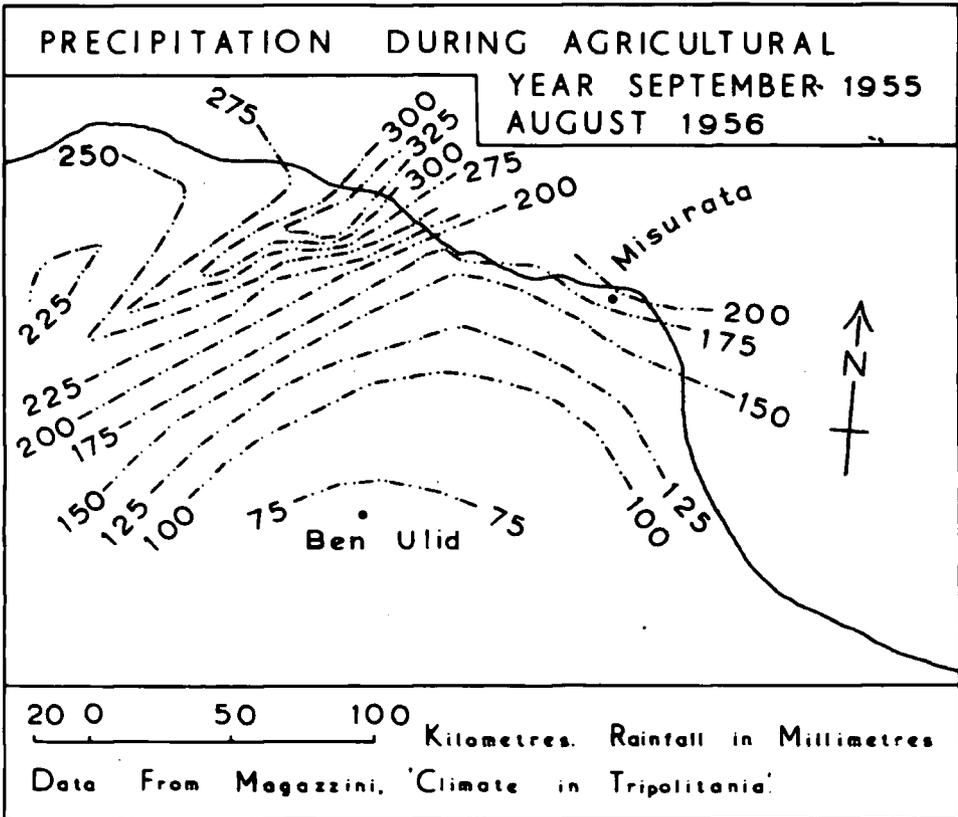


Figure 15

activity in any case in Misuratio. Failure of rainfall over a complete agricultural year may be ruinous, especially for those farmers with only limited sub-surface water resources to draw upon.

In all areas other than the coastal oases, the indigenous population has been able to adapt itself to the preponderance of bad years over good only by a precarious nomadic economy. It is a factor of signal importance, that the intense variability of an insufficient rainfall has been, and will be, a tremendous retarding element in agricultural development. Development and stabilisation are complementary in Libya, each absorbing an equal share of the national and foreign capital resources.

The Libyan Public Development and Stabilisation Agency spent £L 200,000 on stabilisation activities in Tripolitania in 1954-55. In the same financial year, the Agency spent £L 110,700 on agricultural development. In 1956-57 the comparable figures were £L 124,000 and £L 227,496 on stabilisation and development respectively.

Three rainfall seasons emerge from analysis of the average monthly rainfall figures. They are autumn (former), winter, and spring (latter). At all stations in Misuratio, the rainfall maximum is in the restricted period from December to January, with the greatest fall in the latter month. In the coastal oases, autumn accounts for a greater proportion of rainfall than spring. At Homs, for example, an average fall

of 78.8 mms. is recorded for the months of October and November, whilst spring rains in February and March total 58.8 mms. This tendency is characteristic of the littoral steppe zone also, where maritime influences penetrate appreciably.

TABLE 7

RAINFALL SEASONS AT SELECTED STATIONS IN MMS.

STATION	AUTUMN (Oct--Nov)	WINTER (Dec--Jan)	SPRING (Feb--Mar)	PERIOD OF OBSERVATIONS
HOMS	78.8	109.4	58.8	23
MISURATA	89.4	106.0	47.0	30
ZAVIET MAGUIB	66.3	95.5	44.6	18
TUMMINA	47.2	73.0	39.1	15
BEN ULID	12.9	19.0	18.2	15

Source: Pioggie della Libia. Fantoli.

Nevertheless, in this steppe zone, there are indications of a changing balance from greater spring rainfall to greater autumn fall. Figures recorded at Zaviet Maguib and Tummina illustrate this transition. At Ben Ulid, the transition is fully evident, with spring rainfall greater than autumn, and closely approximating to the winter maximum (Vide Table 7).

In any given year, precipitation of any particular month will vary appreciably from the mean values. In the area of Misurata, for the rainy seasons which have been defined, there have been vast divergencies between the maximum recorded in any month and the minimum. Table 8 gives a clear indication

of this divergence. Complete failure of rainfall during the critical growing season has obvious implications for the agricultural community. Table 9 shows the minimum recorded fall at the main stations in Misuratino.

TABLE 8

ABSOLUTE DIVERGENCE BETWEEN MAXIMUM AND MINIMUM MONTHLY RAINFALL AT SELECTED STATIONS FOR PERIOD OCTOBER TO MARCH, IN MILLIMETRES.

STATION	OCT	NOV	DEC	JAN	FEB	MAR
HOMS	148.1	280.5	146.7	101.5	109.2	87.0
MISURATA	221.1	111.2	130.4	177.6	65.6	45.1
TUMMINA	48.8	50.7	39.0	79.7	44.0	37.3

The period of recordings at Homs is for 25 years, at Misurata for 30 years, and at Tummina for 19 years. Source: Serv. Met. Trip.

TABLE 9

MINIMUM RECORDED RAINFALL AT SELECTED STATIONS, FOR PERIOD OCTOBER TO MARCH, IN MILLIMETRES.

STATION	OCT	NOV	DEC	JAN	FEB	MAR
HOMS	0.0	0.0	0.0	4.3	0.2	0.0
MISURATA	0.0	0.1	0.7	2.6	0.0	0.0
TUMMINA	0.0	3.0	8.0	0.0	0.0	0.0

The period of recordings at Homs is for 25 years, at Misurata for 30 years, and at Tummina for 19 years. Source: Serv. Met. Trip.

TABLE 10NUMBER OF DAYS WITH THUNDERSTORMS IN DECADE 1924-1933.

STATION	J	F	M	A	M	J	J	A	S	O	N	D
HOMS	-	-	2	-	-	6	1	1	1	-	1	
ZLITEN	1	-	2	2	3	-	-	-	2	4	1	-
MISURATA	3	-	2	3	-	4	-	3	2	2	1	

Source: Boll. Met. della Col. It. 1924-33.

TABLE 11NUMBER OF DAYS WITH HAIL IN DECADE 1924-33.

STATION	J	F	M	A	M	J	J	A	S	O	N	D
HOMS	1	-	-	-	-	-	-	-	-	1	-	-
ZLITEN	-	1	2	-	1	-	-	-	-	-	-	-
MISURATA	1	-	1	1	-	-	-	-	1	-	-	1

Source: Boll. Met. della Col. It. 1924-33.

Mean monthly figures should, therefore, be viewed rather circumspectly. A wide range of values has been recorded at each station in each month. Although a greater reliability of rainfall in January is apparent, no valid generalisations may be drawn. The maps and diagrams in this climatic section can only give a guide to the possible range of conditions.

Daily rainfall displays highly variable characteristics. Rainfall in Misuratino tends to be of short duration and highly concentrated, even when associated with depression fronts. Heavy falls are not exclusively confined to thunderstorm conditions on the coast, but they are so inland. In late spring and autumn, the frequency of thunder is greatest,

averaging from two to four days per month during those periods. In winter the incidence decreases to one or two per month. During the winter months, particularly in the steppe zone, during the period of depression instability on the littoral, convectional activity leads to hailstorms. The relative frequency of these throughout the year is almost the reverse of the frequency of thunder. Further data are available in Tables 10 and 11.

(viii) Aridity

Reference has been made already to the differences which underlie the climatic zonation of the area. For our present purposes treatment is necessary of two of the climatic zones, i.e. the northern littoral and the pre-desert peripheral steppe. So closely does the peripheral steppe follow upon the coastal strip, that even in dealing with the Oases of Homs, Zliten and Misurata, both climatic spheres must be considered.

In 1939, Fantoli devised a rough division of Libya into climatic areas. His map, reproduced as Figure 4, was based mainly on his own observations, and on an unspecified gradation of zones of lessening maritime influence. Later in the thesis, the reaction of the inhabitants of Misurata to the effects of lessening maritime influence will be suggested as a factor of primary importance.

It will augment the Fantoli thesis here to develop the basic element of aridity, upon which he laid due emphasis. The relative aridity of stations in Tripolitania is

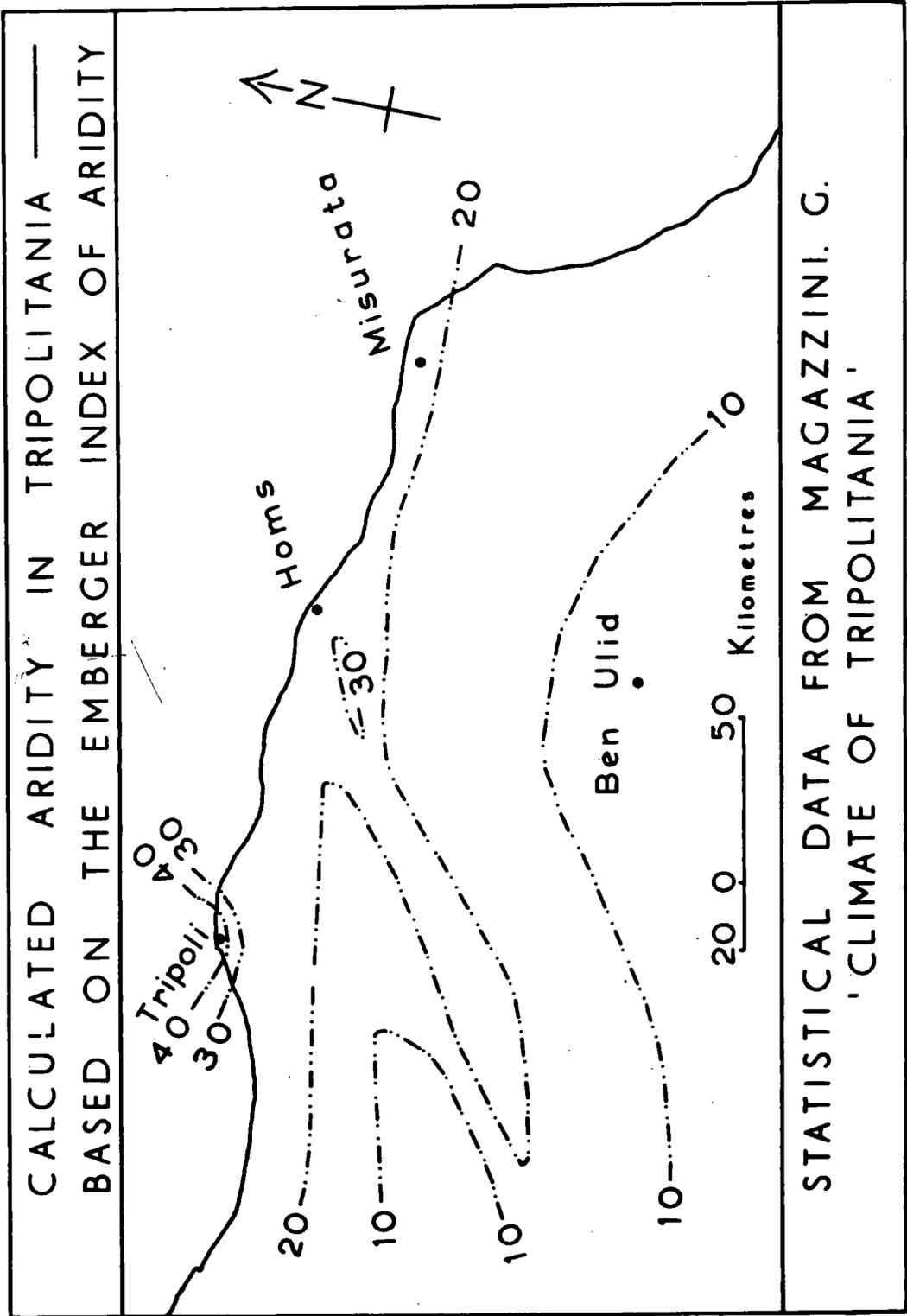


Figure 16

illustrated by the isopleth map Figure 16, using the Emberger formula. Values represented on the map from zero to twenty are indicative of pre-desert and desert conditions. In Misuratio, these values coincide roughly with the area south of the isohyet of 200 mms. Values from twenty to 45 represent arid conditions approximating to the zone of 200 mms. and above. From Figure 16, it may be observed that the greater part of Misuratio falls within the pre-desert as thus defined. Only the littoral belt comes within the less severe arid zone.

We have mentioned earlier in this chapter that the variability of rainfall is one of the major causative forces behind the aridity of the Tripolitanian environment. Nevertheless, it should be noted that the Emberger Aridity Index gives just weight to the variability of rainfall and also includes reference to variation in temperature extremes. Thus, the critical isopleth of 20 in Figure 16 conveys a sound impression of the change from the arid maritime to the pre-desert steppe in Misuratio.

(ix) Relative Humidity

As yet, adequate readings of relative humidity are not available. From those figures which are available, significant daily, seasonal and regional variations may be observed. The mean monthly values for a 23 year period show a tendency for the coastal stations to return a less marked seasonal variation compared with the steppe zone (Vide Figure 17 A). At Homs, the mean relative humidity ranges between 62 - 68%,

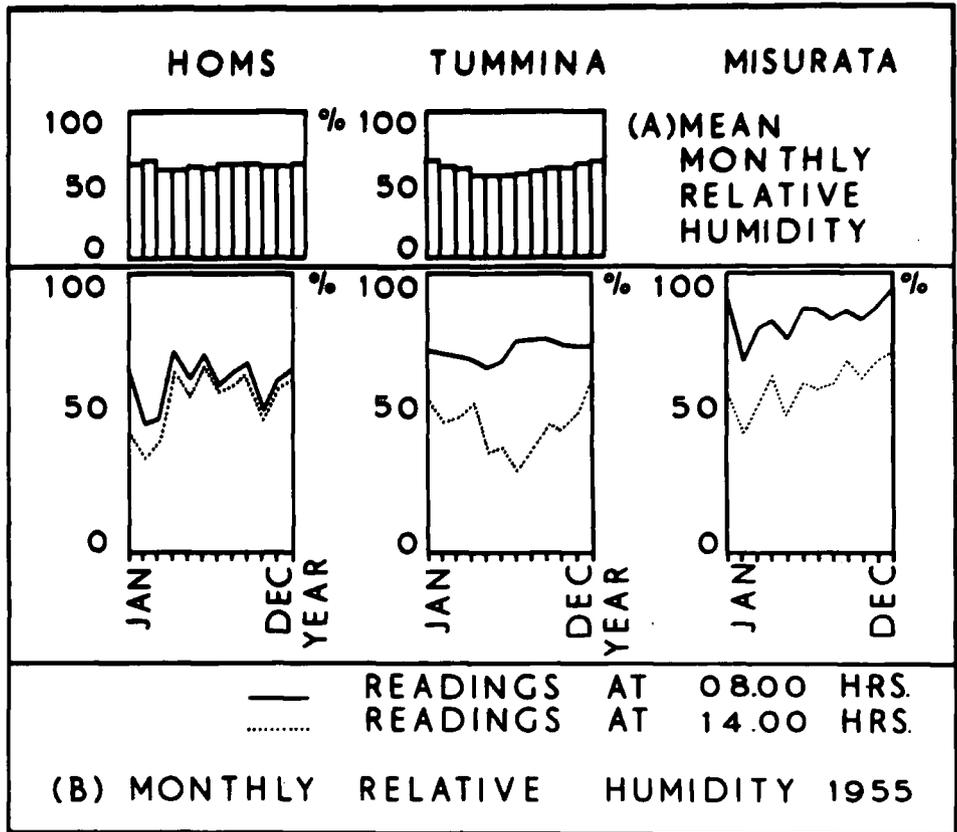


Figure 17

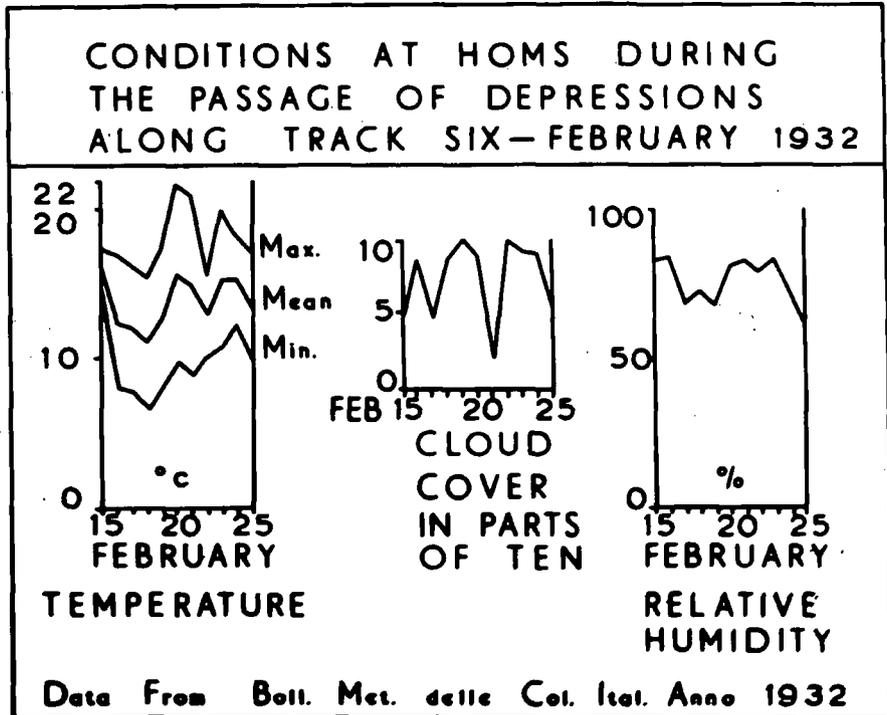


Figure 18

and at Tummina between 57 - 67%.. The higher mean values in both cases are returned for the winter months.

More detailed comparison of the stations is possible by means of Figure 17 B, which illustrates the recordings for 1955 for the hours of 0800 hours and 1400 hours. Tummina tends to show greater humidity during the night and less humidity during the day than Homs. This is partly a result of the more maritime situation of Homs, and the consequent less marked extremes of temperature.

Compared to most Mediterranean stations, the winter mean monthly relative humidity figures are low. Tunis, Bizerte and Benghazi all show higher winter relative humidity figures, averaging well above 80%. At Homs, the relative monthly mean is less than 65% for the winter months. The constant presence of hot, dry air has both beneficial and detrimental effects. On the one hand, the small and cramped villages are more healthy than those in the more humid reaches of the Maghreb. On the other hand, high evaporation rates continue unabated throughout the winter months. Low relative humidity in this period is probably to be accounted to the influence of the dry westerly winds blowing from the arid south of Tunisia.⁽¹⁾

Summer conditions present rather a different situation. The Maghreb, Malta and most of the northern Mediterranean coast have a low relative humidity in summer, with figures ranging in the lower sixties. As illustrated in Figure 13 A Homs and the littoral of Misuratine as a whole, tends to have a relative

humidity which ranges in the higher sixties. Hence the summer months, especially July and August, are most debilitating and inhospitable. Prolonged high summer humidity has a retarding effect upon the ripening of many fruits, particularly on the olive. Olive production from the Volpi Concession near Misurata is commercially negligible, mainly as a result of high relative humidity during the critical maturing months.

Related to this problem is the fact of violent variations in relative humidity with the onset of Ghibli winds. Magazzini has recorded falls of relative humidity from 80% to 10% in a matter of hours. The impact of these changes is of importance to the oasis agricultural society, but it will be left until later chapters to discuss the ecological and economic ramifications of these phenomena.

(x) The Incidence and Effects of Dew in Misuratino

The mean rainfall at Tummina is 175.5 mms., hence any small addition to soil or plant moisture is important. Although there are no data available to cover stations in Misuratino, it is likely from consideration of other arid territories that dew formation takes place at all seasons. The greatest frequency will probably be in late spring, summer and autumn. Mitchell commenting upon the incidence of dew fall in Malta, points out that 66% of the dew fall comes within the period April to September⁽³⁾. This seasonal rhythm is similar to that recorded by Duvdevani in the coastal reaches of Israel⁽⁴⁾. Since the 0800 hours reading of relative

humidity at Tummina in 1955 in many cases averaged over the 70% mark, it is conceivable that earlier readings would show an appreciable proportion of near dew-point readings. Dew deposits in Israel have been as great as some tenths of a millimetre. Hence, if the frequency of dew formation is as high as has been suggested here, the importance of the accumulated plant and soil moisture in Misuratino may be agriculturally significant.

Dew tends to be evaporated rapidly by the early morning sun. The capacity of soils, trees and plants to absorb dew varies greatly. Thus it is not known how efficient dew is as a source of moisture, bearing in mind the intense early morning evaporation. In the steppe zone, the Arabs use cairns to collect dew. Thus, there is some evidence of the quantity of dew which is made available to trees and plants in this zone.

Of final consideration is the influence of dew covering on plants which acts as a dampener on an immediate rise of temperature with sun-up. (4)

TABLE 12

NUMBER OF DAYS WITH FOG AND MIST IN DECADE 1924-1933.

STATION	J	F	M	A	M	J	J	A	S	O	N	D
HOMS	1	2	1	6	1	1	2	3	3	2	-	-
ZLITEN	1	1	2	-	-	-	4	1	-	-	1	-
MISURATA	1	2	7	1	6	6	15	2	4	7	10	10

Source: Boll. Met. della Col. It., 1924-33.

(xi) The Incidence of Fogs and Mists in Misuratio

Table 12 shows the number of days with fog and mist recorded in the decade 1924-33. All stations on the littoral show a high incidence of these phenomena in the late summer to early winter period. Misurata records the highest number of fogs and mists, with a maximum in July. The reason for this high proportion of mists at Misurata may probably be attributed to the fact that the town is open to the in-flow of sea breezes from both the north and the east. In fact, evening sea breezes are the cause of the greater part of the fogs and mists along the whole length of Misuratio. Fogs usually disperse with the rise of the sun.

(xii) The Incidence of Winds in Misuratio.

Consideration of wind force and direction is essential, since by its very nature, it acts as a formative influence upon the amount and form of precipitation. Misuratio is open to the influences of both the Sahara and the Mediterranean hence winds are highly variable in velocity and direction, depending upon the differing interaction of major and minor air masses. Certain over-all tendencies are discernable nevertheless.

The percentage of winds from the respective quarters of the compass for a five year period is shown by Figure 13 B. At Homs and Misurata Marina, north west winds prevail at most seasons. The north west winds of spring tend to be of greater frequency than in winter and also tend to be of greater velocity. Throughout the summer, north west winds are dominant, although they are less strong than in Spring. In

autumn again, the north-westerlies are important. South-east winds have greater prominence in autumn and are stronger than at other seasons.

From Figure 13 B, it is possible to observe the great frequency of winds of southern source. These southern winds, blowing from the arid hinterland are invariably dry, and often of Ghibli intensity. The high frequency of these winds from the south is a key factor in the aridity of Misuratio. As will be seen later in a consideration of fluctuating crop yields, in Section Three of this thesis, inopportune, protracted winds from the south are a perennial menace to farming.

Light local winds do not follow this major wind pattern. In the littoral zone, diurnal shifts of land and sea breezes are well marked. Field observations in 1958-59 showed that the winds did not penetrate far inland, and were of negligible importance in the steppe zone. Moreover, from observation in the same period, it appears that the land-to-sea drift of air predominates from the late morning to the early evening. At approximately 16.30 hours local time, a sudden reversal of direction brings a cooler sea-to-land breeze. Coastal temperatures are slightly moderated in the evening, and occasionally, evening mist is associated with this on-shore breeze.

Other types of local wind movement have been discussed previously in this chapter in respect to local thermal conditions (pp. 5-13).

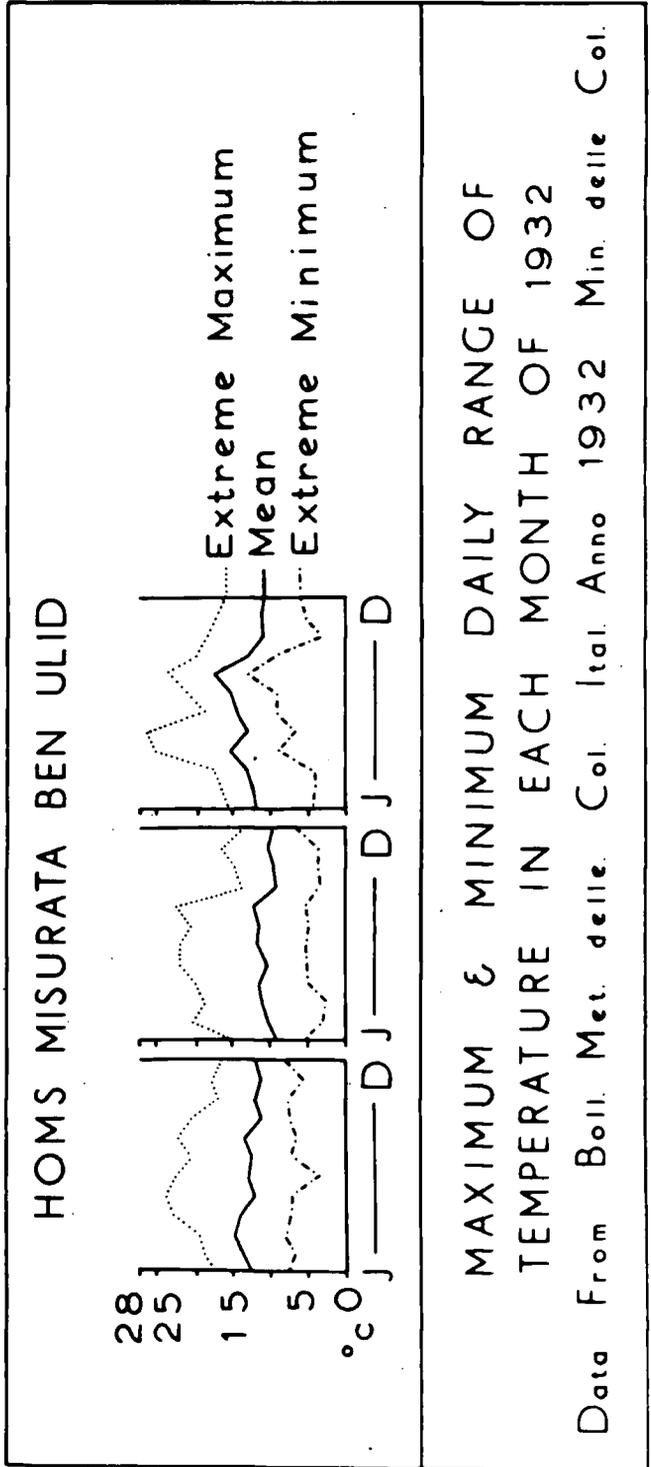


Figure 19

Of significance in Misuratio, is the frequency and duration of Ghibli winds. Detailed reference has been given earlier in this chapter to the effects on temperature and humidity occasioned by the onset of a Ghibli. European colonists in Libya tend to refer to all hot winds from the south as 'Ghibli' winds. In fact, the true Ghibli originates in the south-west. Milder winds from the south-east are less strong and less hot than the true Ghibli, and are associated with depressions passing through the northern Mediterranean.

The Ghibli wind itself is invariably a depression wind. During the spring months the Ghibli is associated with low pressure systems from the Atlantic which are moving more or less parallel to the North African coast. In late spring and summer it is thought likely that the Ghibli is the result of cyclonic conditions which have developed over the western Sahara⁽¹⁾.

The advent of a Ghibli is difficult to forecast, since it develops frequently when there are no obvious meteorological conditions discernable from synoptic charts. Ghibli conditions observed during the writer's tour of duty in 1958-59 showed the following characteristics. They were preceded by a slight lull in the prevailing wind, which lasted for fifteen minutes or more. The onset of the Ghibli was accomplished in a matter of minutes after the arrival of the first breaths of hot air. Wind force generally rose to force six or seven on the Beaufort Scale. Large quantities of sand dust were carried

into the air, reducing visibility to less than twenty yards.

On the average, the first hour was more stormy and hot. Thereafter, the violence of the wind was less intense, and the visibility improved somewhat. Nevertheless, temperatures remained high and visibility poor. The end of the Ghibli came as quickly as the beginning, with a sharp reversal of wind direction and an influx of cool air from the sea. Two Ghibli winds of the four which were observed ended in the evening at the time when the normal on-shore breeze began.

During the Ghibli, out-of-doors activity was impossible and all agricultural work came to an end. Work did not recommence until the wind had completely blown out. Europeans responded badly to the change in thermal conditions. Women especially suffered from the debilitating effects of the prolonged high temperatures and the dryness of the atmosphere.

(xiii) Climatic Influences - Summary.

From the discussion in this chapter, it is possible to discern the basic elements of the sub-tropical mesothermal climate in Misurata. This is especially true of the littoral. Strong influences of the macrothermal desert to the south impose a marked aridity upon this basic structure.

Precipitation is seasonal in incidence, highly variable in nature and small in quantity. The thermal regime tends to show Mediterranean characteristics in winter and Saharan characteristics in summer. Over-all, the area reflects the nature of the Mediterranean Basin as a climatic contact zone,

and the position of Misuratio in one sector of this zone.

Human approaches to the use of the environment are limited by the poor rainfall and the extreme temperature conditions. Even in the coastal region, much of the land is unsuitable for sedentary agriculture unless water is available for irrigation. Inland, in the steppe zone, climatic limitations have restricted agricultural activity to primitive shifting cultivation and stock rearing. Adverse climatic conditions have helped to produce an environment in which man is fighting a hard battle for survival and advancement.

In later chapters, other features of the arid environment and the human reactions to them will be studied further.

SECTION ONE

THE PATTERN OF HYDRO-AGRICULTURAL DEVELOPMENT

Chapter Two - The Balance of Water Supply in Misuratio in relation to the Forces of Economic Growth

- (a) Influences of Geomorphology and Geology.
 - (i) The Foot-Hill Region.
 - (ii) The Quaternary Cover in Misuratio - The Coastal Plain.
 - (iii) A Regional Examination of Quaternary Geology and Hydrological conditions prevailing in the Component Oases of Misuratio.
- (b) Soils of Misuratio.
- (c) Hydrology
 - (i) Resume of Characteristics of Precipitation.
 - (ii) Evaporation.
 - (iii) Surface Hydrology.
 - (iv) Ground-Water Hydrology in Misuratio.
 - (v) Artesian Water Resources in Misuratio.
- (d) Utilisation of Water for Agricultural Development.
 - (A) Indigenous Oasis Development.
 - (B) Exploitation of the Semi-artesian water table - Pumping by electric power at Concession La Valdagno.
 - (C) Exploitation of the Artesian Waters of Misuratio - Italian Development at Tummina.
 - (D) Modern Arab Development at Wadi Gaam.
 - (E) Some Observations upon Costs and Capital Investment in Irrigation Development.
- (e) Summary - Hydro-Agricultural Development.

Section 1 - The Pattern of Hydro-Agricultural Development.
Chapter II The Balance of Water Supply in Misuratino in
relation to Economic Growth.

In the previous chapter it has been shown that the key influence upon human activity in Misuratino is the dominant aridity of the environment arising from the character of precipitation affecting the region. Obviously, the question of precipitation poses only one aspect, even if the most significant, of the problems associated with human occupation of the area; further facets of the physical geography of Misuratino must be taken into account in order to arrive at an assessment of the balance of water supply. Particularly, we must evaluate the amalgam of influences present in the physical environment in terms of those factors which mitigate and those which augment aridity.

In the following pages, we shall examine point by point the quasi-constant features of the landscape in their effect upon water supply in the area; such discussion will also serve as a preface to later analysis of human economy and society in Misuratino. We shall suggest that pure elements such as geomorphology and soils are important in the present context, but that they are subordinate to the final result of water availability since indigenous and alien economies are dependent for existence upon access to permanent supplies of water for both domestic and irrigation requirements. Thus, after discussion of the physical background of Misuratino, we shall go on to examine the broader implications of these influences

as they effect the hydrology of the region.

Throughout this chapter we shall be concerned with the availability of water supply; more pertinently, we shall examine the pattern of exploitation applied by human society to those water resources. In particular we shall refer to the relationship between the varying types of water resources and the economic state of communities occupying Misuratio in the last 75-100 years. We shall demonstrate that there has been a changing appraisal of water supplies by indigenous and alien societies corresponding to the general trends in economic growth and technological advance discernable in the region. Hence, in the following examination of the balance of water supply in Misuratio we shall make consistent reference to the over-all pattern of hydro-agricultural development in the region in terms of economic growth.

(a) Influences of Geomorphology and Geology.

(i) The Foot-Hill Region.

Throughout Misuratio, the foot-hills of the Jebel and Msellata lie some five to six kilometres from the sea. The plain between the Jebel and the littoral belt of coastal dunes which fringe the area to the north is generally from four to five kilometres wide, but is cultivated only in a band some three to four kilometres wide.

This littoral - and at the same time piedmont plain - has been for a long time the most favourable area for sedentary agricultural development. Under nomadic and semi-nomadic occupation, cultivation in the plain was limited to dry-land

cereal culture and sporadic date palm culture. The factors influencing the growth of sedentary agriculture in the area have been the fertile nature of the tinu soils and the existence of ground water at a shallow depth. Even using the most primitive of techniques it was possible to penetrate the surface soils and provide permanent well access to the phreatic water table. Water from the numerous wadis rising in the Jebel spreads over this agricultural land in years of heavy rainfall and leaves a fertile coating of silt. Under certain conditions of slope and soil properties, the water action causes damage to land through scouring. ⁽⁵⁾ The beneficial silting effect is produced by the smaller wadis of the area which have a relatively long passage over the plain, such as the Hasnun and the Lebid wadis. In these cases, the floods rarely reach the sea, and there is no net loss of surface soils during the winter. In other wadis, where the course across the plain is short, scouring presents a major problem and loss of soil is thought to be substantial. ⁽⁶⁾ Wadi Gau-Gau, for example, with a large catchment area and a short passage across the plain, generally loses its flood water to the sea except for small quantities which seep into the wadi bed or into the natural flood zones situated along its course.

Ground water is plentiful in the littoral plain, being supplied mainly in the wet season by the waters of the Jebel, which seep seawards. In areas of natural flooding on the plain, large amounts of ground water seep into the surface to augment the waters of the Jebeline foot-hills, especially in respect to

the smaller wadis which do not reach the sea. As we shall suggest later, an increase in this effect might be brought about by diversion works on the larger wadis, with a view to leading the flood waters of these wadis to areas they cannot reach at present, but in which the soils are fertile enough to warrant agricultural development. The fact that the soils of the plain are highly permeable would lead to further advantage in the build-up of ground water supplies.

The Jebeline foot-hills form a distinct element of the littoral area of Misuratino. They took the form of a vast plateau of limestone and marl cut down, and deeply scoured by run-off and wadi erosion. The plateau surface presents an over-all summit level, made up of numerous mesas. Small outliers are to be found over large areas, especially in the wadi basins such as the Caam-Tarreglat system. Alongside the outliers are depressions which have been scoured out of the marly ground. The depressions or basins have in time been filled in by large quantities of sediment. In terms of nomadic agriculture they present fertile areas suited to shifting cereal cultivation, or alternatively, excellent grazing land. Most of the wadi basins are limited in area, being barely one to two kilometres in width and two to three kilometres in length before they open on to the littoral plain. The largest wadi basin in Misuratino is that of Wadi Caam. The lower basin of the Caam measures more than four kilometres at the widest point and is some eight to nine kilometres in length. At present it has a

flat surface, a slope of about 2% to the north and contains good agricultural finn soils. From the agricultural point of view, it is unfortunate that well developed dune formations occupy a large part of the basin's eastern sector, whereas in the slightly less fertile western sector, the surface relief is indistinct and stationary.

From the Italian 1:100,000 scale map, it appears that the alluvial deposit has reached a level of 28 metres in the downstream part and 33 metres in the up-stream part of the basin. The soil in this depression is very fertile according to reports of local cabila who crop in the area, but at present the cultivation of crops is disorganised and scattered, since, as a component area of the peripheral steppe zone, it is held under communal cabila tenure and is worked by shifting cultivation. The shortage of water in the area resulting from the depth of the water table has discouraged indigenous farm operators from utilising the land in a systematic manner. It is likely that in the present climate of economic growth in the area rational development would take place if the water problem were solved. At present, the most fully cultivated land is found at the foot of the rock slopes, where run-off can be tapped using long catchment channels leading to the cultivated plots.

The Romans carried out a considerable amount of land development in the wadi basins and Jebeline foot-hills. The great number of ruined farm houses in the wadi depressions, and particularly in the region of Wadi Gaam are evidence of the

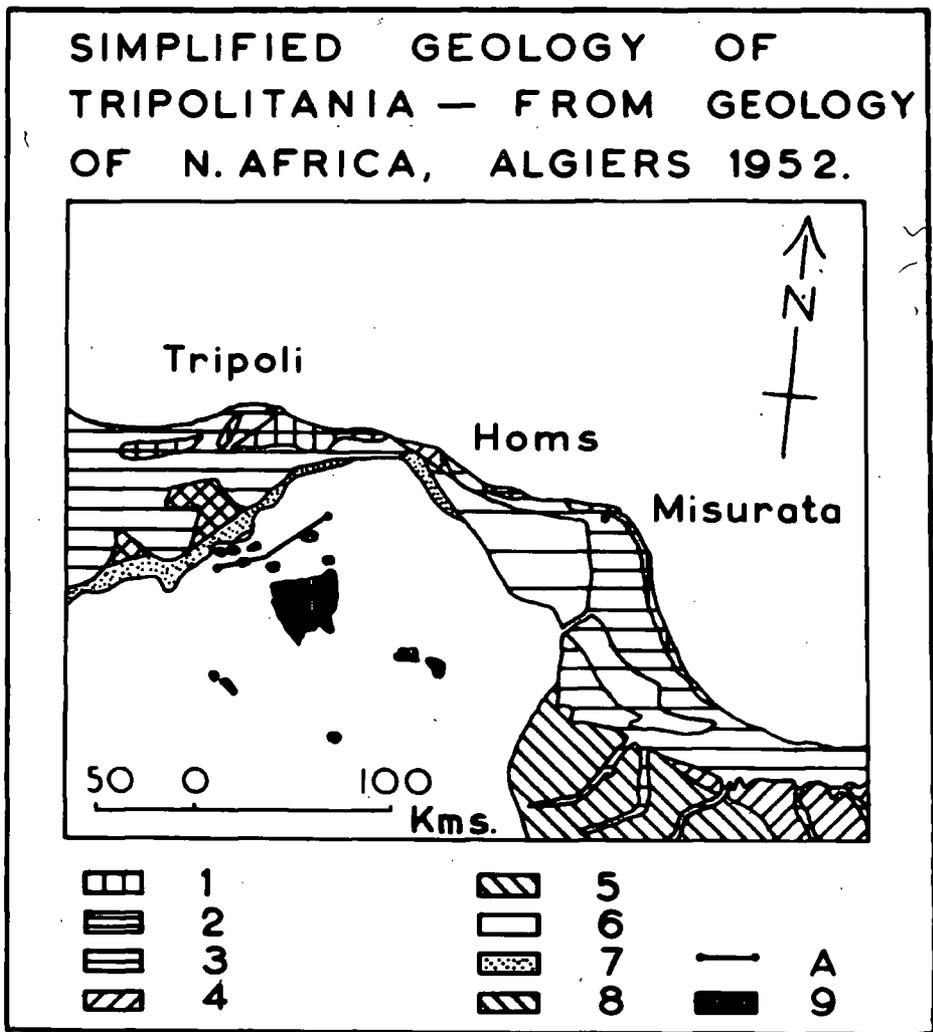
intensive work undertaken by the Romans. In the Caam-Tarreglat system, there are extensive remains of diversion works, which appear to have been reconstructed and used again during the Turkish regime. Further development, seen most intensively in the region of the Caam-Tarreglat, but which characterises much of the area of Misuratino is represented by the wells of some 25 metres depth, and large reservoirs or cisterns at the foot of the steeper rock slopes.

Hydro-agricultural developments on these same principles have a very good chance of success in the regions of the Jebeline foot-hills and wadi depressions. The agricultural future of the peripheral steppe is an unknown quantity, as we shall observe later in the thesis; it is, nonetheless, worthy of note, that the potential for development does exist in terms of water supply. In the Caam-Tarreglat basin, for example, it is estimated that 1500 - 2000 hectares of land is available for development. In the foot-hill zone above the littoral plain and the wadi basins the environment is not favourable to development activity. The zone is particularly arid and suffers from lack of water for most of the year. The altitude of the zone makes it exposed to the full force of Ghibli winds from the south, whilst the combination of high summer temperature and absence of water supplies render it suitable for nothing but the roughest of grazing. The formation of gullies and regressive erosion is very rapid during floods; gullies eight to ten metres in depth, with almost vertical walls are cut in the

alluvial parts of the area. Agricultural development in the wadi basins will have to be matched by equal concentration upon conservation in these upper zones. The extent of erosion is illustrated by the fact that limestone and marl areas are badly eroded and exposed over large areas.

Dune formations characterise both the littoral and the steppe peripheral areas of Misuratio. Along the coast, dunes fringe the entire littoral, with minor seas of sand being concentrated in the eastern region of Dafia towards Misurata. The extent of the littoral dune system is shown in Figures 53 & 54. Dunose areas and the adjacent inter-dunal palmeries offer particular problems of development, the former in respect to technical difficulties of fixation, which we shall examine later in this chapter (b), the latter in respect to their position in indigenous farming, which is discussed in Chapter V. Continental dune formations are to be found in the large wadi basins, particularly that of the Caam-Tarreglat, and in the extensive plain of deposition formed by the east-flowing wadis in the region bordering the Sabkha of Taorga. Mobile in nature, dunes are a constant menace to agriculture throughout Misuratio both in the oases and in the areas of Italian colonial settlement. All the steppe regions, and some portions of the littoral plain, exhibit a relief made up of small fixed dunes some two to three metres high. These small sand accumulations are generally quite fertile when levelled and irrigated; they offer no serious obstacle to development.

SIMPLIFIED GEOLOGY OF
TRIPOLITANIA — FROM GEOLOGY
OF N. AFRICA, ALGIERS 1952.



Key to Symbols

- | | | | |
|---|----------------------------|---|------------------------|
| 1 | Dune areas | 6 | U. Cretaceous |
| 2 | Middle & recent Quaternary | 7 | L. Cretaceous |
| 3 | Old Quaternary | 8 | Permo-Trias |
| 4 | Miocene | 9 | Tert. & Quat. volcanic |
| 5 | Eocene | A | Dyke |

Figure 20

Stratigraphy

The formations making up the area of Misuratio have been thought of as representing 'continental' or 'metamorphosed Pliocene' over-lying beds of the Upper Cretaceous Period, which are a well marked feature of the Msellata area and the Jebeline foot-hills (Vide Figure 20).

The Cretaceous beds outcrop in the hill areas, but are more important since they underlie the wadi basins and peripheral steppe areas of Misuratio. Their particularly calcareous nature (limestone containing large masses of compact limestone, marly limestone with phosphate layers, marl containing gypsum, pure crystalline limestone) is responsible for the large losses of water from the upper reaches of the wadis and their tributaries, and the karstic nature of the hill masses. In areas where marl overlies the limestone, there is much less seepage of water from the wadi basins. Throughout Misuratio, the importance of LUMASCHELLE, that is rock made up of shells held together by a thin marl cement is well marked (Vide Figure 21). These marly limestones rest on a large argillaceous sandstone formation at a great depth. This fact has been determined by engineers of C.O.T.H.A. during their work in Tripolitania in 1956-57⁽⁷⁾. During investigations in the region of the Gaam-Tarreglat Wadi system, sections were taken through a Roman well on the left bank of the Tarreglat some three to four kilometres from the coast (Vide Figure 26). From Data accumulated at

this time, it appears that the fossiliferous marly limestone beds are from 50-60 metres thick along the edges of the wadi basin (Vide Figure 21). They are yellow in colour and easily distinguished from the grey and white out-crop of the dolomitic rock which forms the upper layers of the outliers.

In their upper layers and interstratifications, the fossiliferous marly limestones exhibit a thick layer of resistant sandstone-like limestone containing fine shells (Vide Figure 27). It is in reality a slope formation which tends to be more developed in localised areas of the wadi basins. The shell limestones undoubtedly correspond to a period of coastal sedimentation. After a brief return to deeper sedimentation (LUMASCHELLE marly limestone) there followed a deposit of fine, compact limestones which were subsequently dolomatised. This dolomitic limestone forms the upper beds of the series in the foot-hill areas, being some 10-15 metres in depth. They form over-hanging ledges even on medium slopes and occasionally take on picturesque forms of erosion because of their resistant nature. They are deeply fissured and of cavernous structure so that they contrast with the underlying marly beds. Whereas the marls are perfectly water-tight, at certain depths a limited amount of karstic circulation occurs in the limestone formations during the wet season. This tends to accentuate the local problems of water storage in the area, since cistern storage tends to be located at the rock slopes where maximum run-off may be accumulated; in these same areas water losses through seepage

are at a maximum.

The geological fauna of the area, LAMELLIBRANCES, indicates that the area is Miocene in origin and is probably Helvetian in the particular zone of the Misuratio littoral. Thus, the area may no longer be regarded as 'Metamorphosed continental Miocene' as it was by Italian writers. Work by the oil companies in the region has been tending to discredit Italian findings; this is confirmed also by the work done in connection with the Wadi Gaam Settlement. The beds in the region of Wadi Gaam basin have proved much older than those forming the Miocene promontory of Msellata. The sediment in the basin of the wadi is gravel, sand, layers of compact clay, linn and layers of conglomerate crust (Vide Figures 21 & 27). These recent sediments, whose thickness is not fixed with certainty as yet, present several serious problems to development in the area. They could give rise to intense losses of irrigation water both from storage basins and reticulation channels. The conglomerate crust is a formation which occurs particularly in the peripheral steppe areas of Misuratio (Vide Figure 27). The formation consists of calcium salts and sulphates, rising by capillary action and being fixed in the upper layers of soil when carbon dioxide leaves them. This formation is also present in the slopes of the eroded surfaces. In this case it is formed in a similar way to 'travertine' and includes many pieces of stone from the upper beds (conglomerate crust). In the wadi beds,

especially in the foot-hill reaches, the crust has been much eroded by the sediment carried by flood waters and has collapsed due to under-pressure and piping. In many of the wadi basin areas of western Misuratio the finn is often covered by newly deposited sediment which is either aeolian or caused by old Roman and Turkish dams in flood conditions. (6)

The area of Misuratio exhibits a tabular structure but there is a slight gradient of $5-6^{\circ}$ NNW. The dip of the out-cropping rocks is the same as the general topographic slope east towards the Sirtican Embayment; the upper beds of the Caam series therefore form a structural surface rather than a tectonic one (Vide Figure 20).

(11) The Quaternary Cover in Misuratio - the Coastal Plain.

Much work remains to be done on the problem of Quaternary geology of Tripolitania. In Misuratio geological survey has been totally lacking and the following description of geological conditions is presented to give only a basic sketch of conditions in the area in lieu of any authoritative statement by geologists. The writer acknowledges his debt in this respect to the work completed by early Italian scientific missions to Tripolitania, and in particular to the findings of the Ministero Della Colonia Italiana.

A broad, but working, classification of Quaternary cover in Misuratio was offered by the Italian Scientific Mission during the early period of occupation. (8) The classification ran as follows:-

- i. Aeolian deposits (Lower).
- ii. Reddish sand rich in 'Helix'.
- iii. Upper sandy deposit.
- iv. Marine Deposits.
- v. Littoral dunes.
- vi. Sebkha.

The location and description of these areas may be summarised in the following way:-

(i) Brownish-yellow colour, with a fine grained texture. Found extensively along the extreme littoral of Misuratio, it is uniform over great distances. The uniform type of grain and its resistance to erosion make this an excellent building stone.

(ii) Red sands with 'Helix'. Fine grained formation without any stratification. This strata carries some of the most fertile soils of the coastal plain from Homs Oasis to Misurata Oasis, and is also thought to form the sub-soil of the sebkha regions. The layer is usually found in a single stratum, although the thickness varies from area to area. In some localities, the stratum is intermixed with sandy loess. Along the littoral, the loess red sand mixture forms areas of great homogeneity, where the sands have a fine grain of less than half a millimetre and are essentially quartzose in nature. The quartzose grains account always for more than 50%, and sometimes for more than 90% of the formation. The residue content is made up of mineral calcareous elements and varied silicas amongst sodium calcite, alkaline felspar and heavy minerals. Especially in the lower regions of loess/sand deposits, there are many irregular grains of loess cemented with local sands

through the percolation of water, which carries bicarbonate and calcium into the body of the mass. The permeability of the upper sands and the relative impermeability of the under-rock is a factor causing the formation of perched aquifers. The location of the coastal oases in Misurata is influenced in some part by the presence of these two features of Quaternary geology. Where the under-rock is permeable, as in the case of the limestone areas surrounding the foot-hills, or the limestone areas covering large areas of the littoral east of Zliten Oasis, the phreatic water table is discontinuous or totally absent, and palm oasis cultivation is thus precluded; in certain circumstances local perched water tables occur in areas of calcrete formation.

The layers of whitish sand within the Red Sand formations are known as hard pan (calcrete). Its depth varies greatly from area to area from about a centimetre to one metre. The hard pan layer results from the bicarbonate and calcium elements being leached from the loess into the local sands. The hard pan is frequently quarried for use as building stone in the construction of houses and cisterns. In some of the zones of the Sahel El-Ahamed, in Zliten and Misurata, the hard pan layer has to be perforated before palm cultivation is possible. In the Misurata region, around Zliten and in Homs Oasis, the pan layer appears to be inclined upwards towards the sea at angle of 10-20 degrees. This permits infiltration of sea water into the phreatic aquifer and accounts for the brackishness of well water along this reach of the coast. Infiltration presents

special problems of land management in Misurata Oases, where the highly developed character of the hard pan layer and the tilt north of the formation has led to prolonged and heavy infiltration of sea water into the phreatic water table. In Homs, there is an inclination of several degrees to the east, and in Zliten a slight tilt of the hard pan level to the west is reinforced by a counter-poise to the north. The worst effects of infiltration in both these passes are thus precluded.

(iii) Upper sand deposits exhibit an irregular stratification, comprised mainly of marine elements. This ground rock forms small hills and hillocks of varying altitude from 10-20 to 40-50 metres, the higher formations being well developed to the west of Concession Volpi. Since they are elevated above the general level of the coastal plain, these hills are frequently used by the Arabs for graveyards and forts, as in the case of those at Homs and Zliten. A further function of these areas is in the protection that they afford the surrounding lands from the worst influences of the sea winds and penetration of the mobile coastal dunes. Especially in areas close to the sea, the formations are deeply eroded by wind action.

(iv) Marine deposits are of small importance in the area of Misurata being limited to the areas around Misurata Marina.

(v) The sand dune formations of the coast are formed during prolonged periods of drought on or close to the beaches. Within the same area both marine and continental dunes are formed almost under the same conditions. Nonetheless, they illustrate

different characteristics. In the region of Leptis Magna and east of Darnia, marine dunes and continental dunes are inter-mixed. In these tracts, the dunes are parallel with the effect of the prevailing winds. Ramlet or minor sand seas exist in both areas of intermixture, reaching maximum development east of Darnia, where they are invading agricultural areas around Nabina and the west part of Misurata Oasis on a front of some 15 kilometres.

The dunes are made up of calcareous sands with relatively large grains; 80% of the grains are above half a centimetre. The dunes appear to be affected primarily by the north-west winds, and in the Leptis Magna area lie at North 35° West. The velocity of invasion by dunes varies with the size of the dune sea and the exposure of the coast to sea winds. In the Misurata region, the annual loss to dune encroachment is estimated at 15,000 square metres. In the inter-dunal basins the loss runs at 30,000 square metres, or three hectares per annum.

The inter-dunal palmeries of Misurata (Vide Figures 53 & 54) are floored by a terra rossa sub-stratum. The oasis basins are small, situated chiefly in the Misurata Oasis and exhibit all the characteristics of small oases. The existence of the inter-dunal palmeries testifies to the relatively small movement of the dune masses, and must also be regarded as a factor of some importance in holding back the advance of the dunes. As we shall point out in a later chapter (Chapter V), economic growth within oasis society is tending to bring about a

rationalisation of land values, with a consequent abandonment of the areas of interdunal palmeries. The retarding effect afforded by these cultivated areas against dune encroachment might be lost in the next decade.

(vi) Sebkha areas present particular problems of analysis and are dealt with under the section (b) Soils.

(iii) (a) A Regional Examination of Quaternary Geology and Hydrological Conditions prevailing in the Oases of Misurata.

MISURATA OASIS

The village of Misurata is situated in low lying country; the centre of the settlement is only six to seven metres above sea-level. The minimum distance of the town from the sea is about four kilometres; nevertheless, the great mass of dunes on the littoral flanks force the flow of underground water from the village to drain towards the Sebkha of Taorga, which is two metres below the level of Misurata. This topographical freak means that the sub-soil of the oasis takes on many characteristics of the sebkha itself. The subterranean aquifer at Misurata also comes into contact with that of the sebkha and is therefore somewhat salty. This is especially noticeable when the rains are good and the inter-flow between the two basins is at a great velocity. Some small fragmented basins resting on the hard pan layer at a depth of thirteen to sixteen metres in those areas where undulations in the hard pan surface are favourable, provide a limited amount of sweet water after prolonged rains; in the interdunal palmeries this effect is optimum. To the west of

Misurata Oasis, the flow of water in the phreatic water table is less saline but throughout the area there are always traces of salt in water drawn from wells.

DAFNIA

The area of Dafnia in local Arab terminology is the general coastal zone between the western extremity of Misurata Oasis and the eastern extremity of Zliten Oasis. (In European terms, Dafnia normally carries the implication of the ex-Italian Demographic Settlement of Garibaldi; in the present text, it is the Arab area which is discussed). Physically, the region is very undulating in character, with the pattern of undulations parallel with the trend of the coast. In the tract towards the east the undulations are more marked and made up of the Upper Sand Deposits (iii). The rest of the area is underlain with a uniform sand with a hard pan formation evident at shallow depth. The wells of the area are frequently at a depth of 17 to 38 metres, serving primarily for domestic use under communal ownership as part of the semi-nomadic economy which prevails in the area. Small gardens are to be found at the foot of the dunes to the north, but they are of little significance. Numerous Roman remains of farmhouses and olive presses indicate the erstwhile importance of the area.

ZLITEN OASIS

The hydrological conditions prevailing in the oasis are influenced by two primary factors. A large area of the land enclosed between the dunes of the coast and the Jebeline foot-

hills has no water outlet to the sea and exhibits all the attributes of sebkha, introspective drainage. The underground water in this zone is saline and its value for agricultural use is restricted to domestic and livestock purposes. In the areas north of the main coastal road, and in the west of the oasis towards Suk El-Giuna groundwater drainage is able to escape through the down-tilt of the pan layer to the Caam Basin. In this secondary zone, the Red Sand layer has marked undulations present in the hard pan, which have allowed development of small perched water tables. These water tables are the basis of cultivation in the richer sections of the oasis.

OASIS OF THE SAHEL EL-AHAMED

The oasis is situated between the limestone foot-hills and the coast. To the east in the region of the Wadi Hasnun the line of hills comes close to the coast. Most of the wadis drain to the sea, and the general alignment of the area towards Wadi Caam ensures that saline accumulations are localised and insignificant in respect to agricultural development. The wells are shallow, of some seven to twelve metres in depth and provide sweet water.

OASIS OF HOMS

The coastal plain of Misuratino reaches its narrowest extension in the vicinity of Homs. The hard pan surface of the oasis is fragmented; to the west, the inclination of the hard pan layer tends to be up towards the north with consequent salt-water penetration into the phreatic layer. In the Leptis

agricultural area of Homs Oasis the tilt of the hard pan surface is less aligned to the north and the dune formations along the coast offer some protection from sea water infiltration. It seems likely from experience gained during borings of artesian wells at the Italian farm of La Valdagno south-east of Homs, that there is a second aquifer at a depth of 30 metres. As yet Arab farm operators have not exploited this deeper water table.

Influences of Geomorphology and Geology upon Hydro-Agricultural Development - A Summary.

(i) Features of Geology and Geomorphology in Misuratio have a great influence upon hydro-agricultural development. In many cases, these influences add to the problems inherent in the climatic situation of the area.

(ii) The porous nature of the limestones which make up the greater part of the foot-hill areas is useful in respect to artesian water supplies as Italian pioneer development has shown.

(iii) On the other hand, the losses of surface water supplies, and the exposure of large areas of karst-like out-crops has materially contributed to the poor development of indigenous agriculture in the wadi basins and peripheral steppe areas of Misuratio. As a preface to discussion of economic activity in the area later in this thesis, it should be mentioned that the artesian resources of Misuratio will be an immense asset as capital and technical knowledge rise to advanced levels in Arab society.

(iv) Quaternary geological formations are the paramount influence upon hydro-agricultural conditions on the coastal plain. The presence of dunese areas, sebkha and hard pan zones each have their attendant problems for local agriculture, and over large areas preclude economic, rational agricultural exploitation. As indigenous economic life moves into the sphere of commercial farming, it may be expected that the areas of sebkha, dunes and sea water penetration will be abandoned.

(v) Of the component oases of Misuratiné, only the Sabel El-Ahamed may be classified as consistently fertile throughout its extent, uninfluenced by the problems associated with features of Quaternary geological formation.

(b) Soils in Misuratiné.

Earlier discussion of climatic influences in Misuratiné will have indicated clearly that the inter-related topics of rainfall and aridity are the dominant environmental factors in respect to agricultural development in the area. The distribution of soil types throughout Misuratiné is a localised and generally less significant environmental influence upon cropping activities than that of climate. Nonetheless, land appraisal at a varietal level is governed to a large extent by local conditions of soil fertility. In the succeeding paragraphs we shall examine the nature of soil types present in Misuratiné and their distribution in relation to agricultural development.

Hill⁽⁹⁾ has suggested a provisional classification of soils in the Jefara which has been closely followed by Willmot in his studies of soils of Tripolitania.⁽¹⁰⁾ The classification is

tentatively drawn up as follows:-

- (i) Coastal and inland dunes and sandy areas. These may be looked upon as azonal regosols; horizon formation is immature being composed of dunose or skeletal material.
- (ii) Alluvial soils of the peripheral steppe. Usually exploited for shifting cultivation under a semi-nomadic economy.
- (iii) 'Intermediate type' of soils which are partly aeolian and partly alluvial in origin. (10) Continental and marine sands are inter-mixed with weathered material derived from the Jebeline foot-hills, including a large proportion of limestone and marls in Mksuratino. It is suggested that these soils may be classified as Pedocalic zonal.
- (iv) 'Creute' or cemented soils, in which prolonged calcification has taken place through capillary up-movement of calcium carbonate caused by the prevailing arid conditions. Hill offers a systematic description of hard pan and its incidence in the Jefara; he points out, nevertheless, that both regional and chemical examination of the problem are necessary before any comprehensive conclusions may be drawn. The incidence of wadi bed hard pan in the Wadi Gsam area and in the sand areas of the coastal plain has been mentioned at greater length in part (a) of this chapter.
- (v) Saline soils and salt marsh areas (Sebkha). These are

sand soils of category (1) these soils are azonal.

(viii) Cultivated soils of the coastal plain are classified by Willimot as brown pedocalic regosols. Their general characteristics may be summarised as follows: they are friable and permeable; immature profile development is general and pH values are greater than 8. (10) In fact, these soils include categories 1, 2 and 3 but have been modified by cultivation and, in some areas, by prolonged irrigation. Willimot suggests that 'Although, with sound irrigation techniques the availability of plant nutrients soon becomes limiting, in general, moisture is the controlling factor for crop production'. (10)

The broad scheme of classification of soils in Tripolitania demonstrates the complexity of the situation, but makes it possible for us to visualise the range of conditions and soil types which constitute the agricultural lands of the region. It will be of value at this juncture to bring this general statement into local focus with particular reference to Misuratio. In the first case we shall describe and discuss the characteristics and properties of soils in the region of the coastal oases; in the second case examination will be undertaken of soils at stations within the peripheral and inner steppe margins.

The most important piece of soils research available in Misuratio is that prepared by the American development agency (United States Overseas Mission) in the early 1950's as a prelude to the foundation of the Wadi Gaam Reclamation and Settlement

WADI CAAM SETTLEMENT—TEXTURAL
CLASSIFICATION OF SOILS—FROM GIBBS

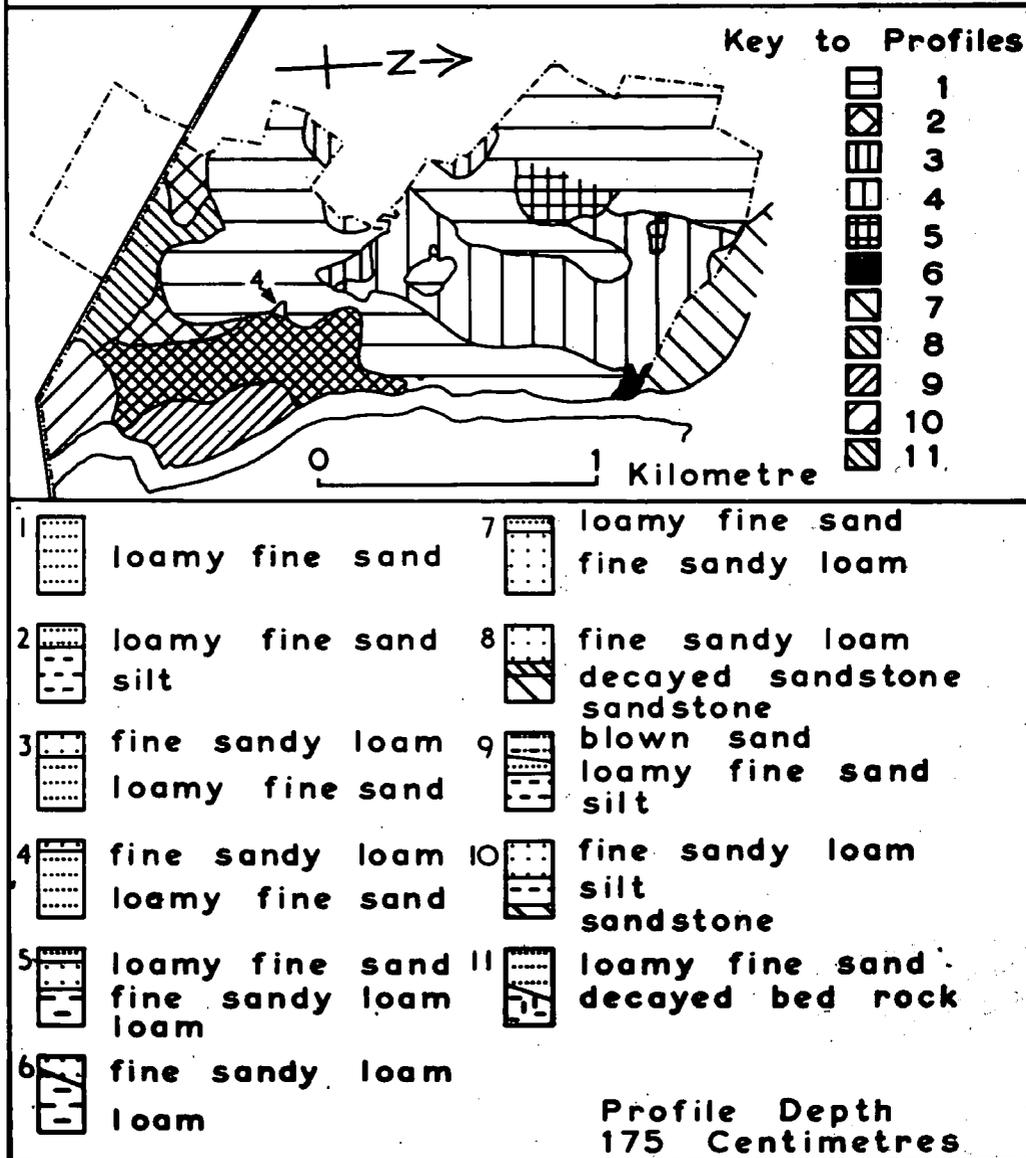
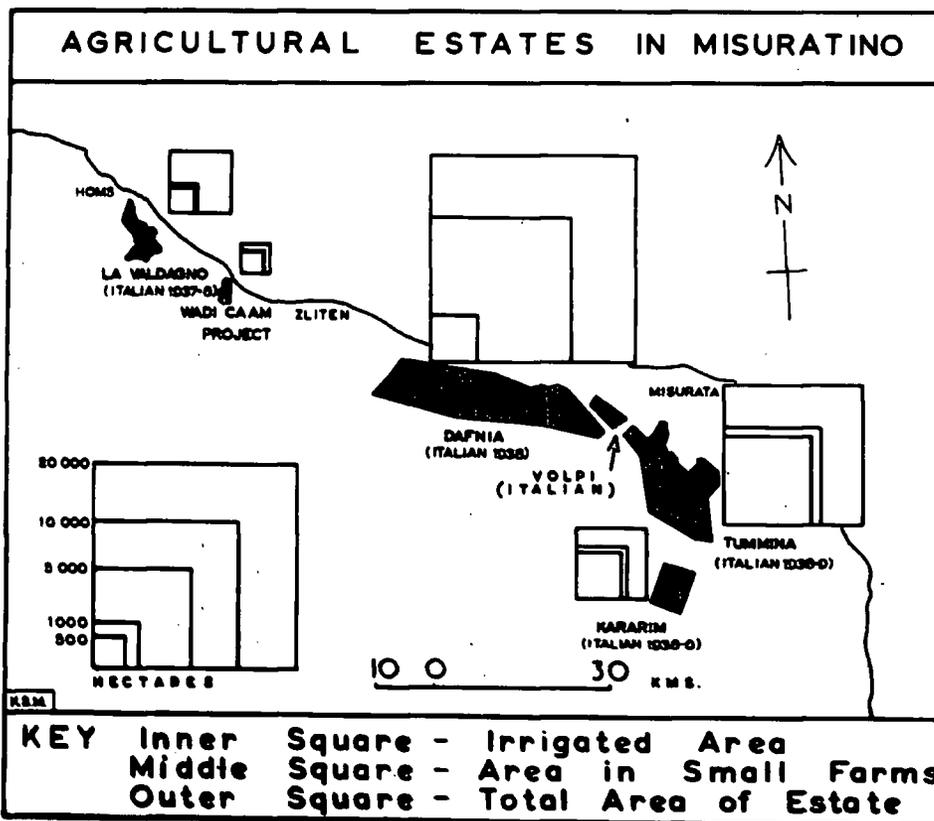
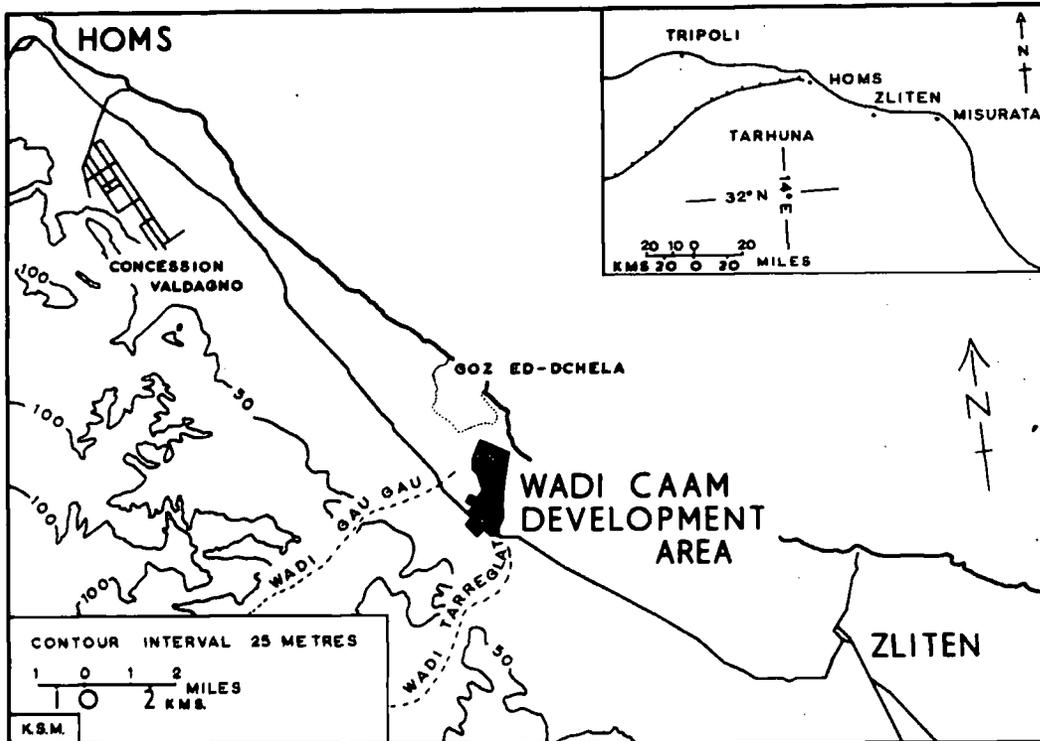


Figure 22

Project. The survey at the site of the Wadi Gaam Settlement was conducted by George Gibbs, a soils specialist attached to U.S.O.M., and it is to him that I am indebted for the soil distribution map (Figure 22) and the diagramatic profiles (Figure 22). Wadi Gaam Settlement is situated in the detached littoral plain of Misuratah some 141 kilometres east of Tripoli. It is sited between the mouths of the Wadi Gau-Gau and Wadi Gaam at the eastern extremity of the Sahel El-Ahamed (Vide Figure 23).

Climatically, the region of the Gaam-Zliten littoral lies in the coastal maritime zone of the Fantoli classification (Vide Chap. I). Precipitation for the years 1930-40 averaged 232.6 metres per annum, with the critical rains distributed from October to March. High summer temperatures are ameliorated to some extent by proximity to the sea, and apart from the ephemeral Ghibli winds, the relative humidity remains high throughout the year. These climatic conditions pertain along much of the coast lands of Tripolitania in the area of the brown pedocalic regosol soils.

The Wadi Gaam Development area presented an aspect of rough camel scrub with small fixed sand accumulation scattered over a generally undulating terrain, which was given over to grazing and occasional patch cultivation of cereals. As a preliminary step towards the establishment of the agricultural estate, the area was levelled; in the greater part only incompletely, but in the land adjacent to the Wadi Gaam heavy levelling was necessary. In scattered areas near to the wadi



Above Figure 23

Below Figure 24

the levelling required fills and cuts of 30 centimetres.

The soils of the Wadi Caam Development area have a good texture with the exception of small pockets in the region of the Wadi Caam and Wadi Gau-Gau. Most of the estate has soil textures which are of the fine sandy loam and loamy fine sand categories. These textures may be expected to respond very favourably to good land management under well adapted crop production. The distribution map (Figure 22) illustrates the lie of the different soil texture areas. Where levelling has been heavy, large areas of clay have been exposed, which are saline in nature and have many of the characteristics of bentonite. Moisture enters the clays slowly and leaves or drains from it only gradually. Thus the inherent salinity of these areas presented immediate problems of reclamation since controlled leaching of the salts in the soil would not be possible; long term problems arising from the saline and impermeable nature of the clay soils arose in respect to drainage of irrigation water. In the extreme northern portion of the estate, is an area of land which is underlain by what appears to be silt. Close examination shows it to be loamy fine sand with a high salt content (Figure 22 Area and Profile 7). The silty feeling is probably due to the saline elements maintaining a high water content in the soil and to the presence of a large organic content. The organic matter appears to be preserved by the salts. Towards the region of the Wadi Gau-Gau, there are several stratified layers of sand, fine sand and silt which have been deposited by the wadi

in times of flood (Area 1 in the N.W. of the estate). Flooding and silting of this area has continued since the inauguration of the agricultural settlement and may be expected to continue for some time as the Wadi Gau-Gau meanders across its flood plain. Some of the deposition in the area has good texture and a fertile soil, but much of it is eroded bed rock and sub-soil from the higher land of the Jebeline foot-hills, which is rather poor and infertile unless supplemented with large quantities of organic and chemical fertiliser.

A brief study was made of the Wadi Gau-Gau to determine its present stage of evolution and the possible course of development in regard to deposition and erosion in the area. This examination illustrated the nature of the influence of the youthful wadi systems upon the soils of Misuretino, particularly in those areas west of Zliten 'Gol', where the foot-hills lie at a distance of less than five kilometres from the coast.

In the upper catchment basin of the Wadi Gau-Gau, much of the upland has been stripped of vegetation, on the one hand by prolonged over-grazing of the annual and perennial pasture, and, on the other hand, by recent destruction of the esparto fields by indiscriminate human activity. The presence of steep wadi banks and the absence of gravel and sand bars in the lower reaches of the river indicate that the wadi has cut down rapidly in the past few years, probably since the decline of the esparto fields. Flooding of the wadi has caused erosion of several deep channels in the flood plain, and has also resulted in the

building up of large alluvial fans at the point where the wadi emerges on to the plain. These conditions obviously imply that agricultural lands developed in the vicinity of the Wadi Gan-Gau will suffer from the effects of temporary flooding and deposition, and that any crops grown in the extreme north west of the estate will be destroyed at these times. (Further examination of wadi regimes in Misurata is given in (6).

It may be expected that the supply of water to and the pressure of water in the phreatic water table will decline in proportion to the accelerated rate of run-off in the area. Maintenance of the pressure of the phreatic water table in the area, together with a more or less level orientation of the under-lying hard pan layer, has prevented penetration of sea water into the water table up to the present day. A reduction in the pressure of the water table will enable penetration by sea water and bring a corresponding risk of salinity to the soils of the estate. The salt area in the northern portion of the estate may be expected to expand steadily unless an organised plan of drainage and leaching is provided for. Experience of Arab farmers using gali irrigation in Misurata Oasis and in parts of Zliten Oasis indicates that accumulating saline elements in the soil can render large areas infertile for agriculture. To secure the future of the irrigation project at Wadi Caem Settlement, and similarly, to protect the established areas of oasis land, re-establishment of the vegetation in the upper catchment of the wadi systems is necessary. Experts of

COTHA⁽⁷⁾, the Forestry Department⁽¹²⁾ and Gibbs⁽⁶⁾ have pointed out that the cost of establishing mechanical means for controlling flood waters will probably equal the cost of systematic re-establishment of the vegetation in the wadi catchment areas in the foot-hills. Furthermore, without the re-establishment of vegetation on the watersheds, destructive forces of erosion and penetration of the water table by sea water may be expected to continue indefinitely. Re-establishment of the vegetation in the drainage area would be a means of reducing the menace of flood to the irrigated areas of Misuratio, and in the case of the Wadi Gau-Gau to the Wadi Gaam Settlement; in addition, it would prove of value in itself since afforestation could be made to pay dividends within a foreseeable future (Vide Land Use, Chap. 5) Valdagno - a case study of forestry development).

At the present time the soils of the Wadi Gaam Settlement will be discussed in terms of their character in relation to problems of agricultural use. Reference to their chemical and mechanical composition is suggested by examples from the work done by Dr. S.G. Willmot in the Jefara region of Tripolitania. (10)

Gibbs' Map of the soils at the Wadi Gaam Settlement area is reproduced as Figure 22 - where the distribution of soil texture areas is delineated. (5) Many variations in texture are apparent within each of the categories suggested in Figure 22, since levelling has affected some areas of the terrain, and obviously the origin of the soil itself is profoundly

important. Past utilisation of the land for intensive grazing and patch cultivation may also be accepted as a possible cause of variations in soil texture. Variations resulting from levelling are not usually extensive and do not affect the 'sample' nature of the soils at the estate for more general reference to Misuratio. Most of the soils within the Wadi Gasm Development area have been transported by wind or water erosion, or both, and this process is still active. At frequent intervals over the area there are stratified layers of textures and materials which appear to hold no relation to the surrounding soils. They have the character of small lenses of silt, gravel, clay and fine sand; their distribution is not extensive and their incidence shows no apparent uniformity of depth or thickness. Towards the Wadi Gau-Gau, stratification is more prominent to a depth of a metre and a half. In the region of the Gau-Gau, there is a certain homogeneity in the lenses, which obviates the necessity of delineating stratified areas. Past utilisation of the area is illustrated by the incidence of straight lines traversing the area. It is likely that sometime previously, the peoples utilizing the area have built walls, or perhaps roadways with clay, and as the structures were neglected they fell into decay and now influence small areas of some delineated textures.

In order to supplement the data contained in Figure 22, we shall examine each of the areas delimited in relation to agricultural development:

(1) Loamy fine sand throughout.

This textural category represents the greatest portion of the Wadi Caam Development area. The soil texture is loamy fine sand throughout. Both surface and internal drainage is good and offers no problems for irrigated agriculture. Experience at the Wadi Caam Settlement has shown that soils of this kind improve with good land management and particularly with the ploughing-in of green manure. This practice improves the moisture holding capacity of the soil as well as the structure and tilth. Within the traditional lands of the oasis, heavy irrigation of these soils tends to be combined with a disregard of manuring, hence they become leached and infertile as plant nutrients are flushed to lower horizons.

(2) Loamy fine sand over silt at 50 centimetres.

The moisture holding quality of this type of soil is good, as the underlying silt restricts the normal excessively free drainage which characterises the loamy fine sands. Both within the confines of the Wadi Caam Settlement and the oasis lands, this category of soil occurs over small areas, although the incidence of it is high throughout the Sahel El-Ahamed, particularly in proximity to the wadi beds which traverse the area.

(3) A relatively deep layer (50 cms.) of fine sand loam or loam over loamy fine sand.

Again, this type of soil texture is present in relatively small quantities. Experience on the estate has shown that it is an area which is exceptionally well adapted to the production

of shallow rooted vegetables. The moisture holding capacity of the top-soil is good and has been improved further on Wadi Gaam Settlement by the use of heavy applications of organic matter. The sub-soil under-lying the area is leached extensively.

- (4) A relatively shallow layer (25 cms.) of fine sandy loam over loamy fine sand.

The depth of the fine sandy loam or loam varies considerably over the area; in the oasis area this soil texture category may exhibit a top-soil covering of only 10-15 centimetres. The variability of the depth of the top-soil is important since it generally precludes specialised land utilisation which was possible in category (3). The advantage of this type of soil over lighter textured soils is that the heavier texture reduces losses of water during reticulation, and permits longer lines of water distribution.

- (5) Loamy fine sand to 25 centimetres over fine sandy loam to 75 centimetres, over loam extending to a metre and a half or more.

Category (5) is represented within the boundary of the estate by two small areas (Vide Figure 22); in the oases, and particularly in the Sahel El-Ahamed, there are large, but discontinuous regions which have a soil covering of this texture. The moisture holding capacity of the soil increases with depth and it is excellently suited to the production of deep rooted crops. The immediate top-soil is heavily leached, hence large quantities of organic matter are necessary under a system of intensive cropping. In the oases, only few farmers practice

green manure techniques, hence many of the subsistence farm operators face steadily declining returns. The future of those areas which are extensively covered with this category of top-soil should be promising, since operators on the Wadi Gasm Settlement have produced consistently good cropping results by careful land management and control of irrigation.

- (6) Fine sandy loam over silt at varying depths. The silt appears to be a marine soil with a high content of gypsum and shells.

This soil texture is essentially confined to those areas where a wadi finds access to the sea, and where dune formations are near at hand. The depth of the fine sandy loam depends upon the proximity of and the incidence of dunes, which are not marine dunes proper but small sand accumulations in camel scrub steppe-land. Under normal economic conditions which pertain in the oases, lands of this type are not utilised for cropping; at best they may be planted with scattered date palms; usually they are left as rough grazing areas. Gibbs suggested that several years of green manure crops would render category (6) available for inclusion within the agricultural framework of the estate. It is now apparent that the influence of the sea winds, penetration of sea water into the phreatic water table and the saline nature of the soil makes the area unfit for field cropping. (5)

- (7) Loamy fine sand or fine sandy loam to 30 centimetres, over fine sandy loam with a high salt and gypsum content.

The surface soil of the area demarcated in Figure 22 is influenced by floods from the Wadi Gau-Gau. At present it

appears that the accumulation of silt will continue with the result that the underlying saline layers will be covered to a considerable depth. Outside the Wadi Gaam Development area there are extensive zones with soils of this texture lying in those regions where internal drainage prevails, especially in Zliten and Misurata Oases. In all areas soils of this texture are associated with a water table which is made saline by steady infiltration of sea water.

There has been no attempt to develop the area for agriculture at the Wadi Gaam Settlement, and the future of area (7) remains in the balance. Under oasis agriculture, areas such as this are utilised for rough grazing, or occasional scattered date palms.

- (8) Fine sandy loam and silt loam to 75 centimetres over decayed sandstone. Firm bed-rock underlies most of this area at 125 centimetres.

Soils of this texture cover only a small area of the Wadi Gaam estate. The profile represented in Figure 22 applies to extensive areas of the peripheral steppe in Misurata, especially to interflaves and higher wadi banks in the southern margins of the coastal plain. The overlying cover of fine sandy loam and silt varies greatly depending upon the effects of erosion and the flood power of any wadi in the immediate vicinity of the area. Thus, in the interflave area of the Wadi Gau-Gau, the cover of fine sandy loam may be as thin as 25 centimetres in the region of Wadi Lebda the depth of superficial deposits may be as great as 100 centimetres and more.

Under sedentary cropping, soils of this texture are suited to shallow rooted crops. Irrigation water tends to pond-up on top of the sandstone sub-rock causing rapid accumulation of salt in the soil, especially where dalu irrigation is practiced. Salinity on the soil is accentuated in those regions where internal drainage is present.

(9) Blown sand, small drifts of loamy fine sand and loamy, very fine sand varying greatly in depth. Stratified silt and loamy fine sand are reached at a depth of about 80 centimetres.

This category of soil texture is typical of areas in close proximity to the lower courses of wadi which find out-let to the sea, and similar profiles are to be seen in the lower reaches of the Hasnun and Lebda. The blown sand element is a variable quantity from area to area, but in most cases it is of sufficient depth to make cropping a hazardous business. On the Wadi Caam Settlement, much of area (9) is given over to wind-break and woodland, a use to which it appears singularly well adapted. Particular problems of utilisation of these areas arises through the presence of stratified silt which causes ponding-up of irrigation water and a consequent accumulation of salt content in the soil. Cropping activities on soils of this texture at Wadi Caam Settlement have been unsuccessful, and it is likely that the whole area will ultimately be transferred from the cropping to the woodland sector of the estate.

(10) Fine sandy loam and loamy fine sand over sandstone.

Category (10) is a further upper wadi and interfluvial area

type of soil texture and represents those basins marginal to the flood areas of wadis which are also affected by dune encroachment. Under indigenous occupation these areas are reserved for grazing: on the Wadi Gaam Settlement much of the land has been given over to eucalyptus plantations.

(11) Loamy fine sand over decayed bed-rock.

The profile of this soil texture category gives a greater impression of homogeneity than is found on the ground. In practice, there are areas of silt loam and clay underlying the superficial cover of loamy fine sand. It is interesting to note that this type of soil texture is widely reported by farmers on the Italian Demographic Settlement of Dafnia. Here it has proved to be excellently adapted to orchard cultivation. At both Dafnia and Wadi Gaam Settlements field cropping has proved difficult and unprofitable.

It will be apparent from this discussion of soil textures within the boundaries of the Wadi Gaam Settlement, that even in the coastal plain, there are many problems arising from the nature of soil areas; their depth, extent and bed-rock. Experience at Wadi Gaam and Italian Settlements in the area has shown that much of the land can be put to agricultural use with careful land management (Figure 2), but that controlled land management is costly and difficult to implement in an area which is still heavily aligned towards traditional economic activity.

After the foregoing description of agricultural development

in relation to the soils of the coastal plain, it will be of value to examine a case example of the influence of soils upon the land management of an agricultural estate located in the steppe regions of Misurata. During the summer of 1960, a research team from the University of Durham was engaged upon soil survey in the inner steppe zone in the region of Taorga Oasis. The full results of this study are not yet available, but on completion it should represent an important contribution to understanding of the nature of soils in the steppe areas of Misurata. (13) Rather than anticipate the findings of the Soil Survey of 1960, we shall limit discussion here to a case example of an area which is already developed for agriculture. This course will also allow assessment of land management in situ.

In the period from 1911 to 1942, Libya was held by Italy as a colonial territory. Various development plans were implemented in the region during this era, the most formative of which was begun under the Fascist Government in the period after 1936. The basic aim of the metropolitan Government was to establish a large and prosperous peasant class of Italian farmers in Libya by means of mass colonisation schemes. Further details of colonising activities undertaken by the Italians are given later in the thesis (Chapter 4). One of the most important component elements in the Italian plan was the utilisation of steppe-land areas, and in particular those areas lying south of Misurata.

Figure 24 shows the position of the settlements. They are situated south of Misurata between Misurata Citta and the Oasis of Teurga. Tummina (ex-Crispi) estate lies contiguous with the southerly extension of the oasis gardens of Misurata. Kararim (ex-Gioda) was situated further south along the main Tripoli-Benghazi road. Kararim was allotted a total acreage of 2,288 hectares, and Tummina 9,140 hectares.

As we pointed out in Chapter 1, precipitation amounts fall rapidly away from the coast. The average rainfall at Tummina is 175.7 millimetres and at Kararim 130.0 millimetres. In this situation, leaching is negligible but capillary action and consequent calcification are intense.

The relief of the area is varied, undulating with gentle slopes and several transverse valley systems crossing the area. Before the reclamation works were begun in 1937, the area was studded with small sand accumulations and several larger areas of small mobile dunes, especially in the north-west of the region. The dunese areas apart, the soils of the area are generally shallow, and in places the superficial deposits are less than a metre in depth. Much of the area of the peripheral steppe in the Tummina district, and of the inner steppe in the environs of Kararim are underlain by a continuous hard pan layer.

Soil analysis by Ente (Ente per la Colonizzazione della Libia, Vide Chapter 4 - The Italian Experiment) indicated that the salt content of soils in the area selected for colonisation differed only slightly from those soils of the coastal plain,

and were better than soils found in Misrata Oasis to the north. The soils of the area are alkaline in reaction pH 8.4, which is about average for this type of area; unfortunately, the Italian authorities tended to be over-optimistic in their approach to demographic colonisation, and data presented by them must be treated with reserve. Official statistics record a pH reading of 8.4, but this is misleading in terms of the vast area (11,428 hectares) covered by the Tummina and Kararim Settlements. Mechanical analysis of soils in the area gave the following results according to the Italian Government statistics:-(14)

Analysis of Soil Sample Tummina - 1937

Skeletal elements	grammes	305°/oo
Fine earth	"	695°/oo
Sand per levitation	"	837
Clay	"	163

It was pointed in respect to the Wadi Gasm Reclamation and Settlement Project, that the presence of a moderate to high salt content in the soils of the area would have been only slightly important had it not been for the fact that the water available for irrigation purposes also recorded appreciable salinity. This same position applied to a greater degree in the case of the Tummina/Kararim Settlements. The Italian administrators of Ente hoped to deal with this problem by adopting what they termed 'irrigation complementary to irrigation'; i.e. official encouragement of winter cropping as against summer cropping. In practice the farmers working on the estate were controlled by the following rotation:-(14)

Cereals	hectares	4.00
Legumes	"	4.00
Alfalfa	"	0.50
Summer fodder crops	"	0.50
Industrial crops	"	1.00
	<u>TOTAL Ha.</u>	<u>10.00</u>

Data from ENTE Op. Cit.

By this means one fifth of the total area of any given farm was cultivated under heavy irrigation in any one year. All other cropping on the estate was to be achieved by winter cultivation using natural precipitation for the greater part of the moisture need.

It will be shown later in the thesis (Chapter 5, Land Use), that the economic premises accepted by the Italian authorities held good only under the rarified politico-economic conditions of the colonial administration. Experience has shown that winter cropping of cereals is barely profitable, and that summer cropping of industrial plants such as groundnuts and fodder crops can be made to give sound returns. This divergence between the advertised aims and the realised aims of land management on the Italian demographic estates has had significant results in respect to the reaction of soil salinity. After several years of operations, the terrain is exhibiting an increase in salt content especially in those areas of the estates where low rainfall and a well developed hard pan are present, and in areas to the east adjacent to the Sabkha of Teurga.

The present dilemma is clear: winter cropping alone is insufficient to guarantee a working income for farmers on the

estate, especially in view of the high costs of irrigation water and the need to amortise the farm and its stock. On the other hand, summer cropping is profitable but brings a corresponding risk of increasing salinity in the soil. (Further consideration of the techniques and possibilities of development in saline areas (15).)

Problems arising from the nature of the soils in both the steppe and the coastal plain represent only part of the general dilemma to be faced by agricultural development in Misuratio. Nonetheless, in association with other elements, - including the features of geology and irrigation water, of erosion and deposition, - it is apparent that the characteristics of the soils of Misuratio will have a strong influence upon the course of economic and agricultural growth.

It has been suggested by the Durham University Soil Survey of Taorga Region, that a further element of great significance in the steppe areas is the depth of soils. (13) In those areas adjacent to the Sabkha of Taorga, underlain by a well-developed calcrete hard pan or covered with hummock sand accumulations the soil depth is generally less than 70 centimetres and thus unsuitable for cultivation. The authors of the Survey came to the conclusion that there were few zones where favourable textural succession of steppe soils occurred over extensive areas with depths greater than 80 centimetres. (13) Problems associated with salinity and alkalinity of soils are present in the areas favourable to development, and land management would

remain as a technical and human difficulty in any scheme of agricultural reclamation.

(c) Hydrology - Introduction.

In Sections II and III of this thesis, it will be suggested that the availability and exploitation of water resources is the critical factor behind the trends in economic development in Misurafino. Under traditional social life in the region, appraisal of land and water resources was dictated by cultural alignment towards nomadism and economic bias towards livestock herding. In this traditional climate of Arab life, water supply was important only in respect to the needs of the herds at the various seasons of the year. Nevertheless, early reliance upon scanty water resources offered a basis of technical knowledge of water availability and extraction which was to be utilised later, as the dynamic forces of social and economic growth created movement towards littoral, sedentary agriculture. In the succeeding paragraphs we shall discuss the relevant elements of hydrology behind the demand for and the use of water resources.

(1) Resume of Characteristics of Precipitation.

It will be apparent from earlier discussion of climate in Misurafino (Chapter I), that rainfall in the littoral regions is sufficient to provide only a poor basis for agriculture. Away from the coast, rainfall declines quantitatively and increases in variability. In fact, it was suggested in the Climatic section, that rainfall conditions in the steppe are to be measured largely in terms of greater or lesser degrees of aridity.

The amount of rainfall in Misuratino permits cultivation of several resistant varieties of cereals and tree crops along the coast, and a dispersed form of shifting agriculture in the peripheral steppe. These cultivations are made unreliable and unprofitable as a result of the extreme variability of rainfall which affects both steppe and littoral alike. As a preface to this examination of the balance of water supply in the area, it should be noted that cultivation of the most simple nature is a hazardous business in the climatic regime which characterises Misuratino. Precipitation alone offers no sound foundation for agricultural expansion in terms of herding, field cultivation or arboriculture. For as long as economic activity was reliant upon the vicissitudes of annual rainfall, primitive social and economic systems persisted. The protracted period of traditional occupation in Tripolitania may be accounted largely to the retarding influences of the rainfall regime.

Later in this chapter, we shall analyse the forces of growth which brought indigenous society to a position where the aridity of the environment could be overcome by technical improvements in exploitation of water resources. More immediately, we shall examine the problems affecting the balance of water supply in the area under selected heads.

(11) Evaporation.

Evaporation of surface water in the arid environment presented by Misuratino runs at a high level. Oasis areas apart, the vegetation cover in the peripheral steppe zones and the

dunose lands of the littoral is exceedingly sparse, limited to clump communities of Pituranthus tortosus-Phymelaea hirsuta and Artemis Variabilis-Zizyphus lotus. Further inland in the inner steppe lands, communities of Gymnocarpus fruticosus-Echiochilon fruticosum and Haloxylon articulatum offer a greater dispersion yet again. This vegetation pattern affords only scant protection for recently fallen rain against the effects of direct heat from the sun.

The thinly distributed nature of the vegetative cover in Misuratio is of importance in this context, since the periods of rainfall in the area are rapidly succeeded by clear skies and high temperatures. Furthermore, the barren surface of the terrain tends to accelerate run-off rather than encourage percolation. Thus, the total effects of evaporation are an important factor in the region.

Assessment of evaporation from open water surfaces in Misuratio is largely a matter of hypothesis, since the only large area of permanent surface water is the spring-fed sweet water basin at the mouth of Wadi Gaam; nonetheless, evaporation from small irrigation ditches, canals and reticulation networks is exceedingly high. Italian estimates of evaporation from open water surfaces were in the region of five millimetres per day. (7) In practical terms this figure is significant; thus, in 1938, when the Italian Government was considering reservoir storage of water in Misuratio, they were faced with an annual evaporation loss of 23,000,000 cubic metres from open reservoirs,

whose total capacity was 75,000,000 cubic metres per annum. Data taken from a similar area in Tunisia illustrates this same problem; the reservoir on the Wadi Kebir to the south-west of Tunis is estimated to have lost some 39,000,000 cubic metres of water through evaporation in twenty years, where the annual carrying capacity is 12,500,000 cubic metres. (16)

The forces of evaporation are greater in the steppe regions than in the littoral zones of Misurating. This is clearly illustrated by consideration of the steppe territory south of Tunmina, in that region where the east flowing wadi systems of the Shibla flow into the Sabkha of Taorga and its southern extensions. In the Jebel catchment area of these small wadi systems annual precipitation is of the order of 300 millimetres, which corresponds to a fall of 10 litres per second for each kilometre square, or 100 cubic metres per second for the 10,000 kilometres square area of the catchment. The flow of the Wadi Mimun Darraigh at the point where it enters the Sabkha is about 50 litres per second, and the flow of the Wadi Saffegin and its many tributaries some 550 litres per second. This gives a nominal total flow of some 600 litres per second in a year of average rainfall. The flow from the spring at Taorga oasis is still unknown with precise certainty, but Italian engineers estimated that its flow averaged 200 litres per second. (13) By direct calculation it is apparent that water is absorbed in the following manner:- wadi flow in the area of percolation at a coefficient of 0.6%; spring flow from the artesian water table

0.2%; which leaves a loss of some 99.2% in the form of evaporation.

We may distinguish four different stages at which losses to evaporation are important :

- (a) Evaporation of run-off.
- (b) Evapo-transpiration from vegetation.
- (c) Evaporation from water table.
- (d) Evaporation from irrigation net works at the Experimental Farm and Taorga Oasis.

Head (a) is the most difficult quantity to ascertain but is certainly the most important element in the situation. Point (b) may be deduced with a large measure of accuracy by taking into account the areas of land occupied by specific crops and calculating the mean transpiration rate for the area; alternatively, account may be taken of the fact that under analagous conditions the formation of one kilogramme of dry vegetable material amounts to an average transpiration of 300 litres of water.⁽¹⁷⁾ The amount of evaporation taking place in the sebkha areas of Taorga and Hescia must vary each year according to the in-flow of waters from the spring. Nonetheless, we may apply a generalised evaporation loss of 1,000 litres per second to the area on the basis of work done in the sebkha zones of Tunisia by Schoeller.⁽¹⁸⁾ Evaporation in the steppe lands of the drainage basin is slower, but the extent of its importance may be gauged by the occurrence of vast areas of calcrete. Using the concept of Total Evaporation ($E = P + Q + R - Ri - Qi$ ($\circ V_s \circ V_m \circ E_c$)) where P is the volume of preeipitation; P and Q are respectively the volumes of water reaching the region via

the ground water and run-off; R_i and Q_i are the amounts of water lost from the region in the same two forms. In the case of the sebkha the variations in the volume of water in the water table (ΔV_s), the volume of soil moisture (ΔV_m) and the variation of water in streams (ΔE_c) were either non-applicable to the internal drainage system or were not known.) it appears that evaporation runs at approximately 200 litres per second in these steppe areas. The amount of water lost by cultivation is minute in the sebkha areas; cultivation takes place in the Oasis of Taorga and on the small experimental farm close to the spring of Taorga.

To summarise these suggestions concerning the losses of water by evaporation in the steppe and sebkha areas we offer the following 'balance sheet' of water supply in the Soffegin basin and the adjacent lands of the Sebkha Taorga and Hescia:-

Flow at Taorga spring	0.2 m ³ /s
Evaporation from the <u>sebkha</u>	1.2 m ³ /s
	—
Coefficient of infiltration into artesian table	1.4 m ³ /s
	1.4 %
Coefficient of run-off for 1958-59	0.6 %
	—
Known quantities of run-off and infiltration	2.0 %
Evaporation of rainfall/run-off	} -- 98%
Evapo-transpiration	
Evaporation in formation of calcrete	

TOTAL RAINFALL - 100%

It must be admitted that this is not a precise estimate of the situation, since much of the evidence is taken from corresponding areas of Libya and Tunisia, nevertheless,

in the absence of more detailed hydrological works, this balance sheet serves to give an impression of the scale of evaporation in its various forms in and around the steppe regions. This intense scale of water loss poses several difficult problems in respect to future development in the steppe which we shall discuss later; in the present context it should be noted that direct replenishment of the artesian aquifers underlying the Misurata zone must be a slow process but that conservation techniques applied to the upper catchment could play a large part in reducing present losses.

(iii) Surface Hydrology.

In terms of agricultural development, the surface water supplies in Misuratino are comparatively insignificant. This situation arises partly through the fact that the wadi systems contain waters only intermittently during periods of heavy winter rainfall and that the prevalence of nomadic and semi-nomadic occupation since the Hilalian invasion has precluded mechanical exploitation of the ephemeral surface waters. Three major groups of wadi systems may be distinguished in Misuratino.

- (a) The Caan-Tarreglat system having its major source in the Jebel Bahama and Msellata but reaching the sea via the northern littoral.
- (b) The Soffegin, Mimun Darragh and other systems of the southern steppe, which have their source in the Ghibia region and flow to the Sebkha of Taorge and Hescia.
- (c) The short wadi systems of the Jebel line foot-hill front, which traverse the plain of the northern littoral.

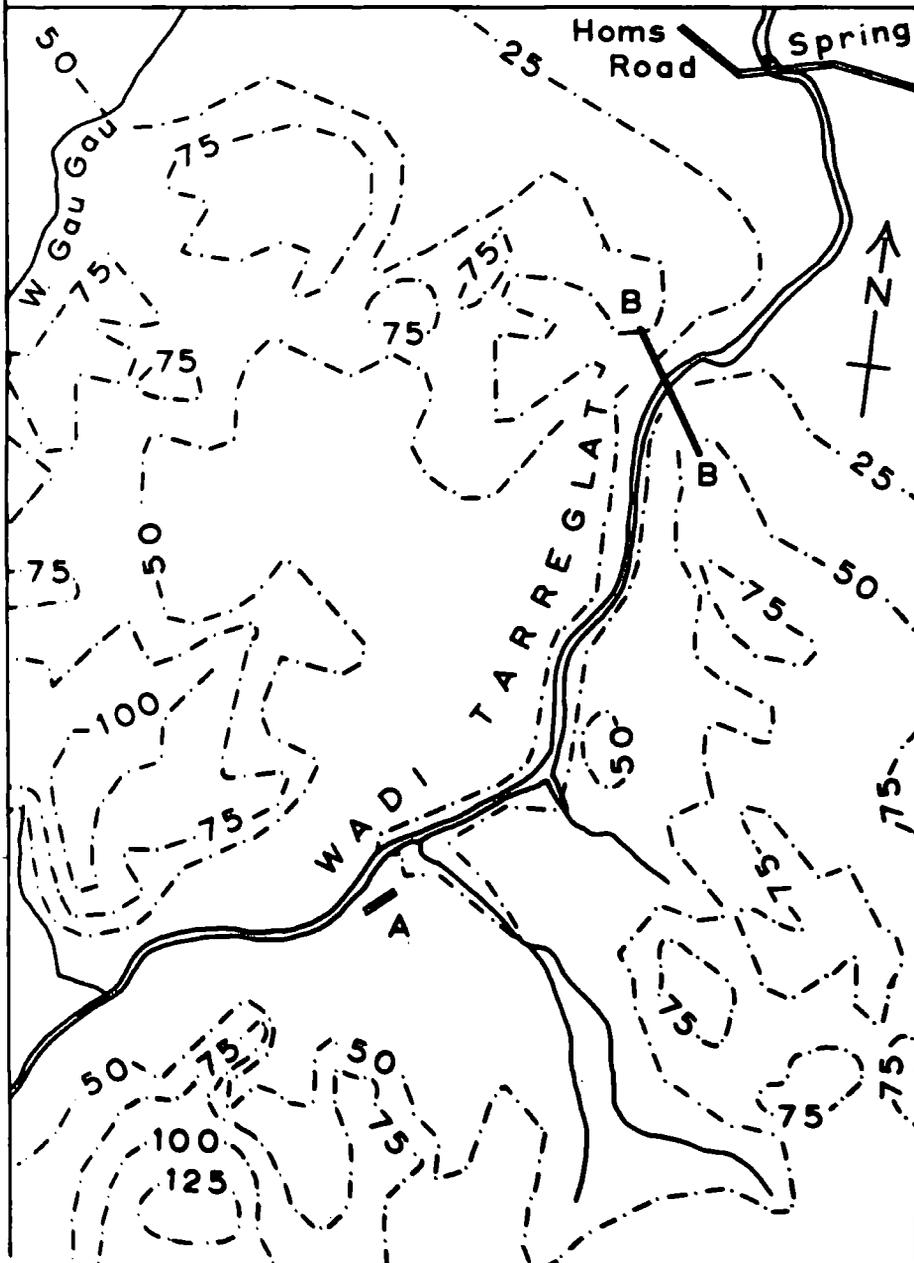
The catchment basins associated with these systems are illustrated

in Figure 25. Several interesting theories concerning changes in the surface hydrology have been advanced by Dasio⁽¹⁹⁾, Brehony⁽²⁰⁾ and Vits-Final⁽⁶⁾; it will not be relevant in this context to examine the merits of these various hypotheses, rather we shall analyse the present position of the wadi systems with respect to their importance in the scheme of economic growth.

As we shall show later (Chapters 3 & 4), trends in economic growth in Misuratio have brought in their train a movement to sedentarisation by the cabila in the areas of the oases. Thus it will be apparent that the wadi systems which will be important in agricultural development will be those which traverse the northern littoral plain or the lower basins of the littoral steppe. The wadi system with the largest catchment, both in terms of area and volume of precipitation, is that of the Gasm-Tarreglat, which reaches the coast between Zliten and Sahel Oases. During the period of the Roman occupation, the basin of the Wadi Gasm-Tarreglat was reclaimed over large areas by systematic water diversion and water storage in dams and cisterns. Possibly Roman activity in the area of the wadi has been over-estimated, since evidence of local works is abundant, but there is little to suggest that any large or integrated estate was operating in the area. Modern development on the lines laid out by the Romans has been envisaged on several occasions in the past fifty years.

In the closing years of the Turkish administration, it is thought that some attention was paid to restoration of the Roman diversion works. Turkish efforts were cut short by the arrival

WADI TARREGLAT
LOCATION PLAN — LOWER BASIN



20 0 40 Kilometres

- A Roman Barrage
- B Sidi Mrabet — Proposed Dam Site
- Contour Interval 25 Metres

Figure 26

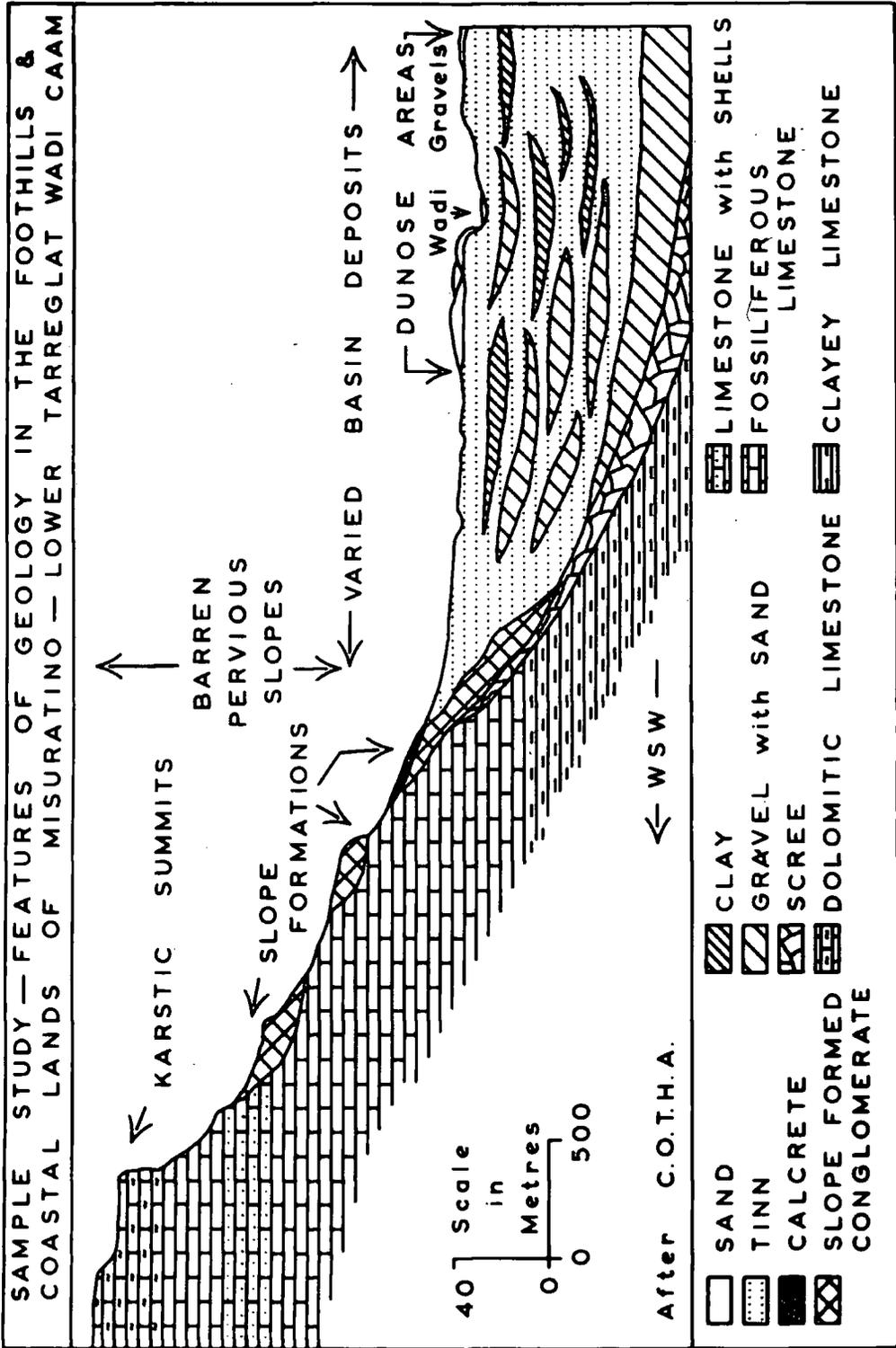


Figure 27

of the Italians. Italian colonial schemes for exploiting the Wadi Tarreglat were devised in 1939/40. The plan was based upon the construction of a large barrage at Sidi Mrabet, which would be able to supply 8,000-10,000 hectares of agricultural land in the Suk El-Giuma area of Eliten Oasis, with water supply (Vide Figure 26). These early estimates were founded on the view that the accumulated flood waters of the Tarreglat and its tributaries would provide some 3,240,000 ms³/hr. which would fill the dam over a 23 hour period. It was thought after a provisional survey had been completed, that the costs of the dam itself would be insignificant, since rock would be struck at a shallow depth.

The technical problems facing a project of this nature are not insurmountable; in both Tunisia and Algeria, smaller and more eccentricly shaped wadi basins have been successfully dammed in regions with identical characteristics of climate. (21) The most difficult problem facing a scheme of this kind is the sealing of the large and varied alluvium deposits below the superficial sands (Vide Figure 27). Although solutions can be found to most of the engineering problems involved in the construction of a dam across the wadi, it has been determined by recent survey that the costs of the construction would be prohibitive. (7) Furthermore, observation of the flow of the Wadi Gaam indicates that the erratic nature and the low volume of flow raise serious doubts whether a large dam could be filled and maintained over a period of years. Using the experience

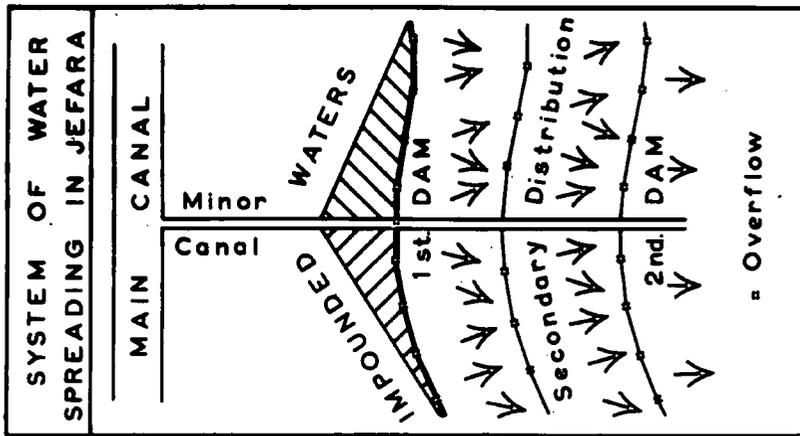


Figure 29

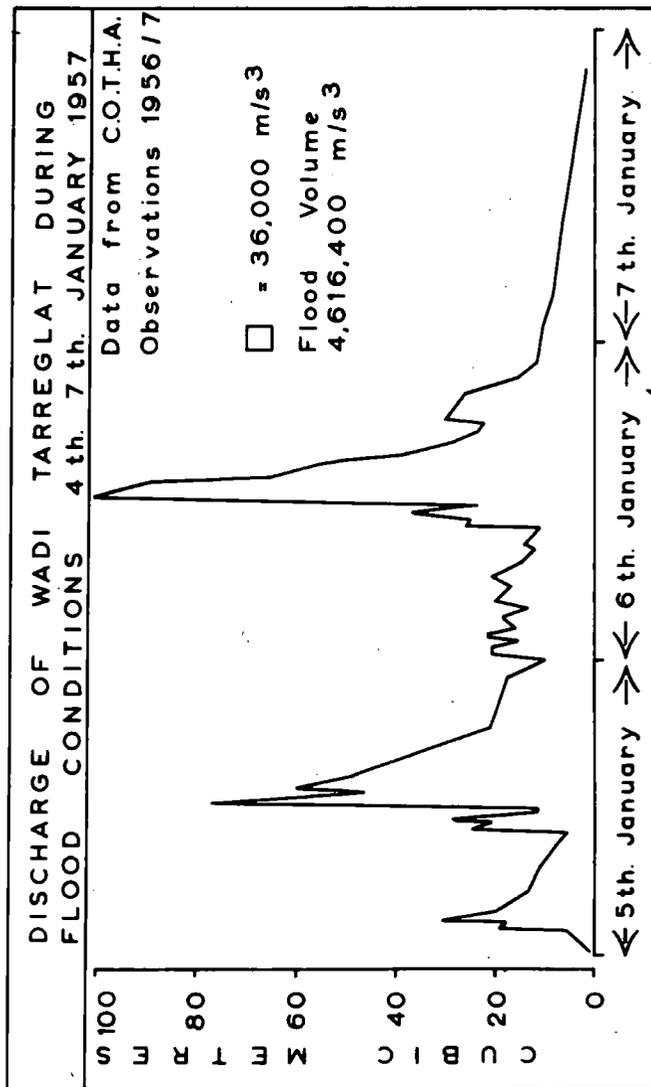


Figure 28

gleaned on the Italian demographic farms, it may be suggested that the Suk El-Giuna development area which would be served by the Casam barrage would need a supply of 48,106,000 cubic metres of water in the course of a year. To allow for losses to evaporation and reservoir and canal seepage an extra 27,106,000 cubic metres would have to be added to this initial total. Observations in 1956/7 and 1957/8 indicate clearly that in normal conditions, the discharge of the Casam-Tarreglat would not be sufficient to supply this total. The flow measurements by COTHA show that the annual flow of 20,106,000 cubic metres is to be counted on as an average. (7)

The following data illustrates the characteristics of wadi flow in Misuratino, and in particular indicates the problems to be faced in any attempt to harness flood waters. In the wet season of 1954/55 a flow of 9,500,000 cubic metres was recorded, distributed over eight floods. The largest of the floods did not last for more than 30 hours and the maximum discharge was 160,000 cubic metres (Vide Figure 28). In the following year, when rainfall in the catchment of the Wadi Casam-Tarreglat approximated closely to the annual average for the area, the hydrological readings were:

Total flow	15,500,000 cubic metres
Maximum discharge	310,000 " "
Longest flood	3 days
Number of floods	9

These results are scarcely encouraging for the attempts to fill even a small dam.

If we use statistics established for wadi systems in other

countries with similar climatic conditions to those which prevail in Misuratino, we see that the annual flow coefficient -

$$R = \frac{\text{annual rainfall}}{\text{total flow}}$$

is generally less than 0.1 for the Caam Tarreglat. From the two surveys of 1954/5 and 1955/6 the coefficient appears as 0.042 from the one, and 0.47 from the other, where the first is for a rainfall year slightly less than average (volume of rain calculated at 328,000,000 cubic metres), and the second for a year approximating to the average (volume of rain calculated at 228,000,000 cubic metres). The figures presented by C.O.T.H.A. represent only two years observations; nevertheless, it may be pointed out, that even when the coefficients are doubled, the volume found would be less than half of the storage capacity of the reservoir. (7)

A further problem of paramount importance in consideration of water storage in Misuratino is the rate of sedimentation in reservoir areas. In the region of the Caam-Tarreglat, sedimentation appears to be very heavy, as is evidenced by the large amounts of gravels and alluvium that can be seen on the banks of the wadi sometimes to a height of ten to twelve metres. In the vicinity of the old Roman dams, and particularly up-stream of the Roman barrage, the terrace formations approximate to the crest level of the dams (Vide Figure 25). Thus, it might be said that the dam was destroyed when the storage basin had been filled and an exceptional flood over-topped the structure at the

right wing. This is hypothetical, but is very likely in view of the finding made by Vita-Finzi in the Hagun and Lebda Wadis,⁽⁶⁾ and serves to demonstrate that the up-stream water level rises rapidly when confronted by an obstacle. C.O.T.H.A. suggest that the Roman dam was in use for some 350 years, and on the basis of this, estimate that the rate of sedimentation was approximately 4.5 centimetres per annum.⁽⁷⁾ Thus the capacity of the storage dam on the Wadi Caam-Farreglat at the site indicated (Figure 26) would be reduced by 500,000 cubic metres per annum, and the reservoir would be completely filled in after 150 years of operation.

We may summarise this discussion as follows:

- (i) The hydrological problems we have outlined, both individually and collectively; erratic and low volume of wadi flow, intensive evaporation, heavy deposition and other associated problems of seepage; render the construction of storage dams difficult and uneconomic.
- (ii) Other cheaper schemes for the utilisation of surface waters are available which appear better adapted to present economic and social conditions prevailing in Libya.

WATER SPREADING AND THE WADI SYSTEMS OF THE JEBEL DWE FOOT-HILLS.

The lack of promise shown by the surveys of the barrage schemes on the Wadi Caam and the Wadi Megemine (which reaches the coast at Tripoli) has made consideration of more practicable and economic methods of utilising flood waters in Tripolitania come to the fore in recent years. Prime amongst the techniques which have risen to importance is that of diversion of wadi floods and water spreading over the wadi basins. Although these

works suffer from those problems of evaporation, seepage and deposition which we noted with respect to barrage construction, their initial cost and day-to-day maintenance is small. As yet water spreading has not been introduced to the wadi systems of Misuratio, but it is likely that when engineering and agricultural experiments have been concluded in the Jefara region of Tripolitania, the technique will be adapted in Misuratio. Great success has been recorded by the French authorities on the Wadi M'Zi in the Laghouat region of Algeria. (22)

The basic principle of water spreading is that the main body of flood water is tapped and distributed over a large area of the surrounding lands rather than left to run to the sea. Control is achieved by means of a major diversion barrage across the main stream of the wadi which leads all flood waters into a canal running more or less transversely according to the lie of the land. Thereafter water is fed in to separate secondary canals and thence distributed over the land. Preliminary to the establishment of the canals and their ancillary networks, the land which is to be developed is cleared of all superficial sands and dunes. The details illustrated in Figure 29 indicate the secondary canals in a position to lead the flood discharge from the main canals to the head of each zone scheduled for agricultural development. The flow in the secondary canals is retained at the first dam; this dam is designed to accumulate the flow and divide it uniformly at the head of the development zone. As shown on Figure 29, the dam is equipped with regular

overflows throughout its length; each overflow leads to a small concrete basin at the foot of the dam which precludes the development of ravines across the agricultural land. The output of water through the overflows in the first dam will flow from dam to dam down the system; each dam is equipped with over-flows at some 50 metre intervals each set being staggered to assure an even distribution of flood waters. Each dam is set at one metre contour intervals from the former dam; the number of auxiliary dams depends largely upon the quantities of flood water available and the area of land which can be developed for agriculture.

The system of water spreading in Tripolitania has not been perfected at the present date and experience with the Wadi Megemine Project has demonstrated clearly that the rapid rate of run-off in the Jebel regions will have to be checked by conservation of the watershed areas before great advances can be made. We shall discuss the question of conservation later in this chapter; in this context it is pertinent to note that, given a degree of re-afforestation in the Jebel and Msellata foot-hills, large areas of the peripheral steppe of Misuratine could be brought into agricultural use. This applies particularly to those areas bordering the short wadi systems (c) which traverse the northern littoral plain: the Hasnun, Lebidi, Ledba, Gan-Gau and other smaller wadis west of Zliten (Vide Figure 25).

It is relevant to mention here, that we have been examining problems of hydrology and hydrological engineering

in relation to possible areas of development. Such discussion has tended to monopolise the councils of the Nazara of Agriculture and the overseas development agencies which are working in Tripolitania. It should be recorded at this juncture, as a preface to later analysis of economic development in Misuratio, that the value of possible development areas must be assessed only in relation to the present state of Libyan agriculture, especially its rate and direction of growth. We shall show in a later section of this thesis, that trends in indigenous land use, which themselves result from the nature of economic growth, are from geographical location in the steppe to location in the oasis lands. (Sect. III, Chapter 5). In this climate of change it would be fruitless for Government policy to be orientated counter to the general trend of indigenous movement. The factors which must be taken into account in appraisal of development, in this case control and utilisation of surface waters, are studied in greater detail in Section III, Chapters 5 and 6 of this thesis.

As a final observation upon this examination of surface waters in Misuratio, it may be said that the wadi systems under heads (a) and (c) (p. 80) do offer scope for future development on the lines suggested. Those wadis of head (b) situated in the inner steppe lands will remain outside the range of agricultural development for many years as far as may be foreseen.

CISTERN STORAGE.

We have seen that the Roman settlers and indigenous farmers

who worked the lands of Misuratio during the flourishing period of imperial rule, made use of the surface flow of the wadi systems which traversed the area. Utilisation of surface waters for agriculture was especially a feature of the Jebeline foothills and the Msellata plateau, and it was in these two zones that utilisation of land was most intense during the Roman era.⁽²³⁾ Water flow in the beds of the wadis was tapped by diversion and barrage works, as we have demonstrated in the case of the Gaam-Tarreglat system. On the upper slopes of the wadis, in the karst basins and the lower water-shed zones, the Romans employed cistern catchment and storage for both agricultural and domestic purposes.

Construction of cisterns tends to be laborious work, since the rock enclosures have to be chiselled out piece by piece by manual means. Roman cisterns in the Misuratio area tend to be standardised in style, averaging some 220/300 square metres in capacity; the range of sizes varies from 96 square metres to 432 square metres in the Homs District of Misuratio (Vide Appendix I). Each cistern is cut out from the rock slopes, or in some cases dug from the consolidated alluviums or finns of the upper slopes. In areas of alluvium or soils, the cavities are lined with hard pan of masonry blocks, leaving only a small door or hole for access at the top of the structure. Cisterns are fed by direct run-off from the interfluvial slopes, which is trapped by small drainage channels which radiate upwards from the cistern. In order to preclude heavy deposition of

sediment inside the cistern, the direct waters from the channels are led into a small sedimentation pit at the entrance to the main storage tank.

The sites of cisterns are influenced by distribution of fertile soils in the foot-hill region, for it is only in such areas that cisterns could be put to economic use. Thus, the structures are situated at the foot of steep and long rocky slopes leading down to pockets or basins of agricultural land so that they can make optimum use of run-off from the slopes and also be well positioned to supply the surrounding gardens. The number of Roman cisterns which are still in use is unknown, mainly because they are often difficult to detect. The distribution of cisterns in Misuratio which were renovated in the course of a recent Nazara of Agriculture and Libyan Public Development and Stabilisation Agency programme is illustrated in the statistics contained in Appendix I. In fact, there must be many more scattered about the foot-hill region which are still in use, and even more which have either collapsed or been undetected. This is borne out by the experience of the military authorities at Homs Camp, whose major difficulty in the training areas of the foot-hills arises through accidents caused by armoured vehicles falling through the tops of unmarked Roman cisterns.

In discussion of cisterns water storage in Tripolitania, the experts of the B.M.A. in 1945 (2+) pointed out that there were several disadvantages associated with this type of

structure:

- (i) In spite of the sedimentation pits at the head of the cisterns, in-filling of the storage tank tends to exhibit a high rate (Vide observations of sedimentation in Caam storage barrage p. 84). Thus, the tanks have to be cleared frequently; this necessitates draining the water away, a practice which is hazardous in the erratic climatic regime of Misuratino, where immediate replenishment is not to be relied upon.
- (ii) Cistern storage depends for its success upon heavy showers of rain and a rapid run-off. The volume of rainfall in Misuratino is small on an average and would not support large capacity storage.
- (iii) The great degree of variability of rainfall in Misuratino tends to make cistern storage inefficient, since during drought periods when stored waters are most necessary, the cisterns would be empty.
- (iv) Exceedingly careful control of the use of water in the cistern is necessary if it is to function throughout the arid period of summer.

Nevertheless, the B.M.A. report⁽²⁾ advised that a system of cistern construction and renovation should be undertaken with a view to providing a measure of supplementary water supply in the foot-hill zone.

It will be pointed out later that there has been a fundamental change in the pattern of indigenous farming since the time of the B.M.A. report. The forces of economic growth, which were present, but not immediately apparent in the situation in 1945 have increased in velocity under the stimulus of income accrued from oil exploration and foreign aid (Chapter 6, p. 696-7), and the economic status of the farmer has changed correspondingly. Cistern storage is essentially a primitive technique of water storage which is relevant only when the standards of rural living

are low enough to support intensive hand labour on construction and maintenance of the tank. For as long as a non-commercial system prevails, the cost of this labour is unappreciated and therefore accepted; cost accounting throws a different light upon the scene and generally makes this loss unacceptable. Similarly, the type of land use allowed by the water resources made available by the cisterns is extremely limited; full irrigation of field crops is not possible beyond the bounds of a 'kitchen garden' plot. As self-sufficiency gives way to commercial farming in Misuratio, so the value of cistern storage declines. Furthermore, tank storage of the cistern type was an easy line of development in a period when technical advance was restricted. During the period of semi-nomadism and in the years following sedentarisation, the Arabs readily took over ex-Roman storage works, since they had not the technical knowledge and materials at their disposal to improve upon these previous works. At the present day, the availability of advanced systems of water prospecting and exploitation and the concurrent trend in the indigenous agrarian economy towards large scale commercial farming will together render cistern storage obsolete.

From the foregoing analysis, it will be apparent that the schemes put forward by the Nazara of Agriculture and various F.A.O. experts (Wheatley),⁽⁶⁵⁾ Bologna⁽²⁶⁾, which are based upon renovation and construction of cistern storage units can only be of ephemeral importance. As a long term policy, they would be utterly dissociated from the deeper trends in the rural

economy.

(vi) Ground-water Hydrology in Misuratio.

The surface waters of Misuratio offer restricted opportunities for development, primarily as a result of the low volume and erratic nature of the precipitation. It will be obvious therefore, that sound agrarian development in the arid environment of the area will have to rely upon water resources of a more consistent nature. Until Italian discoveries of artesian aquifers at great depth in Misuratio, reliable supplies of water in large quantities were to be found only in the areas of deposition - the northern littoral plain and the steppe lands bordering the sebkha zones to the east. Throughout this zone there exists one or more water tables; the major table being the phreatic layer.

The existence of the phreatic water table arises from the fact that the greater part of the plain is underlain by large areas of 'hinn' soils, which are compact, lenticular and impermeable, and which are deposited homogeneously over large areas. A mixed series of wind-blown and alluvial sands, particularly reddish sands with helix (vide p. 45) all of which are permeable are distributed above the impermeable stratum. Rainfall over the littoral strip and supplementary infiltration of flood waters from the wadi systems of the Jebel seeps through the surface sands and accumulates above the hinn stratum (Vide Figure 34). In the region of Homs Oasis, two layers of hinn at different depths result in the existence of two water tables,

the upper corresponding to the phreatic, and the lower being termed the sub-artesian. This sub-artesian layer was discovered during borings at Valdagno Concession to the south-east of Homs village and appears to be at a depth of approximately 30 metres. Unfortunately, the arid nature of the terrain in the Oasis of Homs has discouraged further exploration of this aquifer. In the Jefara of Tripolitania, north of Azizia, the sub-artesian layer is separated from the phreatic water table by a clayey calcareous layer and the water is retained in a stratum of siliceous sand 15-40 metres deep lying above a Miocene clay deposit. (27) Since the geological properties of the Jefara are exactly similar to those pertaining to Misuratio, there is reason to suspect that other areas of Misuratio might well be underlain by the sub-artesian aquifer. Experience on the Jefara plain indicates that the supply of water from sub-artesian sources is greater in volume and of a less brackish character than that from the phreatic layer, which enjoys exclusive prominence for Arab operators in Misuratio at the present day.

Laurenti's observations on the phreatic water table suggest that the depth of the water table increases to the south. (27) He points out that the inclination of the land towards the sea is 3:1000, yet the average slope of the water table is 2:1000, hence the fact that the wells of the littoral are shallower than those of the peripheral steppe regions. The features outlined by Laurenti hold true in Misuratio within defined limits. The declining depth of the water table is apparent in the northern

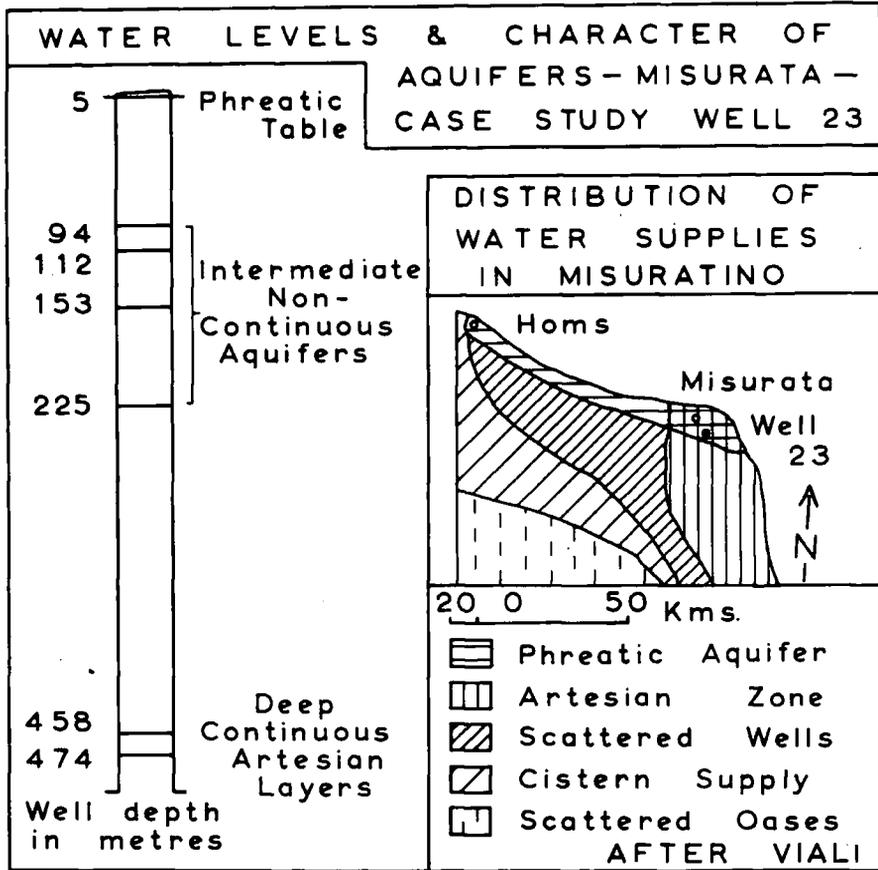


Figure 30

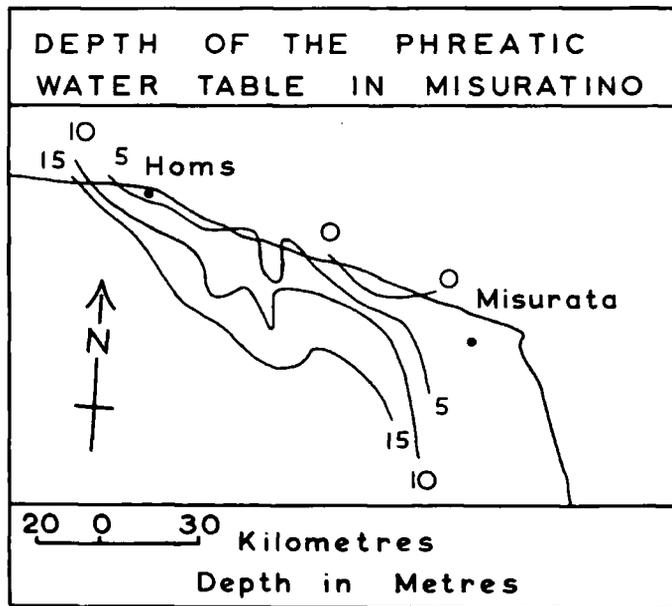


Figure 31

littoral plain, and is particularly emphasised in the Zliten area. This pattern is modified in the east by the influence of the Sebkha zones of Taorga and Hescia, where the land level approximates to sea-level and less, and where the water table lies at one or less metres below the surface of the sebkha. This is illustrated clearly by the isopleths indicated in Figure 31 both in respect to the Taorga-Hescia and the Goz Ed-Dehela sebkha zones.

The ground water hydrology in Misuratio is made complex by virtue of the influences imposed upon the flow of underground water in the phreatic water table by the calcrete layer. In previous discussion, we examined the nature of the calcrete horizon and suggested that the chief agencies at work were the arid factors of climate which caused a net loss of water from the soil during the summer months and a corresponding capillary up-movement of salts. It was demonstrated that the layers of calcrete characterised much of the agricultural land of Misuratio and were important in their effects upon drainage. In fact, there are two major effects upon agricultural development which need our attention:

- (i) The beds of sweet water available on the perched water table created by the calcrete horizon in the soil.
- (ii) The diversion of percolated waters along the plane of the impermeable hard pan layer.

The first point arises with reference to the Oasis of Misuratio, since the development of the hard pan crust is nowhere so strong as in this district. Furthermore, the brackish phreatic waters

of Misurata oasis make the presence of alternative supplies of sweet water important, since any supplement to the normal supplies is valuable. The perched tables are found in small fragmented basins resting upon the hard pan layer at a depth of 13-16 metres. Where the undulations of the hard pan layer are favourable, limited amounts of sweet water may be extracted during and for a short period after the winter rains.

Of more general significance throughout Misuratio are the effects of the continuous horizons of hard pan, the incline of which is biased at a slope of less than 1:1000 towards the south. As we have pointed out previously, this slight incline in the hard pan brings about many features of introspective drainage in the area, especially in the region of Zliten Oasis and the south of Misurata Oasis. The phreatic water table in these areas exhibits a brackish nature and a high degree of salt content; this situation obviously reduces the value of the ground water in the region and makes irrigated farming a hazardous business.

Large areas of the coast of Zliten and Misurata are affected by a secondary influence of the hard pan layer. In these cases, the calcrete horizon along the coast line is biased slightly inland, and the sea water is able to penetrate along the line of the calcrete surface and enter the main body of the phreatic water table. This tendency is reinforced in the Misurata Oasis by the fact that the seepage flow of water from the foot-hills tends to drain to the east into the low-lying area of the

Sebkha Taorga and Hescia. This diversion of water from the main coastwards flow of the phreatic water table reduces the pressure of flow in the northern littoral regions, thereby allowing penetration by sea water. A further factor worthy of consideration in this context is the general decline in the height of the foot-hill region towards the east; in Homs region at Ras El-Hamman the height of the escarpment is 119 metres; at El-Magen above Misurata Oasis, the foot-hills fall away to 22 metres. Thus, the head of pressure accumulated in the fringes of the foot-hills is less in the east than the west, and the rate of flow in the two regions varies accordingly.

In the entire eastern region, i.e. the areas of central, northern and southern of Misurata Oasis and the associated peripheral steppe areas, the utility of the phreatic water table is considerably reduced as a result of the inter-flow of water between the aquifer and the water body of the sebkha. The tendency for inter-flow is thought to be increasing as the surface of the sebkha is reduced by the constant erosion of the friable salt crust and the down gradient to the salt lake accentuated. At the present day, inter-flow takes place mainly during the winter rainfall season, when the two bodies contain appreciable volumes of water. We do not yet know the lines and quantity of interaction between the phreatic water and the sebkha, but it may be assumed from the brackish nature of the irrigation water drawn from the wells in the areas to the east and south, that the degree of inter-flow is sufficient to affect agricultural

activity adversely.

We have already noted that the calcrete layer in the soils of many areas of Misuratio gives rise to local perched water tables which may be put to agricultural use. Local water tables are also important in the littoral zones where sand dunes occur over large areas. The high lying water tables in the dunose areas are not fully understood and are unmapped in Misuratio. In the area of interdunal basins, particularly in the north-west of Misurata Oasis, many of the dunes can be made to support palmeries in their own right; i.e. all the palms in these areas are not merely residual elements overtaken by dune encroachment, rather they have been cultivated from cuttings set in the sand. Further evidence of the presence of bodies of water within the dune mass is furnished by the Forestry Department, which has discovered that dune reclamation in the Misurata area has offered less problems than have been met in other littoral and continental locations, where salinity of the underlying soil horizons is present in small quantities. The reason for this lies in the fact that the seedlings planted on the Misurata dunes have found readily available supplies of sweet water as is testified by the success achieved. Leone, who undertook much of the early experimental work on dune stabilisation remarked - 'nei riguardi dell' acqua le dune possono considerarsi come dei veri serbatoi d'acqua e sotto questo punto di vista le specie arboree su di esse vengono a trovarsi nelle migliore condizioni'. (28)

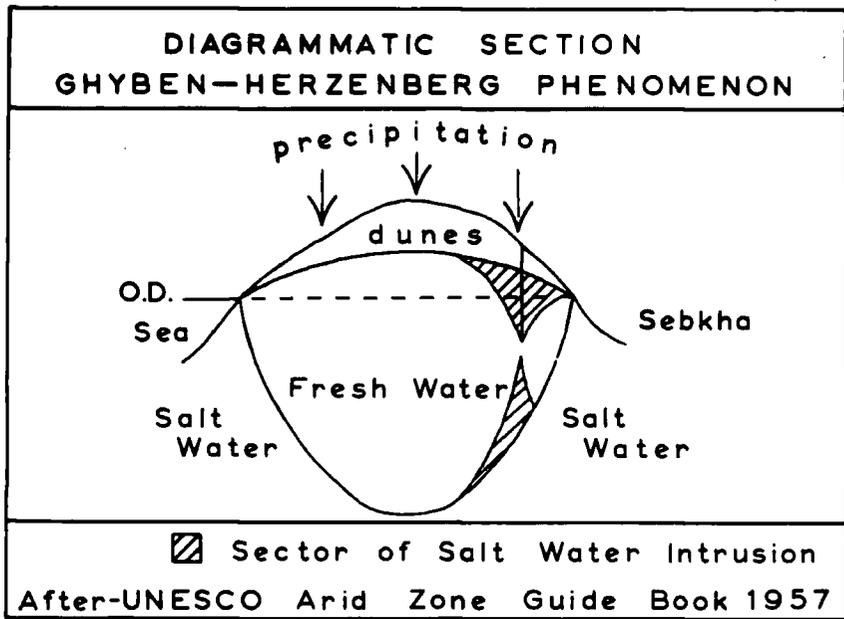


Figure 32

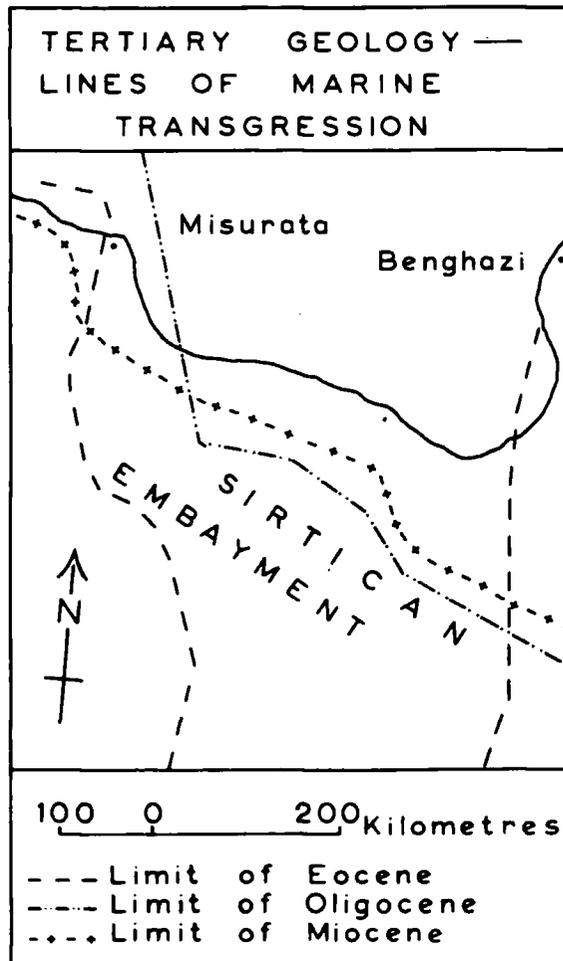


Figure 33

In the absence of any authoritative work on the water table of the sand dunes in Misurata area, we may suggest the most likely explanation of the situation is that it is a manifestation of the Ghyben-Herzberg phenomenon. The mechanism at work is as follows:-

Ghyben-Herzberg Phenomenon.

The upper layers of strata containing saline water on the borders of the sebkha or in the areas where the phreatic water table is heavily penetrated by salty water, contain variable amounts of sweet water, mainly from rainfall percolation but also from influent seepage. Normal mixing between the salty water and the fresh water along the junction surfaces is only slight. Because of the differences in density - '1.026 for salt water and 1.0 for fresh - the height of the fresh water (h) causes the withdrawal of salt water over a height (H) equal to about 40 times (h): a column of height (H) plus (h) of water of density 1 is needed to balance a column (H) of salt water'. (29) - extraction of fresh water results in the intrusion of salt water in this special way (Vide Figure 32). The result is that the expanding body of saline water assumes a position in the water body relative to the size of the body and the level of the water table in a way which has not hitherto been expected. The relative positions of the saline and fresh water bodies is illustrated in Figure 32.

The presence of small and localised water bodies within the dunes cannot be regarded as being of agricultural importance in

any direct form. Nevertheless, the implications in terms of forestry activity and dune fixation are significant.

Spring Systems.

During the Roman occupation of Tripolitania, the area supported the 'tri-polis', the cities of Sabrata, Oea and Leptis Magna. Particularly after the accession of Septimus Severus as Emperor, the city of Leptis, which was his birth place, grew to prominence as a trading emporium. Much of the water supply for the city was taken from Wadi Caam by aqueduct. After the decline of Roman rule in the Seventh Century, the spring source in the Wadi Caam fell into disuse.

The spring system in the Caam furnishes perennial supplies of water for the only water course in Tripolitania with a permanent flow to the sea. The spring is situated at a fracture in the calcareous layer at a point where the east tilt of the calcareous bed underlying the Sahel El-Ahamed meets the western tilting calcareous horizon of Zliten Oasis. The main source of the spring is the ground water out-flow of the Caam Tarreglat drainage basin. A supplementary supply of water to the springs is the seepage flow from the Zliten area to the east, the west-lying gradient of which is inclined slightly to the south. Although the flow from the springs is perennial, it varies slightly throughout the year. After heavy floods in the wet season, output may increase to 2,500 cubic metres per hour. The supply of sweet water is occasionally interrupted when the sea-ward flow of the wadi falls to small proportions during the

summer, thereby allowing in-flow of salty sea water into the reservoir basin. Similarly, after flood conditions in the wadi, mud deposition over the fracture in the calcrete layer temporarily holds the flow of spring water in check.

The value of the springs at Wadi Caam is considerably enhanced by the presence of a natural reservoir in the mouth of the wadi, in which the accumulated supply is held throughout the summer season. The reservoir is caused by the occurrence of a compact sand bar at the mouth of the wadi, which seals off the sweet spring waters from the saline waters of the sea beyond. The containing bar across the wadi mouth is only disturbed sufficiently to allow infiltration of sea water into the reservoir during northerly gale conditions. Conditions of this type prevail infrequently, and the normal balance is soon restored depending upon the season and the replacement rate of sweet water by the springs. During the drought period of 1960, storms along the coast caused disruption of the sand bar and subsequent in-flow of sea water into the wadi; on this occasion the bar was reconstructed artificially, and the water was made fit for use again after some fourteen days.

As we have mentioned earlier, the waters of the Caam spring have been left to run to waste since the end of the Roman occupation. The total storage capacity of the reservoir is small and dependent upon the structure of the sand bar at the mouth of the wadi. Nonetheless, the total annual flow of the wadi is in the region of 17,500,000 cubic metres using the

estimate for drought year flow, and 22,000,000 cubic metres using the estimate of normal flow. Taking into account the aridity of the environment of Misuratio, this source of water is as valuable as it is unique. The major points of interest presented by the springs may be summarised as follows:-

- (i) The total flow of the Caam springs does not equal the rate of artesian springs at Taorga (12,000 cubic metres per hour), but is abundant by local standards.
- (ii) The flow is affected only slightly by the seasonal variations in rainfall and there is no record of the spring having ever dried up in periods of drought.
- (iii) A large and relatively reliable natural reservoir exists alongside the spring.

The non-use of the spring since Roman times may be accounted to the fact that the Sahel El-Ahamed is an area of recent settlement, in a region which was essentially unimproved peripheral steppe. Similarly in the east, the agricultural areas of Zliten have not extended to the Caam. Thus, the Caam littoral was situated central to a broad area of pastoral occupation where the incentive and technical ability of the population to exploit the spring waters was undeveloped. A new period of exploitation of the springs began in 1955/56 with the inauguration of the Wadi Caam Reclamation and Settlement Project. The systems of water use, and the social and economic background to the Project is described later in this thesis.

Ground Water Hydrology - Summary.

(1) The phreatic water table is the most significant element in the structure of ground water hydrology of Misuratio. Until recent years, the presence of sweet water in this aquifer made

possible the development of sedentary agricultural life in the northern littoral plain. In those areas where the layer was absent, at great depth, saline or poor in its water bearing quality, agricultural occupation was restricted to pastoralism and dry-land shifting cultivation. On the other hand, where the phreatic water table was readily accessible and abundant in supply, sedentary agriculture was able to develop rapidly towards the end of the Turkish Administration of Libya (Vide Chapter 4, p. 273). The variability of rainfall, both in terms of quantity and periodicity, which characterises Misurata, renders sedentary agriculture hazardous without the availability of alternative sources of water supply. Thus, sedentary agriculture developed in many areas which were poorly endowed with soils, badly situated with regard to the centres of settlement and exposed to adverse sea and Ghibli winds because reliable supplies of water were available from the phreatic water table. It might be said with truth, that all physical factors bearing upon agricultural production were supplementary to the key factor of availability of water from the phreatic water table. The coincidence of abundant water and fertile soils in Misurata is entirely fortuitous, but the affluence of those regions where this has occurred, such as the Sahel El-Ahamed, merely serves to throw into relief the poverty of other oasis areas.

Full understanding of the part played by the phreatic aquifer in Misurata may be had by reference to the economic and social status of the tribal groups which occupied the area

in the closing years of the last century, when the trend to sedentarisation prevailed throughout most of the nomadic and semi-nomadic cabila. A full account of these conditions is given later in the thesis (Chapter 4), but it will be of value here to note the following points:-

(a) The tribes were accustomed to a pastoral life in the steppe lands of the south, and their knowledge of agriculture was limited in the main to their experience of shifting cereal cultivation in the upper wadi basins and depressions of the interior.

(b) Technical knowledge possessed by these peoples was limited in nature and of necessity was adapted to a pastoral rather than sedentary culture. Tools and building materials of the simplest kind were necessary during the desert life, hence the transition to sedentary farming was in many ways a difficult process.

(c) Large scale works, such as the construction of wells and cisterns had been a matter of communal concern and communal action. The move to sedentarisation was associated with the birth of individual ownership and individual action; this situation increased the force of points (a) and (b).

Naturally, peoples of this kind, faced with the problem of agricultural exploitation on the littoral plain, where economic advance could be made securely only by means of reliable water supplies, turned to the easiest line of resistance. In Misuratio this line was exploitation of the phreatic water

table, which could be tapped by means of shallow wells and an easily constructed pully mechanism. Obviously, the movement of forces was two-way; the tribes of the area were subject to internal pressure to sedentarise (Vide Chapter 4) and the water table offered potentialities for settlement; similarly, the high standard of living enjoyed by the small groups of sedentary Arabi - (residual Arabo-Berber cultivators thought to have survived the Hilalian incursions and maintained oasis life during the long period of nomadic occupation) and the knowledge of the availability of water in the littoral plain created a force of attraction to the littoral plain.

In broad terms of economic growth, the phreatic water table offered a mechanism for advance to a society, whose technological level precluded use of less accessible sources of water supply in an area where successful agricultural practice is not possible without permanent sources of irrigation water being available. As we shall see later (Chapter 6), the speed and direction of exploitation of the phreatic water table, itself gives rise to a further mechanism of growth corresponding to the increase in technical and capital funds accumulated in the sedentary oasis areas.

(ii) The value of the phreatic water table is limited by the following factors:-

(a) The influence of the Sabkha of Taerga and Hescia causes diversion of the water flow in the phreatic aquifer in the regions of the east. A general infiltration of saline waters

in the body of the water table is discernable over large areas of Misurata Oasis. From evidence of more advanced cases of sabkha formations in other parts of North Africa, (30) it is likely that the surface level of the sabkha will continue to fall and thus exert an increasing influence upon the phreatic water table in eastern Misuratio.

(b) Over appreciable areas of Zliten District, particularly in the west, the incline of the calcrete crust in the soil is biased towards the south, a factor which has led to penetration of sea-water into the phreatic water table.

(c) In the peripheral steppe regions of Misuratio, the phreatic table is found at its greatest depth; yet it is in these areas where the shortage of water is most acute.

(iii) Ground water supplies from sources other than the phreatic water table have been exploited accidentally (as in the case of the dune fixation) or have been left untouched until recent years. The establishment of the Wadi Gasm Reclamation and Settlement Project marks the beginning of a re-appraisal of supplementary ground water resources. The significance of the semi-artesian water bearing layer in the Hams region and the perched water tables in the Oasis of Misurata will not be clear until a further hydrological research is undertaken.

(iv) As a preface to the following examination of artesian water resources we should note that the role of the phreatic table in indigenous economic growth will be subject to re-evaluation in the light of the recent discoveries of large bodies of deep

artesian layers in Misuratio and the level of economic advance achieved by exploitation of the phreatic water table.

(vii) Artesian Water Resources in Misuratio.

Before entering into a discussion of the localised effects of the artesian water resources in Misuratio, it will be of value to analyse the large scale effects of geology upon underground water resources of Tripolitania. The Saharan structure is built up on the pre-Cambrian 'islands' represented by the following crystalline blocks ⁽²²⁾ :-

- (a) The crystalline backbone of the western Sahara or Mauritanian chain running north-east to end in the Eglab Massif.
- (b) The Central Saharan Massif of the Hoggar.
- (c) The Tibesti Massif of southern Libya.

Paleozoic materials have been laid down around these three 'island' areas, which in Libya range from lower Silurian to the Nubian sandstone series. These primary rocks exhibit great homogeneity throughout North Africa, and form a uniform base formation throughout Libya, except in those areas where the Hercynian fracturing and faulting makes the situation more complex. Following the Paleozoic period there was a prolonged era of Mesozoic sedimentation, of which the most significant and wide-spread deposit was that of the Upper Cretaceous, which forms the base rock of the vast Hamda El-Hamra and Ghibla region of Tripolitania. The vast areas of Mesozoic sedimentation have been described as Intercalary Continental; their importance arises through the fact that the sediments form huge basins in

the interior, in which it is known that vast reserves of water are stored. (31) As we shall see later, the extent of the deep lying aquifers in Libya associated with the Intercalary Continental basins is not known at the present day, although as oil exploration continues, there is an increasing opportunity that more reliable data may be collected.

Basic to the distribution of the coastal artesian layers in Misurata, is the lay of the Tertiary sediments, thus we shall outline the course of deposition in this period. We shall not enter into argument concerning the exact causes and precise areas of movement in the interior, since they do not affect the situation of the artesian aquifers. The key fact is that prolonged erosion around the Tibesti, or gradual orogenesis resulted in the formation of an extensive sunken basin almost to the foot of the Tibesti massif; this basin is now more familiarly called the Sirtican Embayment. During the period of the Lower Eocene, the seas advanced along the line of the Sirtican Embayment roughly in that region lying between the longitudes of 16 and 20 East and as far south as latitude 25 South. Thereafter the Eocene sediments in the Embayment represent a gradual withdrawal of the sea to the north on an axis aligned approximately from WSW to ENE (Vide Figure 33). At the close of the Eocene period, the line of the sea was probably in a general line from the region of Ben Uliid to the oasis of Marada south of El-Aghella. A less gradual withdrawal of the marine transgression characterised the Oligocene period of

deposition. In terms of the artesian layers at present underlying the Jefara and Misuratino areas of Tripolitania, the post-Oligocene geology is profoundly important. During the Miocene period, deposition in the Miocene sea left behind continuous beds of rock. In Misuratino and the Jefara proper, sedimentation was intermittent dependent upon the fluctuations in marine incursion, but significant layers of material, both Helvetian and Tortonian in age were laid down on the area of transgression (Vide Figure 20). In the post-Miocene era, these sedimentary rocks have been covered by Quaternary deposits of eolian and alluvial origin. This rough sketch of the geological evolution of the water bearing strata, its distribution and sequence indicates the broad outline of physical factors relevant to the following discussion of the artesian layers of Misuratino.

Hydrological research in Tripolitania is in an exceedingly poor state. In the pre-War years, the Italian administration financed a scheme of exploration into the artesian water resources of the region with a view to discovery of new areas where water could be provided for settlement of Italian peasant farmers (Vide Chapter 6, p. 630). The published works of Desio⁽¹⁹⁾ and Della Gatta⁽³²⁾ are still the basic authorities upon which we must draw for information in spite of the fact that Italian work was completed under emergency conditions in the late thirties and early forties. It is now known that Italian activity in the field of exploration was intended to probe those areas where there was a possibility of discovering

oil resources, thus from the late thirties, water prospecting was a secondary consideration. This bias towards exploration for oil resulted in a tendency to conceal most of the findings brought to light during these latter years. Since the war, development of water resources has been sporadic and irrational. Under the British Military Administration, funds and equipment were in short supply, hence activity was restricted to more accessible resources. In the years following independence (1951), a large number of unco-ordinated agencies including the Nazara of Agriculture, the Soils and Water Division of LAJS (Libyan American Joint Services) and United States Overseas Mission to Libya have been responsible for small and unintegrated research and development projects. Inter-departmental rivalries and haphazard Government interference have all contributed to the poor level of advance in knowledge of artesian water resources. It should be appreciated that intense oil exploration throughout Tripolitania will bring new light to bear on the situation provided that all the accumulated material is co-ordinated by one central authority. In the following examination of the artesian formations of Misuratio, the suggestions made are subject to the limitations arising from the situation as outlined above.

The stratigraphical composition of the bed rocks underlying the Jefara and Misuratio was outlined by Desio⁽¹⁹⁾ on the basis of exploration work completed in 1940, and this work must be regarded as the most authoritative statement of the situation.

Laurenti's work in the same period brought slightly differing conclusions, but in principle, the form of the geological strata as suggested by Desio was not seriously challenged. (27)

Desio proposed that the important strata of the Jefara and Misuratino were as follows (Vide Figure 34);

(a) Superficial deposits of sands and rock detritus from the Jebel - Quaternary and recent in origin. The depth of these deposits varies considerably from area to area as we pointed out in earlier discussion of soils in Misuratino (Chapter 2, p. 45); in general it may be said that the superficial sand cover increases in depth towards the Jebel.

(b) Fortonian strata of white or yellow limestone of a highly porous nature. The maximum known depth of the formation is about 80 metres.

(c) Clays and marls with intercalations of sandy limestone of Helvetian age; the clays and marls are very fossiliferous. Thickness of 400 ms.

(d) Sand, sandstone and gravel with small intercalations of shingle and pebbles. Maximum known depth of the formation about 80 metres.

(d) represents the base level of the Miocene transgression into the area. It is underlain by a series of sandstones and limestones, which are not yet fully explored. The sands and gravels of this stratum are permeable and capable of holding large amounts of water in storage. The impermeability of the underlying pre-Miocene substratum and the retaining effect of

the impervious clays and marls of the Helvetian series, results in the high degree of water retention in the Langhian strata. Desio summarises his findings on the nature of the water bearing series by suggesting that the lithological character of the Langhian layer suggests that it is an intrusive deposit. The sub-stratum beneath it exhibits no chronological relationship, and in many ways may be attributed to Cretaceous and Triassic times. Thus, it is concluded that the artesian aquifers of the Tripolitanian Jefara are contained in transgressive strata, which are located at the base of the Miocene and which for the most part may be ascribed to the Langhian era.

The immediate contact of the Miocene series with the pre-Miocene sub-stratum below causes localised differences in the nature of the aquifer corresponding to the topography of the sub-stratum. Hence, the depth of the artesian layers and the output of wells bored into the layer varies over relatively short distances. Further variations arise from the structure of the water bearing stratum itself; in many areas, the sands and gravels, sandstone and pebble lenses change in their ratio one with another over short distances. Until exploration and research reveal more information concerning the topography of the pre-Miocene sub-stratum, the extent and the location of the various structures will not be known with any precision. In the region of Tummina, for example, in the ex-Italian development area, the depth of the aquifer varies in depth up to 100 metres, and the flow of the well varies up to 200 cu/metres per

hour over distances of less than 500 metres on the horizontal. Over greater horizontal distances, the aquifer may vary from 400 cubic metres per hour in well out-put to no out-put whatsoever. These observations will indicate the importance of the need to further exploration of the pre-Miocene sub-stratum. In Misuratio the only conclusive evidence at present at our disposal points to the fact that the sub-stratum falls away to the north and east in the littoral plain, and to the east in the steppe south of Misurata towards the Sirtican Embayment.

It may be seen from the data contained in Figure 34 that the strata of the Miocene series declines in thickness and in depth from the coast to the line of the Cretaceous rock which marks the Jebeline foot-hills and the approximate limit of the Miocene transgression into Misuratio. Similarly, the depth of the Miocene series underlying the lowland from Misurata to the region of Sirte decreases from east to west, terminating along the line where the Miocene Sea met the Paleozoic basement of the interior. In the extreme west of Misuratio, the Cretaceous promontary of Msellata forms a hydrological barrier, separating the two independent basins of Misuratio and the Jefara. The Italian geological survey records a thin covering of Miocene rocks on the Msellata ridge. The origin of the Miocene in this Jebel area was never fully explained by the Italian authorities, (33) and oil company exploration in the area tends to discredit the idea of extensive beds of Miocene in the region. No doubt further research will clarify the situation; in the present

context, these Miocene beds are insignificant, since they do not form a hydrological link between the two Jefaran basins and are unimportant in terms of the hydrology of Misuratino.

The accumulation of water in the permeable Langhian strata in Misuratino may be accounted to the effects of infiltration of precipitation and wadi floods into the aquifer at the junction of the Miocene and the pre-Miocene substratum. In this respect Misuratino and its hinterland differs considerably from the Jefara proper. Viale⁽²⁴⁾ and Desio⁽¹⁹⁾ ascribe the source of artesian waters to infiltration along the bed of the pre-Miocene series via the second water table. In the Jefara region, the second or semi-artesian aquifer lies between the impermeable layers of Tortonian origin, and the impermeable plastic clays of the Helvetian series in a stratum of siliceous sands. Conditions in Misuratino are quite different. As we pointed out earlier in this chapter, the Italian conception of the Miocene geology of the area was exceedingly limited. Miocene out-crops were thought to be limited to the coastal plain and to the area of Melliata. In fact, research by C.G.F.H.A. has indicated clearly that much of the formation of the foot-hill zone is made up of Miocene, the beds of which are to be regarded as Helvetian in date.⁽⁷⁾ This discovery raised two very important questions; is the Tortonian series absent from Misuratino? If this is so, what mechanism of water accumulation applies to the aquifers of Misuratino?

The answer to the former question appears to be that it

is absent from the area of the northern coast, and if it occurs at all in the eastern sector of the region, it will be at depth and confined to the coast immediately underlying the sebkha. Thus the aquifer will be fed by the action of water of flood and rainfall origin moving down the incline of the pre-Miocene basement, in the first place below the Helvetian deposits and thereafter into the Langhian sands and sandstones. In comparison with the Jefara of Tripolitania, the mechanism of water catchment is located over a far greater area; replenishment of the aquifer will be more sporadic in Misuratio corresponding to the sparse rainfall and intermittent flow of the wadis in the area. Discussing the relative merits of the aquifers in the Jefara and Misuratio, Laurenti came to the conclusion that the rate of accumulation of water in the aquifers of Misuratio exceeded that recorded in the Jefara. (27) This contention remains to be proved by boring tests, but the out-put of wells in the Tumina, Kararin and Misurata areas, and the spring flow at Taorga, indicate that the under-ground supplies are abundant and under appreciable hydrostatic pressure.

At the present time the primary points of location of the deep artesian aquifer in Misuratio are in the ex-Italian estates at Tumina and Kararin; little published information is known of other areas outside this zone. Nonetheless there are several recently discovered factors which suggest a possible disposition of the aquifers:

(a) The so-called semi-artesian layer which has been located

in the Homs region associated with La Valdagne concession is known to be positioned in strata, the character of which closely resembles the Langhian sedimentaries of the Jefara. Unfortunately, no final authoritative statement upon the age of the series at La Valdagne has been made as yet.

(b) The thickness of the Helvetian deposits reported by C.O.T.H.A. in the region of Wadi Caam indicate that the Langhian must be at only shallow depth below, especially in view of the fact that the Helvetian strata reach their most narrow section, where they merge onto the pre-Miocene front, some six or seven kilometres inland from the mouth of the wadi. It is tentatively suggested by C.O.T.H.A. that the argillaceous sandstones which were found underlying the Caam basin represent the basal strata of the Helvetian sedimentaries. (7)

(c) The piezometric levels recorded by the wells in the Tummina-Kararim area indicate that the configuration of the aquifer is governed by the eastwards dip of the pre-Miocene substratum into the Sirtican Embayment.

(d) The work of Desio (19) and Laurenti (27) in the Jefara show that the conformation of the artesian layer tends to follow the coast-line of the Miocene Sea.

On the basis of this evidence, we may suggest tentatively, that the deposition of the deep artesian layer in Misurafino is confined to the eastern sector of the region, i.e. east of Dafnia (Vide Figure 30). In the area to the west, factors (a) and (b) would seem to give slight evidence that the artesian

layer rises to the surface in the vicinity of the Cretaceous sub-stratum. Point (d) above gives supporting evidence to the theory, but further deep drillings would be necessary before the exact extent of the Langhian series could be stated with certainty.

Mention must be made here of a fourth artesian layer which has been located both in Misuratino and the Jefara at a depth of some 700-800 metres. At the present day the water resources held by the fourth aquifer are unexplored; Italian boring equipment in the pre-war years was unable to meet the demands placed upon it by the great depths involved in penetration to the fourth artesian layer. In the post-war years, the mass availability of deep boring rigs should bring about a re-appraisal of this latent resource.

Thus far, the discussion of artesian water resources in Misuratino has been confined to examination of the distribution and nature of the aquifers underlying the region. No relationship has been suggested between the trends in indigenous economic growth and utilisation of the artesian basins. This arises from the fact that exploration and exploitation of the artesian waters of Misuratino was undertaken by the Italian colonial authorities without reference to the needs of Arab agriculture. In the years up to 1951, the artesian resources of Tripolitania may be accounted to the sole use of the Italian sector of the agricultural economy. To recapitulate the points we suggested earlier in respect to the development of the phreatic water

table; the indigenous community possessed neither the technical talent nor the financial resources to exploit the deep water bearing strata of the area. The Italian and Arab sectors of the economy continued as separate planes of operation (Vide Chapter 6, pp. 52B) ; to some extent, the indigenous economy was under stress from the European sector - the sum effects of new ideas and new crops introduced into the area by colonists tended to augment the inherent trend in Arab Society towards economic growth. Since 1951, two factors have been important in adjusting the relationship between the artesian resources and the Arab agrarian economy:-

(i) The forces of growth within the Arab economy have culminated in a general break through in the cases from self-sufficient to commercial farming. The incentive to increase production and the increasing availability of investment funds have led to a far reaching re-evaluation of water resources. Some Arab farmers show skill in land use and cultivation which exceed those exhibited by the bulk of Italian peasant colonists in Tripolitania.

(ii) Political and economic difficulties which have beset the Italian sector of the economy have resulted in a wide spread repatriation of the peasant farmers who occupy the demographic estates in Tripolitania. The farms vacated by the Italians have been taken over by Arab operators to a greater or lesser extent depending upon the area (Vide Chapter 6).

Within the last decade, the indigenous economy has moved

gradually to a position where the artesian resources and the units of exploitation of those resources have been integrated into it. We shall discuss the mechanism of exploitation in the following part of this chapter.

SUMMARY - ARTESIAN WATER RESOURCES

(1) The greatest problem associated with the artesian resources of Misuratio is the lack of information concerning their extent and depth. Until further exploration is completed, no authoritative picture of the position can be drawn up.

(ii) Extensive artesian beds underlie the eastern area of Misuratio; the situation in the west is inconclusive although circumstantial evidence indicates the presence of the Langhian layer at shallow depth.

(iii) The initial work of exploration and exploitation of the artesian resources of Tripolitania was undertaken in the 1930's by the Italian Government, and the fruits of the work were intended for use in schemes of colonial settlement. In the period since 1951, the indigenous economy has reached a level of advance where it has been possible to integrate ex-Italian artesian development into Arab farming practice.

(4) Utilisation of Water for Agricultural Development.

In this examination of the balance of water supply in Misuratio, we have seen that the given physical elements in the environmental situation of Misuratio each bear upon the distribution of water supplies, either directly or indirectly. Nonetheless, each of these elements, from soils to relief is

important only in its effects upon the distribution and nature of the water supplies; individually, they are unimportant alongside considerations of water availability. We may re-state here a case example which we have used previously: in the Oasis of Misurata, water resources in the phreatic water table are utilised for agricultural purposes without regard to the fertility or infertility of the soils, exposure to or shelter from prevailing winds and favourability or unfavourability of topography. Thus the pattern of agricultural development will be closely associated with the underlying pattern of water availability in any area.

As we have mentioned previously, the question of water availability must be assessed both in terms of the difficulties of exploitation presented by the environment, and the varying levels of technical advance present in human society, which makes possible, or precludes, exploitation of each of the known water sources. In the succeeding paragraphs we shall analyse by case studies the use to which the various water sources are put in Misurata with particular reference to the position and the importance of each source at the various phases of economic growth. This examination will thus serve as a preface to later study of the broader implications of economic growth in the region.

(A) Indigenous Oasis Development.

The most readily accessible source of water supply in the littoral plain areas of Misurata is the phreatic water table. At the time when the cabilla of the region were under-going a



ABOVE Well superstructure, pulley system and dalu water lift. Location - Sahel El-Ahamed.

BELOW Well head and superstructure without tackle.



process of sedentarisation, the water reserves of the shallow aquifer offered a basis for static agricultural exploitation. The process of sedentarisation was itself protracted and complex (Vide Chapter 4), and the associated factors of readjustment slow to develop. As we shall demonstrate later in the thesis, the evolution of irrigation in the oases tended to be governed by several inter-related forces of economic growth, particularly by the beginnings to commercial agriculture (Vide Chapter 6, p.680). Nevertheless, during the early period of extensive settlement in the littoral oasis areas, the dalū well was the universal means of water exploitation from the phreatic water table.

(a) The Dalū.

The greater part of the suani of Misuratio derive their irrigation water from the phreatic water table by means of a shallow well, of varying depth depending upon distance from the coast. The traditional method utilised to raise water from the aquifer is simple and ingenious. It consists of a goat skin bag (dalu), which is shaped roughly as a cylinder, open at one end and closed at the other; this cylinder is let down in to the well by a long rope, which is guided by a pulley set in a rough gallows framework above the well (Plate 1). During the ascent of the dalu, the rope is drawn over a bobbin pulley set further down the well superstructure. The power necessary for the ascent and descent of the dalu is provided either by the women or by animals. Normally a camel or cow is used for the purpose under the supervision of the farmer. An inclined

culvert is constructed from the well head down at an angle of 35-40 degrees to a length exactly co-mensurate with the depth of the well. Movement of the traction animals down this culvert ramp eases the burden of raising the full container, and the dalu is empty during the ascent. The water brought to the surface by the dalu is fed into a storage tank which lies alongside the well-head.

The simple method of water raising, which is characteristic of several of the oases of Fezzan, much of Cyrenaica, and is found in coastal areas of the Gulf, is tedious and yields low quantities of water; nevertheless, it does provide a reliable source of water for irrigation in the littoral areas of Tripolitania. We may list the other advantages possessed by the dalu as follows:-

- (i) The superstructure of the well may be moved from one bore hole to the next as occasion demands.
- (ii) The simplicity of the mechanism enables water-drawing to be supervised by a child or woman, thus allowing the farmer freedom to continue with the more pressing problems in the fields.
- (iii) Replacement of the dalu and other moving parts is effected easily and cheaply, since most of the structure can be built or made by members of the household.
- (iv) The low out-lay necessitated by the dalu and the low running costs of the system are further factors which enhance the position of the dalu in indigenous farming.

Reticulation practice on Arab farms has tended to grow more diverse as the process of economic growth has gathered momentum; the influence of Italian ideas and machinery has brought an increased number of techniques within the scope of



ABOVE Gedula pattern

BELOW Primitive dal



the indigenous farmers. The wide-spread method of water distribution employed in the oases of Misuretino is the traditional 'gedula' system, in which flood irrigation is guided into small, metre square plots, which have been prepared for cultivation. Depending upon the gradient of the land, the water may be fed through several gedula lying laterally to the main irrigation channel leading from the storage basin alongside the well.

The out-put of galy wells is known to be low compared with mechanised systems of water raising. The main factor controlling the rate of withdrawal is the depth of the well, and thus the length of culvert down which the power animal must drag the ropes attached to the galy. In the same context, variations in the efficiency of withdrawal arise through the use of different animals; donkeys tend to be better in this respect than camels or cows. Bologna⁽³⁴⁾ estimated that, for a well of 25 metres depth, each lift requires roughly one minute fifty seconds. With a galy of 58 litres capacity, it would be theoretically possible to raise 33 galy in one hour, or 1,914 cubic metres per day, and in one year of 300 working days, 5,742 cubic metres. In terms of the day-to-day water needs of the farm, this quantity would not be required, since irrigation is of necessity used only occasionally. The essential factor in the situation, is that only 1,914 cubic metres are available on any given day, hence the area of cropland that may be irrigated is limited. Bologna cites the case of groundnut cultivation, where the limit to the cultivable area would be 1,439 metres, given the above

conditions of dalu capacity.

Thus the greatest disadvantage associated with utilisation of the dalu of water raising is the inherent limitation placed upon the amount of winter, and to a greater extent, summer cropping. A measure of historical perspective must be brought to bear upon the situation, since the out-put of the dalu was adequate to meet the demands placed upon it by self-sufficient farming. Subsistence farm operators, a classification which encompassed all of the farmers of Misuratio in the era following upon sedentarisation, and which includes approximately 60% of indigenous farmers at the present day (Vide Chapters 5 and 6), are able to draw water sufficient to irrigate their so-called 'kitchen-garden' and provide for their domestic requirement with modest use of the dalu. As the agrarian economy advances, increasing varietal specialisation and expanding production for commercial markets renders the dalu obsolete. Nonetheless, the position of the dalu water raising mechanism must be assessed in view of the fact that it provided a well-tryed, cheap and simple means of exploiting the phreatic aquifer for a society alien to sedentary farming and unversed in techniques of a more complex nature.

(b) Modern Diesel Pumping.

The introduction of the diesel pump was associated with the Italian sector of agriculture in the pre-War years. Since the war, the use of diesel pumping methods has spread to the Arab farming economy on a large scale in Tripolitania in the areas

of the Jefara. In large part, use of the diesel pump has been confined to those areas where the second, semi-artesian, water layer is accessible to shallow bores. As we have pointed out previously, the incidence of the semi-artesian water table in Misuratino is limited to small areas in the oases; recent geological research in the Wadi Caam area indicates that the semi-artesian layer as it is known in the Jefaran areas may not exist at all in Misuratino. Certainly, the restricted extent of the second water table, whether it is an equivalent to the sub-artesian layer or not, has discouraged the use of diesel pumping. The replenishment rate of water in the wells pierced to the phreatic water table tends to be slow; in the Misurata district, for example, many wells can be drawn upon only one day in five; in Homs (Leptis) area, wells are normally drawn one day in three, by dalu wells. Thus, the installation of diesel pumps in these areas would be inefficient. In the Jefara area of Tripolitania, the wells drawing from the semi-artesian layer have a high rate of replenishment, hence the diesel pump has proved to be a profitable investment in these areas and has enjoyed a wider distribution than in Misuratino.

In those areas where the water replenishment rate in wells is rapid, the efficiency of the diesel pump may be rated as follows (after Bologna)⁽³⁴⁾ :- In the case of a well, the total head of which is 25 metres with an out-put of 25 cubic metres per hour, the pumping unit normally used in Tripolitania would be a diesel engine of 5/6 H.P. with a KW power generator and an

electric pump of $3\frac{3}{4}$ H.P. In eight hours working, the out-put from this unit would be 25 x 8 or 200 cubic metres; during periods of peak load the daily out-put per hectare would be 800 cubic metres or 133 cubic metres. Thus, assuming the cultivation of groundnuts, the cultivated area could be as large as 15,030 square metres. Bologna took the standard rate of water application to groundnuts as 27,000 cubic metres of water per $1\frac{1}{2}$ hectares during the growing cycle. The performance of the diesel pump in terms of area served surpassed that of the dal by more than tenfold.

The diesel pump has increased in popularity in Misuratio in the years since 1951. At the present day, many commercial farmers in the oases are adopting mechanical water raising to replace the traditional dal; in a Questionnaire Survey conducted in the oases in 1960, of the farmers who were interviewed, all those producing commercial crops reported ownership of diesel pumps. The greatest incidence of pumps was recorded in the Sahel El-Ahamed, where both the phreatic and sub-artesian layers have rapid rates of replenishment in the well bores. In terms of economic growth the position of the mechanised pump is significant; as we shall indicate later, the demand by any farm operator for a diesel pump usually signifies that organised commercial farming is underway on his farm. In concise form, we may say that increased varietal specialisation of cropping takes place during the phase of self-sufficient farming, a tendency which culminates in occasional, fortuitous surpluses

which are sold at market. Accelerating commercial activity implies greater specialisation in cash crops, most of which are summer grown and thus in need of more ample and regular irrigation. The strict limitations upon the out-put from dalu wells becomes insufficient to meet the water demands, and if the normal processes of economic expansion are to take place, the dalu must be replaced by the more efficient diesel pump. Further discussion of the mechanism of investment in subsistence and commercial farming is given in Chapters 5 and 6.

In summary it should be pointed out that:

(i) the ownership of a diesel pump generally signifies that a farmer is committed to commercial production; the costs of installation and maintenance are prohibitive under self-sufficient farming.

(ii) the introduction of diesel pumping is tending to increase localisation of commercial cropping to those areas where the phreatic, or more usually the second aquifer offers a high replenishment rate of water in well bores. At the present time, the greatest number of pumps are located in the Sahel El-Ahamed.

(iii) reticulation methods associated with the diesel pump follow closely the pattern of the gedula, which we have outlined in relation to the dalu well. As we shall indicate later with reference to the direction of investment in the rural economy, rationalisation of water distribution over the farm area does take place during the early period of commercial farming. This process results in more expert use of the gedula system rather

than its replacement.

(B) Exploitation of the Second Aquifer - Pumping by Electric Power at Concession La Valdagno.

The agricultural estate of La Valdagno lies to the south-east of Homs Village. Founded in 1938/39, the estate covers some 1,864 hectares of the land adjacent to the Oasis of Homs. The irrigated area of La Valdagno totals slightly over 600 hectares, two thirds of which is cultivated for field crops, and the residue for irrigated olive plantations.

Electrical power for the pump system is generated in a central power house owned and run by the estate management. The power units consist of one diesel of 375 H.P., one diesel of 250 H.P., and two auxiliary diesels of 80 H.P. Power is fed out from the power station to the pumps associated with each well. A summary of the distribution network, the well depths and related data is given in Figure 35.

The out-put of the wells at La Valdagno varies between 35 cubic metres per hour and 64 cubic metres per hour, the more productive wells being situated in the south-west of the estate immediately bordering the foot-hills of the inner steppe. The siting of the wells was determined in large part by the distribution of share-cropper farmsteads, since each farm is placed more or less geometrically in the central area of the estate, and each farm was provided with a well and pumping facilities.

Each well system is augmented by a tank reservoir of 150 cubic metres, from which irrigation water is distributed by means



ABOVE Distribution of irrigation water by subterranean pipes and syphons - La Valdagne.

BELOW Primary irrigation channels - Tummina.



of underground pipes to the cultivated areas surrounding the farmstead. The piping system was originally of reinforced concrete, but recent sections of the net-work have been executed with metal pipes. The use of subterranean pipe distribution was intended to save the wastage of land that was normally the case where open canals were utilised, and to reduce water losses inherent in the open canal system. As we shall point out later, the underground pipe distribution of irrigation water tends to be a heavy capital investment, but one which can be made to work efficiently on a large scale commercial farming unit.

The initial capital investment at La Valdagno is not disclosed; it is clear nonetheless, that this type of development is beyond the means of most of the indigenous farm-operators in Misuratino. The success of the Valdagno experiment has arisen through the unified control of irrigation equipment; should indigenous society exhibit the predicted tendency towards co-operative development, or should Government control of development lead to large scale settlement estates the example provided by La Valdagno will be significant.

(C) Exploitation of the Artesian waters of Misuratino - Italian Development at Tummina.

The politico-economic background of Italian colonial settlement in Misuratino is out-lined later in the thesis (Chapter 4, pp. 310); in the present context the significant points of note are as follows:-

(i) The Italian Administration in Libya had embarked upon a

scheme of mass colonisation of Cyrenaica and Tripolitania in the early 1930's.

(ii) The main agent of colonisation was Ente, which was empowered to develop the lands sequestered from the Arabs for the purposes of rural settlement of peasant farmers.

(iii) The purpose of colonisation was essentially political; the establishment of a land-based class of Italian peasants was intended primarily to stabilise the area militarily and thereby increase Italian strategic influence in the Mediterranean (Vide Chapter 4, p.309).

(iv) The strong political motive behind colonisation schemes in Tripolitania resulted in a tendency to ignore costs of construction and ultimate profitability of the agricultural holdings granted to settlers. Appraisal of land for development purposes was based largely upon the criteria of the speed with which an estate could be constructed and settled and the number of individual farms which could be built on the estate. Thus it must be borne in mind that the estate of Wummina (ex-Crispi) was constructed because land reclamation and land settlement could be effected rapidly and on a large scale.

As we have mentioned previously, intensive exploration activity in the 1930's to establish the location and distribution of oil and water resources in Tripolitania resulted in the discovery of a deep artesian layer in the littoral steppe south of Misurata. Development and reclamation of the Tummina and Kararim areas was finished in 1940, shortly before the outbreak

of war in North Africa. It will be of value to outline the estimate of water resources drawn up by the planners of Ente, and the nature of technical development of these resources in the estates of Tummina and Kararim. (14)

Table 13 - Depth of Wells at Tummina, in Metres

<u>Well No.</u>	<u>Depth of Aquifer</u>	<u>Depth of Bore</u>
1	353	405
2	336	410
3	413	482
4	399	406
12	400	528

Data from Water Resources Division, L.G.J.S.

Table 14 - Hourly Out-put of the Wells at Tummina - Cu./ms./hr.

<u>Well No.</u>	<u>Out-put per Hour</u>
1	350
2	300
3	350
4	350
12	250

Data from Water Resources Division, L.G.J.S.

Table 15 - Quality of the Water from Wells at Tummina.

Fixed residuum at 110 a litre	grs.	3,290
Fixed residuum at 180 a litre	grs.	3,070
Chloride	grs.	1,200
Magnesium	grs.	104
Calcium	grs.	270
Sulphates (SO ₄)		570
Total Hardness in Fr. Degrees		106

The water also contained traces of hydro-sulph. acid.

Data from Nuovi Centri Agricoli, 1938. (14)

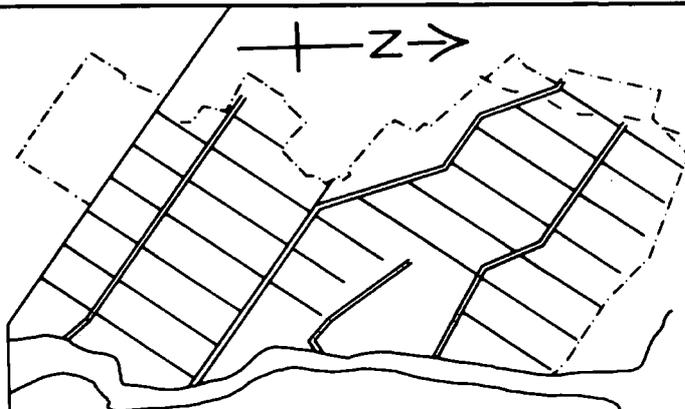
The water bearing layers lie at a depth of some 400 metres below the ground (Vide Figure 30). Table 13 indicates the

variations of water levels from well to well throughout the area of the estates. The water level underlying the zone is fully artesian, the water in each well rising to the surface under its own pressure. Well One at 18 metres above O.D. has a pressure of 1.2 atmospheres and therefore a spout of about 15 metres above ground level. The hourly out-put of wells is shown on Table 14; these figures compare favourably with out-put of wells in the Jefara. It was estimated originally, that from the twelve wells drilled on the estates, there would be an out-put of some 300,000,000 cubic metres of water, the bulk of which would be available exclusively for irrigation purposes.

During this early period of construction difficulties arising through the nature of the water and the soil, both of which elements exhibit moderate to large alkaline content, were passed over rather lightly. From analyses of water samples derived from the provisional borings at Tummina, it was evident that a measure of care would be necessary in the utilisation of water for irrigation. The results of the original water analyses are presented in Table 15. Experience since 1940 has shown that heavy irrigation applied to the rather salty soils may produce localised, and even general concentrations of salts in the soil.

Italian propaganda of the time minimised the problems inherent in the high chemical content of the water from the deep aquifers. The original plans for total irrigation of the farm plots were put aside as the influence of salt concentrations in the soil became apparent. A system of staggered irrigation of

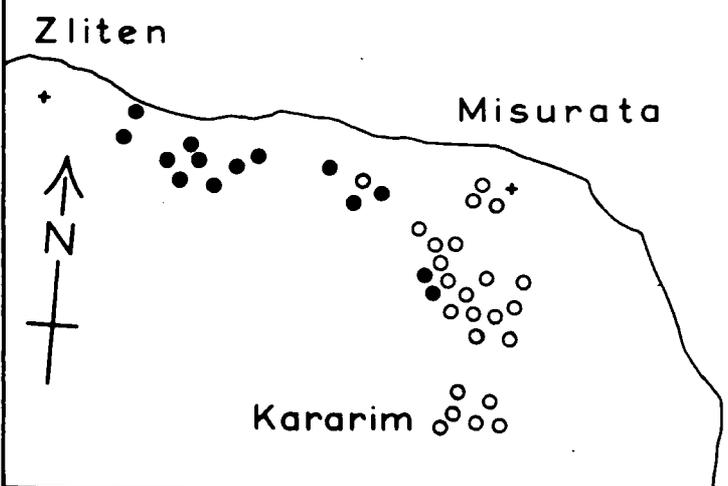
WADI CAAM SETTLEMENT
PLAN OF CANAL SYSTEM



0 ————— 1 Kilometre
 = Primary Canal
 — Secondary Canal

Figure 37

WELLS PERFORATING
3rd. AQUIFER — MISURATINO



10 0 30 Kilometres
 o Artesian Well
 • Non-Artesian Well

Figure 36

the field plots was introduced onto the Italian farms which involved a three year rotation on any given farm unit, in which five hectares were left fallow each year.

The distribution of wells at Tummina and Kararim is illustrated in Figure 36. Wells were drilled to permit each well an exclusive withdrawal zone of diameter one and a half kilometres to prevent over-withdrawal from the water bearing strata and the consequent danger of in-seepage of sea water. In fact, several of the wells which were constructed during the early period of development proved to be dry and secondary bores were sunk in their vicinity; the distribution of wells both flowing and dry is illustrated in Figure 36. The well shafts are drilled to an internal diameter of 280 mms. and are cased with steel tubing; Italian publications of the period put the yield of the wells at Tummina at 360 cubic metres per hour, a figure which varies slightly according to the altitude and the location of the well bores. (14)

Reticulation of the waters is arranged by means of a canal system where the lie of the topography permits. The use of open concrete canals has the advantage that seepage is reduced to a minimum; on the other hand, evaporation from the water surfaces in the canals results in appreciable water losses. Each well on the estate is equipped with an independent canal network fed from a concrete reservoir tank alongside the head of each well. The flat to slightly undulating nature of the terrain allowed the use of gravity irrigation throughout much

of the distribution systems. In the western margins, a mixed distribution system of gravity and underground tubing is in use, since the land surface tends to be more irregular.

The farm units in the centre and east of the estate are served by open canals leading from the central reservoirs on the following pattern:-

(i) Principle canals with a cross section of 0.20 square metres and a gradient of 0.50% . The canals are constructed of reinforced concrete casts, jointed with a mixture of cardboard and bitumenised cord at intervals of six metres. The concrete blocks are raised on reinforced concrete supports spaced at three metre intervals. The principle canals link up the well heads and the reservoir tanks and also convey the water to all the farms on the estate along one border of each farm. The length of primary canal serving any one well varied according to the location of the farms; for Well One at Tummina, it is recorded that there are about 3,000metres of primary canal serving some 32 farms.

(ii) Secondary canals are constructed of exactly the same materials as the primary system although in this case, the dimensions are less, the section being 0.08 square metres and the gradient 0.50% . For Well One at Tummina, 10,000 metres of secondary canal were necessary to distribute the flow from the principal net-work.

(iii) The tertiary canals have a capacity of one third of the secondary system, having a section of 0.03 cubic metres.

Construction of the tertiary canals appears to have been done with the use of clay and plaster, roughly shaped and mounted on earth banking where it forms a junction with the secondary system. It was planned that the tertiary canals should serve irrigated strips of 60 metres on each flank, the distance between each canal being some 120 metres. There are about 20,000 metres of tertiary canal associated with Well One at Tummina, of which the greater part is still in every-day use.

(iv) Final reticulation is effected by means of the gedula system, which we have described with reference to Arab systems of irrigation in the oasis areas of Misuratio. In general, the Italian farmers tend to utilise a larger gedula of 4 metres by four metres rather than the smaller indigenous plan of 4 square metres or less.

(v) A small number of the wells at both Tummina and Kararim utilise an integrated system of open canals and underground pipes. It is significant that agricultural areas served by this type of distribution net-work have been amongst the first to be abandoned. The subterranean tubes have tended to corrode rapidly and thus have reduced the efficiency of the system. At La Valdagno concession, where central authority is responsible for maintenance of the capital installations, underground piping has worked well; at Tummina and Kararim, where authority is more de-centralised, the net-work has been neglected and has fallen into disrepair.

The exploitation of the artesian water resources by the

Italian colonial administration has been a technical success, notwithstanding the localised problems associated with increasing salt content in the soils and the variability of yields of water from the wells serving the estates at Tummina and Kararim. (25)

The experiment has shown that the artesian waters can be made to provide a satisfactory basis for agricultural development in the steppe regions of Misuratio. Assessment of the value of artesian waters in terms of indigenous agricultural growth is confronted by several undermined factors which may be listed as follows:-

(a) The nature of the indigenous economy in rural areas of Misuratio, particularly the absence of any monied or landed class of proprietors appears to rule out the possibility of private development of artesian wells. In the Jefara of Tripolitania, exploitation of artesian resources is in the hands of Italian, Tunisian and Palestinian operators; Libyan participation in large scale developments has been insignificant. This pattern has not been broken in Misuratio, where Arab social and economic development is even more retarded than in the Jefaran areas. Thus, we may say that private reclamation of steppe lands and development of artesian resources will remain outside the scope of the Libyan agricultural economy in the foreseeable future.

(b) A discernable tendency towards rural depopulation is operating in the oases of Misuratio at the present day. This tendency corresponds with the general acceleration of economic growth within the area, a feature which we shall discuss and

enlarge later in the thesis. Successful Arab farmers are expanding their oasis possessions in the fertile areas such as the Sahel El-Ahamed; at the other end of the scale, the rural labouring class is gravitating towards the urban areas, particularly towards Tripoli.

(c) Thus, we are faced with the dilemma - private development of the artesian waters is unlikely, therefore Governmental development will be necessary if the resources are to be exploited. From point (b) it is apparent that such development by the central authorities would meet with the problem that only poor and indifferent farmers would be available to populate the newly reclaimed lands of the steppe. As we shall see later in reference to the Wadi Gaam Reclamation and Settlement Project, development schemes catering exclusively for landless labourers and poor farm operators are unsoundly based.

(d) The difficulties of re-settlement of Arab farmers on modern farm units are more fully examined in Chapter 6, p. 668. In the present context we should note that the existing estates at Tummina and Kararim have been partly abandoned by their Italian owners; in very few cases have these farms been taken over and utilised in a rational manner by the local Arab peoples. This does not appear to be an auspicious omen for further development in the steppe areas.

As a summary of this assessment, we may say that future trends in economic growth, augmented by the spread of rural education and agricultural extension activities may bring the



ABOVE The Caam Reservoir

BELOW A main irrigation canal-Wadi Caam Settlement



level of indigenous agriculture to a position where the ex-Italian estates and other major or supplementary reclamation schemes may be absorbed into the over-all pattern of growth. (Vide Chapter 6, p. 679). When this stage is reached, the artesian waters of Misuratio will become important in terms of Arab agricultural exploitation.

(D) Modern Arab Development at Wadi Caam.

The Wadi Caam Reclamation and Settlement Scheme offers a case study of Government development of water resources in Misuratio. In the present study a concise analysis of the Settlement will help to elucidate the problems which have been mentioned in the preceding section of this chapter, and will serve to outline the technical background to modern developments in Tripolitania.

The Wadi Caam Scheme comprises some 270 hectares of land in the oasis zone adjoining the Sahel El-Ahamed. Each farm is made up of two irrigated plots of two irrigated hectares gross (1.64 hectares net), part of which is taken up by a small two-roomed farmhouse. The plots of each farm are separated by a lateral irrigation ditch.

Three main canals distribute the water from the pumping stations alongside the natural reservoir at the mouth of the Wadi Caam, where the spring out-let from the phreatic water table emerges through a fracture in the calccrete layer. The main canals are raised to a level of three to four metres above the general ground surface of the estate, and their one metre

breadth inner channel is lined with a compound of caliche, gypsum sand and cement. Water is fed out from the main transverse canals by gravity to a series of lateral secondary canals (Vide Figure 37). The final stage of reticulation is achieved through minor ditches leading from the lateral canals across the farm plots. The main canals were built to carry up to 800-1000 cubic metres per hour; the laterals have a capacity of 200 cubic metres per hour. The lateral canals draw from the main canals at 50 metre intervals, and each lateral is provided with subsidiary ditches at intervals of 100 metres. Some 3,850 metres of main canal and 21,000 metres of lateral canals have been constructed to serve the estate.

The water pumped from the wadi tends to be saline in nature, but is no more saline, in fact, than the waters used for irrigation on the Valdagno Concession near Homs; in the oasis areas of Zliten and Misurata water with a much higher salt content is used for irrigation. Three pump houses have been installed to raise the water from the wadi reservoir to the main canals, although it has been found that the total water requirements of the estate may be met by two pumping stations. Knowledge of the spring is incomplete, and at the outset it was thought necessary to construct concrete reservoirs at the head of each pump to hold the accumulated flow from the off-set wells adjacent to the wadi. Experience has shown that the natural rate of water replenishment in the wells exceeds the drawing capacity of the pumps at the well head, hence the storage tanks have been

dispensed with.

An estimate of the carrying capacity of the irrigation works at the Wadi Gaam Settlement is suggested as follows:-

Capacity per canal	per hour	800	cubic metres
	per day	19,200	" "
	per week	134,400	" "
	per year	6,988,800	" "

Pump capacity closely corresponds to this total. The mean annual amount of water available per farm unit is about 70,000 cubic metres, which allows irrigation of all the cultivated land of the estate under a double cropping system. Those farmers who have been sufficiently advanced in their out-look and techniques of farming have been able to exploit summer crops of vegetables, groundnuts and alfalfa with excellent market returns; it should be added that summer cropping on the estate is confined to only a dozen farm operators. The social and economic background to the settlement and development of the estate is described in greater detail elsewhere, ⁽³⁵⁾ but it is relevant to note here that the poor aptitude of many of the settlers on the estate for advanced farming has contributed more to the problems of management of the Settlement than difficulties arising from the nature of the reticulation system. It may be said that the fixed net-work of open canals has proved costly, somewhat inefficient and does not appear to offer a sound basis for future development schemes; as we shall see later under heading (E) following, development at Wadi Gaam has been more expensive than comparable Italian Schemes in Misuratio.

(E) Some Observations upon the Costs and Capital Investment in Irrigation Development.

The earliest of factual statements upon the costs of water resource development may be ascribed to the British Military Administration Report. (24) Since that time, several more detailed examinations of the development of irrigation facilities in Tripolitania have been published, notably by Hill (9) and Bologna (34). We shall not attempt to repeat the work done by these writers; for our present purposes it will be pertinent to discuss the essential characteristics of cost schedules for each of the different types of system we have recognized, i.e. Dalu and Diesel Pump in the oasis areas, and artesian and surface supplies in use at the Tummina and Wadi Caam Settlements respectively.

(i) The Dalu.

The most comprehensive assessment of costs made for both the dalu and the diesel pump used in Arab agriculture in Tripolitania is that prepared by Bologna. (34) The figures used in headings (i) and (ii) of this schedule are taken from Bologna's work. Bologna estimated that the costs of the dalu could be accounted as follows:-

Complete well:-

Lining	£L	50,000
Casing	£L	30,000
Ropes, <u>dalu</u> etc.	£L	10,000
Construction of reservoir (average 20 cu. m/s.)	£L	40,000
Two cows for traction	£L	50,000

Concrete channels at a rate of 225 metres per hectare.
The calculation based on twice the cropped area to take account of the normal rotation one year cultivation, one year fallow used in indigenous agriculture.

Bologna estimated that 64.75 metres of channel would be required for an average farm unit. Costing based upon 15 hectares per metre.

£L 9,700

Total 189,700

Running costs and maintenance:-

6% interest on the invested capital	£L	11,380
Maintenance, amortising the well, reservoir and channels at 3%	£L	4,190
Maintenance of two cows	£L	60,000
Amortising price of cows at 10%	£L	5,000
Labour: 150 days at 15 piastres/day	£L	22,500
Replacement of ropes and <u>dalu</u>	£L	5,000

The figures represented in this assessment of costs are purely 'accountants workings' and must be treated with care. The mechanism of capital investment during the period of self-sufficiency tends to be through the application of labour and money over a long period of years, usually encompassing the accumulated results of several generations' investment. Thus, the allotments under the preceding schedule for amortisation of capital are non-applicable to the economic atmosphere in which the dalu system is maintained. Similarly, a self-sufficient farmer would not need to purchase animals for traction power; as we shall see later, the livestock holdings of self-sufficient farm units are larger than those for commercial farm units in Misuratio. Pressing the point further, it may be observed that labour costs necessitated by the dalu are not appreciated by self-sufficient farmers; unpaid family labour is used for these tasks. Nonetheless, the absolute terms presented by Bologna⁽³⁴⁾ have the great value that they offer a basis for comparison of different systems of water raising (Vide Table 16).

(ii) The Diesel Pump.

Bologna suggested the following estimate of costs for irrigation plant.

Well-head with cement shell	£L	120,000
Drilling with steel pipes	£L	150,000
Descending steps	£L	15,000
Engine group complete with electric pump	£L	420,000
Galvanised pipes for suction and forcing	£L	38,000
Reservoir of 80 cu. metres	£L	160,000
Concrete canals	£L	101,000
Installation of the fittings	£L	50,000
		<hr/>
Total	£L	1,054,000
		<hr/>

Running costs and maintenance:-

6% interest on capital expenditure	£L	63,240
Maintenance, amortisation of the well, reservoir, channels at 3%	£L	15,930
Amortisation of the motor pump (20%)	£L	84,000
Repairs to motor pump (10%)	£L	42,000
Fuel for a 6 H.P. motor	£L	27,670
Lubrication	£L	3,880
		<hr/>
Total	£L	236,470
		<hr/>

The preceding figures suggested by Bologna tend to give over emphasis to the scope of capital investment on Libyan farms using diesel pumps. In Misuratio, the writer found that piecemeal investment was more generally the rule than mass investment in a complete installation. Thus, most farmers purchase the engine and pumping unit initially; thereafter the auxiliary equipment is installed as the availability of capital allows it. The average value of pumps and accessories in Misuratio as returned by a Questionnaire Survey conducted in the component oases of the region, revealed that most farmers claiming ownership of diesel pumps had invested between £L 600

and £L 700 in the installation; this contrasts markedly with the comprehensive figures suggested by Bologna. (34)

(iii) Costs on the Italian estate of Tummina.

Full figures covering the costs incurred during the construction of the estate at Tummina in 1937/38 are difficult to assemble, partly because estimates vary, and partly because the detailed accounts of expenditure are not available in Libya.

The following figures of costs at Tummina are drawn from the estate office at Tummina with the permission of the Capa Zona:-

Original cost of the wells	£L	35,000,000
Cost of the pumps, 12 at £L 1,500	£L	18,000
Original cost of the reticulation net-work	£L	50,000,000
		<hr/>
	Total	£L 85,018,000
		<hr/>
Running costs and maintenance:-	Total	£L 17,094,000
		<hr/>

The calculated total investment and running costs for Tummina estate are re-adjusted to allow for inflation which has affected the currency since the war. This re-adjustment enables ready comparison of cost schedules in Table 16, but it must be borne in mind that the operation of inflationary tendencies in the monetary system has considerably reduced the debt of Italian farmers working farms on the settlement. Costing for the water installations and their maintenance at Tummina represents a more accurate picture of the situation than similar figures suggested for indigenous farming under headings (i) and (ii) above, since all investment and construction activity at Tummina was made within the same period of time rather than haphazardly over an

indefinite period, as is the case with indigenous investment.

(iv) Schedule of Costs at Wadi Caam Reclamation and Settlement Project.

Detailed statements of the costs of development at Wadi Caam are not available, since they are 'classified' information. It is to be hoped that these accounts will be open to public inspection in the near future; without them, accurate evaluation of the viability of the Caam estate is made exceedingly difficult. The present figures are taken from an End of Tour Report by R.H. Lewis, who was Chief of Agriculture and Natural Resources Division United States Overseas Mission to Libya, and who was concerned with the formation of the Project during the mid-1950's. (36)

Estimated Costs of Irrigation Development

Non-expendable equipment	£L	28,000,000
Irrigation development	£L	93,000,000
Other reclamation operations	£L	<u>32,000,000</u>
Total	£L	<u>153,000,000</u>

The non-expendable equipment was later moved to other schemes, the only charge against the Caam Project being for depreciation and maintenance.

Running Costs and Maintenance:

Charged to farm operators	Total	£L	3,960,000
6% on Capital invested		£L	7,500,000
Maintenance (3%)		£L	3,750,000
Estimated running costs, maintenance and amortisation of pumps		£L	<u>1,000,000</u>
Total		£L	<u>16,210,000</u>

Under the headings above we have included only those costs which are known; there must remain a considerable element of expenditure which is not recorded in the ordinary budget. The expense incurred during these periods when sea water intrusion into the Wadi reservoir necessitates re-construction of the sand bar at the mouth of the wadi must be considerable.

(v) SUMMARY - SCHEDULE OF WATER COSTS

Table 16

<u>Unit of Operation</u>	<u>First Capital Cost of irrigation installations per farm £L</u>	<u>Running costs and maintenance per annum £L</u>	<u>Water supplied per day cu. mts. per farm</u>	<u>Cost of water per cu. mtr. £L</u>
Dalu System ¹	189,700	108,070	19.14	41.72 mls.
Diesel Pump ¹	1074,000	205,170	133.00	5.55 "
Tummina ²	622,000	46,200	200.00	0.50 "
Caam ³	465,000	33,000	60.00	1.54 "

1 - Data from Bologna, L.M. (34)

2 - Data from Capa Zona and B.M.A. Report 1945. (24)

3 - Data from Lewis, R.H. (36) and Mr. Morrison, Manager Wadi Caam Recl. & Sett.

All figures adjusted to current values.

The data contained in Table 16 indicates clearly the efficiency per capital investment of the various systems of water raising and distribution used in Misuratino. An obvious division arises between the non-commercial dalu system and the commercial methods employed in the area; the disparity in costs per cubic metre of water in the field is reduced somewhat by the following considerations:-

(a) Self-sufficient farmers do not account the labour, since this is provided by the family.

- (b) The nature of investment in self-sufficient farm units eliminates any real costing for amortisation and interest on investment in the sense that they are not appreciated by the farmer.
- (c) The transition from self-sufficient farming to commercial operations is a gradual evolutionary process, as we shall demonstrate later in the thesis (p. 535). Thus, Arab farmers at a commercial level invest only in the most necessary components of the mechanical water raising equipment.

Both the agricultural estates exhibit substantial reduction in costs over the small private systems, both in respect to the initial capital investment and maintenance required and also in respect to the cost per cubic metre of water in the field. This tendency is confirmed by experience at La Valdagno estate, where the cost of a cubic metre of water in the field is estimated by the farm managers to run at about 2.00 millimes. Of great significance is the fact that in terms of costs alone, the exploitation of the artesian water resources of Misuratino is proving more efficient than exploitation of the more accessible first and second aquifers.

We have discussed the relative merits of water raising systems with sole reference to conditions in Tripolitania. Mention has already been made of the fact, and we shall examine in further detail later, that the successful development of the agrarian economy in Tripolitania will depend upon the advances made towards export of agricultural produce. In the light of this question, it must be asked whether costs in Libya are of the order to permit entry into a competitive world market. The following points are the key factors in the situation:-

(a) the export of agricultural produce from Tripolitania is currently exceeding a million pounds each year.

(b) there are large scale fluctuations in annual exports of each crop; the Libyan producers have failed as yet to establish firm markets abroad.

(c) the important exporters in Tripolitania are those who have large farm units under their control, particularly those exploiting the artesian water resources. This includes both indigenous and alien farm operators.

(d) The Arab commercial farming class has adapted itself well to the market conditions prevailing during the export boom of recent years: nonetheless farmers of this kind represent a significant dilemma, since, using diesel pumping from the second aquifer, their production costs are high. After the present boom in exports has finished, it is possible that their commercial effort in the export field will decline as production becomes marginally economic.

(e) The dalu system of water raising has played an important part in the early development of indigenous agriculture in the oases. In recent years, particularly since 1951, strong trends of growth, signified by increasing movement towards commercial agriculture, have rendered the dalu obsolete. As we shall see in later discussion, the majority of farmers in Misuratio make use of the dalu system; nevertheless, it is apparent from the changing pattern of land use (Chapter 5) and the increasing interaction of commercial activity in Misuratio, that the dalu

may be expected to disappear from the oasis landscape in the near future.

The factors we have mentioned indicate, that the position of irrigation in the framework of Libyan agriculture is a vexed one. Hill, H.W. has demonstrated that irrigation is becoming more wide-spread and more intensively used in the Jefaran regions of Tripolitania.⁽⁹⁾ The mechanism of economic growth operating in Misuratino is closely associated with the extension of mechanical pumping of water (Vide Chapters 5 and 6). Thus it must be accepted that water costs in Libya are not an insurmountable barrier to successful export of agricultural produce in present market conditions. An important effect produced by the impact of the necessity of Tripolitanian agriculturalists to export their goods is to be seen in the changing pattern of land utilisation in the area (Vide Chapter 5). Commercial agriculture is tending more and more to concentrate in those areas where bulk quantities of water are readily available to mechanical means of water raising. In Misuratino, this tendency has enhanced the value and intensified the utilisation of the Sahel El-Ahamed and the more fertile pockets within the Oases of Zliten and Misurata.

(a) Summary - Hydro-Agricultural Development.

We may summarise the situation with regard to hydro-agricultural development as follows:-

(1) Modern indigenous development of water resources is following a complex course of evolution towards more intensive

use of irrigation, In Misuratino, this movement is mainly concerned with those resources available from the phreatic aquifer.

(ii) The exploitation of waters of the artesian basin of Misuratino represent a new phase in appraisal of resources in the region. Their value has been proved by Italian occupation since 1938; at the present time social and political factors bearing upon the utilisation of the Italian estates puts the future of this new resource in jeopardy.

(iii) The dominant theme emerging from this analysis is the paramount influence wielded by the distribution of water supplies; the constant physical elements of the landscape tend to be influential only in terms of their effect upon the distribution and accessibility of water supply for agriculture.

(iv) From the fore-going analysis in this chapter it will be apparent that the balance of water supply must be seen in three ways:-

(a) the deficiencies of natural precipitation, which we out-lined in the previous chapter, are 'compensated' for by availability of secondary water resources, particularly the reserves of the phreatic and artesian aquifers. From both these water bodies appreciable, but not unlimited, supplies are available for domestic and irrigation purposes. In terms of regional variation, conditions for exploitation of these aquifers are optimum for the phreatic water table in the Sahel El-Ahamed, and for the artesian layer in the region of Tummina-

Kararim (Vide Figure 30).

(b) No final or authoritative statement on the distribution of water resources will be possible until further systematically compiled data becomes available. This refers especially to the deep aquifers.

(c) Commercial utilisation of the water resources present in Misuratino by both indigenous and alien agriculturalists indicates that exploitation is profitable in present conditions, in spite of the varied problems arising from the nature of the physical environment. Examination has shown, nonetheless, that irrigation in Misuratino is a high cost operation; under boom conditions in the export market for olive oil and groundnuts commercial irrigation activity has expanded; the problem remains, that small contractions in the quantity of international trade tend to have large scale results upon the prosperity of commercial agriculture in Misuratino. In this climate of uncertainty, it is unwise to impose any rigorous conclusions upon the ultimate profitability or unprofitability of the water supplies of Misuratino.

In this chapter we have hinted that the relationship between the varying water resources and the human society in the area has been under-going a far-reaching change in the last hundred years. In particular we have suggested that the processes of economic growth in terms of both national and regional units have brought new concepts to bear upon the adaptation of society to the physical environment. In the succeeding chapters we shall

analyse the nature of society and the structure of the economy and its evolution in relation to the paramount theme of the environmental situation - aridity.

