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SOILS OF MALTA AND GOZO

By E. M. LANG

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SOILS OF
MALTA AND GOZO

By D. M. LANG

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FOREWORD

This report is the outcome of eight months' fieldwork in the Maltese Islands and subsequent analysis of samples at the Macaulay Institute for Soil Research. To carry out this work, I was seconded from the Colonial Pool of Soil Scientists, and the cost was met by Colonial Development and Welfare funds. The soil survey was intended to provide basic descriptions of the soils of the Maltese Islands and a map of their distribution as an aid to agricultural planning.

While in Malta and Gozo I received much valuable help from the Director and members of the Department of Agriculture and from research workers of the Department of Geography of Durham University. My task was simplified through the ready co-operation of the Survey Section of the Public Works Department of Malta and through the courtesy of H.M. Army and Royal Air Force in supplying maps and aerial photographs. The many soil analyses were carried out under direction of Dr. H. G. M. Hardie to whom the author is much indebted. The survey was begun and this report has been written under the guidance of Dr. D. A. Osmond, Deputy Head of the Soil Survey of England and Wales, for whose helpful advice and criticism I am most grateful.

D. M. Lang.

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CHAPTER I

Introduction

"Every ten years the earth is raised, and the surface of the rock broken with a sharp instrument to destroy a sort of crust which forms and prevents the water penetrating"

"They smooth the surface of the rock giving it at the same time a slight declivity to carry off the superfluous water; they then heap stones broken into small pieces about a foot in height, and cover them with a thinner bed of the same, bruised very small; a layer of earth is then added, brought from some other part of the island, or found in the clefts of the rock, a second of dung, which (is) again covered by earth " (De Saint Priest, 1790.)

Location and Extent

The Maltese Islands are a small central Mediterranean group consisting of two main islands, Malta (area 95 sq. miles) and Gozo (area 26 sq. miles). There are also Comino (1 sq. mile), a number of insignificant islets a few yards away from the coasts of the main islands, and one detached islet, Filfla, about 3 miles from the nearest coast. They lie on the southern edge of a submarine bank, between Sicily (60 miles) and Tripoli (200 miles).

Geology

The geology of the Maltese Islands is straightforward. The rocks are almost without exception calcareous. Saving some Pleistocene and Recent deposits, all the rocks of which the Maltese Islands are composed were laid down in Tertiary times. They are sediments of a former continental coastline, deposited at varying distances from the shore and at different depths depending on oscillations of sea level during their deposition. As a result they tend to pass vertically into each other with a gradual lithological transition, so that the definition of boundaries may be obscure. Some of the formations also show considerable lateral variation in lithology and thickness. The formations are nearly horizontal, so that sequence from old to young rocks is usually also from low land to summit, if the Pleistocene and Recent deposits are ignored.

The lowest member of the succession is the *Lower Coralline Limestone*, which is generally semi-crystalline or crystalline and consists mainly of algal deposits and foram tests of various colours - white, red, cream, or grey. Its upper boundary is usually sharply defined by a seam of hard, irregular, yellowish brown nodules. The total outcrop is relatively small, most extensive in coastal cliffs, and so of comparatively small interest as far as soils are concerned.

The next higher series in the succession is the *Globigerina Limestone*. This can be subdivided into a number of beds which vary from a marl to a calcareous freestone locally known as Franka and include layers of phosphatic and iron nodules, but not crystalline rocks. The *Blue Clay* horizon which overlies the *Globigerina* limestone can hardly be separated from the *Globigerina* marl stratigraphically, according to J. H. Cooke (1896). Lithologically both beds are similar, being composed of tests of forams of the same species. The name *Blue Clay* is rather misleading since the clay although sometimes of grey-blue colour is more often brown or yellow. According to Cooke the yellow and dark blue varieties contain from 6-10% CaCO_3 , the light blue varieties have from 22%-40% CaCO_3 , and where

the clays graduate into the underlying Globigerina limestone there is as much as 67% CaCO₃. There are numerous nodules - mineralized fossils and accumulations of gypsum. The fourth horizon, that called the Greensand, is in some places sharply differentiated from the Blue Clay but in other localities forms a "glaucconitic clay" transition horizon. It is in any case a variable formation including (1) rather compact reddish calcareous sandstone, (2) a loose calcareous sandstone, sometimes highly charged with green grains, sometimes with black grains, and in a few places (3) a rock composed almost entirely of shell fragments. In general it is rather coarse-grained. The Greensand passes through a transition zone to the overlying *Upper Coralline Limestone* the base of which is a rubbly reddish white to brown limestone, passing upwards into more compact rock which is largely crystalline or semi-crystalline.

Subsequent to their emergence in late Miocene-Pliocene time these rocks have been faulted and slightly tilted. There is now a gentle easterly dip, there are numerous graben in the central area of the group and other fault features elsewhere. In general the formations remain nearly horizontal, and so the sequence from oldest to youngest goes uphill and is fairly constant. The lithological variations within particular beds are insufficient to mask the overall vertical sequence of varying resistance to erosion which determines the landscape forms.

During Pleistocene and Recent time, the products of weathering of the Tertiary rocks have been deposited in numerous parts of the islands. Some are discussed in the regional description and it suffices to say at present that cave deposits apart, the deposits are loams, sands, breccias and conglomerates derived from sediments carried by valley - and sheet-flow of drainage water. The materials of which they are composed are weathering products of the calcareous Tertiary rocks and, with the exception of red loams derived from the sesquioxide residuum of limestone leaching, they are all highly calcareous. The distribution is widespread but the areas occupied are seldom large, usually partly eroded, and in many cases have lost their character because of intensive disturbance by farmers.

The following are more detailed notes on the Quaternary deposits.

(1) The character of the alluvium-colluvium which produced the deep Valley Loams was not always the same. In sections there appears to be a definite zoning which could be related to the stage of the Pluvial period when the loam was deposited. It is suggested that when hot wet conditions prevailed (presumably at the beginning of the Pluvial period), Terra material was produced, and washed down later when a colder (periglacial) climate produced a poor vegetation. Later still, the hillsides being virtually bare, the limestone itself was eroded and washed down, together with any patchy rendzinas which may have formed.

(2) The red calcareous sandy loams are presumed to be carbonate raw soil materials subsequently coated with Terra sesquioxide clays.

(3) Raised beaches of glacial age which it had been expected would be present, as in other parts of the Mediterranean, were not observed but they may well have been obscured by farming practices.

(4) A thin layer of "calcrete" (travertine) is found spread over rocks of all ages which are not marly in character. This is believed to be partly of Quaternary and partly of Recent age. It is generally very hard, impervious and resistant to erosion.

(5) The deposits found are (i) alluvial-colluvial

(ii) aeolian

(iii) marine.

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It is usually impossible to distinguish between alluvium and colluvium and mixed deposits, because the streams are very short, the valley sides steep, the drainage frequently sub-surface, and the heavy rainfalls often very localised. All these are conditions which lead to a confusion of the two types of deposit, the conditions of deposition of which may vary within short periods.

Climate

The climate of Malta is succinctly though insufficiently described by "warm wet winters and hot dry summers". It is certainly a climate with very definite seasonal characteristics. In the summer half-year the weather tends to be anticyclonic and in the winter, when cyclone tracks are more southerly, frontal.

This is perhaps most easily borne out by reference to the rainfall. Below are averages for 35 years, (not a single run, the dates are 1868-1891 and 1901-1913), for a station in Malta. The figures for a station in Gozo are nearly identical, differing nowhere from the Malta figures by more than 5 per cent.

Table 1: Rainfall of Malta - 35 year averages

Month	J	F	M	A	M	J	J	A	S	O	N	D
Inches	3.4	2.2	1.5	0.8	0.4	0.1	0.1	0.1	1.4	3.4	3.5	4.0

The frequency graph (Fig.1) shows the winter-summer differences even more clearly, revealing that in most years June and July and parts of May and August are completely dry. Observe the abrupt increase between August and September, the gradual drying in April-May and the enormous variability from year to year. The majority of the fall in any month falls on relatively few occasions and in a very short time. This is particularly evident in October and November when thunderstorms are at an impressive maximum. The annual total varied between 8 and 39 inches in the 35 year period. Thus there is large variability in the amount of rain received, coupled with the dominance of shortlived downpours and intervening dry periods.

The importance of this type of rainfall lies in its effects on

- (i) soil formation - pedological processes.
- (ii) soil erosion - effect of downpours on soil structure, and of rapid runoff producing soil wash.
- (iii) rainfall acceptance - periods of wetting are short, so that a readily wetted soil with low water holding capacity may yet take more water from a heavy fall than a soil which wets slowly but has a greater capacity.

Monthly averages of daily mean temperatures in Malta follow fairly closely a normal sine curve (Fig.2) having a maximum of about 80°F at the beginning of August with a January-February minimum of about 54°F. The mean daily minimum of the coldest month is about 48°F and the temperature never falls below freezing. The mean daily maximum of the warmest month averages about 88°F with occasional daily maxima of over 100°F. The mean daily range is about 10°F in January and about 16°F in August.

The mean windspeed is not particularly high but the bareness and general lack of substantial tree cover make the islands seem very wind-swept indeed on some days.

The average (monthly average daily mean) relative humidity is fairly low, with a minimum at about 73% in June/July and a maximum in March/April at about 82%. There are also noticeable subsidiary maxima when the Scirocco wind arrives, warm and damp. As a result of the low average cloud cover, total insolation in summer reaches a very high percentage

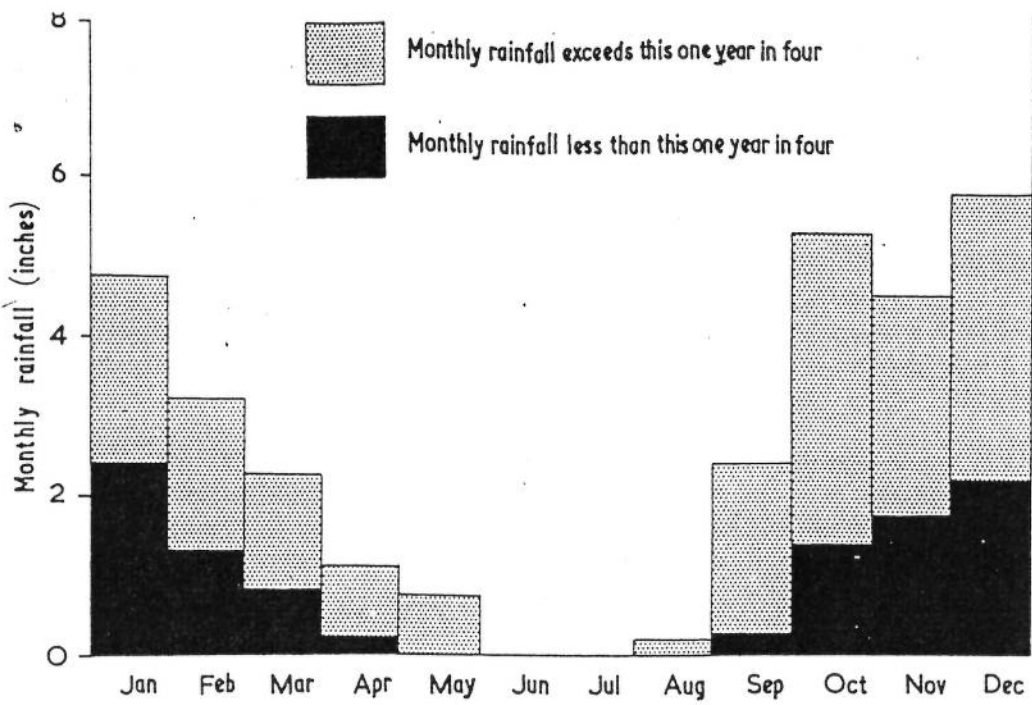


Fig.1. Confidence limits: Monthly rainfall in Malta (35 years).

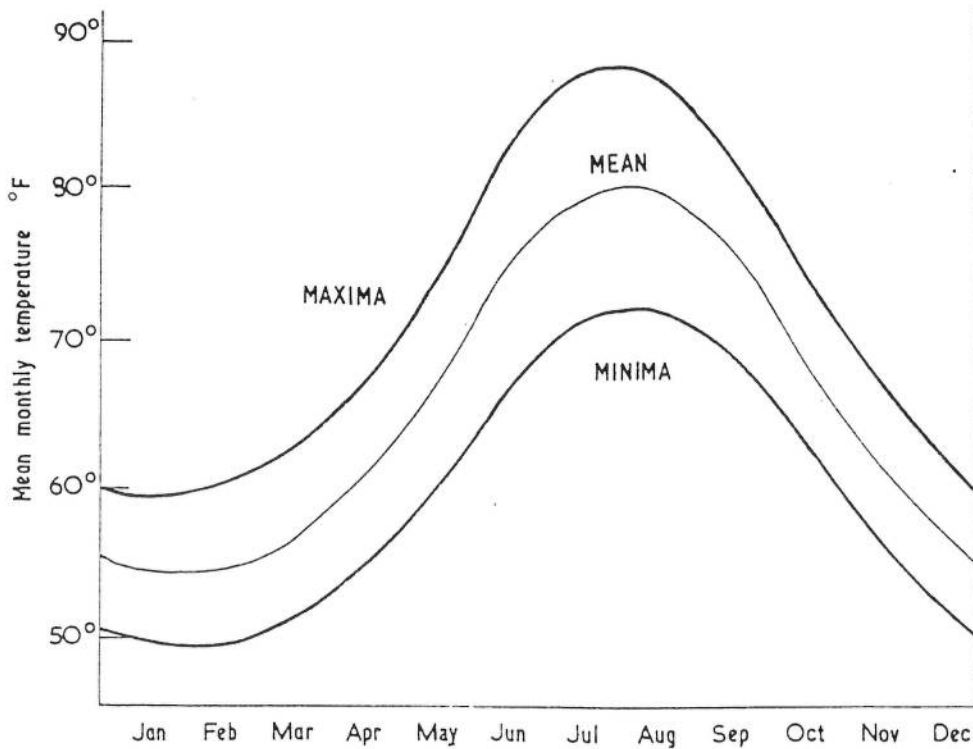


Fig.2. Mean monthly shade temperatures in Malta (1946-1957).

of the "possible" figure, while frontal conditions, bringing increased cloudiness in winter, cause a relatively low insolation figure.

The climatic description has been based mainly on the figures and descriptions for Luqa airport, supplemented by earlier rainfall records. However, the relief of the islands is strongly accidented, and it would be well to consider what variations occur in topographic sites other than that of Luqa which is on the lower Globigerina plateau above the Valetta conurbation. This is a very open exposed site typical of the flat areas. On the other hand the narrower valleys have the appearance of gorges, with extremely steep walls, the principal alignment of which is between E-W and NW-SE, so that strong contrasts in the insolation pattern can be found. This, with attendant surface temperature and evapotranspiration patterns, forms the important variable, while differences in air temperature and local winds can probably be ignored.

However, it appears that despite a very considerable difference in vegetation type and growth between north- and south-facing slopes, and shaded and unshaded sites the pattern remains one of aridity except in minute areas of no drainage. The variation is not from arid to humid, but from very arid to fairly arid, there is always a large rainfall deficit in comparison with the evapotranspiration. The result is that soil differences attributable to present day climate are virtually nil.

Geomorphology

There is no work on the geomorphology of Malta, and it was beyond the scope of this survey to record more than some details relevant to the present soils. In the Quaternary geology section a pattern has been indicated for deposits, and they have been described. In the landscape section the topography has been described, but no attempt has been made to detail the surfaces, the processes nor the chronology of the landscape development. A brief hypothetical sketch in the section on factors in the development of the soils attempts to show some of these things, but it is only a sketch, and avoids the question of post-glacial changes in sea level.

ELEMENTS OF THE LANDSCAPE

Refer to maps in Figs. 3, 4 and 5.

(1) The Karst Landscape Elements

When rain water sinks through jointed limestone and drains away at a lower level it dissolves the rock with the formation of caves and tunnels. When part of the roof of a cave or tunnel falls in there is formed a sink hole or a basin which is called a *doline*. Because solution of the rock takes place most rapidly along joints, the upper surface of the rock becomes deeply trenched, usually in a rectangular pattern, between unweathered stumps. The limestone is not completely soluble and the insoluble residue is usually a dark red clay called *Terra rossa* which descends into the rock through all available crevices and covers or surrounds the unweathered stumps. When these white stumps protrude through the red clay they are called *lapiés*. Together these features form a *karst* landscape. (See plates III and IV).

According to Thornbury (1954) and Cvijic (1924); the essential requirements for the development of a karst landscape appear to be the following:

- (i) A soluble rock, which should be dense, highly jointed and fairly thickly bedded. Permeability should be high, but if it is as a consequence of high porosity and not of well developed larger fissures, karst will probably not form.

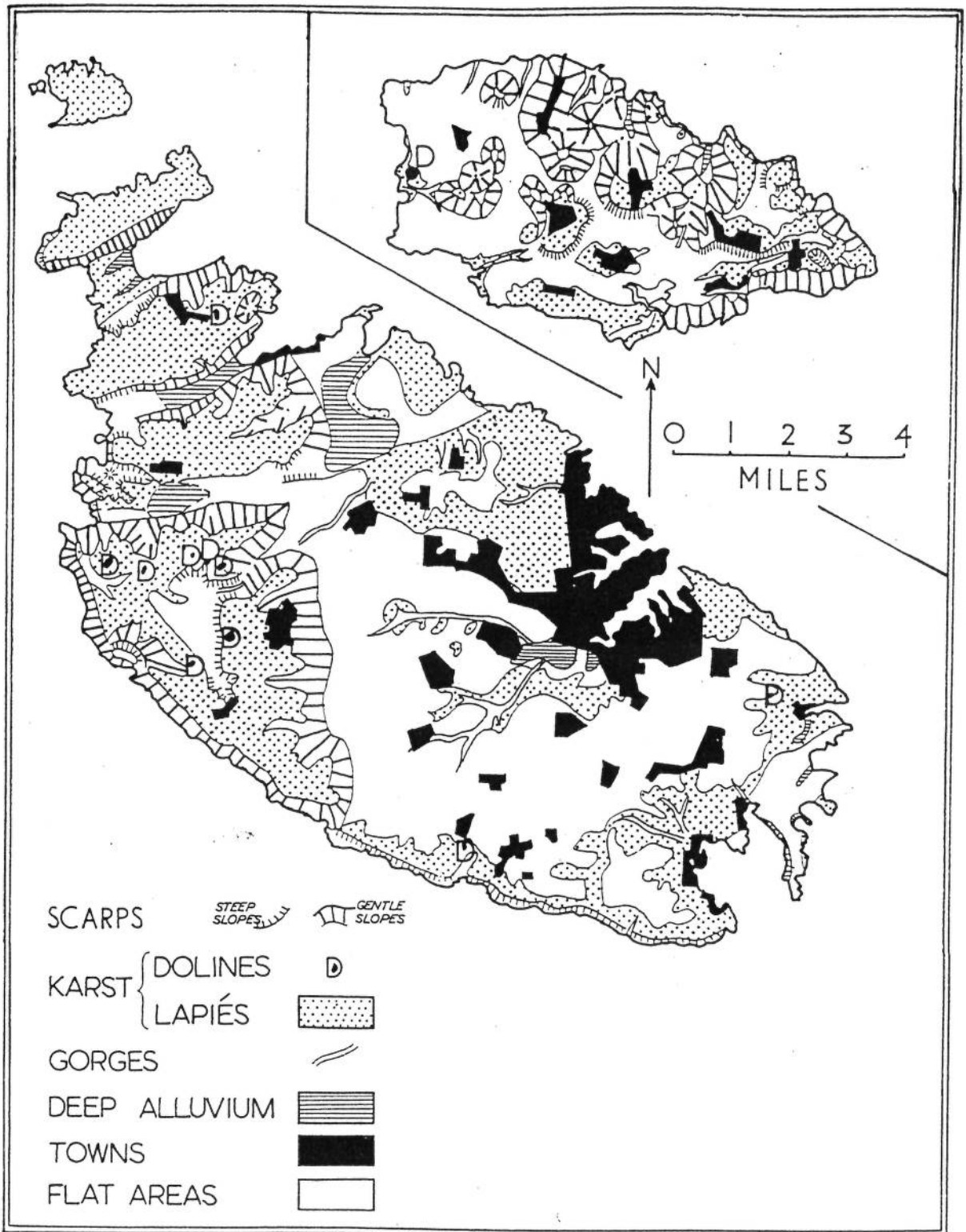


Fig. 3. Some landscape features of Malta and Gozo.

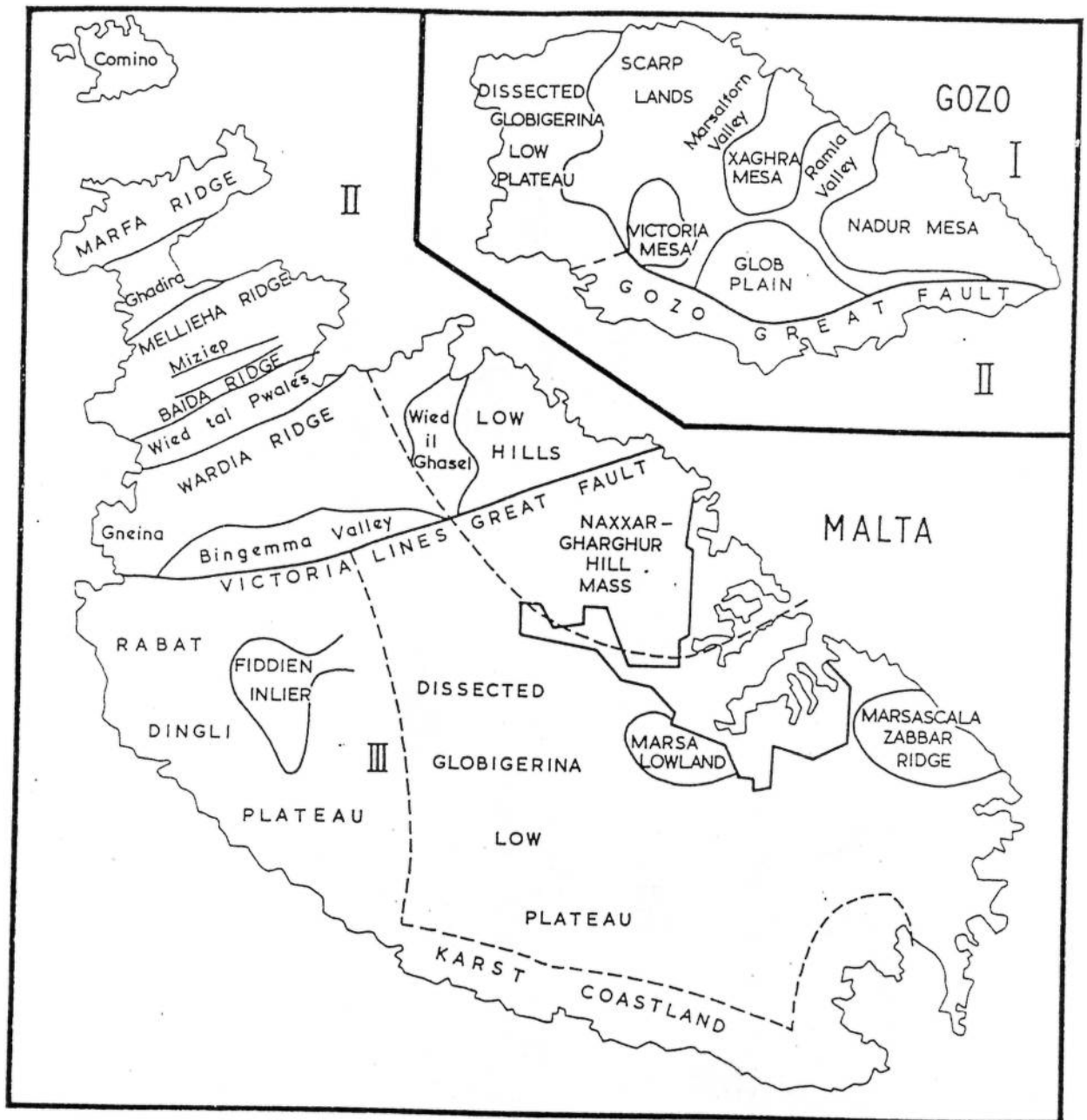


Fig. 4. Landscape regions of Malta and Gozo.

- (ii) Entrenched valleys into which underground descending water can flow.
- (iii) Moderate or heavy rainfall.

The Maltese Islands offer support for these views. The dense well jointed and often crystalline *Upper Coralline Limestone* develops karst features, including lapiés partly covered by Terra soil, (see Plate IV), except where Blue Clay, occurring at shallow depth, has impeded downward movement of water. The Rabat-Dingli plateau of Upper Coralline limestone contains several dolines and its broad central valley may have been a sort of uvala or set of joined dolines. There are several well developed cave systems in the islands for example those below Dingli, the famous catacombs, and Ghar Dalam. No karst features develop in the marls and soft limestones of the *Greensand* nor in the *Blue Clay* nor in the marls and soft limestones of the *Globigerina* beds. These include the Franka limestone which carries some Terra soil but lapiés are only occasionally developed. This is presumably due to the infrequency of the bedding and joint planes

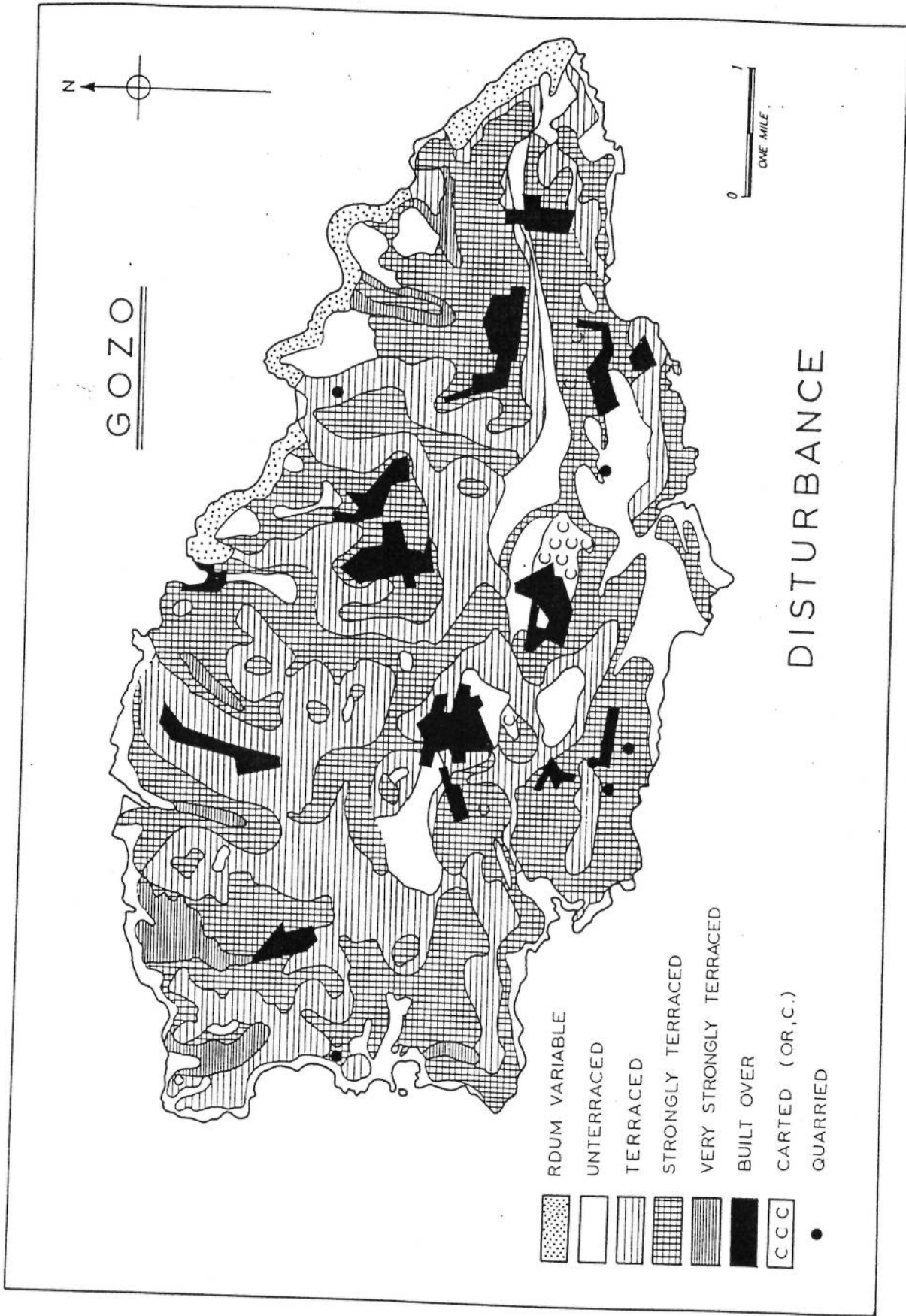


Fig. 5. Disturbance map of Gozo.

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... the irregularity of the rock. However, in a few areas, e.g. near Sannat (profile E, Gozo) and near Marsaxlokk in Malta, Franka shows well developed lapiés rather like those on coralline limestone and one doline has been observed at Ic-Circu near Bidni (596695). Karst features are found also on the *Lower Coralline Limestone* but as mentioned above the total outcrop is relatively small.

The whole karst development appears to be related to an earlier period of solution weathering, probably during the Pleistocene Pluvials. The present low rainfall and summer drought results in a complete absence of permanent streams at the surface, even on the Blue Clay. The occasional heavy showers cause shortlived sheetflows which seem unlikely to be producing karst patterns.

Occasionally the Quaternary beds are sufficiently consolidated to permit the development of a form of lapiés, where Upper Coralline Limestone debris has formed a conglomerate. Here, however, continued solution of the cementing calcium carbonate produces rubble more quickly than on the normal lapiés.

These are the different types of initial karst landscape, but the present landscape is not simply karst. Not only are the dolines used for agriculture (see the circular fields on the 6" maps), but so is every possible accumulation of Terra soil. Extensive terracing has been employed, lapiés have been quarried out, the rock surface has been levelled with rubble infill, and the Terra soil material has been lifted and redistributed. (See Plate VI.) In addition other soil has been carted in to mix with the Terra, irrigation channels have been made, and the surface itself is often completely altered. Even in areas which seem largely untouched the provision of occasional small terrace walls across the lines of surface runoff to catch mobile Terra material is common.

(II) The Landscape Elements on the Soft Limestones

The Globigerina soft limestone, the Greensands, and the Blue Clay probably acquired the major outlines of their present form during the Pleistocene Pluvials. The surface of these rocks, where it is other than vertical is so much modified by man as to preclude conclusions about its earlier appearance and development. These soft limestones appear

(2) (a) in broad low plateaux, strongly dissected with rounded shoulders and smooth slopes, as in south Malta and west Gozo (Plates II, V).

(2) (b) in broad open valleys which in some cases appear to be semi-structural, as the central valley of the Rabat Dingli plateau. Wied L'Iemu. The soft limestones also appear in scarp slopes which are mentioned separately.

The present appearance of these rocks is in almost every case determined by agricultural development. They are, if in steep slopes, heavily terraced with high, quarried backwalls (Plates I and II), if in gentle slopes rock and soil are ploughed together to form a mass of soil material within a boundary wall. Where alluvial Terra material has been deposited, or a restricted development of it has taken place the whole soil is coloured by it, since the mixing is so great. Apart from the relief of occasional carobs or other cropping trees the monotony of ploughed fields is lessened only by the abrupt slopes of the semi-arid landscape, with well defined valleys preserved from a wetter period.

(III) The Deep-Valley-Deposit Landscape Elements

In some of the larger valleys of both the erosional and the 'graben' form there are broad relatively flat infills of eroded soil material which is of mixed alluvial and colluvial origin and under cultivation presents an appearance different from that of any of the other landscapes (Plate III). Whereas the Quaternary and Recent deposits on the upper

parts of the valley sides are generally rather similar to the materials on which they lie (almost without exception on marly Globigerina beds), these lowland deposits make an abrupt landscape change. They are gently sloping, unterraced areas without an uncultivated patch except where strongly saline.

(IV) The Scarp Elements of the Landscape

The most noticeable landscape element is probably the scarp, of which there are several types. These can be classified both by their genesis and appearance, but only the latter method will be used here since the purpose is only to describe the landscape appearance.

Excluding coastal scarps from consideration there are:

(4) (a) Tall scarps encompassing an Upper Coralline Limestone cliff, a rapid sequence through Greensands, Blue Clay, and some of the Globigerina beds, to the plateau surface on the Middle or Lower Globigerina. Formation boundaries are obscured by the slumping of the weathered materials.

These scarps often surround mesa-like plateaux as at Nadur and Xaghra (Plate II).

More limited expressions of the same sequence, e.g.

- (4) (b) In Wied l'Iemu Terminating at the Blue Clay.
- (4) (c) In west Gozo, where the Upper Coralline Limestone and sometimes the Greensand, are missing.
- (4) (d) Globigerina and Lower Coralline Limestone (karstic) bare scarps.
- (4) (e) Globigerina limestone scarps of the cuesta type in the Franka (very weakly karstic), as in south Malta e.g. Has Saflieni (about 545693).

With the exception of the bare limestone scarps (4d) already mentioned, all these are very strongly terraced - except the Blue Clay, which will stand in slopes up to 35°. The representative profiles show that the scarps are seldom very steep, except at the summit of the tall type (4a), where the protective capping of Upper Coralline Limestone, gradually being undermined as the unresistant Greensands are sapped, splits away in tall vertical blocks, producing a cliff. In south Malta the Pleistocene streams have cut back gorges in these scarps from where they debouch on to the lower land. In other areas where the general land form is rounded and there is no true scarp, the valley side, like the gorges mentioned, simulates scarp form.

The abrupt terraced slope is in fact a most common feature of the landscape of the Maltese Islands.

REGIONAL LANDSCAPES

Regional Division after J. C. Dewdney (private communication).

(1) Gozo Northwest of the Great Fault

Northwest of the Great Fault Gozo becomes increasingly dominated by the Globigerina Limestone series. The relatively large dissected Upper Coralline Limestone plateaux of Nadur and Xaghra (elements 1 and 4), give way to the smaller remnant hills of Zebbug and Rabat, then to roughly conical hills like Giordan, and the hill above Ta Pinu (Plate II) each with its small remnant capping of Upper Coralline Limestone. Strong valleys between, (4a), which break abruptly through the Greensands in cliffs, and have steep strongly terraced slopes on the soft limestone,

(Plate V), and very strongly terraced (Plate VI), with the misfit sporadic stream or dry bed along the middle. The emphasis changes from east to west. In the east, the karst tops (1a) are strongly dissected but as extensive as the valleys, further west broad valleys still cut through the complete sequence, (4a), but there are only thin hill cappings (1e) of Upper Coralline Limestone modified by man beyond any real resemblance to karst, (at Tad Dabrani, Ta Kulyat, Ghar Ilma, Ghajn Abdul Giordan, etc.). One or two larger cappings, at Zebbug and Victoria, retain some karst features. Finally in the west there is a dissected Globigerina plateau (Plate V (2a), with very strongly terraced valleys becoming bare on descending to the Lower Coralline Limestone, and small remnant hills of Blue Clay here and there (San Dimitru, Ta Birbuba etc., Plate V). In the same sequence, just as the karst disappears, the Terra soils give way to rendzinas and carbonate raw soils.

Apart from those small areas where the karst has remained untouched, or on the long clay slopes, terracing, carting, and general modification of appearance by man is ubiquitous and on a phenomenal scale.

(II) The area between the two Great Faults is primarily a much faulted area with "horst" ridges rising to about 300 ft. above "graben" valleys (Plate III). In Comino and Malta, west of a line running roughly Falka to St. Paul's Bay and north of Bingemma there are only four small localities in which the Upper Coralline Limestone is not dominant, and they are either in the coastal cliffs or where Quaternary deposits (loams and conglomerates) are not greatly disturbed. Thus as might be expected karst landscapes (1a) are dominant, even where (e.g. Armier) a subsequent overlay of dune sand is to be found. Between the upstanding karst areas, the graben are generally filled with alluvial-colluvial material (3) - in several cases, of downwashed Terra soil. The down-faulted Upper Coralline Limestone is usually the basement of these valleys, and there frequent windmills indicate the more intensive agriculture which characterises the other landscape differences from the Upper Coralline Limestone karst ridges, (Plates III, IV).

East of the line mentioned, which is the locus of the scarp element (4a) and beyond the deep alluvial - colluvial bottomland of Wied-il-Ghasel are low (100' - 200') rounded soft limestone (2a) uplands and Globigerina Lower Coralline Limestone karst (1a) which reaches the coast. The Wied-il-Ghasel itself emerges from a gorge cut in Victoria lines, through an alluvial cone, and is joined by two tributary valleys forming the large bottomland (3) in the islands. Only the confluence of the Wied is Sewda and Wied il Kbir forming the Marsa lowland, or the lower part of Wied Tal Pwales, approach its size.

(III) The area south of the Great Fault of Victoria Lines

This relatively unfaulted area falls naturally into simple subdivision. The fretted karst "mesa" (1a and 1c) of Rabat-Dingli with its central valley, and surrounding scarp elements (4a) is succeeded eastwards by a lower "plateau" (2) with incised stream courses on the Globigerina soft limestone and Franka, terminating in a series of gentle cuesta scarps (4e) above the Marsa alluvial lowland. In the Mosta area the low plateau (2b) passes into Lower Coralline Limestone karst followed eastwards by more Franka and Lower Coralline Limestone karst (1a) in rounded hills up to 400 ft. along the coast. In the south-east beyond the main development of Globigerina soft limestone, on the edge of which lie Siggiewi and Zebbug, i.e. east of a line Qrendi-Marsa the gradually descending plateau (2a) passes on to weakly karstic (1b) Franka varied by softer Globigerina limestone (2a) and Terra basin lands (3). These persist until at the slope down to the coasts a band of well marked karst with incised stream courses is seen again on the Lower Coralline Limestone or Franka (1a). Between Valletta and Marsascala Upper and Lower Coralline Limestone and Franka give areas of karst (1a and 1c) on a well terraced ridge, which has also some areas of soft white limestone.

The faulting south of the Great Fault is not very obvious except where (a) at the west coast there are fault breccias (at Maghlaq e.g.), (b) Lower Coralline Limestone is brought to the surface in the south-east, (c) the direction of the valleys is fault controlled at the ria coast around Valletta, and (d) it produces an Upper Coralline Limestone outlier and a Lower Coralline Limestone inlier on the Marsascala ridge.

The karst mesa of Rabat-Dingli (1a and 1c) is well developed and has systems of caves beneath it, clearly marked dolines, and various patterns of lapiés on it, all mainly relics of an earlier period. The lapiés are partially described under the Xaghra series, the area of which includes most of them - except those which have been disturbed by terrace building. The central valley may have originated as a series of coalescing dolines. In the east and to north and south it is delimited by a cliff 20 to 50 ft. high, comprising the Upper Coralline Limestone and Greensand over the Blue Clay (4b). To the west, an unusually broad exposure of the Greensand climbs slowly to the Upper Coralline Limestone karst top (1a and 1c). The large part of the Rabat-Dingli plateau which has been terraced, carved out (1c) and, in some places, quarried, gives some impression of the large effort which has been expended in agriculture and has so greatly changed the natural landscape. Fretted as it is by wadies along the north and east sides, with the larger valleys of Bahrija and Mtahleb on the west, and the large valley in the centre, only about 40 per cent of the whole "mesa" area is Upper Coralline Limestone karst (1a and 1c) which is best developed in the north-west and south-west corners, near Bahrija and Dingli respectively. In these places (and in general where it has also been strongly terraced), the karst has a rough-textured appearance contrasting strikingly with the Globigerina marl lands below the scarp, the smoothly rounded contours of which are broken only by the incised valleys and terracing. The alluvial - colluvial valleys within the karst areas are generally remarkably flat, and also provide a sharp contrast with the parts where lapiés are developed.

It will be seen that each landscape element enters into the three regional landscapes, but with differing emphasis, and only complete separation into the elements would produce uniform units.

IV. Disturbed Areas

So far the major factor in the development of the landscape, man's effort, has only been mentioned in part - the airfields, barracks and other military installations, the factories, roads, the towns and villages which dominate the appearance of much of Malta are shown on the soil map. There they represent a very large "disturbed" area much of which, however, is no more disturbed than the land which is strongly terraced and ploughed. Some of the military land, however, has been bulldozed, had waste dumped on it and is completely useless for agricultural purposes.

Most of the military and naval installations are on areas of Xaghra or Taş Sigra soil.

Disturbance of the land in agricultural use has been described elsewhere and nothing more will be said of the other disturbed land than that for one reason or another it is semi-permanently out of agricultural use - and this includes a large part of Malta.

CHAPTER II

METHODS AND DEFINITIONS

Field Methods

When surveying soils a general impression of their character is gained by preliminary reconnaissance accompanied by the digging of occasional profile pits at locations which appear typical of particular areas. Subsequently the extent of these 'typical soils' can be delineated by digging small pits or making auger borings, and drawing a line around those holes the characteristics of which are sufficiently similar to the type pit. No two pits will appear exactly the same, and so a range of characteristics is taken as representing a particular soil. This first convenient field-mapping unit is called the soil series, and it is possible that it will lie across the bounding characteristics of higher groupings of classification, unless of course they are considered at the outset.

(Since natural soil can be generally regarded as a continuum, the dividing line between two soil series is merely a convenient one, and does not often represent a very definite natural boundary. However, the boundary usually locates a line of maximal rate of change of the characteristics by which the soils were described.)

Mapping was commenced according to this method, but largely as a result of the intensive use of the land it soon became obvious that:

- (1) the soils change very rapidly over short distances, especially in strongly terraced areas.
- (2) pedological horizons are nearly impossible to distinguish - although, on calcareous parent materials and under the Maltese climate, horizons are not very obvious even in unworked areas.

As a result it was necessary to map much of the islands as complexes of series.

The strong correlation between geology, and the natural and cultural landscapes as indicated in the regional description, enabled some of the mapping to be done from aerial photographs using landscape boundaries as the boundaries of some series and complexes. The method finally adopted involved traverses across the 'grain' of the country examining profiles, and locating boundaries. Then these were extended and others drawn in using landscape boundaries from the aerial photographs.

Some areas, generally of small agricultural significance, were cursorily examined, for example the barer parts of the karst lands, forming part of Xaghra series.

The observations were recorded on 6-inch maps, which were reduced to the 2-inch scale, necessitating some editing and loss of detail. Altogether about 10 sq. miles in two areas were mapped in detail using borings only while the remaining 112 sq. miles were mapped mainly by using aerial photos and checking traverses.

Description of Soil Profiles

During the survey a number of profiles, representative of each series were dug, described in some detail, and sampled. The terms in which these descriptions were made are defined and explained here.

First the characteristics of the site were described, followed by a detailed description of each horizon in the profile.

Site characteristics: Altitude, aspect, crop or natural vegetation, depth of water-table need no further explanation. Geomorphological locations were given in simple topographical terms as they were appropriate. No attempt was made to systematise these descriptions in relation to a time scale nor to correlate erosion surfaces. In each case where river terraces or slump "terraces" were observed, the only description was the slope or height relation to the valley. The terms have in fact been used simply to help give a picture of position or topographic location.

Mesoclimate description. An attempt was made to describe areas where local modifications of the climate could be expected. For example variation of insolation with aspect, and shadowing - in Malta mainly resulting from building; funnel effects of wind in narrow valleys etc.

Topographic amplitude - the height from valley bottom to ridge crest, and the height of the lesser topographic features in the landscape e.g. river terraces. Terracing was described in quantitative terms-breadth of terrace, height, height of back wall, if any. Any notable characteristics of drainage were recorded, as were features of excessive erosion. Soil dumping and carting, manuring - especially with town refuse, and irrigation methods were noted. Where it was possible a local inhabitant was asked his opinion of the quality of the soil. Finally the site or the profile was usually photographed.

The intention was to describe the location of the site briefly but as completely as possible in order to have information (i) regarding possible peculiarities of the profile and (ii) for correlating soil and landscape.

When the profile was described the most easily recognisable and determinable physical properties were taken first, colour, texture, consistence and structure, characteristics which are used in deciding how to divide the profile into layers or "horizons". The characteristics of each of these layers helps to reveal the processes of formation of the particular soil.

Natural soils are not only related to the minerals of which the parent material is composed, but also to the chemical and physical changes which take place under the influence of climatic, vegetational, topographic, and microbiological factors. In certain soils the effects of these are very clear and produce markedly different horizons which can be seen by, say, colour changes alone. Such differentiation is not so clear in calcareous soils under the present climatic conditions of Malta. Where the soils are cultivated the upper few inches, which under more permanent vegetation had well marked characteristics, are overturned and mixed with the subsoil. In many profiles this produces an almost homogeneous "soil", the characteristics of which show little or no vertical differentiation, because of the slowness of the pedological processes. In point of fact some "horizons" are the result of characteristics of geological deposition and not pedological process, as has been observed elsewhere (Worrall 1954).

Soil colour is determined by reference to a series of standard colours in the Munsell Soil Colour Charts. In general it can be fairly closely matched against one of these colours, although this is not always possible, particularly if the dominant hue is not red or yellow.

Soil texture is considered as a function of the proportion of the size-groups of primary particles in the particular soil, which are less than 2 mm. diameter. There is not any universally accepted system of size-groups but the most widely known are the International System and U.S. Dept. of Agriculture scheme (U.S.D.A. 1956). The important difference between the two is in the upper size limit for silt. The triangular diagram in this publication shows the textural classes, i.e. names given to varying combinations of the three separates, sand, silt and clay, under the U.S.D.A. system. The presence of large quantities of other separates larger than

2 mm. is used to give qualifying adjectives to these texture names but in Malta they are not often important enough to be used, with the exception of "gravelly".

The determination of texture in the field is usually made by estimation of the various fractions while working the moistened soil between finger and thumb. The term "gravelly" was used for soils which had a surface cover (before being ploughed for the year) of greater than 25 per cent gravel, estimated by eye. "Gritty" was used to describe soils with a gritty feel produced by sharp-edged coarse sand and fine gravel. It is important to note that in the field the aggregated soil is being used to determine texture while in the laboratory a dispersion method is employed to reduce the aggregates to their component primary particles. Working moistened soil between finger and thumb cannot always achieve this and so some discrepancy is to be expected, related to the strength and mode of aggregation of the soil.

Consistence describes properties of the soil dependent on the forces of cohesion and adhesion acting between the primary particles of the soil, the soil water, and objects touching the soil. These forces act when the soil is neither so dispersed in water as to flow freely, nor completely dry, limiting conditions which are in any case virtually never observed in the field. *Consistence* is of great interest to the farmer since conditions affecting tillage operations, resistance to compression, shear, stickiness and friability etc. are related to this property. The method used for observing consistence is like that for texture, feeling the soil, moulding it and rolling it between the fingers. *Consistence*, is therefore, usually determined at the same time as texture, to which it is partly related (e.g. soils containing less than 15 per cent of clay are usually non-plastic).

Consistence descriptions, using the definitions in the Soil Survey Handbook (U.S.D.A. 1956) have been given for one or more of three states of water content of the soil, for example: dry soil may be soft or hard; moist soil may be friable or firm; wet soil may be sticky or plastic.

However, the descriptions of consistence have the following limitations:

- (a) They are only partly objective.
- (b) They depend very largely on the widely variable soil-water content which is not sufficiently well defined by the three terms and therefore only gross differences between field determinations are significant.
- (c) Variations in organic matter content control variations in the water content. Although generally very low the organic matter content of the soils of the Maltese Islands is locally altered by tillage and the addition of manures.

Consequently consistence descriptions are applicable only in very broad terms, and, lacking any measured quantities, comparisons of particular descriptions need to be treated with care.

Structure. The materials of which the soil is formed are not generally merely heaped together, nor compressed together in a solid mass. More usually the primary particles are "aggregated" into units of differing size consisting of a large number of particles held together possibly by chains of oriented water molecules and partly by organic gums, and the units (peds), are often moulded by soil animals, insects or plants. The peds have more or less continuous channels around them in which air and water, insects, animals and roots can pass. The sort of unit produced being dependent on the physical, chemical, and biological processes of the soil, each soil type tends to have its characteristic structure. Structure description is

therefore important especially since the existence of a "good" structure is often correlated with fertile soil. Soil structure shows best in a dry soil and may not be visible at all when the soil is wetted to field capacity, i.e. when only the macropores are free from water. An abbreviated classification of peds is as follows:

- (a) *Laminar or platelike*, with the vertical dimension much less than the other two. Faces mostly horizontal *platy*
- (b) *Prismlike*, with the two horizontal dimensions much less than the vertical. Vertical faces well defined, and with angular vertices:
 - (1) having rounded caps *columnar*
 - (2) without rounded caps *prismatic*
- (c) *Blocklike*, polyhedral or spheroidal, with three dimensions of the same order of magnitude:
 - (1) *Blocklike*, having plane or curved surfaces that fit into the faces of surrounding peds
 - (i) Flat faces, most vertices sharply angular *angular blocky*
 - (ii) Mixed rounded and flattened faces with many rounded vertices *sub-angular blocky*
 - (2) *Spheroids or polyhedra* with plane or curved faces, which have slight or no accommodation to the faces of surrounding peds.
 - (i) Relatively non-porous peds *granular*
 - (ii) Relatively porous peds *crumb*

In describing structure in the field use was again made of the definitions of the U.S.D.A. Soil Survey and published in the handbook, (U.S.D.A. 1956), which should be referred to for definitions of size ranges and further information about structure.

Soil Disturbance in the Maltese Islands

In their long history, the Maltese Islands always have had a high population density. Even at the time of the Byzantines in 870 A.D. the population was possibly 10,000, and, after successive Arab, Norman, German, Sicilian and Aragonese occupations, had reached 15,000 by the arrival of the Knights in 1530, rising to 50,113 at a census in 1632, 110,000 in 1741, 150,000 in 1881 and to the very high figure of 319,346 i.e. over 2,500 per sq. mile, in 1957.

During this long period of occupation the provision of food has always necessitated widespread agriculture which means that some of the terracing and much of the soil disturbance is of great age. Reference to various writers bears this out - indirect evidence points to a large scale and prosperous agriculture in Greek times - but 18th century authors (Brydone, De Saint-Priest etc.) refer to the methods of making fields by moving soil, and the frequency of terracing and terrace making. The references to walls, and bare appearance are in themselves indicative of this sort of disturbance, since the walls conceal the terrace fields from travellers.

The following paragraphs detail the principal modes of soil disturbance (meaning change from the virgin condition) involved in the intensive use of the Maltese Islands. They are: carting, quarrying, "manuring", terracing.

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There is plenty of evidence in Malta at present of the movement of soil material from its place of origin to another location. In general the purposes served are (1) making fields where there was no soil, (2) increasing soil volume to increase water holding capacity and improve ease of working, (3) improving soil fertility. The government has increased the scale of this movement through the provisions of the Ordinance for the Preservation of Fertile Soil which came into operation in 1935.

This measure requires that all soil must be removed from new building sites during the course of construction and taken where it may be used for agriculture. The following table giving the quantities actually moved has been taken from the annual reports of the Dept. of Agriculture for Malta in which a list of source and recipient areas has been sometimes included. Figures are given for Malta and Gozo together of which Gozo usually comprises about 10 per cent.

Table 2: Soil moved from building sites in Malta and Gozo

Year	Quantity cubic yards	Year	Quantity cubic yards
1935	64,622	1947	57,694
1936	65,029	1948	63,559
1937	75,737	1949	44,513
1938	78,975	1950	75,279
1939	58,366	1951	140,302
1943	3,131	1952	64,919
1944	9,651	1953	60,381
1945	7,987	1954	46,056
1946	47,200	1955	59,815

In 1938 11,274 cubic yards of soil were used to make 187 back gardens, 99 rocky surfaces at the back of building sites were covered with 7,727 cubic yards, 119 fields were "reclaimed" using 29,425 cubic yards and the Government Experimental Farm at Ghammieri which was being made on bare rock, benefited by 11,658 cubic yards. In 1947 "in many instances the soil was used for the formation of back gardens, but extensive reclamation of waste land was carried out, chiefly at the Government Farm."

Thus though in the majority of cases the soil is not moved very far, the bulk of the soil is carried well away from the building site, since the soil removed from the few large sites forms the bulk of the total.

Assuming an average soil depth of 1'6" - perhaps an over-estimate considering the large areas of bare rock - there are on the 121 sq. miles of Gozo and Malta $1.21 \times 6.4 \times 2.42 \times 10^7$ cubic yards of soil, and if, say, 60,000 cu. yds. are moved per year this is equivalent to the movement of 0.1 per cent of the total soil cover every three years - and this refers only to movement under government supervision. Areas of mixed soil and piles of dumped soil awaiting use are frequently to be seen, and certain large areas are covered entirely with carted soil. Examples are the Government Farm at Ghammieri (532,696) Marsa and an area near Xewkija in Gozo (339,882) - from which is taken a "profile of carting". Areas where carting was noted have been indicated by the initial letter C on the map of disturbance, and it will be observed that although they are quite widely distributed they are most frequent in the vicinity of towns. What is carted is not always strictly a "soil", quite frequently a good deal of rubble is included, which is no doubt of some use in terrace building.

In the absence of an adjacent soil dump a field made from carted soil can often be recognised either by (1) random variations in the surface soil colour or (2) where these are not present, non-intimate mixtures below the uniform surface layer.

Importation of soil from Sicily

Various authors have said that soil was imported from Sicily, and it is a current belief in certain quarters in Malta that this is true of all the 'red' soil (terra). There is however no direct evidence of the presence of any large quantities of imported soil, as far as this can be observed.

1. P. Brydone F.R.S. after a short visit in 1790, wrote "There is not an inch of ground lost in any part of it (Malta); and where there was not soil enough, they have brought over ships and boats loaded with it from Sicily, where there is plenty to spare". He did not, however, say where it was taken, nor how much of it had been brought.

2. De Saint Priest, who wrote an interesting and geographically full "Description of Malta" in 1792, although concerned with soil preparation and reclamation of land did not mention the import of soil from Sicily.

3. John Murray in 1895 quoted Seddall (1870) (who refers to a condensed report from Lt.-Col. Porter's writings) on the report of the commission despatched by De L'Isle Adam to visit Malta in 1530, which said "That Malta, about 60 miles in circuit was but an arid rock, covered in many places with sand, and in a few with a light scattering of earth brought from the neighbouring continent or from Sicily". Later, Murray says "There seems to be no foundation for the widespread belief that soil was imported into the islands in past times. The soils of Malta are all in accordance with the strata on which they rest". Then quoting Chadwick: "Roman puzzolana, still imported in considerable quantities has almost certainly been mistaken for earth. It is still much used in Malta for imparting hydraulic qualities to the fat lime of the country It is apparently a clay calcined by the juxtaposition of lava, and is of a chocolate red colour much resembling the red soil fragments of puzzolana are to be seen embedded in mortar of all ages It is quite true that the greater part of the cultivable soil has been prepared artificially and that in many cases it has been collected and carted to considerable distances. At the present day, surplus vegetable soil from any building site, road scrapings, and the like, are removed to cover and reclaim barren tracts of rock".

4. Using the earlier calculation for the total volume of soil in the Maltese Islands the time taken to dump (at one shipload of 200 cubic yds. per day) even 10% of the soil cover (the red soils represent far more than that) would be of the order of 250 years. It seems likely that any large scale soil dumping of the order of 200 cu. yds. per day would take place near a harbour, and it is of interest that near Marsa at the head of the Grand Harbour is large area of dumped soil. However, the soil and rubble there (see descriptions in Appendix I,) appears to be very similar to that from other parts of Malta and of generally poor quality (stony or rubbly). Thus even though no record of its being dumped there could be found, it appears more likely to be the waste from some fairly recent building sites - not within living memory, but possibly from some period in the 19th century. Certainly it seems most unlikely that such useless material would be imported from Sicily, if soil were demanded as ballast.

There appears to be (i) no direct evidence of the presence of Sicilian soil (though if it were terra rossa it would be difficult to distinguish from that of Malta) and (ii) little likelihood that any very great quantities could have been imported without giving rise to more comment from writers of the period, (iii) a great deal of evidence to suggest that the soils have been derived mainly from the rocks over which they lie, even where there is strong terracing. (Correlation of rock type, landform, and soil).

It seems likely that any soil imported from Sicily must have been (a) in very small quantity and (b) rather similar to Maltese soils or mixed with them in the manner of a fertiliser. But large quantities seem to be quite out of the question.

Quarrying

Quarries are widespread in both Malta and Gozo, but one or two areas are particularly favoured for quarrying since the limestone there is very suitable for building, being strong and easily worked. (Plate VIII). Thus quarries are predominantly in the Franka Globigerina areas and it is one of these, Tad-Dawl, which gives its name to the complex of soils arising as a consequence of quarrying. Overlying most of the quarry areas was an over-burden of terra rossa, with, in some cases, Quaternary beds and generally these unconsolidated materials have been replaced after quarrying operations have ceased. They are not however merely dumped on the floor of the quarry.

The normal procedure is that rubble, often 15 feet deep is heaped on the quarry floor and after it has settled, a layer of town refuse, vegetable matter and general rubbish up to a foot deep is laid on it. On top of this the terra soil material, often mixed with rock fragments and rock flour, is replaced; and the field, perhaps as much as 25 feet below surface level, is ready for use. A large number of examples may be seen near Mgabba, where there are usually several terraces at different levels within one quarry, each having soil differences from its neighbour as well as internal variations.

Since quarrying by primitive methods is comparatively easy in the Maltese Islands, the amount of solid rock removed during the centuries has probably been very large. The impressive battlements, the stone houses and the aqueducts are evidence of this, and even where quarries of any size are not seen, there are occasional lynchets large enough to impress the conclusion that stone must have been removed for building purposes elsewhere and has not merely been used for building up the terrace front.

"Manuring"

The frequent applications of "manure" to fields in some areas cause considerable modifications of soil appearance and texture, partly because the material applied contains much insoluble inorganic rubbish and partly because in these particular areas the total soil depth is small. One example is south-east of Tarxien, on the Tal Barrani series where some time after application the dominant elements in the "manure" or at least the most obvious appear to be tin cans, paper-backed novels, and nylon stockings.

The use of town refuse appears to be very widespread, although not on all fields, and the depth of incorporation is sometimes very considerable.

Terracing

One of the most striking things to be observed about the countryside of Malta is that often very little soil can be seen from the road. Everywhere there are stone walls, some of them more than ten feet high, many of them of apparently greater volume than the soil of the field behind them. Often too, the walls are high enough to hide from every eye the difference in height between the two sides, the result of the almost ubiquitous terracing. In general there appear to be fewer high walls on Gozo, and the accompanying map attempts to show how much terracing and disturbance there is. The proportion of terraced and unterraced land, appears to be similar in Malta although perhaps a rather larger proportion is strongly terraced.

The categories delimited in the map (Fig.5) are defined:

- (1) *Unterraced or nearly so* - (a) there is no noticeable height change between fields at the boundary wall. (b) there is no evidence of carting or soil type change at the boundary wall. Catch terraces on Xaghra, are ignored and so is the glaciais slope often found on coastal Xaghra.

(2) *Terraced* - this category covers broad fields with changes of height of only 2 ft. to 3 ft. across a 30-yard field. Greater changes in height are allowed among the soils developed on the Blue Clay, where generally the terraces take the form of rubble walls shoring soil material with a cross section like that of a mud slump. The consequent soil disturbance is much less than in terraces of similar size on other parent materials; the slope upon the terrace is often of the order of 10° (against a hill slope of $15^\circ - 20^\circ$), which requires little movement compared with the flat or gently sloping ($0^\circ - 2^\circ$) terraces for all grades of general slope on other parent materials. These often necessitate considerable building up of the front of the terraces with rubble, as in category 3.

(3) *Strongly terraced*. Herein are grouped those areas, the terraces of which are fairly narrow, say, 10 yds. to 30 yds. wide, with a considerable thickness of rubble at the front, and frequently with back walls cut deep into solid rock (Plate I). The back walls are a characteristic but not an obligatory feature of this category, since on some of the harder rocks, they are rarely of any noticeable size, while terrace build-up may be very considerable or the frequency of the terraces higher.

(4) *Very strongly terraced* occurs only on soft Globigerina rock, and the soft lower series of the Upper Coralline Limestone and the Greensand in scarps or where they form steep-sided wields. Here large back wall cuts up to 6ft. high are found. The terraces are often no wider than 3 yds. and very seldom wider than 10 yds. with very high retaining walls (Plates V, VI.). In the bed of the wields there are frequently large terraces made entirely of carted material,

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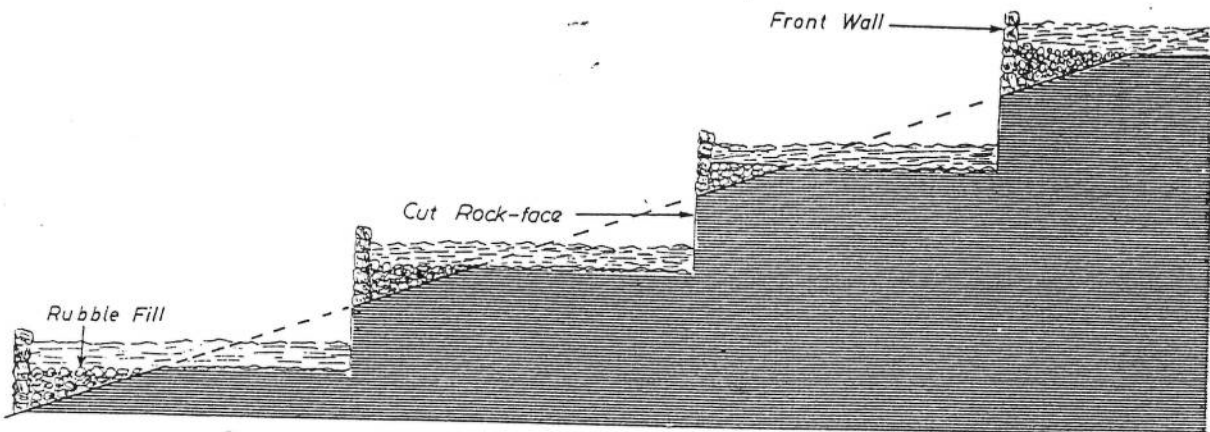
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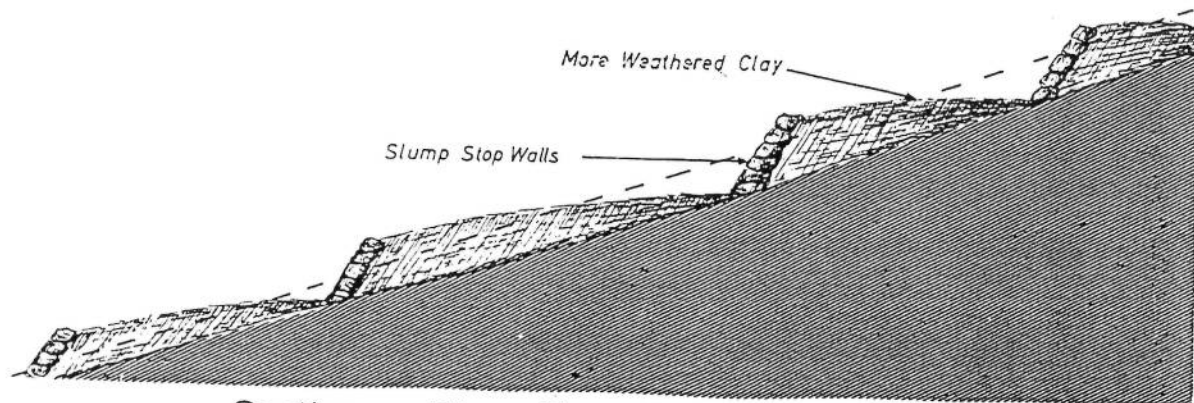
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Section - Strong Terracing On c. 1:3 Slope.



Section - Blue Clay Terracing.

Fig. 6. Types of terracing in the Maltese Islands.

built up well above the level at which water occasionally flows, and forming the walls of a canal, so that all the drainage appears somewhat artificial.

The map showing the terraced areas in Gozo has been prepared from field notes and aerial photographs and may contain errors of classification. However, it does show that a very large proportion of the land surface is terraced, and gives some impression of the widespread and profound soil disturbance which accompanies terracing.

Of the areas marked as unterraced or nearly so the majority are Xaghra series. This soil is difficult to work because of its patchy distribution between limestone lapiés that are generally hard enough to make terracing a very expensive business. The other unterraced areas are in particularly flat, sometimes alluvial locations, little subject to erosion even though left exposed and are uncommon areas in the Maltese Islands.

The accompanying diagram (Fig. 6) illustrates the disturbance of the soil by terracing. Instead of the series of natural soil horizons originally developed on a parent material there is (1) a uniform soil material, sometimes only of the depth of the plough layer on top of (2) rubble that has been carted or made by man rather than by weathering processes resting on (3) solid rock - usually a cut surface.

In some areas the back walls cut into the rock are constantly being undermined by ploughing or hoeing as they weather to a soft product and the result is the production of a carbonate raw soil at the undermined wall with a sequence across the terrace possibly to Terra soil material at the front. Such a sequence is quite commonly seen on the Zonkor ridge near Marsascalea in Malta.

Thus where the land is at all strongly terraced the variation within a terrace maybe as great as the variation between two widely separate series elsewhere.

FACTORS IN SOIL FORMATION IN THE MALTESE ISLANDS

Five factors are involved in the formation of soil (Dokuchaeff) and of these probably three are fundamental in the production of the soils of Malta, viz., parent material, climate and time. Topography, the fourth factor, is largely dependent on the first three, since landscape is largely moulded by erosion and deposition, related to the parent surface, process and time. The fifth factor, biological influences, is presently dominated by man's works, the effects of which are mainly secondary, producing modifications of the existing patterns, which are nonetheless sometimes profound in scale.

It has been said that a landscape can be likened to a palimpsest with remnants of earlier patterns showing through the present pattern. This is true of the Maltese Islands where the slowly fading "cultural landscape" of the Crusader era, is a major part of the present scene, through which fragments of yet earlier culture patterns still show, and which the modern growths of airfields, broad highways, blocks of flats, and factories, are slowly, incompletely overlying. Similarly the present soil patterns are a palimpsest.

There is no clear beginning from which to trace the genesis of Maltese soils unless we return to the emergence of the islands from the sea late in Miocene times, after the consolidation of the Upper Coralline rocks. Since then, the surface has been altered by tilting and faulting as well as by processes more specifically related to soil development. It is conjectured that at some time after the initiation of the faulting system, and before, or during the last Pluvial period, Terra soils were forming, concurrently with rendzinas and carbonate raw soils. At some stage and possibly continuously during the Pluvial period, they were eroded and the erosion

products washed down into valleys which were then being carved out. With the soil material were carried bones of the animals which had inhabited the woodland, to be preserved in the valley and cave deposits of the period, which are now somewhat limited as a result of subsequent erosion.

By the end of the last Pluvial there were deep alluvial deposits much as we know them. However, the sea level has changed since and tilting of the land has been continually depressing the eastern half of the islands, controlling valley development and the exposure of the alluvium. In addition to the mainly alluvial deposits of the bottomlands, colluvial deposits of Terra material and weathered limestone were formed at the valley sides, some being cemented into quite solid rocks.

From the end of the Pluvial period the climate has continued to oscillate between colder and warmer, and wetter and drier periods, but amplitude and period have probably been smaller than during the Pluvial times. At present the climate of the Mediterranean is relatively dry and warm, having passed through a period when it was warm and possibly wetter (the Climatic Optimum) some thousands of years ago. It is believed that a gleyed horizon at Marsascala (profile Malta T) containing monocotyledonous plant remains dates from one of the most recent cold periods and is certainly not earlier than the last Pluvial. It is therefore presumed that the bulk of the three feet of Terra material which overlies that layer (and which must have been downwashed later) was formed during some period of warm and moist climate, if not actually during the Climatic Optimum. Under present climatic conditions it seems as Kubiena says (Kubiena 1953) that little or no Terra soil is being formed, although Reifenberg considers that it is being formed in Mediterranean localities, usually with a Lang rainfall factor of 30 to 60. The rainfall factor for Malta is about 23 which appears likely to reconcile both views as far as Malta is concerned.

By the time of man's arrival in reasonably large numbers, the climate had become almost like that of today, that is, dry and warm. The valleys initiated by Pleistocene erosion had been cut through the Globigerina rocks with their patchy rendzinic soils and the Lower Coralline was exposed by this stripping of the overlying rocks. Left behind were remnant spreads of alluvium at high levels, deep stratified alluvium and colluvium in the broad valley bottoms to which was added marine alluvium at the bay heads. Terra soils between karst lapiés on the Coralline limestone, and also in various favoured locations on the Franka, together with patches of rendzina and raw soils on the non-Coralline rocks supported a new vegetation unable to sustain the soils against erosion in the occasional heavy cloudbursts of the changed climate.

The arrival of man as a factor in the development of the soils was contemporaneous with a situation where the changing climate had left incongruous soil materials and wide areas of nearly bare rock colonised by a xerophytic flora. In the relatively short period of man's effective occupation, say, 2000 years, this effect on the soil of human activity has been most profound, as far as soil appearance is concerned at least, probably more profound than the vastly longer weathering period, despite the fact that man has produced only modifications of the pattern.

Time as a factor in the development of the present soils covers the period during which the present processes have been at work. Thus the 'history' of the soil materials given above, important though it is in accounting for the present soil distribution, is only relevant to the discussion of the parent material of the soils, which follows.

Parent material and soil

In the Maltese Islands the rocks parent to the soils are all closely similar in type chemically and differ only moderately in physical characteristics. Nevertheless from these rocks quite dissimilar products were formed under the influence of climatic conditions moister than those of the present day. In the massive, crystalline, well-jointed limestones solution takes place at rock surfaces, while

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possibly less permeable finer-textured limestones (such as the upper part of the Globigerina), solution takes place principally within the rock pores. In the one case drainage is through major cracks, jointing and bedding planes, in the other drainage is minimal, surface flow is common but more water is absorbed or lost by evaporation. The result has been that in the past, solution took place more freely in the crystalline Coralline limestones, and when the water had drained away, the residues of accessory minerals, mainly rich in silica, and sesquioxides, the impurities in the limestone, were left behind. The eroded surface of the rock (lapiés) yielded rock debris which in turn was added to the material available for solution. On these rocks is left a reddish-coloured soil composed of the residue from the limestone, the properties of which are variable, depending on local variations of the "impurities" in the limestone. Thus in some parts the soil is very plastic, elsewhere it is non-plastic.

On the marly rocks there is no doubt a slight enrichment of the surface horizon in the impurities of the limestone, because of some loss of drainage water, but in general it is not very great, and the main effect of water is physical in breaking up the rock.

Thus two highly calcareous parent rocks under closely similar climatic conditions produced different soil materials, the one becoming largely decalcified, the other slightly decalcified. The final materials produced are very dissimilar.

Much of the weathering, of the red soils in particular, occurred in earlier times in periods of different climate, and it is thought that in the present semi-arid climate processes are nearly at a standstill. The accumulations of unconsolidated "soil material" produced by solution (favoured under warm, wet conditions) or by solifluction (favoured under cold, wet conditions) are themselves the parent materials of the present soil. Where they are absent, rock, quarried by man or merely ploughed by him, largely forms the parent material of the biological soil.

The variations in the chemistry of the parent material and other details of its physical characteristics are important for a number of the soils because the climate is producing relatively little diminution of differences. The soils are thus largely lithogenic rather than climatic, and for most series the parent material has been related to the soil in some detail.

Time and the soils

Maltese soils are all rather young or immature since pedological processes are slow in such calcareous soils. Certain soils, for example the red brown clays of the Terra group, were formed, it is thought, largely under the influence of processes which have been superseded. Under a changed climate the new, very slow processes have so far produced little change in the soil profile. The profile is a relic of the old process and thus the soils are, in a sense, relic soils, but at the same time are very immature, (young) soils under the new climate, because the new process has produced so little change. In the San Biagio series, very young man-made carbonate raw soils, dating only from when they were mined from the rock, are found in front of undermined terrace backwalls. Only a few yards away much older soils are developed from the same parent rock, and they are xerorendzinas. While the raw soil has been subjected to soil-forming processes for less than 50 years, the xerorendzina has been developing over several hundred years.

Climate and soil

The climate of Malta and Gozo is a good example of the Mediterranean type. It consists of hot dry summers, having a high rate of evaporation

and no rain, warm and showery autumns normally with a rainfall deficit, short cool winters with enough rainfall for agriculture in most years, but leaving insufficient reserve in the soil to combat the warm drying springs again having a rainfall deficit. The variation on sites of the same type is obviously small, but between deep-set valleys, north-facing scarp slopes and the main open plateaux or south-facing slopes there are often well marked differences in vegetation, both weeds and crops. The difference is striking because of the difference in insolation, and thus of surface temperature regime. However, soil profiles show virtually no difference between different sites, and it only in exceptional locations that the normal pattern of aridity is sufficiently overcome to allow the development of noticeable humus horizons.

In the past there have been broad oscillations of climate responsible for the production at different times of widely differing soil materials such as the 'red soil' (red brown Terra clays), stony calcareous debris and aeolian sands which are now the materials parent to the present soil. The present climate, however, is not a leaching climate.

This uniformly arid climate is in strong contrast with that of some other latitudes, for example that of Britain, and suggests itself as the reason for the restricted range of soils found in Malta and Gozo.

Topography and soil

Topography influences the development of the soil in a variety of ways, but chiefly through modifications of climate, variable conditions of drainage, and effects on erosion and transportation processes.

It has already been noted that the variation of topography produces sites having radically different insolation conditions, but the effects are negligible. It is only in the extremely freely drained conditions of some hill tops, where lime crust yermas are simulated on parent materials of fine sandy loam texture, that the effect of topography on drainage conditions can be thought to be sufficient to produce soil modifications. It is true that the small pockets of protorendzina soil owe their existence to topography - but they are so small and rare as to be negligible. It is, however, also noteworthy that in the Alcol series, depression of the east coast results in a sea water-table in the old alluvium and some soils are becoming secondarily saline in consequence.

The effect of topography in producing variations of the soil dependent on erosion, transportation and deposition is more noticeable. It has already been pointed out that the present climate is not likely to produce solifluction conditions though this has been the case in the past but sheet or gully erosion occurs during violent showers of late autumn. The Tas Sagra series, although probably largely of earlier alluvial and colluvial origin, is continually fed in some locations by alluvial washes of mainly colloidal soil material from the Xaghra series, and in certain localities is in fact an alluvial phase of that series.

The San Biagio series shows a toposequence (profiles Malta R and S) from a shallow eroded phase at the head of a slope, to a deep alluvial-colluvial phase at the foot, which show slight differences in texture and composition.

In the soils developed on the Blue Clay, startling differences are to be observed between the older, more weathered downslope materials (those of the Light Fiddien and San Lawrenz series) and the relatively raw, newly exposed materials at the head of the slopes (Fiddien heavy clay), the former having fairly normal analyses for calcareous soils, while the latter are sometimes markedly alkaline, and slightly saline.

There is thus a considerable dependence of soil on the topographic factor although it is not generally related to the drainage as is usual in cooler climates and on other parent materials.

Man has already been mentioned as a most potent factor in soil development or modification, but other biotic factors are of relatively small importance. To the naked eye in fact, there is little evidence of the activity of soil organisms except in that very small percentage of the soil carrying a semi-natural vegetation. The development of humus is minimal, the total organic-matter content being in general very low, and the humus-deficient humus forms are generally only observable under the microscope. Here can be seen the spongy fabrics produced by the fused droppings of soil animals, which are chiefly responsible for the more favourable structural characteristics of some profiles, and the reasonably good fertility of the xerorendzinas in comparison with the carbonate raw soils which have a more rudimentary fabric. In some soils, ants, dung beetles or snails abound, contributing by their activities to structure and to a much lesser extent to humus development. In a very few of the wetter soils worms are reasonably numerous, and these soils have a well developed mull humus horizon, although the actual amount of humus is small. Soil organisms produce their greatest developments of humus forms beneath long established carob trees, (see profile Malta A), but the xerophytic vegetation of the Xaghra series is accompanied by a relative paucity of soil fauna, and only ants compete with snails to inhabit this soil.

The vegetation itself is seldom important, the grass mat on the surface of the dune sand soils and the xerophytic vegetation on the Xaghra karst both act as stabilising agents, but add little humus to the soil.

In general the biotic factors have a subdued influence except for man, and where his influence is well marked, the other biotic factors are of almost no interest.

Summary

For each individual soil profile the effect of the various factors is different, but generalizations can be made for each series. The present climate is ineffective in producing horizon differentiation, and topography was previously much more important than it is now. In effect time and the parent materials are generally most important, with man a dominant factor. The table below (Table 3) suggests the dominant factors of soil formation in producing the present soils.

Table 3 Suggested dominant factors in the formation of the soils

Soil name or mapping unit	Factors	Parent Material	Climate	Time	Topography	Biotic factors	
						Man	Others
Nadur		2				D	
Ramla		D					
Fiddien heavy clay		D	2				
Fiddien light clay		D					
San Lawrenz		D					
San Biagio		D					
San Biagio anthropogenic							
San Biagio Carbonate raw soil		CD				CD	
Alcol		CD		CD			
Alcol (saline)				CD	CD		
Tal Barrani anthropogenic		CD				CD	
Tal Barrani (natural)		CD		CD			
Xaghra		D	2				
Tas Sagra		D	2				
Armier							
L'Inglin and Tad Dawl							

D = Dominant

CD = Co-dominant

2 = secondary

Classification of the soils

Soils are complex biological entities so that when classifying them a variety of methods are at hand and among them chemical (hydrogen ion concentration and content of soluble salts), working (texture/consistence), classifications and a variety of others have been used. But, following botanists and zoologists, a morphological system has been established for soils which depends principally on field observations and uses laboratory data as confirmatory and supplementary rather than diagnostic information.

However, the morphological type of classification has not been extended to soils in which man is the dominant agent in the production of profile morphology, and to correlate the soils of the Maltese Islands with those of other lands it is necessary first to find profiles relatively little affected by man, and equate the remainder with them. Using the classification from Kubierna's "Soils of Europe" (1953) this, in broad outline, is not difficult, but attempts to identify more closely sub-type or variety are probably of no more than academic interest, especially since there is a high coefficient of variability between and within fields, and man-induced variation is (apparently) random.

In describing the soils of the Maltese Islands the prime purpose was to provide descriptions suited to the needs of agriculture. Differences in chemistry, physics, and biology of the soil reflected in soil colour, texture, and structure were accordingly mapped in conjunction with the landscape type. The soils are

- (1) largely artificial, being man-made or altered and
- (2) highly calcareous, so that in this Mediterranean climate the evolution of morphology is slow and the dynamic not clearly defined.
- (3) partly relic (some soils of the Terra group) dating back to periods of wetter climate, and now not of their original form.

Even natural profiles show scant differentiation below the very thin humus horizon, so variations of parent material dominate soil differences. This scant differentiation probably induced farmers to treat the soil like the ingredients of a pudding, to be mixed as desired to produce the most delectable result, which has increased the difficulty of classification.

Table 4. Classification (according to Kubiiena 1953)

Div.	Class	Type	Sub-type (qualified)	Variety	Locality/Series
A. Sub-aqueous					
B. Semi-terrestrial	BA. Semi-terrestrial raw soils	VI Rambla	12 Chalk Rambla		Chadira Alcol
	BD. Salt soils				
C. Terrestrial	CA. Terrestrial raw soils	XXIII Syrosem	50. Carbonate raw soil		Fiddlen, San Lawrenz Nadur, Ramla, part S.B.
		XXV Rendzina	60. Humid Rendzina	(36) Protorendzina Mull rendzina	Malta E. Malta P.
	CC. Rendzina-like soils		61. Xerorendzina	Xerorendzina	San Biagio Alcol Tal Barrani
		XXXIII Terra	74. Terra fusca	(47) Earthy terra fusca	Xaghra, Tas Sagra
	CE. Terrae Calx1s		75. Terra rossa	(48) Stiallitic terra rossa	

Secondary Salt Soils

CHAPTER III

CARBONATE RAW SOILS (CARBONATE SYROSEMS)

According to Kubiena (1953) the carbonate raw soil is a "very young raw soil, extremely low in humus, characterised generally by a dry summer (on the surface partly also hot summer) soil climate on calcareous parent rocks".

These soils have an (A)C profile, that is to say, an (A) horizon overlies the C or parent material horizon. The (A) horizon is the zone most strongly colonized by organisms, the well aerated superficial layer of soils in which no recognizable humus horizons have developed. It has a recognizable humus form, raw soil humus, consisting of a few fragments of undecomposed plant remains in which there are cavities containing droppings of mining animals; the mineral grains are calcite. Usually only the sand will be obvious to the unaided eye.

Occasionally the (A) horizon will overlie a Ca horizon of secondary calcium carbonate precipitation above the C horizon.

In Malta and Gozo four series of carbonate raw soils have been distinguished on the basis of the variation in the parent material, from which the biological soil differs very little. These are the Nadur, Ramla, Fiddien and San Lawrenz series. The reasons for classifying them as carbonate raw soils are briefly summarised here, after which they are described.

The Nadur series is a carbonate raw soil, having been produced by dominantly physical weathering (or man) from the coarse limestones of the Greensand, the lower part of the Upper Coralline Limestone, and Quaternary conglomerates. Some of the better weathered highly glauconitic types of very limited extent could be considered xerorendzinas, but in the main the soils are coarse-textured raw soils with non-intimate admixtures of clay minerals.

The Ramla series is developed on stratified calcareous dune sand and, in a semi-natural profile under grass, has a 'forna' layer (a thin decaying grass leaf mat) above the sand. The profile can only be differentiated into horizons by the density of the grass root net at different levels, since there is no other humus form, nor apparent translocation down the profile.

Although this soil is perhaps not the best example, the carbonate raw soil is the only type in Kubiena's classification which fits it satisfactorily.

The Fiddien and San Lawrenz series, soils dominated by their content of Blue Clay, are difficult to fit into any classification. They are calcareous, with field pH values about 8 (about 8.5 in the laboratory), and they are dominantly heavy or very heavy soils. They are raw soils, with little apparent chemical weathering except oxidation of newly exposed clay, little physical weathering and no noticeable translocation in the profile. They have no macroscopic humus development. Where they are worked (everywhere except in slopes $>35^{\circ}$ and where the heavier type is found) the topsoil has been modified by tillage and "manuring", so that the soils are again partly man-produced.

The light Fiddien type and San Lawrenz series are developed from erosion products (colluvial) of the Blue Clay and have normally a calcareous non-alkaline composition, but the heavy Fiddien type, unweathered

Blue Clay, appears to be alkaline in most cases, and probably saline as well in at least some profiles. (Profile Gozo D is alkaline and saline, see Appendix II Table IV).

It therefore seems most fitting to call the lighter soils, (the light Fiddien type and the San Lawrenz series) carbonate raw soils, using Kubiena's classification. The heavy Fiddien series should be qualified by the term alkali, or where applicable, saline alkali.

The Ramla series is found in a variety of topographic locations in northern Gozo and northern Malta.

The Nadur, Fiddien and San Lawrenz series, are found usually in steep scarp slopes (landscape elements 4a and 4b), and the latter pair less commonly on the low plateaux or in broad open valleys, (landscape elements 2a, 2b). Typical developments are in the scarps surrounding the Rabat-Dingli plateau and its central valley, and in that valley, and in the broad valleys of Marsalform and Wied tal Kleigha in northern Gozo.

THE RAMLA SERIES

Location and parent material

The Ramla series, which covers the seaward end of Ramla valley in northern Gozo and the scarp slope on its eastern side is also found as a member of the Armier complex (see page 67) which exhibits a sequence of soils from Xaghra series to Ramla series on Il Qortin tan Nadur in Gozo, and Marfa Ridge in Malta.

The Ramla soils are formed on sands of contemporary dunes at Ramla, and sands from the Quaternary dune sand bed at Armier where they are almost entirely man-made, having been quarried from the consolidated dune sand deposit.

A typical Ramla soil is briefly described below, and profiles described in more detail in the appendix may be compared with that of soil developed in the Armier complex on a mixed parent material. (Profiles Malta Y, and Gozo O, respectively, in Appendix 1).

RAMLA SERIES. Profile Gozo N. Quarry south-east of Ramla Bay. (358908)
Topography. 50 ft. above sea level, on lowest slopes of a main scarp (landscape element 4a), slightly terraced field sloping 6° W.N.W. *Land Use.* Abandoned, now grass covered; nearby fields are growing apples and other tree fruit, some are irrigated.

Profile description

	inches	
L & F	$\frac{1}{4}$ - 0	Dense mat of grass leaves.
S ₁	0 - 7	Brown (7.5 YR 4/4) sand; dry; single grain structure, grains strung on abundant grass roots, raw soil humus; many snail shells, some large pores; no stones; some added material (believed Blue Clay); calcareous; merging to
S ₂	7 - 14	Brown (7.5 YR 4/4) sand; slightly moist; similar to the horizon above, but fewer roots; calcareous; merging to
C	14 - 40 +	Strong brown (7.5 YR 5/6) sand; moist; similar to the horizon above, but with occasional layers of snail shells, illustrating the bedding of the dune sands, and with very few roots; no stones, some added matter.

In agricultural use, without the grass cover, these soils show even more complete uniformity down the profile. However, in some places they have been 'marled' with other soil materials, principally Fiddien clays, and this has made the texture of the surface soil heavier.

Parent material and soil

The dune sands at Ramla are believed to be derived mainly from fallen blocks of the weakly glauconitic facies of the Greensand which is very well developed there. Some blocks of this material are exposed in the sea and appear to be very similar in composition to the dune sand. The sands which are very deep at the coast thin slowly towards the south and east, so that eventually they form a mere thin surface coating over the parent materials of the Fiddien, San Lawrenz and San Biagio series. This contamination is depicted on the 2-inch map.

Both dune sand materials are highly calcareous, that at Armier was determined as 88 per cent calcium carbonate and there appears to be almost no loss through leaching, as the value for the surface horizon is 84 per cent. Total soluble salts amount to about 0.05 per cent. The appearance and chemical nature of the soil is almost unchanged from that of the parent material.

Physical Conditions

The soils are extremely light, lack any noticeable quantity of organic matter and all but a most rudimentary development of structure, the only tendency to aggregation being the attachment of sand grains to roots in the tillage layer. However, the soil is probably sufficiently loosely packed to prevent conduction of water to the surface, and though it is a quickly warming soil it is unlikely to be too hot because of its light surface colour. With some irrigation it is locally considered a rather good soil for tree fruits, which are the major crops of the series, in Gozo at least.

Chemical Analyses

Reaction (pH) and calcium carbonate.

One profile (Malta Y) contained over 80 per cent calcium carbonate. In view of the low content of soluble salts - 0.05 per cent (derived from conductivity, determined as 0.13 millimhos/cm, (Piper 1950)) the pH's determined seem rather high at 8.7 in the surface and 9.3 in the lowest sample. The other profile with about 2 per cent active calcium carbonate shows a more rapid increase in pH from 7.80 to 9.0.

Phosphate.

The higher total phosphate content of the Gozo profile about 0.2 per cent as against 0.1 per cent in Malta Y is accompanied by a lower figure for readily available phosphate about 15 p.p.m. against 50 p.p.m. It appears that differences in the form of the parent material probably account for this.

Organic Matter.

The low figure of about 0.5 per cent organic matter in the surface foot of the new dune soil from Gozo is correlated with a low C:N ratio - about 7.5 indicating more rapid decomposition than in the Malta soil (1.3 per cent organic matter, C:N about 10), which has in any case a slightly heavier texture and less free drainage.

Exchangeable bases.

The ratio of calcium to the other exchangeable bases is noticeably higher than in most soils (despite the relatively low active CaCO_3). In the surface foot 90 - 94 per cent of the total exchangeable bases are calcium, and there is only 2,- 3 per cent sodium + potassium in all, which makes it probable that potassium is insufficiently available to plant. The rapid diminution of bases down the profile in the dune soil

at Nadur (Gozo N) is not paralleled by the 'mined' soil from Malta. Both profiles have a total exchange capacity of about 20 m.e./100 gms. in the surface horizon, but whereas the proportion of calcium increases down the profile in the Malta soil, it decreases in the dune soil. This may indicate a greater proportion of soluble calcium compounds (dependent on earlier climatic conditions) in the 'mined' Malta soil, than in the more freely draining new dune soil.

Notes on chemical analyses of associated soils.

The miscellaneous samples Gozo N I, II, and III (Appendix II) are of various mixtures of Ramla sands and Fiddien and San Lawrenz clays derived from Blue Clay. These are surface samples of progressively lighter texture - from sandy clay loam (I) to sandy loam (III). The two heavier varieties show noticeably good chemical characteristics and appeared, in the field, to have good structure - being favoured by ants they are perhaps locally excessively porous. It is possible that the mixture of clay with Ramla sand is the most advantageous of the Blue Clay group of parent materials.

Horizon Differentiation and Classification

The differentiation of horizons in these soils is limited to the development of a thin humus layer and diminishing density of the roots down the profile. The soils appear to be very little colonized by animals or insects, and the only development apart from that produced by the roots, is (in the unworked soil) a thin litter - 'forna' - layer of grass at the surface. It appears, therefore, that the soil is an (A)C type and can be regarded as a carbonate raw soil since there is no recognisable humus form developed in the mineral soil.

THE NADUR SERIES

In addition to the normal development of the Nadur series, the mapping unit includes 3 variants, the area of each of which is too small to separate.

The Nadur series is found mainly on the slopes of the scarps in which the lower part of the Upper Coralline Limestone and the Greensand formations are developed (see Fig.9). These soft, coarse-sand textured limestones are the principal parent material of the series, but it is occasionally developed on the soft, poorly sorted Quaternary beds developed from colluvium of weathered Upper Coralline Limestone and Greensand. These are very limited in area and the typical and only extensive development is east of Wied ta Dahlet Qorrot in Gozo where the soils are shallower and less well developed than normally.

Normally the Nadur series is only a narrow strip of strongly terraced land along the upper part of the slopes of the main scarps and some of the shorter scarps (landscape elements 4a and 4b) as around the southern part of the mesas of Xaghra and Nadur, round the Rabat-Dingli plateau and on the east side of its central valley. However, where the Quaternary beds extend over the Blue Clay and Globigerina limestone, as near Dahlet Qorrot, or where, as on the west side of the central valley of the Rabat-Dingli plateau and the northern side of the Nadur and Xaghra mesas, a broad open valley has developed and the scarp is missing, the series is more extensively developed.

The following profile is typical

NADUR SERIES. Profile Gozo R. Near Nadur. (373887) *Topography.* Steep sided valley about 400 ft. above sea level, in the softer limestones below the karst mesa surface (landscape element 1a) which it dissects. Small field, strongly terraced, sloping about 3° E.N.E., in general valley slope of 10°. *Land Use.* Vineyard, non-irrigated.

Profile description

		inches
S ₁	0 - 12	Reddish brown (5 YR 5/4) gravelly, gritty loamy sand; single grain; vine roots, raw soil humus; a few ants; calcareous, no secondary CaCO ₃ observed; merging to
S ₂	12 - 27	Reddish yellow (5 YR 5/5) gravelly, gritty sandy loam, otherwise as the horizon above, merging to
C	27	Friable off-white coarse-grained limestone.

The red colouring of the soil is mainly attributable to an admixture of downwashed sesquioxide clay from the Xaghra soils above. The amount of the admixture is small, usually no more than a coating on most of the limestone sand grains, but occasionally the Nadur series exhibits a transition to the Tas Sagra series, as at Miziep and Nadur, where the Terra clay washed across a sequence of soft limestones gives both Nadur and Tas Sagra soils at opposite ends of the sequence.

Variant I

In some small areas, notably at the heads of slopes, the red colouring matter is often missing and a variant is observed with similar profile characteristics but greyish or slightly yellowish colours, for example, very light olive brown 2.5 Y 5/3.

Variant II

In some areas a highly glauconitic facies of the Greensand outcrops and on this is developed a light-textured soil as at Giordan, Gozo, where the profile is as follows:

NADUR SERIES (Glauconitic loamy sand variant). Profile Gozo H. (291921) Ta Kancila, near Giordan, west Gozo. *Topography.* 275 ft. above sea level, on a poorly developed main scarp (landscape element 4a) where the Greensand appears to be extensive at the expense of the Blue Clay, just below fallen blocks of Upper Coralline Limestone. The field, 10 yards wide, has terrace walls 5 to 8 ft. at front and back and slopes gently 2° S.W. in a general scarp slope of 15°. *Land Use.* Fallow after oat crop. Farmer remarked that the field was very good especially for water melon.

Profile description

		inches
I	0 - 10	Greenish buff gritty loamy sand; very weak medium subangular blocky; abundant fine roots, numerous 2 mm. pores, low organic matter, raw soil humus; a few stones; loose; calcareous; sharp boundary to
II	10 - 17	Greenish buff gritty loamy sand; generally similar to the above horizon, but more stones; very loose; some secondary calcium carbonate in the root networks, organic matter content lower.
III	17 - 40 plus	Greenish buff gritty loamy sand; massive; very low organic matter; abundant gravel - mainly reddish pebbles of limestone; compact, hard; abundant secondary calcium carbonate, concentrated along old root networks.

Variant III

Near Hofret-ir-Riz a heavy-textured glauconitic transition facies between the Greensand and Blue Clay is developed, which is of very small extent, on which the following profile occurs.

NADUR SERIES (heavy variant), transitional to Iudren series. Profile Malta B. Grid ref. 435706, near Hofret-ir-Riz. Topography. About 580 ft. above sea level on the gently sloping western side of the central valley of the Rabat - Dingli plateau (landscape element 2b). The field is not terraced and slopes 1° N.W. Land Use. Fallow after sulla.

Profile description

	inches	
S ₁	0 - 10	Dark yellow brown (10 YR 4/4) gritty clay loam; very dry; strong fine to medium crumb; many fine roots, low organic matter; slightly plastic, sticky; calcareous, numerous granules of secondary calcium carbonate on structure faces; humus form - raw soil humus.
S ₂	10 - 20	Dark yellow brown (10 YR 4/4) heavier clay loam; very fine to medium subangular blocky; many fine roots, very low organic matter; compact; more secondary calcium carbonate.
C	20 plus	Dark yellow brown (10 YR 4/4) clay; fine to medium subangular blocky; compact; becomes heavier in texture downwards.

With the exception of Variant III, the landscape of the Nadur series is characteristically everywhere, strongly terraced with backwalls cut deeply into the soft rock.

Horizon Differentiation

This soil is dominantly man-made, having been broken down from the loosened parent rock. Consequently it is difficult to fit it in any "natural" system of classification such as that of Kubiena. Typical Nadur series soil shows (1) little evidence of any organic matter, except where (a) the roots of plants are found, and (b) mummified organic manure and roots are sometimes seen, (2) an absence of active organisms except occasional ants. There is virtually no differentiation down the profile to the solid rock. Characterisation as an (A) C soil, therefore, fits reasonably well, and the soil can be called a carbonate raw soil.

Physical properties

The most important distinguishing feature of the Nadur series is its relatively coarse texture, except for minor variants which are ignored here. Usually a sandy loam or lighter, it has a high percentage of rock fragments of gravel size, up to 80 per cent of the whole soil. The structure is rudimentary, being little more than single-grain usually, reaching its best development under vines or similar perennials, and where there are concentrations of colloidal materials, usually at the bottom of the profile at the front of gently sloping terraces.

The lack of intimate mixture of the colloidal and coarser fractions, (except the coating of most of the sand grains), affects the consistence which is loose, the soil being excessively well drained. When, rarely, the surface has been puddled by very heavy rain, dried out and then been tilled, moderately hard large clods are formed, but less well developed than those of the San Biagio series. Generally the soil is loose and extremely easily worked. It is a quickly warming, relatively dry soil, and probably more than usually prone to drought in spring and summer. It is also given to rapid mummification of organic matter.

Chemical analysis

The glauconitic Greensand facies of the parent material provides, as might perhaps be expected, the apparently most favourable soil analyses.

Calcium Carbonate and reaction (pH).

The pH is over 8 in each case, but the Greensand soil (Profile Gozo H) has the lowest values. It has also only about half the quantity of active CaCO_3 to be found in the other profiles, which with 13 to 15 per cent are above the average for the Malta carbonate raw soils and contain nearly as much as the finer-textured San Biagio soils.

Organic Matter.

The organic matter content is low in each case, ranging from 1-2 per cent, about average for the carbonate raw soils. However, since the fine soil passing a 2 mm sieve is only 20 to 30 per cent of the whole soil this is only about 0.2 to 0.4 per cent of the whole soil material, which partly accounts for the poor development of structure.

Phosphates.

The total phosphorus content of the soil as P_2O_5 was conspicuously low for the non-glaucanitic soils at 0.05 per cent, and conspicuously high for Gozo H, the glaucanitic variant, 1.2 per cent. The readily-soluble fraction is only twice as much in the latter as in the former, however, and is probably deficient in many of the soils.

Exchangeable bases.

The dominance of the calcium ion is particularly marked, and the monovalent ions are at their lowest values as Table 5 below shows.

Table 5. Exchangeable cations, surface horizons, Nadur soils

Profile	Individual cations as per cent of total				Total exch. bases m.e./ 100 gms.	<2 mm. soil as percentage of whole soil
	Ca	Mg	Na	K		
Gozo H (variant II)	88.5	8.6	1.1	2.0	33.7	78
Gozo R	91.2	5.5	0.8	2.6	24.6	35
Gozo P	90.3	6.4	0.7	2.6	27.4	29

This serves to emphasise the extremely calcareous nature of the soils, the lack of minerals apart from calcite even in the apparently highly glaucanitic soils, and thus the raw nature of the soils.

THE FIDDIEEN SERIES

The Fiddien series is developed on the Blue Clay, and is found chiefly in the main scarps (landscape element 4a) as around the Rabat-Dingli plateau and Wardija ridge, where it usually forms the lower slopes a little above the Globigerina limestone plateau. It is sometimes found at the top of the shorter scarps (landscape element 4b) or even in small remnant hillocks on the Globigerina plateau as near Ta Birbuba in western Gozo, where the surface is less steeply inclined. It is only found nearly flat where, as in the central valley of the Rabat-Dingli plateau (landscape element 2b), structure has restricted valley development.

There are two texture types, a very heavy clay and a somewhat lighter clay, the differences between which are of considerable importance to agriculture. Where possible they were differentiated during the field mapping, but they are not separated on the final 2-inch map. However, a fairly fixed relationship exists between the types and the landscape, and two minor types also differentiated can also be related to the landscape facet.

FIDDIEN SERIES (heavy clay type). Profile Cozo D. (312910) Pumping Station near Zebbug. *Topography.* About 300 ft. above sea level on the level of the dissected Globigerina plateau (landscape element 2a), below an isolated, steeply sloping ridge of Blue Clay, and near the foot of the scarp which surrounds the mesa of Zebbug. The field slopes 3° in a general slope of 7° S.S.E., and is slightly terraced (see Fig. 8). *Land Use.* Abandoned, now in sparse rough grass. Obviously a very dry site.

Profile description

	inches	
(A)I	0 - 10	Olive (5 Y 5/3) clay; moderate large polygonal prisms (10 in. across), breaking to fine medium subangular blocky, especially in the surface 4 in.; many fine pores and fine roots, low organic matter, raw soil humus; plastic, sticky; calcareous, secondary calcium carbonate on structure faces, and some clay skins on structures; sharp boundary to
(A)II	10 - 32	Olive (5 Y 5/3) clay; massive, but with occasional very coarse prisms; few roots, very low organic matter; some nodules of gypsum crystals, with iron stains; calcareous, calcite fine sand (secondary) between structures here and there.
C	32 plus	Dark blue green clay; unweathered; massive; calcareous.

Note: This soil is saline, and has 10% Na in the exchangeable bases towards the bottom of the profile. The genetic name has therefore been qualified by the phrases, saline, slightly alkaline.

An example of the light clay type is:

FIDDIEN SERIES (light type). Profile Malta I. Grid ref. 437720, Fiddien-is-Sentini, near Rabat. *Topography.* About 470 ft. above sea level on the flat Blue Clay bottomlands of the broad central valley of the Rabat-Dingli plateau (landscape element 2b). The field is slightly terraced and the profile was taken near the lower terrace wall, where the colluvium is deep. The slope is slight and northfacing. *Land Use.* Cabbages.

Profile description

	inches	
S ₁	0 - 16	Grey brown (2.5 Y 5/2) gritty clay loam; moist; weak fine granular; many roots, occasional worms, low organic matter, poor mull-like rendzina moder; sticky, moderately plastic; some gravel; calcareous; merging to
S ₂	16 - 30	Grey brown (2.5 Y 5/2) gritty clay loam; moist; similar to the surface horizon but compound moderate granular structure in weak angular blocky; many fine roots, some worms, very low organic matter; sticky, moderately plastic, more compact; calcareous; merging to
C	30 plus	Grey brown (2.5 Y 5/2) gritty clay loam; moderate coarse prismatic structure; no organic matter; many stones, some large; downwashed particles accumulated on ped faces; calcareous.

Minor types

Very frequently the lighter soils of the Fiddien series, and less frequently the less extensive heavy soils, have an overwash of largely very recent alluvial material from the soils upslope. This usually results in an appreciable lightening of texture in the surface horizon.

1. In some cases there is an overwash of sesquioxide (non-plastic) clay material as seen below the Coralline Limestone scarp at the top of Wardija Hill on the north side, and at Bahrija.
2. More often there is an overwash of lithosolic material like that of the Nadur series, and the texture of the loose topsoil thus formed is sometimes as light as sandy loam.

THE SAN LAWRENZ SERIES

The San Lawrenz soils are related to those of the Fiddien, having as parent material Blue Clay and Globigerina soft limestone colluvium and alluvium on Globigerina rock. The texture of the soil is clay loam or light clay at the surface, and where the alluvium-colluvium has not produced a clay loam texture, the soil has been included in the San Biagio series formed directly on the Globigerina limestone. The colour is diagnostic, and in dry weather after recent rain, the San Biagio soils appear a brilliant white, the San Lawrenz series remaining damp is still a yellow-brown.

The San Lawrenz series is almost always developed below the Fiddien soils in a scarp slope, as a belt of variable width, often right at the foot of the scarp and on the upper edge of the Globigerina plateau, (landscape elements 4a and 2a). It shows a broad development in this position in western Gozo, but is virtually non-existent in north-eastern Gozo and on many of the steeper scarp slopes in Malta. It is also developed occasionally in the short wields which fret the main scarps, at the point where these valleys debouch on to the Globigerina plateau (element 2a). Here it is surrounded by San Biagio soils on all sides, as in several locations along the scarp foot between Rabat and St. Paul's Bay.

A typical profile near Xewkija, is:

SAN LAWRENZ SERIES. Profile Gozo A. (341887) Ta Hauret, Tan Nuffara near Xewkija. *Topography.* 280 ft. above sea level on the edge of a minor valley on the Globigerina limestone low plateau (landscape element 2a) almost at the head of Ramla valley. The field is flat and unterraced. *Land Use.* Sulla crop just cut.

Profile description

	inches	
S	0 - 13	Light olive brown (2.5 Y 5/3) fine sandy clay loam; slightly moist; weak medium granular structure; few small roots, many fine pores, some associated with insect activity; some gravel; low organic matter, raw soil humus; calcareous, numerous crystalline interflorescences of secondary calcium carbonate; merging to
C	13 - 40	Olive brown (2.5 Y 4/3) fine sandy clay loam; slightly moist; moderate fine angular blocky; a few fine roots, many fine pores and some larger than 2 mm. diam. insect activity common; low or very low organic matter; compact, plastic and sticky; calcareous, much secondary calcium carbonate.

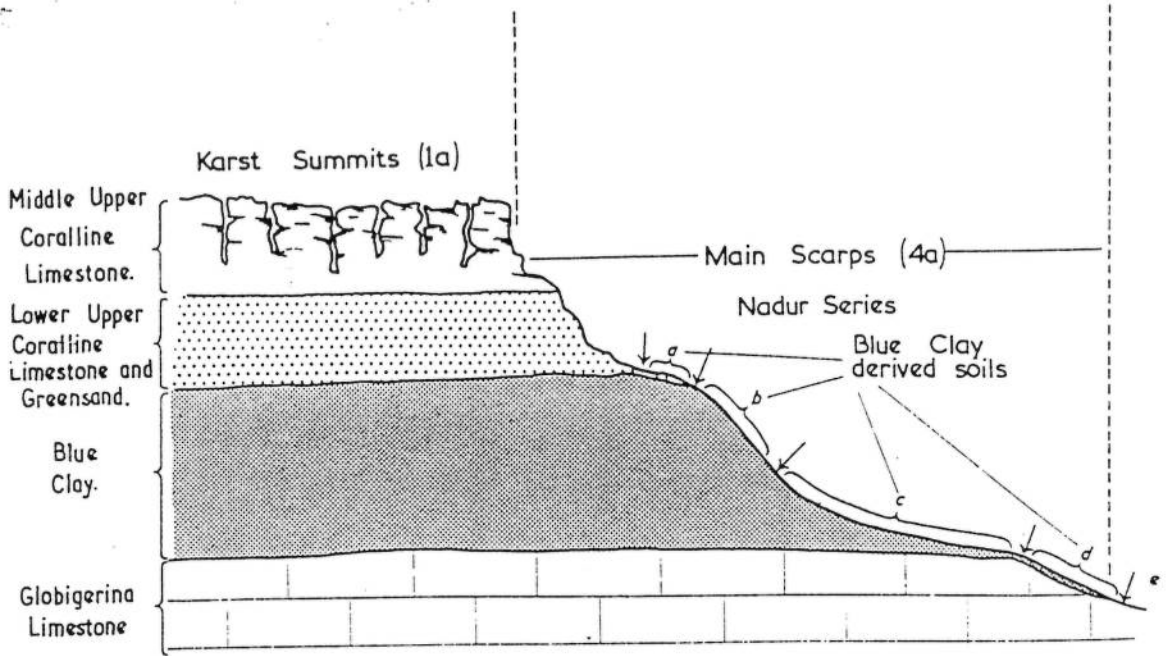


Fig.7. Location of soils of Blue Clay derivation on a main scarp.

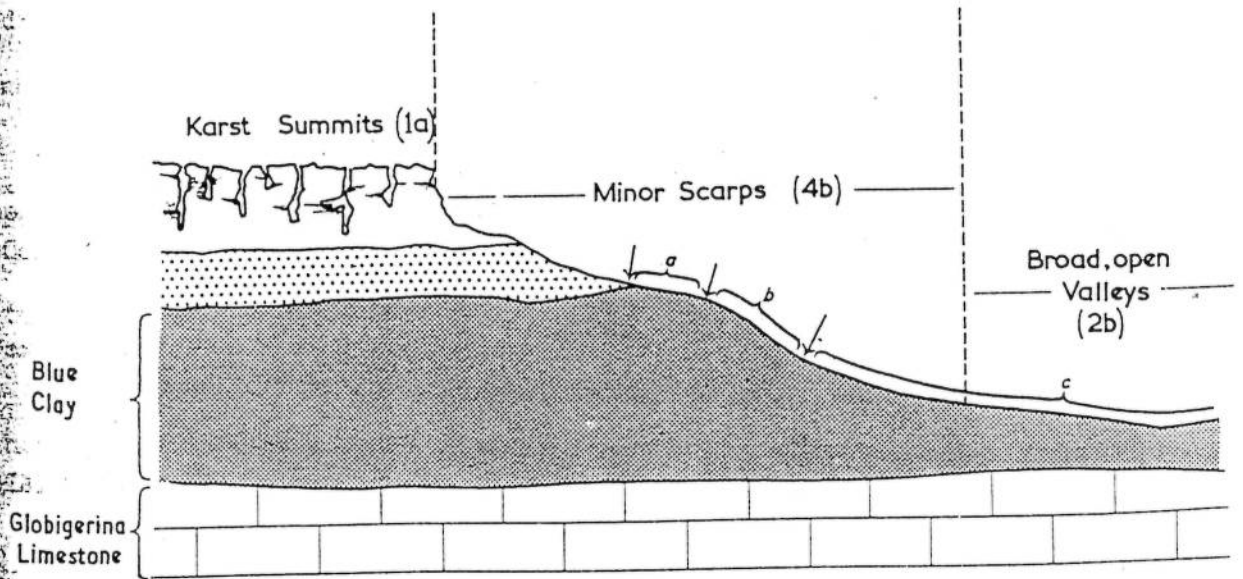


Fig.8. Location of soils of Blue Clay derivation in a valley site.

Profile description

inches
D 40 plus Pale brown (2.5 Y 6/3) fine sandy clay loam; moist; weak fine granular structure; no roots, few insects, very low organic matter; calcareous, no secondary calcium carbonate; predominantly rotten Globigerina limestone.

Characteristics of the Fiddien and San Lawrenz series

The diagrams (Figs. 7 and 8) show the relationships of the series to (i) a typical scarp slope terminating on the Globigerina limestone, for example, near Xaghra in Gozo and (ii) a typical valley where the scarp sequence terminates on the Blue Clay, or immediately below it, for example, Wied L'Iemu near Rabat.

- Key (a) - Fiddien heavy clay with a light surface soil.
(b) - Fiddien heavy clay.
(c) - Fiddien light clay with or without very light topsoil.
(d) - San Lawrenz clay or clay loam.
(e) - San Biagio series.

Terracing

Apart from the Blue Clay slump terracing (see p. 19 and Fig. 6) the Fiddien series is conspicuously unterraced, while the San Lawrenz has few terraces and those not strongly developed, since it is able to stand without noticeable erosion (in normal circumstances) in slopes of 5 - 10°. Fiddien soils of the heavy type are seen in slopes of up to 30°, and the lighter type often in 10° slopes.

Mapping and Boundaries

The two series have a rather ill defined boundary between them for the Blue Clay slumps well over its junction with the Globigerina limestone, and in some places a thick Blue Clay slope overlies a previously weathered Globigerina limestone slope. Consequently the Fiddien-San Lawrenz boundary is sometimes arbitrary because there is a gradual change of characteristics down such a slope and because of this, errors are unlikely to be of importance.

Parent materials and soil

There are basically two variants of the Blue Clay parent material on which soils are formed. Firstly, the slightly weathered or unweathered Blue Clay, more or less *in situ*, from which the Fiddien heavy clay is formed and secondly, the Blue Clay colluvium, mixed with a little lithosolic material, or a great deal of Globigerina lithosolic material, from which are formed the San Lawrenz clay loams.

There are thus, three variables in the nature of the parent material.

- (i) The rock chemistry of the Blue Clay as deposited.
- (ii) The amount and type of weathering to which the Blue Clay materials have been subjected.
- (iii) The amount and nature of the erosion products which have mixed with the Blue Clay.

The Blue Clay is dominantly a heavy clay, very plastic and sticky, according to Hyde (1955). The following analytical data are given by J. H. Cooke:

Carbonate of Lime	
Carbonate of Magnesia	traces
Sulphate of Lime	4 - 30 " "
Phosphate of Lime	traces to 2 per cent
Alumina	25 - 58 per cent
Oxides of iron	4 - 10 " "
Residues insoluble in dilute HCl	3 - 10 " "

There is some doubt as to the interpretation of these figures, those for alumina being remarkably high. It is evident however that the Blue Clay varies greatly in chemical composition. Analyses of some unweathered and little weathered Blue Clay are given in Table 6, with Globigerina limestone and the relatively weathered material from soils for comparison.

1. The chemical analyses indicate that the unweathered Blue Clay material from four locations (in a three dimensional sense) has in each case a rather high content of exchangeable sodium, and a rather high total of exchangeable bases and a large quantity of active calcium carbonate, i.e. large compared with Drouineau's figures which ranged from 1 to 16 per cent. He associated chlorosis in peach trees with values over 10 per cent. The unweathered Globigerina material has similar ratios of exchangeable cations but a much lower total, presumably because of its lack of clay. An almost unweathered Blue Clay material (6 in the table) a Fiddien heavy clay from a hill top has a markedly alkaline exchange complex. The C horizon (8 in the table) of a Fiddien heavy clay profile has a rather high content of exchangeable magnesium, quite high exchangeable sodium content, and a soluble salt content of about 1.2 per cent (conductivity of 5:1 extract 3.25 mhos/cm.) This value is well above the value by which the U.S. Regional Salinity Board defines a saline soil, if allowance is made for the difference in method of extraction, and the soil must therefore be described as saline.

The indications are that the Blue Clay parent material is mostly alkaline and saline or slightly saline. The topsoil from Gozo D (7 in the table) is apparently less alkaline than the parent material, but the difference is not marked and may not indicate any appreciable leaching. The remarkable change in the figure for total exchangeable bases is not necessarily significant since the geological stratum is probably different, and such changes of value have been observed to be unsystematic.

2. The analyses of the Fiddien light clay soils show a generally lower sodium-ion content and one sample shows very little soluble salt. Correlated with this is a jump in the calcium-ion content to a value which is about normal for the soils of Malta. However, one from Bahrija - where the most unfavourable, unweathered Blue Clay came from, has 14.9 per cent exchangeable sodium, just below the limiting value for an alkaline soil.

The San Lawrenz soils show if anything, even lower sodium-ion values, high calcium-ion values, and the drop in total exchangeable bases to be expected with increasing contents of Globigerina limestone material.

The indications here seem to be

(a) that the weathered Blue Clay has been partially leached of its sodium, which has been replaced by calcium that is plentiful in, for example, calcium sulphate in the unweathered Blue Clay.

(b) that soluble salts have probably largely disappeared from the colluvial Blue Clay for the same reason.

(c) that the leaching, most likely, took place under earlier, wetter, climatic conditions and that, in the writer's view, little change is taking place under the present climatic condition.

Table 6. Chemical characteristics of the Blue Clay and soils with a Blue Clay parent material.

Weathering etc.	Location	Material	Soluble Salts per cent	Total CaCO ₃ per cent	Active CaCO ₃ per cent	pH	Total m.e./100 gms	Exchangeable bases			
								Ca	Mg	Na	K
Previously exposed material	Xemxija cutting Miziep bore holes	1 Blue Clay	N.D.	N.D.	13.9	8.8	47.4	69	18	12	2
		2 Blue Clay (nodular)	N.D.	N.D.	12.0	8.7	43.2	57	26	14	2
		3 Blue Clay	N.D.	N.D.	13.7	8.7	52.0	67	20	11	2
		4 Blue Clay (topmost bed)	N.D.	N.D.	14.0	8.1	38.2	69	20	8	3
		5 Globigerina (topmost bed)	N.D.	N.D.	15.1	9.1	10.3	65	20	13	3
horizon coded * short time posed	Bahrija	6 Fiddien heavy clay	N.D.	N.D.	14.0	8.4	30.8	24	37	36	3
horizon	Gozo D profile	7 Fiddien heavy clay topsoil	1.0	28.6	13.0	8.0	31.3	65	24	6	5
		8 Fiddien heavy clay	1.2	36.4	10.3	8.1	61.5	46	37	10	7
horizon	Gozo C profile Malta H profile Malta I Bahrija	9 Fiddien light clay topsoil	N.D.	N.D.	13.5	8.7	45.4	83	12	4	4
		10 Fiddien light clay	N.D.	N.D.	16.8	8.8	45.5	73	14	8	5
		11 Fiddien light clay topsoil	.06	50.8	14.7	8.6	31.1	86	11	1	2
		12 Fiddien light clay	N.D.	47.4	15.6	8.6	29.7	81	16	2	1
horizon	Bahrija	13 Fiddien light clay	N.D.	N.D.	13.4	8.8	29.4	89	8	1	3
		14 Fiddien light clay topsoil	N.D.	N.D.	12.6	8.3	49.1	72	8	15	5
horizon	Malta R Gozo A	15 San Lawrenz light clay	N.D.	54.3	15.4	8.4	28.9	86	11	1	3
		16 San Lawrenz light clay	N.D.	53.1	15.4	8.6	31.2	89	8	1	1
		17 San Lawrenz clay loam	N.D.	N.D.	16.3	8.6	11.3	85	6	4	5
		18 San Lawrenz clay loam	N.D.	N.D.	16.2	9.1	15.2	74	20	3	3

Rudimentary C horizon, very short time exposed, eroded skeletal profile.

The writer concludes (1) the soils developed on the almost unweathered Blue Clay (Fiddien heavy clays) contain sufficient exchangeable sodium for the soil with normal variability to be called locally alkaline, and sufficient soluble salts to be locally slightly saline or saline. This probably accounts partly for their poor structure.

(ii) The light Fiddien soils which appear to be alluvium-colluvium derived mainly from the Blue Clay are normally not alkaline, but occasionally have rather high concentrations of sodium in the exchange complex.

(iii) The San Lawrenz soils are similar to the light Fiddien soils being derived from similar material, though of lighter texture, which accounts for their generally lower total of exchangeable bases.

Physical properties and fertility

It was observed that the crop appearance and even use for agricultural purposes was correlated with texture - the heaviest soils being (in Gozo, for example) largely unused or producing only very poor crops. This appeared to be related to water availability, because water relations tend to be very poor in these soils. The heavy Fiddien clays are often very difficult to wet, and when dry are tough and rock-like. The explanation appears to be that the virtually unweathered clay expands strongly on being wetted. When rain falls the surface is wetted and becomes less permeable. Much rain therefore runs down the structure faces and either flows to the bottom of the large wide cracks, or, when they close, flows off the surface in sheetflood. The water that penetrates the cracks is mostly absorbed only at their base. Consequently the soil largely remains dry, despite the occasional heavy rainstorm, and what water is retained may not be easily withdrawn from the clay by plant roots.

On the other hand, the light type of the Fiddien series has a better structure of reasonably well developed small peds to at least 20 inches. The result is that rain is more readily absorbed and retained, and since the texture is somewhat lighter, water appears to be more readily available to the plant. The San Lawrenz series is similar with usually a very well developed structure but probably has an increased water capacity because of the lighter texture towards the base, consisting of the Globigerina rock.

Horizon Differentiation

In most soils of the Fiddien and San Lawrenz series there is little evidence of soil fauna. With only slight modification produced by the micro-pores resulting from the rootlets of plants entering the structural elements, the peds of the heavier-textured types are smooth walled angular entities produced by physical rather than biological processes. Worms were rarely seen in the soil associated with the Blue Clay and in the lighter-textured types there is virtually no evidence, even within peds with spongy fabric, of faunal droppings. Furthermore, the total organic matter content is low, at 1.5 per cent to 2 per cent in the surface horizons. There is, however, considerable evidence of the activity of ants in these soils in the form of ant-hills composed of fine granules of clay or occasionally of small agglomerates of sand grains and clay and large sand grains permissible. It is, therefore, difficult to arrive at a satisfactory name for the humus form, but it appears to describe it as a raw soil humus.

There are, however, few examples of "natural" profiles, only agriculturally disturbed ones, and the profile form is therefore as shown below.

* Rudimentary C horizon, very short time exposed, eroded skeletal profile.

Fiddien heavy clay (natural)	(A)C (a very thin (a) horizon)
Fiddien heavy clay (cultivated)	S ₁ S ₂ C
Fiddien light clay (cultivated)	S ₁ S ₂ CD D being underlying unaltered Blue Clay.
San Lawrenz (cultivated)	S ₁ S ₂ CD D being underlying Globigerina Limestone.

It appears that the soils are carbonate raw soils, which name could perhaps be modified in the case of the Fiddien series to calcareous raw clay qualified as alkaline and saline where necessary in the case of the heavy type.

THE RDUM SEQUENCE

This is a convenient mapping unit for the steep coastal slopes and cliffs, where a rapidly changing sequence of parent rocks is exposed (Plate VII). In general there are no Terra soils developed on these slopes which average 1 in 2 to 1 in 4, but Terra downwash materials have coloured some of the heavier carbonate raw soils.

The Dingli Cliff, typical of this mapping unit (see Plate VII), shows the following pattern from the cliff top to the sea. The flat land above the first cliff is karst with Xaghra soil. At the foot of this cliff weathering products of the Upper Coralline Limestone and Greensand forming lithosols commence the sequence, spreading out over the slumping Blue Clay, which itself overruns some of the soft Globigerina limestones below. Lower down the more resistant Globigerina rocks are exposed, with weathering products overlying them if the slope is gentle, forming a carbonate raw soil, some of which is lost in each heavy rain. On the steeper slopes the Blue Clay and Globigerina are bare and strongly gullied, and everywhere the bare Lower Globigerina and Lower Coralline Limestone form a very steep second cliff to the sea.

Some parts of the slope are terraced, in particular the upper parts on the Blue Clay - generally Fiddien heavy clay soils are found - but often the terraces are now abandoned, and erosion is dominant along most of the under-cliff slope, with only the most ill-developed variants of Nadur, Fiddien, San Lawrenz and San Biagio Series (carbonate raw soil types) to be seen.

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CHAPTER IV

THE XERORENDZINAS

According to Kubiena (1953), the xerorendzina is a "rendzina, ash grey in colour, usually very loose, when dry in general very powdery, with extremely high chalk content often also of water soluble salts, particularly gypsum; occurring in dry regions". This soil is very similar to the serosem of the dry steppes.

General description

The xerorendzina has an AC profile and is sometimes difficult to distinguish from a carbonate raw soil, differing in little but the form of humus. A grey, shallow, loose calcareous A horizon, with humus in the form of mull or mull-like rendzina moder usually passes through a well developed whitish Ca horizon onto hard parent rock (C).

Mull. In this form of humus there are no recognisable plant remains: decomposition has been complete and the finely dispersed humic substance has become part of mineral-humus (principally clay-humus) complexes. The fabric is mainly spongy (highly porous) and has formed through the fusing of aggregates which are usually earthworm droppings.

Mull-like rendzina moder. This form of humus has a similar external appearance to mull and shows good humification, with humic substances acting mainly as binding materials in the mineral-rich coprogenic aggregates. Generally there is a loose mixture of these aggregates with undecomposed plant and animal remains.

The San Biagio, Alcol and Tal Barrani series have been classified as xerorendzinas.

The San Biagio soils, which have not been observed uncultivated, are usually undifferentiated from just below the surface to the bedrock. Frequently the parent material is largely alluvial and colluvial on the lower slopes, and the profiles are somewhat eroded on the upper slopes. Here they are varied with the very similar man-made ('mined') soils found at the undercut terrace backwalls. There is no macroscopic humus development, but there is sometimes a sparse, extremely calcareous, humus-deficient mull resulting from earthworm activity, and under the microscope a mull-like rendzina moder is usually revealed. Usually no Ca horizon is observed but this may be due to deep cultivation, continual turning over preventing the development of this layer. (The production of a calcrete layer which has to be broken every ten years, (De Saint Priest, 1790) seems likely to be associated with the series.)

The soil can be called xerorendzina, a type associated with karst and having a humus-deficient but distinctive humus form. The mined parts are undoubtedly carbonate raw soils.

The Alcol soil normal profile is rendzina-like and being developed in arid conditions it is convenient to call these soils developed on fossil alluvium and colluvium a variety of xerorendzina having an ACD profile. They are usually reddish or brown because of the terra clay in the parent material. Where they have a saline groundwater they are locally saline and as secondary salt soils the name xerorendzina may be prefixed by saline.

The Tal Barrani series is also a xerorendzina, but of a brown colour.

THE SAN BIAGIO SERIES

This is the most extensive series in intensive agricultural use, partly because its main development is near the largest conurbation. The soils are found principally at the foot of the main scarps (landscape element 4a) where they are strongly terraced, and in the dissected low plateaux which lie below the scarps (landscape element 2a, plate II), where they are often partly unterraced. Where the main scarps give way to more limited expressions of the parent material sequence (landscape element 4c), as in western Gozo, and where there are numerous small valleys the series is found strongly terraced in the steep valley sides, or in the coastal slopes, although unterraced on the plateaux above. In south Malta the intensively used areas between the foot of the Rabat-Dingli scarp and Mosta and Siggiewi have San Biagio soils, and the Mriehel - Wied-is-Sewda area between Qormi and Attard is similar. Relatively minor areas are, in western Gozo, west of a line through Zebbug and Victoria, the hill above Salinas, and scarp slopes near Mellieha and St. Paul's Bay and along Victoria Lines.

The soil is found developed on the Globigerina soft limestones and marls, in fact, virtually on all except the lowest bed, the Franka. In a number of localities the material on which the soil is developed is, however, a Quaternary colluvial deposit consisting entirely of weathered Globigerina material which has slumped downhill. In some places it overlies Franka, or rock approaching Franka in character. These deposits are quite extensive, and although somewhat different from the *in situ* parent materials, they are not sufficiently so to demand separation.

Sections showing colluvial materials are quoted below.

1. Between Falka and Mosta (473740) on a moderately sloping hillside with San Biagio developed on Globigerina marls above, and L'Inglin complex in the Wied tal Insperanza below. Where the colluvium is thinner it has mixed with the Xaghra-like material to produce the transitional soil of the Tal Barrani series mentioned below.
2. A similar sequence is reported from the Hamrun area in a trench at Strada San Giuseppe (about 535715), now mainly covered by building (J. H. Cooke, 1896).
3. Another similar sequence was seen west of Qormi (517707) near the edge of the Tal Barrani series where excavations revealed a deep, fossil alluvial, red clay surmounted by soil of the San Biagio series. Further west along the valley side of Wied-is-Sewda, this fossil alluvium is revealed and mapped in L'Inglin complex where the overlay of Globigerina colluvium is missing. It is believed that similar sections occur in a number of other valleys, e.g. at St. Thomas Bay, Tal Franciz (608676), south of Tarxien (about 558678), and possibly at Tas Salvatur (about 505680), but in each case only the overlying colluvium of Globigerina marls composes the material parent to the soil.

As a consequence of the partly colluvial nature of the San Biagio soils phases of different depth, probably only of large significance in water availability, are observable. The following profile descriptions illustrate these.

I. Eroded phase on a hillside sloping 5°

SAN BIAGIO SERIES. Profile Malta Q. Grid ref. 470692. Ta Bria near San Biagio Church. *Topography.* About 450 ft. above sea level on the higher edge of the dissected Globigerina plateau (landscape element 2a) near its junction with the main scarp front, on the slope of a small ridge overlooking San Antonio Valley. The field which is slightly terraced slopes E.N.E. about 5°, and the profile was taken near the slightly undercut backwall of the terrace. *Land Use.* Fallow after a tomato crop, much convolvulus.

Profile description

	inches	
S _I	0 - 7	Very pale brown (10 YR 7/3) silt loam; moderate medium subangular blocky, with a few large clods (hard, dry, nearly white) on the surface; numerous large roots, some worm casts, very low organic matter, mummified dung on surface; sticky, slightly plastic; some stones; calcareous; merges to
S _{II}	7 - 10	Pale brown (10 YR 6/3) silt loam (heavier than the horizon above); moderate fine angular blocky; numerous roots, some bulbs, very low organic matter; few stones; sticky, plastic; calcareous, some interflorescences of secondary calcium carbonate inside peds; sharp boundary to
C	10 plus	Very soft very pale brown (10 YR 8/3) platy soft rock, becoming harder and more massive downwards. Manganese concentrations between plates.

II. Colluvial phase at the foot of the same hill slope

SAN BIAGIO SERIES. Alluvial-colluvial phase, Profile Malta S. Grid ref. 474690. Near San Biagio Church, Ta Bria. *Topography*. About 420 ft. above sea level on the upper edge of the dissected Globigerina soft limestone plateau (landscape element 2a), in the outwash plain of a young valley descending from the main scarp above (landscape element 4a). The field is only about 80 yards from that in which profile Q is found, and is slightly terraced, sloping gently 1° E.S.E. *Land Use*. Fallow after tomatoes.

Profile description

	inches	
S _I	0 - 10	Light olive brown (2.5 Y 5/3) silt loam; moist, surface with thin cracking illuvial crust just dry after recent rain; weak to moderate medium subangular blocky, with some crumb structures at the surface; numerous fine roots and some large roots, numerous large pores, some bulbs at the base of the horizon, low organic matter, mull-like rendzina moder; some stones; plastic, non-sticky; calcareous; merging to
S ₂	10 - 28	Light olive brown (2.5 Y 5/3) silt loam; moist; weak, massive structure; numerous roots, numerous bulbs at 12 in., low organic matter; slightly compact; calcareous, some secondary calcium carbonate, increasing towards the base, merging to
C _I	28 - 40 plus	Light olive brown (2.5 Y 5/3) silty clay loam; moist; massive; generally similar to the horizon above, but fewer roots, less organic matter; calcareous, much secondary calcium carbonate.

Note: A thunderstorm lasting $\frac{3}{4}$ hour fell on this area rapidly soaking 10 in. of dry topsoil, and left surface puddles, a skin of downwash, and small gullies higher upslope; 24 hours later, when the profile was dug, the surface was dry, and infiltration was more or less complete. This illustrates the low water holding capacity of the soil, and its lack of resistance to erosion, which was emphasised by the deep drifts of downwash on the roads.

Most profiles are between these extremes, neither as deep as the alluvial-colluvial phase nor as shallow as the eroded phase.

Parent material and soil

According to Hyde (1955) there are "at least 4 to 5" layers of nodules intercalated with the *Globigerina* soft limestone beds. The numerous faults throughout the islands and the discontinuity of the layers make correlation and counting difficult. For example, west of San Biagio Church (474695) there is a sequence of excellent exposures up the scarp in the cut rock backwalls of several terraces, but some may be repeated as a fault crosses the area. Similar sequences are seen at Gneina Valley and in Wied Tal Qleigha. The nodules are generally phosphatic coprolites, but some are concretions of iron and replacements of organic remains such as shells. There are also some naturally preserved shells, teeth and corals. Generally the nodule beds are slightly tougher and more resistant to weathering and attack by man so that they form cappings to minor scarps within the general scarp slope and appear within the undercut rock backwall of the terraces as in Fig. 9.

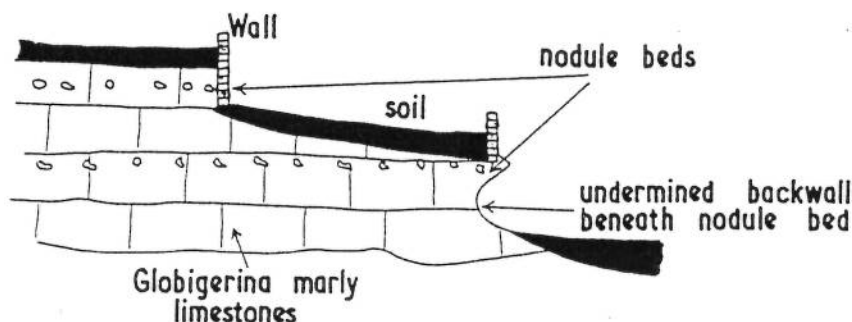


Fig. 9. Terracing in the nodular *Globigerina* soft limestone.

It is almost certain that a considerable quantity of nodule material is incorporated in the body of the soil in the terrace, and a great deal must have been washed down in the Pluvial periods when erosion was more important than at present. So much of the low-lying land has probably had a wash of phosphatic material that, if there is any difference between the soils with and without it the areal differentiation will be determined partly by the present pattern of accumulation and partly by the remnant accumulations from earlier erosion cycles, which should favour the valleys. However, the maximum differentiation is still likely to be found where terracing has incorporated fresh nodule material into the soil. A chemical analysis of soil from near the nodule bed in such a terrace is given, App. II; it shows about three times as much phosphate as in the average soils of the series.

Chemistry of the parent material

Chemical analyses of *Globigerina* rocks made by Colson and published by Murray (1890) show 60 to 95 per cent calcium carbonate, with 3 or 4 per cent phosphate of lime, small quantities of iron oxides, with the remainder largely alumina. Some of the transition beds near the junction with the Blue Clay have less calcium carbonate, but more alumina, together with small quantities of silica. There is not, in the analyses, any apparent indication of the presence of water-soluble sodium salts, but a sample (quoted in Table 6, p. 40) of the topmost beds of the *Globigerina* has a fairly high percentage of exchangeable sodium, and a pH of 9.1, indicating appreciable alkalinity. It is possible that during weathering, especially in earlier wetter periods, leaching was sufficient in these light-textured soils to explain their present freedom from alkaline or saline symptoms.

All the soils are highly calcareous and small variations in the carbonate content are unimportant, they only reflect different conditions of deposition, the clay content being highest in the upper beds.

Terracing

In general the amount of terracing on the San Biagio series varies with the topography. On flat tops it is negligible, on valley sides, especially where they are steep and the rock is resistant to erosion but not very hard to work, very strong terracing is exhibited, for example, north of Gharb in Gozo - see Disturbance map, (Fig.5) and photographs (Plates I, II, V, VI, VIII).

Horizon Differentiation and Classification

Nowhere has a natural or semi-natural profile of San Biagio series been seen; not even a long-established tree with undisturbed soil beneath it, is to be found. Everywhere the soils are so intensively worked that it is impossible to find vestiges of natural pedological horizons, therefore, the nomenclature of horizons must be arbitrary. The only noticeable differences down the profiles are

- (1) Slight colour change: the dry surface is white, the tilled horizons (S), are greyish, the untilled (C) horizon brighter and usually somewhat yellow,
- (2) Very slightly heavier texture lower in the profile,
- (3) (Excluding 'crust' types) a somewhat better developed structure at the surface than lower down, where the inter-ped spaces are often silted up.

Thus the S_1S_2C profile form is little help in classification, but it is obvious that the soil could belong, by virtue of its parent material, climate and topography, to either the carbonate raw soil group or the rendzina group of soils.

Microscopic examination of the soil reveals a mull-like rendzina moder, in which the aggregates are mainly composed of extremely humus-deficient faunal droppings, incorporating finely divided organic matter and mineral matter, and fused together to form a very spongy fabric. However, in some cases the humus form is obviously that of a raw soil, but these occur where the soil is extremely drought-prone and recently derived from the rock, as at terrace backwall cuts, and the soil can be called a xerorendzina despite its occasional mainly mined raw carbonate soil parts.

Thus the San Biagio series is to be considered xerorendzina with relatively small carbonate raw soil enclaves. The distribution of the other carbonate raw soil parts is dependent on the terracing.

Surface crust

The fine sandy loam type of the San Biagio series is frequently found, especially at hill tops in early summer, to have a very hard surface crust up to 4 inches thick (see Gozo profile B, Appendix I). In some cases the crust is so strong that it is difficult to break with a spade and, when broken, fractures like a brick. More frequently a very thin surface crust 1/4 inch thick is found at most seasons of the year. The crust occasionally exhibits polygonal cracks and discontinuous lamination is sometimes encountered. This gives evidence of a method of production of the crust by rainwater, which has also been more directly observed. (See profile, Malta S). Soil material washed over the surface dries and bakes hard, initially in the small hollows holding puddles, but eventually over nearly the whole surface, and a thin crust is formed. It is difficult to account for the thicker crusts which do not always have a laminar structure. Beneath the crust the soil is friable, showing weak subangular blocky structure with few roots throughout the profile. Thus the profile simulates the lime crust yerma of the desert although lacking the horizon of

carbonate accumulation low in the profile, but there is no apparent marked similarity of annual dynamic. In the yerma there is, according to Kubienski (1953), a rise of CaCO_3 -saturated capillary water to the surface under strong evaporating conditions, with a resultant efflorescence on the surface. This condition may occur in summer in Malta so that a crust is formed only to be destroyed again in the next winter rains. When the field has been fallow the crust has a noticeable effect on ploughing. This effect is not marked in normal years, particularly since after the first few rains of autumn the crust becomes weakened and ploughing easy. The main significance of the crust is probably its effect on the aeration of the soil and the availability of what little water is left in or falls on the soil in summer.

Structure

Normally the structure of most of the soils is rather weak, but tillage is very easy compared with the clays and effects a considerable improvement in the soil as a medium for plant growth. It is probably partly because the soil is so very easily worked, although poor looking that it is so extensively used for agriculture.

Water availability

The availability of water in the San Biagio soils depends on the position of the particular soil on the slope, but in general the fine sandy loams are drier all year than the silt loam and silty clay loam types. In fact those same areas which have the crust, are those most quickly dry.

Chemical analyses of the soils (5 profiles)

Calcium carbonate and reaction (pH)

Total CaCO_3 is between 57 and 80 per cent in two profiles examined. The 'active' CaCO_3 , averaging 16.5 per cent, is very high in all these soils and the pH is over 8.0, (only in one profile over 8.5 at the surface), and bears out their essentially calcareous, weakly alkaline, non-saline state

Organic matter

Averaging 2 per cent in the surface horizon the organic matter content is higher than might be expected in such white soils.

Phosphate

The total amount of phosphorus as P_2O_5 is between 0.2 per cent and 0.5 per cent, a quite satisfactory figure, but the amount readily soluble in acetic acid, averaging about 25 p.p.m., is not correlated closely with the total phosphorous and may represent a lack, possibly not serious, of available phosphate. The sample from near the nodule beds seems to be somewhat better endowed with phosphate but again little is readily available - 0.6 per cent. total P_2O_5 ; 34 p.p.m. readily available P_2O_5 .

Exchangeable bases

With the exception of the surface horizon of profile Malta Q (which may have been recently fertilised) the distribution of the exchangeable bases, which changes little down profile, is calcium, 80 per cent to 90 per cent; magnesium 7 per cent to 15 per cent; sodium 0.3 per cent to 2 per cent and potassium 1 per cent to 4 per cent. The total of exchangeable bases is, as befits the relatively light texture, lower than for most Maltese soils, averaging less than 20 m.e./100 grams.

As a whole the analyses are normal for calcareous soils, in which the availability of essential plant nutrients is not easily determined. One of the main problems is liability of plants to lime induced chloroses. Considering the physical state as well, however, these easily worked soils

THE ALCOL SERIES

The Alcol series is found developed in the broader flat valley bottoms (landscape element 3, Plate III) which are limited to a small number of sites. The Wied il Ghasel between Targa (474752) and Calinas Bay is the largest of these sites followed by the Wied tal Pwales (running west from St. Paul's Bay), the Bingemma valley (north of Bingemma 435744) and the Marsa lowland, and a number of smaller sites like the Ghadira (413810).

The parent materials are the valley loams (Quaternary and Recent) composed of partly alluvial and partly colluvial material and are erosion products of Terra, rendzina, and carbonate raw soils, often stratified and generally, but not always, well sorted. Usually, the material parent to the present soil is very deep and of heavy texture although a few sandy types are found, and intercalated gravel or boulder horizons occur. The differentiation of the soil from the parent material is difficult, since there are no well developed horizons, except those produced by tillage, and no examples of natural vegetation or even long undisturbed soil profiles are to be found.

A typical profile is given below of each of two variants, one with stratified parent material derived from Terra and calcareous soil, and another developed on a uniform parent material probably derived from rendzina and Terra material.

Another variant, profile Malta X (Appendix I), is developed on marine alluvium found in one or two of the more open bay heads, but only of any consequence near Mellieha.

The Alcol series is related to the Tas Sagra series, also a transported material, but entirely composed of Terra-derived sediments. Occasionally as in Wied tal Pwales and Il Ghadira there is a transition from Alcol to Tas Sagra soils and the boundaries between are somewhat indeterminate.

Descriptions of two typical profiles

ALCOL SERIES. Profile Malta C. Grid ref. 474777, Ras-is-Siekia, near Burmarrad. Topography. About 10 ft. above sea level on the broad valley bottom of the Wied il Ghasel (landscape element 3). A large unterraced flat field. Land Use. Vine cultivation.

Profile description

	inches	
I	0 - 6	Pale brown (10 YR 6/3) fine sandy clay loam; very dry; moderate medium to large crumb; numerous worm casts, numerous insects visible, low organic matter, humus form, mull-like rendzina moder; a little gravel; loose, calcareous;
II	6 - 21	Pale brown (10 YR 6/3) silty clay loam; weak medium subangular blocky; numerous earthworm casts, many fine roots and bulbs, numerous insects, low organic matter; calcareous, a few crystals of secondary calcium carbonate, merging to
III	21 - 30	Pale brown (10 YR 6/3) clay loam; moist; larger subangular blocky; similar to the horizon above, but more numerous worms, and much secondary calcium carbonate on structure faces.
IV	30 - 45	Yellow brown (10 YR 5/4) silty clay; very similar to the horizon above, but decreasing secondary calcium carbonate in pores rather than on structure faces, ceasing at about 40 ins., merging to

Profile description

	inches	
V	45 - 54	Yellow brown (10 YR 5/4) fine sandy clay, otherwise similar.
	54 - 72 plus	Dark yellow brown (10 YR 4/4) fine sandy clay, similar but very wet and probably partly gleyed. No organic activity.

Note: Nearer the sea in the same area, abandoned fields point to the effects of saline ground waters.

2. Bingemma Valley, *stratified material*.

ALCOL SERIES. Profile Malta K. Grid ref. 436746. Il Wilgia ta Bingemma, near Bingemma village. *Topography*. About 300 ft. above sea level on the flat bottomland (landscape element 3) of Bingemma in which there is a stratified deposit of alluvial-colluvial soil materials. The field is slightly terraced and slopes about 1° N. *Land Use*. Sulla.

Profile description

	inches	
I	0 - 13	Yellowish red (5 YR 4/5) silty clay loam; moist; moderate medium granular; many fine roots, some insects and worms, very low organic matter, mull-like rendzina moder; slightly plastic, slightly sticky; calcareous, efflorescences of secondary calcium carbonate; a few bits of broken pottery.
II	13 - 16	Transitional horizon. Yellowish red (5 YR 5/8) fine sandy clay loam; calcareous; to
III	16 - 22	Reddish yellow (7.5 YR 7/6) very fine sandy loam; weak medium platy structure; very low organic matter; calcareous, some efflorescences of secondary calcium carbonate; numerous faint ochreous mottles.
IV	22 - 45	Reddish yellow (7.5 YR 7/6) bouldery very fine sandy loam; very similar to the above, but for a dense layer of cobbles and boulders at about 27 in., a discontinuous and variable horizon; weak, single grain structure; very low organic matter; calcareous; sharp boundary to
V	45 - 60 plus	Yellowish red, (5 YR 5/6) clay loam; very fine to fine angular blocky; very low organic matter; calcareous; at 48 in. ants still active.

Parent Material and Soil

I. The origin of the materials in Malta broadly classed as 'valley loams' by geologists is only roughly known. There is, however, little doubt that they are alluvial and colluvial deposits derived from the soils of earlier periods, and that they are related to other soils developed at present. That is to say the soils from which they were developed were not unlike those of the present day, some of which are also largely relic soils.

That they were not all laid down in one relatively short period appears to be borne out by the stratification of the deposits, which in places show material remarkably like the present Terra soils (but containing calcium carbonate) overlain by highly calcareous material apparently derived from carbonate raw soils or rendzinas - and even in some places by boulders. Although this whole effect could have been produced by a number of torrential

storms causing rapid erosion and transport during a single period, this seems less probable than that they formed during the Quaternary fluctuations of climate. In one cycle of climates Terra soils were produced, and either slowly eroded and transported into the valley below, or, alternatively, were rapidly eroded when, through further climatic change, the vegetation cover had become too poor to hold them. Subsequently, weathered limestone (carbonate raw soils, possibly rendzinas) was washed down on top of the Terra materials, and at a later date, more Terra soil was added.

The Terra soils between lapiés on the rocks above the valley are unlikely to have all been eroded away immediately, and some probably remained until the next period of Terra soil formation. Terra soils where they remain unworked show no profile differentiation, so that if they belong to more than one period of development, the intervening periods do not appear to have produced any symptoms of degradation - "browning", or podzolization. This tends to strengthen the impression that the alluvium-colluvium has remained largely inert since its deposition.

The analyses indicate that the reddish clay loams, are slightly less calcareous than the other strata laid down, and that the total amount of phosphate, and exchangeable bases does depend on the stratum. See Appendix II.

It seems that at present and for some time past there has been little change in the soils, except perhaps where they are very close to the sea in valleys which are partly submerged. In these locations soils of heavy texture are salinised, at least at depth and are out of agricultural use. One profile sufficiently distant from the sea to be little affected ($\frac{1}{2}$ mile away from Salinas) shows little change in profile appearance but there are high contents of magnesium and sodium at depth, despite the negligible quantity of soluble salts: this is considered to be possibly the legacy of a formerly saline ground water which has descended to a slightly deeper level. (See Table 7).

Table 7: Analyses of profile Malta C

Depth	Total soluble salts per cent.	Active CaCO ₃ per cent.	Reaction PH	Exchangeable bases				
				Individual cations as per cent of total				Total cations m. e. /100 gms.
				Ca	Mg	Na	K	
Surface horizon	0.075	16.1	8.3	77	17	4	2	21.3
2 feet	N.D.	16.0	8.4	69	24	5	2	20.5
3 feet	0.105	15.3	8.9	41	45	11	3	14.7

II. The lighter types of marine alluvium as found at Ghadira are composed of a highly calcareous sand probably derived from materials similar to those which produced the dune sands, parent material of the Ramla series. The sand contains a small proportion of clay, and at lower levels there are intercalated clayey-sand bands, which from their separation are assumed to be alluvial strata rather than translocation horizons.

Although the profile Malta X, taken as representative of this type shows no unfavourable (alkaline) cation relationships nor significant salinity (0.045 to 0.07 per cent), the location of the profile, 100 yards from the sea and not more than 4 feet above sea level, and the level of the permanent (brackish) water-table at about 3 feet, lead to the conclusion that the soils are locally saline in the lower part at least. The fact that crops are grown efficiently in some of the area, indicates that it is probably reasonably salt-free at the surface in winter and spring.

Horizon Differentiation and Classification

The Alcol soils are almost entirely cultivated, and all have been cultivated within recent times. In many cases they show layers that can definitely be considered as geological. Other forms of differentiation have not been distinguished, excepting the levels of microbiological activity (the humus form usually being humus-deficient mull) which decreases slowly down the profile.

The Alcol soils are developed on a fairly broad range of alluvial-colluvial deposits, ranging from almost wholly Terra (decalcified) material through transitions (sometimes alternating beds) to fine calcareous sediments derived from carbonate raw soils and rendzinas, and boulder beds. Also included are some calcareous marine sands. These parent materials have the common characteristics of being dominantly calcareous and, at least partly, water sorted, and can be divided into two groups

- (1) the calcareous, non-saline deposits,
- (2) the soils on recent marine deposits and soils with a salt water table (of very small total area).

The soils developed on the first group are in general well drained, dry soils, flooded only very seldom (perhaps once in a hundred years or more) and incompletely. Thus although the materials developed largely as flood plain soils it seems to the writer incorrect to think of them as such at present since they are merely parent materials to the present soil. Kubiena on the other hand regards this as permissible, and would presumably call these soils semi-terrestrial, perhaps a calcareous form of braunlehm vega.

However, the soils can be regarded as being developed on unconsolidated, mixed, dominantly calcareous sediments of Quaternary and Recent age, and like most soils of Malta are subject to the weak biological influences associated with a xerorendzina. These soils diverge, however, from the typical xerorendzina because of the inclusion of Terra clay in their parent material. This gives them a heavy texture and a brown or reddish colour in contrast to the ashy grey mentioned by Kubiena.

Of the second group the soil developed on marine sands at Ghadira may be considered a chalk rambla (if a marine origin is permissible as well as a fluvial origin) and the soils with a saline water table which as at Salinas are locally saline, may be called simply salinised xerorendzinas, (secondary salt soils).

Physical conditions and Fertility

Excepting the marine Alcol which is a sandy type of very limited area and quite different characteristics, the usual types of the Alcol series are clay loam and light clay, both of which have reasonably well developed structure and good water relations. They are rather similar to the San Lawrenz soils and Fiddien light clay and clay loam in this respect. Like the latter, they are favoured by ants, but have a more varied soil fauna. Other organisms which apparently favour these soils include mice, snails, various beetles and worms. Worms in fact appear more commonly than in any other Maltese soil, and often wormcasts are quite numerous in the upper horizons producing a good spongy fabric. The Alcol series like all Maltese soils has a low organic matter content; it is among those most inclined to be improved physically through the activity of soil organisms by reason of the moderately heavy texture and good water relations which, combined with the relatively low plasticity of the clays, predisposes them to the maintenance of stable structures. The soils are not as difficult to work as the Fiddien, San Lawrenz and Xaghra clays and probably the clay loams also. They are more favoured for general agriculture, particularly since they never exhibit more than gentle slopes and do not need terracing, and are universally in cultivation except where, very near the coast, secondary

Chemical analyses of the soils

(I) Normal profiles (3). These were all taken from the Bingemma valley where the parent material is stratified, and are thus a less representative selection than might be desired.

Calcium carbonate, reaction (pH), and soluble salt content

In one profile examined, calcium carbonate varied from 57 to 70 per cent, least in the horizon most resembling terra material. Active calcium carbonate varied between 9 and 18 per cent, with least in the reddish clay loam strata again. The pH was consistently over 8.5 and reached 9.0 below 3 feet in two profiles, which probably accords with the fact that the soluble salt content, (0.15 millimhos/cm) was negligible where examined in the surface horizon of one of these two profiles.

Organic matter

The organic matter content of the surface horizon averages about 1.7 per cent, and is still about 1 per cent in the second foot of the profile, indicating that although the content is low it is quite well dispersed.

Phosphate

The total amount of phosphorus as P_2O_5 is most variable in the red clay loam strata of the parent material - from 0.42 per cent to 0.06 per cent, while in the coarser more calcareous materials it is more nearly constant at about 0.15 per cent.

"Readily available" phosphate soluble in acetic acid, does not vary with total phosphate, and is in each case at a maximum in the surface horizon, presumably in organic complexes. The values obtained are 15 to 40 p.p.m. in the surface horizon and 6 to 14 p.p.m. below.

Exchangeable bases

Calcium dominates the exchangeable bases with 80 to 90 per cent of the total which is about 20 to 40 milli-equivalents per 100 grams of soil with the higher values in the reddish clay loam strata. Magnesium with 7 to 14 per cent takes up nearly all the variation in calcium-ion content and the monovalent cations are relatively unimportant, sodium, 0.8 to 2.9 per cent, potassium 1.3 to 5.0 per cent. The relative proportions of the ions seem to be related to the stratum but while the values for calcium and potassium are usually greatest in the surface horizon, those for magnesium and sodium are usually greatest in the lower horizons. The presence of magnesium and sodium may result from the continued introduction of small amounts of salt carried in spray from the sea.

In general, variation in analytical results within the profile seems to depend on the stratum, and only the phosphate content and exchangeable bases show any indication of being related to pedological processes.

(II) Abnormal profiles

(a) Wied il Ghasel, uniform parent material, believed to have been affected by saline groundwater, is described earlier under the parent material and soil section p 50.

(b) Ghadira, Malta X, marine sand with intercalated clay. This profile has a very low organic matter content, and an abnormally high pH, 8.8 at the surface, 9.4 at three feet. The soluble salt content is low, (0.045 per cent at the surface, 0.070 per cent at three feet), but sodium + potassium is only about 2 per cent of the exchangeable cations, and Ca is about 90 per cent, which does not account for the high pH, in comparison with other soils. The intercalated clay band has similar characteristics to the rest of the soil, the quantity of active $CaCO_3$ and exchangeable bases is double that of the sands.

THE TAL BARRANI SERIES

Location, parent material and description

The Tal Barrani soils are found mainly in south Malta on the dissected low plateaux of the soft Globigerina limestone (landscape element 2a), between the San Biagio soils of the upper Globigerina limestones and the terra soils of the Franka and Lower Coralline Limestone, for example near Zebbug and Tarxien. They are also found, both simply and as a member of L'Inglin complex on the Naxxar-Gharghur hill mass and the low coastal hills northwest of that hill. As minor members of L'Inglin complex, they are found in a variety of locations from the Rabat-Dingli Plateau to parts of Gozo, but the total area is rather small.

While the San Biagio series covers a narrow range of whitish medium-textured calcareous soils developed on Globigerina rocks, the Tal Barrani series covers a rather broader range of pinky brown and brown medium- to heavy-textured soils developed on Globigerina rocks of rather more massive appearance and fine-sand texture apparently similar to, and sometimes including, the Franka. The soils are mainly artificial which partly accounts for their variability, and have been much disturbed and mixed in process of terracing.

A typical profile is described below:

TAL BARRANI SERIES. Profile Malta V. Grid ref. 486698. Ta Picciottu, near Zebbug. *Topography.* Flat to gently sloping interfluvium about 340 ft. above sea level, about the middle of the Globigerina soft limestone dissected plateau (landscape element 2a). The field is very much disturbed and quite strongly terraced producing complete flatness. *Land Use.* Fallow after potatoes.

Profile description

	inches	
I	0 - 10	Brown (7.5 YR 4/4) gravelly silt loam; moderate fine crumb with a weak thin crust at the surface; many fine roots, numerous large pores, moderate organic matter, mull-like rendzina moder; much inorganic town refuse; numerous small gastropod shells; calcareous; merging to
II	10 - 18	Brown (7.5 YR 5/4) gravelly clay loam, somewhat gritty; weak crumb; numerous small and large roots, many pores, low organic matter; stones more numerous towards the base; calcareous, abundant interflorescences of secondary calcium carbonate below 15 in.; fairly sharp boundary to
III	18 - 27	Layer of variable thickness 1 to 12 in., a mixture of brown (7.5 YR 5/4) gravelly clay loam as above, with Franka rubble, obviously placed to level off the terrace.
IV	27	Partly calcreted, partly man-worked Franka limestone.

The rubble, broken rock surface, and lack of natural horizons are typical symptoms of the artificial preparation of the soil by man, for the soil has not only been thoroughly mixed by cultivation, but the fields have been flattened by breaking away rock hummocks and filling hollows, and spreading the soil evenly afterwards.

Parent material and soil

The Tal Barrani soil appears to be developed naturally on a certain stratum of the Globigerina limestone, which is a coarser texture than the soft upper limestones, and less massive and fissured than the Franka usually is. On this material it is believed, there was a tendency (the time of development, like that of the Terra soils, is believed to be mainly referable to another climatic period) for slow weathering to take place, leaving a residue of sesquioxides in the solum. However, very few profiles show even a semi-natural development and the mode of development can only be inferred from the brown colour and highly calcareous nature of the soil.

It is likely that the uniform brown material of the profile developed elsewhere in the following ways.

(i) In a number of localities a calcareous (xerorendzina-like) colluvium overlies a terra fusca (see p. 44). Where the colluvium is thin, mixing of the two materials by tillage over a long period has produced a uniform brown clay loam soil which has been classified as Tal Barrani.

(ii) In other localities, predominantly those mapped as L'Inglin complex, Franka lapiés have been terraced, and during terracing a great deal of rock flour has been produced, and some has been literally mined from the rock. When the terra fusca was replaced, the rock flour was incorporated in it, to produce a uniform brown soil again.

It is obvious that the amount of sesquioxide material found in these now uniform brown soils varies from profile to profile, and those soils of sandy loam or loam texture, that is, low sesquioxide clay content, have in general inferior properties to the clay loams.

Their distribution is almost confined to the upper parts of the low Globigerina plateaux of the south-east of Malta between the karst lands on the Franka limestone and the marly soils of the upper Globigerina. Similar soils are, however, quite well represented in L'Inglin complex, especially in the eastern hill mass between Victoria Lines and Sliema - Birkirkara.

Terracing

The Tal Barrani series in the south-eastern dissected low plateau lands is often strongly terraced, but also occurs on the flat tops of the dissected surface in relatively large open fields. These show, however, all the other evidence of strong disturbance - flattened bed rock, added rock flour, and rubble. Where the Tal Barrani series is a member of L'Inglin complex it is invariably very strongly terraced.

Horizon Differentiation and Classification

In the Tal Barrani series the normal shallow agricultural profile shows only the differentiation produced by the farmer. In the profile W a uniform surface layer overlies a thin rubble layer on the bruised rock surface. This, together with the rather deeper profiles V and VA is probably representative of the vast majority of the Tal Barrani series, and in its present form must be regarded simply as an anthropogenic soil.

The occasional semi-natural profile like Malta A (which is a borderline case of the series) has a well defined mull-like rendzina moder. Beneath the litter and humus horizons (L & H) a fairly uniform highly calcareous material, with some enrichment in sesquioxides particularly at the base, rests on the solid rock, C horizon or possibly D horizon, which may or may not have a weakly encrusted surface.

It seems probable that all these soils parallel the 'rosé' soil briefly described by Bricheteau (1954) for the piedmont of Tlemcen - an argillaceous calcareous soil, in an area of reasonably similar climate.

Physical Properties and Fertility

The physical properties are variable and dependent mainly on the texture of the various types. On the clay loams the structure is usually moderately well developed, and better than that of the San Biagio agricultural soils, probably because of the greater sesquioxide clay content. The land is almost always in annual cultivation, vines or tree crops are few and potatoes, cereals, and green vegetables seem to be most favoured. With the exception of cereals these involve much cultivation, which may have caused some structural improvement. The sandy loams and loams of relatively limited extent, are more similar to the San Biagio soils and

seem to carry much the same range of crops. They are inclined to have a relatively weakly developed structure especially in the surface, often forming a thin 'puddling' crust similar to that of the San Biagio soils. On the whole these soils appear to bear good crops, and it seems likely that they experience more trouble from the pests and diseases which were quite often observed, than from inherent low fertility.

It is difficult to assess resistance to erosion, but Tal Barrani soils have been observed standing in very steep slopes at a terrace front where the terrace wall has collapsed through inattention, without any very rapid loss of soil (Msida Valley). This may be attributed both to a good state of aggregation and rapid infiltration. It is possible that damper soils in almost flat fields (as near Zebbug) - underlain partly by calcrete layers, would be more prone to erosion because they would more quickly allow surface flow.

Chemical analyses of the soils

Calcium carbonate, reaction (pH), and soluble salt content.

The pH values of the soils are uniformly above 8 but seldom above 8.5, which is probably indicative of the large amount of calcium carbonate in the soil (70 - 80 per cent in one profile examined). The content of active CaCO_3 is high at 12 to 18 per cent, and is probably quite sufficient to induce chloroses by rendering iron unavailable and is above the 10 per cent level determined by Drouineau (1942). A sample of surface soil was found to have a low content of soluble salts (Conductivity of 5 : 1 extract 0.42 millimhos/cm. which perhaps corresponds to about 4 millimhos/cm. of the "saturation extract" as measured in the U.S. Regional Salinity Laboratory).

Phosphate

The total content of phosphate seems usually to be about 0.2 per cent which is a little below the average, but probably about the mode for Maltese soils. It appears that, in the agricultural profiles sampled the readily soluble phosphate, at about 70 p.p.m. in the surface horizon, presumably in humus complexes, is much above the average for Maltese soils, and, if these figures can be taken as a guide one might expect phosphate deficiency to be less noticeable than in the other xerorendzina soils, despite the almost equally high active CaCO_3 .

Organic Matter

With the exception of the Terra group of soils, the Tal Barrani series has the highest organic matter content, in the surface horizons, of the Maltese soils. This is not necessarily the impression obtained when observing the profiles, which appear to be rather low in organic matter: in fact there is a relatively high content of organic matter in the lower part of the profile.

Exchangeable Bases

A total of about 30 m.e./100 gms. appears normal, with about 87 per cent calcium, 7.5 per cent magnesium, 1.5 per cent sodium and 3 - 5 per cent potassium in the surface horizon of the cultivated soils. The contents of both magnesium and potassium decline slightly, while calcium and sodium increase slightly, down the profile, but potassium apart, the changes are probably not significant.

The uncultivated, immature and a typical profile Malta P has relatively more sodium and magnesium and less calcium, but exhibits the same slight changes down profile.

Profile D (Qormi) illustrates a tendency towards salinity perhaps due to irrigating with brackish water from the lower water-table, although the figures for the soluble salt contents show only slightly more than in the

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normal profile, about 0.21 per cent (conductivity of 5:1 extract 0.56 millimhos/cm) against 0.16 per cent in the surface horizon, declining down the profile. The increasing percentage of sodium down the profile among the exchangeable bases is significant especially when compared with the much lower figures from the other Tal Barrani profiles V and W (Table 8). This soil is very well worked, and has an unusually high organic matter content resulting from the application of organic manures in the irrigation water (40" per annum). There is no apparent adverse effect from the increasing sodium except in the weakly developed and nearly massive structure at depth.

Table 8 Percentage composition of Exchangeable cations in Tal Barrani Soils

	Ca	Mg	Na	K		Ca	Mg	Na	K
D surface sample	72	18	7	4	D lowest sample	68	18	10	4
V " "	88	7	2	3	V " "	93	5	2	1
W " "	85	8	1	6	W " "	88	7	2	4

In these soils sums of exchangeable cations were 24 - 35 m.e./100 gms.

CHAPTER V

TERRAE CALXIS; THE TERRA SOILS

The Terrae Calxis soils are, according to Kubiena (1953), "very mature, extensively weathered usually completely chalk free soils with ochre yellow, ochre brown to red coloured (B) horizons which contain iron in the form of ferric hydroxide with varying water content". There are two subtypes: *terra fusca* and *terra rossa*. The subtype *terra fusca* is "usually humus-deficient loamy soil with ochre yellow to reddish brown colour on limestone rocks, which contains ferric hydroxide in the form of limonite", and the variety earthy *terra fusca* is described as, "in the top soil, loose to slightly compacted, usually dark matt brown coloured *terra fusca* with good crumb structure". The earthy *terra fusca* usually has an A(B)C profile, with a humus-deficient, thin, grey-brown, A horizon in which the humus form is generally mull. This horizon overlies a thicker reddish brown ferruginous (B) horizon which usually lies directly on the parent rock, (C horizon). The soil has a marked tendency to form crumbs, and very low plasticity. The other subtype *terra rossa* is described by Kubiena as a vivid red or red soil, usually humus-deficient and decalcified, rich in inorganic colloids containing ferric hydroxide in water deficient compounds; the variety siallitic *terra rossa* being "Terra rossa with high colloid content, when wet highly plastic, viscous, characterized by a dense ground mass rich in silicic acid." In general terms the profile is similar to that of the earthy *terra fusca*, but the soil colour is red and the plasticity is strikingly greater due to the different colloids. The structure is consequently different also, the peds being angular fragments produced by drying and shrinkage.

The classification of the Xaghra and Tas Sagra soils which comprise the Terra soils is discussed in detail later, it is sufficient to say here that both series are regarded as predominantly earthy *terra fuscas*, but with transitions to siallitic *terra rossa* according to Kubiena's classification. They are however referred to throughout this account as Terra soils for simplicity, Terra being the name of the type to which they belong, within the class Terrae Calxis.

The nomenclature of the Mediterranean red soils is not very widely agreed upon and the same terms are used by different writers to refer to different soils or groups of soils. The nomenclature used by Kubiena (1953) is probably the most clearly specified of those in use, and particular attention is drawn to his definitions, which are used in this account.

The names 'terra rossa' and 'Mediterranean red soil' are often used to include all red and red brown soils, from sand to clay texture, on calcareous or non-calcareous, igneous and sedimentary parent materials, provided that they occur in the Mediterranean climatic regions. Attempts have been made to narrow the field - Comel (1952) refers to red soils on calcareous rocks as "Terra rossa", those on silicate rocks as "*Terra rossa ferretto*", and those developed from a red parent material as "*Terra rossa lithochromica*". There are however, several more or less undefined nomenclatures in use and it is difficult to attempt correlations because of the lack of clearly specified definitions or complete profile descriptions. The term Terra as used in this account is strictly related to the definition of the type of Terra in Kubiena's classification except that the soils are not completely decalcified now because of secondary additions of limestone grains, which have blown in or been added through cultivation practices.

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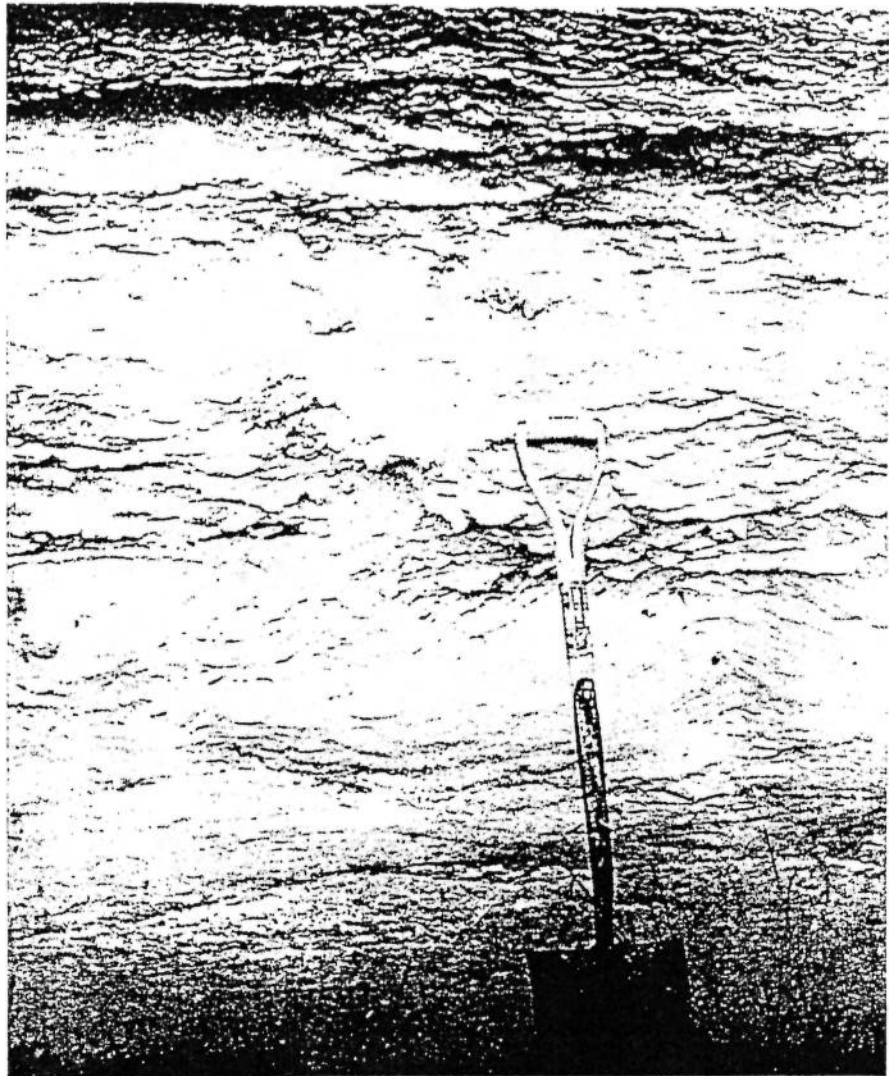


PLATE I. GOZO. San Biagio series, near Ben Gorg. A six-foot terrace backwall cut in Quaternary calcrete deposits.

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PLATE II. GOZO. Scarps and the strongly terraced San Biagio landscape below the Blue Clay slopes Ta Pinu church and Ghammar village in the middle ground.

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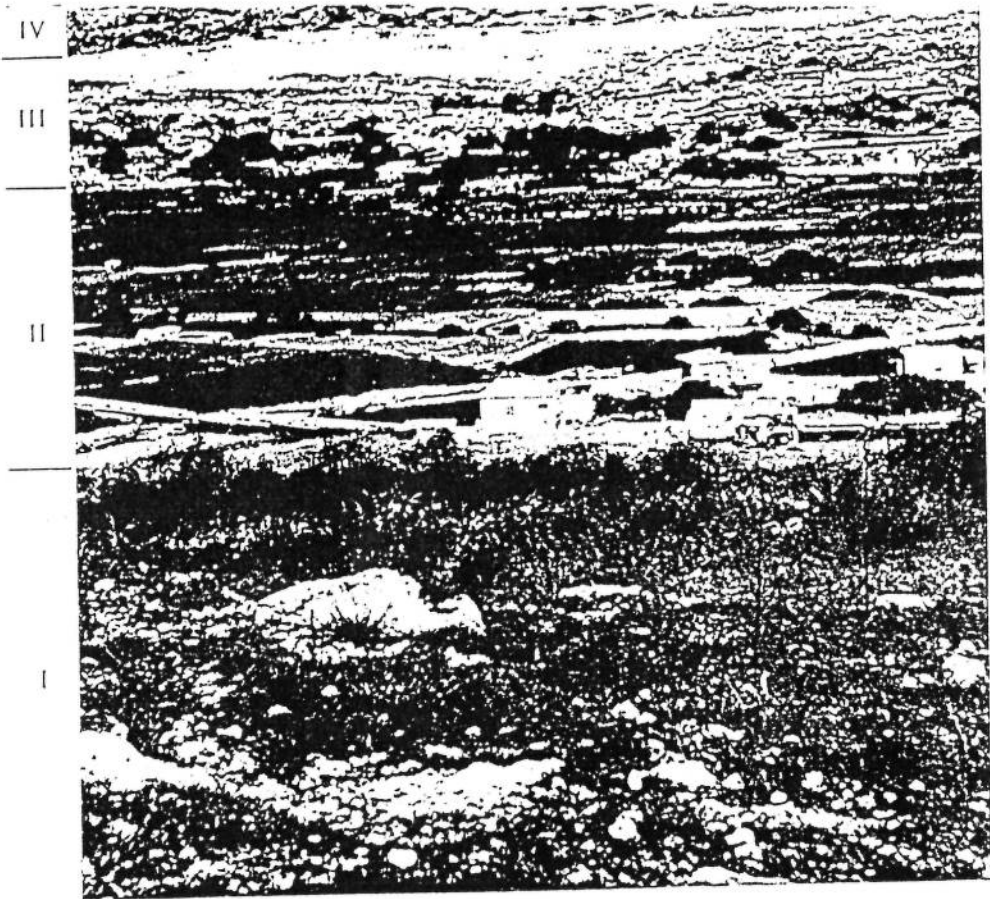


PLATE III. MALTA. Wied Tal Pwales (II) Alcol series, from Wardija Ridge (I) Xaghra series on Quaternary calcrete, with similar Karst ridges Baida and Mellieha (III and IV) to the north. They developed on Upper Coralline Limestone and exhibit Karst phenomena including Xaghra series. Between these ridges, out of sight, is the structural Wied Tal Mistra in which is developed Tas Sagra series.

PLATE IV. MALTA. Xaghra series, profile Malta Z, developed on Upper Coralline Limestone at the top of Marfa Ridge. Illustrating "young" lapies and xerophytic vegetation.





PLATE V. GOZO. Strongly terraced soils of San Biagio series. Wied-ir-Raheb, Ta Birbuba near Gharb. Remnant Blue Clay hillocks on left skyline.

PLATE VI. GOZO. San Biagio series, Wied il Mielah near Gharb, illustrating rock-face cuts, terracing and the mined soils (some carbonate raw soils) behind the solid rock barrier in the foreground.



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PLATE VII. MALTA. Poor terraces of the Rdam sequence near Dingli. (By courtesy of Durham University Geography Department.)

PLATE VIII. GOZO. Quarry in Globigerina Limestone near Gharb. Compare with Plate II photographed from a nearby point (above and to the right of this viewpoint). Behind the quarry are terraces of San Biagio and Fiddien series up to the summit of Giordan in the left background.



The mapping units used for the Terra soils are

- (i) Semi-natural units
 - (a) Xaghra series
 - (b) Tas Sagra series
 - (c) Armier complex (Xaghra soils are one end member in a sequence of parent material types).
- (ii) Anthropogenic soils
 - (d) L'Inglin complex) In which Xaghra-like,
 - (e) Tad Dawl complex) but much disturbed soils are dominant.

THE XAGHRA SERIES

Parent material, location and description

On the soil map the Xaghra series delimits a specific landscape - karst, little altered by man (landscape element Ia) as well as a soil. This is largely a result of the close dependence of landscape and soil on the lithology of the underlying rock. The karst areas which are relatively little altered by man, are mostly rather distant from the larger population centres, those nearer are usually much disturbed. The principal areas of Xaghra series are on the Rabat-Dingli plateau, the coastal hills between Sliema and Salinas, a strip along the south coast west of Zurrieq, the ridges of northern Malta (see Plate III), Wardija, Baida, Mellieha and Marfa, Comino, and a few relatively small areas in eastern Gozo.

The soils are developed on those limestones whether Lower Coralline, Franka or Upper Coralline, which develop lapiés (see Plates III, IV) as microrelief features of the bare rock surfaces. The size and shape of the lapiés is very variable and dependent on lithology, but they all exist as ridges of limestone with soil-filled hollows between them. The hollows are of variable size from several yards to a few inches diameter and the "puddles" of soil in them are generally up to three quarters covered by xerophytic vegetation and a few stones (Plate IV). The word "puddle" is used because it seems expressive of the appearance of the distribution of these soils, and of their origin, being at least partly washed in.

A generalized profile for a fairly deep puddle is:

Surface	A few limestone stones, and an incomplete cover of thyme and other aromatic herbs, thistles, bulbous plants and some grass.
0 - $\frac{1}{2}$ inches	Brown to reddish brown clay or gritty clay loam; moderately well developed medium crumb structure, hard.
$\frac{1}{2}$ - 24 inches	Reddish brown or dark red, very dry, clay; well developed fine angular blocky structure, below the top few inches, which have a crumb structure; very hard.
24 inches	Hard, white semi-crystalline limestone with a calcreted surface.

Figure 10 shows a section through a typical piece of Xaghra ground, through lapiés and soil "puddles".

The soils within the Xaghra series are rather variable, but the main differences, which appear to be unrelated to obvious lithological differences, are in some cases due to utilisation, and are in general too random

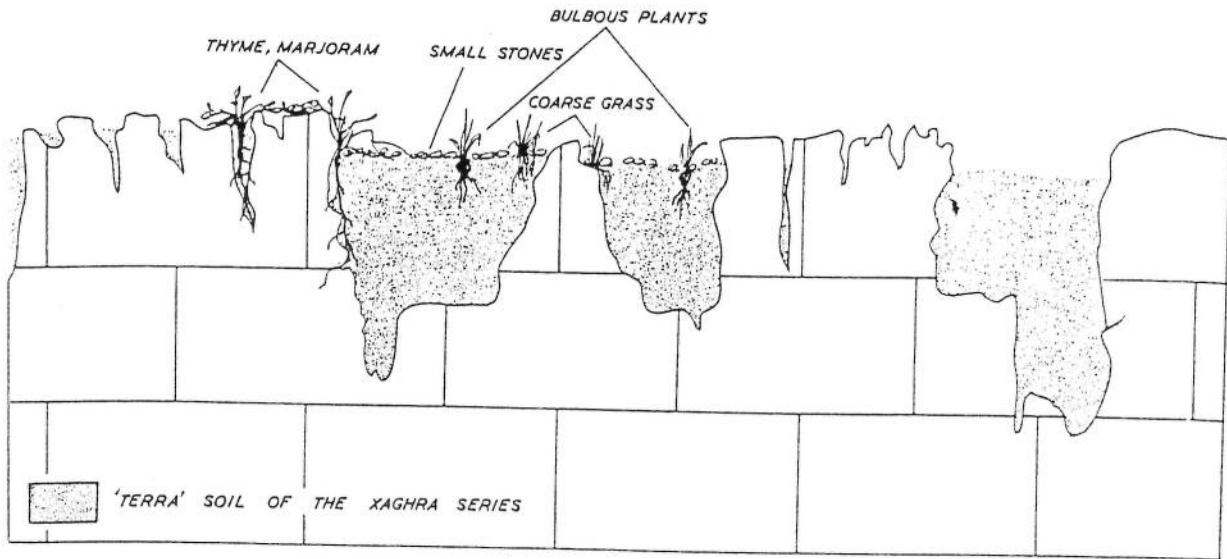


Fig.10. Section through karst lapies illustrating Xaghra series.

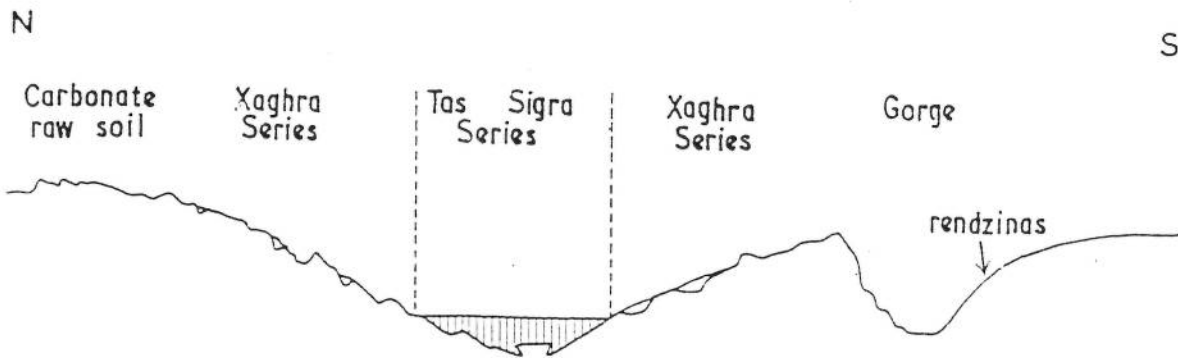


Fig.11. Section through karst landscape.

in distribution to be mapped quickly. There is, however, some indication that the Terra soils on the softer (Franka) limestones are somewhat yellower and their calcium carbonate content is higher than on the Coralline limestones.

Phases can be differentiated on the variations summarised below.

1. The plasticity varies from slightly plastic to plastic while the stickiness was recorded as from nil to sticky as can be seen from the various profile descriptions. This is the most important variation, since varieties can be separated on the basis of these properties.
2. Percentage of land surface covered by lapiés varies from about 30 - 40 per cent inland, and to as much as 80 - 90 per cent in coastal areas.
3. Soil depth between lapiés varies from 2 or 3 inches to 8 or 9 feet. (It can possibly be related to the erosion stage of the lapiés: between both "young" and "old" lapiés the depth will probably be small because the "wall" will be low and incapable of retaining much of such easily eroded material. Between mature lapiés where the "walls" are tall and unbroken the amount of erosion will be more limited.)
4. The amount of superficial limestone gravel varies from 5 per cent cover to 100 per cent cover, with generally higher values between old lapiés and where man has worked Xaghra soil puddles.

Despite these variations the Xaghra series is a well defined unit, found on land that has been relatively little worked by man, and only occasionally in the more intensely worked areas such as those of the L'Inglin and Tad Dawl complexes.

For completeness it should be noted that within the area mapped as Xaghra series are damp patches - resulting from leaking cisterns or frequently overflowing drains - which aided by northern aspects give small patches of *mull rendzinas* and *protorendzinas*. At the heads of slopes in some cases all Xaghra soil material (dominantly clay) has been washed away and a gravelly sand of larger limestone particles is left forming a *carbonate raw soil*. The total area covered by both is however very small, probably of the order of a few acres.

Where the landscape type which Xaghra covers has been modified by terracing (other than the provision of catch terraces across the shallow valleys to prevent soil wash) it has been included in L'Inglin complex, to be considered later.

A diagrammatic section across Xaghra landscape is shown in Fig. 11.

THE TAS SIGRA SERIES

This series is found in a variety of locations, the only constant features of which are flatness, complete lack of lapiés or cut rock surfaces, and almost complete lack of terracing. The landscape elements on which it is formed are 1b weakly karstic Franka landscapes without lapiés; 3 deep alluvial deposits; and valleys and dolines within the main karst area, element 1a, such as are widely found on the Rabat Dingli Plateau. Weakly karstic landscapes are commonly found in south-east Malta, near Zurrieq, Mqabba and Zejtun, in north-east Malta near Naxxar and Charghur and Ghain Silem in Gozo, while the deep alluvial deposits are found in parts of Wied tal Pwales, and near Marsascala.

The series is in fact a convenient mapping unit showing Terra land well suited to agriculture rather than a single pedological type, for although most of these red clays and clay loams are of mainly alluvial

and colluvial origin, some, for example those on the weakly karstic landscapes, are believed not to be. In another case the transition from Xaghra landscapes on middle slopes to a deeper (presumably alluvial) soil development has been mapped as a change to Tas Sagra series, where the laprés cease to break the soil surface, despite the similarity of the soil profile.

The parent material of these soils is thus the same as that of the Xaghra series, the karst-producing Coralline and Franka limestones, although the Tas Sagra soils will often be found on rocks from which they were not formed. They are more widely found on the latter because the Franka is less often observed with laprés than are the Coralline rocks.

A generalised profile of the Tas Sagra series in a cultivated valley, flat and without terrace walls, is as follows:

- | | |
|----------------|--|
| 0 - 15 inches | Dark yellowish red clay loam or clay; medium crumb structure, moderately well developed becoming fine to medium subangular blocky towards the base of the horizon; friable at the surface, becoming harder below; dry. |
| 15 - 36 inches | Yellowish red clay; moderate to well developed fine angular block or subangular blocky structure; moist. |
| 36 inches | Hard, white crystalline limestone. |

Generally the profile is stoneless, but occasionally rubble has been added by the farmer.

In profiles developed on the deeper and obviously relic alluvial Terra deposits as at St. Thomas' Bay a well developed, angular blocky structure extends to a considerable depth below the tillage horizon and there are usually also 'veins' of secondary calcium carbonate between the peds.

The dolines of which about 12 were mapped in Malta, are of rather variable size, but average about 5 acres. They generally have not less than four feet of reddish brown soil in them - "red eyes of the countryside" (Kubiena). Where they occur, as at Hofret-ir-Riz, there is generally more intensive market gardening than on the surrounding land. The intensity of use depends, however, on the availability of water and where because of the depth to an aquifer there are few wind pumps, they are not much more used than the surrounding Xaghra as on the north-western part of the Rabat Dingli plateau, near Bahrija. Hofret-ir-Riz has been intensively worked for so long that the soil profile and properties there probably differ from those of any other part of the island. There is more organic matter in the profile, the soil is almost always moist, being well irrigated, and usually it is less red beneath the surface. No iron concretions were seen nor other evidence of leaching which is sometimes a characteristic of old dolines, and could account for the colour change.

Generally in the Tas Sagra series the depth of soil is 3 feet or more. In some locations where it overlies relic, deep alluvial soils of similar material, from which it cannot easily be distinguished, the total depth of soil may be very considerable as at St. Thomas' Bay and Marsascala.

Physical conditions of the Xaghra and Tas Sagra soils

The Xaghra series is generally not tilled, and in the untilled condition the soils are often hard and compact beneath the A horizon and the upper few inches of the (B) horizon; that is below the surface strata in which plant and more particularly insect activity is at a high level and a loose structure is encouraged. This is probably because of the down-wash of some of the loose material between the peds, when rain first falls.

very difficult to dig. It is noticeable however, that when dug out the rather dry soil is friable, despite its compact condition *in situ*. The top few inches of the solum usually have a moderately or well developed crumb structure (except during wet periods when the surface puddles), while the lower part of the profile even though compact as described above, usually has a well developed angular blocky structure. The better developments of this structure form are associated with the more plastic consistencies, which are presumed to be indicative of transitional forms to siallitic terra rossa.

The water relations of the soil are unusual, in that after heavy rain there is often puddling of the surface, but during most of the year the soil is extremely dry. This is believed to be because of the compact nature of the subsoil and slow infiltration.

By contrast the well worked Tas Sagra soils on the lower lands are at least moist for much of the year and more often have an open loose structure to 18 inches or more. They are also more often modified than the Xaghra series by the addition of (1) various sorts of town refuse which tend to lighten the texture and slightly affect the structure, and (2) dung which probably improves the structure to a small extent but is frequently useful merely in the same way as town refuse, that is mainly in making the soil texture lighter.

The Chemical Properties of the Soils - Xaghra series

Calcium carbonate and reaction (pH).

The soils are not completely decalcified, whether or not they were at an earlier stage in their history. The active calcium carbonate (Drouineau, 1942) which was determined, is used in France as a measure of the likelihood of chlorosis. The values of 2 to 6 per cent (see Appendix II) in the profiles examined are significantly lower than in any of the other soil series. They are also below the threshold values given by Drouineau for chlorosis of asparagus (7 per cent) and some fruit trees (9 per cent). As might be expected active calcium carbonate tends to a maximum value in the most disturbed profiles where fine rock fragments have been incorporated in the soil by agricultural working. There is also an indication of a correlation between the type of limestone of the parent material and the present lime content. The Franka tends to show higher values of active calcium carbonate than the Coralline Limestones (compare Gozo K and L, in Appendix II, both almost undisturbed, having 1.8 per cent and 6 per cent respectively under very similar conditions). Determinations of total calcium carbonate from two profiles show from 2 to 10 per cent in an uncultivated profile on Globigerina limestone and 8 to 15 per cent in a well-worked Coralline Limestone profile, which neither confirms nor denies the distinction mentioned above. It is noticeable that both in the untouched and the well worked profile the greatest amounts of calcium carbonate were in the top horizon, emphasising the blown in or tilled-in origin, particularly since considerable increases in total calcium carbonate were accompanied by only small increases in active calcium carbonate, so that more of the calcium carbonate in the surface must be coarse textured.

pH values in the surface layer at least, appeared to be inversely related to organic matter content, but there is no very notable relationship between the active calcium carbonate and pH. The average pH about 8.1, in the laboratory, about 7.8 to 8.2 in the field (using colorimetric methods), was below that of the other soils.

Organic matter and C:N ratio

The C:N ratio also tends to decline as total organic matter decreases and pH increases, illustrating the more complete decomposition of the organic matter at high pH. The average level for organic matter

is 4.5 per cent, rather less in the cultivated soils, rather more in the uncultivated, significantly more than in all other Maltese soils. In view of the apparent humus deficiency of these soils on inspection and the small evidence even under the microscope, these figures are surprisingly high.

Phosphorous

The total amount of phosphorus as P_2O_5 which is at a maximum in the surface horizon, ranges from 0.1 to 0.4 per cent and, averaging about 0.2 per cent, appears satisfactory, in comparison with values for Sicily (Averna, 1953) and Palestine (Reifenberg, 1947).

However, the readily soluble fraction varies from 2 to 105 p.p.m. indicating a considerable variation in availability which is not correlated with calcium carbonate content or pH as far as can be seen.

Exchangeable Bases

The exchangeable bases in the surface horizon are dominated by calcium, to the extent of 78 to 92 per cent of the total, which is between 23 and 55 m.e./100 gms., averaging 35 m.e./100 gms. The lower values of calcium are correlated with the lowest values for active calcium carbonate and higher values of magnesium. Sodium and potassium are the minor ions but still relatively important compared with the values found in climates where leaching is more important. Both the total exchangeable bases and the ratio of the various ions show little or no evidence of change down the profile except that potassium often decreases slightly downwards.

Table 9: Exchangeable cations in Xaghra soils

	per cent				T. E. B. m. e./100 gms.
	Ca	Mg	Na	K	
Min	78	6	1	2	23 m. e.
Mode	87	8	2	3	35 m. e.
Max	92	14	4	8	55 m. e.

Table 10: Exchangeable cations in Terra soils

		per cent					m. e./100 gms.
		Ca	Mg	Na	K	H	
	Malta (mode) (Xaghra)	87	8	2	3	ND	35
(Stace)	Australia (average)	79	11	2	8	ND	11.5, 24.4
(Reifenberg)	Palestine (Nablus)	84.4	1.7	6.8	2.1	ND	65.4
(Comel)	Italy (average)	Ca>>>	Mg>	Na>	K	ND	50% of theoretical possible total
(Averna)	Sicily (several)						15-, 25-30
(Durand)	Algeria av. of two recalculated without H	(73.8)	(-)	(1.2)	(2.2)	(23.8)	23, 27

due to stop when the few limestone fragments are dissolved. It must at any rate be much less than in some earlier period.

The calcareous nature (2 - 15 per cent CaCO_3) of the Terra soils is largely due to inblown fragments of calcite. Since they are apparently not being leached (the CaCO_3 content is greatest in the surface horizons, and this even in soils little disturbed by man) it seems unlikely that a soil completely decalcified as a result of solution can form at present. It seems probable therefore, that the soils are relic and are gradually increasing slightly in calcium carbonate content in the present climate.

A corollary is that if the present processes, however feeble, are not producing Terra soils but acting on relic Terra soils they are producing alterations, possibly in the general direction of desert or steppe soils. Comel (1952) remarks on the steppe-like appearance of Sicilian soils in summer.

The properties of Maltese Terra soils are:

Colour. Red (10 R 4/8 in a quarry crack at Marsascala), yellowish red, dusky red, reddish brown, but usually dark red (2.5 YR 3/6) or reddish brown (5 YR 4/4). In uncultivated areas they are rather redder than in the well worked areas.

pH and CaCO_3 . Not completely decalcified, and often with secondary calcium carbonate. The primary calcium carbonate in the unworked soils has largely been blown into inter-ped separation cracks it is believed. pH is usually 7.8 - 8.2, according to field determinations, about 8.1 (average) in the laboratory.

Humus form. Where the development can be noticed at all it is a mull-like moder beneath carob trees, (woodlouse droppings and carob litter overlying an earthworm-cast layer - both very humus deficient), or occasionally mull. Under cultivation, with the rare exception of a humus-deficient worm-cast mull formation, there is no evidence of a humus horizon and the only organisms seen are ants and aestivating snails.

Structure. Somewhat variable, but usually well developed crumb structures in the top horizon with strongly developed fine angular blocky below. Occasionally, in untilled locations the surface horizon which has been puddled appears prismatic to a depth of a few inches. Under cultivation crumb or granular structure to at least the depth of the plough layer is normal.

Consistence. Variable, plastic or slightly plastic; sticky, slightly sticky, or non-sticky.

Horizon Differentiation and Profile

The soil usually lies immediately on calcreted hard rock. A negligible depth of A horizon, often missing, coats a deep B horizon below which B/Ca (secondary chalk enrichment) or C, horizons, are occasionally found. In cultivated soils, frequently no differentiation can be seen except the plough-layer structure. There is no evidence of very dark brown topsoils which would suggest the soils were being "brownised" as in Yugoslavia. There is some evidence that calcite grains are being blown onto and into these soils from the calcareous soils, and it is said that much volcanic dust from Sicily is also blown in each year, although no conclusive evidence of this has been seen.

Considering these characteristics, it seems that although the previous form is still very well preserved, the soils are developing towards xerorendzinas as climax forms (Kubiena, 1953) and thus perhaps red xerorendzinas might be a suitable name for them.

However, specifically referring to Kubiena's classification, there appears to be a sequence of soils within which these appear. From colour

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they appear most likely to be mainly terra fuscas - being generally dull red-brown. Humus form is not diagnostic and no microscopic examinations have yet been made which would show the form of the ferric hydroxide minerals. Some profiles were observed to be compact with silted-up cracks between peds and difficult to break with the spade, yet in the hand the soil was found to be porous and friable. They also have a well developed crumb structure in the surface, and are plastic to slightly plastic and slightly sticky. This is unlike either siallitic or allitic terra rossa, but similar to the description of an earthy terra fusca. Typical terra fusca is more plastic and sticky, has more intense colouring, and a similar compact subsoil, but is, according to Kubiena, usually a forest soil whereas earthy terra fusca is usually a maquis soil. This latter is also similar to the condition of the soils in Malta.

Thus earthy terra fusca appears to be the most suitable description to apply the nearly virgin soils, but most of the soils are dominantly man-made and have some abnormal characteristics as a consequence.

A few of the soils are more plastic, sticky, somewhat redder, and have more markedly angular structures, indicating transitional forms to siallitic terra rossa. With further work these could probably be correlated with cherty (silica-rich) limestones mainly found in the Lower Coralline Limestone formation. No such correlation was observed by the author in the field, because time did not permit the seeking out of sites for the investigation which would be necessary because of the considerable local variability of lithology, and the large amount of movement of these soils.

The Xaghra group of soils in the Maltese Islands appear to contain the following forms

(1) Anthropogenic soils only broadly similar to (2)

(2) A spectrum of semi-natural relic soils generally with a xerorendzina dynamic and classifiable as earthy terra fusca with transitions to siallitic terra rossa.

The red alluvium derived from Terra soil should be considered as a braunlehm vega. The mapping unit - Tas Sagra series - includes such soils but, considering the small areal extent of definitely alluvial red soils, the integral unity of the small valley or doline with the karst landscape, and the present xerorendzina dynamic both of the alluvial and 'in situ' soils, it seems unnecessary to regard the series as more than an alluvial phase of the Terra soils just described. It has therefore been included in the variety earthy terra fusca.

ARMIER COMPLEX (a parent material sequence)

In two localities near Nadur in Gozo and at Armier in Malta wind-borne calcareous sands overlie Xaghra soils and are partly incorporated in them. These areas have been mapped as the Armier complex which includes soil ranging from those of the Xaghra series, with a mere thin sandy overlay, to those of the Ramla series - a deep deposit of aeolian sand with virtually no profile development. Where the sand deposit is thin it lies on top of the clay and between the peds, so that although the soil may be looser it has a close general resemblance to a Xaghra soil.

A profile of intermediate characteristics is described below:

RAMLA - XAGHRA TRANSITIONAL SOIL mapped in Armier complex. Profile Gozo O. (366908). Qortin tan Nadur above Ramla Bay. Topography. 275 ft. above sea level, on karstic plateau surface of the Nadur mesa (landscape element 1a) with Terra material and lapiés largely covered by varying depths of blown sand. Large slightly terraced field sloping 4° N, in a general slope of 5° - 10° into a small valley head. Land Use. Fallow, somewhat wind eroded, suitable only for crops requiring little water.

cracks

- S₁ 0 - 12 Strong brown (7.5 YR 5/6) sand; single grain structure; some fine roots; very low organic matter; merging to
- S₂ 12 - 21 Yellowish red (5 YR 4/6) sandy clay loam; mixture of Terra soil and sand, not completely intimate with increasing clay towards base; moderate fine angular blocky to slightly platy; no visible organic matter; extremely abundant secondary CaCO₃.

D Upper Coralline Limestone calcreted lapies.

Note: Mixing of sand and clay, encouraged by infiltration of sand into the structural separation of the clay, is nonetheless entirely due to man, and the soil is therefore anthropogenic.

At Armier some areas are very strongly terraced, and they have been separated on the map since the landscape and soils are considerably affected. Normally however, the complex is not terraced.

Physical Properties

The Xaghra soils of the Armier complex are similar to the driest among the normal Xaghra soils. In this condition they are often unworked, hard, and very difficult to penetrate with a spade, and where they are worked appear to produce very poor crops, probably because of drought. Occasionally they are terraced but usually they are not, and it is only where they are at all strongly terraced and consequently much disturbed that there is an intimate mixture of the sand and clay materials.

Chemical Properties

Analyses of the two horizons of profile 0 sampled show that the blown sand surface horizon appears very similar to Ramla soils in the surface horizon. The underlying horizon of Terra soil is rather like the normal Xaghra soil - to which it is expected the more Xaghra-like soils in the area will be similar. The exchangeable cations are lower, 20 against the average 35 m.e./100 gms., and the pH is higher, but otherwise the pattern is very similar to the normal Xaghra soil.

THE OTHER MAPPING UNITS

The three mapping units so far described are all related to basic semi-natural conditions where disturbance by man is in general relatively unimportant. However, where the processes described in the section on Disturbance have been extensively employed on naturally Terra landscapes the complexity of the soil patterns is much greater. For this reason it has been necessary to use the soil complex as the mapping unit for some areas. The soil complex denotes a fixed relation between a number of component soil series alternating very rapidly, so that the components of the complex are too intricately distributed and their areas too small for accuracy and clarity at the scale of mapping used,

L'Inglin complex is developed on valley sides in the karst lands mainly, and the soil pattern includes carbonate raw soils, and various mixtures of rock flour and Terra material, including some like the xero-rendzina soils, and with soil similar to the original Xaghra series not always dominant. This complex has been produced where very strong terracing, and the breaking of lapies has taken place to allow agricultural development, since even on 2° slopes the Terra soil erodes easily. The result is a characteristic cultural landscape, with high terrace walls, small cultivated plots, and varied soils.

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Similarly the rearrangement in the Tad Dawl complex (described later) produces very mixed soil patterns, and terracing in some parts of the Armier complex has produced a rather L'Inglin-like result.

The result is important mainly because of the extreme variability of the soils, which may be as great within one field as throughout the whole area. Thus to regard any particular mapping unit or soil as typical is fallacious, and may lead to incorrect generalizations, say, respecting the chemistry and needs, unless great care is taken.

The appended table (11) indicates roughly some of the characteristics of the Terra soils of the Xaghra and Tas Sagra series, and attempts generalization regarding the Xaghra-like soils within the complexes.

Table 11: Characteristics of Xaghra and Xaghra-like soils in various mapping units

Mapping Unit	Xaghra series	Tas Sagra series	Armier complex	L'Inglin complex	Terraced parts of Armier complex	Tad Dawl complex
Walls	Very few	Few	Very few	Numerous	Numerous	Numerous
Terracing	Nil	Nil	Nil	Strong or very strong	Strong	Strong
Quarried backwalls to terraces	Nil	Nil	Nil	Frequent	Frequent	Essential
Carting	Nil	Unusual	Nil	Common		Essential
Quarrying	Nil	Nil	Nil	Occasional	Nil	Essential
Manuring	Occasional	Common	Nil	Common	Occasional	Common
Town Refuse	Rare	Occasional	Nil	Common	Occasional	Common
Vegetation	Natural xerophytic vegetation	Annual crops	Natural xerophytic vegetation	Some carobs; some annual crops	Annual crops	Annual crops; trees
Erosion	Occasional wash	Nil	Occasional wash	Nil, if terraces good	Occasional blow	Nil
Water availability	Dry	Often irrigated	Dry	Generally dry	Irrigated Partly	Generally dry
Use	Bird catching, grazing, occasional crops	Intensive cropping	Grazing	Cropping	Cropping	Cropping
Relative value at present	Low	High	Very low	Variable: high to quite low	Medium	Variable
Soil Fertility	Good	Good	Mod. to good	Mod. to good	Mod. to good	Mod. to good
Textures	Clay loam or clay	Clay	Clay and sandy clay	Clay loam or clay	Clay and sandy clay	Clay loam
Sub-surface stones	Very few	Nil	Very few	Generally gravelly	Very few	Generally gravelly

L'INGLIN COMPLEX

The strongly terraced Xaghra landscape is mapped as L'Inglin complex. Where the Xaghra landscape has been strongly terraced with the backwalls of the terrace cut from the solid rock, the lapiés have disappeared and walls have partly taken up the stone. The natural vegetation has gone, and occasional carobs have been planted, so that if it were not for the frequent exposures of bare white rock and the obvious Xaghra derivation of most of the soil, it would be difficult to realise that this was formerly a natural karst landscape.

The obvious variation of the soils from a mere rock flour to Xaghra series with an infinity of intervening types led to the use of the description of the subsoil colour and texture as diagnostic of twelve classes, shown in Table 12, the distribution of which was then mapped.

Table 12: Soil classes, by colour and texture of the subsoil, in L'Inglin complex

Subsoil Hue (Munsell)	Subsoil Texture		
	Clay and Clay Loam	Loam and Silt Loam	Sands and Sandy Loam
10 YR (yellowish brown)	(TF)	(TG)	(TH)
7.5 YR (brown)	TF	TG	TH
5 YR (reddish brown)	TR	TS	TT
Redder	TR*	TS*	TT*

In Table 12, the Xaghra and Tas Sagra-like soils are represented by TR and TR*, and rather similar soils but with large additions of foreign materials by TF. These soils cover perhaps 60 per cent of the total area of the complexes. Soils resembling the Tal Barrani series represented by TG (occasionally TF), cover perhaps 25 per cent of the mapping unit, but are occasionally dominant (as near Gharghur). Soils resembling the carbonate raw soil parts of the San Biagio series, and the Nadur series (whitish variant) are presented by (TG) and (TH) and typical Nadur series by TT. These last cover relatively small areas (perhaps 12 per cent of the whole area), and the remaining classes, all at some time encountered, with the exception of TS*, cover the remaining fraction of L'Inglin mapping unit. No attempt has been made to describe these minor classes, which are products of the mixing of foreign soil materials usually (addition of Blue Clay produces (TF) for example). For the series correlated with classes of the disturbed soils, good descriptions exist already in the relevant chapters. The soils of L'Inglin complex are however, not precisely like those series but resemble quite closely the more disturbed parts of each series. A comparison of a soil from Xaghra series and a Xaghra-like soil from L'Inglin complex is given below to illustrate this difference, which is probably greatest in the Xaghra-like soils, certainly as far as chemical characteristics are concerned, because of the addition of limestone rockflour to the originally almost decalcified soil, the soils of all the other genetic groups being highly calcareous already. The Xaghra-like soils nonetheless represent the least change in the area, because prior to man's occupation, they occupied the entire mapping unit.

Xaghra-like soil within L'Inglin complex 0 - 14", uniform	Xaghra series 0 - 6"	Xaghra series 6 - 30"
Reddish brown silty clay loam; moderately well developed, fine granular structure; moderate organic matter, includes much added refuse; dry, loose; surface 50% covered by gravel, soil stoney or very stoney; highly calcareous;	Reddish yellow clay; moderately to strongly developed, medium crumb structure; low organic matter; very dry, loose; surface 20% covered by gravel but very few stones in soil; weakly calcareous;	Weak red or red clay; strongly developed, fine angular blocky; no apparent organic matter; very dry, very hard; no stones; very weakly calcareous;
lies on limestone scarred by working.		lies on calcreted lapies of same limestone.

In L'Inglin areas, in making the land suitable for agriculture, different combinations of the following activities have taken place, and produced the wide variety of soil types found.

- (1) The surface of the rock has been broken and replaned, and sometimes a series of downslope drainage channels have been made in it. This produces much rubble and rockflour.
- (2) The Xaghra soil has been lifted and replaced, and in the process rockflour rubble has been incorporated in it, and rubble and refuse often placed beneath it. Where sufficient rockflour has been incorporated, the soil appearance becomes similar to that of Tal Barrani soils, TG.
- (3) At the outcrops of softer limestone beds, terrace backwalls have been cut deeply in the rock and so undermined as to produce a large volume of rockflour, which is effectively a carbonate raw soil, similar to those which are enclaves of the San Biagio series (TG) - (TH), or in other cases the Nadur series (TH) and TT.
- (4) In some locations, foreign rubble and rockflour from building sites and even soil, generally from excavations, have been added as well as the usual town refuse.

The result is the complexity previously described, and in order to illustrate the complexity of this pattern a small area situated around Naxxar is described in some detail.

Some soils on the Naxxar-Gharghur hill mass

The Naxxar - Gharghur hill mass which covers most of this map is of Franka and Lower Coralline Limestone, which both produce karst in this locality. Several wields have cut deep valleys in this hill mass, and two, the Wied Angli and the Wied id Dis both near Gharghur form deep gorges where they cut through Victoria Lines onto the lowlands to the north. These valleys, with the Wied Meixu and Wied il Kbir are very strongly terraced, except where they become gorges, and with the exception of the flat hill tops and the towns, the whole of the hill mass is terraced.

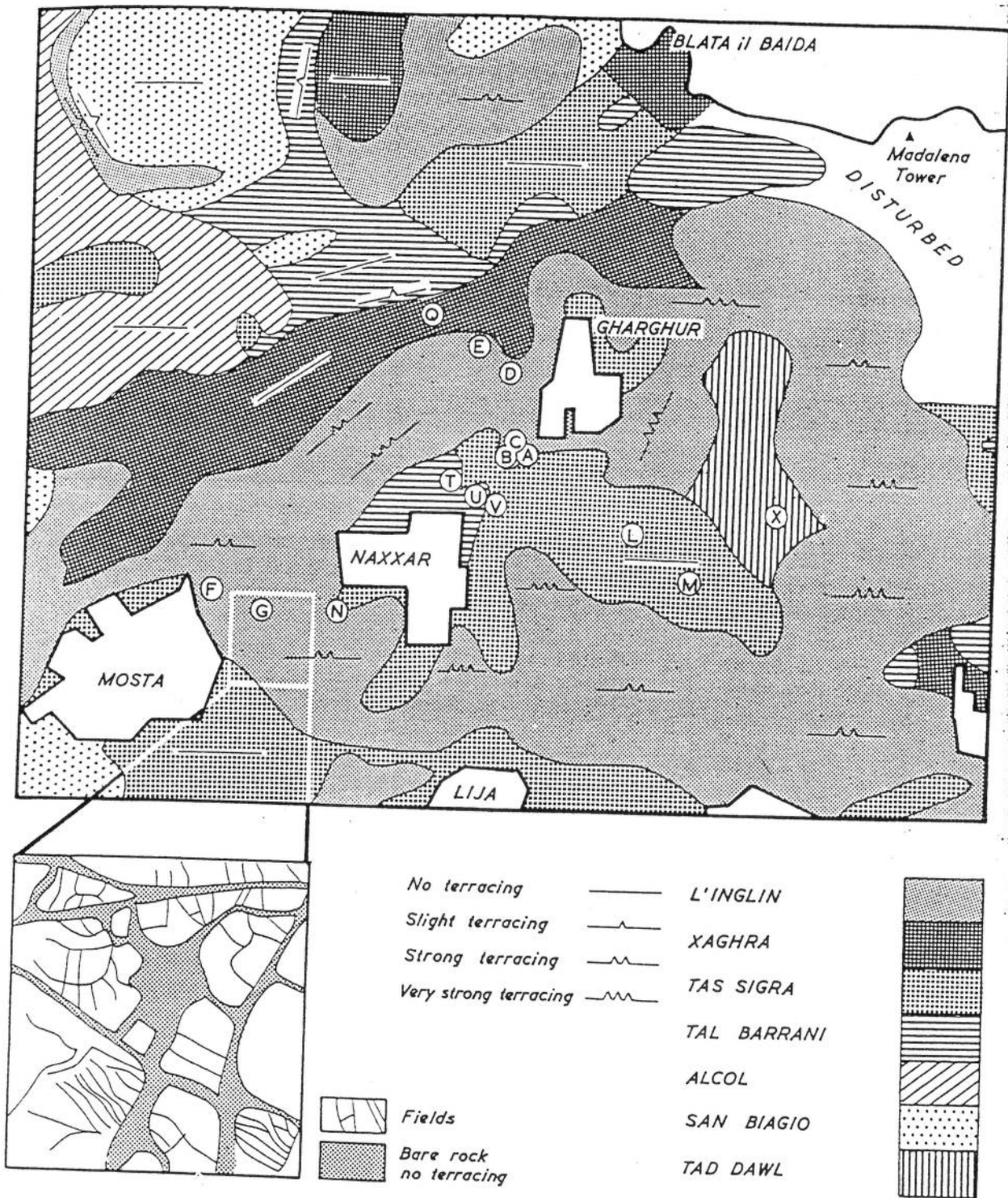


Fig. 12. Soil map of Naxxar - Gharghur hill mass. The inset shows pattern of fields within the L'Inglin complex. Boundaries between fields were built first: roads were made later when fields began to encroach on one another. For symbols A to X see table 13.

It will be seen on the map (Fig. 12) that around the hill-top towns, and flat lands is a belt mapped as L'Inglin complex, and descriptions A to H in Table 13, refer to points in that belt. They have descriptions ranging from Xaghra-like soils, to San Biagio-like soils, but they are mapped in L'Inglin unit, because of the disturbance, principally terracing, and the rapid changes in the area.

The table also shows that the description TR is applied to soils in four mapping units, the basis for differentiation being (1) presence of terracing, (2) presence of exposed lapiés, (3) presence of lynchets, quarries, (4) presence of added materials.

Ref.	Ma
A	L'
B	L'
C	L'
D	L'
E	L'
F	L'
G	L'
H	L'
L&M	L'
N	L'
Q	Ye
T	Tr
U	T
V	T
X	

Table 13: Some Soil Descriptions

L'Inglin - Naxxar - Gharghur Area

Ref. Mapping Unit		Subsoil Colour & Texture	Topographic Location	Terracing	Terrace backwalls cut into rock	
A	L'Inglin	TR-TS	Dk. reddish brown (5YR 3/4) silty clay loam on rock	Gentle slope at valley head	Slight	Noticeable
B	L'Inglin	TS	Reddish brown to brown (5YR 4/4) gritty loam on silt loam	Next terrace at valley head but slightly lower	Strong	Large rock backwalls
C	L'Inglin	TH	Brown to yellowish brown (7.5YR 5/4) gravelly fine sandy loam	Mid-valley field on reworked rock	Strong	Numerous
D	L'Inglin	TR	Reddish brown to brown (5YR 4/4) gravelly clay loam to clay	Mid-valley deep alluvial location	Strong	Nearby
E	L'Inglin	TH	Brown to yellowish brown (7.5YR 5/4) gritty sandy loam	Summit on decaying rock	Moderate	No
F	L'Inglin	TR	Reddish brown (5YR 4/4) gravelly clay loam to clay	Broad terraces on moderate slope	Strong	Yes
G	L'Inglin	TR	Reddish brown (5YR 4/4) gravelly gritty clay loam	Quarry fields	Strong	Quarried
H	L'Inglin	TG	Brown (7.5YR 5/4) gravelly gritty loam	Very steep valley side slope	Slight	Yes
L&M	Tas Sagra	TR	Dk. yellowish red (5YR 3/6) clay	Gently sloping shoulders and valley heads	Virtually nil	Yes occasionally
N	Tas Sagra	TR	Reddish brown (5YR 4/4) clay	Upper shoulder slope	Virtually nil	
Q	Xaghra	TR	Reddish brown (5YR 4/4) clay	Pockets of soil in steep slope	Nil	Nil
T	Tal Barrani	TG	Brown (7.5YR 5/4) gritty loam	Flat summit fields near Naxxar	Virtually nil	
U	Tal Barrani	(TH)	Yellowish brown (10 YR 5/4) sandy loam	A small patch among TG fields at the summit	Virtually nil	This field only
V	Tal Barrani	TG	Brown (7.5YR 5/4) loam	Flat summit near Naxxar	Virtually nil	
X	Tad Dawl	TR	Dk. yellowish red (5YR 3/6) clay loam	Saddle with many quarries this hole being in one	Strongly terraced	Quarried

Thus F and G, belonging to L'Inglin complex are in terraced fields with backwalls cut deep into solid rock, and are markedly gravelly soils, i.e. disturbed soils.

L, M and N are in unterraced flattish areas, mapped as Tas Sagra soil.

Q is on an unterraced, steep slope with TR puddles between lapiés, a normal Xaghra soil.

X is within a quarry, and the terracing and lynchetting there is of the pattern described earlier.

These soils are all apparently approximately similar, but have been placed in differing mapping units because of

- (1) the effects of disturbance, and the extreme variability within the disturbed areas,
- (2) the significance of strong terracing on the type of agriculture and the ability to map a landscape unit rather than diminutive pockets of similar soils.

THE TAD DAWL COMPLEX

This will be only briefly mentioned, since the description under quarrying in the Soil Disturbance section covers the distribution and nature fairly well. As with L'Inglin complex a soil material that looks like Xaghra series but contains added materials and lacks the profile characteristics of Xaghra, is commonest, but by no means ubiquitous, and carbonate raw soils can be observed.

It is separated from L'Inglin complex because of the singular nature of the terraces and their position below general ground level, where they are very sheltered from wind, and also perhaps from excessive sunlight for at least part of the day. In main soil types, however, it closely resembles the L'Inglin complex, and will be considered with that unit.

Chemical Analyses of the Xaghra-like soils of L'Inglin and Tad Dawl complexes

A number of surface samples of these soils were examined and, as might be expected, revealed a startling increase in "active" CaCO_3 in some cases up to the level of the calcareous soils (over 10 per cent, see Appendix II). Despite agricultural working the organic matter content is high compared with the calcareous soils, even in some of the cases of high "active" CaCO_3 . In most cases the pH value determined in the laboratory is about 8.5 compared with about 8 as determined colorimetrically in the field.

It is necessary to bear in mind the high variation in the fertility of these rather mixed Xaghra-like soils. It is presumed that even though they may appear like Xaghra soils the more calcareous examples will react more like Tal Barrani soils, as well as those which obviously look like Tal Barrani soils. Care will therefore be necessary in comparisons for fertility studies.

PARENT MATERIAL AND SOIL

Considering first only soils of the Terra type that can be regarded as more or less autochthonous, - the Xaghra series, the main origin of the soil material is the limestones on which the soils lie or rather, those overlying strata which are presumed to have disappeared to produce the soil. Fuchs in 1875, later supported by Glinka (1914) first related this type of reddish clay soil to the differently coloured, underlying, hard limestone

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G. W. Robinson is one of several authors who agree in restricting the name terra rossa to the red soils associated with hard limestone such as occur widely in Mediterranean countries. He says the soils in this group show a simple kind of profile consisting of a variable depth of red soil sometimes slightly modified in colour by admixture of humus in the upper horizon, and passing abruptly to the limestone rock below without any marked zone of transition. Typically the terra rossa soils are fairly heavy clays. Analysis of the separated clay shows a fairly high content of silica.

Table 14: Analyses of terra rossa

Site		SiO ₂ %	Fe ₂ O ₃ %	Al ₂ O ₃ %	Loss on ignition %
Pikermi, Greece	(a)	42	13	21	15
Sault, Bas Rhone	(b)	44	13	24	14
Saint Christol, Bas Rhone	(b)	42	11	29	13
Rochefort, " "	(b)	42	13	25	13

(a) data of W. Graf zu Leiningen (1917) quoted by G. W. Robinson (1949)
 (b) data of J. Bordas and G. Mathieu - Reverdy (1943)

Robinson notes that the abundant data for the bulk composition of terra rossa soils and the rather few available data for the composition of the clay fraction resemble figures obtained for typical brown earths. It may be added that W. Hollstein (1938) described terra rossa soils in Greece which seem closely to resemble those of Malta. He considered that terra rossa is formed from the residue of weathering of the limestone rock agreeing in this respect with Graf zu Leiningen. J. Bordas and G. Mathieu-Reverdy (1943) consider terra rossa to be of geological origin and to be parent material rather than soil formed by current processes. On the other hand A. Reifenberg (1947) who had studied terra rossa soils in Palestine and had seen them in the South of France and in Algeria considered that these soils have been formed under a climate which is similar to the present one and are still being formed today.

The general facts seem to be fairly well known, there is little doubt that the soils form from the limestone, although it has been suggested (Italy, Comel, 1952; Algeria, Pendleton, 1947) that aeolian dust, carried by the sirocco, may have been an aid, and again by Comel (ibid.) that there are quantities of Saharan dust in Sicilian red soil. Accession of wind-blown dust to earthly terra fusca is mentioned by Kubiena also. In Malta which might be expected to have Saharan dust before Sicily there is no evidence of this latter, all the aeolian sands appear to be very local. The volcanic dust theory is perhaps encouraged by the presence of quantities of silt-size iron concretions in the Maltese Terra soils, but such concretions are usually attributed to pedological processes.

Thus in Terra soils we can presume in general that most of the mineral soil is the residue from the solution of limestone, so that when the calcium carbonate is nearly or wholly gone, some of the accessory minerals of limestone will dominate the soil. If limestone alone were removed it would be simple to understand how much soil would develop from a particular limestone, and what its composition would be but the pedogenic process is not quite so straightforward. However, it appears worthwhile to point out that at least 20 metres of limestone must have been removed to produce 1 metre of soil from a 95 per cent pure limestone. In point of fact, since other materials are removed besides calcium carbonate more will be required.

The table below shows total analyses of Terra soils from a number of countries, which shows the variable composition of the soil material, dependent largely on the accessory minerals in the limestone. The classification of the Maltese 'Terra' soils as earthy terra fusca seems to be borne out by the relatively low ratio of $\text{SiO}_2 : \text{R}_2\text{O}_3$ in the determination given by John Murray although the ratio in the clays alone is not known. (It is likely to be similar because these soils are dominantly of clay texture.)

Table 15: Total analyses of "terra rossa" soils, showing relative proportions of SiO_2 , R_2O_3 , CaO and MgO in the whole soil

		PROPORTIONS OF				
		SiO_2	R_2O_3	CaO	MgO	
Ponte	SICILY	42.98	18.77	37.42	1.30	Averna (1953)
Strasuti		70.64	14.13	13.69	1.57	
Bagheria		73.24	13.09	12.61	1.09	Comel (1931a)
Fossa di Giallo		67.86	30.67	1.74	.88	
Jenin	PALESTINE	56.68	22.35	7.33	2.52	Reifenberg (1938)
Nablus		61.20	28.79	8.08	1.76	
Cyprus		46.74	26.22	21.93	5.11	
Australia		26.28	67.06	6.97	N.D.	Stace (1956)
Comino		26.84	56.81	14.28	1.99	Murray (1890)

The analyses also suggest that the soils usually called "terra rossa" are seldom completely decalcified, although they may have been at some past stage. In Malta 2 to 15 per cent calcium carbonate was found in two profiles examined. It seems probable also, in Malta, that there was more complete decalcification on the Coralline rocks, where a travertinous crust is always found, than on the Globigerina rocks, where there is sometimes a Ca transition horizon at the base of the profile. This is presumed to be because the Globigerina limestones producing karst are not crystalline, and occasionally rather soft compared with the Coralline rocks, and since most of the calcium carbonate in the Terra soils without a Ca horizon is found in the surface its presently largely aeolian origin seems confirmed. This may be true in Greece also for Holstein (1938) observed a notable amount of calcium carbonate in the surface soil.

Where the terra soils have been well terraced (L'Inglin series) but no foreign materials have been added, the soils on Coralline rocks have less conspicuously increased in calcium carbonate content than on the Globigerina rocks. This is noticeable in the values for active calcium carbonate, which are usually above 10 per cent in these soils against about 4 per cent in the Xaghra series. The soft Globigerina limestone is probably more easily broken and disseminated through the soil material than the harder Coralline limestone.

However where foreign materials have been added, the mixing is often so great that nothing can be said other than that each terrace and often each square yard of the terrace has different properties.

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CHAPTER VI

VEGETATION AND AGRICULTURE

Vegetation

It is useless to attempt to describe the 'natural' vegetation of Malta for there is none which is not actually cultivated or at least encouraged by cultivation except here and there on the karst landscapes of the Xaghra series where a xerophytic vegetation is developed, consisting of aromatic herbs, such as thyme and marjoram, with some few grasses, thistles, and bulbous plants such as squills and agaves. The cover is much less than 100 per cent, generally bare red soil or surface gravel covers at least as much of the surface as vegetation does, and some plants appear to prefer the sheltered position of a narrow crack between lapiés to the open space of the soil puddle. This may be due in part to the relative protection from grazing experienced there. Away from these small patches of relatively natural vegetation there is not however, even in the saline areas at the actual coast, a vegetation free from some form of major interference. Usually there is, in fact, either bare surface or planted crop.

Agriculture

The agriculture of Malta is dependent on a very large number of small scale cultivators, working small, usually terraced fields which are often widely scattered although within the unit of one "farm". The small and scattered fields render mechanization uneconomic, except for the car or van to whisk the cultivator from one field to another, or to market.

There are a number of areas of larger fields (e.g. on the Alcol series) where tractors might well be used and indeed some tractors are in use, chiefly hired out by contractors to do specific jobs. It is most unusual to see a tractor however, whereas the rotovator is a fairly common sight and sound in winter and spring, but far more common is the horse-or donkey-drawn light wooden plough and the hand wielded hoe.

A division of agricultural land use in the Maltese Islands is

- (1) Arable (a) market garden crops.
(b) cereals, forage crops etc.
- (2) Tree gardens - mainly citrus fruits.
- (3) Vineyards.
- (4) Flower gardens and ornamental garuens.
- (5) Rough grazing and birdcatching.
- (6) Rough plantings of carobs on rocky land.

The difficulty, however, of dividing land use in this way is that even within very small units of land most cultivators try to grow some of everything. Thus market garden crops are grown between strips of a few rows of cereals, sometimes interspersed with rose bushes, or a patch of cash crop carnations or anemones. Odd carobs, oranges or pomegranates will perhaps occupy a corner of the field, and the boundaries may be marked by prickly pear, all within one small field. This is, however, not the case everywhere, and the particularly mixed sort of use seems to be most common on L'Inghlin complex where the soils are very thin, and on associated landscape types. In some other areas there is a dominance of vine cultivation, particularly in the main scarp slope Fiddien,

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San Lawrenz, San Biagio sequence, on the Blue Clay inlier (Fiddien series mainly), and on some Tas Sagra and Alcol areas (Miziep, Burmarrad and below Ta I'Iskurvit for example). Locally one particular vegetable may be dominant, for example the potato, and in Gneina valley on the Fiddien series and many of the similar slopes in Gozo almost nothing is grown but sulla, a forage crop. However, to relate crops and soils in more than a general way requires study of a detailed land utilisation map in comparison with the soil map. The examples given above are of differences noted in passing, and the impressions of correlation with soil series below are based on the same rather incomplete notes. Use of the Durham University land utilisation map in this connection will probably correct and expand these impressions.

Dividing the carbonate raw soils into textural groups, the generalisations about utilisation can be more conveniently made. The sands, loamy sands and sandy loams are very dry, easily worked, rapidly warming soils which, where practicable, are mainly devoted to vines (Nadur series) and fruit trees (Nadur and Ramla series). The clay loams and light clays (San Lawrenz and Fiddien series) are sticky, water retentive, usually fairly well structured soils, but hard and dry in late summer, and with a tendency towards an alkali-soil condition locally. In some parts of Malta they are used for a wide variety of crops, vines, especially tomatoes, cereals, and potatoes, but are often devoted to sulla, as in Gneina Valley and western Gozo. The Fiddien heavy clay, is usually alkaline, sometimes slightly saline and often has very bad water relations, so that it remains little used.

The carbonate raw soils, with one or two localities excepted, are terraced, or stand in steep slopes, so that there is little prospect of increasing the field unit size. Of the xerorendzinas, the San Biagio sandy loams and silty loams are only unterraced on plateau tops, while the Alcol clay loams and clays are almost never terraced. It is from among these xerorendzinas, together with the level Tas Sagra soils in the karst areas that there is a chance of increasing field size sufficiently to allow mechanization.

The xerorendzinas are moreover, among the more easily worked soils, but appear to be among the chemically less-favoured soils. Observations of potash necrosis and iron chlorosis were mainly on these soils. However, the reasonably satisfactory structure, easy tillage, and reasonably good water relations of these soils appear to compensate, for the soils are universally cultivated and appear to give satisfactory crops. Both series appear to be used for a wide range of crops, cereals, vines, rootcrops and market garden crops generally, the last mentioned, particularly on irrigated land.

The Tal Barrani loams and clay loams, are found almost entirely in the heavily populated area of southern Malta, where they are intensively used, and almost universally terraced. They appear to be entirely devoted, apart from odd fruit trees along walls, to annual crops, principally cereals and potatoes. Their chemical characteristics appear more favourable than those of most of the soils, and their structure and tillage properties appear to be fairly satisfactory. It is not known, however, whether they are more productive, than for example, the nearby San Biagio xerorendzinas.

The clay loams and clays of the Terra soils are all, potentially at least, rather fertile, as is revealed by the analyses (appendix II). However, where they occur as small soil puddles between lapiés (Xaghra series) the mode of working is problematic, and they are generally rather dry, compact, and difficult to cultivate. Here they are usually left uncultivated, and used for birdcatching and very rough grazing for sheep and goats, or occasionally very patchily for poor crops of cereals, prickly pear, fruits or flowers. The alluvial flats and flatter lands without surface lapiés (Tas Sagra series) are by contrast, usually heavily cultivated, bearing a wide variety of crops, especially in the damper

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valley bottoms where vines are sometimes dominant, with potatoes and cereals most important on the non-alluvial flatlands. Where the land is worked intensively the depth of crumb-structured soil is greater, and in the valley bottoms, especially, the water relations seem to be improved.

The terraced Terra soils, that is, members of the various complexes, are usually very dry, and one of the unfavourable features of the carbonate raw soils, is the higher active calcium carbonate because of the incorporated rock flour. They seem to be largely devoted to cereals and potatoes, and in general give relatively poor crops. These soils are in several areas widely abandoned because they are uneconomic to work.

Apart from this the interesting points about agriculture in the Maltese Islands seem to be:

- (1) the ubiquity of arable - virtually the only untilled land being on the Xaghra series where it is leanest, (that is where bare rock covers 50 per cent or more of the surface), or very distant from a village when the poor natural vegetation is left as grazing for sheep.
- (2) the oldness and general poorness of the many fruit trees, and lack of replacements growing.
- (3) the underground life of cattle, which seldom emerge from their caves so that their existence is hardly recognizable to passers-by.
- (4) the universal use of one "artificial" (sulphate of ammonia) and the mode of use of dung and town refuse.
- (5) the terracing and cutting and undermining of the rockface backwall of the terrace producing carbonate raw soils.
- (6) the apparently high level of incidence of crop diseases, both deficiency and bacterial, and the number of plant and insect pests which are left unhindered. (Broom rape for example, affected every field of beans seen and is not grubbed up when the bean plant is removed).
- (7) the amount and effect of irrigation.

Sulphate of ammonia is used presumably to make nitrogen available to the plants and not as a source of sulphur. The residual acidifying effect in such calcareous soils is probably small. Dung is often left in a heap in the sun until it is completely dried and probably of little use. In any case it may be of very little use when applied to highly calcareous and moderately alkaline soils, in which it probably mummifies almost immediately. On the less calcareous soils (Terra) dung would probably be of more use if applied still in a moist condition and worked into a moist soil.

Irrigation is widely practised in Malta and to a smaller extent in Gozo too, but much of the irrigation water is somewhat brackish, and over a long period might have an adverse effect on soil structure and nutrient availability. However, the difference between irrigated and non-irrigated fields is all too apparent at certain times of the year and especially of course in dry years. Yields appear to be much higher, and the crops in some cases more healthy. This is particularly so where manure is applied in the irrigation water and thus kept damp. It is then probably, relatively more able to supply CO₂ and reduce pH, as well as supplying more nutrients (Watenpugh, 1931).

General remarks respecting fertility

The needs of a soil for the improvement of its fertility are not simple to assess and in the Maltese Islands they are not known at present. A fertile soil is considered as one which is in the optimum condition for the growth of crops, and this is dependent on a number of factors, physical and biological, as well as chemical.

Physical needs

A soil with poor physical structure may be unable to support good crops because water cannot be conducted to the plant easily enough or because the soil aeration is poor. The heavy clay soils of the Fiddien series have poor structure, and it is probably the correlated difficulty of wetting the soil rather than the chemistry of the soil (which often has a rather high concentration of exchangeable sodium and soluble salts) which causes it to be nearly useless for agriculture.

The majority of Maltese soils have a reasonably good structure, and the only other soils apparently ill-favoured are the heavy-textured soils of the Xeghra series, the subsoil of which is often very compact, and the separations between structural units are minimal. However, where such soils are well worked, and more particularly where they are irrigated, the structure seems to be much improved, partly no doubt because of the increased and active microfauna. While irrigation is probably difficult to extend, improved cultural practices would probably produce an increase in the soil organic matter content and improvement of the structure. Among such practices the use of nitrogenous fertilizers, improved rotations, encouragement of root growth, avoidance of oxidation of root-derived organic matter through unnecessary turning over of the soil, and the avoidance of pulling cereals as a method of harvesting, might cause considerable improvement. Animal manure applied in irrigation water as already practised locally also appears to be effective in increasing organic matter content.

One of the chief problems of all crops in the Maltese Islands, is water. Certain of the lighter-textured soils are extremely dry, and conservation of rainwater rather than extension of irrigation must be the answer because domestic water needs are already difficult to satisfy. Apart from practices designed to diminish evaporation loss, e.g. hoeing, it is probable that increasing the organic matter content would considerably increase the ability of the soil to hold water. Another simple possible method would be to marl some of the lighter soils with the calcareous clay, e.g. Fiddien heavy clay, which is not in agricultural use, which would also possibly make more nutrients available.

It seems unlikely that aeration is deficient in many soils at present.

Chemical Needs

Despite some other possible deficiencies it seems likely that nutrient deficiencies are likely to be the most important factor involved in soils of low fertility in the Maltese Islands. It is not possible to say immediately what these are because

- (1) there is no simple relation between analytical data and availability of nutrients to plants,
- (2) existing analytical data are few and not correlated with crop performance,
- (3) satisfactory chemical data for calcareous soils are more than usually difficult to obtain and compare.

In spite of the generally healthy appearance of the crops, some symptoms of nutrient deficiencies have been observed and, remembering well known characteristics of calcareous soils, it is obvious that only experimental comparison of fertilizer application with crop yield can give any

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definite answers about needs. Such experiments need to be of a form capable of statistical analysis, to enable tests of significance to be applied and to reveal interactions.

The first step should be to set up trial plots in sites typical of each soil, using only one crop or rotation and only N, P and K fertilizers, each at two levels. Later, additional field tests should be made and foliar analysis or an "application to plant" method could be used to examine crops for specific deficiencies in order to make a more complete picture. At a later stage alternative fertilizers might be compared, and time and mode of application, although these are refinements which would not necessarily yield significant results.

It should be borne in mind that (1) effects of past management may have upset the natural status of the soil - e.g. the addition of town refuse as, in addition to actual toxins, the microbial population may be unfavourable, (2) effects of infestation by parasites and fungi, or diseased remains may be present which will invalidate a trial. This needs strong emphasis since much soil disturbance has taken place in Malta, and the addition of town refuse is common. Further, many plots have been observed infested with broom rape, which is never combatted, and others exhibit root damage produced by insect larvae. The elimination of these alone would result in considerable improvements.

Marginal leaf scorch, perhaps due to lack of potassium, has been observed in fruit trees. Lime-induced iron chlorosis has been observed in citrus trees particularly on the xerorendzinas and carbonate raw soils. It is well known that soluble phosphate becomes insoluble in presence of calcium carbonate. This process is accelerated when the latter is in a state of fine subdivision (Gonzales Garcia and Tristan Matos, 1956). Sulphur, sometimes deficient in marly soils of Spain, may be deficient in Malta also unless use is made of fertilizers containing sulphur such as ammonium sulphate or single superphosphate. Symptoms of nitrogen deficiency were not observed by the author but farmers in Malta are aware of the need to apply nitrogenous fertilizer. Careful experiment is needed to study the effect of organic wastes containing little nitrogen: the town refuse which is widely used does not look a promising material but the local practice receives some support from the observation of Gouny (1956) who obtained good results with market garden crops on calcareous soil in the south of France in the second year after applying straw without additional nitrogenous fertilizer. There was a depression in yield in the first year of application. Experiment is needed also on the use of dung and attention is drawn to the work of Watenpaugh (1931) in New Mexico who found it best to keep dung moist instead of allowing it to become dry before application. It is noted that at present many plants, especially cereals, are pulled out instead of being cut: this removal of the roots means the loss of an important source of nitrogen for the following crop. Not only are nutrients removed but the soil is left loose and is exposed to erosion without the plant roots that would help to bind it.

In arid parts of the U.S.A. Kuykendall *et al.* (1957) have reported success in the control of iron chlorosis by use of chelates: these unfortunately are expensive but it would be of interest to discover whether they can be used with profit in the Maltese Islands.

Land out of cultivation

Where terrace walls are falling or are delapidated because the fields are too small to justify the upkeep, it is suggested that larger fields more economic to work could be formed by dispensing with boundary walls between fields on the same contour level.

Reaction (pH)

The measurement of pH is sometimes a most useful item in soil analysis. It is an aid in determining the soil type and it gives a rough indication of the availability of the major plant nutrients, particularly phosphate. Figures for pH also indicate in a rough way the degree of base unsaturation of the soils. There are, however, some drawbacks as has been noted by E. W. Russell (1950). There is some difficulty in interpreting pH figures when soluble salts are present in appreciable amount. In the laboratory particularly the measurements are made in conditions which are far removed from those existing when active roots are in contact with the soil: as a rule the concentration of carbon dioxide is much less in the laboratory and the ratio of water to soil is usually larger than in the undisturbed soil. It has been stated by R. Bradfield (1941) that the pressure of carbon dioxide within the soil is usually 10 times and frequently over 100 times as high as it is in the atmosphere. This is of particular interest in the case of calcareous soils such as occur in Malta for, within this range of pressures, carbon dioxide has the effect of bringing calcium carbonate into solution as bicarbonate and reducing the pH. Bradfield (1941) quotes from J. Johnston the following figures which relate to a temperature of 16°C.

Pressure of CO ₂ (atmospheres)	(Ca ⁺⁺) x 10 ³ . ionic concentration	pH
0.0003	0.52	8.30
0.0033	1.17	7.62
0.0432	2.87	6.90

The figures for ionic concentration if multiplied by 100 can be read as milligrams CaCO₃ per litre. The figures agree closely with data reported by D. H. Yaalon (1954). For a temperature of 25° C he gives two equations

$$\text{pH} = 0.65 \log P_{\text{CO}_2} + 6.04$$

$$\log S = 0.35 \log P_{\text{CO}_2} - 12.97$$

For CO₂ pressure of 0.0432 atmospheres these equations give 297 milligrams CaCO₃ per litre (say 120 milligrams per litre calcium ion) and pH 6.93. It is to be noted that an increase in pH to values exceeding 9 or 9.5 is usually associated with an undesirably high amount of exchangeable sodium and with a marked decrease in the amount of soluble calcium. The pH value found in the laboratory depends quite appreciably on how the measurement is made but the aim usually is to determine a definite equilibrium value: in field conditions however there is no equilibrium but presumably ceaseless variation in temperature, moisture content, pressure of carbon dioxide, concentration of plant nutrients in solution and other factors on which pH depends and it is difficult to say what precisely is meant by speaking of pH in such a situation. In the present context therefore it seems best to regard pH measurement as a convenient means of obtaining a rough indication of soil properties, no attempt being made to interpret small differences observed in the laboratory in terms of field properties.

Organic Matter Content

The organic matter content is calculated from the determined percentage of organic carbon, by multiplying this figure by 1.724. This method, dating back to Wolff (1864), assumes that carbon forms a reasonably constant 58 per cent of the total organic matter. In Walkley and Black's method (referred to in Piper, 1942) which was used for the determination of the carbon, carbonates and elemental carbon (two sources of error in other methods) have little effect on the result. In calcareous soils like those of the Maltese Islands, where high carbonate contents are common, fragments of elemental carbon are frequently found, and the total organic carbon is relatively low, it is essential that these sources of error should be eliminated. It is still erroneous, however, to regard the ratio of carbon

to total organic matter as a constant - the formulae of the different organic compounds in the soil and their different mutual proportions in various soil climates demonstrate this. However, it represents a convenient estimate, provided comparisons between very dissimilar soils are not attempted. The relative figures are reasonably accurate, and it seems, therefore, that the method is likely to have given as good an estimate as is available at present.

The determinations indicate that in the Maltese Islands, the surface layers of the soils under cultivation have organic matter contents of about 1 - 3 per cent in the case of carbonate raw soils and xerorendzinas and over 3 per cent in Terra soils.

Unworked soils of each type are inclined to be better endowed with organic matter, although this is based on observation rather than analysis since analyses of several unworked soils are only available for the Xaghra series (Terra soils) which show an average of over 4.5 per cent. One Tal Barrani soil in unworked state has an organic matter content of 6 per cent in the surface horizon; soils such as small patches of proto-rendzina which are of limited extent and unworkable have organic matter contents over 10 per cent, but the general level is the low 1 to 3 per cent of cultivated soils.

Below the surface horizon the decrease of organic matter down the profile is not very rapid. In general it appears to be fairly well disseminated, with 50 to 60 per cent of the surface value at 12". In rare cases surface soils of the Armier series show an increase of organic matter in the heavier subsoil which may possibly be because the sand has blown onto an old A horizon. For all soils at 12 inches the range of values becomes narrower between about 1 and 2 per cent, and even below 3 feet in the few soils for which analyses are available, the value is not much less than 1 per cent.

Those few soils in which irrigation water is applied saturated with organic manures give results well above the average for their soil type (Malta D, Tal Barrani, 6 per cent in top 7 inches).

Microscopic examination of the soils reveals a wealth of soil faunal activity in some of the soils despite the deficiency in humus. Whereas humus colouration is not evident below the surface inch, evidence of a fairly high level of faunal activity is found to below 3 feet. For example in the San Biagio Series, whitish, light brown, or light greyish soils with apparently little activity on examination with the naked eye, show peds composed of a largely coprogenic, spongy fabric. It is thought, therefore, that despite the deficiency of humus, some of the soils have a high rate of turnover of carbon dioxide and nitrogen, which will show seasonal variability. This may be significant in two respects (1) that there is actually more nitrogen available to plants during the growing season than there might appear to be, (2) that since not all soils were sampled at the same time the figures for carbon especially are not necessarily comparable between soils.

The C:N ratio

This ratio is widely variable, for some (strawy) plant residues 90:1 for farm-yard manures 30:1, as little as 4:1 for the bodies of some micro-organisms. Organic residues may consist of any combination of a number of organic compounds, (sugars, starches, proteins, hemicelluloses, celluloses, lignin, fats and waxes etc.) some without nitrogen but most with differing C:N ratios. The breakdown of these organic residues by micro-organisms causes displacement of carbon and its liberation as CO₂, lowering the C:N ratio. This occurs during that part of the year when micro-organisms are active. The process may be halted during the dry summer. The nitrate form of nitrogen (normally resultant from microbial

activity) is subject to leaching, which is probably a factor to be considered during the winter in Malta. On the other hand, nitrogen in the form of ammonium may be subject to loss by escape into the air from a calcareous soil.

In soils under the Maltese climate a high annual average of microbiological activity is to be expected, since it is positively related to temperature. This would indicate on average a rather lower mean C : N ratio than in cooler climates. In the Maltese soil samples the value was generally between 8 and 10.5 : 1, with a few exceptionally low figures below 7 : 1 which did not, however, appear to be related to the time of sampling. This accords quite well with the expected figures. No difference was observed in the figures for cultivated and uncultivated soils.

Ratios for similar climatic conditions in Australia (Stace 1956) show values of 7 : 1 to 14 : 1, averaging 11.9 : 1 for "terra rossa" (in the sense of Comel's classification).

Phosphorus as P_2O_5 , total and available

The determined values for total phosphorus indicated that the Maltese soils with from 0.05 to 1.22 per cent, averaging 0.27 per cent, are quite well endowed with phosphorus-containing minerals. Terra rossa soils from Italy had, according to Martinis (Comel 1951), an average of about 0.09 per cent and from Sicily about 0.06 per cent according to Averna (1953). Palestinean analyses (Reifenberg 1938), showed similar values. Even neglecting the three high values (0.90, 0.92 and 1.22 per cent) which are dependent on special conditions, the average remains high (0.2 per cent). It is rather higher in the San Biagio series, in the parent material of which phosphate nodules are found, at about 0.33 per cent which does not include any outstanding figures. The figures so far mentioned refer to the surface horizon only, but there is little change down the profile, most of the series merely showing a gradual decrease of the P_2O_5 content. On the other hand, the San Biagio series, the Tal Barrani series and the glauconite-rich members of the Nadur series and Fiddien light clays generally show increases down the profile. The two parent materials apparently responsible are the glauconitic facies of the Greensand bed, and the Middle and Upper beds of the Globigerina limestone. In Murray's (1890) account of the geology he mentions phosphoric acid as being almost always present and abundant in some nodules within the Greensand. The Globigerina limestone is mentioned as showing up to 3 or 4 per cent $Ca_3(PO_4)_2$ and occasionally over 30 per cent in the nodules that outcrop in occasional bands in the upper strata. A sample taken from a carbonate raw soil at a lynchett formed by a nodule bed, near profile Malta Q, had a phosphate content of about 0.63 per cent, while about 25 yards downslope at Malta Q it was 0.44 per cent and about 100 yards further away in an alluvial phase (Malta A), the content was 0.25 per cent. It seems likely that the content of P_2O_5 of the San Biagio series depends on proximity to the frequent nodule bands, but since the P_2O_5 content of the unweathered ordinary rock is also high this may not be of any importance. It is unlikely to be of economic importance because of the far wider range (unrelated to parent material or total P_2O_5), of the phosphate soluble in acetic acid. This readily soluble P_2O_5 , neglecting one exceptional value, varies from 2 to over 100 p.p.m. Neglecting the few Greensand-derived soils, only the Tal Barrani series appears to have a consistently (comparatively) high value for this determination. If the acetic test is a good guide it seems that there are numerous places in Malta where phosphorus is deficient although it may be present in large quantities according to the total analysis. The test, however, is of doubtful value. The value usually declines rapidly down the profile indicating that most of the readily available phosphorus is probably in organic compounds in the humus layers.

It is noteworthy that the exceptional soil which is not included in the above discussion is a member of the Tal Barrani series (profile Malta D), is unusual because it is heavily irrigated and farm-yard manure is steeped in the water used. With 0.92 per cent total P_2O_5 and 31.2 p.p.m. readily available P_2O_5 there seems little doubt of the adequacy of the supply.

Available phosphorus was determined colorimetrically using 0.5 N-acetic acid as an extractant.

The exchangeable cations

The amount of the exchangeable cations provides a useful indication of the quantity of nutrients available to plants from the soil, and the relative amounts of various bases sometimes indicate toxic or inhibiting conditions as well. The clay minerals or the clay-humus complex are chiefly responsible for variations in the value of these measurements because of their size and molecular structure. In determining the quantity of exchangeable cations present a neutral, N-ammonium acetate extractant was used and the quantities of cations were determined spectrographically. The ammonium ions are presumed to substitute for all exchangeable cations in the soil sample, which can then be estimated in the leachate. The calcium ion is generally overestimated by this method, in a calcareous soil.

No attempt was made to determine exchangeable hydrogen-ion content since it was presumed that a calcareous soil with pH over 8, would be saturated with bases, and no hydrogen-ions would be present. However, Durand (1954) quotes analyses of incompletely decalcified soils with a pH of 7 to 8 on calcareous rocks in Algeria for which hydrogen-ion content of 10 per cent of the exchangeable bases is shown. It is possible that the Terra soils which are thought to have been decalcified, and to contain now mainly blown-in particles of limestone would also prove to be incompletely saturated with bases.

The determinations made in the Maltese soils revealed the following pattern among the carbonate raw soils and xerorendzinas. The Terra soils are discussed separately.

Table 16: Exchangeable cations in the calcareous soils

	Exchangeable cations per cent				Total exchangeable bases m. e./100gms
	Ca	Mg	Na	K	
Range	72-95	4-18	0.6-4.4	0.9-5.6	11-43
Mode	88	8	1.5	2.5	25

A few exceptions to the general rule have been omitted, they are samples of parent material and slightly saline soils which are mentioned elsewhere. One or two profiles which are not notably alkaline but have low calcium:magnesium ratios and high sodium contents, have also been omitted. Excepting these, the pattern is in general rather constant, there is no well marked trend of change with horizon depth in the profile, and where there are such changes they tend to be contradicted within the same series by another profile. It is perhaps true to say that any differentiation is likely to be due to geological layers rather than horizon differentiation, it is certainly true for some Alcol profiles.

If any pattern is to be discovered it is a slight tendency for magnesium to increase down the profile at the expense of calcium, but the effect is not important and not constant. It seems this may possibly be a result of slight leaching, where calcium is more strongly absorbed than magnesium but the total exchangeable bases show no corresponding increase with depth so that the leaching may well be more apparent rather than real.

Calcium carbonate and active calcium carbonate

The calcium carbonate content of a few soils was estimated by determining the carbon dioxide evolved when the soil is treated with acid (Piper, 1942) and then re-calculating it as calcium carbonate, from which it was presumed to have evolved. Some carbon dioxide may have been evolved from organic matter, but the amounts would be unimportant compared with the total in highly calcareous soils. Magnesium carbonate in the soil, if there is any, will have been reported as calcium carbonate, and thus the method is rather inaccurate, but sufficiently good for the purpose of giving an impression of whether the soil is very or slightly calcareous.

The estimations showed 2 to 15 per cent calcium carbonate in Terra soils, and up to 90 per cent in carbonate raw soils. Yaalon (1954) wisely remarks that there is increasing evidence that the surface properties of calcium carbonate are of great biological and pedological significance in calcareous soils. It was observed for example in the south of France that chlorosis in vines seemed to be associated with the amount of finely divided calcium carbonate in soil. According to Drouineau (1942) the fine fraction, consisting of particles less than 20μ in diameter, is chiefly responsible for inducing chloroses. He accordingly put forward his method of estimating this fraction which he designated "active" calcium carbonate.

The method involves shaking the sample with N/5 ammonium oxalate for two hours (time is an important variable in this determination) filtering the resultant liquid and titrating it against potassium permanganate.

In French publications the results are usually quoted as parts per thousand active CaCO_3 , but have been given in percentages throughout this account.

Drouineau mentions that, at values of 7 per cent active calcium carbonate, asparagus exhibits chlorosis, at 9 per cent peach trees begin to be affected, and above 10 per cent all pears, peaches and plums regularly show chlorosis.

For the soils of Malta and Gozo the figures were below 10 per cent only in the Terra soils and sandy carbonate raw soils, yet chloroses were not widespread, perhaps because the plants grown are more resistant to iron deficiency than those mentioned above. However, chloroses were observed most often on the xerorendzina soils which have the highest values for active CaCO_3 , and it is possible that a value nearer 15 per cent than 10 affects citrus trees for example. It seems possible that this method could be very useful in Malta after correlation with plant performance.

Water Soluble Salts

Conductivity determination

Electrical conductivity was determined following the method described by Piper (1942) using a 1 : 5 soil suspension. Figures obtained by this convenient method are not readily comparable with those for electrical conductivity of the "saturation extract" as measured in the U.S. Regional Salinity Laboratory. Very roughly conductivity of 1:5 suspension if multiplied by 10 will correspond to the conductivity of the saturation extract in the case of soils of medium texture. However it is not necessary to consider this matter closely since in most soils of Malta the salt content of the soil is not high enough to damage plants.

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APPENDIX I

PROFILE DESCRIPTIONS

A. CARBONATE RAW SOILS

RAMLA SERIES mapped in the Armier Complex (terraced) Profile Malta Y. Grid ref. 420827, L'Ahrax ta Geooa, near Marfa. *Topography.* 25 ft. above sea level on the remnant of the Quarternary dunes and bed overlying karstic lapiés (landscape element 1a), which emerge locally and especially higher up the slope. The field is terraced, with a one foot high quarried back-wall, and slopes 4° S.W., counter to the general gentle northerly slope.

Profile description

	inches	
S ₁	0 - 15	Light reddish brown (5 YR 6/4) sand; dry; very weak fine subangular blocky; abundant very fine roots, low organic matter, raw soil humus; a few stones; calcareous; fairly sharp boundary to
S ₂	15 - 18	Light reddish brown (5 YR 6/4) sand; dry; moderate subangular blocky; abundant fine roots; many pores; low organic matter, but apparently no less than in the surface horizon; calcareous; (possibly a buried (A) horizon), sharp boundary to
C ₁	18 - 30 plus	Yellow red (5 YR 5/6) sand; dry; very weak subangular blocky; many fine roots becoming fewer towards 30 in., low organic matter; more stones than in horizons above; calcareous; increasing quantities of shelly sand down the horizon which becomes more compact and is obviously transitional to the consolidated dunes and bed.

NADUR SERIES Profile Gozo P. (345911). Wied tal Pergla near Xaghra. *Topography.* Steep sided valley about 275 ft. above sea level in the softer limestones below the karst mesa surface (landscape element 1a) which it dissects. A very strongly terraced small field with backwall cut into the soft rock sloping 1° E.N.E., with the soil piled in ridges across the line of slope.

Profile description

	inches	
S ₁	0 - 11	Yellow red (5 YR 5/6) gravelly gritty loamy sand; dry; very weak medium granular; many fine roots; low organic matter; calcareous, merging to
S ₂	11 - 24	Reddish brown gravelly gritty sandy loam; slightly moist; moderate medium granular; a few roots; calcareous; merging to
C ₁	24 - 34	Similar material mixed with large lumps of rotting, soft, incoherent yellow, sandy limestone.
C ₂	34	Yellow sandy limestone.

FIDDIEN SERIES (light type). Profile Malta H. Grid ref. 438718, Fiddien-is-Sentini, near Rabat. *Topography.* About 470 ft. above sea level on the flat Blue Clay bottomlands of the broad central valley of the Rabat-Dingli

plateau (landscape element 2b). The field which is not terraced slopes gently southwards. *Land Use.* Vines.

Profile description

		inches	
S	0 - 12		Olive (5 Y 5/3) silty clay; moist after recent rain; moderate fine to large crumb; abundant roots; some insect activity; low organic matter; raw soil humus; some gravel; calcareous; abrupt change to
C ₁	12 - 25		Olive (5 Y 5/3) clay; dry; apparently massive but breaking easily between the fingers to moderate medium subangular blocky; few roots, very low organic matter; a few stones; compact, plastic, sticky; calcareous; merging to
C ₂	25 plus		Olive (5 Y 5/3) clay; moist; similar to the horizon above but tendency to prismatic structure, and some accumulation of washed down particles between peds; calcareous; a sample from 53 in. with the auger, was similar but rather brighter in colour.

FIDDIEN SERIES (light clay type). Profile Gozo C. (382896). Wied ta Dahliet Qorrot, near Nadur. *Topography.* About 225 ft. above sea level on minor scarp (landscape element 4b) at the side of a small valley breaking through the Nadur karst mesa. The field is strongly terraced, and slopes 4° on a general valley side slope of 15° S.E. *Land Use.* Sulla crop.

Profile description

		inches	
S	0 - 10		Light olive brown (2.5 Y 5/3) gritty light clay; slightly moist; moderate medium subangular blocky; a few roots, low organic matter; slightly stony especially at the surface; plastic; moderately sticky; calcareous; sharp boundary to
C	10 plus		Light yellowish brown (2.5 Y 6/3) slightly gritty light clay; massive, with a tendency to coarse prismatic structure; a few roots, very numerous fine pores, very low organic matter; a few stones; plastic, moderately sticky; calcareous, interflorescences and veins of secondary calcium carbonate, moderate in quantity above 16 in., but very abundant below.

FIDDIEN SERIES (light clay type). Profile Gozo I. (293922). Ta Kancila, near Giordan. *Topography.* 275 ft. above sea level, just above a col between Ta Kancila hill and Giordan, at the foot of an abbreviated scarp (landscape element 4b), where Greensand alluvium overlies Blue Clay. The field is strongly terraced and slopes 3° E.S.E. in a general slope of 15° to 20°. *Land Use.* Fallow after barley.

Profile description

		inches	
S	0 - 10		Light olive brown (2.5 Y 5/3) sandy clay loam; moderate fine prismatic structure, breaking to granular easily; abundant fine roots, numerous bulbs, numerous fine and large pores; low organic matter; hard, plastic, sticky, (soapy feeling); calcareous; accumulation of clay along pores.
C	10 plus		Light olive brown (2.5 Y 5/3) sandy clay; coarse prisms; fewer roots, some bulbs, very low organic matter; abundant gravel; hard, plastic, sticky,

calcareous, abundant secondary calcium carbonate in root channels especially.

SAN LAWRENZ SERIES. Profile Malta R. Grid ref. 473689. Near Ta Bria, above San Biagio Church. *Topography.* 510 ft. above sea level on the (here) gently sloping main scarp (landscape element 4a) just above a break in slope to a steeper gradient on the Globigerina limestone. The field is slightly terraced and slopes 1° E, in a general slope of 5°. *Land Use.* Fallow after garlic; much convolvulus.

Profile description

	inches	
S	0 - 9	Light olive brown (2.5 Y 5/3) light clay; weak medium subangular blocky with some fine granules; a few very large roots, some ants observed, many large pores, very low organic matter, raw soil humus; some stones; very plastic, very sticky; calcareous, a little secondary calcium carbonate.
C	9 plus	Light olive brown (2.5 Y 5/3) light clay; very little change from the horizon above, more secondary calcium carbonate below 36 in. but more compact than the horizon above, and with a very weak large prismatic structure.

B. XERORENDZINA SOILS

SAN BIAGIO SERIES. Profile Malta F. Grid ref. 437737, Bingerma slopes above Bingerma village. *Topography.* About 450 ft. above sea level, a small cliff on the edge of a stream-originated valley in the soft Globigerina limestone at the foot of a main scarp (landscape element 4a). A strongly terraced field sloping 5° N. *Land Use.* Abandoned, growing some poor grass.

Profile description

	inches	
I	0 - 8	Light brownish grey (10 YR 6/2) silt loam; moderate medium granular structure; many fine roots, many worm and insect borings; low organic matter, mull-like rendzina moder; a few marl stones; slightly plastic, non-sticky; calcareous, secondary calcium carbonate.
II	8 - 27	Light yellowish brown (10 YR 6/4) silt loam; moderate fine angular blocky; very low organic matter; very few stones; calcareous, secondary calcium carbonate.
III	27 - 36	Brown (10 YR 5/3) silty clay loam; discontinuous horizon of variable thickness; many fine pores, very low organic matter; clay accumulations on structure faces; calcareous, secondary calcium carbonate.
IV	36	Brown (10 YR 5/3) silty clay loam; solid Globigerina soft limestone.

SAN BIAGIO SERIES. Profile Gozo B. (280918).

Profile description

	inches	
I	0 - 1½	Very pale brown (2.5 Y 7/3) fine sandy loam; hard crust, simulating that of a lime-crust yerma, massive with slight tendency to lamination, but broken into polygonal lumps with flat upper and lower surfaces; low organic

- matter, humus-deficient mull-like rendzina moder; few roots; calcareous; merging to
- II 1½ - 4 Light yellowish brown (2.5 Y 6/4) fine sandy loam; very weak subangular blocky; few roots, low organic matter, some pores, some produced by worms; compact; calcareous; merging to
- III 4 - 8 Light yellowish brown (2.5 Y 6/4) fine sandy loam; very similar to the horizon above but friable; fairly sharp boundary to
- IV 8 - 30 Light yellowish brown (2.5 Y 6/4) fine sandy loam; very weak subangular blocky; very few roots, very low organic matter; compact; calcareous; merging to
- V 30 - 44 Light yellowish brown (2.5 Y 6/4) heavier fine sandy loam, otherwise similar.
- VI 44 - 50 Pale yellow (2.5 Y 7/4) fine sandy loam with cobbles of decaying Globigerina limestone.

SAN BIAGIO SERIES. Profile Gozo F. (283885). Ta Klula, Ta Ben Gorg, S.W. Gozo. *Topography*. 510 ft. above sea level near the top of the dissected Globigerina plateau (landscape element 2a), a flat hill top. The field is open, virtually unterraced and slopes gently south (1°). *Land Use*. Sulla crop.

Profile description

inches

- I 0 - 8 Brown (10 YR 5/3) fine sandy loam; weak medium to coarse crumb breaking to fine crumb, with a smooth very dry, fairly hard ¼ in. thick 'baked' layer at the surface, forming a crust on which blown soil fragments can be observed, plus stones; numerous large (2-4 mm) pores, many roots, low organic matter, humus-deficient, mull-like rendzina moder; friable to very friable, slightly plastic, sticky; calcareous; merging to
- II 8 - 18 Brown (10 YR 5/3) fine sandy loam; moderate medium subangular blocky breaking to weak fine granules; many roots, many pores, very low organic matter; slightly plastic, sticky, compact becoming very compact lower in the horizon; calcareous, some interflorescences of secondary calcium carbonate; merging to
- III 18 - 27 Brown (10 YR 5/3) gravelly fine sandy loam, very similar to the horizon above but with many angular cobbles of broken limestone, and a large increase in the amount of secondary calcium carbonate.

27 Soft, off-white Globigerina rock.

ALCOL SERIES. Profile Malta G. Grid ref. 434744. Il Wilgja ta Bingemma, near Bingemma village. *Topography*. 350 ft. above sea level, on the edge of the second break in slope (above Bingemma valley) of an outwash fan from a small valley (landscape element 3). A large field, slightly terraced, sloping 2° N. *Land Use*. Fallow after sulla.

Profile description

inches

- I 0 - 28 Light yellowish brown (10 YR 6/4) silty clay loam; weak fine subangular blocky, some medium crumbs; roots abundant to about 18 in., frequent below; many ½ mm. pores, low organic matter; compact below 20 in.;

calcareous, efflorescences of
recrystallised below 12 in. resemble tiny geodes; line
of boulders forms boundary to

- II 28 - 50 Light yellowish brown (10 YR 6/4) silty clay loam;
similar to the above but very full of boulders, few
roots, sharp boundary to
- III 50 plus Strong brown (7.5 YR 5/6) silty clay loam; moderate
fine to very fine angular blocky; calcareous.

ALCOL SERIES. Profile Malta N. Grid ref. 435749. El Wita ta Sebbieh,
Bingemma. *Topography*. 275 ft. above sea level in the middle of the flat
bottomland of the Bingemma valley in which there is a stratified alluvial-
colluvial deposit. The field is flat and unterraced. *Land Use*. Potatoes.

Profile description

- inches
- I 0 - 14 Dark yellowish brown (10 YR 4/4) silty clay loam; dry;
weak coarse angular blocky, composite peds breaking to
moderate medium crumb; abundant fine roots, low organic
matter (some mummified); plastic, non-sticky, friable;
calcareous; efflorescences of secondary calcium
carbonate between peds;
- II 14 - 28 Yellowish brown (10 YR 5/6) silt loam; dry; moderate
fine angular blocky; fewer roots than above, very low
organic matter; slightly plastic, non-sticky;
calcareous, efflorescences of secondary calcium
carbonate; merging to
- III 28 - 36 Dark brown (7.5 YR 4/5) silty clay loam; moderate fine
angular blocky; very low organic matter; plastic,
non-sticky; calcareous, no secondary calcium carbonate;
merging to
- IV 36 plus Yellowish red (5 YR 4/8) silty clay loam; moderate fine
angular blocky; similar to the horizon above.

Note - This profile illustrates stratification of the parent material with
a rendzina-like deposit on a largely 'Terra' soil material below
3 ft.

ALCOL SERIES (sandy type). Profile Malta X. Grid ref. 413811.
Il Ghadira, Blue Lagoon, near Mellieha. *Topography*. About 3 ft. above sea
level and 100 yards from the sea at the end of a deep alluvial-colluvial
infill of a partly structural valley (landscape element 3) between two
karstic ridges, and about 10 yards away from a shingle dune or storm beach.
The field is flat and unterraced. *Land Use*. Fallow after oats.

Profile description

- inches
- I 0 - 30 Yellowish brown (10 YR and 2.5 Y, 6/5) sand and loamy
sand; dry to 15 in., then moist; very weak medium
subangular blocky, with a thin surface crust; few
roots, many pores, numerous dung beetles and ants, very
low organic matter, raw soil humus; numerous gastropod
shells and a few stones; calcareous; abrupt boundary
to
- II 30 - 31 Olive yellow (2.5 Y 6/6) sandy clay loam; massive;
very few roots, very low organic matter; calcareous;
abrupt boundary to

III 31 plus

Pale yellow (2.5 Y 7/4) sand with occasional thin clay strata, more or less permanently waterlogged, massive; calcareous.

TAL BARRANI SERIES. Profile Malta A. Grid ref. 506704. Tal Kuncizjoni, near Qormi. Topography. 220 ft. above sea level in a small north-facing valley on the edge of the broad E-W valley in the soft Globigerina limestone (landscape element 2a). The field is strongly terraced with a 7-foot high quarried sidewall and slopes 1° N. Land Use. Abandoned land but carobs cover most of the land and the canopy gives a 50% cover.

Profile description

- | | inches | |
|-----------------|-----------------------|--|
| L | $\frac{1}{2}$ - 0 | Dead leaves of grass, ground elder, broom rape and other herbs and leaves and twigs of carobs. |
| H _I | 0 - 1 | Variable thickness ($\frac{1}{4}$ - 1 inch); loose dark brown cylindrical to spherical mineral-rich excreta about 0.25 mm. maximum diameter, humus form, mull-like rendzina moder; calcareous; uneven sharp boundary to |
| H _{II} | 1 - 2 | Pale brown roughly spherical mineral-rich excreta average diameter 5 mm. with concentric conical imprints of the end segments of worms, elsewhere less definite excreta forms, but extremely porous crumb structure; calcareous; |
| A ₁ | 2 - 3 | Alternating thin laminae of pale brown (10 YR 6/3) fine sandy loam and reddish brown (ferruginous) fine sandy loam ending in a half-inch reddish layer; weak medium crumb independent of colour laminae; calcareous; sharp boundary to |
| A ₂ | 3 - 13 | Pale brown (10 YR 6/3) silt loam; weak medium crumb breaking to single grain; numerous large pores many containing excreta, low organic matter; no stones; calcareous; |
| (B) | 13 - 13 $\frac{1}{2}$ | Brown (7.5 YR 5/4) silt loam; calcareous; sharply on |
| C | 13 $\frac{1}{2}$ | Quarried surface of soft Globigerina limestone. |

TAL BARRANI SERIES. Profile Malta D. Grid ref. 527706. Tal Biedi, off Strada Victoria, Qormi. Topography. About 60 ft. above sea level, within the confines of the town, an extremely disturbed location, probably largely carted material; a flat field within high terrace walls. Land Use. Cabbages, irrigated with the equivalent of 40 in. water per year, in which farmyard manure sludge is dissolved.

Profile description

inches

- | | | |
|-----|---------|--|
| I | 0 - 10 | Dark grey brown (10 YR 4/2) silt loam; moderate, fine to medium granular; numerous fine roots, numerous worms, numerous fine pores, few insects, high organic matter, mull; slightly plastic, slightly sticky; calcareous; sharp boundary to |
| II | 10 - 20 | Dark brown (7.5 YR 4/2) clay loam; weak fine to medium granular; numerous fine roots and worms, moderate organic matter; plastic, slightly sticky; calcareous. |
| III | 20 - 54 | Brown (7.5 YR 4/3) clay loam; structure becoming nearly massive at the base, becomes stony at 40 in.; otherwise very similar to horizon above; calcareous. |
| IV | 54 | Globigerina limestone. |

TAL BARRANI SERIES. Profile Malta W. Grid ref. 537746. Tal Minsija above Wied Balluta. *Topography.* About 230 ft. above sea level on a Globigerina soft limestone hill top (landscape element 2a), at the end of an east-pointing ridge, extending from the karstic Naxxar-Gharghur hill-mass. The field is very much disturbed, with, probably, a considerable quantity of carted soil in it, slightly terraced and almost flat. *Land Use.* Fallow after cereals.

Profile description

		inches	
I	0 - 12		Brown (7.5 YR 4/4) gravelly sandy loam; weak subangular blocky, becoming crumb near the surface, below a surface layer of large hard dry clods, with loose single grain soil; numerous very fine roots, low organic matter; much inorganic town refuse; stony, some large (cobble size) stones; friable; calcareous; sharply on
II	12		Soft, calcreted Globigerina limestone showing evidence of flattening.

C. TERRA SCILS

XAGHRA SERIES. Mapped in L'Inglin Complex. Profile Malta U. Grid ref. 602689. Wied il Ghajn (Marsascalea). *Topography.* About 50 ft. above sea level on a fairly steep slope to the sea in a karst landscape which has been strongly terraced and much altered by man (landscape element 1c). The field is only slightly terraced and slopes 3° E. *Land Use.* Fallow after oats.

Profile description

		inches	
S	0 - 8		Dark red (5 YR 3/6) silty clay; dry; moderate fine crumb becoming subangular blocky at base; numerous pores, abundant fine roots, a few animals, moderate organic matter, mull-like rendzina moder, (very well illustrated in an undisturbed area beneath a carob tree where litter overlay a half inch layer of loose insect excreta, above a mineral-rich worm-worked horizon); some stones; loose, plastic, slightly sticky; moderately calcareous; merging to
(B)	8 - 27		Dark red (5 YR 3/6) clay; dry; subangular blocky, with enclaves of crumb structure, worm casts; some pores, numerous roots and bulbs, low organic matter, generally similar to the surface horizon; slightly calcareous; sharp boundary
C	27		Crystalline limestone lapiés, partly man-worked.

XAGHRA SERIES. Profile Malta Z. Grid ref. 416820. L'Ahrax, near Marfa. *Topography.* About 180 ft. above sea level a soil puddle between karst lapiés near the ridge top of Marfa ridge (landscape element 1a). The land is unterraced and unused and the soil surface is flat, although the general slope of the ridge is gentle northerly. *Vegetation.* Xerophytic plants and grasses.

Profile description

		inches	
A(B)	0 - 6		Reddish yellow (5 YR 6/5) clay; dry; moderate to strong medium crumb; abundant fine roots, low organic matter, without noticeable concentration at the surface; many stones; very slightly calcareous; merging to

(B)_I 6 - 15 Red (2.5 YR 4/6) clay; dry; strong fine angular blocky; roots abundant, numerous 2 mm. diam. pores, low organic matter; slightly sticky and plastic, compact, but friable when dug; very slightly calcareous; merging to

(B)_{II} 15 - 30 Red (10 YR 4/4) clay; dry; strong fine angular blocky; very low organic matter, very few roots; very compact very difficult to dig, but friable when dug, and plastic and slightly sticky; very slightly calcareous; sharp boundary to

C 30 Calcreted Upper Coralline Limestone lapiés.

Note: Genetic type - terra rossa (an extreme form of the Xaghra series, which is usually earthy terra fusca). The variety has not been determined but the characteristics of the profile appear to be transitional between the siallitic and allitic forms.

XAGHRA SERIES. Profile Gozo E. (328867): Reservoir near Sannat, southern Gozo. Topography. Globigerina limestone karst upland (landscape element 1a), about 430 ft. above sea level, and sloping 2 1/2° S.E.; unterraced. Vegetation. Grasses and xerophytic plants - squills etc., but no aromatic plants - e.g. thyme.

Profile description

inches

(B)_I 0 - 4 Reddish brown (5 YR 4/4) gritty clay; moderate medium crumb; nearby anthills, many large pores, numerous roots, some bulbs, very low organic matter; plastic, slightly sticky, friable; slightly calcareous; sharp undulating boundary

(B)_{II} 4 - 8 Reddish brown (5 YR 4/5) clay; moderate medium crumb; fewer pores, a few fine roots, very low organic matter; plastic, slightly sticky; very slightly calcareous; merging to

(B)_{III} 8 - 14 (but depth of this horizon varies between 2 and 10 in.) Reddish brown (5 YR 4/5) clay; moderate fine angular blocky; very low organic matter, few roots; plastic, slightly sticky, very compact; sharply

C 14 (but at variable depth, and rising above the surface in a few ridges) Globigerina limestone lapiés.

XAGHRA SERIES. Profile Gozo G. (326876). Wied Hanzira, near Xewkija. Topography. About 320 ft. above sea level on a small fragment of weakly karstic landscape (landscape element 1b). The field has occasional lapiés (insufficient to prevent cropping) and slopes 5° W.S.W. with slight terraces catching the downhill soil-wash. Land Use. Fallow after sulla.

Profile description

inches

S 0 - 9 Brown (7.5 YR 4/4) clay loam; weak fine prismatic structure breaking to fine granular; numerous 1 - 4 mm. diam. pores, moderate organic matter content; some stones; slightly plastic, slightly sticky, 'earthy' material; slightly calcareous.

(B) 9 - 36 Reddish brown (2.5 YR 4/4) clay; moderate medium to coarse prismatic structure; numerous 1 - 4 mm. pores in upper part of horizon, numerous roots and bulbs to 24 in.; low organic matter; plastic, slightly sticky; very slightly calcareous.

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(B)Ca 36 - 48 Reddish brown (2.5 YR 4/4) clay; very similar to the horizon above, but with increasing amounts of secondary calcium carbonate on peds and in root channels from 36 in. downwards, and some fragments of rotting limestone.

C 48 Globigerina limestone.

Remarks: (1) Humus form - mull-like moder.
(2) Genetic type - earthy terra fusca.

XAGHRA SERIES. Profile Gozo K. (347870). Ix-Xini, near Ghajnsielem, eastern Gozo. *Topography.* 250 ft. above sea level, flat karstic summit (landscape element 1a) of a main (coastal) scarp, exhibiting 'old' sharp lapiés with soil puddles between. *Land Use.* Unused, xerophytic vegetation; thyme, thistles, bulbous plants and some grasses.

Profile description

inches

A 0 - 1 Dark reddish-brown (2.5 YR 3/3) clay; dry; moderate fine angular blocky structure; no evidence of animal activity, but a few small gastropod shells, many fine roots and some large roots, some gravel; very hard; low organic matter; slightly calcareous; merging to

(B) 1 - 9 Dusky red (10 R 3/4) clay; dry; moderate fine angular blocky; numerous fine roots; no stones; hard to very hard; very slightly calcareous, no noticeable secondary calcium carbonate;

C 9 Upper Coralline Limestone calcreted lapiés.

XAGHRA SERIES. Profile Gozo L. (344872). Ix-Xini, near Xewkija. *Topography.* 250 ft. above sea level, karstic summit (landscape element 1a) sloping 2° S.W., overlooking broad valley. *Land Use.* Unused, xerophytic vegetation, dry grasses, and lichens on the surface. Nearby slightly terraced lands with carted soil on them are being planted in firs.

Profile description

inches

A(B) 0 - 9 Reddish brown (5 YR 4/3) silty clay loam; slightly moist; weak medium subangular blocky, breaking to fine crumb, largely strung on fine roots which are dense in upper 2 in.; numerous bulbs at 1½ in.; many fine pores, some aestivating snails; much small gravel; plastic, non-sticky; low organic matter; slightly calcareous, no secondary calcium carbonate observed.

C/D 9 Globigerina limestone lapiés.

TAS SIGRA SERIES (with saline ground water). Profile Malta T. Grid ref. 605689. Wied il Ghajn (Marsascala). *Topography.* About 5 ft. above sea level at the seaward end of a valley in the karst landscape filled with a deep alluvial-colluvial deposit (landscape element 3). The field is flat and unterraced. *Land Use.* Fallow after potatoes.

Profile description

inches

I 0 - 20 Reddish brown (5 YR 3/6) clay loam; dry; top 3 in. moderate fine and large crumbs, becoming weak subangular blocky below; a few fine roots, many small fragments mummified dung; mull-like rendzina moder; a few pores associated with roots, some cocoons of clay containing small grubs, moderate organic matter; plastic, slightly sticky; some stones; numerous very small gastropod

shells; slightly calcareous, some secondary calcium carbonate, merging to

- II 20 - 32 Yellowish red (5 YR 4/6) clay; massive, tendency to angular blocky; a few roots, low organic matter; slightly calcareous, some secondary calcium carbonate and a few grains of common salt; sharp boundary to
- III 32 - 36 Reddish yellow (7.5 YR 6/6) loamy sand; wet; structureless; probably level of the permanent water-table.
- IV 36 plus Blue grey sandy clay on clay, with pockets of red clay, and all diversified by pores, root holes and pockets of preserved monocotyledonous plant tissues (thought to date to a Pluvial period).

CARTED SOIL. Profile Gozo Q. (341878). Ta San Bartilmow, near Xewkija. *Topography.* 320 ft. above sea level on the gentle upper slopes of a valley side on soft Globigerina limestone (landscape element 2a) faulted in below Lower Globigerina limestone. An unterraced, large field sloping 2° S. with bare Globigerina limestone exposed to the south side. The soil appears to be carted Fiddien clay overlying a thin Terra-like development above the limestone, but both materials (and limestone fragments) are mixed together.

Profile description

inches

- I 0 - 12 Dark yellowish brown (10 YR 4/4) clay; moderate fine subangular blocky; numerous worm casts towards base of horizon, many fine pores; low organic matter; calcareous; some fragments of clay of the colour of the horizon below, not intimately mixed with this material; sharp undulating boundary
- II 12 - 20 Dark brown (7.5 YR 4/3) clay; moderate fine angular blocky and platy; many fine roots, some fine pores, some worm casts; very low organic matter; calcareous, merging to
- III 20 - 24 Soft yellow Globigerina limestone mixed with material of the horizon above; transition horizon merging to
- 24 Soft yellow Globigerina rock.

ANTHROPOGENIC SOIL. Grid ref. 545703. Near Jew's Cemetery at Marsa. *Topography.* About 10 ft. above sea level near the coast (220 yds. away) at the centre of the alluvial-colluvial valley infill of Marsa (landscape element 3). Most of the bottomland nearest the coast appears to have been artificially built up with rubble and soil material. The land is virtually flat, and is abandoned at present, but nearby fields of the same type are growing cereals.

Profile description

inches

- 0 - 16 Light olive brown (2.5 Y 5/3) fine sandy loam; moderate medium angular blocky; porous, low organic matter; burnt layer at 14 in.; (a Globigerina carbonate raw soil material, very highly calcareous); sharply on
- 16 - 21 Brown (7.5 YR 4/4) gritty clay loam; a structureless material of variable depth, not present everywhere.
- 21 - 72 Very coarse Franka rubble overlain by a gravel layer all stratified in a slope of about 45°, as if tipped from a lorry.

APPENDIX II

Table I	Summary of analyses of normal soils
Table II	General chemical analyses
Table III	Exchangeable bases (* denotes high exchangeable sodium)
Table IV	Selected samples analysed for total CaCO_3 , and soluble salts (* denotes high exchangeable sodium or soluble salts)
Table V	pH measurements at different dilutions

ABBREVIATIONS

FS - Fine sand	Lt - light
S - Sand/sandy	V - very
Si - Silt/silty	Gra - Gravelly
C - Clay	Gri - Gritty
L - Loam	

Table I: Summary of averages of chemical analyses of samples from the surface horizon of normal soils of each group

GENETIC CLASSIFICATION	SERIES	TEXTURE	No. of Samples	Organic Matter per cent	Active CaCO ₃ per cent	pH	Total phosphates per cent	Readily soluble phosphates P.P.M.	Total exchangeable bases, m.e. per 100 gms	Calcium as per cent of total bases	Magnesium as per cent of total bases	Sodium as per cent of total bases	Potassium as per cent of total bases
CARBONATE FAM SOILS	Ramla and Nadur	sands & sandy loams	5	1.4	8.2	8.34	0.12	-	24	91	7	0.8	2.2
	San Lawrenz & Lt. Fiddien	clay loam and light clay	7	1.6	14.8	8.50	0.14	18	36	85	11	1.0	2.6
	Fiddien	heavy clay	1	1.4	13.0	8.70	0.19	22	24	65	24	5.8	4.8
XEROPENDZINAS	San Biagio and Alcol	sandy loam to loam	9	1.9	16.0	8.53	0.23	30	22	85	11	1.5	2.6
	Tal Barrani	silt loam and clay loam	4	3.0	13.9	8.35	0.18	81	32	83	10	1.7	4.4
TERRA SOILS	Xaghra Tas Sagra	clay loam and clay	6	4.5	4.0	8.08	0.21	30	43	85	9	1.9	3.7

Table II: General chemical analysis

Series, Profile No.	Horizon	Depth (Inches)	Texture	Moisture per cent	Loss on ignition per cent	Carbon per cent	Nitrogen per cent	Phosphate (P ₂ O ₅)		Active CaCO ₃ per cent	PH	Total exchangeable bases m.e./100 gms.	Remarks
								Total per cent	Readily soluble p.p.m.				
CARBONATE RAW SOILS													
Ramla Series													
(Terraced Armier)													
Malta Y	S ₁ S ₂ /C ₁ C ₁	2 - 6 15 - 19 30 - 34	S S S	1.4 1.4 1.1	15 7 8	0.97 0.65 -	0.10 0.07 -	0.10 0.12 0.06	59 52 20	- - -	8.7 8.8 9.3	21 22 20	pH is rather high despite low content of exchangeable sodium (see Table III)
Gozo N	S ₁ S ₂ C	2 - 6 9 - 12 28 - 32	S S S	0.8 0.6 0.5	18 25 25	0.39 0.18 0.11	0.05 0.03 0.01	0.28 0.18 0.22	N.D. 16 14	2 2 2	7.8 8.7 9.0	18 11 5	
1. Ramla plus Blue Clay	(	topsoil	SCL	4.3	29	-	-	0.10	11	15	8.5	46	
2. Topsoil	(	topsoil	L	2.3	29	-	-	0.15	50	12	8.6	23	Note increased total exchangeable bases and active CaCO ₃
3. From nearby fields	(	topsoil	SL	1.5	30	-	-	0.17	37	8	8.5	10	
Gozo O	S ₁ S ₂	4 - 10 12 - 15	S SCL	1.0 3.2	15 21	0.35 0.81	0.04 0.09	0.23 0.11	16 4	3 4	8.9 8.6	11 20	
Nadur Series													
Gozo H	I II III	3 - 7 12 - 16 28 - 32	Gr1 LS Gr1 LS Gr1 LS	3.8 3.9 4.1	18 17 12	0.59 0.66 -	0.05 0.06 -	1.22 1.24 1.45	57 52 59	7 7 7	8.2 8.2 8.8	34 33 37	Glauconitic parent material
Gozo P	S ₁ S ₂ C ₁	2 - 6 16 - 20 24 - 28	Gra Gr1 LS Gra Gr1 SL Gra Gr1 SL	2.8 3.0 1.6	21 21 27	1.13 0.51 -	0.09 0.05 -	0.06 0.04 0.04	26 8 5	13 14 13	8.4 8.7 8.9	27 29 17	Less than 2 mm. soil 29 per cent 26 " " 27 " "

Table II (continued)

Series, Profile No.	Horizon	Depth (Inches)	Texture	Moisture per cent	Loss on ignition per cent	Carbon per cent	Nitrogen per cent	Phosphate (P ₂ O ₆)		Active CaCO ₃ per cent	pH	Total exchange- able bases m.e./100 gms.	Remarks
								Total per cent	Readily soluble p.p.m.				
CARBONATE RAW SOILS													
<i>Nadur Series</i>													
Gozo R	S ₁	0 - 6	Gra Gr1 LS	1.3	27	0.86	0.09	0.05	N.D.	15	8.6	25	Less than 2 mm. soil 35 per cent 24 per cent
	S ₂	18 - 24	Gra Gr1 SL	1.4	22	0.82	0.07	0.06	9	16	8.9	22	
<i>Fiddien Series</i>													
Light clay Malta H	S	4 - 8	S1C	6.5	18	0.98	0.12	0.10	12	15	8.6	31	
	C ₂	30 - 34	C	5.3	11	-	-	0.11	4	16	8.6	30	
	S	4 - 8	S1C	6.7	13	0.69	0.06	0.09	4	16	8.9	41	
	C ₁	16 - 20	C	8.6	15	0.78	0.08	0.10	6	15	8.6	40	
	C ₂	30 - 34	C	5.3	24	-	-	0.11	10	14	8.4	33	
Gozo C	S	3 - 7	Lt.C	5.2	21	1.24	0.13	0.16	54	13	8.7	45	
	C	12 - 16	Lt.C	6.1	21	0.57	0.08	0.15	26	14	8.9	52	
	C	28 - 32	Lt.C	5.8	24	-	-	0.07	9	17	8.8	45	
Gozo I	S	3 - 7	SCL	3.7	14	0.88	0.10	0.88	N.D.	4	7.7	41	Glauconitic clay
	C	20 - 24	SC	5.7	14	0.53	0.07	1.00	68	4	7.7	37	Parent material
Heavy clay Malta I	C	36 - 40	Gr1 CL	6.4	22	0.53	0.07	0.08	5	13	8.8	29	
Gozo D	(A) I	3 - 7	C	6.9	17	0.84	0.10	0.19	22	13	8.0	36	Saline (see Table IV) with some exchangeable sodium (see Table III)
	(A) II	16 - 20	C	7.8	15	0.42	0.07	0.17	31	11	7.8	58	
	C	32 - 36	C	7.3	14	-	-	0.23	33	10	8.1	61	

Table II (continued)

Series, Profile No.	Horizon	Depth (Inches)	Texture	Moisture per cent	Loss on ignition per cent	Carbon per cent	Nitrogen per cent	Phosphate (P ₂ O ₅)			Active CaCO ₃ per cent	pH	Total exchange- able bases m.e./100 gms.	Remarks
								Total per cent	Readily soluble p.p.m.	Total				
CARBONATE RAW SOILS														
San Laurenz Series	S C C	4 - 8	Lt.C	5.5	21	1.05	0.11	0.18	20	15	8.4	29		
		12 - 16	Lt.C	5.4	22	0.86	0.09	0.18	17	16	8.5	26		
		24 - 28	Lt.C	5.8	17	-	-	0.17	10	15	8.6	31		
Gozo A	S C C D	4 - 8	FSCL	5.9	26	0.98	0.12	0.23	17	16	8.6	11		
		16 - 20	FSCL	6.4	17	0.76	0.10	0.17	9	15	8.7	21		
		28 - 32	FSCL	6.6	24	-	-	0.16	4	16	9.1	15		
		44 - 48	FSCL	4.2	28	-	-	0.17	19	17	8.9	23		
XERORENDZINA SOILS														
San Biagio Series	I II III	2 - 6	SIL	4.1	27	1.18	0.11	0.25	14	19	8.7	18	) High active) calcium) carbonate
		12 - 16	SIL	4.5	27	0.74	0.09	0.20	11	19	8.8	19		
		28 - 32	SICL	3.1	25	-	-	0.26	14	19	8.7	18		
Malta Q Sample from near nodule bed	S _I S _{II} S	2 - 6	SIL	3.1	29	1.57	0.16	0.44	25	17	8.3	13	High total phosphate.	
		7 - 10	SIL	3.0	23	1.02	0.11	0.49	18	17	8.6	24		
		topsoil	SIL	2.6	23	-	-	0.63	35	16	8.3	15		
Malta S	S ₁ S ₂ C	3 - 7	SIL	3.4	18	1.24	0.12	0.25	27	17	8.2	25		
		16 - 20	SIL	3.7	14	0.62	0.07	0.25	18	17	8.8	16		
		30 - 34	SICL	3.8	26	-	-	0.23	18	17	8.6	15		

Table II (continued)

Series, Profile No.	Horizon	Depth (Inches)	Texture	Moisture per cent	Loss on ignition per cent	Carbon per cent	Nitrogen per cent	Phosphate (P ₂ O ₅)			Active CaCO ₃ per cent	pH	Total exchangeable bases m.e./100 gms.	Remarks
								Total per cent	Readily soluble	P.P.M.				
X E R O R E N D Z I N A S O I L S														
San Biagio Series	I	surface crust	FSL	4.3	23	1.00	0.13	0.47	19	14	8.5	15		
	II	1 1/2 - 4	FSL	4.1	23	0.93	0.12	0.52	18	14	8.6	20	High total phosphate, relatively low soluble phosphate.	
	III	4 - 8	FSL	4.0	25	1.00	0.12	0.56	22	14	8.6	19		
	IV	12 - 16	FSL	3.8	23	-	-	0.60	12	14	8.7	22		
	V	26 - 30	FSL	3.6	21	-	-	0.62	8	14	8.8	24		
	VI	36 - 40	FSL	3.7	21	-	-	0.64	7	13	8.9	21		
Gozo F	I	2 - 6	FSL	2.9	19	1.06	0.10	0.23	37	16	8.4	38		
	II	10 - 14	FSL	2.7	19	0.83	0.07	0.23	34	16	8.4	20		
	III	20 - 24	FSL	2.9	21	-	-	0.23	23	16	8.8	22		
A l c o l S e r i e s														
Malta C	I	1 - 5	FSCL	4.9	25	N.D.	N.D.	0.19	15	16	8.3	21	Some exchangeable sodium (see table III)	
	II	12 - 16	SICL	5.2	22	N.D.	N.D.	0.14	12	16	8.7	24		
	III	23 - 27	CL	5.1	21	N.D.	N.D.	0.17	10	16	8.4	20		
	IV	36 - 40	SIC	4.4	21	0.48	0.04	0.18	11	15	8.9	15		
Malta G	I	2 - 6	SICL	4.1	16	0.92	0.11	0.17	24	16	8.7	27) Stratified parent material	
	I	12 - 16	SICL	4.5	16	0.63	0.07	0.15	12	16	8.7	22		
	I	22 - 26	SICL	4.8	18	-	-	-	7	17	8.8	20		
	II	38 - 42	SICL	4.9	19	-	-	-	11	17	8.9	19		
Malta K	I	8 - 12	SICL	6.0	23	1.13	0.14	0.12	15	14	8.7	25) Stratified parent material	
	II	13 - 16	FSCL	5.9	27	-	-	0.11	7	17	8.6	25		
	III	17 - 21	VFSL	3.9	29	0.45	0.06	0.10	14	18	9.0	22		
	IV	32 - 36	VFSL	3.7	27	-	-	0.18	13	17	9.1	24		
	V	48 - 52	CL	6.3	23	-	-	0.06	6	17	8.9	29		

Table II (continued)

Series, Profile No.	Horizon	Depth (Inches)	Texture	Moisture Per cent	Loss on Ignition per cent	Carbon per cent	Nitrogen per cent	Phosphate (P ₂ O ₅)		Active CaCO ₃ per cent	pH	Total exchange- able bases m.e./100 gms.	Remarks
								Total per cent	Readily soluble p.p.m.				
X E R O R E N D Z I N A S O I L S													
Alcol Series													
Malta N	I	4 - 8	SICL	5.5	21	1.05	0.12	0.15	40	14	8.8	31	) Stratified parent material,) higher bases, lower) carbonate in Terra material.
	II	18 - 22	SIL	5.0	24	0.68	0.08	0.17	7	16	8.8	21	
	IV	38 - 42	SICL	8.0	28	-	-	0.42	14	9	8.9	43	
Malta X	I	2 - 6	S	1.4	18	0.54	0.06	0.17	34	5	8.8	14	High pH, despite low content of exchangeable sodium (see table III)
	I	12 - 16	S	1.0	15	0.32	0.04	0.15	32	5	8.9	15	
	I	22 - 26	S	1.1	9	-	-	0.13	15	5	9.1	17	
	II/III	30 - 33	SCL	2.4	10	-	-	0.14	14	9	9.2	37	
III	38 - 42	S	0.9	8	-	-	0.13	14	5	9.4	24		
T a l B a r r a n i S e r i e s													
Malta A	A ₂	10 - 14	SIL	2.6	23	N.D.	N.D.	0.23	11	18	8.3	11	
Malta D	I	3 - 7	SIL	5.3	28	3.59	0.35	0.96	312	14	8.4	29	Some exchangeable sodium (see table III)
	II	13 - 17	CL	5.4	26	2.25	0.21	0.67	215	16	8.8	32	
	III	23 - 27	CL	5.2	24	-	-	0.45	156	17	9.0	26	
	III	33 - 37	CL	5.0	22	-	-	0.68	178	17	8.5	23	
Malta V	I	3 - 7	Gra	3.9	23	1.85	0.19	0.20	68	15	8.3	34	
	II	12 - 16	SIL	4.1	23	1.25	0.15	0.19	47	16	8.7	35	
	III	19 - 23	Gra	3.5	23	-	-	0.08	25	17	8.6	37	
	I	topsoil	SIL	5.0	17	-	-	0.29	107	14	8.5	38	
Nearby similar soil, VA	I	1 - 5	Gra	2.7	19	1.63	0.16	0.23	79	15	8.5	31	
Malta W	I	7 - 11	SL	2.5	22	1.20	0.13	0.26	56	15	8.6	32	

Table II (continued)

Series, Profile No.	Horizon	Depth (inches)	Texture	Moisture Per cent	Loss on Ignition Per cent	Carbon Per cent	Nitrogen Per cent	Phosphate (P ₂ O ₅)		Active CaCO ₃ Per cent	pH	Total exchange- able bases m.e./100 gms.	Remarks
								Total Per cent	Readily soluble p.p.m.				
TERRA SOILS													
Xaghra Series	Malta U	2 - 6	S1C	4.2	15	2.05	0.22	0.20	42	5	8.6	47	Low active CaCO ₃
		12 - 16	C	6.6	13	1.52	0.18	0.20	30	5	8.7	52	
		22 - 26	C	7.3	11	-	-	0.16	14	3	8.6	52	
Malta Z	A(B) (B) (B)	1 - 5	C	5.0	10	1.79	0.19	0.12	1.9	1.7	8.5	30	Low active CaCO ₃ and very low readily soluble phosphate
		12 - 16	C	9.0	9	1.05	0.10	0.12	0.3	1.7	8.9	39	
		26 - 30	C	9.1	8	-	-	0.08	0.4	1.5	8.5	38	
Gozo E	A(B) I (B) II (B) III	0 - 4	Gr1 C	6.4	13	2.27	0.21	0.21	18	3	8.2	43	Low active CaCO ₃ and low soluble phosphate
		4 - 8	C	6.7	11	2.05	0.22	0.20	9	3	8.3	49	
		10 - 14	C	8.7	10	-	-	0.18	2	2	8.3	43	
Gozo G	S (B) (B) Ca	2 - 6	CL	7.3	13	2.52	0.29	0.37	105	5	8.2	56	High soluble phosphate only in the cultivated horizon
		24 - 28	C	9.4	9	1.09	0.12	0.16	3	2	8.2	51	
		38 - 42	C	6.0	10	-	-	0.15	3	2	8.3	51	
Gozo K	A (B)	0 - 1	C	6.7	13	3.72	0.30	0.14	5	1.9	7.4	44	Low soluble phosphate
		7 - 9	C	5.8	9	1.20	0.11	0.10	2	1.7	8.1	40	
		0 - 4	S1CL	5.7	20	3.31	0.32	0.20	12	7	7.7	39	
Tas Sagra Series													
Malta T	I I II	2 - 6	CL	4.4	21	1.59	0.17	0.22	79	12	8.5	39) Saline (see table IV) with) exch. sodium (see table III)
		12 - 16	CL	4.4	22	1.41	0.15	0.18	56	11	8.6	43	
		24 - 28	C	5.1	20	-	-	0.15	17	10	8.6	48	
Carted Soil Gozo Q	I II	5 - 9	C	4.9	21	1.41	0.13	0.19	N.D.	13	8.4	56	Blue Clay material Terra soil material
		14 - 18	C	5.6	16	0.98	0.09	0.19	17	13	8.7	54	

TABLE II (continued)

Series, Profile No.	Type	Depth (Inches)	Texture	Moisture per cent	Loss on ignition per cent	Carbon per cent	Nitrogen per cent	Phosphates (P ₂ O ₅)		Active CaCO ₃ per cent	PH	Total exchange- able bases m.e./100 gms.	Remarks
								Total per cent	Readily soluble p.p.m.				
<i>Miscellaneous samples from L'Inglin Complex areas</i>													
Gozo XIV	Terra (TR)	topsoil	C	5.1	20	1.13	0.14	0.61	163	9	8.4	N.D.	Note the great variability of chemical characteristics
Gozo XIX	Terra (TR)	topsoil	CL	4.1	13	2.37	0.19	0.22	10	3	8.4	N.D.	
Malta XVII	Terra (TR)	topsoil	CL	5.7	19	1.54	0.17	0.74	63	10	8.7	24	
Malta XIX	Terra (TR)	topsoil	C	5.7	15	1.84	0.21	0.10	4	4	8.6	28	
Malta XX	Terra (TR)	topsoil	CL	10.5	14	0.20	0.03	0.89	107	8	8.3	57	
Malta XXI	Terra (TR)	topsoil	C	9.2	9	0.78	0.10	0.11	1	2	8.4	33	
Malta XXIV	Terra (TR)	topsoil	CL	5.4	20	1.84	0.21	0.23	9	1	8.6	24	
<i>Fiddien topsoil samples from Bahrija and Mtaħleb</i>													
Malta XXVIII		topsoil	C	9.6	15	0.36	0.06	0.13	27	13	8.3	49	Alkaline bases. (see table III)
Malta XXX		topsoil	Lt.C	7.7	26	0.31	0.07	0.14	5	14	8.4	31	

Series, Profile No.	Sample Depth inches	Total m.e./100 gms.	Individual cations per cent of total			
			Ca	Mg	Na	K
CARBONATE RAW SOILS						
<i>Ramla Series</i>						
(Terraced Armier)	2 - 6	21	89	8	0.6	2.5
Malta Y	15 - 19	22	91	7	0.7	1.7
	30 - 34	20	95	2	1.5	1.2
Gozo N	2 - 6	18	94	4	0.6	1.0
	9 - 12	11	91	7	0.5	1.1
	28 - 32	5	83	15	0.6	2.2
1. Ramla plus Blue Clay 2. Topsoil mixtures 3. From nearby fields	topsoil	46	89	9	0.9	1.4
	topsoil	23	84	11	0.6	4.3
	topsoil	10	84	11	0.6	4.2
Gozo O	4 - 10	11	90	7	0.4	2.1
	12 - 15	20	86	11	0.8	3.1
<i>Nadur Series</i>						
Gozo H	3 - 7	34	89	9	1.1	2.0
	12 - 16	33	88	8	1.6	2.2
	28 - 32	37	88	9	1.9	1.1
Gozo P	2 - 6	27	90	6	0.7	2.6
	16 - 20	29	90	7	0.7	1.6
	24 - 28	17	86	11	1.3	1.7
Gozo R	0 - 6	25	91	6	0.8	2.6
	18 - 24	22	89	9	1.4	1.0
<i>Fiddien Series</i>						
Light Clay Malta H	4 - 8	31	86	11	1.0	2.4
	30 - 34	30	81	16	2.3	1.3
Malta H ₂	4 - 8	42	81	16	1.6	1.2
	16 - 20	40	87	11	1.2	1.3
	30 - 34	33	87	9	1.6	1.9
Gozo C	3 - 7	45	83	12	0.9	3.4
	12 - 16	52	80	12	3.7	4.1
	28 - 32	46	73	14	7.5	5.0
Gozo I	3 - 7	41	84	11	1.3	3.5
	20 - 24	38	70	22	4.8	3.1
Heavy Clay Malta I	36 - 40	29	89	8	0.7	2.5
Gozo D	3 - 7	36	65	24	5.8	4.3
	16 - 20	58	55	31	9.4	4.2
	32 - 36	62	46	37	10.3	6.8
<i>San Lawrenz Series</i>						
Malta R	4 - 8	21	86	11	0.8	2.7
	12 - 16	22	88	9	1.0	1.6
	24 - 28	17	89	8	1.3	1.4

Series, Profile No.	Sample Depth inches	Total m. e. /100 gms.	Individual cations per cent of total			
			Ca	Mg	Na	K
<i>San Lawrenz Series</i>						
Gozo A	4 - 8	11	85	6	4.4	4.8
	16 - 20	21	78	18	1.9	1.9
	28 - 32	15	74	20	3.4	2.6
	44 - 48	23	83	12	3.4	1.2
X E R O R E N D Z I N A S O I L S						
<i>San Biagio Series</i>						
Malta F	2 - 6	18	86	11	1.4	2.0
	12 - 16	19	86	11	1.1	1.4
	28 - 32	18	86	12	1.7	0.8
Malta Q	2 - 6	13	68	24	4.0	3.9
	7 - 10	24	82	14	2.2	1.1
	nodule topsoil	15	77	17	2.1	4.3
Malta S	3 - 7	25	88	9	1.1	1.9
	16 - 20	16	83	14	1.4	1.7
	30 - 34	15	78	18	1.7	1.9
Gozo B	surface	15	79	15	1.6	3.9
	1½ - 4	20	85	12	0.3	2.9
	4 - 8	19	81	15	0.3	4.0
	12 - 16	22	86	12	0.6	1.7
	26 - 30	24	86	12	1.0	1.0
	36 - 40	21	73	19	3.6	1.2
Gozo F	2 - 6	38	90	7	1.3	1.1
	10 - 14	20	87	10	1.1	1.1
	20 - 24	22	88	10	1.5	1.0
<i>Alcol Series</i>						
Malta C	1 - 5	21	77	17	4.2	2.2
	12 - 16	24	79	16	3.1	2.4
	23 - 27	20	69	24	4.5	2.3
	36 - 40	15	41	45	11.2	2.8
Malta G	2 - 6	27	85	9	1.4	5.0
	12 - 16	22	86	9	1.0	4.3
	22 - 26	20	85	12	1.3	2.5
	38 - 42	19	81	14	2.9	2.3
Malta K	8 - 12	25	87	9	0.8	2.9
	13 - 16	25	88	8	1.2	2.2
	17 - 21	22	91	7	0.9	1.6
	32 - 36	24	90	8	0.8	1.3
	48 - 52	29	87	9	1.5	1.7
Malta N	4 - 8	31	86	10	1.2	3.0
	18 - 22	21	86	11	1.2	1.8
	38 - 42	44	85	12	1.6	1.6
Malta X	2 - 6	14	91	7	0.6	1.5
	12 - 16	15	92	6	0.4	1.5
	22 - 26	18	89	9	0.6	1.5
	30 - 33	37	84	13	1.9	0.9
	38 - 42	25	93	5	2.2	0.5

Series, Profile No.	Sample Depth inches	Exchangeable Cations				
		Total m.e./100 gms.	Individual cations per cent of total			
			Ca	Mg	Na	K
<i>Tal Barrani Series</i>						
Malta A	10 - 14	12	90	8	1.4	1.4
Malta D *	3 - 7	29	72	18	6.9	3.8
	13 - 17	32	73	15	8.4	3.5
	23 - 27	26	68	18	9.5	4.7
	33 - 37	23	68	18	10.4	4.0
Malta V VA	3 - 7	34	88	7	1.8	2.7
	12 - 16	35	92	5	1.9	1.0
	19 - 23	37	93	5	1.9	0.8
	topsoil	38	90	8	0.6	1.6
Malta W	1 - 5	31	85	8	1.3	5.6
	7 - 11	32	88	7	2.0	3.8
T E R R A S O I L S						
<i>Xaghra Series</i>						
Malta U	2 - 6	47	90	7	0.7	1.4
	12 - 16	52	87	11	1.0	1.2
	22 - 26	52	86	12	1.3	1.2
Malta Z	1 - 5	30	82	10	1.7	6.0
	12 - 16	39	80	14	3.5	2.3
	26 - 30	38	78	15	4.7	2.4
Gozo E	0 - 4	43	88	9	1.5	1.8
	4 - 8	49	87	8	3.1	1.8
	10 - 14	43	86	11	1.6	1.7
Gozo G	2 - 6	56	87	10	1.2	2.8
	24 - 28	52	89	8	1.5	1.6
	38 - 42	51	89	8	1.4	1.5
Gozo K	0 - 1	44	76	13	2.9	7.7
	7 - 9	40	83	11	2.8	3.1
Gozo L	0 - 4	40	87	7	3.5	2.7
<i>Tas Sagra Series</i>						
Malta T * *	2 - 6	39	74	16	5.7	4.4
	12 - 16	43	59	20	16.7	3.7
	24 - 28	48	55	23	18.0	3.7
<i>Carted Soil</i>						
Gozo Q	5 - 9	56	89	9	1.0	1.4
	14 - 18	54	88	10	1.0	1.1
<i>Miscellaneous T.R. samples from L'Inglin areas</i>						
M XVII	topsoil	24	87	9	1.6	2.3
M XIX	topsoil	28	81	9	2.2	7.8
M XX	topsoil	37	80	12	6.5	1.8
M XXI	topsoil	34	92	4	1.6	2.0
M XXIV	topsoil	24	83	10	2.2	4.3
<i>Fiddien samples</i>						
M XXVIII	* topsoil	49	72	8	14.9	4.7
M XXX	* topsoil	31	24	37	36.1	3.3

Table IV Calcium carbonate and conductivity of selected samples

Series, Profile No.	Sample Depth inches	Conductivity millimhos/cm. 5/1 suspension	Total CaCO ₃ per cent	Active CaCO ₃ per cent
CARBONATE RAW SOILS				
<i>Ramla Series</i>				
Terraced Armier	2 - 6	0.13	84	-
Malta Y	30 - 34	0.13	88	-
<i>Nadur Series</i>				
Gozo P	2 - 6	-	90	13
<i>Fiddien Series</i>				
Light clay	4 - 8	0.15	51	15
Malta H	30 - 34	-	47	16
Heavy clay	3 - 7	2.6 *	29	13
Gozo D	32 - 36	3.25 *	36	10
<i>San Lawrenz Series</i>				
Malta R	4 - 8	-	54	15
	24 - 28	-	53	15
XERORENDZINA SOILS				
<i>San Biagio Series</i>				
Malta F	2 - 6	-	70	19
	28 - 32	-	80	19
Gozo B	topsoil	-	60	14
	36 - 40	-	58	13
<i>Alcol Series</i>				
Malta C	1 - 5	0.20 *	-	16
	36 - 40	0.28	-	15
Malta G	2 - 6	0.15	70	16
	38 - 42	-	57	17
Malta X	2 - 6	0.12	-	5
	38 - 42	0.19	-	5
<i>Tal Barrani Series</i>				
Malta D	3 - 7	0.56 *	-	14
	33 - 37	0.41	-	17
Malta V	3 - 7	0.42	-	15
Malta W	1 - 5	-	81	15
	7 - 11	-	69	15
TERRA SOILS				
<i>Xaghra Series</i>				
Malta U	2 - 6	-	15	5
	22 - 26	-	8	3
Gozo E	0 - 4	-	10	3
	10 - 14	-	2	2
<i>Tas Sagra Series</i>				
Malta T	2 - 6	0.44	-	12
	24 - 28	1.93 *	-	10

Table V pH measured at various dilutions of the soil solution

Sample	Depth inches	soil : water ratio				
		1 : 1	1 : 2.5	1 : 5	1 : 10	1 : 25
CARBONATE RAW SOILS						
Gozo N Ramla	2 - 6	7.91	7.80	8.20	8.51	8.91
Gozo R Nadur	0 - 6	7.99	8.59	8.50	8.60	8.79
Gozo I Fiddien	3 - 7	8.15	7.73	8.43	8.50	8.83
Gozo A San Lawrenz	4 - 8	8.21	8.55	8.72	8.78	9.27
XERORENDZINA SOILS						
Gozo B San Biagio	topsoil	7.69	8.49	8.29	8.80	9.10
Malta K Alcol	17 - 21	8.40	8.95	8.81	9.10	9.30
Malta X Alcol	2 - 6	8.12	8.75	8.70	8.97	8.58
CARTED SOIL						
Gozo Q	5 - 9	7.80	8.37	8.17	8.38	8.42

AVE

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BOI

BOI

BRAI

BRAI

BR

COR

COO

CVI

DE S

DEI

DROU

DUI

GLI

GONZ

GOU

HEF

HII

HOLI

HOWA

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HYD

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