QUATERNARY EVOLUTION OF A MOUNTAINOUS AREA IN N.W. TUNISIA.

- A GEOMORPHOLOGICAL AND PEDOLOGICAL ANALYSIS -

Dr. R. H. G. Bos

PUBLICATIES VAN HET FYSISCH-GEOGRAFISCH EN BODEMKUNDIG LABORATORIUM VAN DE UNIVERSITEIT VAN AMSTERDAM

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CONTENTS

ABSTRACT

An anticlinal valley developed in Oligocene flysch deposits (soft shale, marl, sandstone), including a diapyric injection of Triassic breccia, was subjected to a detailed geomorphological study.
It was established that periods of areal mass movements of the flow-type (including humid solifluction) have been active on all parent materials of the flysch area. At present mass movements are operative in the flysch deposits by means of linearly concentrated slide movements limited to one of the parent materials: the soft shales. Neither now nor in the past have mass movements affected the Triassic breccia, as is evidenced by the fossil and polygenetic character of the soils in these breccia.
Three types of slopes were distinguished dependent on the rock; the slope development proved to be highly related to the parent rock and the nature of the mass movements.
Due to the periodically unstable conditions in the flysch area the soils encountered date nearly all from the Holocene.
The geomorphological phenomena closely match the pedological data and may truthfully project the evolution of the landscape in this part of NW Tunisia. It was established that the inter-pluvials were the stable, soil forming periods in this morphogenetic environment.

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SUMMARY

All geomorphological and pedological data discussed in this summary have been compiled in figure 26, the scheme of the landscape and pedogenetic evolution in the area studied.

The purpose of this study has been to reconstruct the evolution of the landscape in a mountainous part of the Kroumirie (NW Tunisia) on the basis of geomorphological and pedological observations. Two valleys were studied, the narrow anticlinal valley of the Oued Seloul and the wide synclinal valley of Ben Metir.

THE VALLEY OF THE OUED SELOUL

Geological Structure

The steep anticlinal valley of the Oued Seloul was given special attention to in the course of this study. The interfluves consist of sandstone, and lower in the valley soft shales and marls occur. Together these rocks constitute the Oligocene flysch deposits. Folding of these sediments took place during the lower Miocene and is directed NNE-SSW. The folding is on the whole of a rather simple anticlinal-synclinal nature, locally with injections of Triassic material ('Triassic' diapyr). The eastern valley side of the Oued Seloul locally consists of this Triassic breccia (fig. 6).

Mass movements

The geomorphological forms in the valley of the Oued Seloul are determined especially by processes of mass movement. Results of the mass movements still visible in the landscape indicate that nature and extent of these processes were dependent on the rock on which they

were active and on the fluctuating climatic conditions during the Quaternary. Three criteria were used to arrive at a first subdivision of the mass movements. Apart from water content of the masses and the nature of the movement (flow or slide), two criteria already used by Sharpe (1960), the lithology of the material served to subdivide the mass movements (fig. 18).
Present shape and position of the deposits made it possible to designate the processes as active or no longer active, which proved to be an important factor in the reconstruction of the landscape development in the Seloul valley (fig. 10). This permitted a second subdivision into active and fossil (stabilized) mass movements (fig. 18).

With regard to the relations rock/mass movement and geological time/mass movements the following has been observed:

--- On the Triassic breccia no traces have been found indicative of recent or past activity of mass movements. Furthermore, a steep valley-side still bears witness of very old vertical incisions of the Oued Seloul in the Triassic deposits. This observation is another indication of the considerable immunity of the Triassic breccia towards the mass movements. Similar valley-sides in the other rocks and especially in the soft shales have been subject to a certain planation.

--- In the marls rockslides - very local falls of bedrock - are very rarely observed: generally the slopes in the marls are relatively stable nowadays. On the slopes underlain by the marly series frequently material transported by areal types of mass movement (humid solifluction and mudflow) was encountered. These processes are no longer active under the present climatic conditions. The stabilized character of these coarse detrital deposits is evidenced by the overlying colluvial layer. The above-mentioned observations are indicative of a much poorer resistance of this type of rock towards mass movements under different climatic conditions.

--- The sandstone slopes are very stable at present and, similar to the marls, are covered with the detrital deposits of the humid solifluction, here too often overlain with a layer of colluvium.

--- On the soft shales, in addition to the variety of stabilized materials derived from earlier areal mass movements and nowadays covered with colluvial deposits, many indications are also found of active earthflows, slumps and debris avalanches (plate 7-10), which, unlike the earlier mass movements, are more linearly concentrated. These recent and concentrated types are absent on the other parent rocks.

Consequently in the flysch country a distinct difference can be observed between the earlier, stabilized flow movements operative on all flysch rocks and the active, linearly concentrated slide movements operative on the soft shales only. The Triassic deposits are almost completely isolated from the flysch deposits by steep fluviatile valleys and consequently, are not affected by the areal solifluidal movements originating in the flysch country.

Effect of the Parent Rock on the Slope Development

In the unstable soft shales only the most recent V-shaped incision in the most extreme part of the valley head can still be observed (fig. 9). The sharp V-shape of these forms is only very short-lived, because subsequent to every phase of vertical fluviatile incision (=undercutting) the soft shales in a series of slump movements slide from the more elevated sandstone, as a result of which a steep slope is carved out in the sandstone (fig. 7). In this way a break in the slope is effected on the transition from the sandstone to the soft shales lower down. Slumping is not operative in the marls and consequently, the break in the slope at the transition from the sandstone to the marls is much less pronounced (fig. 7).
It is interesting to note that due to the absence of slumping, the various phases of incision of the Oued Seloul can distinctly be traced in both the marls, which are stable compared to the soft shales, and in the Triassic breccia.

Effect of the Pluvial Climate

The stabilized coarse detrital deposits from the late-Pleistocene are nowadays covered by Holocene colluvium of a sandy-clayey texture**. Consequently, the material of the slope deposits underwent a clear change from coarse and angular into fine grained.
Equally a change has been observed in the nature of the mass movements: the areal types, which are stabilized at present, were typical flow movements not related to a specific parent material. They differ from the recent mass movements, which as a rule are of the slide-type and highly dependent on the kind of material: they are active on the soft shales only.
The stabilized type of flow movements can only have been effected by a factor which superseded the present dominant influence of the rock. It has been assumed that during the Soltanian (Würm, compare Awad 1963) different conditions have prevailed which caused other types of mass movement. Apparently these conditions were such that the influence of the rock - dominant now - was overruled.

Areal mass movements such as humid solifluction require a landscape with a highly intermittent precipitation and the absence of a substantial vegetative cover (geomorphic aridity, Dylik 1957). The degradation of the vegetation, also apparent from palynological study (fig. 20), was caused by a decrease in temperature. The mean temperature of the coldest month in the Seloul valley, because of this fall in temperature, did not exceed a value of approximately 0°C. The congelifracts (rock fragments brought about by frost splitting) transported in the areal mass movements in which they constitute the coarse, angular debris, are well in line with the extensive mechanical erosion to be expected in view of the mean temperature.

** Colluvium is considered as a form of mass transport, hence it has no connection to the mass movements, see VIII. 1.

A fall in temperature, not an increase in precipitation, is thought to be characteristic of the so-called pluvials in this part of N. Africa. These colder periods with intense areal degradation are considered unstable phases in the landscape development, i.e., as geomorphologically active periods in which soil formation was strongly inhibited. Due to the intense geomorphological activity of the areal degradation, inter-valley planations (glacis d'érosion) formed in the Seloul valley (Dylik, 1957).
The altiplanative lowering of the crests of the first-order interfluves was another consequence of the areal degradation. This degradation also stripped these crests of their deep Tertiary weathering layer formed under tropical conditions. The projecting parts of the weathering front nowadays are represented as tors.

Difference between the Effect of Pluvial and Inter-pluvial Conditions

The higher temperature in the inter-pluvial caused the vegetation cover to regenerate with resultant formation of a stable landscape and strong pedological development. At this time the previously formed 'inter-valley planations' were dissected as a result of linear drainage and linearly concentrated slide movements.

The Holocene colluvium covering the coarse detrital deposits from the late-Pleistocene may be subdivided into a relatively sandy layer and an older, somewhat more clayey layer. The clayey character of the oldest colluvial deposits may well point to a period of chemical weathering more intense than the weathering operative in the present climate (compare Beaudet, Maurer and Ruellan, 1967). The results of the palynological study also suggest a relatively humid and warm early-Holocene period.

Influence of the Geomorphological Processes on the Distribution of Soil Types

The distribution of the soil types in this valley is to a large extent determined by the afore-mentioned landscape-forming processes. Due to the effect of the humid solifluction almost all profiles are rather stony, with the exception of the higher parts of the first-order interfluves where no solifluidal material accumulated.
The areas of the recently active earthflows and the stabilized mudflows are characterized by very heterogeneous profiles and as a consequence clearly occupy a special position among the soil map units. The most recent fluviatile incision in the shales at those sites where the unweathered parent material crops out, gives also rise to a separate mapping unit on the soil map. Consequently, the pattern of the soil map generally bears many similarities to the geomorphological map (fig. 21 and fig. 9).

Recent Pedogenesis

The recent pedogenesis on the non-calcareous clayey materials is restricted to a brown colouring of the soils, extending especially deep under forest, and formation of a Cambic horizon: acid brown forest soil (Dystrochrept). Remnants of a brown Bt horizon, which under the influence of the recent pedogenesis would seem to disappear, are still of frequent occurrence in the soil profiles originating on the non-calcareous clayey materials.
The brown textural B horizon always occurs in the oldest (relatively clayey) part of the recent colluvium and its formation, therefore, is contemporary with the early-Holocene period with relatively high humidity and temperature. In sandy material the process of soil formation has a tendency towards podzolization with resultant formation of an eluvial horizon (A2) (Spodic Entisol). The calcareous clayey materials are locally decalcified and brown coloured, to form Eutrochrepts. The most developed soil profile on these rocks is, therefore, characterized by a Cambic horizon (structural-B).

Polygenetic Phenomena in the Soil Profiles

There is only a limited occurrence of polygenetic phenomena in the soil profiles, as is to be expected in a valley which underwent such extensive geomorphological activity during the most recent pluvial. Only two of these phenomena were observed:

--- The base of most soil profiles in the non-calcareous clayey materials is constituted by a red-grey mottled clay. The clay was incorporated in the mudflow (i. e., during the most recent pluvial) and, consequently, dates from a period of soil formation, the Eemian, prior to this pluvial.

--- On flat parts of the terrain in the marls (calcareous clayey materials), separating the various phases of incision of the Seloul, remnants are found of an intensely degraded Vertisol**, which dates from the same period as the red-grey mottled clay.

The area underlain by the Triassic breccia was not affected by areal mass movements originating in the flysch country during the most recent period of geomorphological activity. Consequently, on these Triassic breccia the soil profiles are usually very old and distinctly polygenetic. In the majority of these soil profiles a deep red Bt horizon can be distinguished, apparently succeeded by formation of a brown Bt horizon considering that brown clay skins for a substantial part cover the red clay skins. The brown clay illuviation, however, was not found to extend as deep as the red clay illuviation. The most recent pedogenetic processes result in brown colouring (brunification).

Dating of these phases of soil formation would have been difficult but for the fact that the Triassic rocks at one location are not separated from the flysch area, by a river valley. At this locality the solifluidal

** The term degradation is also used in soil science to refer to a heavily leached soil. In this text, however, degradation of the Vertisol indicates diminishing importance of the Vertisol characteristics.

processes could from the flysch country penetrate into the landscape of the 'Triassic' diapyr. The red and brown illuvial clay horizons are also found here, in this case separated by a so-called stone-line, composed of detrital sandstone (flysch) and deposited by processes of humid solifluction.

The foregoing considerations lead to the conclusion that the red textural B horizon has been formed in a period immediately prior to the most recent pluvial, while the brown textural B horizon dates from a period subsequent to this pluvial. The brown clay illuviation in the Triassic breccia was coincident with the one in the oldest colluvium of the flysch area. The red clay illuviation in the soils of the 'Triassic' diapyr coincides with the formation of the red-grey mottled clay in the soft shales and the Vertisol formation in the marls.
The disparate character of the parent rocks may well account for the concurrent formation of such highly divergent soils. The soft shales, because of the impermeable substratum and the level location, must have suffered considerably from excess of water. Pseudo-gleying still develops in the soils on the more level slopes in the shaly country. The 'Triassic' diapyr is built up of breccia, which is very permeable. Furthermore the diapyr is surrounded by deep valleys. The soil profiles on these breccia, therefore, have always been subject to good drainage. On the Triassic material a soil formed with a deep, red illuvial clay horizon, whereas under the same climatic conditions the less permeable clays saw the formation of a profile with a red-grey mottled gley horizon (compare Fédoroff, 1966). Concurrently a Vertisol developed on the calcareous clays.
The subsequent unstable period (pluvial) in the flysch area truncated the soil profile, generally down to the compact red-grey mottled clay.

THE VALLEY OF BEN METIR

Geomorphology and pedology of the synclinal valley of Ben Metir are compared to those of the anticlinal Seloul valley. The geomorphological processes operative in the anticlinal valley are also observed in the synclinal valley: both the detrital deposits of the areal flow movements and the recent (Holocene) colluvium are present. The humid solifluction in the Ben Metir valley rather frequently obtained a mudflow character.
The first-order interfluves of the valley of Ben Metir (among others constituting the boundary with the valley of the Oued Seloul) have as a matter of course also been subject to altiplanative denudation as a result of areal flow movements.
The recent mass movements belong to the slide-type, are linearly concentrated and operative on the soft shales only.
In the Seloul valley slope development depends on the nature of the parent material. This phenomenon, however, has not been observed in the valley of Ben Metir due to the absence of the Medjanian Flysch

(forming the marl ridges in the Seloul valley) at the surface and of fluviatile phases of incision. The absence of this kind of slope development in the synclinal valley has resulted in a better preservation of the red illuvial clay horizon from the Eemian than in the Seloul valley. Although this Eemian soil formation may also be found on the shales, remnants of this old pedogenesis generally occur in the sandy Mio-Pliocene deposits.
Signs of the more recent pedogenetic period during which a brown illuvial clay horizon was formed may frequently be encountered in various soil profiles. The only difference with the recent pedogenesis in the Seloul valley is that in the extensive, non-wooded parts of the terrain the soil profiles are characterized by a certain 'steppisation', homogenization of the organic material extending as deep as 40 to 50 cm into the profile.

PART ONE: GENERAL ASPECTS OF THE AREA STUDIED AND ITS SURROUNDINGS

Chapter I

INTRODUCTION

I.1. Material

During the field work liberal use was made of aerial photographs to facilitate mapping and orientation in the terrain. The following photographs were used: XVII bis/250 005-001, 075-078 and 099-091; XVIV /250 084-090, 061-056 and 046-052 Tunisia 1963, scale approx. 1 : 25,000 and size 18 x 18 cm.
The following topographical map sheets were also available: 'La Calle' (Algérie, dépt. de Constantine Flle. no. 19) and 'Fernana' (Flle. no. XXIV) scale 1 : 50,000.
The only geological map available was mapsheet 'Fernana' scale 1 : 50,000. In the northern part, mapsheet 'La Calle', field work had to be started without geological data. Those data essential to this study have been obtained in the field (fig. 6).
For the borings a soil auger was used and further an Abney level and a 'Büchi' compass came in very useful. Soil profiles were described by means of the FAO Guidelines for Soil Profile Description. The colours of the soil profiles were determined by means of the 'Munsell Soil Color Charts'.

I.2. Field Work

Field work was carried out during the months of May and June of the years 1966, 1967 and 1968. The area studied, the 'Kroumirie', is located in NW Tunisia north of the lower reaches of the Atlas mountains (fig. 1 and 2).
Field work was started south of Ain Draham, the centre of this region, in the valley of the Oued Seloul. To gain an idea of the geomorphology and pedology of the area, during the first few months a 'sample strip' was mapped on a scale 1 : 10,000, extending, across the valley, from divide to divide. After the physiographical interpretation at the Institute for Aerial Survey and Earth Sciences (I.T.C.) with the aid of aerial photographs, several months were spent in soil mapping, scale 1 :

25,000 of a part of the area interpreted. Several months of geomorphological study provided a comprehensive range of data which permitted the synthesis of all concepts and theories.

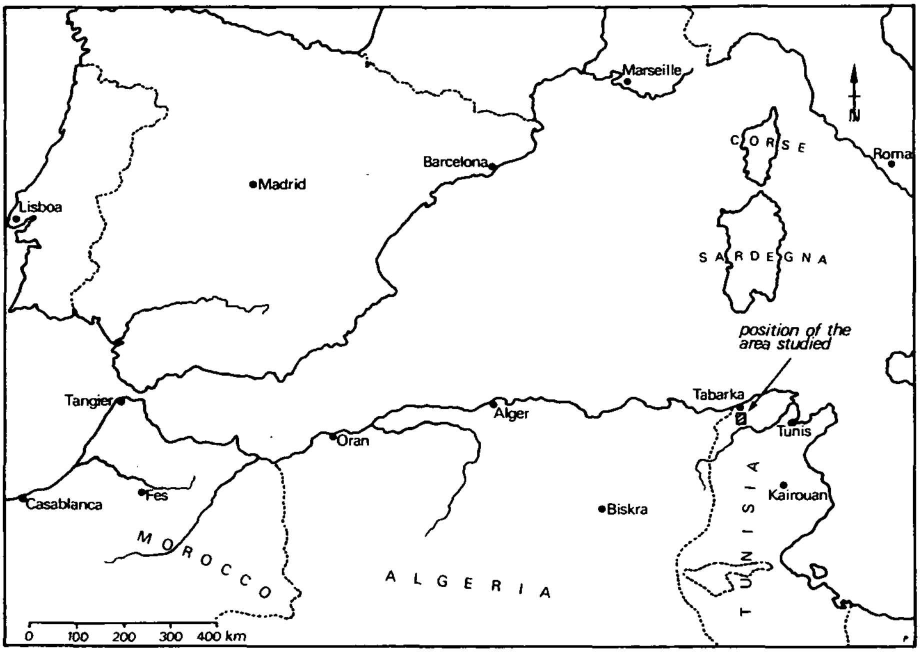


Fig. 1. Location of the area studied.

To illustrate the relation between soil and landscape the soil map scale 1 : 25,000 of the valley of the Oued Seloul (south of Ain Draham) has been added to the text (fig. 21).

For study of a landscape with emphasis on both pedology and geomorphology warrant may be found in particularly the Soil Survey Manual (1963) in which it says on p. 6: 'a soil is dynamic three dimensional piece of landscape'. The significance of the geomorphology to the pedology has been pointed out by Wooldridge as early as 1949 and by Edelman (1957) and is generally recognized nowadays. This is also evidenced by the system of physiographical interpretation developed by Buringh (1960) and Vink (1968) in the Institute for Aerial Survey and Earth Sciences (I.T.C.).
Less wide-spread is the insight that study of the soil profile may furnish valuable data and facilitate a true appreciation of the geomorphology. Already in 1958 Butler propounds that: 'Soil development is the unique organization involving vertical differentiation which occurs at an exposed ground surface. It is proposed that this is influenced by the environmental conditions of the site and that time is a factor in it'.

This being so a soil profile may be considered a sensitive recorder of changes in the 'geographic associates' (climate, lithology, topography and vegetation - see Jungerius 1969 -) and the action of the exogenic forces on the earth's crust can often more distinctly be inferred from the soil profile than from the landscape (Jungerius, 1964).
Further the possibility should be referred to of the soil becoming a factor in the morphogenesis, for when the parent material is a soil forming factor only, the resultant soil is a landscape forming factor (Jungerius, 1964).

Chapter II:

CLIMATE

In Ain Draham the climate is rather humid. The annual precipitation amounts to approximately 1600 mm. This precipitation is of a highly torrential nature and falls during a rainy season extending from medio September to medio May. The months of July and August on the other hand are extremely dry.

The following statistical data are known from the weather station in Ain Draham:

Temperature (1901-1950)

1. half sum of the mean extreme daily temperatures (^{o} C):

j	f	m	a	m	j	j	a	s	o	n	d	year
6.6	7.1	9.7	12.5	16.0	20.2	23.9	24.9	29.0	17.1	11.9	7.9	15.0

2. mean daily maxima:

9.4	10.2	13.7	17.1	21.0	25.8	30.2	31.3	27.6	21.6	15.4	10.4

3. mean daily minima:

3.9	4.0	5.8	7.9	11.0	14.6	17.7	18.6	16.5	12.6	8.4	5.1

4. absolute minima:

-4.0	-5.0	-2.0	0.0	2.0	7.0	9.0	11.0	9.0	4.0	-1.0	-5.0

5. absolute maxima:

19.0	24.0	27.0	32.0	35.0	42.0	43.0	43.0	41.0	39.0	28.0	26.0

Precipitation (1901-1950)

1. mean number of days with a precipitation of at least 0.1 mm in 24 hours:

16	14	13	11	8	5	2	3	7	11	13	15	118

2. mean amount in millimetres:

250	196	159	124	80	25	6	9	66	140	204	275	1534

According to the classification of Köppen a Csa climate is concerned with a dry hot summer and a moist mild winter. Ain Draham, however, has some frosty days every year and generally some snow occurs for several days.
The foregoing data apply only to Ain Draham.
The climate, due to the high location of the area, is much more extreme here than in the other parts of the Kroumirie. The amount of precipitation, which decreases to 800 mm/y near Fernana, 20 km to the south may serve as an example of this.

Chapter III

GEOLOGY

III. 1. General

The nature of the sediments in the various geological periods is as follows:

--- Holocene - recent colluvium and alluvium; the colluvium is of a variable texture, the alluvium is sandy.

--- Pleistocene - deposits on river terraces with a sandy or clayey texture.

--- Mio-Pliocene - sands with pebbles, conglomerates and sandy marls: continental deposits.

--- Miocene - clays and sandy marls, microconglomerates and gypsiferous marls with more sandy banks: lagoonal deposits.

--- Upper Oligocene - 'flysch' in the Numidian facies, consisting of an alternation of banked sandstone (1,5-2 m in thickness per bank) with thin more shaly layers. The series forms a complex of more than 600 m in thickness. At the base soft shales are encountered.

--- Lower Oligocene / Upper Eocene - this series also occurs in a flysch facies, the Medjanian Flysch, and consists of an alternation of marl and sandstone layers, with a predominance of marls at the base.

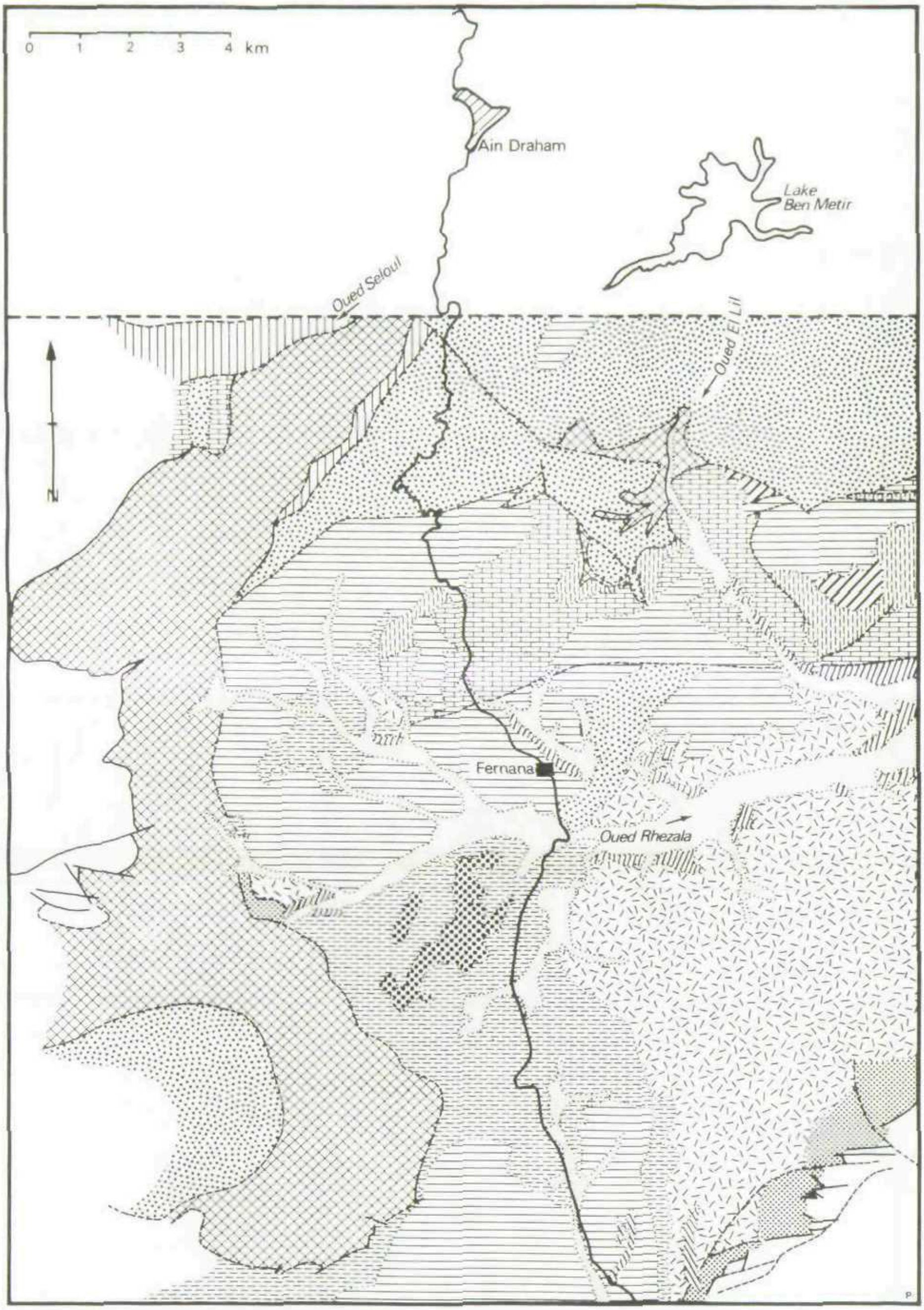


Fig. 3. Geological map (after 'feuille Fernana', No. XXIV)

With regard to the landscape, two parts may be distinguished in the area studied:

- the mountainous area in the north and
- the rather flat landscape in the south forming a subdivision of the basin (fossé d'effondrement) of the Oued Medjerda. The transition of the mountains to the plain is formed by a piedmont. (see fig. 2 -inlay-, fig. 3, plate 1).

Plate 1. Photographed from the fault zone facing SSW
View of the piedmont, the river landscape, the 'Triassic' diapyr looking towards the folded flysch, visible as skyline.

III. 2. Northern Part

This mountainous area, in the centre of which the small town of Ain Draham is located, is built up of sandstone, marls, soft shales and some fluviatile and slope deposits. The geology of this part of the Kroumirie is determined especially by a regime of rapid subsidence during the Oligocene, with consequent enormous accumulations of sediments, in the words of Gottis and Sainfeld (1956): 'A partir au Miocène les orogénèses post-oligocène et post-burdigalien ont accentué les plis antérieurement ébauchés: le reserrement de tout le système a eu pour résultat le chevauchement de la grande masse des sédiments oligocène, avec d'importantes montées triasiques le long des plans de chevauchement (le diapir de 'Trias'). C'est la phase orogénique majeure, qui se poursuit durant tout le Quaternaire'.

In the valley of the Oued Seloul the Triassic deposits are being exposed approximately three km down-stream from Ain Draham. At this site they consist of: 'une brèche argileuse à éléments de grès phylliteux versicolores, parfois très fins, simulant des argiles' (Gastany, 1953).

The folding is of the rather simple anticlinal-synclinal type with a NNE-SSW orientation. In some zones folds have been aligned horizontally along small transverse faults; because of this later tectonic activity the older deposits became locally uplifted and were easily brought to light by vertical, fluviatile erosion. The oldest Tertiary deposits (Medjanian Flysch) took part in this activity and attained a location high enough for the Oued Seloul to incise.

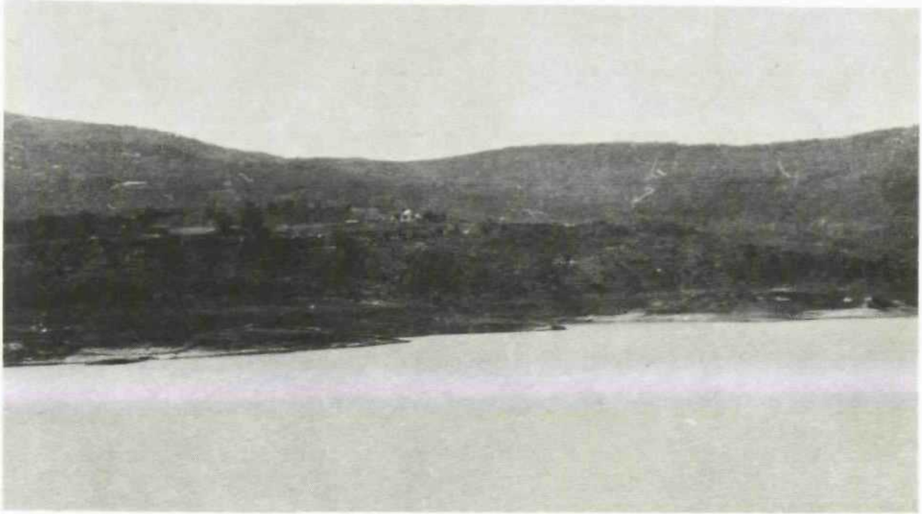


Plate 2. The synclinal valley with the storage lake of Ben Metir.

In this folded area a system of both synclinal and anticlinal valleys developed. A valley was taken from each of these types for closer study: the anticlinal valley of the Oued Seloul and the synclinal valley of Ben Metir, in which the Oued el Lil is converted into an artificial lake by means of a dam (plate 2).

III. 3. Southern Part

The uplift in the Lower Miocene was succeeded by intense erosion with an almost uninterrupted rejuvenation of the relief producing coarse, continental deposits at the edges of the mountains in the form of a 'glacis d'accumulation' (Raynal 1956, Birot 1969). At present the Mio-Pliocene deposits of the piedmont area are located here, which forms the transition of the mountains to the plain of the Medjerda in the south. This plain is part of the 'fossé d'effondrement d'allure O-E',

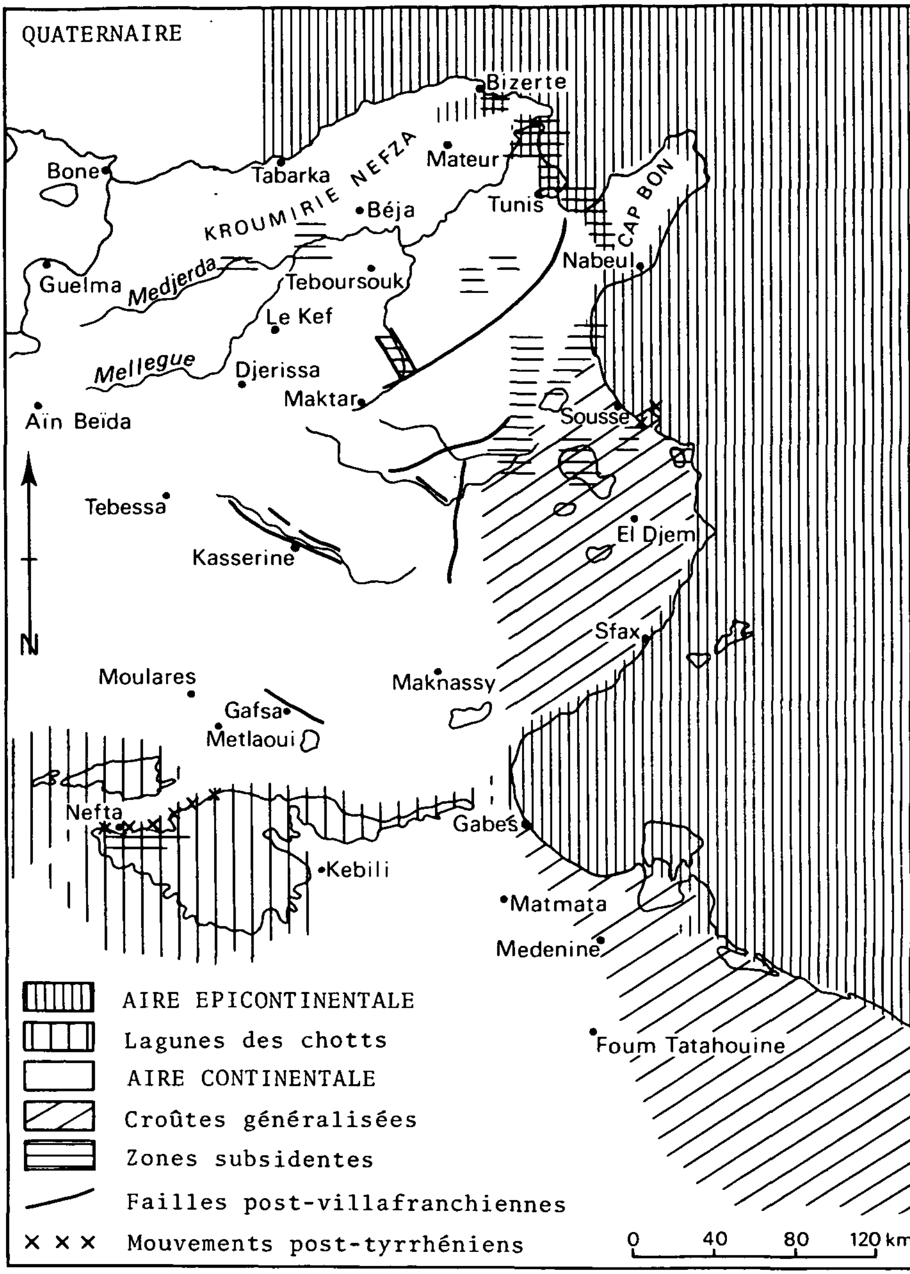


Fig. 4. Areas of subsidence in Tunisia during the Quaternary (after Castany, 1953).

which, represents an area where subsidence continued from the Lower Miocene till the Quaternary (fig. 3 and 4).
In this W-E striking graben the Miocene lagoonal deposits developed, which towards the mountains in the north pass into the Mio-Pliocene of the piedmont. During the Quaternary these deposits were highly dissected. As a result river terraces, which are well developed especially in the surroundings of Fernana, originated at various levels.
The boundary between the Mio-Pliocene continental deposits and the Oligocene flysch in the north is formed by a fault system running very nearly W-E (fig. 3).

Chapter IV

HYDROGRAPHY

IV.1. General

Except for the concise geological data no literature is known dealing with the physical features of the area studied.
With the aid of the topographical maps 'la Calle' and 'Fernana' a river map has been drawn (fig. 5) to permit the study of the drainage system. The crests of the first-order interfluves in the folded flysch deposits have also been indicated on this map together with the principal altitudes. The map has been supplemented with the valley-floor divides observed in the terrain, which furnish significant information about the evolution of the hydrographic network in the Kroumirie.

IV.2. Subdivision of the River System

From study of fig. 5 it becomes evident that, relative to the area studied, the river system is roughly divisible into two systems:

--- a drainage system in the mountains, which constitute the northern part; here a distinctly NNE-SSW hydrography is found adapted to the direction of folding. The dense drainage pattern is caused by the high precipitation in these mountains and by the lithological character of the flysch sediments.

--- a drainage system in the plains constituting the southern part; this river pattern is predominated by the Oued Rhezala, an affluent of the Oued Medjerda flowing in a W-E direction. The direction in which the Rhezala and the Medjerda flow is determined by the general direction of the graben. The relatively low precipitation in Fernana (about half of that of Ain Draham) is clearly reflected in a greatly diminished density of the drainage pattern. Moreover the lithological character of this southern part may be conducive to the same.

The boundary between both systems is formed by the fault zone between the mountains and the piedmont area, separating the folded Ter-

tiary series from the more recent, unconsolidated deposits.
Because of its effect on the drainage system, the location of this fault zone stands out clearly on the river map. Arising in the mountains only one affluent of the Rhezala, the Oued el Lil, flows accros this fault zone.

IV. 3. Development of the River System

Quite a large number of valley-floor divides have been mapped. They are always associated with radical alterations in the drainage pattern. To explain the location of these valley-floor divides in the landscape a hypothesis has been formulated. For this purpose and depending on size and location in the landscape the valley-floor divides have been subdivided into four groups.

a. the three valley-floor divides near to and to the northwest of Ain Draham. The small town of Ain Draham itself has been built on one of these three valley-floor divides (plate 3). The divides are located in large NNE-SSW striking valleys and consequently, are of relatively large dimensions.
b. the valley-floor divide four km to the south of Ain Draham along the road to Fernana. At present this dry valley constitutes the divide between the Oued Seloul and the reservoir of Ben Metir (the Oued el Lil).
c. The valley-floor divides at the northwestern edge of the 'Triassic' diapyr (see III. 2.). Nowadays they form the divides between the Oued Seloul and the Oued Krouldjana, an affluent of the Rhezala.
d. two valley-floor divides located southwest of Babouch (in close proximity to Ain Draham) and in the extreme southwest of the river map, respectively.

The three valley-floor divides of type a., in the large NNE-SSW striking valleys, are located on a line. Noticeable is the location of the highest peaks of the area on the first-order interfluves at either side of these valley-floor divides (fig. 5). From here, the first-order interfluves decrease in height towards the NE and the SW. Draining to the north the distance to the Mediterranean Sea is about 20 km, to the south about 200 km. This suggests that the location of the valley-floor divides is determined by tectonic activities. This is borne out by the culmination of the old flysch deposits (Medjanian Flysch) particularly near Ain Draham and Babouch, the centre of this uplift, which split the original continuous drainage into a NNE and SSW directed system.

The drainage adapted to the structure in this way became subsequently disturbed from two directions:

--- The Algerian Oued Kebir, of which the Oued Seloul now represents the extreme upper course, captured from the west. The effect of this piracy is reflected in the two valley-floor divides of type d.. Vageler (1955) places this phase of intense headward erosion and piracy by the Oued Kebir during the late Tertiary and early-Quaternary. The Oued Seloul exhibits excellent evidence of this piracy: four kilometres south of Ain Draham this river leaves its NNE-SSW course and curves outward into a western direction. As a result of this capture by the Oued Kebir the divide southwest of Babouch came into being. The Oued Barbara, in one of the fold-vallies in the southwest, even came to flow in opposite direction over long distances, with resultant formation of a second valley-floor divide of type d.. This latter capture did not affect the eastern part of the area. A strong tendency towards subsidence prevailed in the area of the Oued Medjerda, which is separated from the NNE-SSW folded mountains by the 'Triassic' diapyr.

--- The last drastic change of the river pattern was effected by piracy due to headward erosion of affluents of the Oued Rhezala cutting backwards from the Miocene zone of subsidence. From this graben and across the fault zone, for example, the Oued el Lil has captured the 'cuvette' of Ben Metir and given rise to the valley-floor divide of type b..
Equally the Oued Krouldjana entered the 'Triassic' diapyr due to headward erosion. The valley-floor divides at the northwestern edge of the 'Triassic' diapyr originated from piracy of several upper courses of small tributary streams of the Oued Seloul. Valley-floor divides of the c.-type are encountered here.

Plate 3. The small town of Ain Draham situated on a valley-floor divide. Also clearly visible is the break in the terrain at the transition of the soft shales to the sandstone. This break in the terrain coincides with a vegetation boundary: the flatter parts more downslope are usually non-wooded.

IV.4. Conclusions

Originally a NNE-SSW striking river pattern adapted to the structure of the folded flysch was present north of the fault rim and west of a diapyr exposing breccia of Triassic age. In the sinking area an E-W drainage prevailed also determined by the structure of the basement. Tectonic movements disturbed the pattern in the surroundings of Ain Draham and separated it in two components directed NNE and SSW respectively. Further disturbance was effected by the Oued Kebir from the west and by two rivers in the Miocene zone of subsidence from the south.

Chapter V

THE GEOLOGICAL SETTING

The Seloul valley is an anticlinal valley no more than two to three kilometres in width. The Oued Seloul has cut down rather steeply, as a result of which the difference of altitude between the river and the culmination of the divides amounts to approximately 500 m. No geological map is available of this valley and its surroundings, and consequently, the geology cannot be discussed in detail. To furnish the data required for geomorphological study a map has been drawn on which an outline has been given of the distribution of the parent rocks in the valley of the Oued Seloul (fig. 6).

V.1. Numidian Flysch

The more recent flysch deposits consist of sandstone and soft shales. The resistant sandstone constitutes the first-order divides, while the lower parts of the valley, unless consisting of marl and limestone, are built up of soft shales.

The steep sandstone ridges are wooded with cork oaks and have gradients of 20-35 %. The much flatter slopes in the soft shales of 12-14 %. Marls and marl-limestone of the Medjanian Flysch protrude from the soft shales as ridges.

The flatter parts of the landscape are often non-wooded and covered by grass. The difference in vegetation accentuates the transition to the steeper forested parts.

V.2. Medjanian Flysch

Tectonic movements have elevated the oldest complex of flysch deposits to such a degree that incision by the river ensued. The flysch consists of black and grey marls with yellow boulders of 'calcaires silicieux'. The map (fig. 6) reveals that the marl and marl-limestone

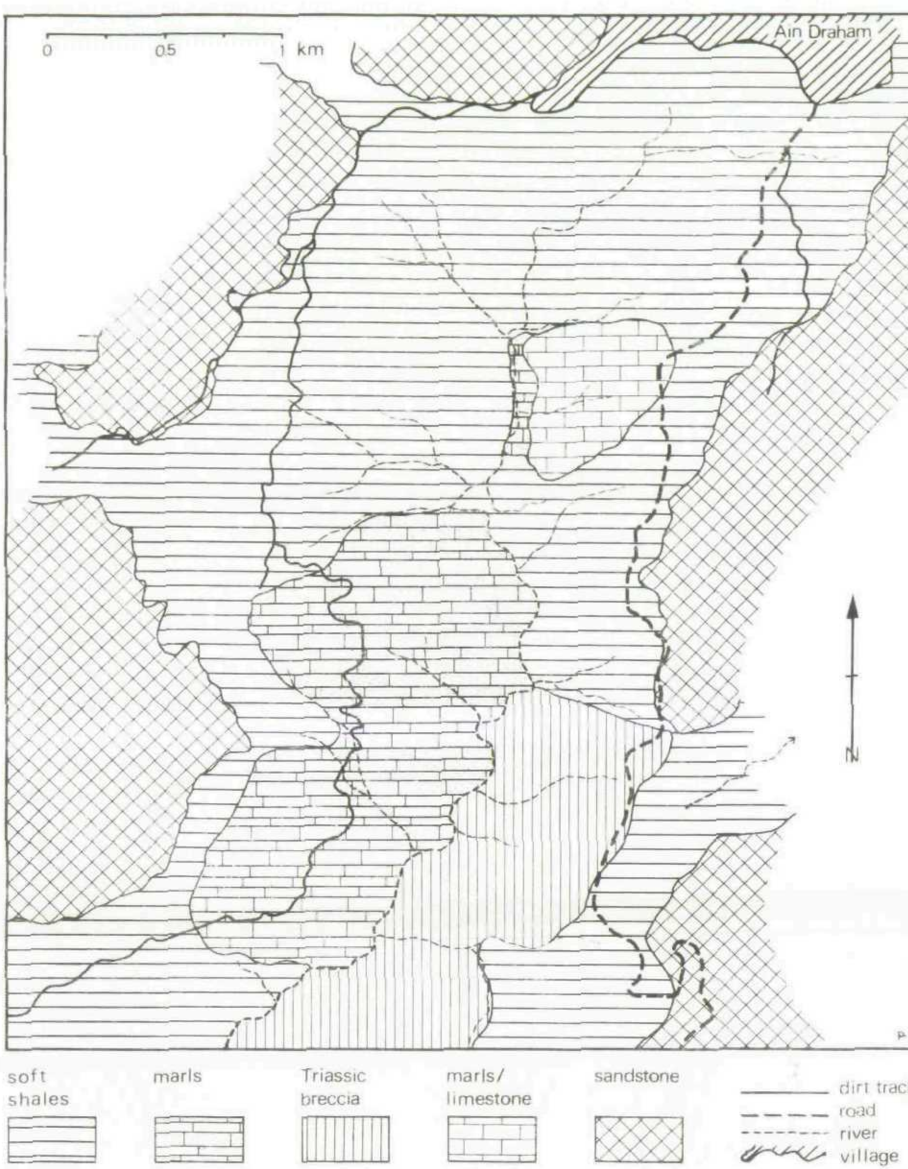


Fig. 6. Map showing the different parent materials in the valley of the Oued Seloul.

are located in the valley at either side of the Oued Seloul. The upper surfaces of these ridges are flat, but towards the Seloul they quickly grade into relatively steep slopes.
The vegetative cover consists of grasses and shrubs and small fruit trees planted on terraces constructed by the 'Service des Forêts'.

V. 3. Triassic Breccia

In the south a diapyric injection occurs, the Triassic breccia of which constitute the eastern valley-side of the Oued Seloul three kilometres down-stream from Ain Draham. The surface of this diapyr is gently undulating and flat but the valley-side towards the Oued Seloul is a steep slope 100 m in height descending with a gradient of approximately 50 %.

V. 4. Relationship between Parent Rock and Slope

Dependent on the parent rocks the cross-section of the Seloul valley may assume three different shapes. Plate 3. gives an impression of the valley where the sides are formed by sandstone and soft shales. The steep, wooded sandstone slopes with a sharp and pronounced break in the terrain pass into the flatter slope of the soft shales lower in the valley.

Plate 4. On the foreground the marl-limestone ridge; in the centre of the photograph the marl ridge is visible and on the background the flat 'Triassic' diapyr.

The transition of the slope in the sandstone to that in the marl is clearly different. The former is somewhat less steep here and the break in the terrain on the transition into the flat marl ridges is much less pronounced. Figure 7. shows a cross-section of these types of slopes.

From plate 4. an idea may be gained of the location in the landscape of such a marl ridge. In the background of this photograph the location of the 'Triassic' diapyr may be observed. In this Triassic breccia the third type of slope has been formed; a striking feature in this slope is the abrupt transition of the gently undulating surface into the steep valley-side of the incised Oued Seloul (fig. 8).

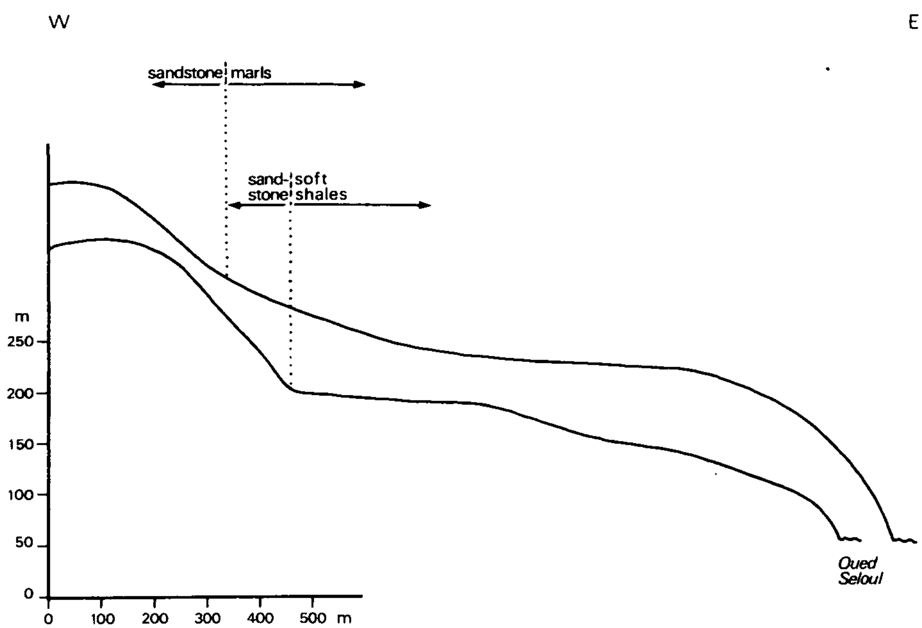


Fig. 7. Cross-section of the sandstone-soft shale slope profile and of the sandstone-marl slope profile.

PART TWO: THE VALLEY OF THE OUED SELOUL

Chapter VI

THE OUED SELOUL

At present the Oued Seloul forms the upper course of the Algerian Oued Kebir. Prior to the capture by the Kebir, the Oued Seloul flowed in a SW direction. Nowadays, five kilometres down-stream from Ain Draham, the river cuts through a fold while the direction of the stream changes with a distinct bend from SW into W.

VI.1. Phases of Incision of the Oued Seloul

Subsequent to the capture by the Oued Kebir the Seloul began to incise sharply. Where the eastern valley-side is formed by Triassic material the influence of this vertical, fluviatile erosion can clearly be discerned in the landscape. At this site the gently undulating landscape of the 'Triassic' diapyr passes abruptly into a steep slope towards the river. Besides, the streamlets flowing towards the Seloul from the Triassic breccia exhibit a pronounced nickpoint which nowadays, as a result of headward erosion is located some ten metres further from the Seloul than the break in the terrain (fig. 8, plate 5. and 6). Since the capture the vertical erosion of the Seloul at this spot amounts to about 100 metres.

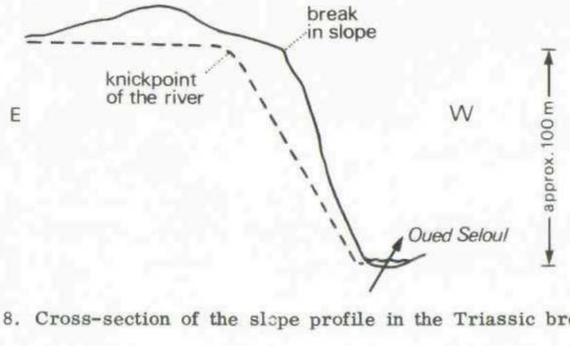


Fig. 8. Cross-section of the slope profile in the Triassic breccia.

Plate 5. 'Triassic' diapyr: photo taken upstream from the knickpoint in a tributary of the Oued Seloul.

Plate 6. 'Triassic' diapyr: photo taken downstream from the knickpoint in a tributary of the Oued Seloul.

Traces of deep vertical erosion are also found in the more northerly located part of the valley, but only in the resistant marls.
At the west side of the river two phases of incision, separated from each other by a small flat part of the terrain, can be distinguished in the marl ridge of Sidi Abdullah. Both phases of incision can also clearly be traced in the limestone and marl on the east side of the river (compare fig. 6. and 9).

Immediately south of the valley-floor divide of Ain Draham, the valley head is flat and bowl-shaped (fig. 9). In the soft shales of this valley head the effect of the most recent fluviatile erosion is manifest in a steep V-shaped valley-side. Growing older towards the south this erosion side looses its V-shape and the type of slope comes into being which is characterized on the geomorphological map as exposing relatively unweathered parent rock. The distinct boundary at the upper side of the incision is absent here. If these V-shaped valley-sides in the soft shales become older still, their initial shape can neither be traced in the field nor on aerial photographs.

VI. 2. Old Flat Parts of the Terrain on the Marls

Two flat surfaces have been mapped in the higher part of the valley, in which the effect of fluviatile dissection can be discarded (fig. 9). The first flat part is located on the marl ridge west of the Oued Seloul and the second along the road from Ain Draham to Fernana, approximately 1.5 km south of Ain Draham on the marl and limestone at the east side of the Seloul. Both flat parts are located at a height of 700 m.

The slopes between these elevated flat parts and the river being the only slopes in the flysch deposits bearing evidence of fluviatile phases of incision, the conclusion seems warranted that these marls, at any rate compared with the soft shales, are resistant to a degree which permits preservation of older geomorphological forms.
Consequently the flat parts of the terrain on the marl ridges east and west of the Seloul are considered as the remnants of an old surface, which nowadays has a slope of 2-5 %.

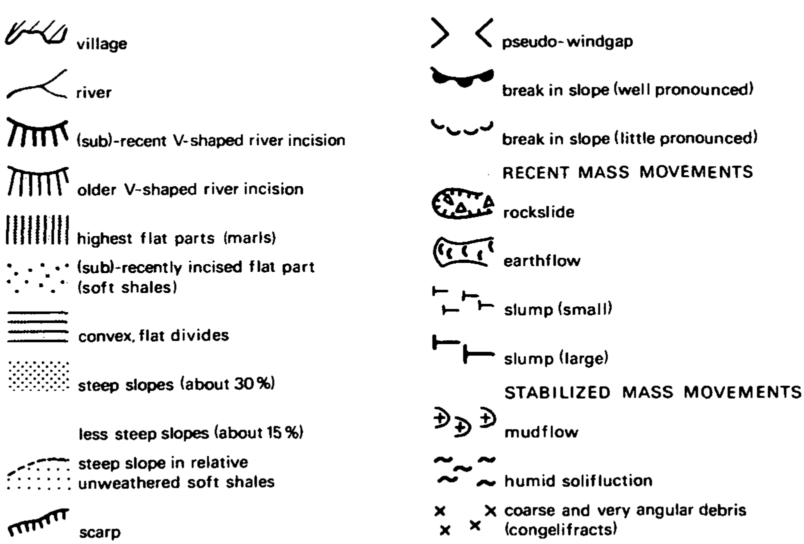
VI. 3. The Flat Part of the Terrain on the Soft Shales

Remnants of a flat part can be traced not only on marls but also on the less resistant soft shales. The flat, bowl-shaped valley head directly south of Ain Draham is concerned here, which extends from the transition of the sandstone to the soft shales as far as the river. This flat part of the terrain is located distinctly lower than those on the two marl ridges and moreover its slope of 8-10 % is steeper. In the valley head this surface has been well preserved although it is being affected by the most recent vertical river erosion. Down-stream the fluviatile dissection is older and the flat part much less pronoun-

ced, whereas in the most southern part, opposite the 'Triassic' diapyr, there is no question of a flat part of the terrain in the soft shales. At this site the soft shales display a very irregular and highly disturbed surface. Naturally this only obtains for the western bank; the steep eastern valley-side is formed by the resistent Triassic material.
As the flat part of the terrain on the soft shales is being eroded now, it must have been initiated intermediate to the present phase of incision and the one before that.

VI. 4. Conclusions

In the valley of the Oued Seloul two remnants may be traced of old flat parts of the terrain well developed on the marls. The levelling period has been succeeded by at least two phases of incision of the Oued Seloul, traces of which can still be found on the marl and marl-limestone ridges.
The steep valley-side formed by the incision has been well preserved in the Triassic material, but cannot be subdivided into phases with the same explicitness.
Prior to the last phase of incision a flat part of the terrain formed on the soft shales, which, due to the effect of the most recent phase of incision, has almost entirely disappeared now. Only in the upper course of the Oued Seloul, in which the most recent incision dates from the recent past, remnants of this flat part still occur in between the steep, V-shaped incisions.



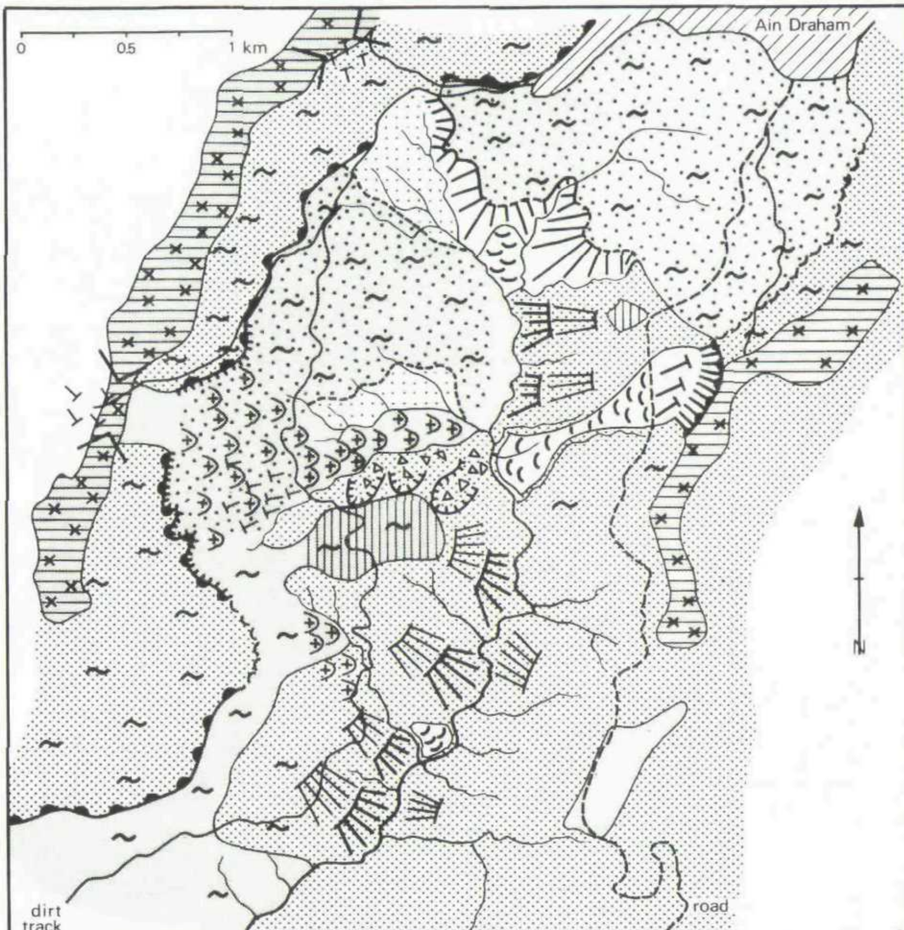


Fig. 9. Geomorphological map of the valley of the Oued Seloul.

Chapter VII

MASS MOVEMENTS

The relief of the valley of the Oued Seloul is strongly determined by the same geomorphological processes which, as will be demonstrated, have had a far-reaching influence on the origin and the distribution of the various soils. Mass movement is the most significant geomorphologic process. The rock-type (flysch), the geomorphological evolution (producing a steeply incised anticlinal valley) and the high precipitation have contributed to the strong development of this process.

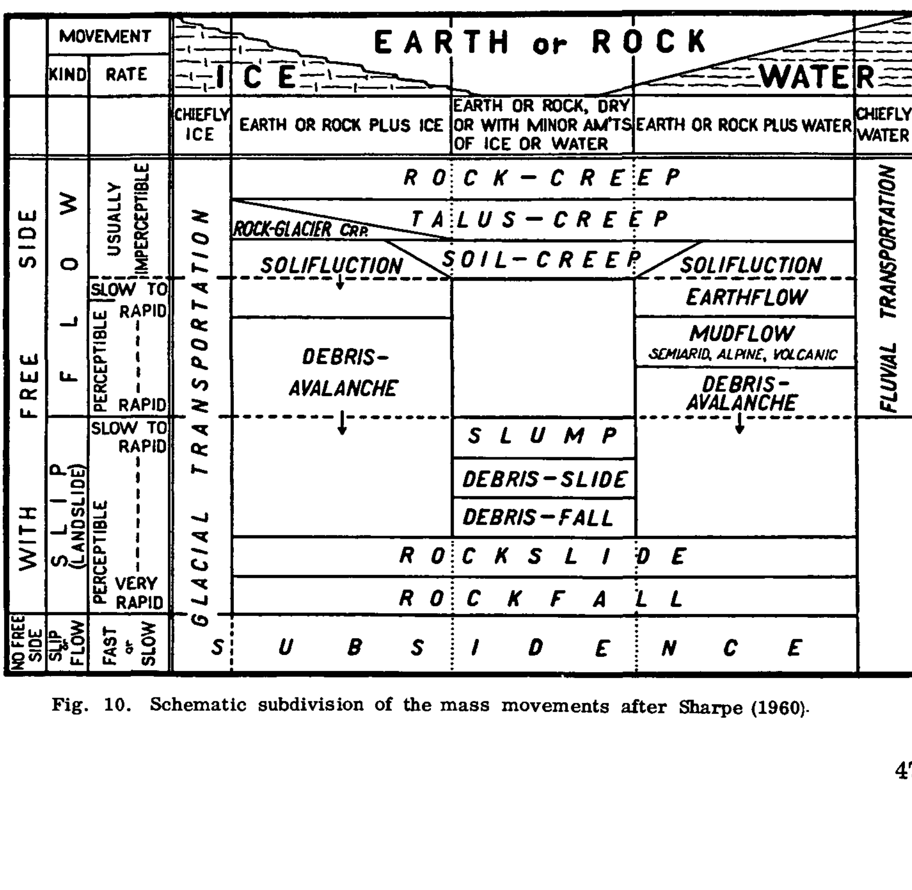


Fig. 10. Schematic subdivision of the mass movements after Sharpe (1960).

VII. 1. General Classification of the Mass Movements

The various types of mass movement to be discussed have been classified following a subdivision of Sharpe (1960). This subdivision is based on the water-content of the material (fig. 10), the nature of the movement (flow and slide, fig. 11) and the kind of material. Furthermore, mass movements have been subdivided into active and stabilized types (Milliès-Lacroix, 1965; Maurer, 1968).
This differentiation makes it possible to draw material conclusions relative to the geomorphological development of this valley (compare chapters IX, X and XI).

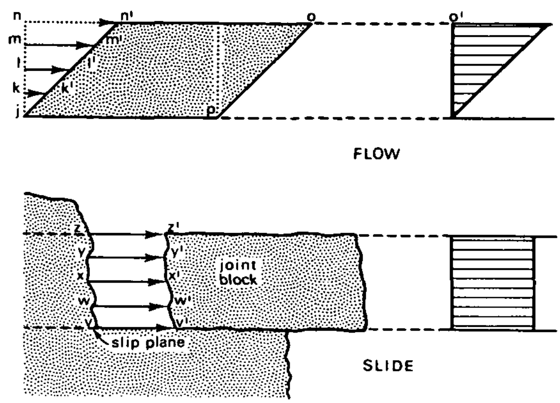


Fig. 11. Flow and slide movements (after Sharpe, 1960).

VII. 2. Concentrated Types of Mass Movement on the Soft Shales

The mass movements on the various parent rocks display a highly disparate intensity.

--- Mass movements are absent on the Triassic material.
--- The marls and sandstone are also relatively stable.
--- In the past and at present, especially the soft shales have been strongly affected by the activity of mass movements.

VII. 2. 1. Earthflow

One of the finest and also most remarkable examples of mass movement in this valley is an earthflow crossing the road to Fernana 1.5 km south of Ain Draham. The earthflow** as a rule belongs to the rapid flowage type, yet the actual movement cannot directly be obser-

** Earthflow: 'a typical association of slumping and flowage. It would seem advisable to class as earthflows the slower-moving types usually found on gentle slopes, placing the more rapid examples in the debris avalanche group' (Sharpe, 1960).

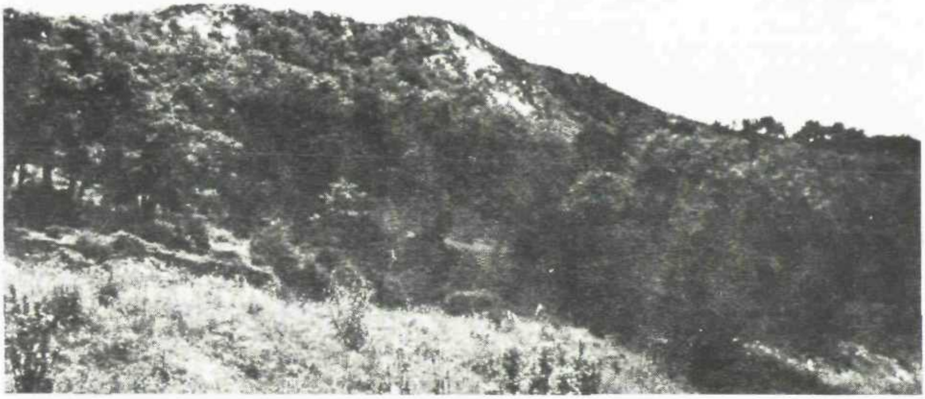


Plate 7. The scar in the sandstone first-order interfluve caused by an earthflow.

Plate 8. A concrete wall constructed over an earthflow along the road from Ain Draham to Fernana.

ved in the terrain. However, the movement may be established from several secondary indications. For instance, road and walls have to be repaired regularly at the site where they are constructed across the flow (plate 8).
This earthflow is almost identical to the type Sharpe (1960, p.54) described as a typical example. Figure 12. shows a cross-section of this movement, which displays the characteristic association of a slump up-slope and a flow movement more down-slope. Near the Oued Seloul the latter forms a 'bulging dome', with many small faults, scarps and fissures. As a result of the slide movement, and directly above the earthflow in the divide a large scarp came into being, the scar of this slump (plate 7). Directly below this scar a marshy part of the terrain with several small lakes is the consequence of backward rotation of the blocks, which in sliding down caused a slope inversion.

Very characteristic of this mode of transport is the somewhat triangular shape of the 'dome' below in the valley; the 'dome' is bordered by streamlets on either side. Just as remarkable and indicative is the typical semicircular bend of the principal river around the foot of the mass (fig. 12). These indications permit mapping of old and in the field less striking earthflows by means of aerial photo-interpretation (fig. 9).

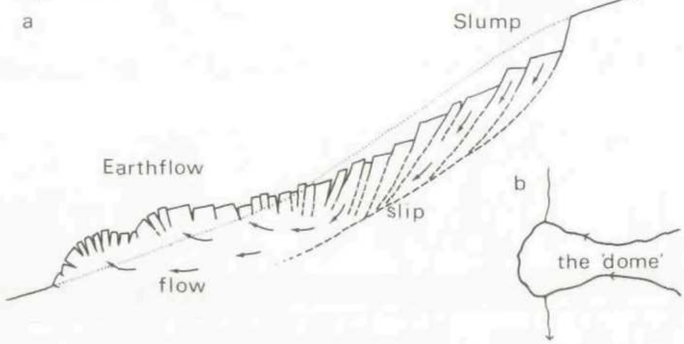


Fig. 12. a. Cross-section of an earthflow (after Sharpe, 1960)
b. The bulging dome of an earthflow.

VII.2.2. Debris Avalanche
A very recent example of this type of mass movement has been observed at one location only (May 1967). One kilometre north of Ain Draham at the valley side of the road to Tabarka a debris avalanche** very suddenly came into being and in its rather narrow path carried part of the road with it (plates 9 and 10). The asphalt road has been built on a rather steep slope (20-25 %) in the soft shales, which at this site are covered with an unconsolidated layer of debris.
The debris avalanches are usually related to a high water content,

** Debris avalanche: 'a sudden and even catastrophic movement of the soil mantle' (Sharpe, 1960).

generally incidental to heavy rainfall, but at this locality also to the spring welling up at the mountain side of the road. The water of this spring is caught in a gully running parallel to the road. From here the shale under the road becomes saturated, thus increasing the weight of the unconsolidated debris and at the same time reducing the internal friction. A simple remedy seems the construction of a culvert under the road through which the water can drain off without saturating the rock.
The debris avalanche, like the earthflow, may also be considered an example of rapid flowage, but unlike the earthflow the movement is very sudden, very fast and very short-lived.

As is the case of the earthflow the immediate cause of this phenomenon is a slip movement, which lower down on the slope looses it typical slip-plane and passes into a flow movement.

Plate 9. The result of the debris avalanche. In the top left corner the little source is visible.

The 'Service des Forêts' has constructed terraces in a comprehensive programm of reforestation to cope with the soil erosion in the Kroumirie. Initially terraces were built in series without interruption and parallel to the contour-lines. These terraces are conducive to infiltration of water in the soil with a consequent increase in the danger of sliding. It is, therefore, advisable to resort to reforestation without terracing, as is more and more done in practice.

Plate 10. The *debris avalanche.* Clearly visible is the great influence of the water content on this movement.

VII. 2. 3. Slump

Locally intense slump movements** are active on the slopes in the valley, especially on the parts of the slopes below those depressions in the crests of the interfluves which closely resemble wind gaps (plate 11). However, wind gaps need not be concerned here, for the depressions in the interfluves are not the remnants of an old river system located at a higher level, but are bound to zones of weakness in the sandstone, aligned along the cross faults mentioned before (chapter III. 2.). The intensity of the erosion at these locations caused the gaps to be carved out. At present particularly the slump (slipping) process has been very active here.

Two types of slump movement could be distinguished:

--- Slip while retaining angle of slope (fig. 13).
This process manifests itself in the form of especially 'terracettes' and rumples (=washing-board pattern) on grass-covered slopes. Rumples are also known in literature as 'rynkeli', lines of equal pressure and as 'cow-steps' (plate 12) (Ødum, 1922).
The preservation of the angle of slope is indicative of the absence of rotation.

** Slump: 'the downward slipping of a mass of rock or unconsolidated material of any size, moving as a unit or as several units, usually with backward rotation on a more or less horizontal axis parallel to the cliff or slope from which it descends' (Sharpe, 1960).

Plate 11. Pseudo wind-gap.
Intense activity of slump movements on the slopes under this wind-gap.

Plate 12. Terracettes: slip without rotation.
Note the important amounts of coarse and angular sandstone debris on these slopes.

--- Slip with consequent change of the angle of slope (fig. 13). Fine examples of this process have been called 'pseudo-pedimentation', and could be found on the grass slopes (plate 13). In the terrain a 'pseudo-pediment' is noted by:
- a pediment-like flat part of the terrain and
- a well-developed scarp as a boundary up-slope.

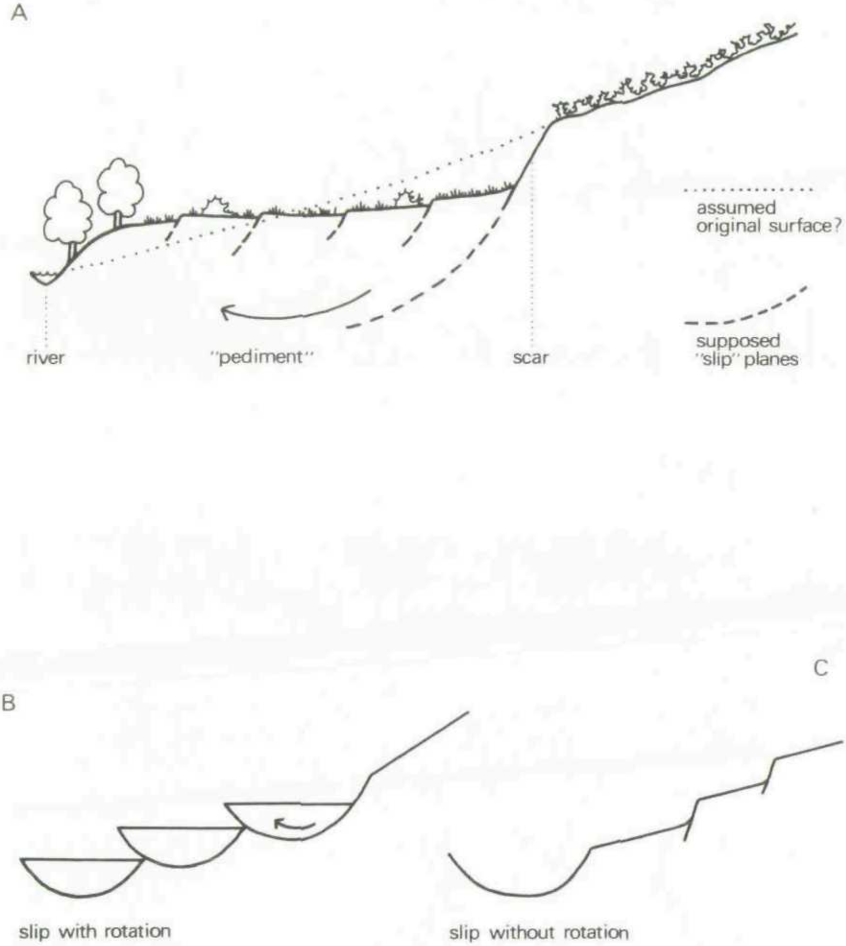


Fig. 13. a. 'Pseudo-pedimentation'.
b. Slip movements with backward rotation.
c. Slip movements without backward rotation.

In figure 13. the cross profile of a slope subject to 'pseudo-pedimentation' has been shown in full lines (compare plate 13). The 'pediment' itself is covered with grass; the scarp has no vegetation at all. Higher up the slope is grown with shrubs.
The phenomenon may be described as a complex of slump movements, each with a clear backward rotation (tilt). The result is a flat part of the terrain covering several hundreds of square metres. The scarp is the boundary between the mass subjected to slump and the stable rock and consequently, it may be considered a scar of the downward slipping.

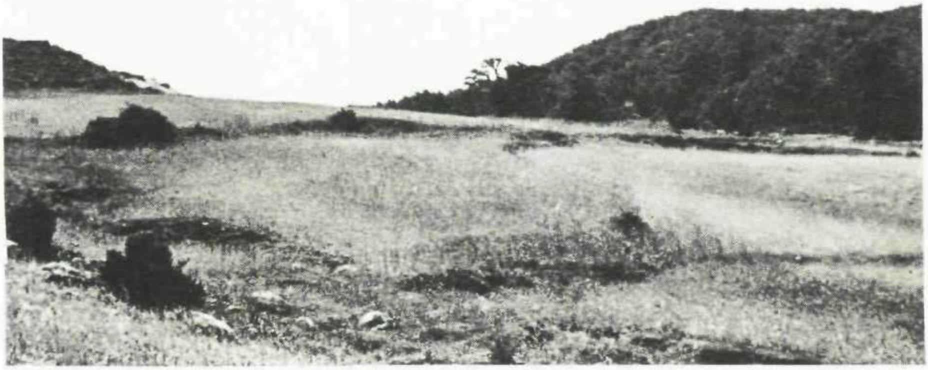


Plate 13. A 'pseudo-pediment'.
On the left the non-vegetated scar of the movement; slip with rotation.

The occurrence of downslope bending and drag of bedded rock ('Hakenwerfen') at the base of the unstable layer is indicative of a process of rather superficial slip movements and is closely related to the origin of the 'terracettes'.

Geomorphological importance attaches to this phenomenon, for in this way pediment-like flat parts of the terrain may arise simultaneously and at various heights in the soft shales. Consequently, the flat parts do not point to interrupted fluviatile downcutting.
This process is not observed on the marls; hence it is assumed that the flat parts of the terrain on the marls indicate phases of decreased downcutting and therefore may be used for correlation purposes.

Also determined by slump movements a rather particular type of valley has developed in the soft shales. Although usually met with in the pseudo-wind gaps in the interfluves this type may also be found

Plate 14. Wide and bowl-shaped valley head. Slump of the valley sides.

more down-slope (fig. 9). The head of such a valley is very wide and bowl-shaped; noticeable in this respect is the contrast in dimension between the very small rivulet and the relatively wide valley (fig. 14). A cross-section shows that the shape of the valley is determined to a high degree by the slip-off of slabs of soil mass several metres in width at either side of the incision, which affords a very fine example of slumping (plate 14).

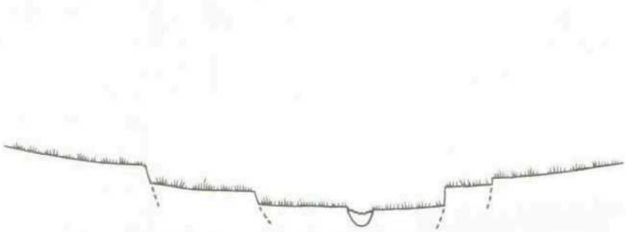


Fig. 14. Cross-section of a bowl-shaped valley head.

Although the above described type of valley developed as a result of slumping, subsidence also played a substantial role.

VII. 2. 4. Subsidence

The up-slope surfaces of the wide, bowl-shaped valleys are always very marshy. Down-slope from these marshy spots hollow spaces developed some 30 to 40 cm below the sod, and in due time caused the top layer to cave in over an area of several square metres. Lower in the valley often tunnel-like structures came into being below the top layer.

Analysis of samples of the seemingly stable layer and the layer that is being removed reveals no substantial differences in texture, structure or clay-mineral composition (fig. 15). The only explanation can be that the rootlets in the upper 30-40 cm (=rooting depth) i.e., the sod, to a certain extent inhibit the transport of material. Directly below the sod the water will effect a sub-cutanic creep or washing out, with resultant development of hollow spaces. Kirkby (1969) describes a 'subsurface wash' affected by throughflow carrying material in solution and in suspension within the soil mass, causing a subsurface network of small tunnels in soil and poorly cemented sediments: piping. Summarizing: the cause of the development of this peculiar type of valley is subsidence due to undermining of the sod, and the immediate cause is the subsequent slump of the valley-sides.

VII. 3. Concentrated Types of Mass Movement on the Marls

Unlike the soft shales the marls are very stable. Only on the steepest parts of the valley-side are fragments of the unweathered material wearing away locally. Thus originates the only type of mass movement observed on the marls.

VII. 3. 1. Rockslide

On the geomorphological map (fig. 9) the sites showing rockslide** activity are indicated. From this map it becomes evident that the traces of the phases of incision of the Oued Seloul have been removed by either a tributary of the Oued Seloul or a rockslide.
At many sites traces of the two phases of incision can clearly be recognized, which indicates that mass movements in general and the rockslide in particular have been of little consequence on the marls.

** Rockslide: 'the downward and usually rapid movement of newly detached segments of the bedrock sliding on bedding, joint, or fault surfaces or any other plane of separation' (Sharpe, 1960).

	0– 2 micron	2–50 micron	50–+ micron	S– value	T– value	V– value	Ph H_2O	Ph KCl	MIXED LAYER 28 Å	SMECTITE	CHLORITE/ VERMICULITE 14 Å	MICA 'WELL' ** CHRYSTALLIZED	MICA 'POORLY' ** CHRYSTALLIZED	KANDITE	ANATASE	QUARTZ
subsidence 10 cm depth:	51.5	29.0	19.5	15.6	23.5	66	5.7	4.6		(+)			tr.	+	x	2-4%
subsidence 90 cm depth:	55.5	19.5	25.0	22.3	27.9	79	6.8	6.0		(+)			tr.	+	x	2-4%

** for distinction between 'well' and 'poorly', see Appendix.

N.B. range from ++++: dominant, to (+): small amount.
x : present

Fig. 15. Table showing the analytical data concerning subsidence.

VII. 4. Areal Types of Mass Movement

After the concentrated and local forms the mass movements will be discussed that effected an areal denudation of the terrain. The areal influence of this type of mass movement is manifested in the slope deposits that cover all the slopes in the Seloul valley, irrespective of the parent rock, with the exception of the Triassic breccia. These deposits are found on both soft shales, sandstone and marls.
All (areal) processes to be mentioned in this study have been called stabilized because their correlative deposits are covered by recent colluvium.

VII. 4. 1. Humid Solifluction

Nearly all slopes in the Seloul valley are overlain with a detrital cover of coarse, angular material in a loamy matrix. The coarse detrital material in the thicker layers can occasionally be observed to have a certain degree of arrangement parallel to the slope; as a rule, however, the orientation is irregular.
The coarse detrital material consists of blocks of sandstone, which, being found at distances far removed from the source area (the sandstone slope), can only have been transported there. They are embedded in the loamy, very heterogeneous and unsorted material (plate 19). These deposits are highly suggestive of solifluction material in the atypical form as described by e.g., Raynal (1956, 1964), Butzer (1964) and Joly, Raynal (1961) in North Africa and Spain. These authors called the deposits humid solifluidal (pluvial solifluction) (compare also Dresch et. al, 1960, Guillien and Rondeau, 1966).

Plate 15. Mudflow, stabilized slope deposit, covered with recent colluvium. Local erosion of this colluvium has recently exposed the coarse and angular sandstones at the surface.

VII. 4. 2. Mudflow

Approaching the river the amount of coarse detrital material in the solifluidal deposits generally decreases. More down-slope, however, many lumps of coarse sandstone locally have been transported as far as the river. The areas in which the detrital sandstone occurs at such low elevation are shaped like the tongue of a flow movement (see the geomorphological map, fig. 9). Furthermore, rivulets run at either side of the weakly 'dome-like' shape. It has to be concluded that locally the humid solifluction has passed into a mudflow (plate 15).

VII. 4. 3. Distribution of the Areal Types over the Slopes

The first-order divides exhibit a remarkably flat, gently convex shape and reach a maximal width of 100 m. Deposits of humid solifluction and mudflow are not met with on these highest parts of the valley. These flat crests of the interfluves are overlain with a fairly thick cover of detrital sandstone, ranging in size from coarse sand to angular lumps of 1 cubic metre, which may best be considered 'congelifracts', rock fragments broken up by frost splitting (plate 16) (Hamelin and Cook, 1967). At some sites on these crest of the interfluves tor-like sandstone outcrops are found (see chapter VII. 4. 5.), (Linton, 1955 and 1964; Palmer and Radley, 1961; Demek, 1964 and Caine, 1967). The sandstone constituting these tors shows rounded weathering shapes which are almost identical to those of 'woolsack' weathering (plate 17).

Plate 16. Firebreak on the very wide first-order interfluves. Very coarse angular sandstone debris on the foreground (congelifracts); contrast with the rounded, woolsack-like appearance of the tor in the background.

Plate 17. Tor-like sandstone outcrop.

Locally the steep sandstone slopes are covered with deposits of humid solifluidal processes. Especially on slopes with a NW strike this complex can be rather thick (1 to 2 m).
Trench-like depressions are often found at sites that are not covered with solifluidal deposits. Nowadays the detrital covers on the steep slopes covered with cork oaks are overlain with recent, sandy and humose colluvium, which has accumulated considerably especially in the depressions.

Deposits of humid solifluction are also found on the flatter slopes of the marls and soft shales lower down the valley-sides. On the flatter slopes the products of humid solifluction vary in thickness, yet it is evident that the slopes have undergone distinct planation, in the course of which all depressions were filled and finally became part of a continuous slope. Locally on these slopes the humid solifluction passed into a mudflow.

VII. 4. 4. Explanation of the Complex of Stabilized Slope Deposits
According to Anderson's (1906) definition of solifluction** a frozen subsoil is not an essential condition and the phenomenon is certainly

** Solifluction: 'this process, the slow flowing from higher to lower ground of masses of waste saturated with water (this may come from snowmelting or rain), I propose to name solifluction (derived from solum, 'soil', and fluere, 'to flow')' (Anderson, 1906).

not restricted to cold climates. Later there was a growing body of opinion (i.a., Eakin, 1916) which held that solifluction was a phenomenon of areas with permafrost. However, also the classification of Sharpe (1960, p. 54) indicates that solifluction may be operative under highly humid conditions without permafrost.
The term solifluction is now almost inseperably bound up to periglacial conditions. For this reason the process operative in the valley of the Oued Seloul can be more accurately designated as humid solifluction. Humid solifluction has to be considered a process operative in a landscape with a very sparse vegetation and without permafrost, on which spasmodic and torrential showers of rain exert intense sheetflood erosion.

It should be noted that humid solifluction is active under very much the same conditions that Sharpe (1960, p. 56) mentioned for mudflow, viz:
--- abundant but intermittent watersupply and
--- absence of any substantial vegetative cover.

The process is no longer active and the deposits are stable, yet as a rule the precipitation is still torrential and spasmodic.

Furthermore, abundant amounts of detrital material are essential to both humid solifluction and particularly mudflow (Sharpe, 1960 and Zaruba and Mencl, 1969). In this connection reference is made to the coarse, angular detrital material on the flat divides, rock fragments broken off as a result of frost splitting. Frost weathering of the sandstone has provided the large amounts of detrital material essential to humid solifluction and mudflow. According to St. Onge (1969) 'is frost shattering most effective in relatively soft, very porous rocks such as sandstone'. Moreover, the fine-grained matrix is indicative of a period of more pronounced chemical weathering prior to the cold period.

VII.4.5. Tor-like Sandstone Outcrops

An explanation of the origin of a tor is implicit in the definition given by Linton (1964): 'A Tor is a residual mass of bedrock produced below the surface level by a phase of profound rock rotting effected by groundwater and guided by joint systems, followed by a phase of mechanical stripping of the incoherent products of chemical action'. Palmer and Radley (1961) consider an exclusively periglacial explanation possible (mechanical stripping only), yet, as far as the Kroumirie is concerned, preference has to be given to the two-phase theory of Linton.

This preference is based on the sandstone of the scar effected by the large earthflow, and of various quarries as well as having been observed to display a red hue down to a depth of 30 to 40 m and to be jointed by numerous deep fissures. The clay fraction of thin clays skins sampled in the joints at great depth (30 m) below the present surface, were almost entirely composed of kandite, e.g. sample 10-7-1,

SAMPLE NO.	SAMPLE TAKEN FROM	MIXED LAYER 28 Å	SMECTITE	CHLORITE/ VERMICULITE 14 Å	MICA 'WELL' ** CRYSTALLIZED	MICA 'POORLY' ** CRYSTALLIZED	KANDITE	ANATASE	QUARTZ
10-7-1	deep fissures in sdst.					?	+++	xx	0 %
10-7-2	deep fissures in sdst.					(+)	+++	xx	0 %
17-6-1 I	recently weath. sdst.					tr.	(+)	x	1-3 %
20-6-1 BC	soil on sandstone			(+)		(+)	+(+)	x	3-5 %
29-5-1	recent colluvium					tr.	+	x	5-8 %
6-6-4	mudflow		(+)			+	++	xx	2-4 %
30-6-1	earthflow	tr.				tr.	++	xx	3-5 %
17-6-2	rec. weath. soft shale	x		?		?	(+)	xx	1-3 %
10-7-7	slump		(+)			tr.	+	x	2-4 %

** for distinction between 'well' and 'poorly', see Appendix.

Fig. 16. Table showing the clay-mineralogical data concerning the deep weathering of the sandstone.

which is unique for the flysch rocks in this area (fig. 16). The samples taken here were also the only samples in which quartz is absent in the fraction smaller than 1 micron, consequently, it seems likely that the clay skins are remnants of a deep, tropical weathering.

Furthermore, the lumps of sandstone at the surface are nowadays hardly being rounded at all. The congelifracts occurring in the deposits of humid solifluction and mudflow are also very angular. The inference is that the tors obtained their 'woolsack-like' appearance in a period of attack by tropical weathering of the sandstone below the surface level.

VII.4.6. Conclusions

The stabilized slope deposits and terrain forms in the highest parts originated in a landscape with a greatly reduced vegetation, on which torrential rains effected a humid solifluction locally passing into a mudflow. This type of mass movement brought about a pronounced altiplanation** on the crests and thus removed the deep weathering layer which had come into being under preceding tropical conditions; also it carved out the prominent parts of the weathering front as tors.

** Eakin (1906) pointed to the levelling effect of solifluidal processes, which effect he designated as 'equiplanation'.
The levelling action is reflected of the filling of existing depressions lower in the valley (see chapter X.2.). Altiplanation is a less comprehensive conception and is used here in the original meaning following Eakin (1916): 'a special phase of solifluction that, under certain conditions, expresses itself in terrace-like forms and flattened summits and passes'.

Chapter VIII

COLLUVIUM

With the change of climate outlined in chapter VII.4.6., into the present climate, the type of weathering changed as well. At present a fine weathering product is formed instead of the angular detrital material. This produces a sandy colluvium which locally covers the angular detrital material.

VIII.1. Mass Movement and Mass Transport

A clear distinction has been made between mass movement and mass transport. This very workable distinction has been introduced by A. Penck as early as 1894.
Mass movements operate under the influence of gravity, with water acting as a lubricant mainly. In this process aggregates and structural elements are shifted down the slope for the greater part in their natural coherence, in the course of which process the coherence may become disturbed to a certain degree.
Mass transport on the other hand is a process in which soil particles are transported along the slopes in 'single grain' condition. Also very small aggregates may be concerned. In any case there is a strong tendency towards sorting during mass transport. Water acts as the transporting agent. The particles loosened by so-called rainsplash erosion, are carried further down-slope by unconcentrated rill wash.

The rain-washed material, colluvium (slope wash), may accumulate either in depressions or at the foot of the slope, or when it reaches the valley floor it is carried away as alluvium by the rivers. Due to the selective action of the water which is little concentrated or not concentrated at all and washes away on the surface (overland flow), the grains of the transported particles range in size from fine clay to coarse sand (Strahler, 1969).

VIII. 2. Normal Soil Erosion and Accelerated Soil Erosion

The higher parts of the area are usually subject to degradation ('degradation is levelling down', Thornbury 1960). In the opinion of Strahler (1969): 'such a slow removal of soil is part of the natural geological process of landmass denudation and is both inevitable and universal. Under stable, natural conditions, the erosion rate in a humid climate is slow enough so that soil with distinct horizons is formed and maintained, enabling vegetation to maintain itself. Soil scientists refer to this state of affairs as the geologic norm'.
Scheffer and Schachtschabel (1966, p. 373) also refer to colluvium as a normal soil erosion: 'Auch unter natürlicher Vegetation ist die Erosion nicht restlos ausgeschaltet. Bei Löss-Parabraunerden unter Wald im niedersächsischen Mittelgebirge (Einbeck) würde z.B. von Grosse (1962) festgestellt, dass die Mächtigkeit des Al-horizontes von 33-40 cm bei weniger als 5 % Gefälle infolge Erosion des Oberbodens auf 25 cm bei mehr als 15 % Gefälle absinkt'.
The colluvium yielded as a result of this process has specific properties. The material derived from soils with a humose A-horizon contains a higher proportion of well-humified organic material. In Tunisia the colluvium contains a high proportion of organic matter (see profile description soil unit 2). Besides, from pollen analysis it became extremely plausible that this colluvium has been formed by rain wash in an area with a predominantly forestal vegetation. Following the terminology in use, this material is referred to as 'geological colluvium'. It is clearly distinct from the colluvium that owes its origination to 'accelerated soil erosion', which may occur as a consequence of human interference in the landscape.

The ratio rain wash - infiltration is of material significance to the rate of degradation of a surface. The degree of infiltration determines the amount of precipitation that remains and washes away on the surface. Destruction of the vegetation brings about drastic changes in the ratio infiltration - rain wash. The precipitation is no longer intercepted by the foliage and rain drops fall immediately on the soil.
Intense action of 'splash erosion' moves the 'single grains' down-slope, but more important, the structure of the soil is being destroyed whereas at the same time the topsoil becomes impermeable. The result is a significant decrease of the infiltration capacity and a distinct increase in the amount of 'overland flow', with a consequent pronounced increase in the extent of the mass transport (Kirkby, 1969).
Under these conditions a soil profile may be truncated and the geologic colluvium laid down at sheltered sites in an earlier period with natural vegetation, may even be eroded away as is now clearly the case in the valley of the Oued Seloul.
Not only the humose topsoil but also the non-humose, deeper horizons have contributed to the formation of this anthropogenic colluvium, which consequently is less rich in organic matter. The latter is also less humified.

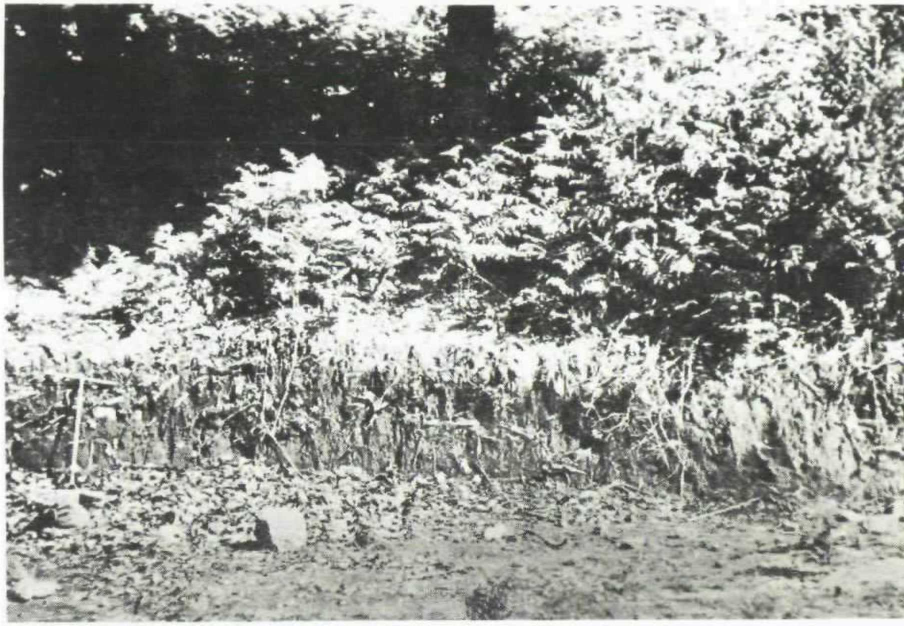


Plate 18. Depression in the deposits of the humid solifluction filled with recent colluvium.

Plate 19. Deposits of the humid solifluction on the steep slopes in the sandstone. Soil shows tendency towards podsolization.

VIII. 3. Accumulation of Colluvium in the Corrasional Troughs

The colluvium covers the deposits of humid solifluction. This solifluidal process has eroded trough-shaped depressions (corrasional troughs) in the steep sandstone slopes (see chapter X. 2.).
At present the depressions are filled with thick deposits of the very humose colluvium (plate 18).
In this respect it is interesting to note that in slope deposits in Algeria which consist of an abundance of angular rocks Beaujeu Garnier (1956) observed small pockets filled with (clayey) sandy material surrounded by coarser components (fig. 17).

Fig. 17. Longitudinal and transversal cross-section of a corrasional trough.

These highly humose accumulations in depressions are also known from other regions such as the humid coastal area of the Iberian peninsula. Here they are referred to as 'Rankers Atlantiques'. Guitian Ojea y Carballas (1968) and Franz (1967) recognized their colluvial origin.

Chapter IX

NATURE OF THE MASS MOVEMENTS RELATIVE TO THE CLIMATE

It has been indicated in VII.1. that a systematic subdivision of the mass movements made it possible to draw important conclusions concerning the geomorphological history of the valley of the Oued Seloul.

IX.1. Scheme of the Mass Movements in the Valley of the Oued Seloul

All mass movements discussed have been arranged systematically in figure 18. The type of the movement has been given in the first column. In the second and third column a distinction has been made between active and stabilized movements. In the fourth column the extent of each type of movement has been given in detail by expressing the surface taken up by each type of mass movement in percentages of the total surface of the Seloul valley. Whether the movement is of the flow- or slide-type has been indicated in the fifth column. Finally, the nature of the parent rock on which a mass movement operates is indicated in the sixth column.

Very distinct tendencies with regard to the changes in nature and extent of the mass movements may be derived from this scheme (fig. 18).

IX.2. Changes in the Nature and Extent of the Mass Movements

It is a striking feature that both stabilized forms are typical flow phenomena. At present, however, the slide-types prevail strongly. Even earthflow and the debris avalanche are the consequence of an extensive slide movement that, lower in the valley, looses the characteristic slip-plane and passes into a flow movement (the slump causing the scar in the sandstone of the interfluve, plate 7).

NAME	ACTIVE	STABILIZED	SURFACE %	NATURE	PARENT ROCK
rockslide	x		1.5	slide	marl
slump	x		3.5	slide	soft shale
subsidence	x		2.0	-----	soft shale
debris avalanche	x		0.5	slide/fl.	soft shale
earthflow	x		2.5	slide/fl.	soft shale
mudflow		x	7.0	flow	sndst/mrl/s. shale
humid solifluction		x	30.0	flow	sndst/mrl/s. shale

sndst = sandstone
mrl = marl
s. shale = soft shale

Fig. 18. Scheme of the mass movements occurring in the valley of the Oued Seloul.

It carries great importance that the disparities in the parent rocks did not affect the stabilized mass movements, whereas the recently active types are very clearly limited to one specific parent rock: the soft shales. Marls and especially the sandstone are hardly subject to mass movements in present times.
At the time that mudflow and humid solifluction were active, the rock factor, at present highly dominant, will have been of far lesser significance than other factors, presumably climate and vegetation.
When these factors changed, the rock took over the role of dominating factor: the flow movements ceased while the slides became active on the soft shales.

Column 4 of figure 18 distinctly shows the changes that occurred in the extent of the area involved in the mass movements. Deposits of the areal types are still found at approximately 40 % of the area taken in by the slopes; the recent, concentrated types cover about 10 % of the present surface area of the Seloul valley.

Chapter X

SLOPE DEVELOPMENT IN CONNECTION WITH THE PARENT ROCK AND THE NATURE OF THE PREVAILING PROCESSES

The shape of the slopes in the Seloul valley is highly dependent on the character of the underlying parent rock, although other factors also affected the present slope profile.

X. 1. Effect of the Parent Rock on Slope Development

In chapter V.4. three types of slopes have already been mentioned that occur in the valley of the Oued Seloul. The three types are correlated to the various parent rocks:
--- cross profile sandstone - soft shale (fig. 7)
--- cross profile sandstone - marl (fig. 7)
--- cross profile in the Triassic breccia (fig. 8)

The transition of the gently undulating surface of the 'Triassic' diapyr to the steep valley-side of the Oued Seloul has been discussed before (chapter V).
Comparison of the other two cross profiles (fig. 7) provides some interesting data.
As is indicated on the geomorphological map the traces of two vertical phases of incision can clearly be recognized at several sites where the Seloul has cut into marls. In the soft shales on the other hand traces of the most recent river erosion can be detected only in the very beginning of the stream incision.
Unlike the marls, which remained stable after incision of the Oued Seloul, the soft shales began to slide in a way that approached the slope movements accompanying the 'pseudo-pedimentation' mentioned before (chapter VII. 2. 3.). The boundary between the stable and unstable parts of the terrain in this case can be explained because of a different lithology, as it is also the transition of the sandstone to the soft shales. Hence, the scarp at this boundary is identical to the steep slope encountered directly above a pseudo-pediment (fig. 13). Here too the scarp is the scar of the most recent movement (sliding) in the soft shales.

The complex of soft shales, by sliding as it were off the sandstone in a series of slump movements (with rotation), carves out a steep sandstone country.
Every new incision of the river leads to undercutting of the slope (= the flat part of the terrain) on the shales and disturbance of the equilibrium. This explains the short existence of the V-shaped fluviatile incision in the soft shales and also why in slopes crossing the sandstone - soft shale boundary the break in the terrain is so much more pronounced than in the cross profile sandstone - marl.
In the profiles of figure 7. a small flat part of the terrain can also be observed in the long slope on the soft shales, which is very similar to the one on the marl ridge. On the soft shales, however, this small flat part of the terrain is the result of a rather recent 'pseudo-pedimentation' (slump movement), whereas on the marls it is a residue of an old surface.

> N.B. The flat part of the terrain in the soft shales (chapter VI.3) is a result of areal types of mass movement (see chapter X.2.). Due to the slidings in the soft shales, small flat parts of the terrain may develop locally on the extensive original flat part: the 'pseudo-pediments'. By 'the flat part of the terrain on the soft shales' is always meant the one caused by the areal flow movements and never the smaller pseudo-pediments.

X.2. Effect of the Areal Types of Mass Movement on Slope Development

Both the high-lying flat part of the terrain on the marls and the lower one on the soft shales consist of fixed rock. They are covered with a relatively thin layer of deposits composed of a heterogeneous, unsorted and comparatively fine-grained matrix with many angular, coarse boulders. The material of this cover is very different from the local rock, which excludes a common origin. The detrital sandstone for example is derived from the higher parts of the terrain and has been transported by the very processes that caused the planation: the humid solifluction.

The mode of formation of the flat parts of the terrain or planations in the Seloul valley appears from the nature of the overlying, stabilized slope deposits and from the morphology of the slope.
The presence of trough-shaped depressions in the steep sandstone slope (nowadays filled with highly humose colluvium) and the irregular distribution of the solifluidal deposits on these slopes are indicative of the humid solifluction having been slightly concentrated on the steeper slopes, due to which a modest erosive action could bring about the trough-shaped depressions and a less homogeneous distribution of the deposits.
Below the break in the terrain the slope is less steep, and consequent-

ly the humid solifluction lacks any form of concentration. On these more level parts of the terrain the unconcentrated action of the process was intensified by the absence of a continuous vegetative cover, the presence of large amounts of detrital material (congelifracts and finer weathering products) and a sudden, excessive water-supply (torrential regime).

Formed in softer rocks, pediments like these are generally referred to as 'glacis d'érosion' (Dresch, 1957). However, there still being a good deal of confusion about this term, the flat parts of the terrain in the Seloul valley were denominated as 'inter-valley planations' (Dylik, 1957).

It is evident that the inter-valley planations in the valley of the Oued Seloul bear great resemblance to the pediments known from arid regions. It may seem strange on the face of it that in an area like the Kroumirie, which is very distinctly non-arid, land forms are found which, as to genesis and shape, are very similar to the pediments of the desert regions; the more so as conditions at the time of formation of the inter-valley planations do by no means point to a period with a dry and hot (desert) climate. Yet the similarity between the desert pediments and the inter-valley planations of the Seloul valley, paradoxical as it may seem, has to be largely sought in the climate and the resultant vegetation.
The period of humid solifluidal and mudflow activity assumed for the Seloul valley was characterized by a discontinuous vegetative cover, a prevailing mechanical weathering and a regime of torrential, spasmodic precipitation.
Hence, instead of arid desert conditions a set of factors prevailed that warrant use of the term 'geomorphic aridity' (Baulig, 1952; Dylik, 1957; Cailleux, 1950).

Summarizing it can be said that, with regard to the activity of mudflow and humid solifluction, conditions of 'geomorphic aridity' obtained. It was a period of intense, areal mass movement and extensive slope development which caused the formation of the pediment-like, continuous slopes of the inter-valley planations (glacis d'érosion).

N.B. The term 'geomorphic aridity' has been ill-choosen. In the arid regions similar processes were of widespread occurrence and not obscured by the vegetation.
However, in view of the fact that processes of pedimentation are not related to arid (desert) conditions, retention of the term 'geomorphic aridity' seems unwarranted. The absence of a continuous vegetative cover being the distinct factor, it may be advisable to concoct a term that has a bearing on the vegetation, considering that 'the influence of both man and climatic changes is chiefly through their effect on changing the vegetation cover' (Kirkby, 1969). A characteristic aspect of the vegetative cover in the areas subject to pedimentation is the: deficiency in structure for

which the term OLIGOMORPH may be applied (e.g., Walther, 1951, who for structural deficiency due to deficiency in nutrient matter uses the term Beinomorf). In such an oligomorph environment pedimentation is caused by torrential rain fall.

X. 3. Effect of the Concentrated Types of Mass Movement on Slope Development

The recent slope development diverges greatly from the one occurring under the influence of areal processes. A well-developed, natural vegetation and an increased chemical weathering, yielding fine-grained products mainly, did effect not only the present, concentrated drainage of water, but also the change from areal flow movements into concentrated slide movements.

The consequences of these changes are particularly clear on the initially continuous slope of the inter-valley planations. Concentrated river erosion dissects these slopes nowadays, and the slump activity on the soft shales gives the parts of the terrain in between the river incisions a very irregular relief.
Furthermore, the slope of the inter-valley planation on the soft shales has been affected by the recent, vertical erosion of the Oued Seloul (compare chapter X.1.), which caused the sliding of the shales. As a consequence of this sliding the remnants of this initially far more extensive planation are only present at the very beginning of the valley head; at this site the most recent dissection is found.

Chapter XI

EVOLUTION OF THE SELOUL VALLEY AS EVIDENCED BY GEOMORPHOLOGICAL DATA

To simplify the discussion of the geomorphological history the geomorphological processes mentioned in the preceding chapters, and the resultant phenomena, wherever possible have been arranged in chronological order and provided with a reference number. In the explanation in XI. 2. the numbers concerned are given, placed between brackets.

XI. 1. Table of the Geomorphological Processes

1. Deep red colouring of the sandstone. Remnants of a weathering under tropical climatic conditions; no quartz in the clay fraction and a strong dominance of kandite.
2. Accumulation of the erosion products of the mountains formed in the Mio-Pliocene. Coarse, continental deposits of detrital material. Formation of the 'glacis d'accumulation' in the piedmont region.
3. Intense headward erosion of the Algerian Oued Kebir. Capture of the NNE-SSW running rivers in the folded flysch deposits.
4. Areal denudation. Formation of the inter-valley planation in the Triassic breccia.
5. Areal denudation. Formation of the inter-valley planation in the marls.
6. Vertical incision of the Oued Seloul. In the marl ridges two at present still clearly recognizable remnants of the fluviatile phases of incision separated from each other by a small flat part of the terrain.
7. Sliding of the soft shales in a series of slump movements. Formation of the pseudo-pediments, the sharp break in the terrain at the transition of the sandstone to the soft shales, and of the scarp at the transition as scar of the most recent sliding. The marl ridges are being carved out.
8. Altiplanative lowering of the crests of the first-order interfluves. Removal of the regolith gave rise to the flat shape of the divides and carved the less weathered parts out as tors.

9. Humid solifluction. Its concentrated form has a somewhat erosive effect on the steep sandstone slopes with resultant formation of corrasional troughs. On the more level slopes lower in the valley humid solifluction had a mainly planational effect.
10. Mudflow. Locally the humid solifluction passed into this type of mass movement. At present mudflow and humid solifluction are stabilized movements, the deposits of which are found on sandstone, marls and soft shales.
11. Areal denudation. Formation of the inter-valley planation on the soft shales.
12. Earthflows. At present active on the soft shales.
13. Slumps. At present active on the soft shales.
14. Debris avalanche. At present active on the soft shales.
15. Rockslides. At present active on the marls.
16. Concentrated denudation. At present dissection of the surface by the concentrated types of mass movement and the concentrated drainage.

XI. 2. Relative Dating

The remnants of the deep weathering under tropical climatic conditions in the Seloul valley (1) which are still present in fissures in the sandstone, are considered the oldest geomorphological phenomenon. None of the other phenomena, including the most recent, bear evidence of such weathering and pedogenesis.

The typical geomorphological development of the Seloul valley started subsequent to the capture of the Seloul by the Oued Kebir (3). Consequent upon this the Seloul began to incise vertically.
All processes (4 to 16) were and still are active in the Seloul valley formed by incision. Consequently, the process of capture by the Kebir may be considered older than these processes.
Only the accumulations of the Mio-Pliocene continental deposits (2) are absent in the Seloul valley; however, these are present in the synclinal valley of Ben Metir and in the piedmont region (see chapter III and XIII). Hence, the assumption is warranted that the capture and the commencement of the incision of the Seloul are of younger date than the accumulation of coarse detrital material deposited during the Mio-Pliocene. The vertical river erosion removed these deposits.

The direct cause of the differentiation of the slopes, having regard to the parent rock, is the undercutting of the soft shales due to the incision of the river (6). In other words, carving out of the marl ridges (7) concurred with the vertical erosion of the Oued Seloul. The two phases of incision that are still recognizable are separated from each other by a small flat part of the terrain, representing a phase of rest in the vertical river erosion. The younger of these two phases of incision is still active. The younger phase of incision obviously was already active at the time of the areal mass movements, as is evidenced by the tongue of the mudflow (10) which advanced deep into the valley of this incision. The deposits of the humid solifluction are also found very near to the present river level.

The surfaces on the Triassic breccia (4), the marls (5) and the soft shales (11) must have been formed during periods of areal denudation, which were connected with 'geomorphologically arid' periods.
The planation on the soft shales (11) being very unstable, it can have been formed only in the youngest of these periods, the slope deposits of which (9 and 10) may still be traced.
The planation surface on the marls (5) on the other hand is very stable (the marls are resistant) and in its initial state may date from an earlier period with such an areal effect on the relief. However, traces of this older effect are no longer observed. The same applies to the altiplanation of the crests of the interfluves (8), which need not date from the youngest 'geomorphologically arid' period, to the exclusion of other periods.
As stated in VII.4. the flat surface of the diapyr (4) is not overlain by deposits of the humid solifluction and mudflow. This may be explained by the near-isolation of the 'Triassic' diapyr from the flysch country (sandstone, marl and shale) by the deep valleys of the Oued Seloul and the Oued Krouldjana.
Consequently, the planation of the 'Triassic' diapyr has to date from a period of areal denudation active prior to the time when the Triassic breccia became isolated from the flysch rocks. Subsequent to the isolation the areal types of mass movement could no longer supplement to the inter-valley planation on the Triassic series (no solifluction from the flysch), which gradually became somewhat dissected. Thus the recent, gently undulating surface came into being on the Triassic breccia.

The recent, concentrated erosion (16) dissects the surface of the soft shale country by means of i.a., the present types of mass movement (12 to 15). Consequently, this planation surface and the youngest period of areal denudation have to date from a phase in the landscape evolution directly preceding the present phase.

XI. 3. Scheme of the Relative Dating

The geomorphological data relative to each other have been incorporated in a scheme (fig. 19). The occurrences are given in chronological order from bottom to top.

The formation of the valley-floor divides (see chapter IV) has not been included in the scheme, as inclusion would become a random matter. The assumption seems warranted that the valley-floor divides of the a. type (originated as a result of tectonic activity) are very old and fall outside this scheme (older than period 1). As for types b. and c., these (for pedologic reasons) must be older than period 4.,

period	FLYSCH, ANTICLINAL VALLEY	TRIASSIC BRECCIA, DIAPYR	
7	-colluviation, fine sandy/ -still vertical erosion of the Seloul, undercutting of the soft shales/ -still sliding of the slopes in the soft shales in a series of slump movements, pseudo-pediments, scarp and sharp break in the terrain/ -concentrated types of mass movement only on the soft shale, primarily slide-type/ -denudation by means of concentrated erosion, dissection of the landscape/ -fair natural vegetation/	slight dissection of the inter-valley planation into a gently undulating surface/	
6	-humid solifluction and mudflow, coarse and angular detrital deposits/ -vertical erosion of the Seloul/ -areal mass movements on all parent rocks, primarily flow-types/ -areal denudation of the landscape, planation of the more level slopes, formation of the inter-valley planation on the soft shales, altiplanative lowering of the first-order divides, carving out of the tors/ -poor natural vegetation/ -'geomorphologically arid' period/		
5	-phase of rest of the river, formation of the flat parts of the terrain separating the two phases of incision that still can be recognized/		
4	-oldest recognizable vertical incision of the Oued Seloul/ -considerable sliding in the soft shales, carving out of the marls as ridges, sharp break in the terrain/		isolation of the 'Triassic' diapyr due to the vertical fluviatile erosion at either side/ No longer affected by areal types of mass movement from the flysch country/
3	-phase of rest of the river/		
2	-incipient vertical erosion of the Seloul, removal of the Mio-Pliocene continental deposits, incipient divergent slope development dependent on the parent material, carving out of the parent material, carving out of marl as ridges/ -formation of flat parts of the terrain on soft shales and marls (inter-valley planations)/	formation of an inter-valley planation on the Triassic breccia/	
1	-weathering under tropical climatic conditions, deep red colouring of the sandstone/ -accumulation of the erosion products of the orogenesis, coarse Mio-Pliocene continental deposits, 'glacis d'accumulation' in the piedmont region/		

Fig. 19. Scheme of the relative dating of the geomorphological processes in the valley of the Oued Seloul.

as will be shown in chapter XII. Evidence of this is provided by the remnants found of a soil which was formed during period 4.

XI. 4. Absolute Dating

In attempting to place some of the processes and deposits given in the scheme (fig. 19) in the absolute chronology, the whole problem of the Quaternary in the Mediterranean region and especially in N Africa must inevitably be introduced. The geomorphology of the anticlinal valley appeared to be connected to particularly the development of the recent-Pleistocene.

TERTIARY

It seems best to date the deep tropical weathering as Tertiary, for from this period tropical climatic conditions are known to occur in N Africa (Exc. en Maroc, 1966; Coque, 1965 ; Dresch, 1960; Cailleux, 1961). The transition of Tertiary to Quaternary is considered to coincide with the boundary between period 1 and period 2 (fig. 19). If this obtains the Mio-Pliocene continental deposits are correctly classed with period 1.

The characteristic development of the valley of the Oued Seloul commenced at the transition of Tertiary to Quaternary and progressed in keeping with the climatic changes.

PLEISTOCENE

Little can be said about the old-Pleistocene: it is known that the incision of the Oued Seloul has been the direct cause of the instability of the soft shales and the divergent slope development in these soft shales relative to the slope development in the marls. There must have been periods in the old-Pleistocene, which may be compared to the 'geomorphologically arid' period 6. from the scheme (fig. 19). They gave shape to e.g., the 'glacis d'érosion' or inter-valley planation on the Triassic breccia of the diapyr.

As for the phases of incision of the Oued Seloul it may be observed that nowadays the so-called pluvials are considered as fluviatile phases in the landscape evolution (Dresch, 1957; Butzer, 1963). The name pluvial already indicates that initially the phases were considered as periods with strongly increased precipitation with resultant abundant vegetation. Modern investigations, however, especially in the field of palynology (i.a., Coetzee, 1967), demonstrated that the pluvials are characterized in particular by a lowering of temperature,

while the amount of precipitation seems to have decreased rather than increased.
In the tropics the lowering of temperature seems to amount to 4° C or more (Frenzel 1967, after Flohn) and in the temperate regions to 10° or 12° C (Frenzel, 1967, after Poser). Consequently, a lowering of 7° to 8° C seems a reasonable assumption for the Mediterranean region. Butzer (1964) in basing his opinion on the findings of Emiliani (1955), for the Mediterranean region in general arrives at 4° to 5° C and for Mallorca at 6° C. Emiliani (1955), however, works with the temperatures of sea-water, which may explain the lower values.
The lowering of temperature during the 'pluvials' is considered responsible for the strong degradation of the vegetation.

Further observations of Butzer (1963) and Flohn (in Butzer 1963) are of great significance:

Butzer: 'Although rains in the Mediterranean are largely of brief duration, and comparatively great intensity today, their torrential character must have been much more strongly emphasized during the pluvials'.

Flohn : 'It seems most likely that at the last glacial epoch the surface temperature of the Mediterranean Sea was not lowered more than 4-5 degrees C as compared with the recent value. The existence of the Alpine glaciation, however, indicates a larger decrease of the temperature in the middle troposphere which may be estimated 7 or 8 degrees C in the area of a rather persistent upper-air trough.
Under such conditions the average vertical lapse of temperature was substantially larger than it is today, frequently conditionally unstable, which favoured torrential cloudbursts'.

The torrential character of the pluvials was very marked (see also Butzer 1957[a] and [b]), but especially in N Africa their character seems to have been cold and not extremely humid.
The scarse vegetation was of the grass-steppe type on which the cloudbursts mentioned above made their influence felt. Due to the episodically very strong precipitation, the rivers could cut down.

The literature on this subject is full of inconsistencies. Consequently, the considerations given above do not obtain generally, especially not since it appeared (Coetzee, 1967; Flohn, in v. Zinderen Bakker 1965) that locally the pluvials could differ considerably in character.

For all that a combination of the new ideas about the pluvials in N Africa has much to offer in that it is fairly representative of the circumstances under which the phenomena from period 6. of the scheme (fig. 19) occur. Indeed, the highly reduced vegetation required for this type of mass movement appears to be in general agreement with the fall in temperature (and the dryness) that caused the decline in vegetation, and also with the pollen-analytical data of Coetzee (1967). The type of spasmodic precipitation that Sharpe (1960) made a condition of for i.a. the mudflow seems also to have prevailed with great intensity during a 'pluvial'.

As for the fall in temperature during the pluvials, 7° to 8° C seems a reasonable assumption. Applied to the neighbourhood of Ain Draham the average temperature of the coldest months less this fall in temperature comes to approximately 0° C (compare chapter II).
It is this average temperature which, as a result of the many fluctuations around zero, will cause an intense mechanical weathering: the congelifracts. Not permafrost, which is not a condition for humid solifluction anyway.

Hence, period 6. of the scheme (fig. 19) represents a pluvial and, similar to the most recent phase of incision resulting therefrom, has been dated as 'Soltanien', the youngest cold period of the Pleistocene. Choubert (1961) and other authors consider that this period corresponds to the Würm (Raynal, 1956; Flohn, in v. Zinderen Bakker, 1965; Dresch, 1960; Awad, 1963; Exc. en Maroc, 1966).
This being so the boundary of Pleistocene and Holocene coincides with the transition of period 6. to period 7. (fig. 19).

To verify several conclusions concerning changes in climate and vegetation, which until now are based only on the interpretation of geomorphological data, two samples have been selected for pollen-analytical investigation (fig. 20). Sample POL/1 has been taken from a highly rumpled, very humose layer from the mudflow, and sample POL/2 from the bottom of the very humose accumulation of colluvium in one of the corrasional troughs. Mr. O.K. Hulshof, who carried out the counting, considers that the sample from the mudflow presents the picture of a highly reduced, open vegetation: a very small number of varieties and the absence of tree and grass pollen. The sample from the bottom of the recent colluvium is fairly representative of the modern vegetation that may be expected: much tree pollen and yet no dense forest vegetation. At any rate the two samples display great differences.
Although only two samples are concerned, the pollen-analytical results support the conclusions drawn from the geomorphological data.

HOLOCENE

The recent fine-sandy colluvium represents the Holocene deposits (period 7. in fig. 19). It appears that the youngest period of the scheme (fig. 19) can be further subdivided.
Sample POL/2 (fig. 20) was taken from the oldest colluvium. Pollen-analysis shows distinct occurrence of the alder (alnus), a tree no longer found here.
Consequently, the climate, which may be inferred to have been more optimal at that time, is bound to this period of accumulation of the

	POL / 1 in % of pollen counted	POL / 2 in number of pollen counted
ericaceae	78.5 %	12
compositae	12.5 %	28
polypedium	8.0 %	7
gramineae	0.5 %	5
equisetum	0.5 %	-
alnus		17
pinus		1
querqus		41
artemisia		6

sample POL / 1 taken from a mudflow
sample POL / 2 taken from colluvium

Fig. 20. Table of the pollenanalytical data of a sample taken from a mudflow (latest 'pluvial') and of a sample taken from early-Holocene colluvium.

oldest colluvium. In conformity with this, study of a profile description (see soil unit 2) in chapter XII.1.3. of the colluvium clearly reveals that this recent colluvium may be subdivided into two phases of which the older colluvial period (early-Holocene) is of a somewhat loamier character than the most recent period.
The finer texture, which may point to a more intense chemical weathering of the oldest colluvium from which sample POL/2 has been taken, also points towards a somewhat warmer and more humid climate.

Consequently, the Holocene may be subdivided into an early-Holocene and a late-Holocene period on climatological considerations. It will appear in chapter XII that also pedologically two highly divergent periods coincide with these periods. As a result the scheme (fig. 19) may considerably be added to in another chapter (compare fig. 26).

As dating of the other periods in figure 19. would be a fully speculative matter it has been dispensed with.
It remains to be noted that there are many pedological data that fit well in with the scheme of the geomorphology and even make considerable additions to it.
For the pedological scheme (fig. 25) on its own and in combination with the geomorphological scheme (fig. 19) reference is made to chapter XII.4.

Chapter XII

PEDOLOGY

The Quaternary in the Kroumirie is characterized by an alternation of pluvial and inter-pluvial climates. This resulted in periodicity in landscape development and soil formation. During the inter-pluvials a well-developed vegetative cover existed which inhibited the occurrence of areal processes of mass movement and favoured soil development on the stable slopes.
These periods of soil formation were followed by periods of landscape instability during which the vegetative cover was depleted and areal mass movement became active (Butler, 1959; Jessup, 1960 and 1961; Walker, 1962[a] and [b]).
As a result of this periodicity a close relationship exists between the occurrence of the various soils and the distribution of geomorphological phenomena (Mulcahy, 1961).
A soil map, scale 1 : 25,000 (fig. 21), may serve to discuss the distribution of the soils in the Seloul valley. The similarity of the patterns on the soil map and the geomorphological map (fig. 9) is indicative of the great effect of the geomorphological processes on the soil distribution.
The absence of periods with an intensive landscape evolution resulting in the formation of very old, polygenetic profiles is manifest particularly in the areas that showed no specific reaction to the climatic changes of the Quaternary ('Triassic' diapyr). It is these soil profiles which are of great potential value to the geomorphology, for their complex pedogenetic development may be incorporated in the geomorphological scheme.

XII. 1. Soil Map, Scale 1 : 25,000 (fig. 21 - inlay)

XII. 1. 1. Introduction

The first six weeks of the field work were spent in mapping a sample-strip, scale 1 : 10,000, which, oblique to the valley, ran from

divide to divide. After the physiographical interpretation at the Institute for Aerial Survey and Earth Sciences (I.T.C.) in Delft, the sample-strip was worked into a soil map scale 1: 25,000. During the first phase approximately 120 borings were made, normally at intervals of 50 m, along two reconnaisance lines set across the valley. At the same time use has been made of profiles along roads and of other accidental exposures.
During the work on the soil map many additional borings were made to verify and supplement to the soil boundaries that could be identified on the aerial photographs by means of physiographical analysis.

To classify and describe the soil profiles use was made of natural exposures mainly. Profile pits are to be preferred, but could not be dug due to lack of man-power.
Profile descriptions were made with the aid of the Soil Survey Manual (1963) and the F.A.O. Guidelines for Soil Profile Description. The soil profiles were classified following the 7th Approximation (1960) and its supplement of 1967. The pedogenetic processes and phenomena, as far as possible, have also been classified by means of the criteria from this classification system, with the result that adjectives like 'mediterranean', which are unduly geographical, could be avoided (Mancini, 1966). As adjectives derived from geography and vegetation are still widely used, occasionally French, German or English terms are added to elucidate the new American terminology.

The following terms used in the course of this chapter may give rise to confusion:
a. red colouring, rubefaction, 'rubéfaction', 'Rubefizierung'.
b. brown colouring, 'brunification', 'Verbraunung'.
c. 'steppisation'.
In explanation it may suffice to quote the description of some authors:
ad. a. Benayas (1970): 'La rubéfaction est le processus pédologique qui donne naissance aux sols rouges. Ils ont tous un Horizon B de couleur rouge et c'est sans doute leur seul caractéristique commune'.
Duchaufour (1965, p. 322): 'Les oxydes de fer liberés peuvent rester hydratés si le microclimat interne du sol est humide, ou au contraire se déshydrates en période sèche: la couleur du sol devient alors rouge, c' est le processus de rubéfaction décrit par Bordas (1943) et Reifenberg (1947)'.
Scheffer and Schachtschabel (1966, p. 362): 'Rubefizierung..... leuchtend-rote Farbe. Die Ursache dieser Farbe ist das Vorhandensein von Goethit und/oder Hämatit in einer sehr fein verteilten, gut kristallisierten Form'.
Kubiena (1956, p. 247): 'Rubefizierung ist die Neigung tröpischer Böden von Braunlehmcharakter zu rötlicher bis grellroter Verfärbung in ausgeprägt wechselfeuchten Klimaten'.
ad. b. Duchaufour (1965, p. 163): 'Evolution vers le "sol brun forestier" sous la forêt méditerranéenne de Chène vert, dans les régions à climat subhumide'.

Scheffer and Schachtschabel (1966, p. 354): 'Die Fe-Freisetzung, verbraunung, erreicht meist erst dann ein höheres Ausmass, wenn das pH des Bodens unter 7 sinkt'.

ad. c. Duchaufour (1965, p. 246): 'Il s'agit, du processus le plus récent post-glaciaire; sous l'influence de la steppe, il se produit une incorporation profonde de matière organique de couleure brune (hor. mollique)'.

> N.B. In text and schemes of this chapter it is postulated that the recent pedogenesis is limited to brown colouring and formation of structure (Cambic horizon).
> The recent pedogenesis, therefore, will bring about an Eutrochrept on the calcareous clayey materials (marls) and a Dystrochrept on the clayey materials (soft shales), which is the reason why these terms have been used in both text and schemes to indicate recent soil formation. An Inceptisol has not been found everywhere, due to the persistent influence of earlier pedogeneses in the soil profiles. Addition behind such a soil of the words: recent formation of a Dystrochrept, signifies only that, but for the presence of fossil pedological features, a Dystrochrept would have formed nowadays.

The numeration of the various soils in the legend has been based on their occurrence in any of the physiographical units as distinguished by interpretation from aerial photographs and during the mapping in the field.
The valley of the Oued Seloul has been subdivided into the following units:

--- flat, first-order divides: soil unit no. 1.
--- steep slopes : soil units no. 2, 3 and 4.
--- flat slopes : soil units no. 5, 6, 7, 8 and 9.
--- ridges : soil units no. 10, 11 and 12.
--- 'Triassic' diapyr : soil units no. 13 and 14.

XII.1.2. Legend

The legend has been built up as follows: Particularly because soil mapping was only meant as an aid to geomorphological investigation, the first subdivision has been based on the depth of the soil profiles as determined by the intensity of the erosion. Distinction has been made between:
A. severely eroded soils, B. moderately eroded soils, C. non-eroded soils and D. a miscellaneous group of soils including a complex of several very disparate soils, such as a highly humose, deep accumulation of colluvium, and recent fluviatile deposits.
In each of these groups a further subdivision has been made on the basis of the parent rock in which the soil profile has developed. This offers the advantage that in every group the soil units which have formed on the various parent materials can quickly be discerned.
Gley-mottling occurs in certain profiles only. Consequently, drainage

conditions have not been applied as a criterion of subdivision in this legend.

XII.1.3. Description of the Individual Soil Mapping Units shown on the Map (supplemented with Profile Descriptions and Tables)

A. severely eroded soils

This group comprises five different soil units, the severely eroded phase of the soil profiles on the four parent materials soft shale, marl, sandstone and Triassic breccia, occurring in the Seloul valley. The fifth soil unit represents the truncated profiles in the parts of the terrain formed by deposits of such mass movements as earthflow and mudflow. These deposits, due to the great stoniness and the considerable variation in transported material, provide a very heterogeneous parent material for the pedogenesis.

3. complex of sandy lithosols, stony (LITHIC UDIPSAMMENT) + clayey lithosols, stony (LITHIC -AQUIC- UDORTHENT).

This complex occurs on the convex parts of the steep slopes below the first-order divides. These areas are characterized by a strong dominance of sandstone outcrops, on which, very locally, thin clay lenses are found. The sandy soils are very shallow and consist of only a thin weathering layer, reason why a profile description was dispensed with. Locally on the clay lenses water stagnates occasionally. As a consequence the soils are saturated with water during some period within 1,5 m of the surface, and use of the term - Aquic - is admitted.

7. complex of brown, clayey lithosols (LITHIC UDORTHENT) + grey, clayey lithosols, with locally a weathering layer not exceeding 40 cm in thickness (LITHIC UDORTHENT).

These profiles are found on the steep slopes in the soft shales, which originated as a result of the most recent vertical erosion of the Seloul. Locally the thin weathering layer has browned, especially in the V-shaped incisions more down-stream. The thickness of the weathering layer at this site generally exceeds that at the valley head (compare chapter VI.3.).

9. complex of shallow sandy clay soils occasionally with remnants of a Bt hor., very coarse stony + shallow brown clay soils, occasionally with remnants of a Bt hor., very coarse stony, much pseudo-gley mottling, sometimes up to the surface (eroded HAPLUDALF + ENTISOLS).

This complex is characteristic of the area that originated as a result of earthflow and mudflow activity, with resultant deposition of much coarse and angular sandstone debris.
In a more recent period these landslides have been covered with Holocene colluvium. This is also true of the earthflow, although this movement dates from the Holocene as well. In the oldest colluvium a brown Bt horizon has been formed, remnants of which may be found in the still active earthflow.
The area in which the mudflow operates at present is subject to severe erosion due to linearly concentrated slide movements truncating

the profiles. The recent activity of the earthflow has a similar effect on the soil profiles. The erosion of the colluvium and the Bt horizon gives rise to the profile described (see also plate 15).
At present pedogenesis seems to be restricted to a brown colouring: formation of a Dystrochrept (Acid Brown Soil, compare data analyses; Bunting, 1965; Tavernier and Smith, 1957). The pseudo-gley mottling, normally occurring rather deep in the profile, occasionally crops out as a result of truncation.

profile description

location: 20 m below the road from A.D. to Fernana; 1,5 km S of A.D.
legend: shallow sandy clay soil, occasionally with remnants of a Bt hor., very coarse stony.
classification: eroded HAPLUDALF.
elevation: 680 m
physiographic position: earthflow
slope: moderately steep (20 %)
vegetation: cork oaks and grasses
parent material: generally soft shales transported in earthflow
drainage: poorly to imperfectly drained
moisture conditions: moist throughout
presence of surface stones: stony; boulders

B2t 0-25 cm, yellowish brown (10 YR 5/6, moist), sandy clay; moderate angular blocky; firm when moist; patchy thin cutans, probably of clay minerals (and organic matter); few fine pores; few minute rounded quartz grains, many angular boulders and few angular stones (sandstone); some ant activity; few fine roots; gradual and wavy boundary.

B3 25-80 cm, yellowish brown-brownish yellow (10 YR 5/6 - 6/6, moist), sandy clay; moderate angular blocky; very firm when moist; very patchy thin cutans, probably of clay minerals and iron oxides and hydroxides; very few fine pores; few minute rounded quartz grains, many angular boulders (sandstone); very few fine roots.

Analyses

hor.	depth	-2μ	2-50	50μ-	text.cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr.ir.
B2t	15 cm	31.5	30.0	38.5	s.l.	6.2	5.2	3.1	--	3.9	11	13	85	5.6
B3	50 cm	49.0	34.5	16.0	l.	6.5	5.5	1.0	--	7.1	9	32	25	7.7

Clay minerals

hor.	depth	mix.l.	smect.	chlor/verm.	mica 'w'	mica 'p'	kand.	anat.	quartz
B2t	15 cm	tr.				tr.	+(+)	x	5-8 %
B3	50 cm	tr.				+++	+	x	2-4 %

10. complex of shallow, calcareous dark-brown clay soils with wide cracks and occasionally a Cambic horizon, few stones (VERTIC EUTROCHREPT) + limestone lithosols + clayey calcareous lithosols, few stones.

These soils have developed on the steeper slopes in the marls and are very similar to the soils of unit 7, with the difference that the parent material of these soils is calcareous.
The profiles also show a recent brown colouring. The calcareous rocks, however, have given rise to an Eutrochrept formation instead of a Dystrochrept formation (Braunerde by Kubiena, 1950). The weathering layer on the steep slopes in the marls is thicker than that on comparable steep slopes in the soft shales. Yet pedogenesis is unsubstantial and, except for the brown colouring, restricted to a locally poorly developed structural B (Cambic) horizon; it is usually associated with a process of homogenization of the organic material in the profile consequent on the weak self-mulching activity of these soils.

profile description

location: 50 m W of road from A.D. to Fernana; 1,5 km S of A.D.
legend: shallow, calcareous dark-brown clay soils with wide cracks, and occasionally a Cambic horizon, few stones.
classification: VERTIC EUTROCHREPT
elevation: 700 m
physiographic position: marl ridge
slope: sloping (10 %)
vegetation: grasses
parent material: marls
drainage: well drained
moisture conditions: dry throughout the profile
presence of surface stones: fairly stony; boulders and stones

A 0-15 cm, pale-brown (10 YR 6/3, moist), clay; weak to moderate prismatic; slightly hard when dry; few fine pores; few to many minute rounded quartz grains, few angular stones and few angular boulders (limestone and sandstone); few fine and medium roots; some wide cracks; moderate ant activity; calcareous; merging and wavy boundary

B 15 cm +, (dark) brown (10 YR 5/3 - 4/3, moist), clay; moderately strong prismatic; hard when dry; few fine and medium pores; very few to few minute rounded quartz grains, few angular stones and few angular boulders (limestone and sandstone); moderate ant activity; calcareous; few medium roots; moderately wide cracks.

Analyses

hor.	depth	-2μ	2-50	50μ-	text.cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr.ir.
A	10 cm	60	28	8	c.	7.7	7.3	2.5	30.6	6.9	-	-	-	5.3
B	30 cm	70	22	3	c.	7.8	7.4	2.9	28.0	4.0	-	-	-	4.3

Clay minerals

hor.	depth	mix.l.	smect.	chlor/verm.	mica 'w'	mica 'p'	kand.	anat.	quartz
A	10 cm	tr.		?		tr.	+	x	5-8 %
B	30 cm	tr.		?		tr.	+	x	5-8 %

14. complex of very shallow, clayey loam soils with remnants of a red and brown Bt hor. (eroded PALEUDALF) + lithosols in breccia.

In the area of the Triassic breccia this complex is found on the steep slopes especially on those formed as a result of the vertical erosion of the Oued Seloul. As a rule these slopes have been eroded down to the original parent rock, but locally remnants are found of a profile which has a less rudimentary appearance on the flat parts of this diapyr (unit 13).

B. moderately eroded soils

This group comprises three different soils.
In the marls the vertical phases of incision are separated from each other by small, flat parts of terrain. The soil found on these flatter parts is deeper than on the remainder of the marls.
The flat, non-wooded slopes in the soft shales are unlike the wooded slopes with almost uneroded profiles, characterized by a moderately eroded profile (see group C).
The third unit of the group has been formed in the parts of the earthflow and mudflow that have not been subject to recent erosion.

12. moderately deep calcareous dark clay soils with wide, deep cracks, locally browned, few coarse stones (ENTIC PELLUDERT).

The Vertisols concerned here have not been formed on the marls recently. Similar to the other clayey rocks they are subject to recent brown colouring (on the non-calcareous clayey rocks the tendency is towards formation of a Dystrochrept and on the calcareous clayey rocks towards formation of an Eutrochrept).
The angular sandstone constituents in this soil also derive from the humid solifluction.

profile description

location: 300 m W of the road from A.D. to Fernana near Sidi Abdullah
classification: ENTIC PELLUDERT
elevation: 620 m
physiographic position: marl ridge
slope: gently sloping (5 %)
vegetation: shrubs and grasses
parent material: marls
drainage: somewhat excessively drained
moisture conditions: almost dry
presence of surface stones: very few to fairly stony; angular boulders

A 0-90 cm, dark grey (10 YR 4/1, moist), clay; strong medium to coarse prismatic; hard to very hard when dry; few slickensides; common fine pores; few minute rounded quartz grains, few angular boulders (sandstone); many deep and wide cracks; strongly calcareous; moderately few ant casts.

Analyses

hor.	depth	-2μ	2-50	50μ-	text.cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr.ir.
A	20 cm	62.5	28.5	9.5	c.	7.6	7.1	5.7	16.1	8.7	-	-	-	5.1

Clay minerals

hor.	depth	mix.l	smect.	chlor/verm.	mica 'w'	mica 'p'	kand.	anat.	quartz
A	20 cm	tr.		?		tr.	+	x	10-15 %

8. shallow to moderately deep (sandy) clay soils with a brown Bt hor., very coarse stony, browned in the upper decimetres, much pseudo-gley mottling up to the Bt hor. (HAPLUDALF).

This is the orginal profile in the deposits of mudflow and earthflow. At sites of recent truncation of the soil, unit 9 is formed.

5. moderately deep to shallow clayey soils with a brown Bt hor., upper decimetres browned, moderately stony, pseudo-gley mottling locally and at varying depth (AQUIC HAPLUDALF).

The non-wooded flat slopes in the soft shales are characterized by this soil unit.
Processes of humid solifluction are the cause of the stoniness of these profiles, which at present are being affected by colluviation. A brown Bt horizon was formed in the oldest colluvial deposits, but this pedogenesis is no longer active. The recent pedogenesis is a brown colouring (formation of a Dystrochrept).
In the non-wooded areas the profiles are only moderately deep because of the intense degradation of the surface.
The C horizon in these profiles consists of a red-grey mottled clay. In the shallow profiles several red patches of this clay show brown colouring.

profile description

location: beside the track to Sidi Abdullah, 3 km S of A.D.
classification: AQUIC HAPLUDALF
elevation: 720 m
physiographic position: flat slope in the soft shales
slope: sloping (10 %)
vegetation: shrubs and grasses
parent material: soft shales
drainage: imperfectly drained
moisture conditions: top 45 cm of profile dry, moist below
presence of surface stones: very few angular boulders

A1 0-10 cm, dark brown (7,5 YR 4/4, moist), clay; weak to moderate blocky; soft to slightly hard when dry; frequent fine and few medium roots; many very fine to fine pores; many rounded minute quartz grains; intense ant and worm activity; clear and wavy boundary

B22g 10-40 cm, dark brown (7,5 YR 4/4, moist), clay; common fine to medium, distinct and diffuse mottles, yellowish red (5 YR 5/6, moist): pseudo-gley; few medium to coarse distinct and clear mottles red (10 R 5/8, moist) weak to moderate angular blocky; soft to slightly hard when dry; thin to moderate thick broken-patchy cutans, probably clay minerals with iron oxides and hydroxides, brown (10 YR 4/4, moist); few rounded minute guartz grains, deeper than 30 cm: few to many angular stones and boulders (sandstone); clear and wavy boundary

Cg 40 cm +, light grey (5 Y 6/1, moist), clay; many coarse to medium, prominent and clear mottles, red (10 R 5/8, moist); many fine to medium distinct and diffuse mottles, yellowish red (5 YR 5/6, moist): pseudo-gley; weak to moderate angular blocky; firm to very firm when moist; none to very few fine roots; none to very few fine pores; few to many rounded minute quartz grains, very few angular stones (sandstone).

Analyses

hor.	depth	-2μ	2-50	50μ-	text.cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr.ir.
A1	5 cm	53.1	25.6	18.8	c.	5.2	3.9	3.2	-	11	16	27	58	5.0
B22g	20 cm	66.3	21.8	9.9	c.	5.4	3.9	1.8	-	5	18	35	50	5.2
Cg	50 cm	65.1	19.4	·13.2	c.	4.8	3.6	2.2	-	4	12	34	35	5.2

C. stable soils

Deep, well-developed and as a rule fairly complete soil profiles have been brought together in this group. The occurrence of these deep profiles is restricted to the flat, wooded parts of the terrain.

1. deep to moderately deep (sandy) clay soils with a slightly eroded profile, pseudo-gley mottling up to the brown Bt hor., deeply browned, almost stoneless (AQUIC HAPLUDALF).

These soils are found on the wide and very flat, wooded first-order divides of the Seloul valley.

The profiles may be compared to those of unit 5. (compare chapter XII.4.), the difference being that the latter have not been affected by the deposits of the humid solifluction. This accounts for the absence of coarse, angular sandstones in these profiles, although the surface is not entirely stoneless. Another difference is that under the present circumstances these profiles are subject to very slight erosion, due to the forest vegetation and the flat location.

In these soil profiles the C material is also formed by a red-grey mottled clay. The brown Bt horizon may have been effected by a still .

active process, but there is every likelihood, also in these profiles, that recent pedogenesis did not go beyond the formation of an Acid Brown Soil (Dystrochrept). Occasionally the red-grey mottled C horizon already shows brown colouring.

The effect of the forest vegetation on the depth of the profiles of these flat, first-order divides can be observed beautifully in the firebreaks that were cleared in the forest some 40 years ago (personal communication, 'Service des Forêts' at Ain Draham).
The soil profiles in the firebreaks can already be seen to be less deep than the profiles under forest (compare XII.1.4.). As a result of the flat location and the compactness of the red-grey mottled clay in the subsoil the profiles usually are strongly affected by stagnant water. This gave rise to a pseudo-gley mottling penetrating into the Bt horizon.

N.B. Unit 1 being almost identical to unit 6 (varying only in stoniness and pseudo-gley mottling), for the profile description reference is made to unit 6.

6. deep to moderately deep (sandy) clay soils, with a slightly eroded profile, pseudo-gley mottling usually deeper than 60 cm in the profile, upper decimetres browned, coarse stony (ULTIC ** HAPLUDALF).

This soil unit represents the deep, slightly eroded phase of unit 5. and consequently, bears strong resemblance to unit 1., the only difference being the degree of stoniness and depth of pseudo-gley mottling. The compact red-grey mottled clay shows little variation in depth under the surface, the slope of the terrain being about 10 %, the slope of the impermeable horizon may be considered of the same order. The stronger 'throughflow' (Leopold, 1964; Kirkby 1967 and 1969, and More, 1969) in these profiles compared to that on the flat crests reduces the influence of stagnant water. As a consequence pseudo-gley mottling occurs deep in these profiles.

profile description

location: 100 m W of the Seloul, 2 km S of A.D.
classification: ULTIC** HAPLUDALF
elevation: 600 m
physiographic position: flat, wooded slope in the soft shales
slope: sloping (10 %)
vegetation: cork oaks, shrubs and grasses
parent material: soft shales
drainage: top layers are moderately well drained
moisture conditions: top 20 cm of profile dry, moist below
presence of surface stones: very few angular boulders

** Uncertain, has to be determined at depth of 125 cm.

0 2-0 cm

A1 0-20 cm, brown (7,5 YR 5/4, moist) sandy clay loam; weak angular blocky; hard when dry; abundant very fine to medium roots and common coarse roots; common very fine to medium pores and few coarse pores; many rounded minute quartz grains, very few angular boulders (sandstone); high ant activity; gradual and wavy boundary

B21t 20-50 cm, yellowish brown (10 YR 5/8, moist), sandy clay; moderate angular blocky; friable to firm when moist; broken to continuous moderately thick cutans, probably clay minerals with iron oxides and hydroxides, brown (7,5 YR 5/4, moist); common fine and medium roots, few coarse roots; very fine to medium pores; few rounded minute quartz grains, very few angular boulders (sandstone); some ant activity; gradual and wavy boundary

B22t 50-80 cm, yellowish brown (10 YR 5/8, moist), sandy clay; moderate angular blocky; friable to firm when moist; patchy moderately thick cutans, probably clay minerals with iron oxides and hydroxides, brown (7,5 YR 5/4, moist); common and fine medium roots (decreasing deeper in the profile) and few coarse roots; few very fine to medium pores; few rounded minute quartz grains and very few angular boulders (sandstone).

N.B. the exposure defied description at greater depth. Borings revealed that the profile became increasingly stony deeper down and that its C material consisted of a red-grey mottled clay.

Analyses

hor.	depth	-2μ	2-50	50μ-	text.cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr.ir.
A1	15 cm	33.1	46.3	18.0	s.c.l.	5.1	4.0	2.6	-	10	7	20	34	5.7
B21t	30 cm	39.8	45.3	13.2	s.c.	5.2	3.9	1.7	-	7.6	8	22	35	6.9
B22t	60 cm	42.2	43.5	12.8	s.c.	5.1	3.9	1.5	-	6.1	6	18	33	6.8

13. deep to shallow clayey soils with a red and brown Bt hor., no stones, upper decimetres browned or weak homogenization of the organic material (TYPIC PALEUDALF).

This soil unit is of great significance to the reconstruction of the evolutional history of the Seloul valley and is found on the flatter parts of the 'Triassic' diapyr.

It derives its significance from the fact that it occurs on the only surface in the Seloul valley in which a fossil, red Bt horizon is present in the soil profiles. At present a younger, less deep, brown Bt horizon partially covers the red one.

The recent formation of a Cambic horizon, which, dependent on the parent material generally led to the formation of a Dystrochrept or Eutrochrept in the flysch area is less pronounced than in the soil profiles in the flysch area and can be observed only in the wooded parts of the terrain. Pedogenesis in the non-wooded parts is now-

adays characterized only by a certain degree of homogenization of the organic material: 'steppisation' (see Aubert, 1965, p. 37: sols isohumiques, and Ruellan, 1966; see also chapter XII. 2.).
Unit 14. (group A) represents the severely eroded phase of these profiles.

p r o f i l e   d e s c r i p t i o n**

location: along the road from A.D. to Fernana; 4,5 km S of A.D.
classification: TYPIC PALEUDALF
elevation: 600 m
physiographic position: 'Triassic' diapyr
slope: gently sloping (3 %)
vegetation: shrubs, grasses and some cork oaks
parent material: Triassic breccia
drainage: excessively drained
moisture conditions: top 120 cm of profile dry, moist below
presence of surface stones: nil

A1 2/B21t 0-30 cm, dark brown (7,5 YR 4/2, moist), clay loam; weak to moderate sub-angular blocky; slightly hard to hard when dry; broken to patchy thin cutans, brown (10 YR 5/3, moist), probably clay minerals with iron oxides and hydroxides; many very fine and fine pores; high worm and ant activity; many fine roots; gradual and wavy boundary

2/B22t 30-130 cm, strong brown (7,5 YR 5/8, moist, deeper than 50 cm grading to 5 YR 5/8) and reddish brown

3/B21t (2,5 YR 4/4, moist) mottled, clay loam; moderate prismatic; hard when dry; broken to continuous thick cutans, reddish brown (2,5 YR 4/4, moist) probably clay minerals with iron oxides and hydroxides; patchy to broken moderately thick cutans, brown (10 YR 5/3, moist) possibly clay minerals and organic matter, decreasing deeper in the profile; common fine pores; high worm and ant activity; many fine roots; clear and wavy boundary

3/B22t 130 cm +, yellowish red (5 YR 5/8, moist), many fine to coarse prominent clear mottles, reddish brown (2,5 YR 4/4, moist), clay-sandy clay; moderate to strong prismatic; firm when moist; broken and thick cutans, reddish brown (2,5 YR 4/4, moist), probably clay minerals and iron oxides and hydroxides; common fine pores; some worm and ant activity; few fine roots.

Analyses

hor.	depth	-2µ	2-50	50µ-	text.cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr.ir.
A1	15 cm	33.7	35.1	27.7	c.l.	7.0	6.2	3.9	-	12.0	19	22	89	6.4
B21t	50 cm	38.6	32.0	29.1	c.l.	7.0	5.7	0.3	-	5.4	10	12	83	7.2
B22t	150 cm	43.4	40.0	16.3	c/s.c.	5.9	4.4	0.3	-	4.3	7	12	54	6.3
+	200 cm	37.5	29.7	32.7	c.l.	6.3	5.2	0.1	-	4.7	3	8	37	7.0

** In the profile description the polygenetic character of these profiles has been indicated with 3/ for the period in which the red Bt horizon was formed. The period of formation of the brown Bt horizon has been indicated with 2/.

				Clay minerals					
hor.	depth.	mix.l.	smect.	chlor/verm.	mica 'w'	mica 'p'	kand.	anat.	quartz
A1	15 cm			tr.	++		(+)	tr.	1-3 %
B21t	50 cm			tr.	++		(+)	?	ca. 1 %
B22t	150 cm			tr.	+		(+)	?	1-3 %
+	200 cm			tr.	++		(+)		?

D. miscellaneous

Several divergent soils have been classed with this group.

2. deep, silty loam soils, deeply and strongly humose, pseudo-gley mottling at varying depth, stony (AQUIC UDORTHENT).

The Holocene colluvium accumulated in the depressions in the sandstone divides. The depressions mapped (fig. 21) are as a rule structurally determined. The depression below the scar of the large earthflow (chapter VII. 2. 1.), which was effected by a slip movement with backward rotation, forms one of the exceptions. Further depressions in which the colluvium could accumulate (compare block profiles XII. 1. 4.) have developed on the crests of the first-order interfluves in zones of weakness (chapter III. 2.) in the rock.
Colluvium has also accumulated in the corrasional troughs described in chapter VIII., with resultant formation of a soil profile identical to unit 2. These troughs, however, could not be mapped, as their size falls short of the basic mapping unit (Steur and Westerveld, 1965; Vink, 1963).

N.B. Brown Bt horizons are rarely absent in early-Holocene colluvial deposits. This clay-illuviation does not occur where the colluvium accumulated strongly as in these depressions.

profile description

location: 50 m below the first-order divide of the Seloul valley, near Sidi Abdullah
classification: AQUIC UDORTHENT
elevation: 760 m
physiographic position: depression in the steep sandstone slope
slope: moderately steep (18 %)
vegetation: shrubs and grasses
parent material: colluvium
drainage: moderately well drained
moisture conditions: top 70 cm of profile dry, moist below
presence of surface stones: none to very few angular gravel, stones and boulders

A1 0-10 cm, dark brown (7,5 YR 4/2, moist) clay loam; weak sub-angular blocky; friable when dry; common very fine and fine pores; many to very many minute rounded quartz grains; few fine roots; merging and wavy boundary

g 10-50 cm, very dark brown (10 YR 2/2, moist) clay loam; few to common fine distinct and clear mottles, brown (10 YR 5/8, moist): pseudo-gley; weak sub-angular blocky; slightly hard to hard when dry; common very fine and fine pores; many to very many minute rounded quartz grains; few fine roots; merging and wavy boundary

g 50-70 cm, dark brown (7,5 YR 4/4, moist), clay loam; common fine distinct and clear mottles, brown (10 YR 5/8, moist): pseudo-gley; weak sub-angular blocky; hard when dry; common very fine and fine pores; many to very many minute rounded quartz grains; few fine roots up to 60 cm, deeper no roots; clear and smooth boundary

IIg 70-90 cm, strong brown (7,5 YR 5/8, moist), clay; many medium distinct and clear mottles, brown (10 YR 5/8, moist): pseudo-gley; moderate sub-angular blocky; firm to very firm when moist; few fine pores; few minute rounded quartz grains.

Analyses

hor.	depth	-2μ	2-50	50μ-	text. cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr. ir.
A1	5 cm	30.2	28.6	32.2	c.l.	5.4	4.1	8.1	-	16	8	22	32	5.2
g	20 cm	33.2	30.3	31.4	c.l.	5.5	4.1	8.1	-	2.7	7	21	33	6.4
g	60 cm	33.1	26.6	34.5	c.l.	5.3	4.0	5.8	-	4.2	-	-	-	6.9
IIg	80 cm	67.3	19.3	13.0	c.	5.1	3.7	0.4	-	5.6	6	54	11	7.3

Clay minerals

hor.	depth	mix. l.	smect.	chlor/verm.	mica 'w'	mica 'p'	kand.	anat.	quartz
A1	5 cm	?	?	?		tr.	+	xx	3-5 %
g	20 cm	tr.		(+)		tr.	+	x	3-5 %
g	60 cm	?				tr.	+	x	4-6 %
IIg	80 cm		tr.	?		tr.	++	xx	2-4 %

11. moderately deep, sandy clayey loam soils, deeply humose, very stony (TYPIC UDIFLUVENT).

This soil unit is found on a small terrace formed after damming up of the Oued Seloul by an earthflow.
The humose profile was not effected by so-called 'steppisation' or homogenization of the organic material, but by the Holocene humose colluvium being transported along the slopes down to the river.

profile description

location: along the Oued Seloul, 1,5 km S of A.D.
classification: TYPIC UDIFLUVENT
elevation: 530 m
physiographic position: fluviatile terrace

slope: flat (1 %)
vegetation: grasses
parent material: fluviatile deposits
drainage: well drained
moisture conditions: almost dry
presence of surface stones: stony

0-110 cm, very dark greyish brown (10 YR 3/2, moist), sandy clay loam; very weak sub-angular blocky; firm when moist to hard when dry; common to many very fine to medium pores; from 10-50 cm many rounded stones (sandstone and limestone) and deeper than 70 cm many rounded boulders (sandstone and limestone) and some shells; slightly calcareous; many to very few fine roots and common medium roots.

Analyses

hor.	depth	-2μ	2-50	50μ-	text.cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr.ir.
	30 cm	19.8	26.3	49.1	s.c.l.	7.7	7.3	3.8	2.5	24	-	-	-	5.4

Clay minerals

hor.	depth	mix.l.	smect.	chlor/verm.	mica 'w'	mica 'p'	kand.	anat.	quartz
	30 cm	x				tr.	+	x	5-8 %

4. complex of sandy lithosols + clayey lithosols + deep to moderately deep loamy sand to sandy loam soils with remnants of a Bt hor. and a tendency towards formation of an A2 hor., stony to very coarse stony (SPODIC) ULTIC UDIPSAMMENT + deep silty loam soils, strongly and deeply humose with considerable pseudo-gley mottling at varying depth (AQUIC) UDORTHENT.

This complex is found on the steep, wooded sandstone slopes below the crests.
The sandy lithosols have been formed on the sandstone outcrops and the clayey lithosols on the local clay lenses. The very stony deposits of the humid solifluction on these slopes have been strongly affected by the Holocene colluvium. A brown Bt horizon has formed in the oldest colluvium (early-Holocene).
Recent soil formation gave rise to a horizon with bleached quartz grains and to illuviation of organic material lower in the profile. These phenomena may be evidence for a recent tendency towards podzolation of the soils that have been formed in the sandy materials. The humose accumulations of the colluvium in the corrasional troughs has also been included in this complex.

profile description

location: 50 m below the eastern divide; 1 km S of A.D.
legend: deep to moderately deep loamy sand to sandy loam soils with

remnants of a Bt hor. and a tendency towards formation of an A2 horizon, stony to very coarse stony
classification: (SPODIC) ULTIC UDIPSAMMENT
elevation: 800 m
physiographic position: slope below the first-order divide
slope: steep (33 %)
vegetation: cork oaks, shrubs and grasses
parent material: sandstone
drainage: somewhat excessively drained
moisture conditions: profile dry throughout
presence of surface stones: stony to very stony

A1 0-20 cm, grey (5 YR 5/1-6/1, moist), loamy sand; weakly granular; soft when dry, common pores very fine to coarse; very many minute rounded quartz grains, some of the quartz grains are bleached; few medium and coarse roots; merging and irregular boundary

A2 20-40 cm, brown (7,5 YR 5/2, moist), loamy sand; weakly granular; many coarse distinct and clear mottles, pinkish grey (7,5 YR 6/2, moist); common very fine to coarse pores; very many minute rounded quartz grains, most of the quartz grains are bleached, and few angular boulders (sandstone), few coarse roots; gradual and irregular boundary

B2h 40-55 cm, dark brown (7,5 YR 4/2, moist), loamy sand; weakly granular; soft to slightly hard when dry; broken to continuous thin cutans, probably dominant organic matter and clay minerals; common very fine to coarse pores; very many minute rounded quartz grains, many angular boulders (sandstone); few coarse roots; gradual and irregular boundary

B2t 55-65 cm, strong brown (7,5 YR 5/6, moist), sandy loam; soft to slightly hard when dry; broken thin cutans, probably clay minerals and organic matter, importance of the cutans in the profile decreases with depth; common very fine to medium pores; very many minute rounded quartz grains and many angular boulders (sandstone); few coarse roots; diffuse and wavy boundary

C 65 cm +, light brown - reddish yellow (7,5 YR 6/4-6/6, moist), sandy loam; weak sub-angular blocky; soft to slightly hard when dry; common very fine to medium pores; very many minute rounded quartz grains and many angular boulders (sandstone).

Analyses

hor.	depth	-2μ	2-50	50μ-	text. cl.	PH_2O	PKCL	humus	$CaCO_3$	C/N	S	T	V	fr. ir.
A1	10 cm	4.5	11.2	82.0	l.s.	4.6	3.4	2.3	-	22.5	0	7	-	0.8
A2	30 cm	5.5	13.0	80.2	l.s.	5.0	3.9	1.3	-	13.0	0	8	-	0.9
B2h	50 cm	8.4	11.6	78.2	ls/sl	4.7	3.8	1.8	-	12.1	1	6	-	2.2
B2t	60 cm	10.0	12.0	75.8	s.l.	4.7	3.8	2.2	-	12.1	0	7	-	2.3
C	80 cm	11.5	12.1	75.2	s.l.	5.5	4.3	1.2	-	8.8	0	5	-	2.4

				Clay minerals					
hor.	depth	mix.l.	smect.	chlor/verm.	mica 'w'	mica 'p'	kand.	anat.	quartz
A1	10 cm		tr.			(+)	+(+)	x	3-5 %
A2	30 cm					+	+(+)	x	5-8 %
B2h	50 cm					tr.	+	x	3-5 %
B2t	60 cm			?		(+)	(+)	x	3-5 %
C	80 cm			(+)		(+)	+(+)	x	3-5 %

XII.1.4. Relationship Between Some of the Most Widespread Soil Units in the Valley of the Oued Seloul (Block Profiles, fig. 22)

Subject of discussion in this section are: a. the flat first-order divides (map units 2 and 1), b. the flat slopes in the soft shales lower down in the valley (map units 5 and 6), and c. the areas in which deposits of earthflow and mudflow are found (map units 8 and 9).

--- a. The soils on the wooded, flat crests are generally slightly eroded and show a relatively deep development. A brown Bt horizon has developed in the oldest colluvium and an A1 horizon in the younger colluvium. Pseudo-gley (perched water-table) is found high up in the Bt horizon (unit 1).

The narrow firebreaks did already display degradation of the profile several tens of years after having been cleared. The A1 horizon is considerably thinner, and the Bt horizon is more or less truncated. However, this eroded phase was not indicated separately on the soil map, the firebreaks being smaller than the basic mapping unit (Vink, 1963; Steur and Westerveld, 1965).

A thick humose top layer originated due to very thick accumulations of the youngest colluvium in structural depressions on the divides. Where the humose horizon is more than 60 cm thick, the profile has been classed with unit 2. A borderline case has been drawn in the block profile (fig. 22). Generally the accumulation is considerably thicker than 60 cm.

--- b. The two soil units on the flat slopes in the soft shales are characteristic of the wooded and non-wooded parts of the terrain respectively.

Compared to the profile in the wooded parts (unit 5) the soil profile in the non-wooded parts (unit 6) has been eroded and this in a way highly similar to the erosive process operating in the firebreaks very recently cleared on the flat crests of the interfluves. The profiles on the slopes lower in the valley are stony (humid solifluction) and pseudo-gley mottling is found deeper in the profile.

--- c. These two profiles give an impression of the differences between the otherwise closely related units 8. and 9. Both units have developed in the 'landslide areas' on very heterogeneous parent material. Unit 9. is the highly eroded phase of unit 8., with even the heterogeneous parent material cropping out. Due to this development the profiles produce an impression of disarray.

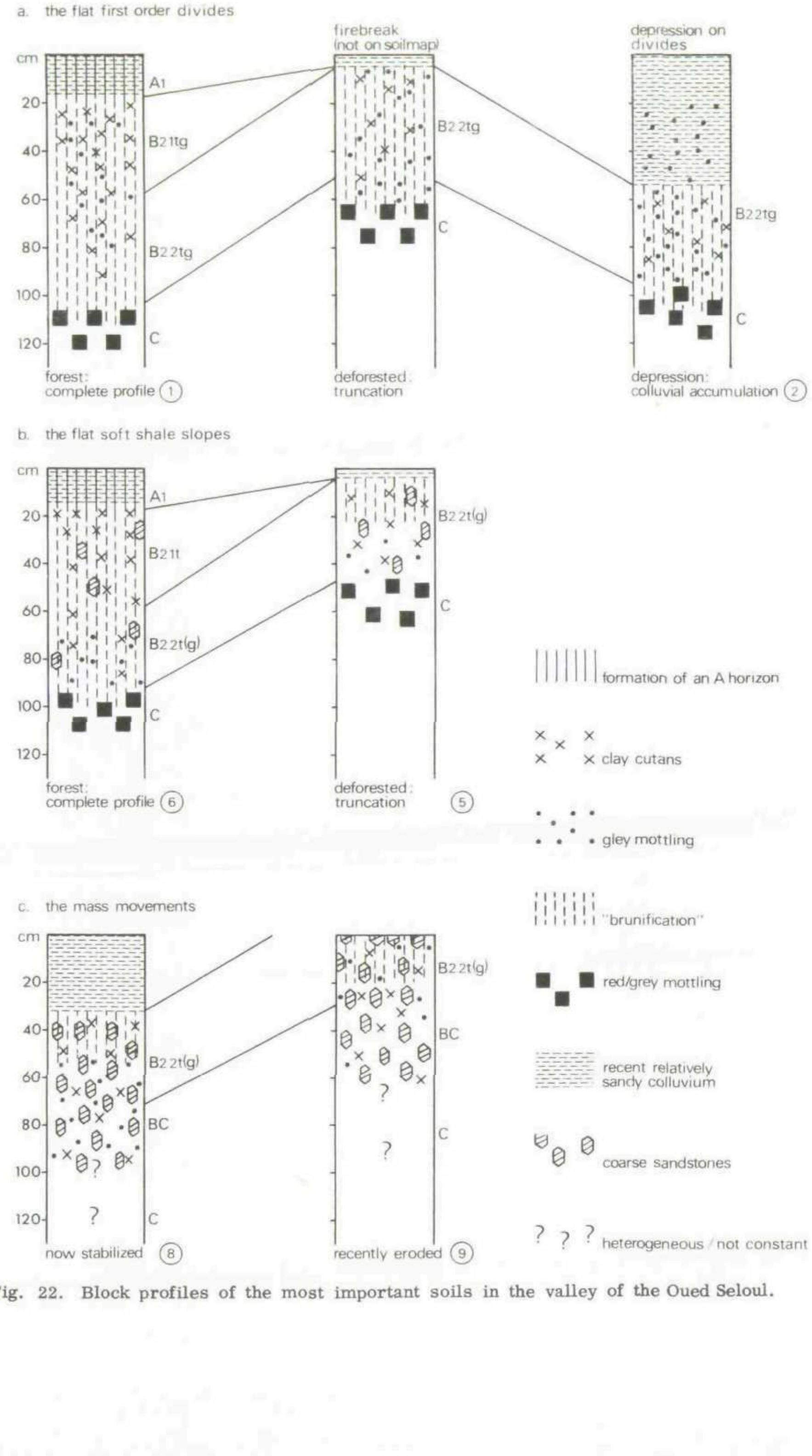


Fig. 22. Block profiles of the most important soils in the valley of the Oued Seloul.

XII. 2. Summary of the Recent Pedogenesis

It may generally be argued that on the soft shales the recent pedogenesis has been restricted to the formation of a Dystrochrept (Acid Brown Soil), which, especially under forest, results in deep brown colouring.
Perhaps a brown Bt horizon is still being formed, but even in the wooded parts of the Seloul valley brown colouring seems to be the dominant process, whereas formation of the brown Bt horizon seems to be limited to the early-Holocene colluvial deposits.

Brown colouring and locally decalcification are the only processes operative on the calcareous clayey materials (marls), usually with resultant formation of a structural B (Cambic) horizon: tendency towards formation of an Eutrochrept (Braunerde, by Kubiena, 1950; Brown Forest Soil). Cambic horizons are usually found in the soils on the marls.

In the soils that have developed in parent rocks of a more sandy texture present pedological processes led to formation of a weakly developed eluvial horizon (A2) containing bleached quartz grains (plate 19).
The underlying horizon is clearly subject to illuviation of organic material. The overall picture is that of a recent development towards a Spodosol (podsol), and is in general agreement with the data derived from the pedological map of Tunisia scale 1 : 500,000 (Hamza, 1966, see also Mori, 1966).

In the area of the 'Triassic' diapyr the soils in the wooded parts are subject to recent brown colouring (formation of an Eutrochrept); particularly the soils in the non-wooded parts are subject to a weak 'steppisation', homogenization of organic material extending deeply into the profile. About this homogenization Ruellan (1966) says: 'Cette répartition n'est pas le résultat d'une végétation steppique mais plus probablement d'une végétation forestière qui existait encore récemment; on sait en effet que sans forêt méditerranéenne les sols sont profondément enrichis en matière organique; cependant, sous forêt les sols sont également très riches en matière organique en surface et on ne peut pas dire que la répartition soit isohumique, c'est-à-dire lentement decroissante. On peut cependant penser que l'isohumisme actuel de ces sols est le résultat de la disparition de la végétation forestière qui a été suivie par une minéralisation de la matière organique plus rapide en surface qu'en profondeur; et plus cette disparition est ancienne, plus l'isohumisme a tendance à disparaître également par apauvrissement du sol en profondeur; la végétation steppique plus ou moins dense qui a suivi la forêt ne pouvant maintenir un certain taux de matière organique que dans les horizons superficielles'.

XII. 3. Polygenetic Phenomena

XII. 3. 1. Soils of the Triassic Breccia

Unit 13 is a soil profile from the 'Triassic' diapyr and has been described in chapter XII. 1. 3. The profile is characterized by three successive periods of soil formation (see plates 20 and 21). The location of the described profile in the terrain has been outlined in figure 23. As will be seen from this figure a depression (= a type b. valley-floor divide, chapter IV. 2.) isolating this part of the terrain from the flysch area, afforded protection against the erosive processes operative during the latest pluvial (Würm).

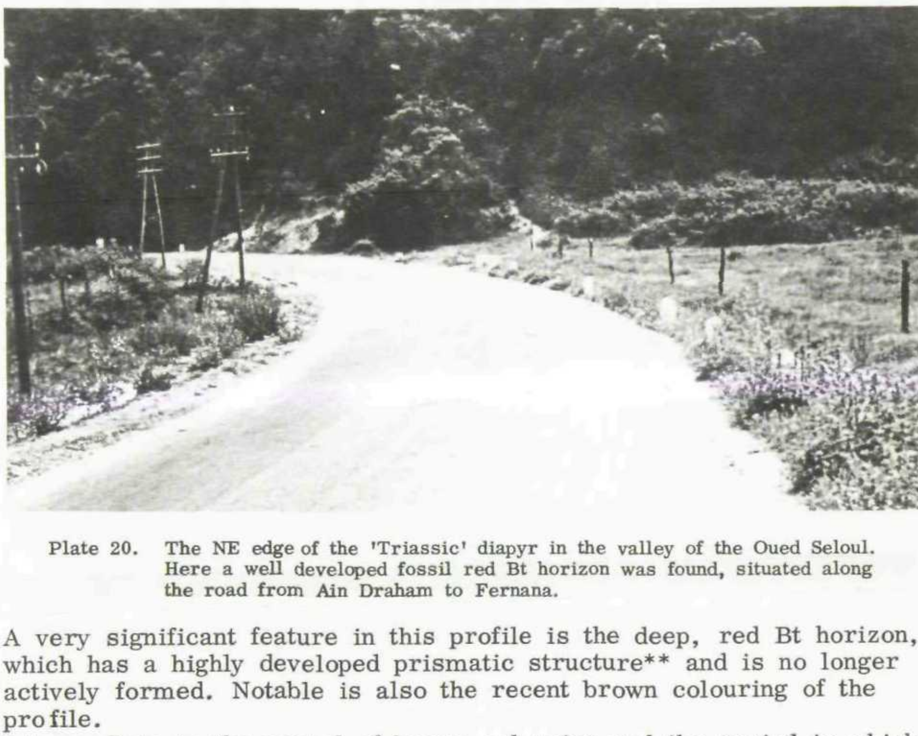


Plate 20. The NE edge of the 'Triassic' diapyr in the valley of the Oued Seloul. Here a well developed fossil red Bt horizon was found, situated along the road from Ain Draham to Fernana.

A very significant feature in this profile is the deep, red Bt horizon, which has a highly developed prismatic structure** and is no longer actively formed. Notable is also the recent brown colouring of the profile.

Intermediate to the period of brown colouring and the period in which the red Bt horizon was formed, a brown Bt horizon originated partly covering the red one but extending less deep.

Summarizing: an older period with clay illuviation and consequent formation of a presently fossil, red Bt horizon succeeded by another period with clay illuviation during which a brown Bt horizon, presently also fossil, was formed, and finally a period of brown colouring (formation of an Eutrochrept).

** D'Hoore, Soil Map of Africa, p. 155: 'the brown Mediterranean soils have a blocky or prismatic structure which is less marked than in the red Mediterranean soils'.

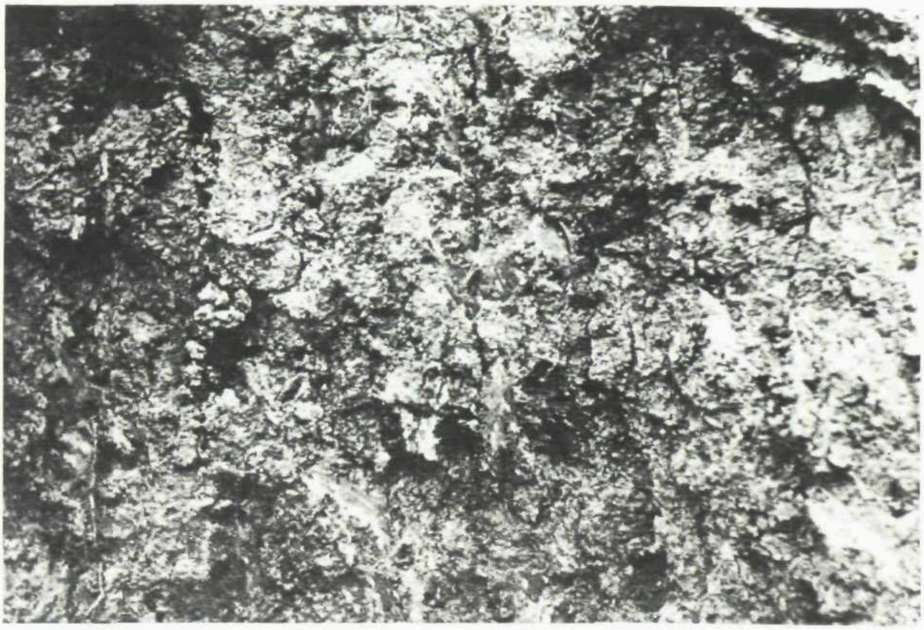


Plate 21. A close look at the polygenetic Bt horizon.

A notable feature is that the red Bt horizon, or rather its remnants, can be traced nearly everywhere in the valleys of the diapyr. The conclusion seems warranted that there is very little difference between the present relief in the diapyr and the relief during formation of the red Bt horizon. This is indicative of a soil formation which does not predate the most recent inter-pluvial (Eemian), for it may be assumed that predating river incisions would have considerably changed the relief.

There is every indication that the red Bt horizon was formed during the stable phase in the landscape development preceding the stable phase during which the brown Bt horizon originated.
The two stable phases are separated by an intermediate unstable phase in the landscape development which, unlike in the neighbouring flysch area, was rather indistinct in the 'Triassic' diapyr.

XII. 3. 2. Soils of the Transition of the Triassic Breccia to the Oligocene Flysch Deposits

The Triassic is almost entirely isolated from the flysch; deep fluviatile valleys such as the valley of the Oued Seloul separate the Triassic breccia nearly everywhere from the soft shale, marl and sandstone. However, at some localities the slope of the terrain gradually passes from the flysch materials into the Triassic breccia. It is here that both the red and brown Bt horizon are found in the soil profile, but this time clearly separated by a stone-line composed of sandstone debris (plate 22). The stone-line lies upon the somewhat truncated, red Bt horizon. A brown Bt horizon that originated in the colluvial layer overlying the stone-line penetrated the stone-line to partially cover the red horizon. The stone-line is the result of the humid solifluction during the last pluvial (Würm) indicating that the red Bt horizon dates from the last inter-pluvial (Eemian) and the brown Bt horizon from the early-Holocene.

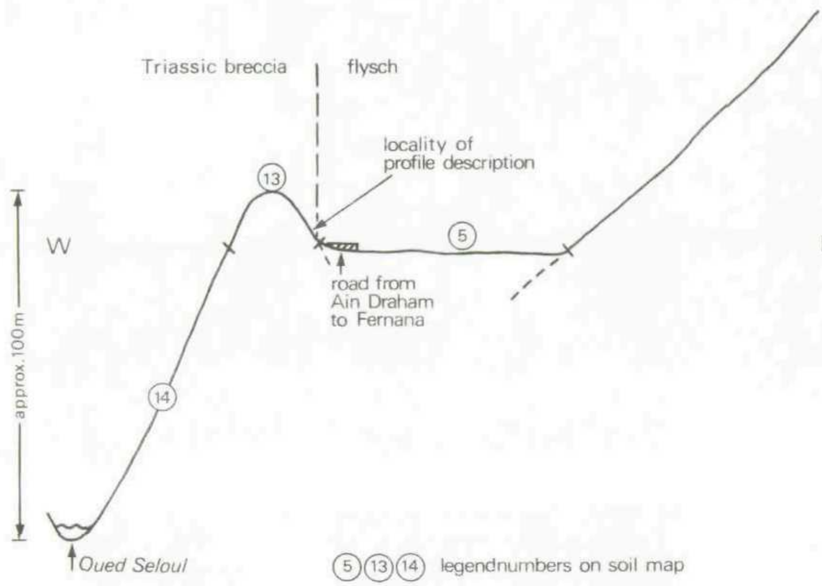


Fig. 23. Locality of the profile description of soil unit 13.

It is interesting to compare the opinion of French pedologists on red fossil clay illuviation with the data obtained in the Seloul valley. Duchaufour (1960) in Précis de Pédologie, p. 292, for instance says: 'La plupart des sols rouges sont fossiles et datent soit du pluvial Würmien, soit du pluvial Thyrrénien'. This passage has been dropped in the new edition of 1965 and replaced by: 'Il y a depuis la fin du Tertiaire plusieurs périodes "rubéfiantes": le Villafranchien (Wilbert, 1960), le Mindelien (Concaret et Mahler, 1960), le pluvial Würmien', on p. 246.
The French pedologists obviously considered the pluvials as periods with a highly increased precipitation (compare the term 'pluvial'), which would give rise to a well-developed forest vegetation essential to formation of a deep and well-developed illuvial clay horizon.
From the findings of the field work an entirely different conclusion

was arrived at. With reference to the periodicity in the landscape development all evidence goes to show that the pluvials, or at any rate the most recent pluvial, are characterized particularly by a fall of temperature and represent a period of intense geomorphological activity with a severe degradation of the forest, whereas the inter-pluvials were characterized by regeneration of the forest vegetation.

Beaudet, Maurer and Ruellan (1967), however, making use of both pedological and geomorphological data, also report in Morocco that the effect of the pluvials may show distinct variations according to morphogenetic environment. It is their estimate that, with respect to specific morphogenetic environments, especially the inter-pluvials should be considered as soil-forming periods.

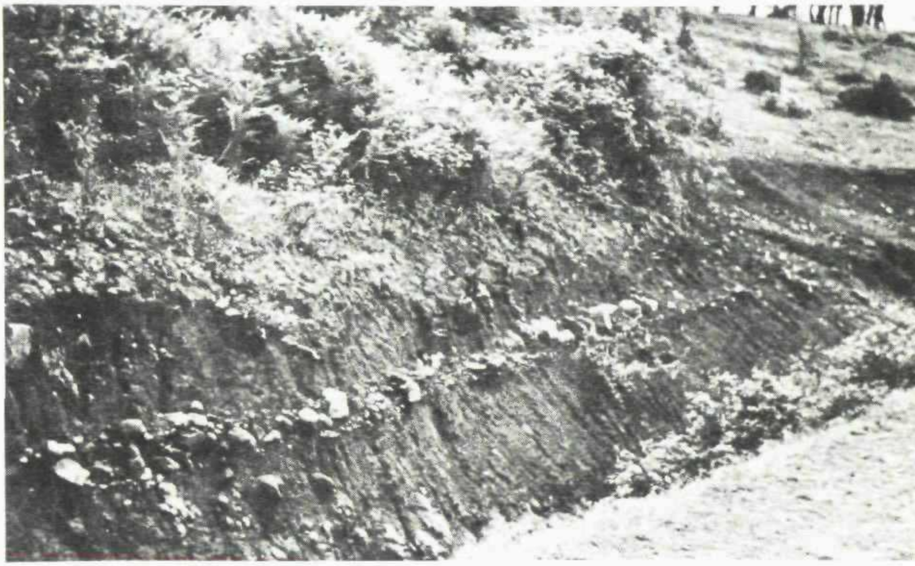


Plate 22. The stone-line composed of sandstone debris developed on the scarce locations where the Triassic breccia is in direct contact with the flysch.

XII. 3. 3. Soils of the Oligocene Flysch Deposits

The south side of the b. type valley-floor divide (chapter IV. 2.) is presently severely dissected by a tributary of the Oued Seloul. In these incisions it is to be observed that the flat valley-floor divide is filled with deposits nowadays reaching a thickness of about 12 m. The lower seven metres consist of a red deposit and the upper five metres of a brown deposit. The two deposits are separated from each other by a 50-80 cm thick stone-line composed of sandstone debris. The depression in the landscape has the ideal location to function as the accumulation area for the surrounding slopes, which indeed are almost depleted of their soil cover.
The assumption is that the red material represents the red soil and

brown material the brown soil. Here too the stone-line is derived from humid solifluction.

From the discussion of the soil map scale 1 : 25,000 (XII.1.3.) it became apparent that the flysch materials in the Seloul valley contain no remnants of soil formation comparable to the red Bt horizon found in the Triassic breccia; all soils in the valley of the Oued Seloul are brown. The only exception is the typically red-grey mottled clay which usually occurs as C horizon in the soil profiles on the soft shales. The mottled clay has been carried along in the mudflow during the last pluvial (Würm) and consequently, dates from a period of soil formation prior to the mudflow activity: presumably the last inter-pluvial (Eemian).
The brown Bt horizon postdates the mudflow and is, therefore, a Holocene pedogenesis.

There was also reference to Vertisols in chapter XII.1.3.
At sites where the clay is calcareous (marls) remnants of a Vertisol are found and no remnants of the red-grey mottled clay. Recent brown colouring (as a rule formation of an Eutrochrept) is indicative of the Vertisols not having a recent origin but being remnants of an older, no longer active soil formation.

The Holocene colluvium, see chapter XI.4., may be subdivided into two phases. The oldest and early-Holocene phase is somewhat more clayey than the most recent phase.
Furthermore pollen analytical investigation shows that relatively humid and warm climatic conditions prevailed during the deposition of the oldest colluvium. The brown Bt horizon has always been formed in the relatively clayey, early-Holocene phase of the colluvium. Unlike the most recent colluvium which is limited to the formation of a Dystrochrept). In other words it appears that the two phases in the colluvium coincide with strikingly different periods of soil formation.

XII.3.4. A Pseudo-fossil Phenomenon
Although otherwise stated in XII.3.3., some reddish and brown soil profiles do occur in the valley of the Oued Seloul**.

Soils of a distinctly red colour are met with to either side of the humose colluvial fill in the corrasional troughs (fig. 24). A possible explanation of the phenomenon may be provided by the reddish hue of the sand having been brought about by an older soil forming period, remnants of which have been preserved on either side of the filled up depression. A notable feature is that the reddish hue is always encountered adjoining the lower parts of the terrain, which may point to a location in these accumulation areas not subject to erosion.

** In chapter XII the colour 'red' is used to differentiate from the distinctly brown colours of by far the greater part of the profiles. There is no correlation with the red of the Munsell Color Charts notations.

physiographic position: flat part of otherwise rather steep slope
slope: sloping (7 %)
vegetation: cork oaks, oaks and shrubs
parent material: soft shales
drainage: moderately well drained
moisture conditions: almost dry
presence of surface stones: very few stones and boulders

A1	0-15 cm, dark reddish brown-grey (5 YR 3-4/2, moist), sandy clay loam; weak sub-angular blocky; soft to slightly hard when dry; many very fine and fine pores; many minute rounded quartz grains; high ant and worm activity; many fine roots and some coarse roots; merging and wavy boundary
2/B22t	15-50 cm, dark reddish brown (5 YR 3/4, moist), sandy clay; weak to moderate sub-angular blocky; slightly hard when dry; broken moderately thick cutans probably clay minerals with iron oxides and hydroxides and broken thin cutans probably organic matter; many very fine and fine pores; many rounded minute quartz grains and none to very few angular boulders (sandstone); high ant and worm activity; many fine roots; merging and irregular boundary
3/B22t	50-100 cm, yellowish red (5 YR 5/6, moist), sandy clay; moderate sub-angular blocky; hard when dry; broken thick cutans probably clay minerals with iron oxides and hydroxides, red (2,5 YR 4/6, moist) and patchy thin cutans probably organic matter; common to many fine pores; few rounded minute quartz grains; high ant and worm activity; many fine roots; gradual and irregular boundary
3/BC	100-130 cm, yellowish red (5 YR 4/8, moist), sandy clay; moderate sub-angular blocky; hard when dry; patchy thick cutans probably clay minerals with iron oxides and hydroxides, red (2,5 YR 4/6, moist); few to common fine pores; few rounded minute quartz grains; some worm and ant activity; common fine roots; gradual and smooth boundary
3/Cg	130 cm +, yellowish red (5 YR 4/8, moist), sandy clay; many coarse to medium prominent and clear mottles, red (10 R 5/8, moist); moderate sub-angular blocky; hard when dry; few fine pores; very few rounded minute quartz grains; common to few fine roots.

XIII. 4. 2. Soils of the Miocene Lagoonal Deposits and the Mio-Pliocene Continental Deposits

The more elevated parts of the Mio-Pliocene alluvial fans were only little affected by humid solifluction. However, nowadays these sandy deposits are subject to severe erosion, especially in the non-wooded parts of the terrain. Locally only, near clusters of trees, denudation was so much less that the soil profiles have not been truncated down to the C material (see plate 23 and 24).

XIII. 4. Pedology of the Valley of Ben Metir

The Mio-Pliocene continental deposits have been laid down in a system of alluvial fans grown together.
The conical shape of these separate fans may often be observed in the terrain. Particularly the lower parts of the terrain, where two fans merge, have been subject to mudflow activity and humid solifluction originating from the flysch rocks higher up the slopes.
The areal mass movements displaying intense activity elsewhere left the higher parts of the alluvial fans relatively undisturbed. Moreover, the fluviatile phases of incision that caused considerably slope instability in the Seloul valley are absent here; consequently, the break in the terrain at the transition of the sandstone to the soft shales is much less pronounced in the valley of Ben Metir (compare chapter X.1.)

XIII. 4.1. Soils of the Oligocene Flysch Deposits

In view of the greater slope stability in the valley of Ben Metir, the assumption seems warranted that distinct traces of Eemian soil formation are more widespread here than in the Seloul valley where these traces could only be observed in the landscape of the 'Triassic' diapyr.

For the purpose of illustration a profile description is given. The profile has been formed on the soft shales on a flat part of the slope. The site was obviously well protected against the influences of the humid solifluction, because very little sandstone debris is found in the profile. The profile is very clearly polygenetic. The assumption is that the red clay illuviation represents the Eemian soil (3/ in the profile description). A very significant feature is that the red-grey mottled clay as C horizon appears to constitute one profile with the red Bt (illuvial clay horizon) and consequently, originates from one and the same pedogenesis.
Also in this profile a younger brown clay illuviation partly covers the red Bt horizon.

> N.B. Vertisols are also found in the valley of Ben Metir. Unlike the Seloul valley where they occur on the marls of the flysch rocks, which are not exposed in the synclinal valley, the Vertisols are met with on the calcareous Miocene lagoonal deposits (see chapter XIII. 4. 2.).

profile description**

location: 100 m below the W divide separating the valley of Ben Metir from the Seloul valley
classification: HAPLUDALF
elevation: 730 m

** In the profile description the polygenetic character of these profiles has been indicated with 3/ for the period in which the red Bt horizon was formed. The period of formation of the brown Bt horizon has been indicated with 2/.

The Seloul valley is characterized by several deep fluviatile incisions during the Pleistocene accompanied by powerful slope movements with consequent obliteration of all traces of possible Mio-Pliocene deposits.

The valley of Ben Metir is drained by the Oued el Lil. In chapter IV. 3. it has been reported that the Oued el Lil is the only river which from the zone of subsidence of the Oued Medjerda area crosses the fault zone and captures the 'cuvette' of Ben Metir, thus causing the b. type valley-floor divide (fig. 5). However, the capture by the Oued el Lil with its strong headward erosion has not yet resulted in strong dissection of the valley of Ben Metir.

The soils and deposits found in the Seloul valley do not predate the late Pleistocene. The occurrence of Mio-Pliocene deposits in the synclinal valley points to the possible presence of older soil formations and deposits.

XIII. 3. Mass Movements in the Valley of Ben Metir

Mass movements operative during the unstable phases in the landscape development have strongly affected the relief in the Seloul valley (e.g. during the last pluvial) and have also left distinct traces in the valley of Ben Metir. On the relatively steep slopes in the flysch rocks, upslope from the Mio-Pliocene filling, the deposits of humid solifluction are found, here too locally passing into a mudflow. Large surfaces of the valley are covered by these tongue-shaped mudflows.

Also the humid solifluction has indubitably affected the lower parts of the terrain.
The Mio-Pliocene continental deposits being composed of coarse detrital sandstone, absence of the typical tongue-shape of the mudflow seriously impedes the assessment of the influence of the flow movements, which are also characterized primarily by coarse sandstone components. Here too the deposits of the flow movements are stabilized and overlain by a cover of Holocene colluvium.
The coarse angular sandstones deep in the Mio-Pliocene continental deposits are severely weathered and somewhat disintegrated (corona of several centimetres), whereas unweathered sandstone is of widespread occurrence on the surface, which may be indicative of the unweathered sandstone deriving from the humid solifluction and the weathered sandstone belonging to the old Mio-Pliocene continental series.

At present, like in the Seloul valley, the local, linearly concentrated slide movement prevails especially on the soft shales.

PART THREE: THE VALLEY OF BEN METIR

Chapter XIII

SIMILARITIES AND DISSIMILARITIES BETWEEN THE VALLEY OF THE OUED SELOUL AND THE VALLEY OF BEN METIR

The synclinal valley of Ben Metir (cuvette, see plate 2) has been accorded a less extended study than the adjoining valley of the Oued Seloul. However, much of what has been reported with respect to the processes and materials of the Seloul valley, obtains for the valley of Ben Metir as well. Yet there are appreciable dissimilarities.
In this chapter especially the differences between the anticlinal and the synclinal valley will be discussed.

XIII. 1. Geological Setting of the Valley of Ben Metir

The valley of Ben Metir also consists of the usual flysch rocks: soft shales and sandstone. Due to the synclinal character of this valley and the absence of a significant fluviatile dissection, the oldest flysch rocks are not exposed (marls: Medjanian Flysch).
Another outstanding difference is that the valley has been filled with lagoonal Miocene deposits (calcareous clays), which are largely submerged at present as a result of the construction of a storage lake. Towards the edges these lagoonal deposits gradually merge into the Mio-Pliocene continental deposits similar to the system that has been described for the zone of subsidence of the Oued Medjerda and the piedmont area.

XIII. 2. Geomorphology of the Valley of Ben Metir

In the valley of the Oued Seloul the difference in level between river and divide has been effected by vertical fluviatile erosion, but in the valley of Ben Metir the structure is the determinant factor. The synclinal valley is deeper, yet its width of approximately 7 km considerably reduces the relief energy and the valley consequently conveys an impression of wideness and flatness.

It depends on the relative magnitude of the complex formation constants and the solubility products of the hydroxides, whether an organic metal complex is stable in neutral and alkaline medium or not. If a high Ca-ion concentration (better: activity) coincides with a high pH, the statement of Duchaufour may be true. However, high Ca-ion activity in calcareous materials coincide with low pH-values as can be easily deducted from a study of the system $CaCO_3(s)$ - $CO_2(g)$ - $H_2O(1)$. As a result of this study it can be concluded that the conditions promoting the precipitation of ironhydroxides are - in mediterranean regions - more favourable at the end of the dry season and in winter (low partial CO_2-pressure) than in spring and summer (high partial CO_2-pressure).

In the flysch area the activities of mudflow and especially humid solifluction (Würm) have generally truncated the soils derived from the Eemian on the non-calcareous clays down to the compact, red-grey mottled gley horizons and subsequently covered these soils with coarse detrital deposits. These detrital deposits have also been traced on the marls.

The unstable period has had little effect on the landscape of the 'Triassic' diapyr. A stone-line of humid solifluidal sandstone debris was deposited on the somewhat truncated red Bt horizon, but this only at sites where a deep fluviatile valley did not separate the Triassic from the flysch deposits.

After this unstable period there must have been a regeneration of the forest, and during the subsequent period of soil formation the brown Bt horizon originated, which in the flysch area, was associated with the accumulation of the early-Holocene colluvium.
In the Triassic breccia the less deep extension of the brown Bt horizon prevents it from entirely covering the red Bt horizon.
The current forest vegetation is somewhat degraded compared to that of the early-Holocene and the recent soil-forming processes may lead to formation of a Dystrochrept respectively Eutrochrept on calcareous rocks and podzolation on the more sandy materials.
In the 'Triassic' diapyr the non-wooded parts of the terrain show a tendency towards homogenization of the organic material (compare chapter XII.2.).

The scheme of the various pedogenetic processes may be correlated with that of the geomorphological phenomena. Only period 7. of fig. 19. may be differentiated, due to the dual character of the recent colluvium, which duality may also be inferred from the difference in pedogenesis.
The combined scheme has been given in figure 26.

The soils formed in the flysch shales suffered and still suffer from excess of water as is evidenced by the pseudo-gley mottling on the flatter slopes.

Prior to the youngest unstable phase in the landscape development (Soltanian or Würm) a soil with a deep, red Bt horizon came into being on the clayey Triassic breccia. Under the same climatic conditions strong gleying occurred on the less permeable flysch shales causing red-grey mottling (rubefactional conditions). With respect to the basin of Paris Fédoroff (1965, 1966[a and b]) seems to arrive at the same conclusions:
'During the late-Pleistocene, on highly permeable parent material developed a 'sol lessivé rouge' and on impermeable substrata, we find 'sol lessivé' with strong gleying, these soils are always rubefied, their base saturation is often low and we note a beginning of evolution of various clay minerals towards kaolinite'.

This red colouring has left no traces in the calcareous, clayey rocks of the flysch deposits. Instead of a red soil with an illuvial clay horizon a Vertisol formed on these rocks at that time, which is certainly true of the parts of the terrain where remnants of this Vertisol can still be found. This observation is in agreement with a comment of Boulaine (1966): 'En région méditerranéenne la saison sèche est en été (climat xérothique). On trouve les sols rouges sur presque toutes le roches, y compris les calcaires, sauf sur celles qui sont riches en calcaires actif et peu perméables (marnes et certain calco-schistes)'. The explanation is sought in the concentration of Ca^{2+} ions in the soil solution (Duchaufour, 1965 p. 198): ' s'il y a plus de 100 p.p.m. de Ca^{2+} dans la solution du sol, le fer ne se complexe pas avec la matière organique; au contraire s'il y a moins de 100 p.p.m. de Ca^{2+} il y a passage du fer sous forme pseudo-soluble pendant la période où le sol est humide. Le déssèchement permet en suite la peptisation irréversible du fer qui imprègne et recouvre les aggrégats du sol'.

In mediterranean regions where rain falls in winter when vegetation is least active (low evapotranspiration) the concentration of Ca^{2+} may become less than 100 p.p.m. also in the calcareous rocks (such as the Triassic breccia), except for rocks with 'calcaire actif' and a poor permeability such as marls (Boulaine, 1966; Cointepas, 1966).

On the other hand, serious doubts on the postulation of Duchaufour (1965), that Ca-ions hinder the complexation of iron should be had (personal communication Dr. J. van Schuylenborgh). The Ca-complexes are very much weaker than iron-complexes (Martell, 1964), so that calcium can not compete with iron. As a matter of fact, complexation is dependent on the pH of the medium. Its effect is two-fold:

1. ionization of the organic acid favours the formation of organic metal-complexes.
2. high pH values promote the hydrolysis of the complexes, especially when the hydroxides of the metals under consideration are insoluble.

scheme may be correlated with that of the geomorphological development (see fig. 26).

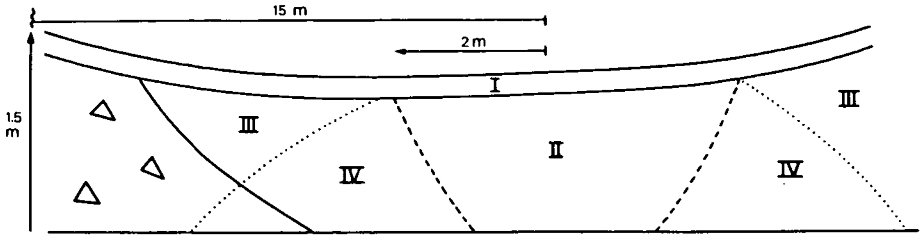
FLYSCH AREA	TRIASSIC BRECCIA
Vegetation: mainly cork oaks, some oaks and shrubs. Recent formation of a Dystrochrept or Eutrochrept. Materials of a sandy texture show tendency towards formation of an A2 horizon. Degradation** of the Vertisols. Degradation of the brown Bt horizon. Colluvium: clay loam.	Very substantial reduction of the forest (anthropogenic?). Recent homogenization of the organic material: 'steppisation' in non-wooded areas. Recent formation of an Eutrochrept in wooded areas.
Vegetation more abundant than recently (including alder). Formation of a brown Bt horizon. Colluvium: clay loam, somewhat more clayey than present colluvium.	Forest vegetation. Formation of a brown Bt horizon.
Mudflow and humid solifluction activity: coarse detrital deposits.	Locally deposition of a stone-line.
Forest vegetation. Rubefactional conditions during soil formation, with resultant formation of the red-grey mottled clay now present as a remnant. Formation of a Vertisol on the marls.	Forest vegetation. Rubefactional conditions during soil formation with resultant formation of a deep, red Bt horizon.

** The term degradation is also used in soil science to refer to a heavily leached soil. In this text, however, degradation of the Vertisol indicates diminishing importance of the Vertisol (or any other soil) characteristics.

Fig. 25. Scheme of the pedological development in the valley of the Oued Seloul.

XII. 4. 2. Effect of the Parent Rock and the Geomorphological Development on the Soil Profile

In the Appendix it is pointed out that, given the absence of expansible clay minerals, the permeability of the clayey Triassic materials by far exceeds that of the clays of the flysch deposits. It is further described how these materials obtained a 'texture pseudo-sableuse' as a result of Eemian soil formation, which may well have led to a substantially improved permeability. At any rate at the time of formation of the red Bt horizon the 'Triassic' diapyr was already surrounded by deeply incised fluviatile valleys, which was highly conducive to good drainage of the profiles.



I .... very recent colluvial cover

II black 5YR 2/1 ⎫
III very dark grey 5YR 3/1 ⎬... recent sandy, humose colluvium
IV reddish brown 5YR 4/4 ⎭

△ .... coarse sandstone debris

Fig. 24. Colluvial accumulation in a corrasional trough.

However, considering that the corrasional troughs are erosional forms from the last pluvial (Würm) and moreover, that the reddish hue occasionally extends to the solifluidal debris and consequently dates from the Holocene, this explanation remains unsubstantiated.
A more likely explanation is provided by the fact that humid parts of the terrain are concerned with a concentration of ferriferous groundwater. From the humid zone the water will seep through the adjacent sand, the accumulated iron-humus complexes oxidize and, favoured by the sandy character of the material, a zone of red colouring originates**.

XII. 4. Interpretation of the Polygenetic Phenomena Relative to the Climate

XII. 4. 1. Pedological Scheme

Given the data obtained the following scheme for the pedological history of the valley of the Oued Seloul can be drawn up (fig. 25) The

** Compare Duchaufour (1965, p. 325): 'La rubéfaction récente en climat méditerranéen est un processus localisé, réduit à des stations où les variations microclimatiques sont très contrastées. Ces fortes oppositions microclimatiques siasonières s'observent:
1. dans les stations dépourvues ou peu couverte par la végétation;
2. dans les zones à pluviosité élevée et cependant à radiations solaires particulièrement intenses donc en altitude (Moyen Atlas, Mensching 1956);
3. dans les bas fonds peu drainés, à nappe d'eau riche en fer (Pujos 1957)

Plate 23. The valley of Ben Metir. In the vicinity of the trees, protected from the degradation of the surface, remnants of a fossil red Bt horizon are present.

Plate 24. A close look at the locality seen in plate 23.

This being so, the profiles that occur are clearly polygenetic, however, in view of their very local and rudimentary distribution, a detailed profile description proved impossible.
Some idea of the profile may be gained from the following brief description:

A1 2/B2t	0-20 cm, greyish-brown (10 YR 5/2, moist), loamy sand
2/B2t	20-120 cm, strong brown (7,5 YR 5/8, moist) sandy loam; patchy to broken moderately thin cutans brown (7,5 YR 5/4, moist)
3/B2t	120-130 cm, brownish yellow (10 YR 6/8, moist) sandy loam; patchy to broken moderately thick cutans reddish brown (2,5 YR 4/4, moist)
3/Cg	130-300 cm +, reddish brown (2,5 YR 4/4, moist), many coarse prominent clear mottles yellowish red (5 YR 5/8, moist), sandy loam.

On the calcareous Miocene lagoonal deposits the equivalent is found of the remnants of the Vertisol occurring in the Seloul valley on the marls of the flysch rocks.

profile description

location: near the track along the W bank of the storage lake
classification: ENTIC PELLUDERT
elevation: 520 m
physiographic position: flat floor of the synclinal valley
slope: gently sloping (3 %)
vegetation: grasses
parent material: Mio-Pliocene lagoonal deposits
drainage: somewhat excessively drained (when cracks are present)
moisture conditions: almost dry
presence of surface stones: very little limestone gravel

A	0-80 cm, weak red (2,5 YR 5/2, moist), clay; strong medium to coarse prismatic; hard to very hard when dry; few slickensides; few medium pores; little limestone gravel; many deep and wide cracks; strongly calcareous merging and smooth boundary
B	80 cm +, like A, but pale red (2,5 YR 6/2, moist)

XIII. 4. 3. Recent Pedological Development of the Valley of Ben Metir
The conclusions relative to the recent pedogenesis of the Seloul valley (chapter XII. 2.) generally obtain for the valley of Ben Metir.
The difference is that extensive parts of the synclinal valley are non-wooded and apart from a severe denudation are subject to a weak 'steppisation', i.e., homogenization of organic material till deep into the profile (chapter XII. 2.), however, these profiles are, due to the severe denudation, only present as 'pedestals' (plate 25).

Plate 25. 'Pedestal' representing the remnants of a soil profile in an intensely degraded part of the valley of Ben Metir.

The following profile description conveys an impression of such a 'pedestal' in the valley of Ben Metir in which profile the denudation, compared to the profile described in XIII. 4. 2., clearly shows up. In this soil profile scarse remnants are found of the red illuvial clay horizon as well as a distinct younger brown illuvial clay horizon.

profile description (see note in XIII. 4. 1.)

location: near the track, at the N side of the valley of Ben Metir
classification: eroded HAPLUDALF
elevation: 530 m
physiographic position: long slope
slope: gently sloping (5 %)
vegetation: shrubs and some scattered trees
parent material: Mio-Pliocene continental deposits
drainage: moderately well drained
moisture conditions: dry throughout
presence of surface stones: nil

A1 2/B2t 0-5 cm, dark brown (7,5 YR 3/2, moist), loamy sand; very weak sub-angular blocky; soft to slightly hard when dry; patchy thin cutans probably clay minerals with iron oxides and hydroxides, dark brown (7,5 YR 4/6-5/6, moist); common very fine to medium pores; few to common fine roots; merging and wavy boundary

2/B2t 3/B2t	5-35 cm, strong brown (7,5 YR 5/8, moist) sandy loam; sub-angular blocky; slightly hard when dry; broken to continuous moderately thick cutans probably clay minerals with iron oxides and hydroxides, strong brown (7,5 YR 5/8, moist) and broken thin cutans probably organic matter, dark brown (7,5 YR 3/2, moist) and very patchy moderately thick cutans probably iron oxides and hydroxides, reddish yellow (7,5 YR 6/8, moist); few medium pores; few medium roots; merging and irregular boundary
3/BC	35-55 cm, reddish yellow (7,5 YR 6/6, moist), medium and coarse mottled light grey (10 YR 7/1, moist) and red (2,5 YR 4/8, moist), sandy loam; sub-angular blocky; very few medium roots; merging and irregular boundary
3/C	55 cm +, like BC but no brown colours left, only red and grey mottles.

XIII. 5. Conclusions

The geomorphological and pedological data obtained from the valley of Ben Metir have been represented in the table of figure 26. and are further correlated with the data from the Seloul valley.

XIII. 5. 1. Conclusions as to the Geomorphology

The processes operative in the anticlinal valley are also observed in the synclinal valley: both the detrital deposits of the areal flow movements and the recent (Holocene) colluvium are present. The humid solifluction in the Ben Metir valley rather frequently obtained a mudflow character.

The first-order interfluves of the valley of Ben Metir (among others constituting the boundary with the valley of the Oued Seloul) have as a matter of course also been subject to altiplanative denudation as a result of areal flow movements.

The recent mass movements belong to the slide-type, are linearly concentrated and operative on the soft shales only.

In the Seloul valley slope development depends on the nature of the parent material. This phenomenon, however, has not been observed in the valley of Ben Metir due to the absence of the Madjanian Flysch (forming the marl ridges in the Seloul valley) at the surface and of fluviatile phases of incision.

XIII. 5. 2. Conclusions as to Pedology

The absence of this kind of slope development in the synclinal valley has resulted in a better preservation of the red illuvial clay horizon from the Eemian than in the Seloul valley. Although this Eemian soil formation may also be found on the shales, remnants of this old pedogenesis generally occur in the sandy Mio-Pliocene deposits.

Signs of the more recent pedogenetic period during which a brown illuvial clay horizon was formed may frequently be encountered in various soil profiles. The only difference with the recent pedogenesis in the Seloul valley is that in the extensive, non-wooded parts of the terrain the soil profiles are characterized by a certain 'steppisation', homogenization of the organic material extending as deep as 40 to 50 cm into the profile.

EVOLUTION AS TO GEOMORPHOLOGY

	Per.		Flysch, anticlinal valley	'Triassic' diapyr	
HOLOCENE	stable	recent	Colluviation, texture clay loam/ Still vertical erosion of the Seloul, undercutting of the soft shales/ Still sliding of the slopes in the soft shales in a series of slump movements, pseudo-pediments, scarp and sharp break in the terrain/ Concentrated types of mass movement only on the soft shales, primarily slide-type/ Denudation by means of concentrated erosion, dissection of the landscape/ Fair natural vegetation/	Slight dissection of the inter-valley planation into a gently undulating surface/	
	stable	(sub)	Like period above but for: Colluviation, texture clay loam, somewhat more clayey than recent colluvium/ Vegetation more abundant than at present (including alder)/		
PLEISTOCENE	instable	Würm ?	Humid solifluction and mudflow, coarse and angular detrital deposits/ Vertical erosion of the Seloul/ Areal mass movements on all parent rocks, primarily flow-types/ Areal denudation of the landscape, planation of the more level slopes, formation of the inter-valley planation on the soft shales, altiplanative lowering of the first-order divides. Carving out of the tors/ Poor natural vegetation/ 'geomorphologically arid' period/		
	stable	Eemian?	Phase of the rest of the river, formation of the flat part of the terrain separating the two phases of incision that still can be recognized/		
	instable	?	Oldest recognizable vertical incision of the Oued Seloul/ Considerable sliding in the soft shales, carving out of the marls as ridges, sharp break in the terrain/		Isolation of the 'Triassic' diapyr due to the vertical fluviatile erosion at either side/ No longer affected by areal types of mass movement from the flysch country/
	stable	?	Phase of rest of the river/		
	instable	?	Incipient vertical erosion of the Seloul, removal of the Mio-Pliocene cont. deposits, incipient divergent slope development dependent on the par. mat., carving out of the marl as ridges/ Formation of flat parts of the terrain on soft shales and marls (inter-valley planations)/	Formation of an inter-valley planation on the Triassic breccia/	
TERTIARY			Weathering under tropical climatic conditions, deep red colouring of the sandstone/ Accumulation of the erosion products of the orogenesis, coarse Mio-Pliocene cont. deposits, 'glacis d'accumulation' in the piedmont region/		

	EVOLUTION AS TO PEDOLOGY.		
Synclinal valley	Anticlinal valley	'Triassic' diapyr	Synclinal valley
Recent rel. sandy colluvium/ Intense denudation	Recent formation of a Dystrochrept or an Eutrochrept; sandy text. mat. show tend. towards podzolisation/ Degradation of the Vertisol and the brown Bt horizon/ Vegetation: mainly cork oaks, some oaks and shrubs/	Very substantial reduction of the forest (anthrop. ?) Recent homogenization of the organic material: 'steppisation' in non-wooded areas/ Recent formation of an Eutrochrept in wooded areas/	Recent formation of a Dystrochrept or an Eutrochrept/ Recent homogenization of the organic material: 'steppisation' in non-wooded areas/ Degradation of the brown Bt horizon/
	Formation of a brown Bt horizon/	Formation of a brown Bt horizon/	Locally formation of a brown Bt horizon/
Slope deposits by means of humid solifluction/ Mudflows/ Altiplanative lowering of the first-order divides/ Carving out of the tors/	Truncation of the 'rubefied' soil profile resulting in the red-grey mottled clay as a remnant/	Not influenced by mass movements: preservation of the 'rubefied' soil/ Very locally deposition of a stone-line on the Bt hor. of the truncated 'rubefied' soil/	Moderately influenced by the areal mass movements leaving some remnants of the 'rubefied' soil/
Due to strong headward erosion the Oued el Lil starts draining this valley/	Rubefactional conditions during soil form. resulting in the red-grey mottled cley/ Formation of a Vertisol on the marls/	Rubefactional conditions during soil formation with resultant formation of a deep, red Bt horizon.	Formation of a 'rubefied' soil with a red Bt horizon/
Deep weathering of the sandstone: thick regolith/ Mio-Pliocene cont. and Miocene lagoonal deposits/			

Fig. 26. Combined scheme, showing the pedological and the geomorphological evolution of the valley of the Oued Seloul and the valley of Ben Metir.

SAMENVATTING

Alle geomorfologische en pedologische gegevens die in deze samenvatting worden besproken zijn samengebracht in fig. 26: de schematische landschappelijke en bodemkundige ontwikkeling in het onderzochte gebied.

Met dit onderzoek is getracht, op grond van geomorfologische en bodemkundige waarnemingen de ontwikkeling van het landschap in een bergachtig deel van de Kroumirie (NW Tunesie) te reconstrueren. Twee dalen werden bestudeerd, het smalle anticlinale dal van de Oued Seloul en het wijde synclinale dal van Ben Metir.

HET DAL VAN OUED SELOUL

Geologische opbouw

Het onderzoek spitste zich vooral toe op het steile anticlinale dal van de Oued Seloul. De waterscheidingen worden gevormd door zandsteen terwijl zachte schalies en mergels lager in het dal voorkomen. Tezamen vormen deze gesteenten de Oligocene flysch afzettingen. De plcoiing van deze sedimenten vond plaats in het onder-Mioceen en is NNO-ZZW gericht. Het is in het algemeen een vrij eenvoudige anticlinaal-synclinaal plooiing met hier en daar injecties van Triassisch materiaal ('Trias' diapier). Plaatselijk bestaat de oostelijke dalwand van de Oued Seloul uit deze Triassische breccie (fig. 6).

Massabewegingen

De geomorfologische vormen in het Selouldal zijn vooral bepaald door massabewegingen**. Uit de nog in het landschap waarneembare resul-

** Massabeweging is de verplaatsing van gesteente massa's en/of detritus onder invloed van de zwaartekracht; natuurlijke media hebben bij deze beweging geen functie als transportmiddel.

taten van deze massabewegingen blijkt dat de aard en de omvang van deze processen afhankelijk zijn geweest van het gesteente waarin en de Kwartaire klimatologische omstandigheden waaronder ze optraden. De eerste indeling van de massabewegingen in deze dissertatie is gebaseerd op drie criteria. Behalve het watergehalte van het materiaal en het soort beweging (flow / slide), twee criteria die door Sharpe (1960) voor zijn indeling werden toegepast, werd de lithologie van het materiaal als derde criterium benut (fig. 18).
Het feit echter dat, op grond van de huidige vorm en positie der afzettingen het mogelijk was te onderkennen of deze processen al of niet meer actief waren bleek belangrijk voor de reconstructie van de landschapsontwikkeling in het Selouldal (fig. 10). Dit resulteerde in een vierde onderverdeling van recente (actieve) en fossiele (gestabiliseerde) massabewegingen (fig. 18).

Betreffende de relaties gesteenten / massabeweging en de geologische tijd / massabeweging is het volgende waargenomen:

--- Op de Triassische breccie zijn geen aanwijzingen gevonden die duiden op het voorkomen van massabewegingen nu of in het verleden. Bovendien zijn zeer oude verticale insnijdingen van de Oued Seloul in deze Triassische afzettingen in de vorm van een steile dalwand nog te herkennen. Ook deze waarneming vormt een aanwijzing voor de grote immuniteit van dit gesteente voor massabewegingen.
  In de andere gesteenten, vooral in de zachte schalies zijn dergelijke wanden reeds min of meer vervlakt.

--- In de mergels worden zeer lokaal kleine, recente afstortingen van vast gesteente waargenomen: rockslides, maar in het algemeen zijn de hellingen in de mergels momenteel betrekkelijk stabiel. Wel is op deze mergels materiaal van onder de huidige klimatologische condities niet actieve areale flowbewegingen (humiede solifluctie en mudflow) frequent waargenomen. Het gestabiliseerde karakter van deze grove puinafzettingen blijkt uit de bedekking ervan door een colluviaal pakket. Dit alles wijst erop dat dit gesteente onder andere klimatologische omstandigheden aanzienlijk minder resistent ten opzichte van massabewegingen is geweest.

--- De zandsteen hellingen zijn recent zeer stabiel, maar zijn, evenals de mergels, bedekt met de puinafzettingen van de humiede solifluctie waar ook hier veelal een colluviaal pakket overheen ligt.

--- Behalve dat op de zachte schalies vele, thans gestabiliseerde materialen van vroegere areale massabewegingen worden aangetroffen, die thans bedekt zijn met colluviale afzettingen, vindt men ook vele aanwijzingen voor een huidige sterke activiteit van earthflows, slumps en debris-avalanches (foto 7-10).
  In tegenstelling tot de vroegere massabewegingen manifesteren deze bewegingen zich meer lineair geconcentreerd. Deze recente en geconcentreerde vormen ontbreken op de andere moedergesteenten.

In het flysch gebied is dus een duidelijk waarneembaar verschil tussen de vroegere, gestabiliseerde flow-bewegingen die op al deze flysch gesteenten zijn opgetreden en de tegenwoordig actieve lineair geconcentreerde slide-bewegingen die alleen op de zachte schalies voorkomen. De Triassische gesteenten zijn vrijwel van het flysch gebied geisoleerd door diepe fluviatiele dalen en werden daardoor niet beinvloed door de areale massabewegingen vanuit dat flysch gebied.

Invloed van het moedergesteente op de hellingontwikkeling

In de instabiele zachte schalies is alleen de allerjongste V-vormige insnijding in het uiterste dalbegin nog waarneembaar (fig. 9). De scherpe vorm van de insnijding heeft slechts een zeer kort bestaan omdat na iedere fase van verticale fluviatiele insnijding (=ondermijning) deze zachte schalies in een serie slump-bewegingen van de hoger gelegen zandsteen afglijden en deze steil uitprepareren (fig. 7). Zo ontstaat op de overgang van de zandsteen naar de lager gelegen zachte schalies een scherpe terreinknik.

In de mergels treedt dit proces van slumping niet op en de terreinknik bij de overgang van de zandsteen naar de mergels is ook veel minder uitgesproken (fig. 7).
Interessant is dat door het ontbreken van deze afglijding in de, ten opzichte van de zachte schalies stabiele mergels, evenals in de Triassische breccie nog duidelijk sporen van de verschillende insnijdingsfasen van de Oued Seloul zijn terug te vinden.

Invloed van het pluviale klimaat

De gestabiliseerde grove puinafzettingen uit het laat-Pleistoceen worden momenteel bedekt door Holoceen colluvium met een kleiige-zandige textuur**. Het karakter van de hellingafzettingen is dus duidelijk veranderd van grof en hoekig in fijnkorrelig materiaal.
Ook het karakter van de massabewegingen veranderde: de nu gestabiliseerde areale processen waren typische flow-bewegingen die niet aan een bepaald moedermateriaal waren gebonden, in tegenstelling tot de recente massabewegingen die in het algemeen tot het slide-type behoren en sterk gebonden zijn aan de aard van het gesteente: ze komen alleen voor op de zachte schalies.
De thans gestabiliseerde flow-bewegingen moeten veroorzaakt zijn geweest door een factor die de huidige dominerende invloed van het gesteente hebben overtroffen zowel in de aard van de massabewegingen als ook in het al of niet op gang komen van deze processen.

Sterke intermitterende neerslag en de afwezigheid van een gesloten vegetatiedek (geomorfologische ariditeit, Dylik 1957) zijn voorwaarden voor het optreden van areale massabewegingen als humiede solifluctie in een landschap. De degradatie van de vegetatie die ook uit het palynologisch onderzoek blijkt (fig. 20) werd veroorzaakt door een daling

** Colluvium wordt gezien als een vorm van massatransport en derhalve niet behorend tot de massabewegingen, zie VIII. 1.

van de temperatuur. Door deze daling bereikte de gemiddelde temperatuur van de koudste maand in het Selouldal ongeveer de waarde 0°C. De congelifracten (gesteentefragmenten ontstaan door vorstsplijting) zijn tijdens de areale massabewegingen getransporteerd. Het resulterende grove, hoekige puin in deze afzettingen is in goede overeenstemming met de, op grond van de gemiddelde temperatuur, te verwachten sterke mechanische verwering.

Niet een toegenomen neerslag, maar een daling van de temperatuur wordt in dit deel van N. Afrika karakteristiek geacht voor de zgn. pluvialen. Deze koudere perioden met sterke areale degradatie worden gezien als instabiele fasen in de landschapsontwikkeling, als geomorfologisch actieve perioden waarin de ontwikkeling van de bodemprofielen sterk werd belemmerd. Door de grote geomorfologische activiteit van de areale degradatie vormden zich 'inter-valley planations' (glacis d'érosion) in het Selouldal (Dylik, 1957). Een ander gevolg van deze areale degradatie was de altiplanatieve verlaging van de primaire waterscheidingsruggen. De resten van een diepe, onder tropische omstandigheden gevormde Tertiaire verwering die op de zandsteen aanwezig waren, werden opgeruimd en de uitstekende delen van het verweringsfront als tors uitgeprepareerd.

Verschil tussen de invloed van de pluviale en de inter-pluviale omstandigheden

De hogere temperatuur in de inter-pluvialen deed het vegetatiedek regenereren met als gevolg een stabiel landschap en een sterk pedologische ontwikkeling. Door de lineaire waterafvoer en de lineair geconcentreerde slide-bewegingen werden in deze tijd de eerder gevormde 'inter-valley planations' versneden.

Het Holocene colluvium dat de grove puinafzettingen uit het laat-Pleistoceen bedekt, kan worden onderverdeeld in een relatief zandig pakket en een ouder pakket dat iets kleiiger is. Het kleiiger karakter van de oudste colluviale afzettingen wijst waarschijnlijk op een periode met een sterkere chemische verwering dan in het huidige klimaat plaatsvindt (vgl. Baudet, Maurer en Ruellan, 1967). Ook de resultaten van palynologisch onderzoek wijzen in de richting van een relatief vochtige en warme vroeg-Holocene periode.

Invloed van de geomorfologische processen op de verspreiding van de bodemtypen

De verspreiding van de bodemtypen in dit dal is in hoge mate bepaald door de genoemde landschapsvormende processen. Zo zijn vrijwel alle profielen zeer stenig door de invloed van de humiede solifluctie, uitgezonderd de hoogste delen van de primaire waterscheidingen waar geen solifluidaal materiaal accumuleerde. De gebieden van de recent actieve earthflows en de thans gestabiliseerde mudflows zijn gekarakteriseerd door zeer heterogene profielen waardoor ze onder de bodemeenheden duidelijk een eigen plaats innemen. Ook de jongste fluviatiele insnijding in de zachte schalies, waar het onverweerde moedermateriaal aanstaat, vormen op de bodemkaart een aparte kaarteenheid. Het patroon van de bodemkaart vertoont daarom in het algemeen een grote verwantschap met dat van de geomorfologische kaart (fig. 21 en fig. 9).

Recente pedogenese

De recente pedogenese op de kalkloze kleiige materialen beperkt zich tot een verbruining van de bodem die vooral onder bos vrij diep gaat, en de vorming van een 'Cambic' horizon: zure bruine bosgrond (Dystrochrept).
Vaak worden in de bodemprofielen, ontstaan op de kalkloze kleiige materialen nog de resten van een bruine Bt horizont aangetroffen, die onder invloed van de recente pedogenese lijkt te verdwijnen. De bruine textuur B horizont komt altijd voor in het oudste (relatief kleiige) deel van het recente colluvium en de vorming ervan valt daardoor samen met de vroeg-Holocene periode met relatief hoge vochtigheid en temperatuur.

Het verloop van de bodemvorming in zandig materiaal neigt naar podsolering waarbij een uitspoelingshorizont (A2) ontstaat (Spodic Entisol).

De kalkhoudende kleiige materialen zijn plaatselijk ontkalkt en verbruind, vorming van een Eutrochrept. Het meest ontwikkelde bodemprofiel op deze gesteenten is dan ook gekenmerkt door een 'Cambic' horizon (structuur B).

Polygenetische verschijnselen in de bodemprofielen

Polygenetische verschijnselen in de bodemprofielen zijn beperkt, zoals is te verwachten in een dal dat in het jongste pluviaal een zo sterke geomorfologische activiteit kende. Slechts twee van deze verschijnselen werden waargenomen:
--- De basis van de meeste bodemprofielen in de kalkloze kleiige materialen wordt gevormd door een rood-grijs gevlekte klei. Deze klei is in de mudflow, dus in het jongste pluviaal, getransporteerd en dateert daarom uit een periode van bodemvorming van vóór dit pluviaal, het Eemien.
--- Op vervlakkingen in de mergels (kalkhoudende kleiige materialen) die de insnijdingsfasen van de Oued Seloul onderling scheiden, worden de resten van een sterk gedegradeerde Vertisol aangetroffen, die van dezelfde ouderdom is als de rood-grijs gevlekte klei.

Het gebied van de 'Trias' diapier werd tijdens de jongste geomorfologisch actieve periode niet door de areale massabewegingen vanuit het flysch gebied beinvloed doordat de diapier van dit gebied is geschei-

den door diepe fluviatiele dalen zoals o.a. het Selouldal. Op deze Triassische breccie zijn dan ook veel bodemprofielen duidelijk polygenetisch en hebben een grote ouderdom. In de meeste profielen hier kan een diepe, rode Bt horizont worden onderscheiden, die blijkbaar gevolgd is door de vorming van een bruine Bt horizont aangezien de rode kleihuiden voor een belangrijk deel bedekt zijn door de bruine. De bruine klei-inspoeling reikte wel minder diep dan de rode.
Het jongste pedogenetische proces is een bruinkleuring van de bodem (brunification).

Datering van deze fasen van bodemvorming zou moeilijk zijn geweest ware het niet dat op één plaats de Triassische afzettingen niet door een diep rivierdal van de flysch gesteenten zijn gescheiden. Op dit punt konden de afzettingen van de solifluidale processen in het landschap van de 'Trias' diapier doordringen. We vinden hier ook de rode en de bruine klei-inspoelingshorizont maar nu gescheiden door een zgn. 'stone-line', samengesteld uit zandsteenpuin (flysch) en afgezet door de humied solifluidale processen.

De conclusie is dat de periode waarin de rode Bt horizont werd gevormd dateert van direct vóór het jongste pluviaal en de vorming van de bruine Bt horizont uit een periode direct ná dit pluviaal. De bruine klei-inspoeling in de Triassische breccie valt dan samen met die in het oudste colluvium uit het flysch gebied. De rode klei-inspoeling in de bodems van de 'Trias' diapier valt samen met de vorming van de rood-grijs gevlekte klei in de zachte schalies en de Vertisol vorming in de mergels.
Een gelijktijdige vorming van zo sterk afwijkende bodems is zeer goed verklaarbaar gezien het verschillend karakter van de moedergesteenten. De bodems in de zachte schalies moeten door het ondoorlatende substraat en de vlakke ligging veel last hebben gehad van wateroverlast. Ook momenteel vormen zich pseudo-gley kenmerken in de bodems op de vlakkere hellingen in de zachte schalies.
De breccie waaruit de 'Trias' diapier is opgebouwd is daarentegen zeer doorlatend. Bovendien is de 'Trias' diapier omringd door diepe fluviatiele dalen. De bodemprofielen op deze breccie zijn daarom altijd goed ontwaterd geweest. Op het Triassische materiaal vormde zich een bodem met een diepe, rode Bt horizont terwijl op de minder doorlatende zachte schalies onder dezelfde klimatologische omstandigheden een profiel met een rood-grijs gevlekte gley horizont ontstond (vgl. Fédoroff, 1966). Op de kalkhoudende kleien kwam gelijktijdig een Vertisol tot ontwikkeling.
De instabiele periode (pluviaal) die in het flysch gebied hierop volgde trunceerde het bodemprofiel, meestal tot op de compacte rood-grijs gevlekte klei.

HET DAL VAN BEN METIR

De geomorfologie en de pedologie van het synclinale dal van Ben Metir worden vergeleken met die uit het anticlinale Selouldal. De geomorfologische processen die in het anticlinale dal zijn waargenomen worden ook in het synclinale dal teruggevonden: zowel de puinafzettingen van de areale flowbewegingen als het recente (Holocene) colluvium zijn aanwezig. Vrij frequent echter kreeg de humiede solifluctie in het Ben Metir dal een mudflow karakter.
De primaire waterscheidingen van het dal van Ben Metir (één van deze waterscheidingen is tevens een waterscheiding van het Selouldal) zijn vanzelfsprekend ook altiplanatief verlaagd door de areale flowbewegingen. De recente massabewegingen zijn van het slide-type en zijn lineair geconcentreerd en beperkt tot de zachte schalies.
De hellingontwikkeling afhankelijk van het moedermateriaal, zo typerend voor het Selouldal, werd niet opgemerkt hetgeen te wijten is aan het ontbreken aan de oppervlakte van de Flysch Medjanien (die in het Selouldal de mergelruggen vormt) en de afwezigheid van fluviatiele insnijdingsfasen. Als een gevolg van het ontbreken van deze sterke hellingontwikkeling zijn in het synclinale dal de restanten van de rode klei-inspoelingshorizont uit het Eemien beter bewaard dan in het Selouldal. Hoewel ook op de zachte schalies deze Eemien bodemvorming nog is terug te vinden, zijn het toch vooral de meer zandige Mio-Pliocene afzettingen waarin de resten van deze oude pedogenese zijn terug te vinden. Ook de jongere pedogenetische periode met de vorming van een bruine klei-inspoelingshorizont is veelvuldig in de diverse bodemprofielen terug te vinden. De recente pedogenese is identiek met die in het Selouldal, alleen zijn veel bodemprofielen in de grote onbeboste terreingedeelten gekenmerkt door een zekere homogenisatie van het organische materiaal tot 40 à 50 cm diepte in het profiel: 'steppisation'.

APPENDIX:

INVESTIGATION INTO THE PROBABLE CAUSES FOR THE DIFFERENCES IN STABILITY OBSERVED ON THE SLOPES IN THE TRIASSIC BRECCIA AND IN THE SHALES OF THE OLIGOCENE FLYSCH

The interpretation of the analyses was completed
with aid of:
Mr. D. Karel for the X-ray analysis,
Mr. P. C. Beukenkamp for differential
thermal and thermo-gravimetric analysis,
Mr. E. A. Kummer for the morphoscopic
analysis and the X-ray diffractometer
analysis.

In the area studied in N. W. Tunisia the formation and preservation of very steep slopes are regular features in the Triassic breccia. Older or recent mass movements have not been observed in areas where these breccia constitute the parent material, whereas at present and in the past a variety of mass movements have strongly affected the slopes formed in the area where soft shale constitutes the parent material.
It is the purpose of this analytical investigation to find out whether the field observations are substantiated by the physical and chemical differences between the rocks from the two areas. Twelve samples, six from each area, were investigated. Figure 27 shows to which analyses each sample was subjected.

1. Grain-size Distribution

For the determination of the grain-size distribution the soil has been pretreated with 6% H_2O_2 to remove organic carbon, followed by boiling with 2N HCl to break up aggregation by ferric oxides. A Na-pyrophosphate - Na-carbonate mixture has been used as a peptizing agent, and the grain-size fractions have been determined by sieving and pipeting.

A first indication of the properties of the two materials may be derived from the grain-size distribution given in figure 28a.
The clay content of the 'unstable' samples generally exceeds that of the 'stable' samples. Yet it would seem that the differences in stability between both groups of samples cannot be traced to the difference in clay content which is too small, compared to the important percentage smaller than 2 micron in both groups of samples.
Despite the high percentage smaller than 2 micron the high stability in the Triassic breccia, rather than the instability, stands out.

N. B. It appears from figure 28a, that the histograms of some samples taken from deposits in which soft shale is found, do not wedge out. This may point to admixture of the coarse fractions as recent colluvium or as solifluidal material.

2. Morphoscopic Rounding Index Analysis

For determination the method of Kummer (1963, 1970) has been followed. For interpretation of the data obtained according to this method the following has to be taken into consideration:
--- Investigated are the fractions 2000–50 micron.
--- Analyses were carried out with one mineral: quartz.
--- Only corresponding grain-size fractions can be compared.
--- Aequidimensionality or non-aequidimensionality was not considered.
--- The reproduceability approximates + or - 5 AI % (AI = rounding

	SAMPLE NO.	SAMPLE TAKEN FROM	GRAIN-SIZE	MORPHOSCOPY	X-RAY CAMERA	SWELLING CAP.	AGGREG. STAB.	PLASTICITY IND.	MOISTURE ADS.	PHASE DISTR.	DTA / TGA	X-RAY DIFFR.	S AND T	ADSORPTION COMPL.	AMORPHOUS MAT.
INSTABLE	29-5-1	recent sandy colluvium	x	x	x	x					x	x	x	x	x
	6-6-2	recent sandy colluvium	x	x	x								x	x	
	30-6-1	earthflow	x		x	x		x	x		x	x	x	x	x
	10-7-7	slump	x	x	x								x	x	
	10-7-8	slump	x		x	x		x			x	x	x	x	x
	6-6-4	mudflow	x		x	x	x	x	x	x	x	x	x	x	x
STABLE	7-6-3	colluviated red soil	x		x	x		x			x		x	x	x
	7-6-5	influenced by flysch	x	x	x							x	x	x	x
	7-6-9	C-hor. of red soil	x		x	x		x			x	x	x	x	x
	7-6-8	Bt hor. of red soil	x	x	x	x	x	x	x	x	x	x	x	x	x
	12-6-3	colluviated red soil	x	x	x							x	x		
	7-6-6	colluviated red soil	x		x	x		x	x		x	x	x	x	
		Fig.	28a	29	30	31	32	33	34	35	36	37	28b	28b	28b

x = sample analysed

Fig. 27. Table showing the different analyses that have been used for the examination of the various samples.

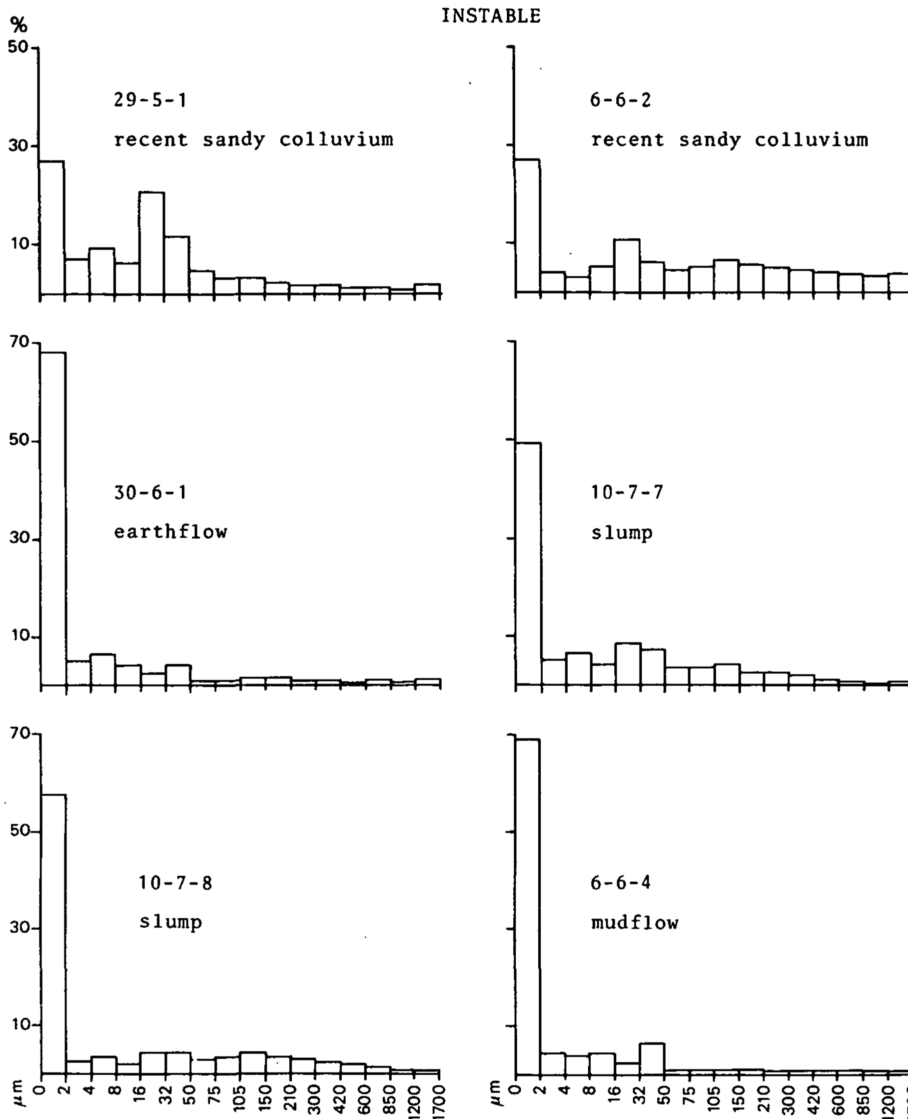
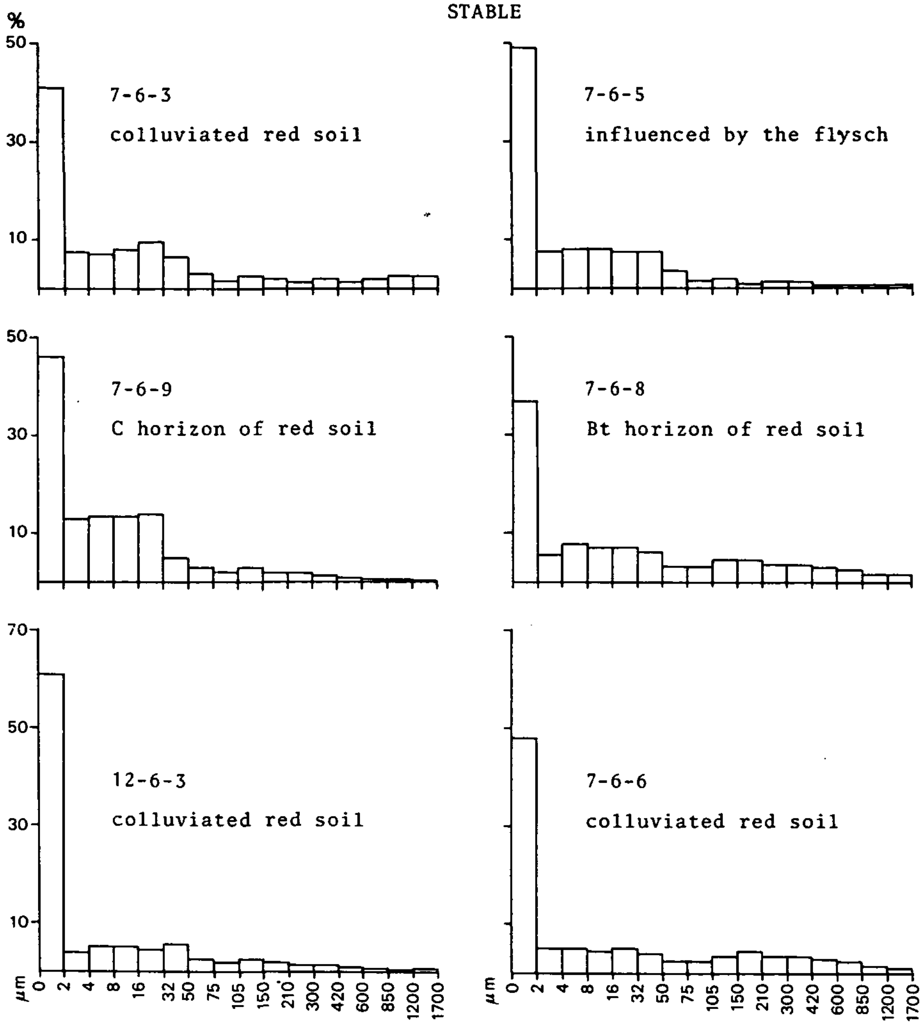


Fig. 28. a. Histograms of the grain-size distribution.
b. pH, S, T and V data of the analysed samples, supplemented with the content of the amorphous material.

STABLE



%
50
30
10
7-6-3
colluviated red soil
7-6-5
influenced by the flysch
7-6-9
C horizon of red soil
7-6-8
Bt horizon of red soil
70
12-6-3
colluviated red soil
7-6-6
colluviated red soil
μm
0 2 4 8 16 32 50 75 105 150 210 300 420 600 850 1200 1700

	SAMPLE NO.	SAMPLE TAKEN FROM	S-VALUE	T-VALUE	V = S/T in %	Ca^{2+}	$Ca^{2+} + Mg^{2+}$	Na^+	K^+	AMORPHOUS %	pH H_2O	pH KCl	$CaCO_3$ %	T-VALUE FOR 100 % SMALLER AS 2 MICRON
INSTABLE	29-5-1	recent sandy colluvium	10.6	19.5	54	5.5	9.7	0.4	0.6	52.9	5.2	4.1	0.0	72
	6-6-2	recent sandy colluvium	8.4	18.3	60	4.3	6.9	0.3	1.2		5.4	4.4	0.0	69
	30-6-1	earthflow	14.2	30.1	49	9.3	12.9	0.4	0.9	55.3	5.5	4.7	0.0	45
	10-7-7	slump	15.6	23.5	66	8.5	14.3	0.7	0.6		5.7	4.6	0.0	47
	10-7-8	slump	26.6	27.9	96	14.0	24.5	1.0	1.1	53.8	6.8	6.0	0.0	50
	6-6-4	mudflow	30.2	31.2	97	12.5	26.8	2.7	0.7	48.5	5.2	4.5	0.0	44
STABLE	7-6-3	colluviated red soil	4.2	11.1	38	1.1	3.2	0.3	0.7	53.9	5.3	4.1	0.0	28
	7-6-5	influenced by flysch	10.4	16.7	62	4.5	8.4	0.7	1.3	64.4	5.5	4.6	0.0	28
	7-6-9	C hor. of red soil	8.9	12.4	72	2.8	7.1	0.3	1.5	64.5	6.5	5.1	0.0	27
	7-6-8	Bt hor. of red soil	5.9	8.1	73	3.5	5.2	0.3	0.4	48.1	6.4	5.3	0.0	21
	12-6-3	colluviated red soil	14.7	18.2	81						6.1	5.3	0.0	30
	7-6-6	colluviated red soil	2.8	7.1	40	0.8	2.3	0.3	0.1		4.7	3.8	0.0	15

index) with a probability of 99% (compare fig. 29a) and + or - 3 AI% with a probability of 80%.
--- A clear distinction has been made between the degree of roundness on the one hand and the more or less equidimensional character of the grains on the other hand.

Figure 29a clearly shows that the quartz grains from the 'stable' and the 'unstable' samples, regard being had to the 5% margin, differ distinctly in roundness in the fractions between 1000 micron and 105 micron.
A notable feature is the intermediate position of sample 7-6-5, which has been affected by the colluvium from the flysch area. The extent of the influence may be seen in figure 29.
The differences between the 'stable' and the 'unstable' samples are also apparent in the classification into alpha, beta and gamma groups of the samples investigated (fig. 29b). The grains in the alpha group are angular to very weakly rounded, the grains in the gamma group are very strongly rounded to oviform. The grains in the beta group are weakly to very rounded (Kummer, 1970).
From these data it is apparent that a correlation exists between the rounding index of the quartz-sand fraction and the stability or instability of the samples investigated.
As sample 29-5-1, taken from the recent colluvium of one of the first-order divides, is also strongly rounded, this roundness has to be considered as a property inherent to the unstable rocks and not as a consequence of the activity of mass movements. Apart from Tunisia, also in Southern Spain, Morocco and Sicily an Oligocene-Miocene deposit with a high percentage of well-rounded quarzitic gravel and sand is found: the Numidian Flysch (de Booy, 1969; de Waart, 1971).
The sand fraction is strongly rounded, but its effect on the stability cannot properly be established. The coarser fractions display the strongest rounding but are of a relatively rare occurrence in the samples (Kummer, 1970). Be that as it may, the strong rounding will not add to stability.

N.B. In the samples taken from the Triassic breccia, characterized as stable, very many euhedral quartz crystals are found. Of these crystals the ratio of length and sectional dimension very often is 12 : 1 or higher. On the other hand the quartz in the 'unstable' flysch sediments, is relatively aequidimensional. Hence in addition to the degree of roundness the degree of aequidimensionality or non-aequidimensionality may play a significant part.

3. X-ray Analysis with the Guinier-de Wolff Camera

The X-ray analyses of the fraction smaller than 1 micron were carried out by means of the Guinier-de Wolff camera after glycerolation and disorientation (Porrenga, 1958) of the samples in order to gain an idea of the clay mineral composition.

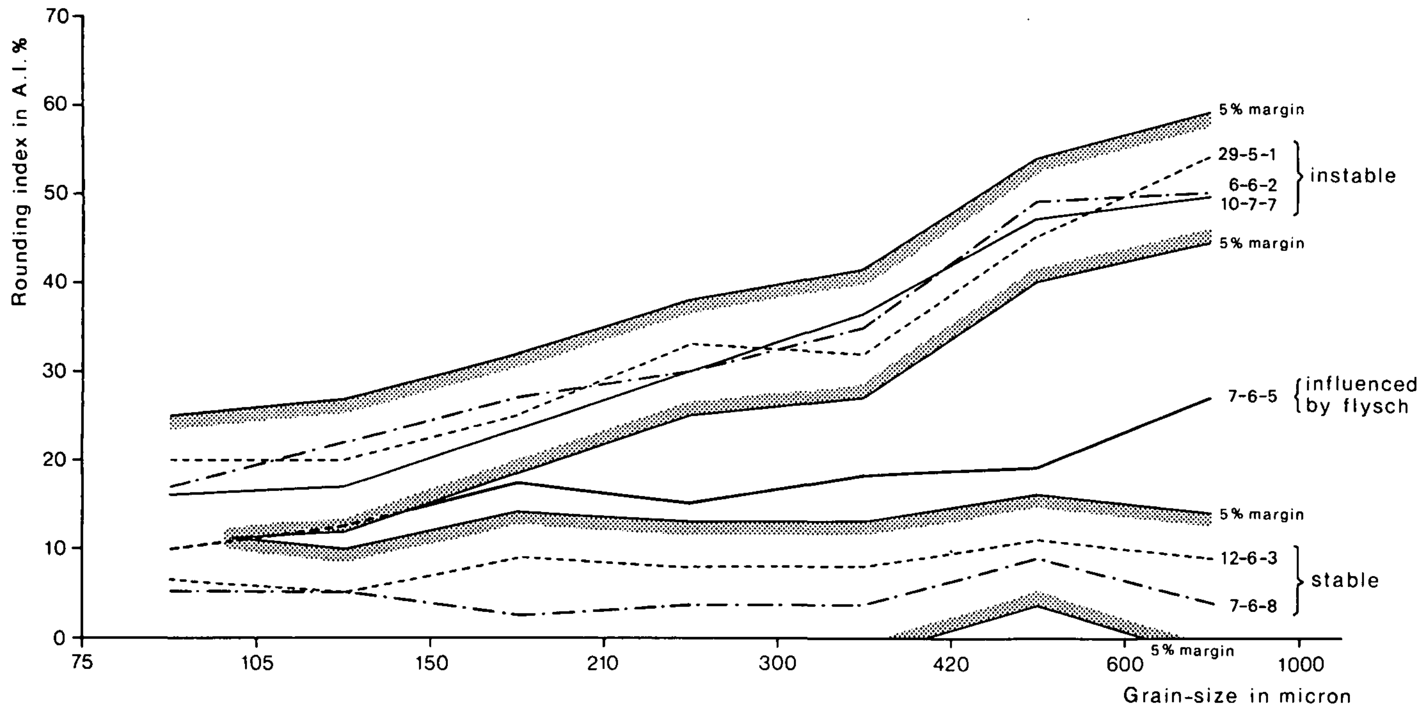
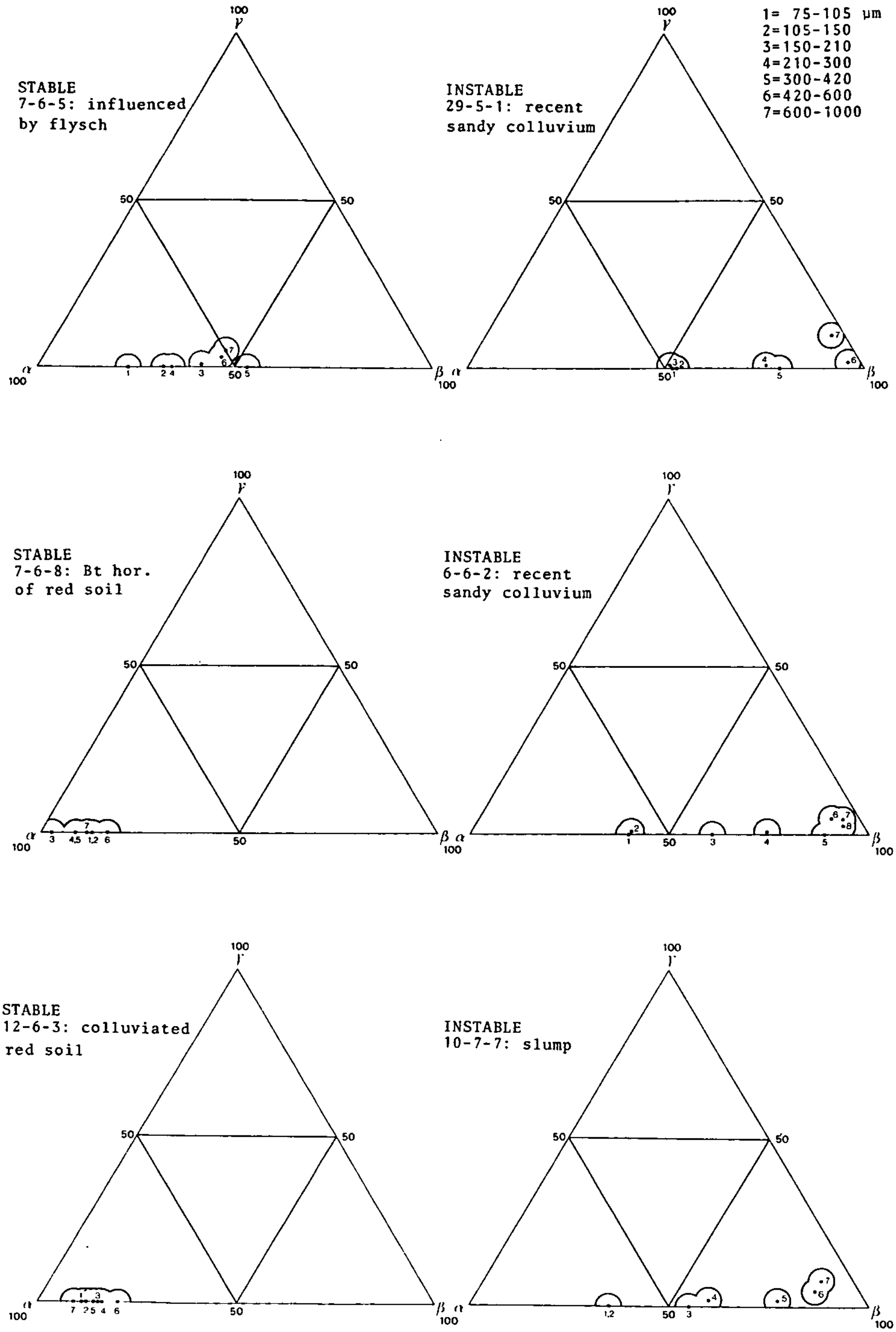


Fig. 29. Morphoscopic analyses.
a. Graphs of the morphoscopic analyses.
b. Triangular graphs representing the distribution of the roundness-groups of the various samples.


1= 75-105 µm
2=105-150
3=150-210
4=210-300
5=300-420
6=420-600
7=600-1000
STABLE
7-6-5: influenced by flysch
INSTABLE
29-5-1: recent sandy colluvium
STABLE
7-6-8: Bt hor. of red soil
INSTABLE
6-6-2: recent sandy colluvium
STABLE
12-6-3: colluviated red soil
INSTABLE
10-7-7: slump

	SAMPLE NO.	SAMPLE TAKEN FROM	MIXED LAYER 28 Å	SMECTITE	CHLORITE/ VERMICULITE 14 Å	MICA 'WELL' CRYSTALLIZED *	MICA 'POORLY' CRYSTALLIZED *	KANDITE	GOETHITE LEPIDOCROCITE HEMATITE	ANATASE	QUARTZ
INSTABLE	29-5-1	recent sandy colluvium	tr.				tr.	+	lep.	x	5-8 %
	6-6-2	recent sandy colluvium					tr.	+		x	2-4 %
	30-6-1	earthflow					tr.	++		xx	3-5 %
	10-7-7	slump									
	10-7-8	slump		(+)			tr.	+	lep.	x	2-4 %
	6-6-4	mudflow		(+)			+	++		xx	2-4 %
STABLE	7-6-3	colluviated red soil		?	?	(+)		tr.		tr.	1-3 %
	7-6-5	influenced by flysch			(+)	(+)		(+)		tr.	1-3 %
	7-6-9	C hor. of red soil			tr.	(+)+		(+)			1-3 %
	7-6-8	Bt hor. of red soil			tr.	++		tr.		?	-1 %
	12-6-3	colluviated red soil				+		(+)			-1 %
	7-6-6	colluviated red soil			?	+++		+		?	-1 %
	PARENT MATERIAL TRIASSIC BRECCIA					++++		tr.			1-3 %

* The difference between 'well' and 'poorly' crystallized mica's is made by respectively presence or absence of the stacking lines between 4.50 Å and 2.80 Å (Brown 1961, p. 237).

Fig. 30. X-ray analysis data.

The intensity of the blackening of the X-ray patterns of the various clay minerals on the film, after comparison with standard minerals, has been indicated by means of a range of + signs, which, however, do not denote fully corresponding quantities of the minerals in the clay fraction. They do render it possible to gain an idea of the nature and the degree of significance of the various clay minerals, of which the divergent physical and chemical properties may to a great extent affect stability.
The samples from the Triassic breccia and the soft shales possess distinct clay mineralogical associations as can clearly be seen in figure 30.
The pictures, however, do not bring a solution any the nearer, for the differences in significance of the smectitic minerals within groups are larger than between groups. In the samples from the unstable area, contrary to the expectations because expandible clay minerals determinate the instability of slide processes, kandite seems to be dominant. Pictures of samples from the stable area reveal a dominance of well crystallized mica. The mica observed in the unstable samples is very probably poorly crystallized**.

To form a true appreciation of the physical behaviour of the two materials, the samples have been subjected to several mechanical tests, which permitted determination of especially the behaviour towards water.
From the results of these tests, which are discussed below, a subdivision into two groups may be inferred, as was the case with the X-ray analysis, i.e., samples from the stable area and from the unstable area.

4. Swelling Capacity

To determine the swelling capacity glass beakers were used with bottoms of sintered glass; these porous bottoms permit the ascent of water. The beakers were filled with airdry soil up to a height of 2 cm and placed in a Petri-bowl filled with water so that the water could moisten the soil through capillary rise. The water level in the Petri-bowl was kept as low as to prevent moistening by over pressure from this water level. To determine whether the size of the aggregates has any influence on the swelling, tests were carried out on the fractions smaller than 2 mm and smaller than 0.4 mm of two samples. The results have been given in figure 31.

The samples from the unstable area exhibit a very strong swelling of 20 vol.%.
Only the recent sandy colluvium displays a very slight increase of volume

** The difference between 'well' and 'poorly' crystallized mica's is determined by respectively presence or absence of the stacking lines between 4.50 Å and 2.80 Å (Brown 1961, p. 237).

	SAMPLE NO.	HEIGHT OF SAMPLE BEFORE WETTING *	HEIGHT OF SAMPLE AFTER WETTING *	SWELLING CAPACITY IN VOLUME % *	SAMPLE TAKEN FROM	HEIGHT OF SAMPLE BEFORE WETTING **	HEIGHT OF SAMPLE AFTER WETTING **	SWELLING CAPACITY IN VOLUME % **
INSTABLE	29-5-1	2.0 cm	2.1 cm	2	recent sandy colluvium			
	6-6-2				recent sandy colluvium			
	30-6-1	1.5 cm	1.7 cm	13	earthflow			
	10-7-7				slump			
	10-7-8	2.0 cm	2.4 cm	20	slump			
	6-6-4	2.1 cm	2.5 cm	20	mudflow	2.2 cm	2.6 cm	18
STABLE	7-6-3	2.0 cm	1.95cm	0	colluviated red soil			
	7-6-5				influenced by flysch			
	7-6-9	2.0 cm	1.85cm	0	C hor. of red soil			
	7-6-8	1.80cm	1.75cm	0	Bt hor. of red soil			
	12-6-3				colluviated red soil			
	7-6-6	2.0 cm	1.95cm	0	colluviated red soil	2.2 cm	2.2 cm	0

* fraction smaller as 400 micron used

** fraction smaller as 2 micron used

Fig. 31. Table showing the swelling capacity of the samples.

The 'stable' samples, in which no swelling is effected, probably develop a somewhat tighter packing only.

A very notable feature of the samples from the area of the Triassic breccia is that the entire 2 cm of soil in the beaker became moist within a matter of seconds. The samples from the unstable area behave very differently. The lower 6 to 8 mm of these samples became moist very fast but before the entire 2 cm were moist 30 minutes had elapsed (with the exception of sample 29-5-1, the sandy colluvium). One beaker filled to a height of 5 cm with material of sample 6-6-4 (smaller than 2 micron) stood for 24 hours and the water did not rise higher than 3 cm.
The strong swelling probably closes all the pores of the soil and renders it impermeable, which might explain for the many springs and pseudo-gley phenomena in the unstable areas (Southard, 1970).

This is in contrast to the sandy colluvium covering a large part of the soft shale slopes, which is relatively permeable and swells only to a slight degree.
Its subsoil, however, becomes poorly permeable within a fairly short time, with consequent rapid saturation with water of the soil mass in the topsoil. The resultant positive pore pressure may be highly conducive to the occurrence of mass movements (Carson, 1969).

5. Soil Aggregate Stability

The aggregate stability was determined according to the somewhat adapted 'natte buitel' method (Koenigs, 1961). The soil aggregates mixed with sand are tumbled round at constant speed in bottles filled with water by means of an 'end over end' shaker. After a number of rotations the fraction larger than 40 micron is allowed to settle, the remainder is pipetted. The weight of the fraction smaller than 40 micron is a measure of the stability of the aggregates in water relative to mechanical forces.

Eight grams of soil smaller than 2 mm (A) and eight grams of sand were tumbled round at 30 rotations per minute.
Sample 6-6-4 (unstable):

30	rotations:	x_1-0.7887 g	smaller than	40 micr.	;	in % of A	:	0.97
30+ 60	,,	x_2-0.3384 g	,,	,, ,,	;	,,	:	0.42
90+ 60	,,	x_3-0.1511 g	,,	,, ,,	;	,,	:	0.19
150+150	,,	x_4-0.1988 g	,,	,, ,,	;	,,	:	0.25

Sample 7-6-6 (stable):

x_1	: 0.7022	in % of A	: 0.88
x_2	: 0.2504	,,	: 0.31
x_3	: 0.1209	,,	: 0.15
x_4	: 0.1278	,,	: 0.16

The values of these samples have been plotted in a linear graph in figure 32.

It is apparent that mechanical forces do much less affect the stability of sample 7-6-6 than of sample 6-6-4. Deterioration of the aggregates in the 'stable' sample is checked after a very short time and the aggregates remain almost intact, very much in contrast to the aggregates in the samples from the unstable areas.

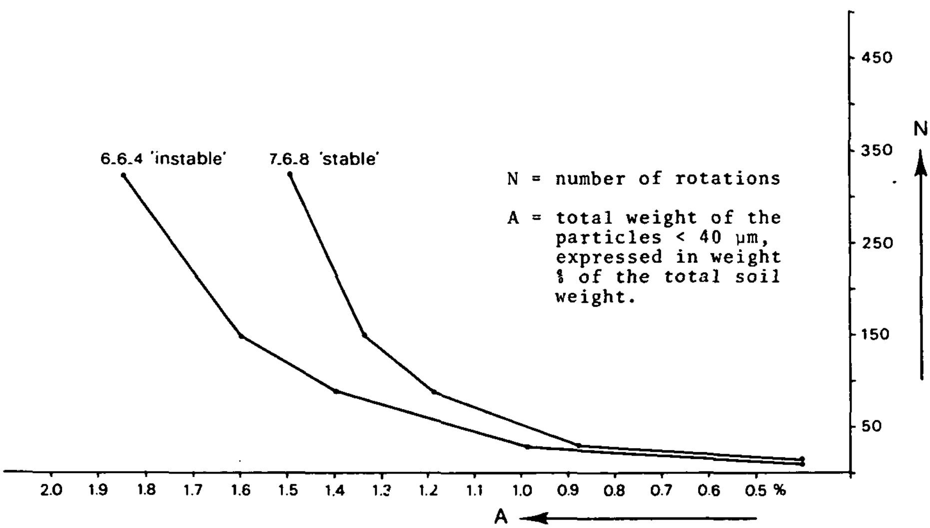
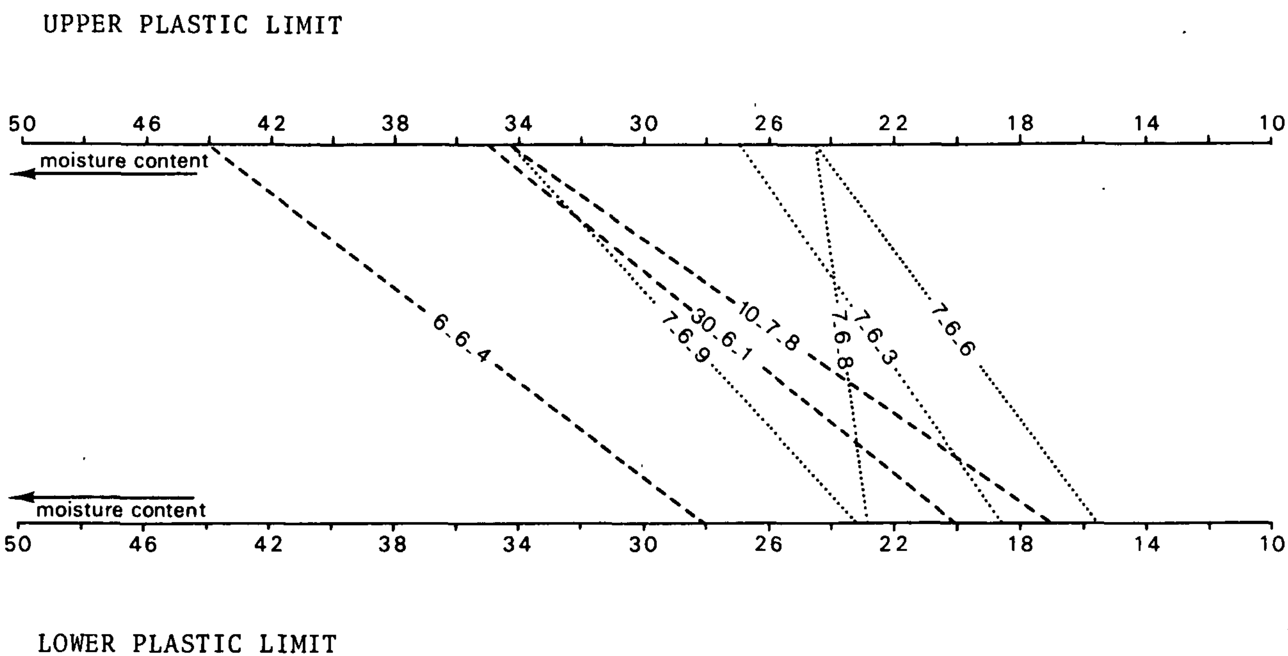


Fig. 32. Graph of the soil aggregate stability under the influence of mechanical forces.

6. Plasticity Index

The plasticity index is the difference in moisture content between the liquid limit (upper plastic limit) and the lower plastic limit. The lower plastic limit is the moisture content at which the soil can no longer be rolled into a wire of 1 cm diametre. With the apparatus of Casagrande the liquid limit was determined by placing a small amount of soil that has been worked into a stiff paste in the little bowl. In this mass a standard V-shaped groove was made. The liquid limit is defined as the moisture content at which the groove is closed over 1 cm by the two segments flowing together after 25 jarrings with the bowl-shaped dish (Baver, 1959).



stable	7-6-6: colluviated red soil 7-6-3: colluviated red soil 7-6-8: Bt hor. of red soil 7-6-9: C hor. of red soil	instable	6-6-4: mudflow 30-6-1: earthflow 10-7-8: slump

Fig. 33. Graphic representation of the Plasticity Index.

In the graphic representation of these values a steep line signifies a small change in moisture content, which may designate a transition from flowing to crumbling (compare fig. 33) so typical of sandy soils. It follows that clayey soils exhibit a less steep line in the plasticity diagram.
The results have been given in figure 33.

It can clearly be collected from the graph that two groups can be separated, a group of 'unstable' samples and a group of 'stable' samples. The slope of the line of the 'unstable' samples is in agreement with their clay content.
The 'stable' samples, which have a high clay content, behave as if they are rather sandy.
It is plain that the slope of the line of the material sampled from the C-horizon of the soil (7-6-9) shows a greater correspondence to the percentage smaller than 2 micron.
Finally, it may be observed that the sandy character is most pronounced in a sample (7-6-8) taken from a red Bt horizon of the Eemian soil (see chapter XII. 3. 1.).

7. Moisture Adsorption in a Climatic Cabinet

The ovendry samples were placed in a climatic cabinet kept at a temperature of 21°C and a relative humidity of 88%.
The weight increase as a result of the adsorption of water vapour was determined after 30 minutes, one hour, 2 hours and 3 hours respectively.
The values obtained are put in percentages of the ovendry weight.

Study of the fractions smaller than 1 micron and the fractions smaller than 40 micron yielded the following results (see also fig. 34):

smaller than 1 micron

	30 min.	1 hour	2 hours	3 hours
6-6-4	11.3 %	13.0 %	14.3 %	14.3 %
30-6-1	11.0 %	12.4 %	13.2 %	13.2 %
7-6-6	7.4 %	8.2 %	9.1 %	9.1 %
7-6-8	8.6 %	9.1 %	10.3 %	10.3 %

smaller than 40 micron

	30 min.	1 hour	2 hours	3 hours
6-6-4	9.4 %	9.7 %	10.3 %	10.3 %
30-6-1	9.0 %	9.2 %	9.6 %	9.6 %
7-6-6	4.3 %	4.4 %	4.9 %	4.9 %
7-6-8	5.0 %	5.0 %	5.5 %	5.5 %

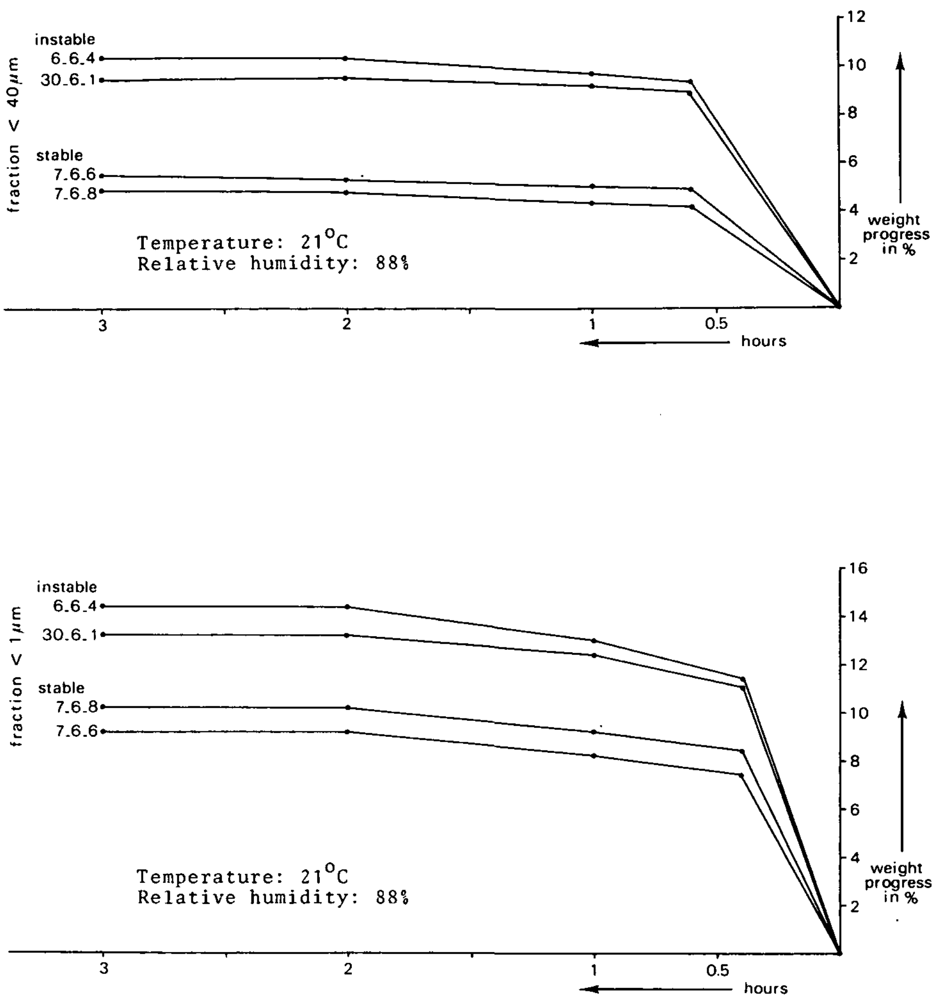


Fig. 34. Moisture adsorption in the climatic cabinet.

The weight increase of the fractions of the samples 7-6-6 and 7-6-8 (both 'stable'), in both cases may be ascribed to illite.
However, the high values found for the fractions of sample 6-6-4 and sample 30-6-1 (both 'instable') presupposes the presence of expandible minerals (Bakker et. al. 1968 and 1970; Levelt, 1965).

8. Determination of the Liquid, Solid and Gaseous Phase

First the specific weight of the two samples was determined. A mean value of 2.68 g/cm^3 is normally adopted for the specific weight of the solid phase, but because this value may be considerably higher for samples as ferriferous as those taken from the stable areas (strong red colouring due to Eemian soil formation) the density of the solid phase of two samples is more adequately determined by means of a 'Pycnometer'.

First, empty and cleaned, the two pycnometers were weighed:

	empty (Go)	+ sample (G2)	sample + water(G3)	water (G1)
no. 46	35.6006	52.2465, T:25^o	95.9351, T:22.9^o	85.4401, T:21^o
no. 31	35.2846	45.3175, T:24.7^o	91.2999, T:22.6^o	85.0988, T:20.7^o

Sample 7-6-8 in pycnometer no. 46,
sample 6-6-4 in pycnometer no. 31, both after having been grinded in a mortar.
Subsequent calculation of the specific weight is as follows:

$$\text{weight of the solid phase } Gv = (G2 - Go) \; . \; \frac{100 - \text{moisture content}}{100}$$

density of the solid phase is:

$$\frac{\text{weight mat.}}{\text{volume mat.}} = \frac{Gv}{G1} - \frac{Go}{1} - \frac{G3-Go-Gv}{2}$$

1 and 2, the densities of water, have been obtained from tables.

For sample 7-6-8 the density of the solid phase was calculated at 2.71 g/cm^3.
For sample 6-6-4 at 2.63 g/cm^3.
The influence of the iron on the density of the soil is clearly observable in sample 7-6-8.

Next the moisture contents were determined: 6-6-4 a = 0.04312
7-6-8 a = 0.01458

To determine the phase distribution a small clod (soil aggregate) was separated from the soil and held by a thread immersed in liquefied paraffine. After cooling down the clod is covered with a thin coating of paraffine, which closes the pores (Delvigne, 1968).

Figure 35

SAMPLE NO.	PHASE	VOLUME % OF PHASES; FIRST TIME	VOLUME % OF PHASES; SECOND TIME	SPECIFIC WEIGHT IN g/cm^3	SAMPLE TAKEN FROM
6-6-4	solid	68	67	2.63	mudflow
	liquid	8	8		
	gaseous	24	25		
7-6-8	solid	68	69	2.71	Bt hor. of red soil
	liquid	1	1		
	gaseous	31	30		

Fig. 35. The distribution of the solid, liquid and gaseous phase of some samples (phase distribution).

The clod is then equilibrated in water and the upward pressure is measured. The volume of the aggregate, the moisture content and the volume of the solid constituents can now be calculated and subsequently the phase distribution in volume percentages.
The results of the calculations have been given in figure 35.

The pore volume of sample 7-6-8 is exactly the same as that of sample 6-6-4, at any rate in airdry condition, even though sample 7-6-8 has a lower moisture content.
The results of the tests naturally do not give a conclusive answer about the shape, size and distribution of the pores.

Given the result of the determination of the swelling capacity and the moisture adsorption capacity (4. and 7.), evidence seems to be that, compared to the 'stable' samples, a considerable greater abundande of swelling minerals is present in the 'unstable' samples. No proof of this could be found in the pictures taken with the Guinier-de Wolff camera.
To obtain further evidence use was made of Differential Thermal Analysis, Thermo-gravimetric Analysis and X-ray diffraction analysis.

9. Differential Thermal Analysis and Thermo-gravimetric Analysis

For differential thermal and thermo-gravimetric analyses a Linseis DTA and TG apparatus has been used, containing Pt - Pt/Rh (10 %) differential thermo-couples and a platinum specimen holder. The Mg-saturated clay fraction was equilibrated at 45% relative humidity over a saturated solution of K_2CO_3 prior to analysis. The differential thermal reactions within the diluted specimen (400/400 mg) were measured against Al_2O_3 as a reference, both heated up to 1000°C at a constant rate of 10°C per minute. The temperature (T) and the temperature difference (ΔT) were recorded in a recorder, by testing the samples in the 0-0.1 and the 0-0.2 mV sensitivity range.
After DTA reactions the loss in weight between 20°C and 800°C were measured by recording thermo-balance.

Of two samples, 6-6-4 and 7-6-6, the fractions smaller than 1 micron were analysed with a recorder sensitivity of 0-0.2.
To discover whether the soil exhibits certain physical and chemical properties in the fractions larger than 1 micron, the fraction smaller than 50 micron was tested in the sensitivity range 0-0.1. Obvious differences were absent (fig. 36a).
Finally, to make the peak system at higher temperature somewhat clearer the fraction smaller than 1 micron was tested with two recorder sensitivities. Up to 390°C in a sensitivity range of 0-0.2 and above 390°C in a range of 0-0.1.

As can be seen in figure 36a. sample 6-6-4 consists for a large and possibly dominant part of kandite.
The shoulder at 560°C (in the second endothermic peak) is induced by the presence of illite.
The first strong endothermic peak system may point to the presence of swelling components and/or to the presence of amorphous material. In view of the amorphous material content a large part of the peak system may be considered to be due to the amorphous material. However, the influence of smectitic minerals is very apparent in the endothermic inversion at 840° - 890°C.
TGA of sample 6-6-4 corroborates these conclusions; given the loss in weight between 450° and 600°C, 35-45 weight % is a conservative estimate of the amount of kandite.

In sample 7-6-6 the amount of kandite is much smaller than in 6-6-4. The shoulder at the second endothermic peak also points to illite, which, compared to sample 6-6-4, is probably present in higher proportions. The temperature inversion of 840° - 890°C is very weak here, indicating that very little smectite is present.
It may be inferred that the strong first endothermic peak system is caused by amorphous constituents mainly.
The conclusions arrived at after differential thermal analysis of these samples are also corroborated by thermo-gravimetric analysis.
The results obtained from the other samples are given in figure 36b.

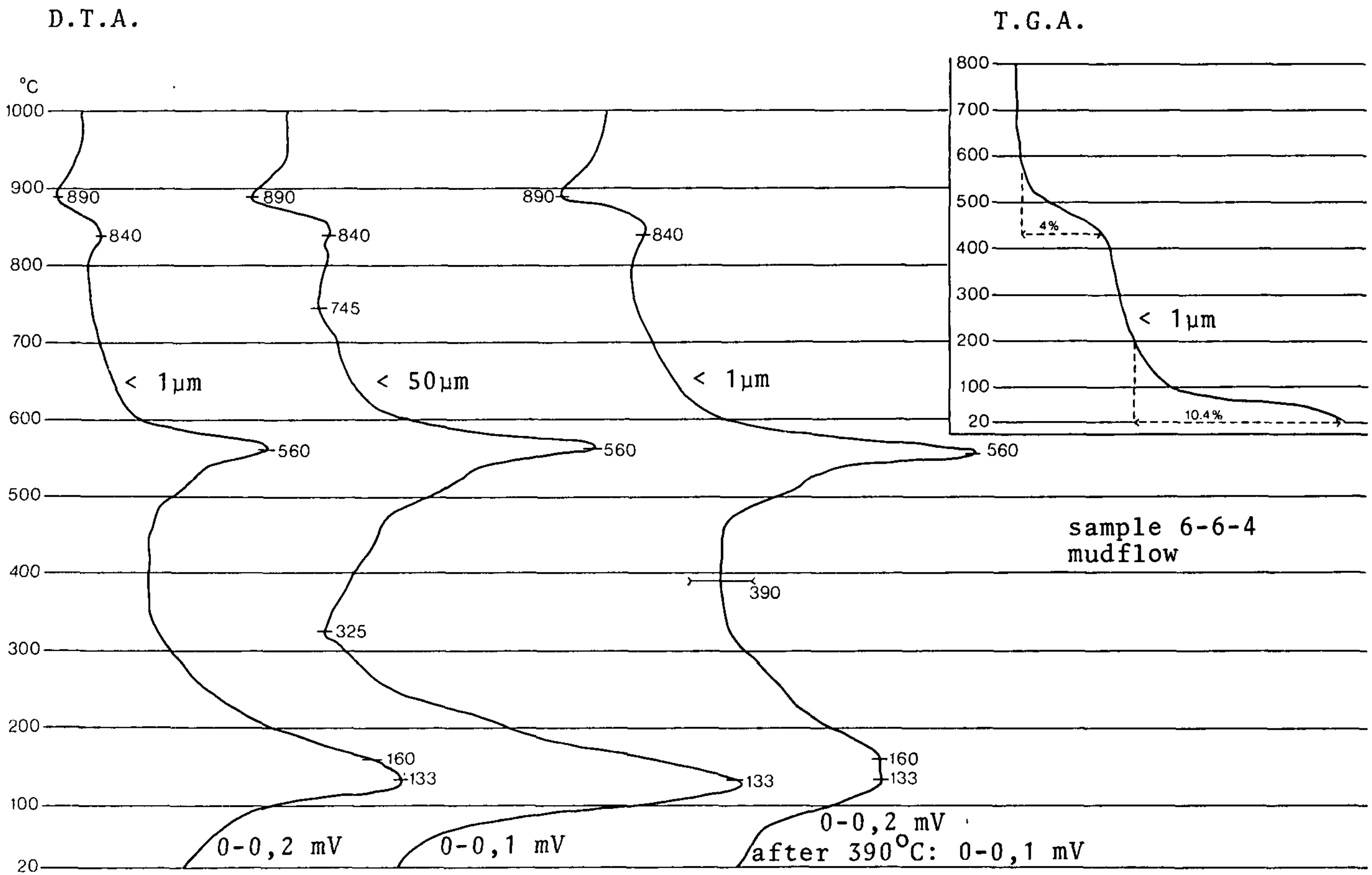
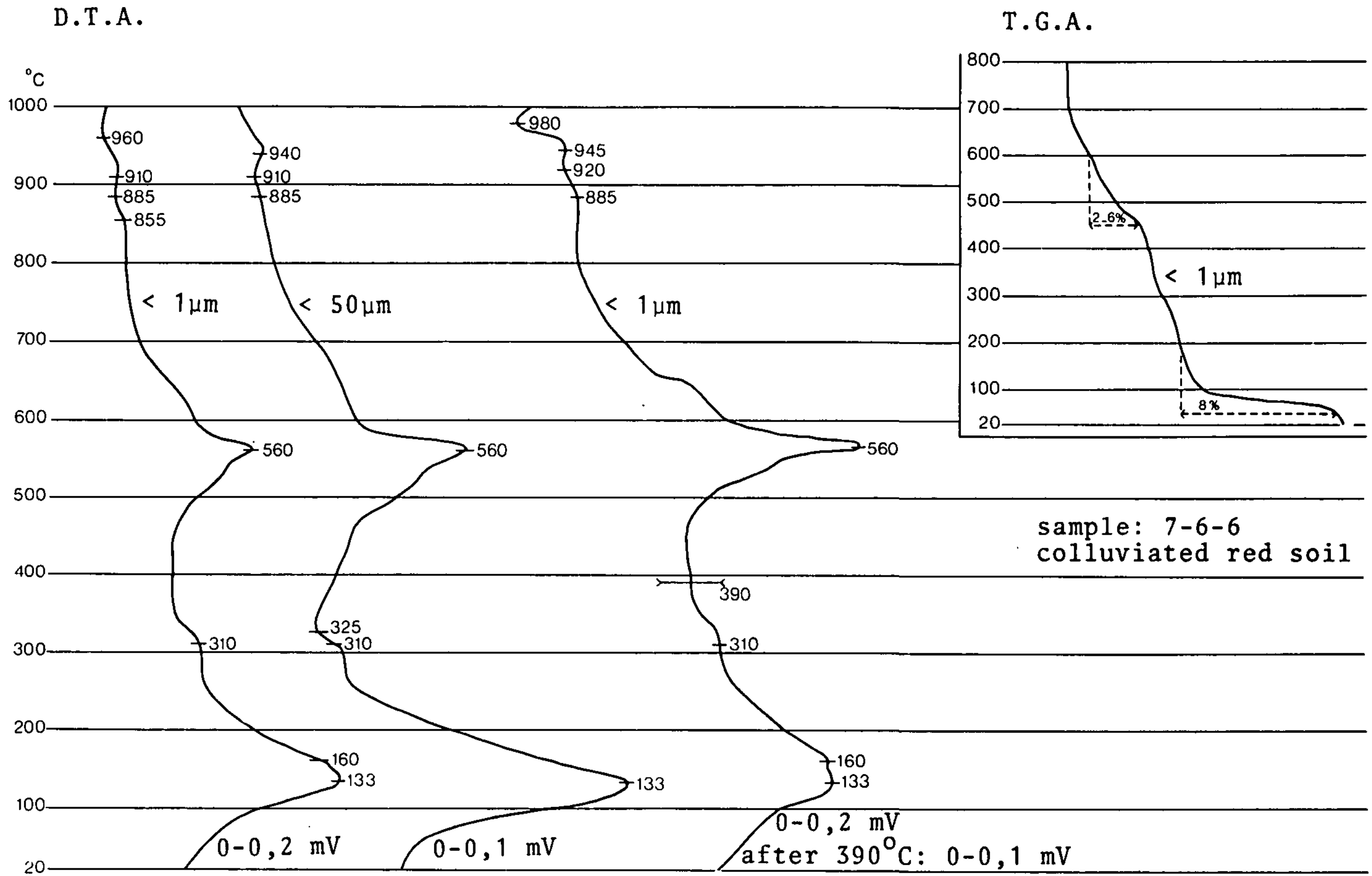


Fig. 36. Differential Thermal and Thermo-gravimetric analyses.
a. Curves of Differential Thermal and Thermo-gravimetric analyses of two samples.
b. Results of the interpretation of the Differential Thermal and Thermo-gravimetric analyses.


D.T.A.
T.G.A.
°C
1000
900
800
700
600
500
400
300
200
100
20
960
910
885
855
< 1µm
560
310
160
133
0-0,2 mV
940
910
885
< 50µm
560
325
310
133
0-0,1 mV
980
945
920
885
< 1µm
560
390
310
160
133
0-0,2 mV
after 390°C: 0-0,1 mV
2.6%
8%
< 1µm
sample: 7-6-6
colluviated red soil

	SAMPLE NO.	SAMPLE TAKEN FROM	SMECTITE	KANDITE	ILLITE	AMORPHOUS
INSTABLE	29-5-1	recent sandy colluvium	tr.	+	+	xx
	6-6-2	recent sandy colluvium				
	30-6-1	earthflow	(+)	+(+)	(+)	xx
	10-7-7	slump				
	10-7-8	slump	(+)	+	(+)	xx(x)
	6-6-4	mudflow	(+)	+	(+)	xx
STABLE	7-6-3	colluviated red soil	(+)	tr.	+(+)	xx
	7-6-5	influenced by flysch				
	7-6-9	C hor. of red soil	?	(+)	+(+)	xx
	7-6-8	Bt hor. of red soil	?	tr.	+(+)	xx
	12-6-3	colluviated red soil				
	7-6-6	colluviated red soil	tr.	(+)	++	xx

10. X-ray Diffractometer Analysis

Method Kummer (1964) based on Johns, Grimm and Bradley (1954) was applied.

Finally, of each sample specimens were prepared for semi-quantitative analysis with the X-ray diffractometer. The results of interpretation of the diffractograms have been given in figure 37.

In the table of figure 37. taken into account the percentage of amorphous material, the results can be seen to be in general agreement with those obtained from the Guinier-de Wolff camera.
The samples from the unstable areas generally show a dominance of kandite (with the exception of the sandy, recent colluvium) and those from the stable areas a dominance of mica.
Sample 7-6-5 is the only sample deviating from this pattern. Its high kandite content may very well have been caused by colluvial influence from the flysch area.

N.B. Mica in the 'stable' samples probably is well crystallized, which may be inferred from the reduction of the peak width of the 001 reflections.

	SAMPLE NO.	SAMPLE TAKEN FROM	SMECTITE	MICA	KANDITE	SEPTE CHLORITE	VERMICULITE	CHLORITE
INSTABLE	29-5-1	recent sandy colluvium	3-13 %**	10-20 %	22-23 %	45-55 %		
	6-6-2	recent sandy colluvium						
	30-6-1	earthflow	trace	38-48 %	52-62 %			
	10-7-7	slump						
	10-7-8	slump	trace	26-36 %	64-74 %			
	6-6-4	mudflow	3-13 %	13-23 %	63-73 %			1-11 %
STABLE	7-6-3	colluviated red soil						
	7-6-5	influenced by flysch		26-36 %	54-64 %		4-14 %	
	7-6-9	C hor. of red soil		45-55 %	27-37 %	13-23 %		trace
	7-6-8	Bt hor. of red soil		68-78 %	18-28 %			1-9 %
	12-6-3	colluviated red soil		61-71 %	25-35 %			1-9 %
	7-6-6	colluviated red soil	trace	85-95 %	5-15 %			

** For all samples are given the intensity percentages, which are corrected in such a way that they will most probably equal the weight percentages if the crystalline part of the clay-fraction.

N.B. For the x-ray diffractometer analyses method Kummer (1964) has been used.
This method is based on Johns, Grimm and Bradley (1954).

Fig. 37. Results of the interpretation of the X-ray diffractograms.

11. Conclusions

The stability differences observed in the terrain cannot be explained by the grain-size distribution. The clay content of the 'unstable' samples exceeds that of the 'stable' samples, yet, given the excessive ratio of material smaller than 2 micron in the 'stable' samples, this difference cannot be considered as a possible explanation.

The results obtained by X-ray analysis with the Guinier-de Wolff camera did not give a conclusive answer about the cause of the stability differences either as kandite seemed to be the dominant clay mineral in the 'unstable' samples, whereas, considering the types of instability, expandible clay minerals are required. Greater significance may be attached to the finding that, compared to the 'unstable' samples, the mica of the 'stable' samples seemed better crystallized and further that smectitic minerals proved to be present in some samples from the soft shale area.
A marked feature is that the results of the mechanical tests are highly indicative of the presence of swelling materials in the 'unstable' samples. Aggregate stability was clearly less, swelling capacity much higher and the moisture adsorption in the climatic cabinet cannot be explained but for the presence of swelling components in the 'unstable' samples.

The results obtained after X-ray diffractometer analysis may well provide the solution. Fact is that the samples from the unstable areas, although the crystallized part consisted for 60 to 70 % of kandite, appeared to contain a residual group consisting entirely of potentially expansible clay minerals.
From what has gone before it has to be assumed that this residual group - chlorites, vermiculite, poorly crystallized mica - is indeed strongly expansible.
The samples from the stable area contain no clay minerals with this property.

Determination of the content of amorphous material yielded the same results for both groups of samples.
It may rightly be argued that crystallized constituents make up only about half of the fraction smaller than 1 micron (fig. 28b), and that the influence of possible, swelling materials is consequently reduced to 50 %.

Further, the influence of the (fossil) pedogenesis respectively pedogeneses should not be underestimated.
From determination of the specific weight it appeared that the 'stable' samples contained more iron. In view of the high specific weight, the high aggregate stability and the fact that these samples with a high clay content possess a plasticity index characteristic of sandy samples, the assumption seems warranted that one or more earlier pedogeneses have brought about a 'texture pseudo-sableuse' as a result of iron

cementing the soil aggregates. This 'texture' not only greatly suppressed the clayey character of the material from the stable area, but to every likelihood also supplemented to the stable character of these parts of the terrain. Compare Duchaufour (1968, p. 78):
''Kubiena (1953) a distingué dans la masse de l'horizon (B) deux fractions d'une part un gel plasmatique ocre, qui correspond aux argiles ferrugineuses, encore non ou peu rubéfiées, relativement dispersables donc mobilisables, d'autre part des fins agrégats argilo-ferriques très stables, de couleur rouge: il s'agit évidemment des concrétions cimentées par le fer en exces''.
This feature described by Kubiena was also observed in a thin section of the Triassic material influenced by the fore-mentioned fossil pedogenesis.

N. B. A marked feature of these analyses was that the results of the tests were not as divergent per test as to allow a plausible explanation of the large stability differences. Yet the results differed to a point that for the 'stable' samples was conducive to stability and for the 'unstable' samples to instability.

So an accumulation of small differences rather than one dominant factor is concerned.

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Fig. 2 Topographic map of the area studied and its surroundings.
Limits of the area studied; the topographical names used in the text.

Inlay: Quaternary Evolution of a Mountainous Area in N.W. Tunisia
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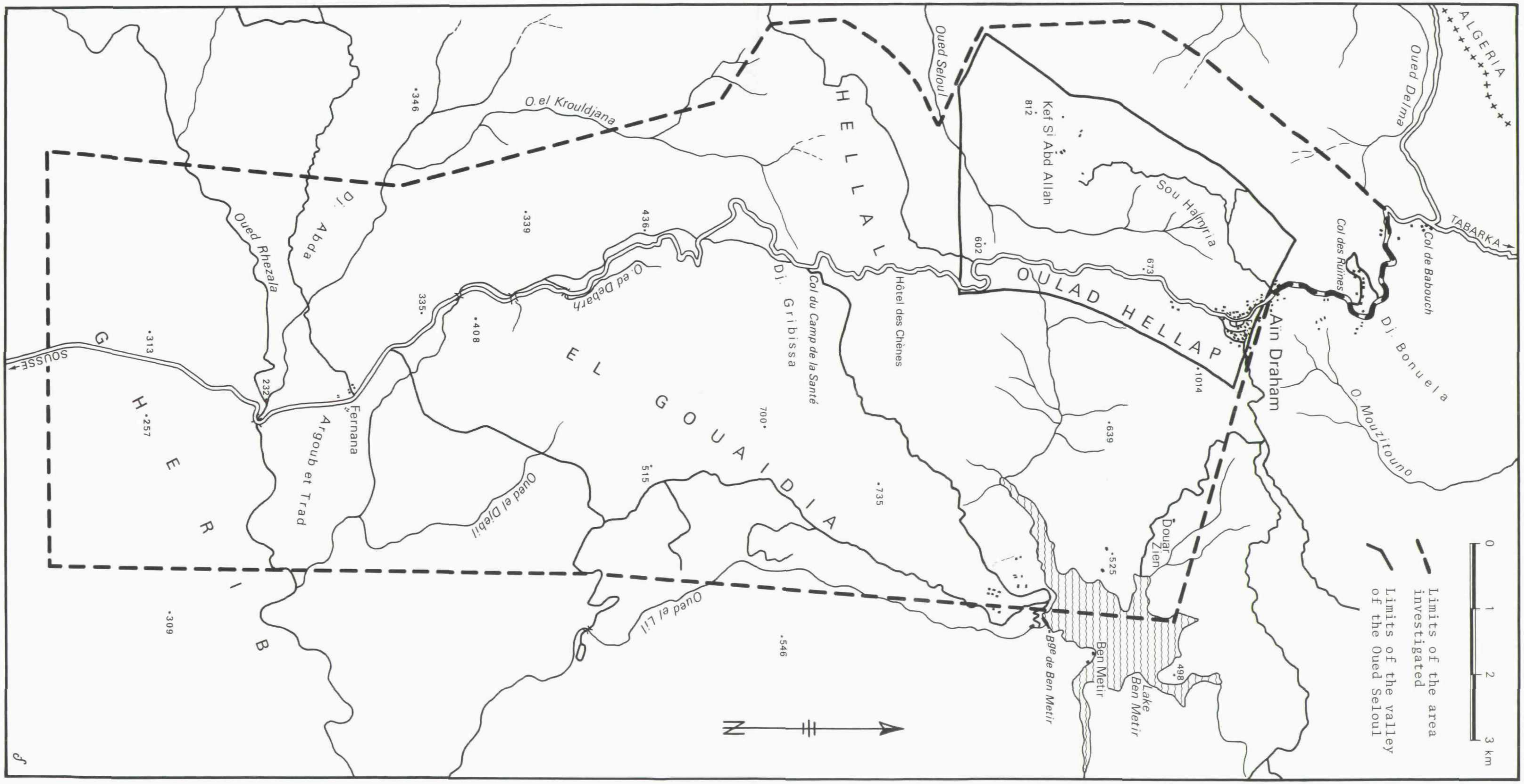

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Fig. 5

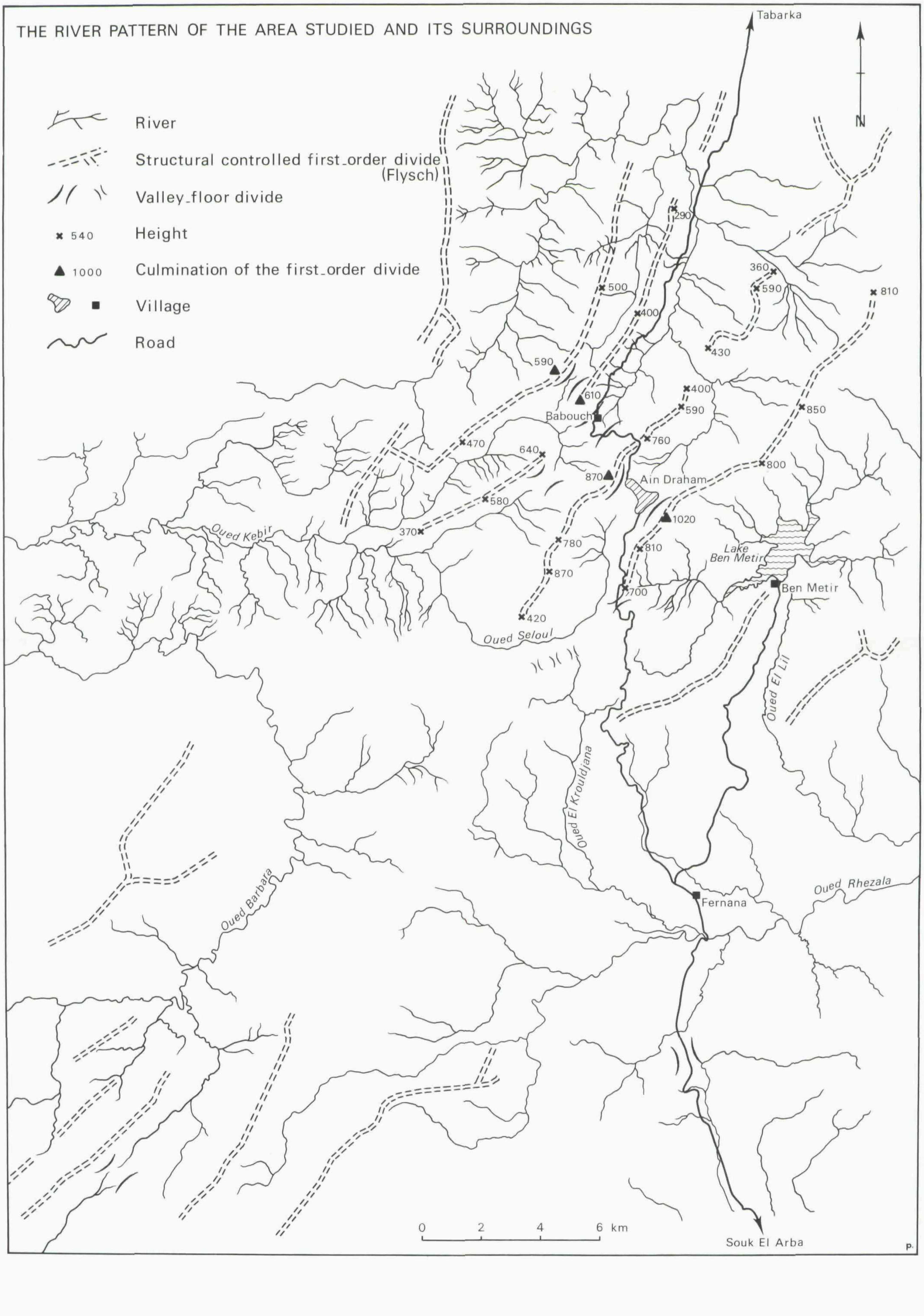
THE RIVER PATTERN OF THE AREA STUDIED AND ITS SURROUNDINGS
River
Structural controlled first-order divide (Flysch)
Valley-floor divide
540 Height
1000 Culmination of the first-order divide
Village
Road
Tabarka
Babouch
Ain Draham
Lake Ben Metir
Ben Metir
Oued Kebir
Oued Seloul
Oued El Krouldjana
Oued El Lil
Oued Barbara
Oued Rhezala
Fernana
Souk El Arba
0 2 4 6 km
290
500
400
590
610
470
640
870
580
370
780
870
420
760
590
400
1020
810
700
360
590
430
810
850
800
p.

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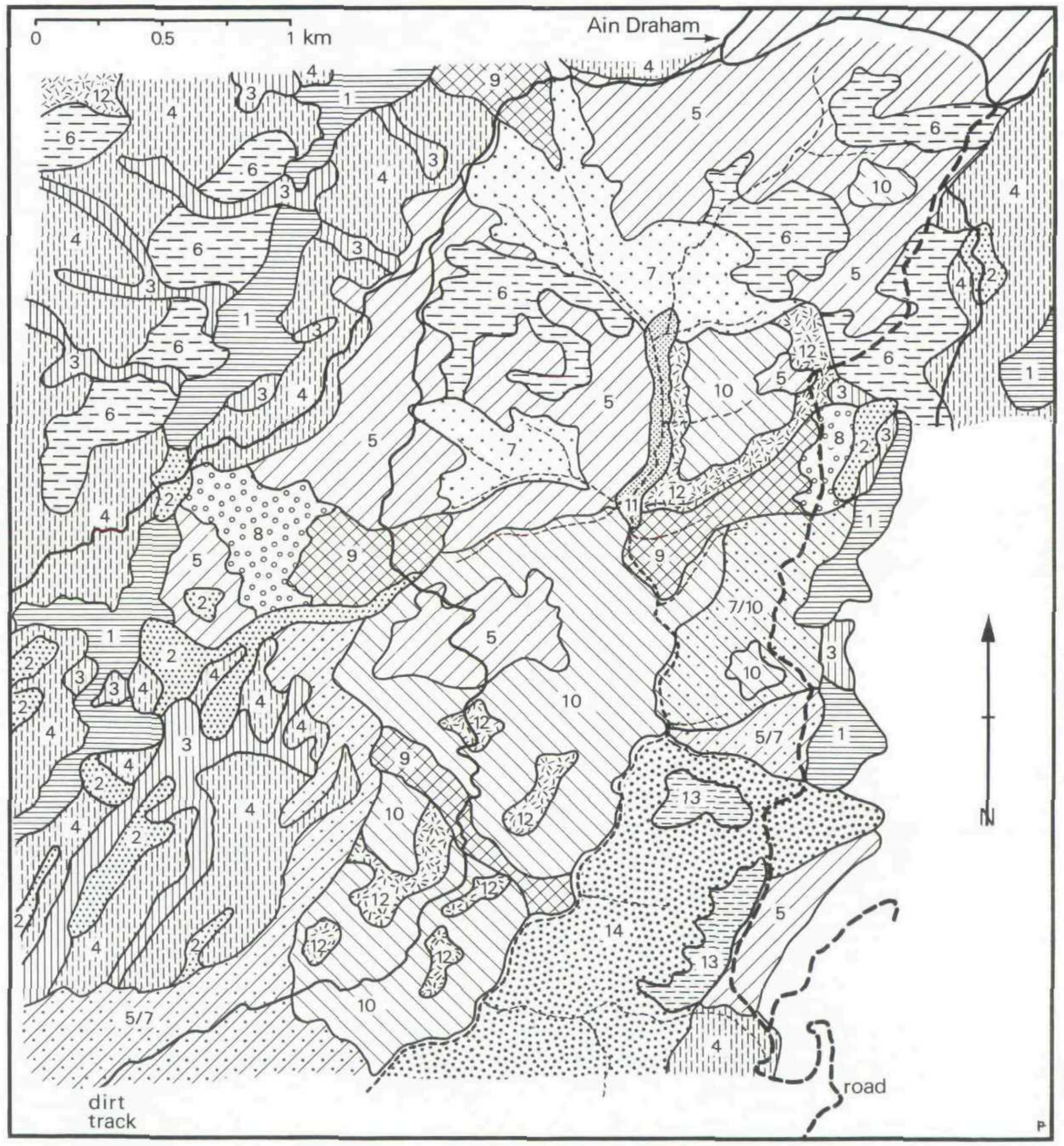
Fig. 21

Soil map of the valley of the Oued Seloul, scale approx. 1 : 25,000



basic mapping unit

Inlay: Quaternary Evolution of a Mountainous Area in N.W. Tunisia - a Geomorphological and Pedological Analysis -

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	No.	Parent rock	Physiographic unit	Soil Unit	Polygenetic Features
SEVERELY ERODED SOILS	3.	sandstone	sandstone outcrops and sharp sandstone ridges.	complex of sandy lithosols, stony (LITHIC UDIPSAMMENT) + clayey lithosols, stony (LITHIC -AQUIC- UDORTHENT).	in the sandstone remnants of a deep, red weathering; in the clay locally remnants of a fossil soil formation: red-grey mottled clay.
	7.	soft shale	most recent fluviatile dissection	complex of brown, clayey lithosols (LITHIC UDORTHENT) + grey, clayey lithosols, with locally a weathering layer not exceeding 40 cm in thickness.	-----------
	9.	heterogeneous	areas strongly influenced by earth slide activity	complex of shallow, sandy clay soils occasionally with remnants of a Bt hor., very coarse stoney + shallow brown clay soils occasionally with remnants of a Bt hor., very *coarse stony, much pseudo-gley mottling sometimes* up to the surface (eroded HAPLUDALF + ENTISOLS).	originally covered with recent colluvium. Colluvium has been eroded by means of concentrated mass movements. The Bt hor. being a remnant of an early-Holocene soil formation. The red-grey mottled clay is a remnant *of a fossil soil formation.*
	10.	marl	steep slopes of the marl ridges.	complex of shallow, calcareous dark-brown clay soils with wide cracks and occasionally a Cambic horizon few stones (VERTIC EUTROCHREPT) + limestone lithosols + clayey calcareous lithosols, few stones.	-----------
	14.	Triassic breccia	dissected, steep slopes of the diapyr	complex of very shallow, clayey loam soils with remnants of a red and brown Bt hor. (eroded PALEUDALF) + lithosols in breccia.	remnants of a fossil red Bt hor. and of a (sub) recent brown Bt hor.
MODERATELY ERODED SOILS	12.	marl	the flat slopes of the marl ridges	moderately deep calcareous dark clay soils with wide, deep cracks, locally browned, few coarse stones (ENTIC PELLUDERT).	the recent soil formation is a browncolouring of the soil. The formation of the Vertisol dates from a fossil pedogenesis.
	8.	heterogeneous	areas strongly influenced by earth slide activity	shallow to moderately deep (sandy) clay soils with a brown Bt hor., very stony (coarse), browned in upper decimetres, much pseudo-gley mottling up to the Bt hor. (HAPLUDALF).	the recent soil formation is a browncolouring of the soil. The formation of the brown Bt hor. is (sub) recent. Deeper in the profile the red-grey mottled clay being a remnant of a fossil pedogenesis may occur.
	5.	*soft shale*	*flat non-wooded slopes.*	*moderately deep to shallow clayey soils with a* brown Bt hor., upper decimeters browned, moderately stony pseudo-gley mottling locally and at varying depth (AQUIC HAPLUDALF).	*recent soil formation is a browncolouring of the soil.* The formation of the brown Bt hor. is (sub) recent. Deeper in the profile remnants of the red-grey mottled clay. Remnants of the recent colluvium.
NON-ERODED SOILS	1.	soft shale	flat and convex first-order divides	deep to moderately deep (sandy) clay soils with a slightly eroded profile, pseudo-gley mottling up to the brown Bt hor., deeply browned, almost stoneless (AQUIC HAPLUDALF).	the recent soil formation is a browncolouring of the soil. The formation of the brown Bt hor. is (sub) recent. Deeper in the profile remnants of the red-grey mottled clay. Influenced by the recent colluvium.
	6.	soft shale	flat, wooded slopes.	deep to moderately deep (sandy) clay soils with *a slightly eroded profile, pseudo-gley mottling* usually deeper than 60 cm in the profile, upper decimetres browned, stony (coarse) (ULTIC HAPLUDALF).	see 1.
	13.	Triassic breccia	flat slopes of the diapyr	deep to shallow clayey soils with a red and brown Bt hor., no stones, upper decimetres browned or weak homogenization of the organic material (TYPIC PALEUDALF).	deep red Bt hor. as a remnant of a fossil soil formation partly covered by a younger formation of a brown Bt hor. Recently browncolouring of the soil or 'steppisation'.
MISCELLANEOUS	2.		depression, dominantly structurally controlled	deep silty loam soils, deeply and strongly humose, pseudo-gley mottling at varying depth, stony (AQUIC UDORTHENT).	-----------
	11.		valley bottom/terrace.	moderately deep, sandy clayey loam soils, deeply humose, very stony (TYPIC UDIFLUVENT).	-----------
	4.	sandstone/ soft shale	steep slopes below the crests of the interfluves.	complex of sandy lithosols + clayey lithosols + deep to moderately deep loamy sand to sandy loam soils with remnants of a Bt hor. and a tendency towards formation of an A2 hor. stony to very coarse stony (-SPODIC- ULTIC UDIPSAMMENT) + deep silty loam soils, strongly and deeply humose, with considerable pseudo-gley mottling at varying depth (AQUIC UDORTHENT).	locally remnants of a (sub) recent Bt hor. and of a red-grey mottled clay. Recently tendency towards podsolization.