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Erosion due to cultivation of calcareous clay soils on the hillsides of south west France. I. Effect of former farming practices

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Abstract

Between the principal river valleys of south west France, the tertiary molasse outcrops have produced a deeply undulating surface relief. Soil distribution in this upland landscape is highly disordered and the spatial organisation can only be understood from detailed examination of soil profiles. The considerable modifications to which the soil cover has been subjected may be explained by factors other than natural agents of erosion. Careful examination of former gullies and the hillside relief reveals the important erosive effect of the methods of cultivation used on these sloping soils. A simple model is proposed to test the effect of former contour ploughing in which soil was turned over towards the base of the slope. Simulation over a broad time scale gave the same results as those observed in the present landscape.

Keywords: Erosion; Soil on slope; Tillage; Landscape

1. Introduction

The region studied is situated in the Aquitaine Basin, north of the Pyrenean mountain range. Throughout the Tertiary, this basin served as an emergent zone of subsidence that received all the sandy, clay and calcareous sediments derived from erosion of the Pyrenees, that were in orogenic phase at that time. These heterogenic materials were of low energetic value and gave rise to a thick detrital formation of molasse type. From the Quaternary onwards, the rivers became channelised, cutting broad valleys in the molasse deposits and leaving terraces of coarse alluvium. Molasse outcrops appeared in the interfluvial zones and these soft impermeable materials were eroded by a dense network of small, often intermit-

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tent, streams. This region is commonly known as Terrefort (heavy soil). Erosion has produced a deeply undulating surface relief in which the hills are frequently asymmetrical. Those hillsides exposed to the north and east are longer, more even and have gentler slopes than those facing south or west (Hubschman, 1974; Taillefer, 1951). The soil mantle is highly heterogeneous and has already been the subject of numerous studies (Cavaille, 1969; Hubschman, 1974; Revel, 1982). The aim of this study was to determine the factors of erosion responsible first for the currently observed spatial organisation of the soils, and second, for the formation of the present mesorelief.

2. Materials and methods

2.1. Soil distribution within the landscape

The soils in this upland landscape are extremely variable, both in the horizontal and vertical planes. Despite such apparent complexity, Revel (1982) demonstrated a certain logic in their spatial organisation. This author produced a palaeogeomorphological reconstruction of the region based on a chronological hypothesis. To start with, major landscape features visible today as hillsides, crests, strips and valleys, are inherited from periods prior to Würm II, approximately 23 000 years ago. After that, the pre-existing soil mantle was removed by a great periglacial cold phase of morphogenesis. The climatic crisis was brief but intense. Because of the scanty vegetative cover, the hillsides were poorly protected against erosion and became dissected by deep gullies. Colluvium accumulated locally at the base of the slopes. Then, the climate warmed up again, the vegetative cover developed and differentiation of the molasse gave rise to calcic cambisols (according to FAO taxonomy) except on the colluvium where luvisols were produced by more extensive soil evolution. During Würm IV (14 000 years ago), a new more discrete phase of morphogenesis again brought the molasse to the surface on the steepest slopes. Between 14 000 and 2000 years ago, the processes of pedogenesis continued, giving rise to calcic cambisols on the rejuvenated molasse, luvisols in place of the former calcic cambisols and luvi-redoxisols on the former colluvium where leaching was more intense. Finally in these areas, pedogenesis always resulted in the same soil types (i.e. calcic cambisols initially, followed by calcic luvisols). Both exhibit a horizon with calcareous deposits at a depth of 1.5–1.8 m.

The currently observed soil profiles are the result either of truncations of varying degree, often to the parent rock or, in contrast, of accumulation of material. The S, BT, K and C horizons (Baize and Girard, 1992) may be brought to the surface, thus giving the currently tilled horizon its highly variable morphological characteristics. Owing to the juxtaposition of patches of different colour in the present landscape, soil scientists have described the soil cover in this region as a mosaic (Fig. 1).

Finally, the actual depth of the K horizon (the calcic horizon) is witness to these modifications and can be used to determine the thickness of the truncation or mantle. The soil distribution within the landscape can thus be more easily understood in the following way. First, at the shelf level, very weak erosion led to the development of calcic luvisols on the tertiary substratum and local rendosols on the hard calcareous sandstone beds. On the long hillsides with very gentle slopes (less than 12%), the calcic cambisols were subjected



Fig. 1. Soil mosaic of the Terrefort area.

to moderate erosion. Removal of the upper horizons of such soils produced calcic cambisols truncated soils in which the K horizon was rarely at the surface. The short steep slopes (over 12%) were worn away, often uncovering the calcareous K horizon, except in the former gullies. In contrast, in the valley bottoms the accumulated materials gave rise to calcic colluvium at the base of the slopes. Detailed descriptive analysis of the soil profiles has thus revealed the extensive soil modifications that have occurred in this region. New soil profiles have had to be examined to determine which factors of erosion have been responsible for such modifications.

2.2. Erosion due to water or to cultivation?

Run-off, producing sheet or rill erosion, might have been responsible for wearing away the slopes and accumulating material in the valley bottoms, some of which may contain 4–8 m of colluvial deposit. However, certain facts remain difficult to explain. First, if run-off had played a very active part in soil erosion it would have left its mark on the sensitive areas (i.e. the former gullies). This is not what is observed, since these true ravines have not been eroded but have, on the contrary, been filled with accumulated material. Barlier (1977) examined soil displacement in these gullies by describing a soil sequence parallel to the contour that cut across a former gully (Fig. 2(d)). He found that the soil on one edge was calcareous without any soil or mineral differentiation. In the centre, the soils had been modified with a calcic cambisol characterised firstly by decalcified upper horizons, rich in

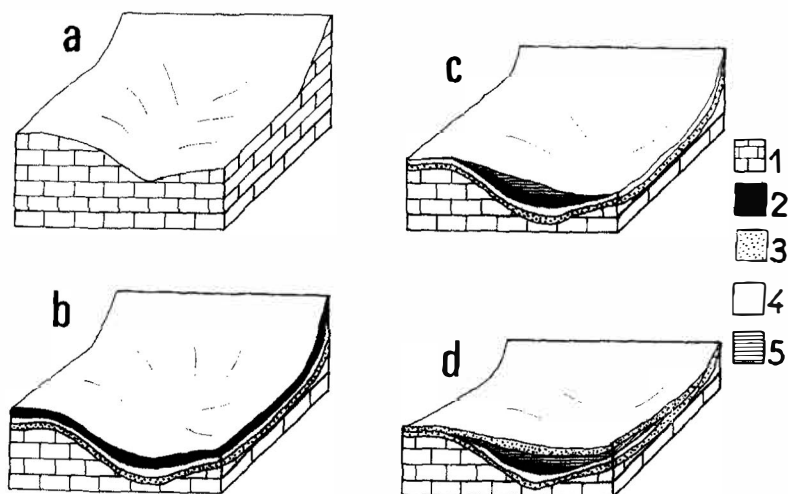


Fig. 2. Reconstitution of gully evolution. (a) Excavation of the gully. (b) Differentiation of calcic cambisol. (c) Crest abrasion and bottom filling due to ploughing. (d) Present state. 1, molassic substratum; 2, A horizon of a calcic cambisol; 3, S horizon of a calcic cambisol; 4, K horizon of a calcic cambisol; 5, remaining A and S horizons.



Fig. 3. Filled former large gully of hillside.

organic matter and containing vermiculite at the bottom of the gully, and secondly redistribution of calcareous material throughout the profile with the formation of a K horizon. The same horizons could be found above this buried soil but in reverse order with the decalcified vermiculite-rich horizons surmounted by a lime-rich layer. The same series was apparent on the other edge of the gully but the buried organic horizon was absent.

To explain the evolution of the observed sequence, the author proposed the palaeomorphological reconstitution shown in Fig. 2. Following excavation of the substratum (Fig.

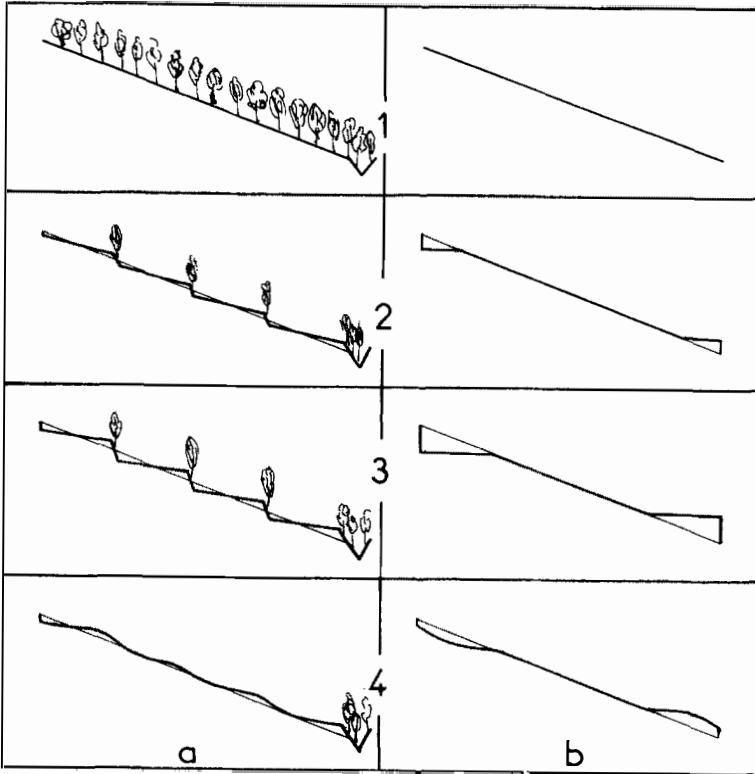


Fig. 4. Evolution of a hillside (a) and plot (b) under the effect of ploughing. 1, original form; 2 and 3, effect of contour ploughing; 4, superimposition of ploughing up and down the slope.

2(a)) during Würm IV, a calcic cambisol developed along the slopes of the gully (Fig. 2(b)). Later cultivation of such soils may have led to abrasion of the high points (Fig. 2(c)) and accumulation in the lower portions. This type of modification has already been observed in tropical zones where analysis has been facilitated by the stone-line (Bourgeat and Petit, 1966). Secondly, accumulations exist half way down all the steep slopes, constituting veritable embankments, even on slopes as steep as 35%. The formation of such embankments cannot be attributed to surface water. Gimpel (1975) and Neboit (1983) think that these embankments marked the lower limits of previously cultivated plots. Finally, detailed examination of the colluvium has shown such modifications to be recent as no pedogenesis, with the exception of fine pseudomycelial calcareous coatings on the walls of tubular pores, is apparent.

Fragments of pottery are frequently found in the colluvium which is therefore contemporary with the arrival of early man in this region. Certain remains date from Roman times, others are more recent. These soils are heavy and difficult to till. Ploughing would have required four to six oxen. The first farmers preferred to settle on the sporadic superficial deposits of lighter loams. Historians have estimated that the beginning of land clearance in the commune of Lezat, situated in the molasse region, goes back to the year 968 (Ourliac, 1963). This corresponds to the invention of the shoulder yoke and rigid harness, which

made it possible to till these rich but very heavy soils. Thus repeated ploughing over several centuries led to the inversion of material (Fig. 2(d)) observed today in the soil-filled former gullies (Fig. 3).

During the Middle Ages when use of the mouldboard plough became generalised, ploughing was carried out parallel to the contour, the soil being turned over towards the base of the slope. The plots were therefore elongated in the direction of ploughing, with the upper limit in the form of a tree-planted bank. Even though the soil was only worked to an average depth of 10 cm, such a practice over several centuries has led to considerable modification of the slope relief as illustrated in Fig. 4. The overall result was a levelling of the top of the plot and accumulation in the valley bottom. The same type of landscape was observed by Carnet et al. (1979) in the mixed woodland and pastures of Brittany. The shorter and steeper south-facing slopes were affected by this phenomenon to a greater extent.

We shall use these initial observations to determine the effects of repeated ploughing on landscape morphology.

2.3. Simulation of the effect of former ploughing

A soil erosion model was produced to predict the long term effect of former cultivation practices. Validation would, in theory, have required experiments over the period of a

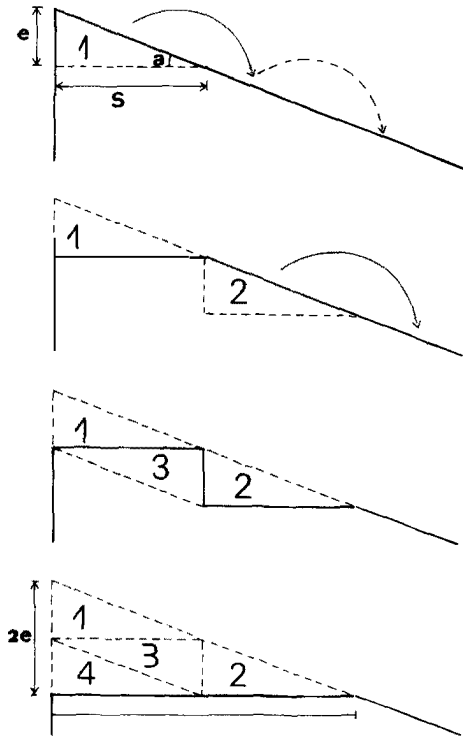


Fig. 5. Simplified model of hill top levelling due to ploughing. 1, first ploughing; 2, second ploughing; 3, third ploughing; 4, fourth ploughing. S , furrow width; a , slope; e , truncated thickness.

century. In practice, we will compare the truncation values obtained by simulation with those observed in the field.

As a first hypothesis, our model assumes that each ploughing operation displaced towards the bottom of the slope a constant soil volume which depended not on ploughing depth but on the slope and furrow width. It is impossible to accurately determine the form of this volume so we have assumed its cross section to be a right-angled triangle with the longest side representing the width of the furrow (S) and the shortest side (e) the truncated thickness (Fig. 5). If the slope (a) is expressed as a percentage, and S and e are in meters, this gives

$$e = aS/100 \quad (1)$$

We have also assumed that flattening of the relief is a nonlinear process. The converse assumption would produce much greater abrasion than that observed in situ. The thickness removed from the top of the plot during the first year of cultivation, is e along a horizontal line S (Fig. 5). Three further ploughing operations are required to remove twice this thickness over a width of $2S$. In the long term this gives the following arithmetic progression

$$N_i = 1 + 3 + 5 + 7 + \dots + \text{ith uneven number} = i^2 \quad (2)$$

Where N_i is the number of ploughing operations required to remove i thicknesses of e from the top of the slope. This gives

$$i = \sqrt{N_i} \quad (3)$$

Finally, after N_i ploughings, the total thickness removed from the top of the slope is E meters and the width converted to the horizontal is L , where $L = iS$ and

$$E = ie = aS\sqrt{N_i} \quad (4)$$

In our model the width (L) of the flattened top is, in conformity with field observations, independent of the slope. The tops are in fact always flattened over a width of 5–10 m and these observations have to be compared with the calculations obtained with the model.

3. Results

Eq. (4) is graphically represented by the curve in Fig. 6. This shows that the rate of truncation is not constant but slowly decreases without attaining a limiting value, there being no asymptote parallel to the x -axis. The downward displacement of soil induced by such cultivation techniques in the long term would therefore occur more and more slowly, without reaching an equilibrium. The thickness removed from the top of the slopes (E) and the width of the levelled summits (iS) can easily be calculated from Eqs. (3) and (4), as a function of the number of ploughings (N_i) carried out on the different slopes (a). Ploughing has been carried out once or several times annually, depending on the rotation system, since the first cultivation of such soils approximately 1000 years ago. During the Middle Ages, fallow land was ploughed two to three times annually to control weeds.

The total number N_i of ploughing operations carried out since the beginning of cultivation varies, giving a truncation that increases with the slope, as shown in Table 1. These estimates are totally compatible with the traces left by such levelling activities on the walls of pigeon

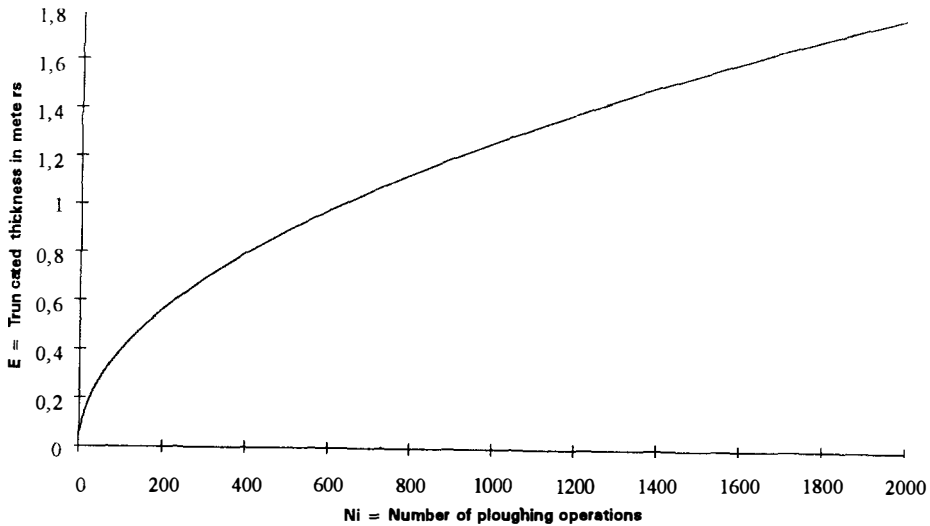


Fig. 6. Truncation evolution in relation to the total number of ploughing operations carried out on a 20% slope with a 0.2 m furrow. N_i , number of ploughing operations; E , truncated thickness (m) with $E = 0.04\sqrt{N_i}$.

houses, built on the tops of the slopes when the plots were cultivated and that are still present today. The width (L) of the levelled summits calculated from the model varies from 4 to 9 m, depending on the number of ploughing operations and this result, which agrees with field observations, again supports the initial hypotheses.

The calculated truncation thicknesses (E) also correspond to modifications observed around ancient gullies. The fossil slopes of these deep gullies are 40% on average, whereas the hillsides that they dissect have gentler slopes of between 10 and 25%. According to our calculations, the truncations of such slopes are 2–3 m in thickness in the first case, and 0.4–2 m in the second. Colluvium several meters in thickness is observed in the field in the gully bottoms whereas it is only a few tens of centimetres thick on the long hillsides with gentle slopes. On either side of the former gullies, traces of intense levelling are clearly apparent in the present landscape, providing clear patches 4–8 m wide, parallel to the fossil edges of ravines. Such observations agree with our calculations.

Table 1
Simulation of slope erosion due to ploughing operations between the years 1000 and 1950 with furrows 0.2 m in width

Frequency of ploughings	N_i ^a	Width of the levelled summits (m) ($0.2\sqrt{N_i}$)	Truncated thickness for different slopes (m)				
			5%	10%	12%	25%	40%
Once every 2 years	475	4.4	0.2	0.4	0.5	1.1	1.7
Once per year	950	6.2	0.3	0.6	0.7	1.5	2.5
Twice per year	1900	8.7	0.4	0.9	1.0	2.2	3.5

^a N_i is the total number of ploughing operations carried out since the first cultivation.

4. Conclusions

This descriptive review of upland soils in south west France provides a better understanding of the agents of erosion in this region. On the steep hillsides all the upper horizons have accumulated in the valley bottoms and gullies (Fig. 3). Less displacement has occurred on the gentler slopes and truncations in the calcic horizons were only apparent where levelling has also occurred, on the gully edges and tops of the plots. Mechanical erosion produced by farm implements has thus had a preponderant impact on hillside morphology and levelling of the relief. Water does not seem to be a major factor of erosion in this region on this type of soil.

Simulation of repeated ploughing operations produced a relief similar to the one observed at present. The results provide a rate of hill-top truncation that decreases with time, which is reassuring. The model used is based on a former cultivation technique, however. Ploughing is at present carried out along the line of the steepest slope which modifies the data and has been the subject of new experiments (Revel et al., 1990, 1993; Guiresse and Revel, 1995).

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