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Erosion under Forest Cover and Erosion in Deforested Areas in the Humid Tropical Zone



Photo 1. Peruvian Amazon. Andes foothills. Landslips on steep wooded slopes. The lower slopes have been cleared of forest to plant crops. Photograph A. Aubréville, 1959.

RÉSUMÉ

ÉROSION SOUS FORÊT ET ÉROSION EN PAYS DÉFORESTÉ DANS LA ZONE TROPICALE HUMIDE

L'érosion par décapage ou par ravinement reste insignifiante sous la forêt dense tropicale. Une érosion sérieuse peut certes se manifester localement sous couvert forestier, sous la forme de glissement de terrains saturés d'eau. De tels cas peuvent être observés à Madagascar, dans la forêt d'Anamalazoatra ou dans celle de Marojejy. Un cas connu d'érosion généralisée sous forêt dense se situe en Amazonie péruvienne, près de la petite localité de la Merced, sur des pentes très abruptes. Mais ce sont là des exceptions. Dans les temps géologiques, durant les périodes de transformations tectoniques, l'érosion peut aussi avoir été intense sous forêt dense, générant des reliefs tourmentés, parfois des « badlands ». Mais dans tous ces cas, l'érosion ne se produit sous forêt que lorsqu'il y a élévation du niveau de base des fleuves par rapport au niveau des océans, comme cela s'est manifesté durant les glaciations quaternaires. Là où la forêt manque aujourd'hui, se manifestent en revanche des phénomènes d'érosion parfois spectaculaires. Ceux-ci peuvent prendre des proportions spectaculaires dans des régions autrefois forestières, récemment et sévèrement éclaircies. Les situations les plus extrêmes sont observées à Madagascar, au Congo, au Gabon, au Brésil et dans la partie tempérée des USA, tout particulièrement dans le bassin cuprifère du Tennessee. Ces exemples confirment pleinement la vertu antiérosive des forêts. Lorsque l'érosion est déclenchée, celle-ci ne peut être arrêtée qu'à grands frais, et dans des zones restreintes. La forêt joue donc un rôle anti-érosif préventif à la fois naturel, peu coûteux, et opérant sur de larges étendues.

Résumé adapté par la rédaction de la revue.

Mots-clés : déforestation, glaciations quaternaires, *lavaka*, lutte anti érosive, protection des sols, ruissellement, Madagascar.

ABSTRACT

EROSION UNDER FOREST COVER AND EROSION IN DEFORESTED AREAS IN THE HUMID TROPICAL ZONE

Although surface erosion and gullying are insignificant under dense tropical forest cover, severe erosion can occur locally as a result of land slippage in saturated soils. Examples may be observed in Madagascar, in the forests of Anamalazoatra and Marojejy. Another documented case of widespread erosion under forest cover may be found in the Peruvian Amazon, on a steeply sloping mountainside near the village of Merced. These are exceptions, however. During geological periods of tectonic transformation, intense erosion could have occurred under dense forest cover, forming a jagged relief or what are referred to as "badlands". But in all these cases, erosion under forest cover could only have occurred when the level of riverbeds rose in relation to the level of the sea, as during the Quaternary glaciations. In places where the forest cover has disappeared, the soil is sometimes spectacularly eroded. The same is true of previously forested areas that have recently been severely thinned. Extreme cases may be found in Madagascar, Congo, Gabon, Brazil and the temperate regions of the United States, particularly in the Tennessee copper basin. These examples clearly confirm the anti-erosive value of forests. Once erosion begins, it can only be halted at great cost and over limited areas. Forests are therefore a means to prevent erosion naturally, cheaply and over large areas.

Abstract adapted by the editorial team.

Keywords: deforestation, Quaternary glaciations, *lavaka*, erosion control, soil protection, runoff, Madagascar.

RESUMEN

EROSIÓN EN BOSQUES Y ÁREAS DEFORESTADAS EN ZONAS TROPICALES HÚMEDAS

La erosión por decapado o escorrentía no tiene apenas importancia en las selvas tropicales. Es verdad que localmente pueden darse importantes erosiones bajo la cubierta forestal en forma de deslizamientos de tierras saturadas de agua. Estos fenómenos pueden observarse en Madagascar, en los bosques de Anamalazoatra o Marojejy. Un caso conocido de erosión generalizada bajo la selva se ubica en la Amazonía peruana, en unas laderas muy abruptas cerca de la pequeña localidad de La Merced; pero todos estos casos suponen excepciones. En el tiempo geológico, en los períodos de movimientos tectónicos, la erosión también pudo ser intensa bajo las selvas, originando relieves accidentados y, a veces, tierras abarrancadas. Pero en todos estos casos la erosión sólo se produce en los bosques cuando sube el nivel de base de los ríos con respecto al nivel de los océanos, como se produjo durante las glacitaciones cuaternarias. Sin embargo, en donde los bosques están actualmente ausentes, se producen fenómenos erosivos que, a veces, pueden alcanzar proporciones espectaculares en regiones antes cubiertas por bosques y que recientemente han sufrido intensos desbroces. Las situaciones más graves se observan en Madagascar, Congo, Gabón, Brasil y la parte templada de EE. UU., especialmente la cuenca cuprífera de Tennessee. Estos ejemplos confirman plenamente la capacidad anti-erosiva de los bosques. Una vez iniciado el proceso erosivo, sólo puede frenarse mediante intervenciones muy caras y en áreas limitadas. El bosque desempeña por tanto un papel anti-erosivo preventivo que es, a la vez, natural, barato y cubre amplias superficies.

Resumen adaptado por la redacción de la revista.

Palabras clave: deforestación, glacitaciones cuaternarias, *lavaka*, control de la erosión, protección de suelos, escorrentía, Madagascar.

The most widely recognised value of forests is certainly their role in maintaining soils on slopes by preventing erosion. The effectiveness of tree planting in mountain areas to fix soils on slopes that have been denuded or eroded, or are threatened with erosion, has been demonstrated many times over. An important branch of forestry is the art of restoring mountain soils, where replanting has a crucial role. Spectacular successes of French forestry can be observed in the Alps in particular, where corrective work on mountain streams together with reforestation on slopes have succeeded in quieting the most tempestuous and devastating torrents.

In forest stations, however, studies are still under way to define the role of forests in controlling erosion through trials in which comparisons are made between forested and deforested parcels with comparable topography, exposure and soils. Comparative measurements made between run-off and the quantities of soil washed away to provide quantitative estimations of the protective role of forest cover in comparison with herbaceous cover or bare soil.

My intention here is not to discuss this very well-known topic which already has a substantial bibliography, at least for temperate regions. It is generally agreed that in tropical climates, there is a greater risk of severe soil erosion on denuded slopes than in temperate countries, either because of the alternation of heavy rains in the wet season and drought in the dry season or because of high year-round rainfall. Here again, trials are under way to measure the scale of soil erosion depending on the nature and methods used for cultivation and under different types of forest or herbaceous cover.

Contrary to expectations for heavy plant cover, erosion has been reported under dense humid tropical forests. I reported in this publication on a communication on the

subject from M. Fournier to the French Academy of Agriculture. Erosion by gullying or topsoil leaching is probably insignificant under dense tropical forest cover, as the shallow roots of forest trees form a dense mat in the upper soil horizon, which prevents fast-flowing run-off and soil leaching. Erosion under forest cover appears to occur mainly through soil creep, when the soil becomes saturated with water. As the soil gradually creeps downwards, it is eventually deposited in thalwegs where, depending on circumstances, it accumulates as marshy alluvium or is swept away by run-off.

I have always taken an interest in erosion phenomena and sought to memorise those I have been able to observe. I will first describe a general case: in primary forests in the rainy season, streams of clear, but slightly muddy water will form after a heavy downpour. This is the observation that leads to the conclusion that forests protect from erosion, especially when compared with the yellow or red-coloured waters that flow across denuded or cultivated ground after a downpour.

But I have also occasionally observed landslips in primary forests. Two photographs taken in Madagascar's eastern forests (Périnet area) clearly show gullying in one case, and in the other a landslip down a slope that has torn down trees and bushes. The lack of resistance of the forest stand to such landslips is accounted for by the very rainy climate, the nature of the ferrolateritic soil, which has the aspect and consistency of clay, and by the consistently shallow root systems of the trees and bushes. A photograph taken in the same forest in eastern Madagascar around Périnet (Anamalazoatra forest) of a freshly opened section of earth on a slope shows the very thin layer formed by the shallow rooting system, in which there are very few taproots. More generally, it is well known that even very large trees in dense humid forest have shallow, but sometimes very extensive root systems, which do not always prevent them from being blown over by tornados during the rainy season.

Sometimes, therefore, the combination of climatic and soil conditions and forest type prevent the forest from fulfilling its usual protective role. It should be noted, however, that these landslips are highly localised and not common. In fact I know of only one example of widespread soil degradation under forest cover, and this forest, in the Peruvian Amazon, was untouched by man. The vertiginous route down the Andes from Tarna (3000 m.) to the Péréné River, a tributary of the Rio Ucayali, which itself flows into the Amazon, leads to the small town of La Merced in the middle of the Amazonian eastern montane forest, from which can be seen the jagged silhouette of a wooded mountain range. From the mountaintops, numerous yellowish strips plunge downwards through the mantle of green forest. The slopes are very steep. My first thought was that these were strips that had been cleared by farmers, despite the steep terrain. On closer inspection, this was clearly not the case. There was no human occupation on this mountain range, the landslips had started at the top and the earth was being washed down by mountain torrents to form alluvial fans in the narrow valley of the Péréné River. What is surprising is the extent of this phenomenon in an Amazonian region that civilisation



Photo 2.

Erosion due to a landslip in a primary upland forest in Madagascar.

Photograph Madagascar Forestry Service, 1959.

**Photo 3.**

From top to bottom:

Erosion by gullying in a primary upland forest in Madagascar.

Photograph Madagascar Forestry Service, 1959

A soil section showing the very shallow humus layer and shallow root system in a primary forest, Madagascar.

Photograph A. Aubréville, 1959.

has barely reached. Almost every mountaintop is affected by the same leprosy of the soil. Some are completely denuded. Nevertheless, these deposits are eventually covered over and apparently fixed by grassy vegetation. Older grass-covered deposits can be identified. The high savannah lands in this area are known as *pajonal*. A “*gran pajonal*” is even shown on the map of the region, although I have not been able to find any information about it. I wonder whether these *pajonal* could all be the result of such landslips. It must be remembered that the area has a western Amazonian climate with high annual rainfall, probably around 3 m, and no dry season. I only travelled through this remote country, where beyond the small Peruvian villages begins the great Amazonian forests inhabited only by a few Indian tribes. I was therefore unable to closely observe this strange phenomenon of spontaneous erosion that is so frequent in this mountainous wooded landscape, an unusual form of transformation into savannah of which I know of no other example.

On the steepest, densely wooded slopes of the Marojejy range in Madagascar, Professor Humbert has also observed how soils are washed away during the rainy season along with their thick blanket of shrubs and lianas, leaving bare rock. With great perseverance, vegetation then becomes re-established.

These are clearly instances of spontaneous erosion in which man has had no part, even as a trigger, but they are isolated, limited in extent and localised in a few mountain forests in very humid climates. But the reality of these landslips under primary forest cover has prompted some to cast doubt, with some sophistry, on the recognised protection against erosion afforded by forests in general, and thus to question the policy for forest protection that we are attempting to implement in tropical countries. If forests do not effectively protect soils, why protect listed forests from clearing?

Some have become so used to linking increased productivity in tropical agriculture with increased clearing in virgin forests that they find the policy to limit clearing by establishing listed forests and reserves shocking as liable to prevent the expansion of agriculture. If there is really no other possibility for agronomy in the tropics, then one must surely despair of the future of agriculture in tropical countries. We do not believe this, but because there is a tendency, although not widespread and somewhat masked, to minimise the protective role of nature and forests, I feel it is necessary to bring these false arguments into the light of day on the basis of a few known facts.

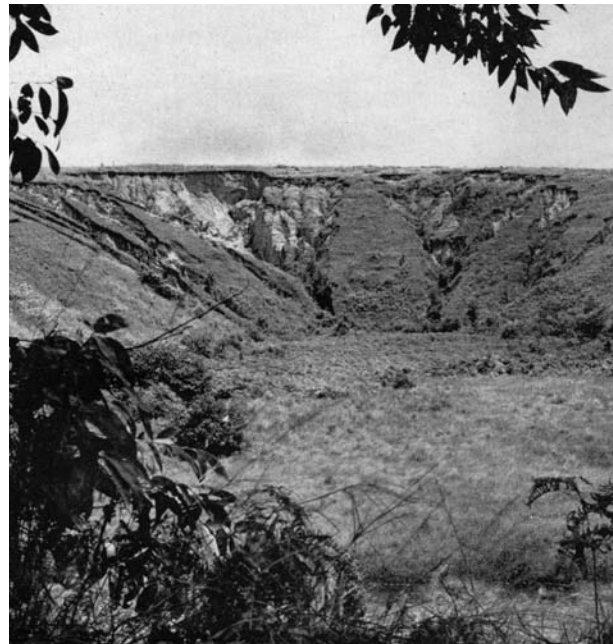
Besides, although it is a good idea to establish the comparative effectiveness of different types of soil cover in preventing erosion on the basis of measurements made in a few experimental parcels, the demonstration is even more valuable when observations are made of how erosion develops in areas that have been recently deforested, whether partly or entirely. Where forest cover is lacking today, as a result of direct or indirect destruction by man, the scale of the erosion observed can be spectacular, as many examples show (figure 1).

The clearest example, and also the saddest, is on the Madagascar Central Highlands. Personally, I do not know of

**Photo 4.**

A *lavaka* on a sandy hillside. State of São Paulo, Brazil.
Photograph A. Aubréville, 1959.

any other country where erosion has occurred on such a scale and with such severity. Every form of erosion can be observed: scars on mountain ridges, long gullies winding across the gentler slopes, and especially *lavaka*. This is the local term referring to the eroded hollows that sometimes form in large numbers across the red lateritic soil in low hilly country. This type of erosion is therefore quite different to those described above. These *lavaka* are formed by landslips that occur on hillsides. First, a crack appears in the soil and gradually widens, roughly following a contour line. As it becomes swollen with water, the loosened earth begins to slip down through a narrow gully, eventually spreading out into the thalweg and leaving a crater with vertical sides sometimes several metres in height. Year by year, the crack opens further upstream, becoming deeper and branching out laterally before it eventually stabilises, usually before reaching the ridge, although it sometimes cuts through it. Sometimes, two *lavaka* will form on either side of a hill and eventually join up by cutting through the top. Once they have at least partially stabilised, they are colonised by herbaceous and woody vegetation. Two questions need to be answered: what eventually halts their progress? And why do we find such an intense and widespread form of erosion on Madagascar plateau Central Highlands? It is possible that a *lavaka* will stabilise when it has become so deep that the soil is sliding on an impermeable layer or even on the underlying rock. The phenomenon is

**Photo 5.**

A *lavaka* in Madagascar.
Photograph Letourneux, 1959.

truly a disease of the soil that occurs on very thick ferrolateritic soils (up to 10 m). The nature of the soil, the climate and the thickness of the lateritic clay layer are also involved. It does not occur on Madagascar's volcanic soils, which are also very deep (Ankaratra). There is also another factor, which is denuded soil. Meagre steppe grasses are the only soil cover in these areas, which are actually former forest

lands. In the past, Madagascar plateau Highlands were entirely covered by heterogeneous tropical montane forest. There is no doubt about this, given the few endangered fragments that remain, showing that the deep soils became decomposed under forest cover. How did these forests disappear over such large areas, leaving only high steppe? Like the remaining vestiges, they were very vulnerable to fire.

LAVAKA IN THE AMBATONDRAZAKA REGION

From the Longuefosse surveys made in 1915

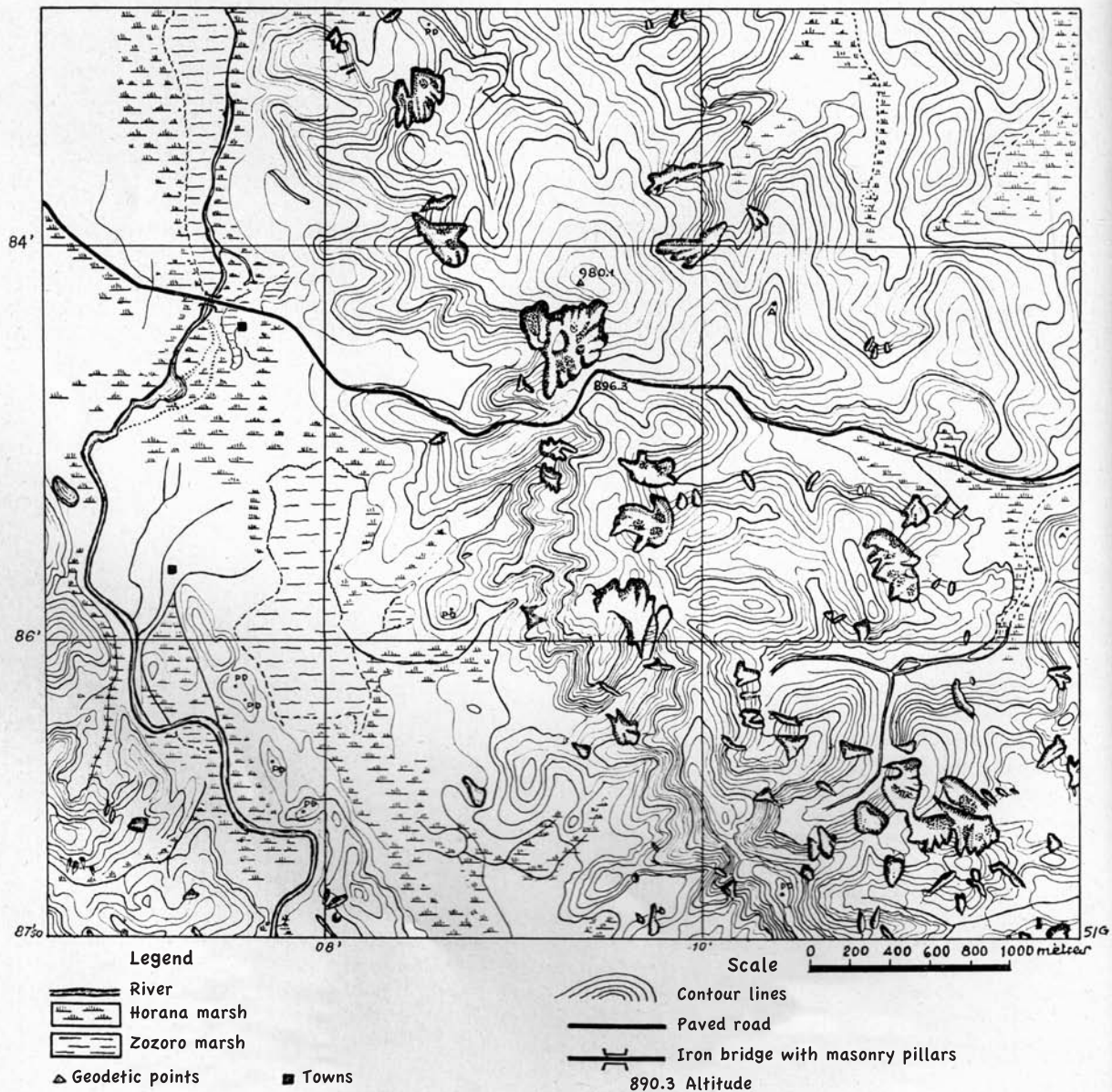


Figure 1.
Map of the *lavaka* in the Ambatondrazaka region, Madagascar.



Photo 6.

Erosion hollows at Diosso near Pointe Noire. Republic of Congo.
Photograph Le Ray, 1959.

In a recent issue of *Bois et Forêts des Tropiques* (1), M. Vignal gave a detailed description of how a vestigial forest of 1500 ha in area was destroyed in just a few days in 1955 by a fire that broke out in the neighbouring steppe and spread below the surface through roots, stumps and leaf litter. Traces of the fire can be seen everywhere along the edges of these relict forests as charred ferns and logs, but the fire also burned below the surface. Madagascar's montane forest was highly vulnerable to fire to which its plant species were not adapted, unlike many in the dense dry forests of continental Africa. The long dry season, lasting for five ecologically dry months, is favourable to forests fires. These fires were set by herdsmen to promote grass growth.

In the montane forests covering the same eroded soils in eastern Madagascar, *lavaka* rarely occur, if at all. They are observed after a forest has disappeared. The fragment of the map made by Longuefosse in 1915, in the Lake Alaotra region (Ambatondrazaka), in which he plotted all the *lavaka* in detail, clearly shows the intensity of soil degradation. From a *lavaka* close to the road, I was able to check the accuracy of the map, since its configuration had barely changed 40 years after the survey. The basin of Madagascar's largest river, the Betsiboka, is pitted with red craters; the river runs red with

their sediment, leaving it in great banks of reddish mud across the Bay of Mahajanga. This is the most spectacular manifestation of erosion in a land that was virtually stripped of all its forests in the distant past.

Madagascar is not the only country with the unenviable legacy of such spectacular *lavaka*. Between the Gabon estuary and the Congo, in a strictly coastal sediment formation known to geologists as a series of cirques, lie a number of impressively deep craters, especially near the shore around Pointe Noire. Others in Gabon, in the lowlands in the interior, are several kilometres in diameter (2). These hollows are always found in hilly areas covered in grassy steppe. Forest vegetation grows rapidly in the bottom of the hollows on the denuded sandstone clay, but never – as far as I know – up to the lips of these giant funnels.

In the Belgian Congo, in Brazil in the state of Minas Gerais, and on the sandy soils around São Paulo, I have also seen recently or long-deforested landscapes with similar erosion

(1) N° 49, September-October 1956.

(2) See the description of the "Grand Ban Ban" in my study on the forests of French Equatorial Africa and Cameroon, Bull. Sc. n° 2, STAT, May 1948.

craters. Although not as spectacularly frequent as in Madagascar, they are nevertheless signs of the disease affecting former forest lands now covered by meagre grassy steppe.

The most telling example of what erosion can do to recently deforested land is indisputably that of Tennessee's Copper Basin in the USA (figure 2). We are no longer in the tropical zone here, but because the entire history of deforestation followed by erosion in these lands is contemporary and known in detail, there is no more compelling proof of the dangers of erosion on certain deforested soils, and I therefore believe it is useful to describe it to both the advocates and opponents of forestry in France.

The story begins in 1843 in the heart of the Appalachians, with their splendid deciduous forests of oak, dogwood, sourwood and black tupelo, mixed with a few conifers (shortleaf, pitch and white pine), cloaking parallel mountain ranges separated by broad valleys (450-750 m. asl). This is the former land of the Cherokee Indians who were allied with the French. A settler at the time discovered a deposit of almost pure copper on a hillside. Mining began around 1850. The exceedingly rich copper ore was transported by mule and wagon to the railway, over great distances, 40 miles to the Cleveland (Tenn.) and 70 miles to the Dalton (Ga.). But soon, as the rich ore deposits became exhausted, it became impossible to transport the lower quality ore, which had to be processed on the spot. The first smelters began to operate at Ducktown in 1854. And so began the destruction of the surrounding forest. Enormous quantities of wood were needed to roast the ore in the open in huge piles of layered logs and ore. The forest was therefore logged over, but also, thick sulphurous smoke from the roasting ore spread across the country, destroying the vegetation. The activities of these open-air copper smelters peaked at around 1890-1895. By 1904, the entire surrounding country was completely barren. The soil, a thick layer of friable clay, was fully exposed to erosion, all the more so as rainfall in the

area is abundant and regular (1375 mm); it soon became the ravaged red desert I visited.

At the turn of the century, the mining company had to stop its open-air smelting, and because the copper content of the ore was too low, it began to manufacture sulphuric acid.

To reach the copper basin from North Carolina, the road crosses the splendid Appalachian forest until suddenly, at the Tennessee border, a vista of barren red hills appears, horribly scarred by hundreds of thousands of deep gullies. This is the Tennessee Copper Basin, where only smokestacks and pitheads can be seen in the desolate wastes of its ruined red earth. Not a bush or tree, only a few scraps of grassy steppe between the gullies. Erosion has bitten deep, sometimes down to bare rock. Such devastation might have been wrought by a giant earthquake. But the relief is not abrupt, the relative height of the hills is only 30 to 60 m. The centre of the basin lies 480 to 540 m above sea level.

The central area of the copper basin extends over 2800 hectares and is completely barren. It is surrounded by 1.5 to 3 km of grassy steppe, covering about 5800 ha, where the soil is also fissured. The forest lies away in the distance, separated from the devastated area by an ill-defined transition zone of about 12,000 ha, partly wooded and partly grassland, where forest broadleaves and pines are beginning to be re-established. Altogether, this is a huge involuntary experiment covering some 25,000 ha. The conclusions are obvious: the complete destruction of the forest was followed in less than 50 years by catastrophic erosion.

This area also offered an outstanding opportunity to study the influence of forests on rainfall, by comparing annual rainfall between the denuded area and the surrounding forests. Weather stations were set up in the three concentric zones, in forest, grassy steppe and on bare soil. Temperatures and wind speeds were also measured and reports were published on the first results. Unfortunately, these measurements were only taken for four years. They are of interest, but the measurement period was too short to be statistically significant. One day I may write a commentary, but this article on erosion is not the place to do so.

These examples will, I hope, confirm the opinions rightly held by those who believe in the anti-erosion qualities of forests and who consider that excessive deforestation, in humid tropical countries on lateritic clay soils, is liable, sooner or later, to cause severe erosion. Once erosion begins, there is actually nothing man can do to stop it, except in a few specific points and at great expense. The best policy is therefore to prevent erosion, by protecting forests on soils that are exposed to degradation by erosion and by applying anti-erosion soil conservation techniques wherever soils with obviously outstanding agricultural value are to be cultivated.

I still need to examine another objection that could cast doubt on the protective effect of forests and soils in the very long term. The erosion under forest cover that we believe to be nil or not apparent or barely significant nevertheless has, like every other type of erosion, sufficient force to model the relief over time. The problem here is on the scale of geological time and not on the scale of the present or near future. Dense humid tropical forests not only cover valleys modelled by erosion, but also plateaux and lowlands, and even very steep slopes.

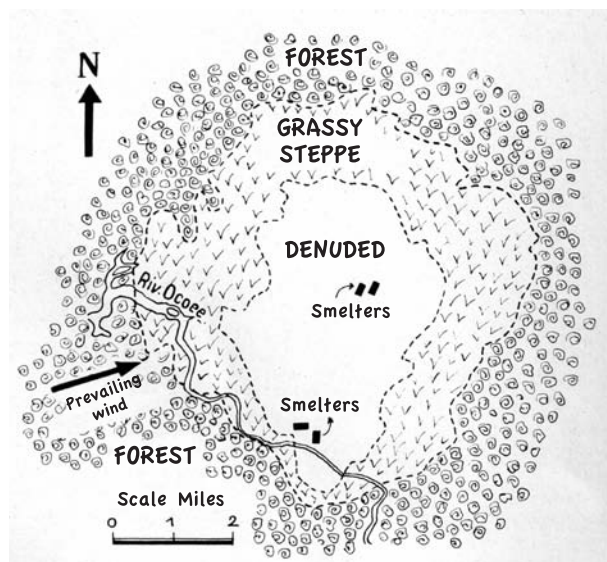


Figure 2.
Sketch of the Tennessee Copper Basin, from C.R. Hursh



Photo 7.

The denuded and eroded central area of the Tennessee Copper Basin, USA.
Photograph Letourneux, 1959.

Ancient heavily eroded peneplains that have been shaped into hummocks are entirely forested. Should we then conclude that forests established since very ancient times ultimately do not fulfil their role of stabilising the soil, but merely slow down the erosion that will occur in any case, as a general rule, or that the erosion process was intense before the forest became established on non-forested soils during periods when the climate was dry? Apart from regions with a young mountainous relief, it is in semi-arid desert regions with torrential rains in the wet season that erosion is most active. The question is obviously only of interest in terms of dynamic physical geography, but I believe it should be raised. The idea that mild erosion will in the end form the same relief as more intense erosion over a shorter time can certainly be considered on the scale of geological time. But other explanations are possible. In the event of an overall rise of the land, or a drop in sea level – both of which occurred during the Quaternary glaciations – in other words, in both cases, when the level of rivers rises compared to the level of the sea, this will trigger erosion with additional gullying that will progress upstream. If the land is forested, the trees cannot prevent the base of the slopes from eroding or the subsequent landslips. The slopes will then find a new equilibrium, which the forest will maintain. Erosion can therefore be very active

during these periods despite the forest cover, but the forest will remain in place, eventually healing the eroded soils and stabilising the slopes. I believe this hypothesis can be applied to the Quaternary morphogenesis of many very hilly areas covered in dense humid forest.

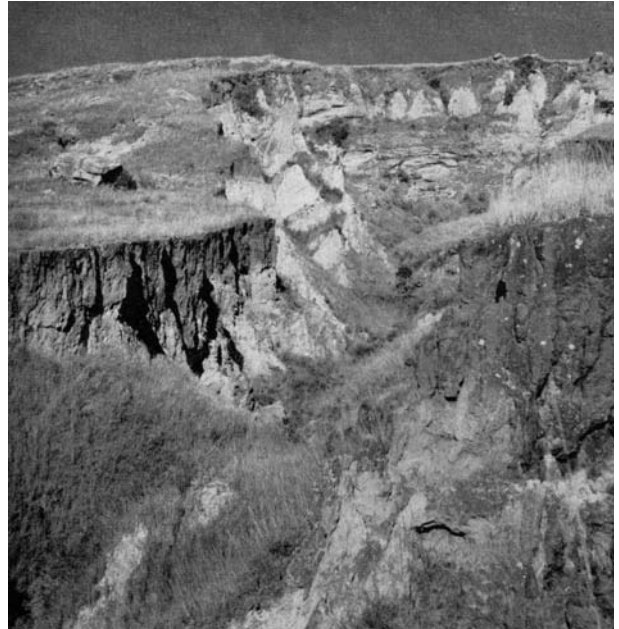
It seems obvious to me that in countries where marine regression has occurred in this way, forests could only adapt their protective effect to the new profile of the land. But in stable periods, when profiles are once more in equilibrium, forests can successfully prevent the erosion that is constantly working to level them.

A special case is that of the so-called “badlands”, where erosion has carved the naked earth into deep ravines that branch out indefinitely between sharp ridges, without leaving a single flat area. The most extraordinary I have seen, for its sheer extent and jagged relief, is the landscape around the Tsaratanana range, the highest in Madagascar, especially around the high valley of Sambirano. The climate is very wet, with rain ceasing only during a very short dry season. Some parts of the range are nevertheless entirely forested, including up to the highest peaks and even on very steep slopes; in other words, the relief below the forest cover is practically the same as in the “badlands” of the lower slopes. In the very

**Photo 8.**

An erosion crater (large *lavaka*) in a deforested hilly area around Pointe Noire, now covered in grassy steppe. Rep. of Congo.
Photograph A. Aubréville, 1959.

humid climate of eastern Madagascar, as long as there is no human intervention, the mountains and their steepest slopes are always covered by more or less stunted scrub (see Professor Humbert's descriptions of the Marojejy range). The higher slopes of the Tsaratanana range are similarly wooded. So why the "badlands" that surround them? Human settlement does not appear to be at issue. At present, there is no climate or soil-related reason that would account for these barren "badlands"; we can only assume that they were wooded in the past, as are certain mountain ranges, and draw the conclusion that, at some point in the past, the forest cover could not prevent the aggressive erosion that carved the badlands into their current barren state. There are two possible hypotheses in my opinion. Gigantic forest fires could have partly destroyed the forest cover on the lower slopes of the Tsaratanana, exposing the unprotected soil to erosion, or the badlands could be the result of contemporary tectonic land movements that profoundly modified the topography and triggered extremely active erosion that swept the soil away together with its already unstable forest cover on the steep slopes. This is the general

**Photo 9.**

From top to bottom:
A large *lavaka* eroded down to the rock and now stable. Madagascar.
Photograph A. Aubréville, 1959.

The barren Upper Sambirano range above the badlands. Madagascar.
Photograph A. Aubréville, 1959.

case that I discussed above, but with the particularity that the contemporary phenomena would have been accentuated by the high altitude of these mountains close to the sea. It is understandable that in such extreme cases, a forest would not have the slightest chance of preventing erosion; a climate characterised by torrential rains in the wet season is favourable to forests, but it is also favourable to erosion.