32. LATERITIC SOILS IN DISTINCT TROPICAL ENVIRONMENTS: Southern Sudan and Brazil

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The myth of fertility of tropical soils is giving way before abundant evidence to the contrary. Many areas of the tropics have soils which are in a more or less advanced stage of natural laterization, which occurs when the soil is leached of silica, leaving residual minerals such as iron, aluminum, manganese and nickel. These widespread laterite-prone soils are usually covered by rainforests or savannas. Most available organic matter is quickly reused by the living plants on such soils instead of forming a layer of humus. Thus, the soils are quickly impoverished when forest or other plant cover is gone.

The southern Sudan and parts of Brazil have such laterite-tending soils, and the history of development projects in these areas exposes an almost complete disregard for the limits and conditions which such areas impose for productive development. In the Sudan, the peoples living on laterite soils had developed their agriculture in harmony with the requirements of the land and practiced a shifting agriculture which allowed a long fallow period for rejuvenating and preventing the loss of soils. Development projects have restructured traditional agricultural styles, often forcibly, resulting in overuse of the land, with consequent social and agricultural disasters. Other areas are threatened by a proposed canal to regulate the flow of the White Nile and conserve its waters. Studies indicate that the intimate and delicate relationship of the surrounding lands to the annual flooding would be disrupted, with consequent permanent destruction of much of the grazing and farming land and possible serious problems for fishing.
In Brazil, many thousands of hopeful pioneers have been lured into rain-forest areas of the Amazon basin and have cleared the forest for agriculture. Little thought had been given to adapting the type of agricultural practices and crops to the nature of the soil. As a result, the soils have quickly become exhausted as the closed tree-soil-tree cycle has been destroyed. In addition, the minerals in the soil have tended to cake, producing a hard semi-desert over much of the colonized areas. The colonizers have moved yet deeper into the forest trying to make a go of agriculture, but with the same results. A small group of Japanese colonists had the insight to plant useful trees; their example offers some hope for a nondestructive and realistic development of the area.

These case studies show how crucial it is for man to recognize all the many forces operating when he tries to permanently modify the environment. The price paid in terms of an altered ecosystem must be worth what man gets in return. Survival of a small segment of humanity or a whole nation often depends upon how well we can distinguish between the real costs and real benefits of our development programs. With knowledge of the entire ecosystem involved, these costs and benefits can be better defined.

The myth of fertility of tropical soils which has been around since the days of Alexander von Humboldt is slowly giving way. The lushness of the tropical rain-forest has proven to be more apparent than real. Close examination of large portions of these forests in Africa and South America has shown them to be relics of a former climatic regime: the so-called rain-forests in many cases are subject to periods of little or no rainfall. Through clearing, construction and cultivation, man has disturbed the delicate balances of relief and biology. In many instances these interferences have led to a rapid acceleration of the process of laterization.

We shall consider two widely separated areas of the tropics, both ranging in vegetation from savanna to rain forest. The climate in these rain-forested areas is closer to the savanna type than to the true rain-forest. The selected regions are in northern South America and southern Sudan. The South American area comprises three different locations within the vast Amazon region. Included are the savannas of Roraima which stretch from the province of Rio Branco, Brazil, into Guyana. Within these savannas are the laterite uplands. The second location is the Bragantina region of the state of Pará in what was formerly true rain-forested terrain; the final one is on the Amazon plains in the territory of Guaporé, Brazil. Whereas the South American area is subdivided, the region in southern Sudan is contiguous, with separate belts ranging from the Ironstone (laterite) Plateau in the south to the savannas along the Bahr el Ghazal River (see Fig. 32-1).

The case histories in this study show many parallels. Although geomorphologists have often found comparisons of land forms valuable to their interpretation, it is not usual for these comparisons to include the man-land relationships in any great detail, nor is it usual to compare very widely separated areas.

In both northern South America and southern Sudan, the slopes tend to be more fertile than the plateau surfaces, and indigenous populations have long relied on them and the seasonally flooded lowland areas for food production. These slopes are easily eroded and must be skillfully worked.

The weathering process in these widely separated regions is one of laterization and is represented by many different stages. Laterization is the wearing down of the earth’s surface
which results in the removal of silica and other solubles from the soils and the accumulation of residual minerals such as iron, aluminum, manganese and nickel. The process in its mature stage has resulted in some of the major mineral deposits of the world and great expanses of infertile soils.

Similar facets of topography often carry the same type of vegetation, an ecosystem of landforms, soil types, and plant communities, now usually referred to as a “catena” (Eyre et al., 1953). Milne defined the catena as a regular repetition of soil profiles and vegetative cover in association with a certain topography, relief, and soil climate. His purpose was to simplify general areal mapping. His concept may be extended for our use. The existence of one member of the laterite catena, i.e., the laterite crust or laterite nodules, should lead us to suspect the presence of complementary members. We may assume general characteristics for large areas of the tropics and more readily predict the types and productivities of the soils by relating the vegetation and topography to the catenary sequence. This “catena concept” serves as a basis for evaluating the possible long-term effects of modern agricultural technology on the soils of northern South America and southern Sudan.

In the laterite catena, soils are related to relief and moisture levels in the drainage basins.
In the areas dissected by erosion the crestal surfaces are covered by a thin veneer of red soils supporting forests, often no longer true rainforest. Beneath this soil is a lateritic crust of varying thickness which, because of its resistance to erosion, gives the hills a characteristic scarp. The slopes below the cap of laterite bear lateritic soils, characteristically reddish with boulders and nodules of lateritic debris. They are forested, but when cleared they provide the most arable of these lands. These soils are also the most subject to erosion in the form of sheetwash and gullying.

At the base or “toe slope” there are interzonal soils of grayish-red color, bordering the hydromorphic or swamp soils because of the increase in soil moisture (Bunting, 1965). The plains below these slopes, i.e., the basin areas, have true hydromorphic soils consisting of black clays. They are often peaty in nature due to their high organic content.

This sequence has a variant in those areas in the South American forested plains where groundwater laterites are present below the surface. If we realize that these are the original peneplained surfaces that have not been uplifted and dissected, we may relate these laterites to the crestal laterite crusts. It must be kept in mind that neither the lateritic crusts nor the soils are end products, though the former are more durable. Both are stages in the geomorphic process itself.

The environment of this weathering process of laterization is an important variable. Climate is critical, especially the microclimate of the mass being weathered. The amount and regime of precipitation and run-off are important in laterization since this process is one of leaching, though this is an oversimplification. The natural environment includes the biota within and upon the physical mass. This organic complex is extremely important to the establishment of equilibrium through time.

The closed “plant-soil-plant” cycle of the rain-forest, which is responsible for its continuity and survival under conditions of excessive soil leaching, is not easily re-established once broken. Eyre (1963) has pointed out that deep weathering could so impoverish the soils as to deprive root structures of needed nutrients, even without human intervention in this environmental balance. Most ecologists have concluded, however, that human endeavor has been most instrumental in the retreat of the rainforests.

In northern Brazil, where the weathering process is farther advanced, massive exposed laterites are fewer. Instead the mass has weathered to laterite gravel, often formed into ridges. Where massive laterite occurs, however, it is within a few feet of the surface of the plateau, and as in Sudan, varies in thickness but is rarely less than a few feet thick. This laterite can be broken up mechanically, but since most of the readily soluble minerals have long since been removed, deposited detritus is very similar in composition to the massive laterite. In Brazil, large areas of deposition of lateritic debris are distributed by sheetwash on the lower slopes and onto the plains. Many of the plains are literally paved with aggregations of this material, locally termed “canga.”

Both of the subject regions are characterized by laterite uplands which are, however, at different stages in the weathering cycle: those of northern South America are far more dissected and broken by erosion than those of southern Sudan. There are hill remnants or Inselberge found on the plains of Rio Branco Province, Brazil, but the greatest expression of these is located across the frontiers in Guyana (Sinha, 1968). The uplands of Roraima Province, Brazil, are similar in many respects to the Ironstone Plateau of southern Sudan. The presence of shale beds below the laterite in the Brazilian profiles, however, makes for a striking difference in detail.
Southern Sudan and northern South America have many differences as well as similarities. One of the major differences is the length of the dry season. It is more humid in northern South America; however, wholesale clearing of areas has led to a lengthening of the dry season, with a lessening of the rates of precipitation (Ackermann, 1962).

**THE SOUTHERN SUDAN**

The southern Sudan is a vast, little known portion of Africa between 4° and 10° north latitude. The landscape is a very diverse one, sparsely inhabited by many tribes. Ardrey (1967) states in African Genesis that “timid people tend to live at unfashionable addresses,” and this is certainly true of the tribes scattered through the many inhospitable environments of the southern Sudan. The possible single exception has been the Azande, who suffer the trauma of the conquered conqueror. To survive, all these tribes have developed traditional methods of agriculture, hunting and fishing, which are adaptive responses to the environment.

The whole area is only sparsely inhabited by Nilotic and Central African tribes, essentially agriculturalists who have been competing among themselves for the rare arable lands. Basinski (1957) speaks of the equilibrium with the environment which has been established by these people through trial and error. “Any revolution in these methods, unless well thought out and tested, may lead to deterioration rather than improvement of agricultural output.”

The key words here are “well thought out.” We shall explore some of the instances where there has been either consideration or lack of it regarding ecological implications of development programs. In the cases where ecological studies were made, we will note whether the information was included in the implementa-

**THE JUR RIVER DISTRICT OF SOUTHERN SUDAN**

In 1863, Dr. Theodore Kotschy described the country we know today as the Jur River District around Wau as the “best of all those in the Bahr-El-Ghazal.” The country offered “great advantages to the inhabitants by its soil being somewhat elevated, ferruginous and very fertile” (Tothill, 1947, p. 35). Dr. Kotschy was describing what we now call the Ironstone Plateau, the hills of which are flat-topped and of massive laterite, which outcrops throughout the area. The ridge of this plateau now supports the all-weather road from Wau to Tonj.

On closer inspection these “very fertile” soils show evidence of widespread erosion of the thin veneer of lateritic loams which have been extensively worked by the Jur tribes in a traditional system of shifting cultivation.

All this region and more of the Ironstone Plateau is covered by savanna-type vegetation composed of a largely fire climax genre. Of the some 28% of the Ironstone Plateau country considered to be “middle level” in terms of slope, a sizable amount is not cultivatable due to distances from water supplies, shallowness of soils, outcrops of ironstone laterite, presence of stumps and tribal conflicts of ownership. Thus, we have people widely scattered on the “good sites,” which have been carefully selected and distributed in an equally careful manner by the tribes. An estimate of 10% of the plateau as suitable for cultivation may well be high.

The system of cultivation used by the Jur limited agriculture to the gentlest slopes, thus limiting the man-made erosion in the area (Eyre et al., 1953). In order to have ready access to water, these people settled in the areas of the permanent streams. The Jur River district has
many broad stream valleys which frequently become waterlogged in the flood season. Therefore, the Jur selected the middle-level slopes for their fields. They usually cropped their lands for five to eight years and then let them lie fallow for twenty to thirty years. For its rotation, this traditional system required some 17 hectares per family to permit subsistence.

In 1953, Eyre et al. recommended an elaborate ecological survey of the Jur River district, since the evidence at that time indicated that there was little agricultural land in the area which was not already incorporated in the clan system of the Jur and cultivated. Such a survey has not yet been made, in part due to the conditions of civil war which have prevailed in the region since 1956.

Resettlement programs sponsored by the government have brought havoc to the traditional systems of rotation. Instead of receiving recognition for the enormous adjustments they have made to subsist, the Jur have been summarily uprooted and forced into strip settlements, primarily to make problems of civic administration easier. This has inevitably resulted in a reduction of the productivity of the area, and an additional burden has been placed on the carrying capacity of the land.

The opening of the Jur River district by the extension of Sudan Railways, which now terminates in Wau, has served to further increase the pressures on the land. The total pressure exerted on the Jur is such that unless some reevaluation is made, the 1980’s will find a population which will be unable to sustain itself.

THE ZANDE\(^1\) SCHEME OF SOUTHERN SUDAN

The Azande\(^2\) occupy a district of the Sudan along the Nile-Congo Divide in an estimated area of 54,000 square kilometers. This Zande country is largely a tropical forested area. Zandeland is composed of the higher portions of the Ironstone Plateau, which receives a greater annual precipitation than the Jur River district to the north. It is more densely covered with bush and forest. A greater percentage of the area is covered by woodlands recently derived from rain-forest but there are still patches of true rain-forest vegetation.

McCall and Wilson (1954) summarize the region: “Zandeland is therefore not a land of milk and honey where an easy livelihood can be gained without real effort. The soils are not particularly fertile and can speedily become unproductive if great care in their cultivation is not exercised. Food or cash crop production is not easy and is limited by the difficulties of cultivating in thick bush country with poor implements, poor health and a lack of any real desire to produce more than the bare necessities of life.”

The Azande people in the Sudan represent only a portion of the entire Zande nation which crosses into the Congo and the Central African Republic. The latest population figures for the Azande give an estimate of over 180,000 people in the Sudan. As is common in Africa, the arbitrarily established boundaries have greatly disturbed the nation. Until the time of the European invasions, the power of conquest and assimilation was in the hands of the Azande. The Zande nation was then the dominant cultural influence in this part of Africa.

The freedom of the Azande has been greatly curtailed and they have been “compelled to give up their traditional mode of territorial distribution and live herded together in settlements which they abominate” (Evans-Pritchard, 1931b, p. 146). This “herding” began as far back as 1922 when the colonial administration

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\(^1\) Zande—term used for nation.

\(^2\) Azande—term used for people.
forced them into settlements along the roads in efforts to control sleeping sickness among them. The roads were built along the ridges which are relatively free from the tsetse flies which abound in the valley bottoms. The Azande have been moved three times since that first resettlement, always as a result of governmental orders. One of the main difficulties with the Zande Scheme for agricultural development has been this disregard for the residential preferences of the Azande (Wanji, personal communication).

As part of an attempt to introduce cash-cropping to the district, the Zande Scheme opened in the 1940’s with the commissioner resettling five thousand homesteads in the Yambio area. The theory was that the cotton-producing scheme would be more successful if the supervision were easier. Although the rationale for this effort was supervision of the cash crop, ultimately fifty thousand families were resettled, almost the entire population. An examination of the evidence surrounding this wholesale redistribution of people seems to show that there have been a number of misplaced good intentions involved and very little real knowledge of the ecology of the Azande.

Professor Reining (1966) found that the “Azande regarded themselves as good and industrious agriculturalists, able to choose the best land and knowing the various requirements for their various crops. They practiced what is usually referred to as shifting cultivation, involving the clearing of forests for small fields that were useful only for two to four years after which they had to be allowed to regenerate the natural vegetation.”

Reining (1966) set out to discover why the Azande became disenchanted when they had originally been enthusiastic about the development program. The scheme, which began shortly after World War II, had been evolved from the original proposals of Dr. Tothill, who surveyed the Equatorial Region in the thirties. He suggested that there might be development of agriculture, transport and internal trade and that cotton would be suitable and profitable.

Dr. Tothill followed up his original proposal to the Ministry of Agriculture with some more specific recommendations. His plans were to bring the Azande from subsistence to a state of community self-sufficiency in view of the remoteness of the area (Tothill, 1948). The enterprise called for a vertically integrated operation of cotton production with the finished cloth to be sold on the Khartoum market. Export from the region was to consist of cotton, palm oil, jute and coffee. There was to be concomitant industry for sugar, charcoal, timber and iron, all for local consumption. This scheme was very quickly emasculated by the various committees charged with its feasibility, the end result being one crop for cash—cotton. The evils of monoculture were not considered.

The cotton crop was a success for the first few years and the yields were high, but after three years of operation the production dropped off markedly. Force was then applied to attain the desired production levels and the Azande became plantation “peons” instead of the prime actors in a great drama of the advance out of the Neolithic Age. From this point on, the scheme deteriorated in terms of its original objective of self-sufficiency.

What is of special importance is what happened to man’s relationship to the land and its capability to provide for him. The cotton crop reached over eight million pounds by 1950. With cotton prices high, planting expanded well into land which ecologists had declared unsuitable. Since settlement expanded with the expanding acreages, there were homesteads on marginal lands, and these homesteads were soon without their promised cash crop. The executors of the Zande Scheme chose to ignore the information which had been provided to them by an ecological survey made prior to the institution of the Zande Scheme. Ferguson
(1954), in reviewing the available information, described Zandeland as a “problem region” lying between the equatorial forest and the savanna, with a limited potential for the production of plantation crops.

The present family holding is roughly 14 hectares, allowing for a fixed grass rotation system to develop, a form of bush fallow thought by the designers of the scheme to be sufficient for the infertile soils. Strip cropping was introduced to control erosion to which these lateritic soils are susceptible. But strip cropping was not carried out properly. The “close supervision” which was made so much of as a part of the Zande Scheme broke down and the cultivators did not maintain the ten years’ fallow required by the system. The length of the fallow period was selected as a minimum requirement. We have seen earlier that traditional systems of rotation gave twenty to thirty years for fallow, a figure arrived at empirically.

The capability of the soils to replenish themselves varies widely with the grass length and time of fallow. Ferguson (1954) notes that the soil “might not adequately maintain fertility in perpetuo or [for agriculture to] be possible at all if the population were to increase.” To regenerate soil fertility, “bush fallow must be sufficiently long to permit the growth of deep rooted species which mine the nutrients from deeper soil levels and deposit them in the form of litter on the soil surface” (Basinski, 1957).

Besides the length of fallow, there are other problems besetting production in the Zande Scheme. The increase of the cotton pests with expansion of cotton production has been difficult to deal with. Perhaps the greatest problem of all, however, is the control of bush fires. These frequently become so hot that they destroy the surface layers of the soils as well as the vegetative cover. These fires have been steadily increasing in number and extent with population growth in the area.

Changes in climate are occurring as clearings of the bush by fire and cultivation continue, resulting in a lengthening of the dry season and an increase of the “derived” savanna with permanent destruction of the forested areas. Morrison et al. (1948) describe a profile from the Yei area taken halfway down-slope on a typical hill of this Ironstone Plateau, the crest of which had the usual ironstone cap. They found a thick horizon of pea iron with intermixtures of blocks of iron. The area was channeled by termites, and the channels in turn had iron oxide around them due to fluctuations in the water table; the iron apparently precipitated in the dry season. These authors theorize that the “ironstone sheet” was once part of the subsoil and hardened when exposed by erosion. The subsequent drying out of the mass resulted in the irreversible separation of the iron.

THE AWEIL RICE PROJECT AND THE TOICHLANDS OF SOUTHERN SUDAN

Where drainage becomes seriously impeded by changes in slope and contour, the fringing and gallery forests are replaced by open grassland known as toich (Smith, N.D., p. 19). Along the frontier where the Ironstone Plateau is in abrupt contact with the Clay Plains or the “toe slope” of the catena, we find extensive toichlands. These toichlands join the Ironstone Plateau at about the 418 meter contour above sea level. Other toichlands are found along the White Nile. Morrison et al. (1948) made an ecological study of the tropical lateritic clays and vegetation of these seasonally flooded areas.

The distinguishing feature of these toichlands is that they are flooded by the overspill of the rivers and remain under water many months of the year. They are not the result of flooding from runoff in the rainy season, which would result only in intermittent water-logging. Because of their higher organic content, the toichlands are among the more fertile soils of the
southern Sudan. The usual use of the toichlands in the dry period is for cattle grazing. Cultiva-
tion of these lands is very sporadic due to the
natural reluctance on the part of the population
to accept the role of farmer and the difficulties,
especially drainage problems.

Sudan is an importer of rice and, as changes in custom have been occurring, rice consump-
tion in the country has been increasing. After
many trials, the natural conditions around
Aweil, Bahr el Ghazal Province, appeared to the
Ministry of Agriculture to be the best in
Sudan for the production of rice. The Ministry
decided on a series of pilot projects in the
Aweil area which confirmed the earlier trials.
Increases in world prices of rice became an ad-
tional spur and the Aweil Toich Rice Project
was initiated in 1954 (Hakim, 1963).

The Aweil Toich parallels the river Lol and
is about 35,000 hectares in size. By 1963, about
500 hectares were under rice cultivation. The
project has been considered successful by the
Government and there have been plans to bring
the acreage up to 4,000 hectares, sufficient to
supply the Sudanese demand for rice.

There seems to be little doubt that the area is
suited for rice production, but some of the cul-
tural practices used on the Aweil Toich bear
careful scrutiny. Mechanization has been intro-
duced to the scheme, and as yet its effect on
soil structure is unknown. Dikes have been
constructed, and more will be, to control the
water in the additional acreages. This practice
tends to limit new silting of the soils which is
one of the ways in which the soils are enriched
by a natural regeneration in necessary nutrients.

According to Hakim (1963), no land is to be
left fallow nor is there to be another crop in ro-
tation with the rice. The Senior Inspector of the
Aweil Rice Project feels that the heavy weed
growth that would result on fallow land would
make the project uneconomic. No fertilizers
whatever are used. Declining yields are blamed
on excessive flooding, which may or may not
be the critical factor. It seems logical to assume
that cultural practices such as these will inevi-
tably lead to a decline in yields. Since there will
be no regenerative silting and constant flooding
will cause a transition to swamp soils, these
lands will become unproductive.

If the purpose of the project is to improve
the standard of living of the Dinka of the area,
it has its drawbacks in that the Dinka are tradition-
ally cattle people, and these toichlands have
been their grazing lands. Few Dinka wish to be
farmers, and few will work for wages. There-
fore, the scheme is plagued with labor prob-
lems, and rice is a labor-intensive crop. Mean-
while, the people must search out new grazing
areas.

The Aweil Rice Project is neither an eco-
nomic nor a social success. The savings in for-
eign exchange are a mirage in view of costs of
production and the capital investment, which
might have been better employed elsewhere.
The costs of cultivation presently not included,
such as rotation, weeding and fertilizers, should
be added. This accounting would show the dom-
estic rice to be much more expensive than the
imported article. Under the present cultivation
plan, the life of the project will be limited, and
it will be years before these lands will again be
usable for grains, forage crops and grazing,
unless the changes brought about by diking can
be reversed.

THE JONGLEI CANAL PROJECT,
SOUTHERN SUDAN

Sir William Garstin in 1904 conceived the
idea of conserving the waters lost through
evaporation and transpiration in the Sudd of
southern Sudan. The Equatorial Nile Project,
which is the name given to the Victoria-Albert-
Jonglei Scheme, was designed not only to save
part of the water now lost but to regulate com-
pletely the flow of the Nile.
The proposed Jonglei Canal would be a series of cuts through the Sudd to a point near Malakal at the mouth of the Sobat River, a distance of 280 kilometers. Their purpose would be to increase the average flow of the White Nile while reducing the variability of the flow.

The Sudd is one of the largest and most important swamps in Africa. It is built on an inland delta with its apex at Mongalla and its base from Lake No to the Sobat River (Glennie, 1957). This is an area of about 8,000 square kilometers, which the Jonglei would delimit (Debenham, 1954). Some estimates have been made that the total area which would remain as swamp would be 1,000 square kilometers. This swamp has served for thousands of years as a natural relief valve for the lower Nile and saved Sudan and Egypt from many a disastrous flood. It is also a spawning ground for fish and affords the toichlands a natural flood irrigation, making agriculture possible.

The seasonality of the Nile in this region is its most distinguishing characteristic and is of primary importance to both man and animals between Mongalla and Malakal. The banks of the Nile are above the surrounding countryside north of Jonglei, and when the river is in flood, its waters overspill these banks and spread out over the almost flat plain. Of the 27 billion cubic meters entering at Mongalla, it has been estimated that 14 billion, more than half, are lost in the Sudd.

The Colonial Sudanese Government in 1946 was aware of the potential disruption which the project might create and, therefore, set about to determine the magnitude of the problem. They established the Jonglei Investigation Team which reported on their findings in 1954. The team was charged with determining the effects on the regime of the Nile on agriculture, grazing, fisheries, people and other problems related to engineering alternatives (Howell, 1954).

The area to be surveyed by the team stretched from Nimule on the Uganda border to Kosti, a distance of 1,625 kilometers on the Nile. The directly affected area is estimated at 300,000 square kilometers. No estimates, much less studies, have been made of the indirectly affected areas.

The team found that the first need was for further research, or that the effects of this proposed Jonglei Canal were still somewhat unknown (Barbour, 1961). They recognized the need for the “nutritive pasture” provided by the Nile and that changes in the “ecological characteristics of the flood-plaints” would result. In their report they carefully discuss potential changes in the Nile, reach by reach. In terms of actual pasture lost, estimates were given at 35% as best guesses. No real estimates could be given of fisheries lost, although an assumption was tacitly made that the fish would adapt to the complete reversal of the regime of the river in some of its reaches. On the effects on spawning, which is intimately related to flood cycles in the toich, no real prognosis could be given. An assumption was made, however, that introduced commercial fisheries could make acceptable substitution for the losses.

The Nilotic tribes of the region are “minutely related to the existing regime of the Bahr-El-Jebel and other rivers of the region” (Barbour, 1961). These people rely completely on the pasture formed in these toiches in the dry season, since the pasture away from the swamp areas which they use during the flood period becomes valueless as fodder once the rains subside. The existence of the Sudd pastures is also dependent upon the floods. Barbour (1961) again states the situation well: “If no remedial steps were taken ... the effect of the Jonglei Canal would be to destroy the livelihood of many of the Nilotes and completely alter their way of life which is intimately related to the keeping of cattle.”
These people, numbering some 700,000 in 1954, have developed a rhythm of life in tune with the floods on the Nile. They move to high ground in the rainy period of April to December and return to the riverain lands in the dry period to graze their cattle, grow a few crops, fish and hunt. The five months spent on the floodlands provide for their cattle when natural forage on the uplands becomes inedible.

The Jonglei Canal Scheme would destroy this rhythm of life by making these floodlands unavailable at just those times of year when they are most necessary. The seasonality of the river itself would be altered. The floods would cease to invade their former areas in part of the Sudd, and soil and vegetation changes would be inevitable. In other parts of the Sudd, the area would be permanently flooded and valuable lands permanently lost.

Morrice and Winder of the Investigation Team stated:

“It would be an exaggeration to say that all peoples in this area rely exclusively on animal husbandry as a source of livelihood, for rain grown crops are of great importance in their subsistence economy. Yet the production of grain crops is on the whole a precarious undertaking. In this region the mean annual rainfall is usually adequate, but its monthly distribution is extremely variable. Moreover in most parts the soil is heavy and impermeable, the slope is exceptionally small, and the drainage system often inadequate to carry away the accumulations of rainfall. In the early months of the wet season there is sometimes so little rain that the newly planted crops perish from drought, whereas later in the year they may be damaged by torrential storms or drowned by heavy flooding. The very laborious processes of crop production for these reasons are cut to a minimum and the people rarely attempt to grow more grain than would be sufficient to meet their own needs were they successful. Cattle and other animal stock are therefore of paramount importance because they provide the only reliable alternative to crop husbandry. Peoples in all parts of this area also rely on fish to supplement their diet and fish are usually available in large quantities in the pools and lagoons on the flood plain of the Nile.” (Howell, 1954).

The assumed effects on topography and climate were considered negligible in general but effective on the microscale. The cessation of seasonal inundation and, hence, seasonal anaerobic conditions will result in the oxidation of a considerable proportion of the organic matter in the soils (Howell, 1954). The investigation team therefore expected a loss of fertility in the toich soils. In all probability the actual soil type would in very few years be so altered that the toich would be obliterated in some areas and greatly reduced in others. It would be possible to predict the probable extent of this destruction by careful mapping of the present toichlands in relation to the proposed engineering design.

Soil mosaics, such as found in southern Sudan and described by Morrison et al. (1948) are related to the stage of relief and dissection of the topography. The soils may vary somewhat with the lithology but, certainly in the case of the lateritic soils, the parent rock is not the decisive factor. We can expect, therefore, to find the catenary sequences; such sequences have been described by Morrison and by the Jonglei Investigation Team. Although non-catenary sequences of soils will be found in the area, the concept will highlight the edaphic changes which will result with the implementation of the Canal Project. It should be realized that individual soil profiles will react individually.

Figure 32-2A shows a generalized picture
Figure 32-2 A. Present-day laterite catena from Southern Sudan; B. Projected laterite catena with drying-out of parts of the Sudd area in the Sudan; C. Projected laterite catena in flooded areas in Southern Sudan
topography in relation to flood levels by completely inundating certain areas and leaving others to permanently dry out, we must expect an alteration toward the “type” environment newly created. Thus, if we slide up or down the profiles as indicated, we will be able to predict the new soil type which will be developed and make some predictions as to the type of vegetation, if any, it will support. The most interesting result is that the valuable toich-lands tend to become greatly diminished whether we move the water level up or down (Fig. 32-2).

Earlier it was pointed out that these lands, which are so very important to the local economies, are the result of seasonal flooding, not natural runoff. If these soils are permanently submerged they will become lake or swamp sediments. From an inter-zonal soil they will be transformed into true hydromorphs. Permanently dried out, they will tend to move toward the type classification “impeded drainage,” such as is usually found at the base (toe slope) of these catenae. Either possibility makes them unavailable for cultivation, forage, hunting or fishing. We are perhaps able to estimate the loss in all these activities with the exception of the fisheries. Whether the lost spawning grounds or the reversal of the time of flood will result in permanent damage is as yet unknown; but it is an eventuality which must be recognized.

THE PROPOSED BOA VISTA DEVELOPMENT PROJECT, BRAZIL

Boa Vista is located on the Rio Branco River which drains the territory of Roraima, Brazil. The Rio Branco flows south to join the Rio Negro, which is a major arm of the Amazon. The region is part of a vast savanna of 54,000 square kilometers extending from Brazil into Guyana.

Laterite in this savanna is in a belt parallel to the Kanuku Mountains located across the frontier in Guyana (Sinha, 1968). These mountains have a foothill region composed of laterite uplands which trend northeast to southwest and which are strikingly similar to those described for the Ironstone Plateau of southern Sudan. These uplands are primarily on the Guyana side of the border. The “Baixadas” or toichlands equivalents are to be found along the many stream courses. The dunes and swamps occupy an intermediate position between the laterite uplands and the plains (Sinha, 1968).

Guerra (1957) found extensive areas of laterite on the peneplain of Rio Branco. This laterite is absent only in the northeastern part of the territory of Roraima where there is a large structural depression from which the laterite has been removed. The laterites of the savannaland surface are largely detrital, but massive laterite has been found extensively ranging from a few inches to many feet. The profile at Boa Vista shows the lateritic gravel to be 33 feet thick.

Sinha (1968) found that the laterite on the Guyana side was even more widespread. Until further explorations of the soils of the Rio Branco savanna are made, its true extent in Brazil will not be known.

Throughout the region we have laterite catenae, related to topography, bearing a distinctive vegetative cover. The repetitive pattern differs in detail from that of southern Sudan. These differences appear directly related to their different geomorphic histories. “It is clear that once a laterite deposit is exposed, it may be broken down mechanically and transported mechanically and in solution, but the minerals are likely to reappear elsewhere in the same area as secondary laterites” (Sinha, 1968). The exact origin of the laterite is an academic question for
a farmer in these areas. He cares little whether they are in situ or transported in the geologic sense. In all probability these laterites of the savanna of Rio Branco are both, the detrital portion originating in the Kanaku Mountains and their foothills, the laterite uplands.

The Indian farmer has carefully selected his small cultivated areas to take maximum advantage of recent alluviums along the riverbanks. He has drainage problems but on the whole has managed to utilize well the available arable land. His system of moving his plot after a year or two of production and allowing a fallow period has made it possible for him to continue marginal agriculture. The limited area which would be suitable for agriculture makes the further opening up of the plains to agricultural development hazardous. Yet the “pioneer” is encouraged, though the lessons of colonial agriculture in laterite zones have been hard indeed.

THE BRAGANTINA COLONIES

If you take the railroad from Belém in the state of Pará, Brazil, and travel the 228 kilometers eastward along the Amazon mouth, you pass through a region which is being progressively transformed into a semi-desert by man. The process began in 1883 with the penetration of the railroad into what was then true Amazon rain-forest (Ackermann, 1962). In the first thirty years thirty thousand colonists settled this region, using slash-and-burn techniques of land preparation.

People moved in from southern Europe and northeast Brazil to farm what they thought were fertile soils. Disheartened by their inability to sustain themselves, these settlers moved farther and farther north and south away from the railway line, clearing more and more land.

This part of Brazil is a lowland, presumably an ancient peneplain (Ackermann, 1962). The region is dissected by many rivers and streams draining east and north. The landscape today will do nothing to excite the naturalist. The Amazon rainforest has been replaced by scrub, mute “testimony to the destructive activity of man under the pretext of colonization” (Gourou, 1961). Everywhere, gullying has transformed the even plain into an undulating one. The whole regime of the rivers has been altered, and many streams have been reduced to trickles in the dry season.

“Progress” has come with the building of towns and cities in the region populated by people deserting the deteriorating farms. Here urban areas with all the attendant difficulties have resulted, due primarily to the shortsightedness of planners.

The Government established many colonies in Bragantina. No studies were made, but colonists were encouraged to move in. The forest was destroyed and subsistence farms were established, to be later abandoned due to the infertility of the soils; in place of the forest the brushland grew. “With successive clearing and burning, the land was exhausted up to the actual point where the Region is being transformed into a semi-desert forming stony pavements” (Ackermann, 1962).

Extensive areas are now covered by the “Pará gres,” as it is called in the region. This material is none other than lateritic nodules of limonite. The desiccation of the area which has a pronounced dry season has carried iron and aluminum by means of capillarity to the surface, where they have been precipitated. Although laterization in the Bragantina region has not yet reached that of the states of Maranhão and Amapá where it is mined as ore, it has progressed greatly. These areas are more useful for road construction than for agriculture.

Today this region with one of the largest populations in the state of Pará is unable to feed itself. The only crops which are still being grown are native plants utilized for fibers.
Yields are diminishing yearly, and some of the lands devoted to this culture have ceased to produce.

The laterization process here has taken about fifty to seventy years to produce a semi-desert. No records have been kept for us to actually pinpoint the time, which for a given acreage is surely shorter.

**The President Dutra (IATA) Colony, Brazil**

In Guaporé uplands capped with laterite again are part of a peneplain which was uplifted and dissected. Geologists still dispute the extent of the peneplain. The landscape is dotted by eroded uplands cut by the Guaporé, Madeira, and Mamoré rivers and a multiplicity of tributaries. The region stretches from these foothills of the Plateaus, or “Chapadas” as they are called in Guaporé, to the confluence of the Madeira and Mamoré rivers at Porto Velho (see Fig. 32-3). The area was opened up originally in the early part of the twentieth century by the famous Amazon rubber boom. A railroad was constructed in the dense Amazon Forest between the present-day towns of Porto Velho and Guajará-Mirim, a distance of 366 kilometers. When the railroad, which “cost a life a tie,” was completed, the boom was over, but for better or for worse this inhospitable area was opened up.

The city of Porto Velho differs in elevations with the upper part capped in laterite up to 17 feet thick (Guerra Teixera, 1953). We have again a series of laterite catenae and the complications of transported and *in situ* laterites.

At the confluence of the Madeira and Madre de Dios rivers (see map in Fig. 32-3) an agricultural colony was established in the late 1940’s. President Dutra Colony was to be the new homeland for some of those forced off the land in Bragantina, Pará.

Here the forest is also true Amazon rain forest. The climate in this region is true humid tropical. “Laterization is in an advanced state, in some areas almost in the final stage” (Guerra Teixera, 1953). The terminology “final stage” may be deceptive but is extremely apt from the colonist’s point of view. Guerra Teixera is referring to the drying out and hardening of the mineral residues into a rock formation of aggregated laterite.

The colonists found the story of Bragantina repeated. Traditional agriculture did not provide them with even a subsistence living. The fertility of the so-called soils was exhausted within three years and had to be left to the bush. The life of an individual *roca* or individual cultivation was even less than the colonist was used to in Pará. The toil to survive was unbelievable. Fields were cultivated among blocks of laterite. The laterite was aggregated on the surface or just below it, and the farmer had simply exposed it. The soils he worked compacted to rock in five years. They were
really not soils at all but residual minerals mixed with the organic materials of the forest. When these were exhausted or leached by the heavy rains, the settler was left with only the residue.

**THE JAPANESE COLONY AT TOMÉ AÇU**

A small ray of hope for man’s adaptation to the laterite zones can be found in the successful Japanese colony at Tomé Açu on the River Acará-Mirim south of Bragantina. These people replaced the forest species with tree crops, particularly the black pepper. Their success both in productivity and soil conservation is beginning to have a salutary effect on the Bragantina region itself, where their example is being emulated today. Some efforts to produce other tree crops in the region, among them rubber trees, are beginning to prosper. Much of the region has been ruined, however, and must wait until structural rejuvenation for the surface laterites to be eroded off or until technology finds a way to remove them mechanically.

**CONCLUSION**

We note that there are areas which are more fertile than others. We can generally relate these to relief as we could in southern Sudan. In the vicinity of Iata and the city of Porto Velho at the confluence of the Madeira-Mamoré the soil mantle is thicker on the slope sides. When profiles are cut, we find, as we did at Yei in Sudan, that the laterites are exposed beneath the mantle; thus these highly erodible slope sides require great care for their preservation. The excessive leaching in Guaporé makes their usefulness limited since the nutrients were mere remnants of the forest which was removed and these are quickly carried off in solution.

Camargo (1942) called the “great error” of colonizing these lands an action which could only result in their devastation and the loss of valuable forests which took centuries to develop.

When we consider the speed with which modern technology and population pressures can institute enormous changes in the environment, it is necessary to consider the consequences of these changes. Adjustments in the balance of nature made necessary through man-made intrusions in the environment have in the past been rendered possible by the allotment of much time. Thus, the impact of these changes has been spread over time and the curve covering the positive and negative effects smoothed out. Today, we make these changes rapidly and we compound them. We look with pride to the positive aspects and consider man’s industry rewarded, but too often we ignore the negative ones.

Man will continue to modify his environment, but if these modifications are to have lasting value, he must recognize the forces operating. The price paid in terms of an altered ecosystem must be worth what we get in return. Survival of a small segment of humanity or a nation depends upon how well we can distinguish between real costs and real benefits of our development programs. With knowledge of the entire ecosystem involved, these costs and benefits can be better defined for the projects and programs developed.

Whether mankind will be able to utilize these tremendous laterite areas depends on how well we have learned our lessons. The deceptiveness of many of the soil mantles hiding laterites beneath both rain-forest and savanna needs to be understood. The distribution of late-rite catenae should be studied in detail with the view to using what appears to be a useful tool in locating those areas most suitable for productivity.

Some of these case histories of southern Sudan and northern South America indicate a recognition of the role of ecology in planning, insufficient though it is. In the case of the Jonglei
Canal Scheme, the investigation team actually performed a Herculean task when we consider the vastness of the affected area, the costs involved, the limited time, and the bureaucratic difficulties. Other case histories show ignorance of ecological implications. Still others sadden us when we consider the almost criminal negligence.

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The myth of the fertility of tropical soils is giving way to vast evidence to the contrary. Many areas of the tropics have soils that are in a more or less advanced stage of natural laterization, the wearing down of the earth’s surface, which results in the removal of silica and other solubles from the soil and the accumulation of residual minerals such as iron, aluminum, manganese, and nickel. This process has resulted in some of the major mineral deposits of the world.

These widespread laterite-prone soils are usually covered by rain forests or savannas. Due to continuously high temperatures and often heavy rainfall, most available organic matter on such soils is quickly reused by living plants instead of forming a layer of humus. Thus, soils are quickly impoverished when forest or other plant cover is replaced by cash cropping “development.”

In her paper **LATERITIC SOILS IN DISTINCT TROPICAL ENVIRONMENTS** (Page 591), Mary McNeil illustrates the dangers of altering tropical ecosystems, citing case histories from the southern Sudan and Brazil. The photographs show laterite formations in Brazil. Photo 32-1: A laterite formation over a possible pre-Cambrian horizon found along the Maranhao road, Brazil. The elongated blocks of laterite were apparently formed by precipitation of the iron hydroxides from ascending waters. Photo 32-2: A laterite formation overlying pre-Cambrian filites on the Para Maranhao road. Photo 32-3: This cut on the Para side of the Belem-Brasilia road shows the undulating topography of the area. Laterite may be observed in the upper strata overlying the Barreiras clays, which here appear without their characteristic grooves. The surface laterite resulted from infiltration of iron oxides and surface phenomena. (Photographs courtesy of Dr. Fritz Ackermann.)