CONFERENCE ON THE
ECOLOGICAL ASPECTS OF
INTERNATIONAL DEVELOPMENT
AIRLIE HOUSE, WARRENTON, VA. DEC. 9-11, 1968

LATERITIC SOILS IN DISTINCT TROPICAL ENVIRONMENTS:

SOUTHERN SUDAN AND BRAZIL

Mary McNeil
Development Geologist
Lockheed Aircraft International

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The myth of fertility of tropical soils which has been around since the days of Alexander von Humboldt, is slowly giving way to realism. The lushness of the tropical rainforest 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 relicts of a former climatic regime: For the so-called rainforests in many cases are subject to periods of little or no rainfall.

It is those areas of the tropics which have pronounced seasons of drought that are thought to have the most extensive development of massive laterite (Eyre, 1963). For those areas where the laterite crusts are capping old uplifted peneplained surfaces as in the Savannas of Rio Branco in Brazil, the forested Ironstone Plateau of Sudan and the laterite uplands of Guyana are closer to Aw or Savanna on the Köppen scale than rainforest, Af.

It seems evident that we have in these two distant geographic areas many stages of laterization. We can better understand both the process and its meaning to agricultural development if we compare them. We can learn much from earlier efforts to develop these areas and evaluate some of the potential projects.

Similar relief facets usually carry the same type of vegetation, an ecosystem of land-forms, soil types and plant communities, now usually referred to as a "catena" (Eyre, et al 1953). This "catena concept" serves

as basis to evaluate the possible long term effects on the soils of Northern South America and Southern Sudan. Changes which have and will result in the soils and their plant communities through time as a result of alterations of the ecosystem are offered here for serious contemplation by development planners.

Milne (1935) who developed the concept, 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 simply develop a method to make general areal mapping simpler. His concept may be extended for our purposes. 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, in advance, assume general characteristics for large areas of the tropics and can more rapidly predict the types and productivities of the soils by relating the vegetation and topography to the catenary sequence.

In the Laterite Catenae, soils are related to relief and moisture levels in the drainage basins generally in the following way. In the dissected areas the crests 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. These soils are the most subject to erosion in the form of sheetwash and gullying. They are forested but when cleared do provide the most arable of these lands. For any long term productivity they require skillful management.

The "toe slope" has interzonal soils of greyish-red color and are bordering the hydromorphic as a result of the increase in soil moisture (Bunting 1965). The plains below these slopes or the basin areas have true hydromorphic soils consisting of black clays. These clays are flooded at least part of the year. Swamp clays become peaty in nature due to their high organic content.

This sequence has a variant in those areas of South America which are part of the 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 can relate these laterites to the crestal crusts.

Laterization which gives rise to these conditions is a weathering process resulting in the desilification of soils and the accumulation of residual minerals such as iron, aluminum, manganese and nickel. The process has resulted in some of the major mineral deposits of the world, but also results in infertile soils.

The environment of weathering is another important variable. Climate is critical, especially the micro-climate of the mass being weathered. In laterization the amount and regime of precipitation and runoff are critical since this process uses leaching of the soils to achieve desilification. The natural environment includes the biota both within and upon the mass. This organic complex is extremely important to the establishment of equilibrium through time.

Each of our subject areas can be subdivided generally into environmental regions. Both 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 however 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.

The lateritic soils of Southern Sudan, Brazil, and Guyana have many similarities as well as differences. One of the major differences is the length of the 'dry' season. It is generally more humid in Northern Brazil, however, wholesale clearing of areas has led to a lengthening of the dry season generally, with a lessening of the rates (Ackerman, 1962).

The savannahlands which frequently fringe the rainforests, and in many cases have replaced them, often suffer periods of drought. Many authorities refer to these savannahs as "derived", and although this concept is subject to much controversy, the evidence in favor of it is mounting.

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) in African Genesis states 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. All these tribes to survive have developed traditional methods of agriculture, hunting and fishing which are an adaptive response 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. As one moves farther south, there are fewer cattle due to the incidence of biting flies. 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 a consideration or lack of same regarding ecological implications of development programs. In the cases where there were ecological studies made, we will note whether the information was included in the implementation phases and what were the results to date. We will also consider some of the programs still envisioned for the area.

The Jur River District

In 1863, Dr. Theodore Kotschy described the country we know today as the Jur River District around Wau as the "best of all those of the Bahr-El-Ghazal". The country offering "great advantages to the inhabitants by its soil being somewhat elevated, ferrugious 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 in a traditional system of shifting cultivation.

The system used by the Jur limits 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 settle in the areas of the permanent streams. The Jur River District has many broad stream valleys which frequently become water-logged in the flood season. Therefore, the Jur select the middle level slopes for

their fields. They usually crop their lands for five to eight years and then let them lie fallow for twenty to thirty years. This traditional system requires for its rotation some 40 feddans* per family, to permit subsistence.

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. An estimate of 10% of the Plateau as suitable for cultivation may well be high.

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

* 1 feddan = 1.038 acres

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.

The word Jur is Dinka for "foreigner" and Evans Pritchard (1931a) has referred to these tribes as giving the impression of a "routed army". The causes for this appearance, which has not changed to date, can be found in the pressures in the past century from Arab slave traders and the Zande invasions from the south. Since these times the Jur have suffered further economic and social harassment from their neighbors the Dinka, with whom they have a symbiotic relationship with regard to cattle. In addition, they have been subjected to arbitrary decisions of the government both Colonial and Republican. Some of this harassment has been in the nature of programs supposedly organized to benefit the tribes. In the case of these programs, the difficulty comes from too little respect for the traditional system developed by the Jur, and too little has been done to relate programs to the environment. The opening up of the Jur River District by the advent of 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 re-evaluation is made the 1980's will find a population which will be unable to sustain itself.

The Zande* Scheme

The Azande+ occupy a district of the Sudan along the Nile-Congo Divide in an area estimated to be 21,000 square miles. This Zande country is largely a tropical forested area. McCall and Wilson (1953) summarize the region thus: "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."

This 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. The greater percentage of the area is covered by woodlands recently derived from rain forest but there are still patches of true rain forest vegetation.

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. 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 latest population figures for

* Zande -- term used for nation

+ Azande -- term used for people

the Azande give an estimate of over 180,000 people in the Sudan.

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 forced them into settlements along the roads in efforts to control sleeping sickness among them. The roads were built along the ridges where it is relatively free from 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, 1967).

As part of the attempt to introduce cash cropping to the District, the Zande Scheme opened with the Commissioner resettling 5,000 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 50,000 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.

Reining (1966) in his research set out to discover why, when the Azande had originally been enthusiastic about the development program, they had become disenchanted. The Scheme which began shortly after World War II had been evolved from the original proposals of Dr. Tothill who surveyed the Equatorial Region. He suggested that there might be a 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, 1939). 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 in favor of the 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 in three years of operation the production dropped off markedly. Force was 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 objective.

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."

From the point of view of this discussion what is of special importance is what happened in terms of 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, the expansion went well into land which ecologists had declared unsuitable. Since settlement had gone ahead with the expanded acreages, there were homesteads on the 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, since an ecological survey had been 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, and that it had a limited potential for the production of plantation crops.

The present family holding is roughly 30 feddans allowing for a fixed grass rotation system to develop, a form of bush fallow thought

to be sufficient for the infertile soils. Strip cropping has been introduced to control erosion to which these lateritic soils are susceptible. 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. Nor did they properly strip crop. The length of the fallow period was selected as a minimum requirement. We have seen earlier that traditional systems of rotation gave 20 to 30 years for fallow, an empirically arrived at figure.

With regard to the whole problem of length of grass and bush fallow, there is a wide variation in the capability of the soils to replenish themselves. Ferguson (1954) notes that "they might not adequately maintain fertility in perpetuo or 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.

Changes in climate are occurring in the area as clearings of the bush continue from fire and cultivation resulting in a lengthening of the dry season, and a furtherance of the 'derived' savanna with permanent destruction of the forested areas. Morrison et al (1948) describes a profile from the Yei area taken halfway downslope on a typical hill of this Ironstone Plateau, the crest of which had the usual ironstone cap. The 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 precipitating 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 Toichlands

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 "toeslope" of the catena, we find extensive toichlands. These toichlands join the Ironstone Plateau at about the 418 meter contour above sealevel. 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 over-spill 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 periodic water-logging. The natural use of the toichlands in the dry period is as a grazing area for cattle. Cultivation of these lands is a very sporadic affair due to the natural reluctance on the part of the population to accept the role of farmer and the difficulties, especially drainage problems. Because of their higher organic content, they are among the more fertile soils of the Southern Sudan.

The natural conditions around Aweil, Bahr-El-Ghazal Province, appeared to the Ministry of Agriculture, after many trials to be the best in Sudan for the production of rice. Sudan is an importer of rice and as changes in custom have been occurring, rice consumption in the country has been increasing. 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 additional spur and the Aweil Toich Rice Project was initiated in 1954 (Hakim, 1963).

The Aweil Toich parallels the River Lol and is about 70,000 feddans in size. By 1963 about 1,000 feddans were under rice cultivation. The project has been considered successful by the Government and there have been plans to bring the feddanage up to 8,000, sufficient to supply the Sudanese demand for rice.

There seems to be little doubt that the area is suited to rice production but some of the cultural practices used on the Aweil Toich

bear careful scrutiny. Mechanization has been introduced to the scheme and as yet the effect on soil structure is unknown. Dykes have been constructed, and more will be, to control the water in the additional feddans. This practice tends to limit new silting of the soils which is one of the ways in which the natural regeneration takes place and the soils are enriched in necessary nutrients.

According to Hakim (1963), no land is to be left fallow nor is there to be another crop in rotation 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 have been described will inevitably lead to a decline in yields.

If the purpose of the Project is to improve the standards of living of the Dinka of the area, it has its drawbacks in that the Dinka are traditionally cattle people and these toichlands have been their grazing lands. Few Dinka wish to be farmers, and few will work for wages, therefore the scheme is plagued with labor problems, and rice is a labor intensive crop. Meanwhile, the people must search out new grazing areas.

The Aweil Rice Project cannot be said to be either an economic or a social success. The savings in Foreign Exchange are on the order of a mirage in view of the costs of production and the capital investment which might have been better employed elsewhere. The costs

of cultivation not included, such as rotation, weeding, and fertilizers, should be added and this would make the price of the rice much more expensive than the imported article. Under the present cultural plan, the life of the project must be limited and it will be years before these lands would again be useable for grains, forage crops and grazing unless the changes brought about by dyking could be reversed. This area could with proper technology produce a rice crop if Sudan planners wish to pay a premium to do so. These toichlands are also in jeopardy from the Jonglie Canal Project.

The Jonglei Canal Project

In February of 1967 a series of talks began in Dar-Es-Salaam, Tanzania to discuss the Equatorial Lakes Project aimed at the conservation of Nile Waters. The significance of these meetings to the nations involved cannot be underestimated. Efforts to control the Nile have already been undertaken and others are projected. In extent they range from the East African Lakes to the Delta in Egypt. The latest and most spectacular of these efforts is the Egyptian High Dam at Aswan.

While this dam became a household word around the world because of the archaeological sites which it disturbed, comparatively little thought has been given to the long range ecological changes which also have been initiated. The ecological alterations which result from changes in the regime of this famous river should be viewed objectively and as a whole. The dam located at Jebel Aulia in the Sudan has appreciably altered the White Nile and the effects are felt up stream as far as Melut, three hundred kilometers away (Wright, 1949). The

benefits of this dam were obvious to all in that a control of the White Nile's flow while the Blue Nile was in spate provided a more desirable year round flow in the main Nile. But the costs in terms of the ecological effects were not greatly considered, though they included such economic losses as terrain inundated, spawning grounds for fish lost, and displacement of human population. The population affected was relatively small and not considered. No consideration of soil changes was made or has been made. The Jonglei Canal Project would so alter the soil moisture levels as to convert them into true hydromorphs or true lateritic soils, instead of intra-zonal members of the Laterite Catena. Decisions such as this tend to be made considering only the assumed benefits.

When the High Dam at Aswan was decided upon in 1960 it was a political decision affected by Cold War Conflict (Lebon, 1961). The choice was one of priority and made between the High Dam and the Jonglei Project. This decision represented a reversion to main Nile storage and represented an expression of Egypt's fear that control of the Nile would be out of her hands. Thus, in spite of the disadvantages inherent in the High Dam at Aswan, Egypt went ahead with the project. The problems included construction over 200 meters of unconsolidated valley fill, losses through evaporation amounting to as much per year as had been stored in the former Aswan Dam Lake, or ten billion cubic meters per year, and enormous costs not only for construction but flooded farms and indemnization to the Sudanese for the destruction of the Wadi Halfa area (Barbour, 1961).

The needs of both Sudan and Egypt for irrigation water had been estimated at 125 billion cubic meters per year. We have seen that the three billion stored at the Jebel Aulia Reservoir had affected the White Nile upstream a tremendous distance due to the relative lack of slope in this Port of Sudan. It would therefore appear to be impossible to store the needed water in the Sudan. For this reason Lake Victoria, between the Rift Valley walls in Uganda was chosen. This choice was also based upon the fact that over Lake Victoria itself, precipitation and evaporation are almost equal and outflow over Owen Falls is virtually equal to the stream inflow into the Lake. As we can see over-year storage in this type of evaporation regime is much more tenable than that of the High Dam.

In accordance with these designs for Nile control, Owen Dam was completed in 1954 and is a source of hydro-electric power for Uganda. Its function as an over-year reservoir for the lower Nile is not yet a fact. The effectiveness of this reservoir for this purpose depends upon the construction in the Sudan of the Jonglei Canal. The Canal would make an effective channel through the swamps now bordering the Bahr-El-Jebel, as the Nile channel through the Southern Sudan is called.

Sir William Garstin in 1904 conceived of 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 to not only save part of the water now lost but to regulate completely 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 many a disastrous flood. It is also a spawning ground for fish and affords in 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 are lost in the Sudd, more than half.

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; on grazing; on fisheries; and on people together with 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 findings of the Team was first of all the need for further research, or rather 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 floodplains" would result. In their report they carefully discuss potential changes reach by reach of the Nile. In terms of actual pasture lost estimates were given at 35% as rather best guesses. In terms of fisheries lost no real estimates could be given 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 again states the situation well, "If no remedial steps were taken therefore 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". (ibid, 1961).

These people numbering some 700,000 in 1954 have developed a rhythm 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 become inedible.

The Jonglei Canal Scheme would destroy this rhythm of life because it would make 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 its 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."

The assumed effects on topography and climate were considered negligible in general but effective on the micro-scale. 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, p. 1i). 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 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 and 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 2 shows a generalized picture of the catena to be found where Ironstone Plateau meets the flood plains. If we vary 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 can make some predictions as to the type of vegetation it will support, if any. The most interesting

result is that the Toich lands tend to become greatly diminished whether we move the water level up or down.

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 interzonal 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 (toeslope) of these catenae. Either eventuality makes them unavailable from the point of view of cultivation, forage, hunting or fishing. We are able to perhaps estimate the loss in all these activities with the exception of the fisheries. Whether the spawning grounds lost or the reversal of the time of flood will result in permanent damage is as yet unknown, but is an eventuality which must be recognized.

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In both areas, 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 lowlands areas for food production. They are easily eroded and must be skillfully worked.

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.

The closed "plant-soil-plant" cycle of the rainforest which is responsible for its continuity 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 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.

It must be kept in mind that soil formation is not an end product, neither are the lateritic crusts, though their durability is far greater. Both are stages in the geomorphic process of weathering going on at the surface of the earth.

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 we have large areas of deposition of lateritic debris distributed by sheetwash on the lower slopes and onto the plains. Many of the plains are literally paved with aggregations of this material.

Boa Vista Region

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 21,000 square miles extending from Brazil into Guyana.

Laterite in this savanna is in a belt parallel to the Kanuku Mountains which are located across the frontier in Guyana. (Sinha, 1968). These mountains have a foothill region composed of laterite uplands which trend NE - SW 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. (Oliveira, 1939).

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 the true extent in Brazil will not be known.

Throughout the region we have laterite catenae related to morphology and 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 particular origin of the laterite is academic 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 river-banks. 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 to continue his marginal agriculture. The limited area which would be suitable for agriculture makes the 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.

Bragantina Region, Brazil

If you take the railroad from Belem do 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 about eighty-five years ago with the penetration of the railroad into what was then true Amazon Hylea (Ackermann, 1962). In the first thirty years 30,000 colonits 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 with their inability to sustain themselves, these settlers moved farther and farther north and south away from the railway line, clearing more and more land. The area has since been crossed by roads from Belem.

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."

Everywhere, gullying has caused the even plain to become an undulating one. The whole regime of the rivers has been altered, 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 short-sightedness 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 forthwith abandoned due to the infertility of the soils and 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 dessication of the area which has a pronounced dry season or Aw climate has through capilarity carried iron and aluminum 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. They are more useful, however, for road construction than as agricultural lands.

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 50 to 70 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.

Porto Velho Region

In Guaporé we have uplands capped with laterite which again are part of a peneplain which was uplifted and dissected. Geologists are still in dispute as to the extent of the peneplain.

The eroded uplands appear in Guaporé, Madeira, and Mamoré Rivers and their multiplicity of tributaries.

The Region stretches from these foothills of the Plateaus or Chapadas as they are called in Guapore to the confluence of the Madeira and Mamoré Rivers at Porto Velho. 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 Hylea 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 finally completed, the boom was over but for better or for worse, this inhospitable area was opened up.

The city of Porto Velho has differing elevations with the upper part capped in laterite up to 17 feet thick (Guerra, 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 Madrede Dios Rivers (see map) an agricultural colony was established in the late 1940's. President Dutra Colony (IATA) was to be the new homeland for some of those forced off the land in Bragantina, Pará.

Here the forest is also Amazon Hylea or true Amazon rainforest. The climate in this region is true humid tropical or Af on the Köppen classification. And here "laterization is in an advanced state, in some areas almost in the final stage." (Guerra, 1953). The terminology "final stage" may be deceptive but if viewed by the colonist extremely apt. Guerra is referring to the drying out and hardening of the mineral residues into a rock formation of aggregated laterite.

The colonists found that the story of Bragantina was repeated. Traditional agriculture did not provide them with even a bare living. The fertility of the so-called soils was exhausted within three years and had to be left to the brush. Here if anything the life of an individual "roça" was even less than the colonist was used to in Pará. The toil to survive was unbelievable. His fields were cultivated among blocks of laterite. Here the laterite has aggregated on the surface or just below it and he has simply exposed it. The soils he was working 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 he was left with the residue only.

We note that there are areas which are more fertile than others and generally we can 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 this tends to be borne out in that the soil mantle is thicker on the slope sides. When profiles are cut we find as we did at Yei in Sudan, that the laterities are exposed beneath the mantle, thus these highly erodable slope sides require great care for their preservation. The excessive leaching in Guaporé makes their usefulness limited also since the nutrients were mere remnants of the forest which was removed and these are quickly carried off in solution.

Camargo (1942) called attention to the "great error" of colonizing lands which could only result in their devastation and the loss of valuable forests which took centuries to develop.

"The building of a Railway, the construction of a dam, the installation of a drainage system, and the application of fertilizers may be looked upon as changes imposed on the topography, climate and geology of a region (Greene, H. 1939).

When we consider the speed with which modern technology and population pressures can institute enormous changes in the environment, it behooves us to consider the consequences of these changes. Adjustments in the balance of nature made necessary through man-made

intrusions on 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 ignore the negative ones.

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 an Herculean task when we consider the vastness of the affected area, the costs involved, the limited time and the bureaucratic difficulties. Others of these case histories show ignorance of the ecological implications. Still others sadden us when we consider almost criminal negligence.

Man will continue to modify his environment, but if these modifications are to have lasting value, he must recognize all 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 defined, and projects and programs developed.

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 today their example is being emulated. Some efforts to produce other tree crops in the region are beginning to prosper, among them rubber trees. Much of the region has been ruined, however, and must await structural rejuvenation for the surface laterites to be eroded off or until technology finds a way to mechanically remove them.

Whether mankind will be able to utilize these tremendous laterite areas depends on how well we have learned our lessons from experience. The deceptiveness of many of the soil mantles hiding laterites both beneath rainforest and savanna needs to be understood.

The distribution of Laterite 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. Planners should be extremely careful about encouraging "pioneers" in these areas. Where populations are already dense, efforts to utilize the lands rationally should be made with the assistance of technology and the growing fund of knowledge concerning these ecosystems.

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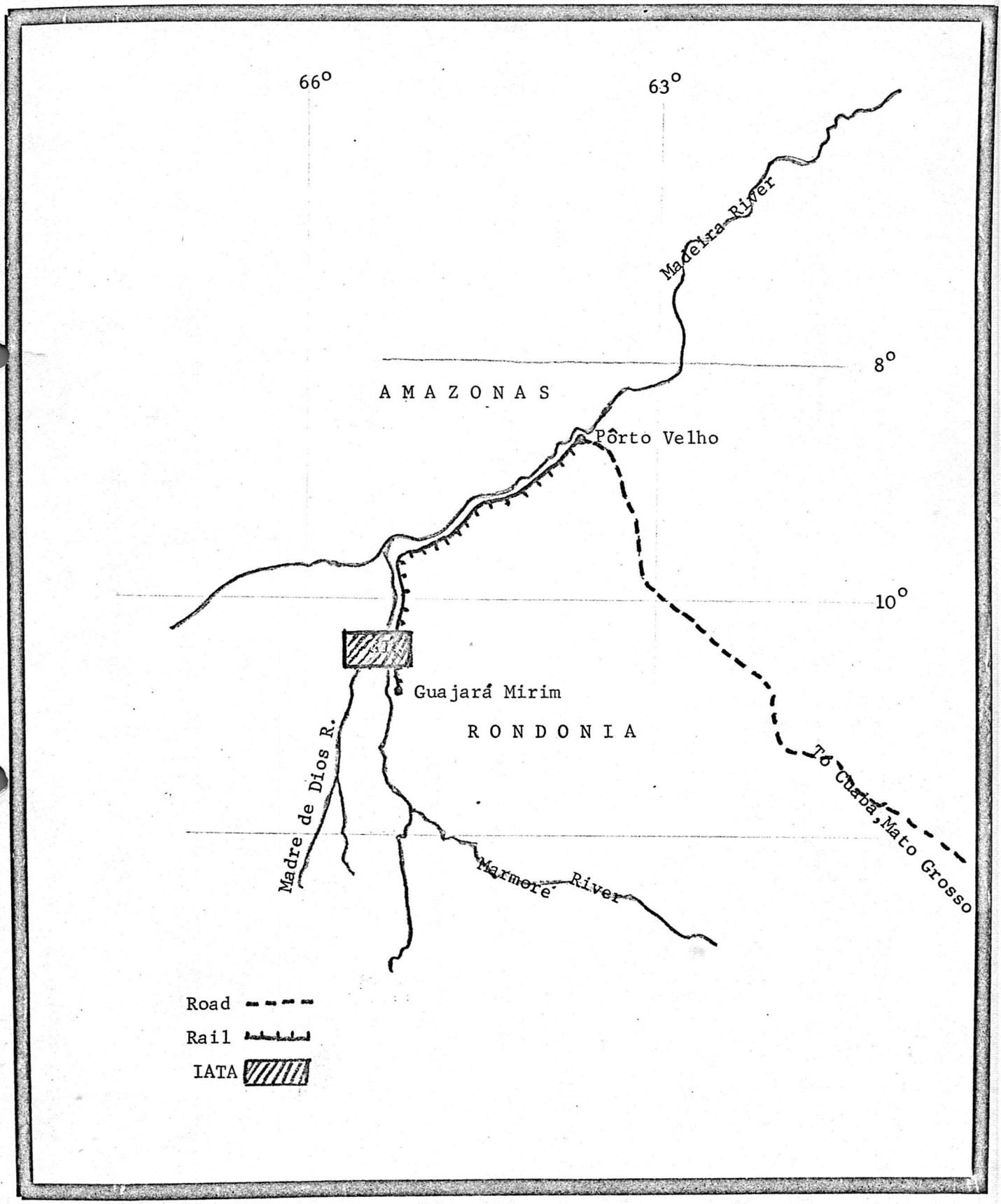
66°
63°
8°
10°
Madeira River
A M A Z O N A S
Pôrto Velho
Guajará Mirim
R O N D O N I A
Madre de Dios R.
Marmoré River
To Cuiabá, Mato Grosso
Road
Rail
IATA

SOUTHERN SUDAN