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Vegetation as a geological agent in tropical deltas

by

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A delta is a mosaic of deposits of loose, fine-grained alluvium, principally silt and sand, mostly saturated with water, and inherently unstable but tending to be stabilized by vegetation. These deposits are separated by and interspersed with channels and bodies of water.

The basic arrangement of these features is simple. A river, toward its mouth, splits into a fan-shaped arrangement of channels called distributaries, through which its waters enter the ocean. These are lined on both sides by strips of land called natural levees, which become lower toward the mouths of the distributaries. Between these distributaries, toward the head of the delta, may be remnants of older deltas in the form of terraces. Farther down, the distributaries are separated by large basins, either of open water or filled in to form swamps and marshes. The swamps and marshes are drained by tortuous channels that originate within them. Around the seaward margin are continuous or broken sand ridges. At the mouths of distributaries the delta may grow by extending fingers, usually double linear deposits of silt, into the sea, or turbulent water may restrict this type of growth. In most actual deltas this simple pattern has been much obscured by irregular growth, shifting of channels, and storm damage. This blurring of the pattern has, in many deltas, been greatly emphasized by human agricultural and engineering activity.

In the tropics, especially, most rivers are subject to great fluctuations in water level, and consequently their deltas are frequently flooded. The floods tend to shift and rearrange the sediments and to deposit more of them, especially silt, adding to the levees and silting up the basins. Accumulation of silt in the channels increases this propensity to flooding. One of the principal factors tending to counteract this shifting and instability in a delta complex is vegetation, several types of which are very characteristic features of deltas. The best known of these are salt-marshes and mangrove swamps. Fresh-water swamps and marshes, as well as peat swamps, are very extensive, also.

The principal physiographic features of deltas may be classified as follows (in part following the ideas of Esther Aberdeen Holm):

A. Water.

1. Distributaries.
2. Delta channels and tidal channels.
3. Lakes and ponds.
   (a) Interconnecting basins.
   (b) Levee flank depressions.
   (c) Abandoned channels or ox-bow lakes.

B. Wet lands.

4. Filled lakes and ponds.

C. Dry lands.

5. Delta terraces.
6. Natural levees.
7. Sand ridges and flats.

Each of these land-forms is influenced in some measure by vegetation, and the relationships will be briefly brought out in the following paragraphs. It must be understood that these remarks are based on very inadequate observation, mostly made incidentally in the course of other work. Studies of the rôle of vegetation in humid tropical deltas, or even of any aspect of the vegetation of these deltas, are few, except for works on mangrove swamps. Some of what would seem the more obvious phenomena of delta vegetation are not at all adequately understood.

A. Water:

One of the most pervading and ever-present features of deltas is water. This comes from three sources - the river, rain, and the sea. The water level in most parts of a delta fluctuates with the tide. Tidal influence brings about a mixing of salt and fresh water along the seaward margin of the delta, and a salinity gradiont is established between the fresh-water in the headward parts of the delta and the salt at the outer margins. This gradient profoundly affects the distribution of plants and vegetation types. The tidal fluctuation also exposes sand banks and mud banks, at times for long enough that certain plants may become established. The average periods of inundation and exposure may have a decisive rôle in determining which plants may grow in certain areas and consequently the distribution patterns of certain vegetation types.

1. Distributaries:

These, the main branches through which the river empties into the sea, tend to be the larger channels in the delta, and to be from relatively straight to meandering with large curves. They are arranged fan-wise, forking and spreading out, and often becoming very wide in their lower reaches. They are normally lined on both sides by strips of land called natural levees, which become heavily vegetated.

This vegetation, by stabilizing the levees, constrains the channels of the distributaries and lessens their shifting. On the convex side of a meander the vegetation tends to be cut away by the current, while on the concave side silt and sand tend to be deposited and a footing is provided for mangrove vegetation. Because of the relatively strong currents rather little floating vegetation accumulates in the active distributaries, and transported sediments even tend to scour the bottoms clean of submerged aquatic plants. However, during low water periods water hyacint (Eichhornia) may form a solid blanket over the surface of at least the more sluggish distributaries. Where these are used for navigation this growth may at times become a great nuisance. During flood season, such vegetation is usually swept out to sea or into the lakes and ponds. Then, also, the distributaries may frequently shift their courses. This happens for two reasons. The natural levees that contain the channel are built up higher than the intervening basins. As the level of the water in a distributary rises during the season of high water, it may be substantially higher than that in the basins, so that any weak point in the levee may be cut through. Also, as silt-laden water in the distributary slows down, it tends to deposit so much silt that the channel no longer can carry the water and overflows.

2. Tidal channels or delta channels:

Channels that originate in the delta itself, draining the lakes, ponds, swamps and marshlands, tend to be closely meandering and intricately branched. This pattern is striking, very uniform, and immediately identifiable from the air or on an air photo. Its origin is not very clear. Perhaps this will be explained in other papers in this symposium. The water escaping through these channels is from rain, floods, and that which entered at high tides. In frequently flooded or actively tidal areas, the water in these channels tends to be turbid, or sometimes greenish. Where there is little outside influence, and the water is mainly rain or ground-water, it is clear, or more often it may be black, showing the presence of peat in the swamps. Vegetation tends to spread into these channels, but since they are almost invariably open, except for floating plants, an equilibrium must exist between the effects of the moving water and the vegetation. Floating plants may, at least locally, cover the water of these channels completely, but this is not as common as might be expected.

It is probable that in most deltas all or most of the water channels are influenced by the tides. However, the term delta channel may well be reserved for those where the tidal influence is slight enough that they are filled with clear or black water. True tidal channels, obviously under tidal influence, may anastomose in their lower reaches and form a network, isolating islands of marsh or swamp. Tidal and delta channels ordinarily do not form natural levees along their banks.

3. Lakes and ponds:

Bodies of still water are frequent features of most humid tropical deltas. They range from extensive basins down to small ponds and pools. Some have outlets, others do not. All have a tendency to fill with sediments and plant remains and to change gradually to marshes or swamps. The salinity in those that are connected with distributaries by tidal channels tends to approach that of the part of the delta in which they are located. The ones that have no outlet, or outlets closed

by bars of sand or silt, tend to contain fresh water, often sour black peaty water. All tend to have both submerged and floating vegetation. The dead remains of this, as well as of the surrounding vegetation, accumulate as peat if the nutrient status of the water is low, as a slimy muck or as a component of silt or clay deposits if it is high. On the basis of origin, these water bodies may be grouped into three categories.

(a) Interconnecting basins:

These originate as areas of shallow sea cut off by sediments deposited as the delta builds outward, and natural levees, sand bars and ridges form. At first they may be practically open to the sea - merely deeper areas in the shallow water over the extensive silt deposits of the extending delta. As the features that enclose them build up, become vegetated, and achieve stability, the lakes are better defined and more permanent. Unless one happens to be cut by a shift of a distributary so that it is kept somewhat clear by current action, the remains of floating and submerged vegetation, and periodic increments of silt from flood waters will fill it in a relatively short time. Mangrove swamps form around its shallow margins, especially if tidal currents can bring in the floating plantlets that characterize so many mangrove species, or fruits or seeds of others. In the Old World deltas, Nipa fruticans becomes established over large areas. Mangroves and Nipa produce large amounts of coarse organic matter and also act as baffles and also the flood waters down during periodic inundations, so that they drop more of their loads of sediments. This hastens the change from a lake to a swamp.

(b) Levee-flank depressions:

The sediments that make up deltas normally contain a large component of water and much organic matter. Organic matter may be especially abundant in the swampy strips along the outer slopes of natural levees. During periods of low water, both decomposition of organic matter and loss of water from the sediments by evaporation and gravity flow take place at greater than normal rates. Compaction and settling, both from the above processes and from slow but continuous action of gravity, tend to produce long narrow ponds aligned along the outer edges of the natural levees. Ponds of similar origin but of different shapes may form anywhere in the delta where for any reason compaction becomes more rapid than accretion of sediments. Such ponds are likely to be choked with floating, submerged, and rooted aquatic vegetation. They are more likely to present the appearance of swamps than as open water in tropical deltas, and are likely to fill rapidly with vegetable debris and silt and to be very temporary features.

(c) Abandoned channels or ox-bow lakes:

As channels, especially distributaries, fill up with silt, they tend to cut through their enclosing natural levees and assume new courses. This commonly takes place on the seaward side of a seaward loop of a meander, and the new channel, being straighter at first, takes most of the water. The old is soon cut off by newly formed natural levees and is left as a C-shaped lake, called an ox-bow, of still water. Such lakes are a very characteristic feature of deltas (also of flood-plains), and where they remain undisturbed, showing varying stages of being filled by vegetation and silt, they may reveal much of the history of the delta to a practised eye. More often than not, even while an ox-bow is still too deep for rooted woody

vegetation to take hold, the surface is covered by a thick blanket of floating vegetation and of rooted plants with floating leaves, such as water-lilies. The debris from this vegetation, plus silt from floods, fills these lakes rather rapidly.

B. Wet land:

As lakes, ponds, and channels fill with silt and organic debris, they gradually change from areas of permanent standing water to land that, although still wet, is firm enough to support emergent vegetation. The water table usually fluctuates so that the surface is inundated for a part of the year, or, tidally, for periods of a few hours. The soil tends to become compact during periods of emergence and to retain its compactness during submergence. Accretion of silt and organic matter continues, the silt being added as long as the land continues to be flooded. In the tropics the vegetation of such land tends to be woody - trees or shrubs, and the ecosystem is called a swamp. Marshes and wet savannas, with herbaceous vegetation, are, however, not completely lacking. Areas of wet sand, with the water table near the surface of the sand, are frequently covered by grasses, sedges, and other herbs, with or without scattered shrubs and trees, and are termed wet savannas. Where trees become dominant in such wet sandy areas, peat accumulates, and a peat swamp results. Wet savannas and peat swamps usually occur well away from the strongly salty end of the salinity gradient, toward the head of the delta. They are also confined to areas where the water supply is principally rain and ground water seepage rather than floods. Perhaps the low mineral content of such waters and the low-nutrient status of the sand are responsible for the peat accumulation in these situations, because the resulting plant debris may not provide a very nutritive medium for decay producing organisms. It may also be suggested that the acidity of this water inhibits the growth of the bacteria and fungi that normally bring about rapid decay of dead plant parts.

In areas subject to flooding and active tidal inundation, with silt accretion, other kinds of swamp and marsh vegetation are found. Swamp is the rule. Toward the head of the delta, various trees with adaptations to inundation by fresh water dominate these swamps. Limited areas of marsh, often dominated by reeds and other tall grasses occur. I will suggest no general explanation of these, except that perhaps the grasses became established and abundant early and that it may be difficult for trees to colonize a dense stand of reeds. Toward the sea, the swamps are more and more dominated by mangrove plants of various species. Where the salinity is significantly high, mangrove vegetation including, in the Old World, nipa, tends to dominate large areas. In the transition zone between fresh water and mangrove swamps, mangroves and nipa tend to line the larger tidal channels, and fresh-water swamp trees to dominate away from the channels in the interior of swampy islands.

Swamp trees, especially the mangroves, tend to form a very substantial root mat, and to have many ingenious types of pneumatophores or aerating organs. These may take the form of stilt roots, knees, thin sinuous buttresses, bulbous swellings, and what appear to be inverted roots, growing vertically upward. The resulting vegetation makes a very effective silt-catcher and resists disturbance by floods. Differing salt-tolerances of the various species tend to bring about a rather conspicuous zonation of different swamp types as the sea is approached. Silt accumulation may be rather rapid in swamps. In Old World deltas, the nipa palms often have buried vertical or ascending stems as much as one or two metres long.

It can be assumed that the plants grew upward as the silt accumulated around them. While their life span is not known, this gives us some idea of the rate of silt deposition.

The rôle of vegetation in the wet-land areas just described seems two-fold. It tends to add organic matter to the sediments in the form of fallen leaves and twigs, roots, and fallen branches and trunks. It also slows down the rate of flow of flood water and causes more abundant deposition of silt and other grades of sediment.

C. Dry land:

Dry land is a relative term, especially when applied to deltas, since any land in a delta has a high water table and most are subject to relatively frequent flooding. However, land that is above water long enough so it is usually ordinary moist or dry earth, rather than mud, is regarded as dry for our purposes. Such land, in tropical deltas, takes three forms, and all are vegetated. They differ in location on the delta, nature of the sediments, degree of soil development, and in the nature of their vegetative cover. The vegetation plays three important rôles in these situations. The primary rôle is in stabilizing the sediments. Contributing organic materials directly to the sediments, and influencing soil development, are the other two.

5. Delta terraces:

On many deltas, there are erosion remnants of former delta land surfaces formed at higher sea-levels. They are flat or very gently sloping platforms, found near the head or the landward margins of the present-day deltas. The surface may show some slight relief due to erosion, or even persisting from irregularity in the original delta surface. They are normally drier than the rest of the delta. The soil is older and more weathered, often severely leached, if the delta is in a rainy region. In very humid regions the vegetation may be the normal lowland rain forest of the region, or more likely secondary forest resulting from disturbance or clearing of the land. Shifting agriculture, or even more permanent agriculture may be practised, but the soil is likely to be rather more sterile than ordinary delta soils, depending on the age and degree of leaching. In drier or more seasonal regions the vegetation may be savanna, probably burned over annually. Such savannas are probably the result of man's activities, but their floras may in part be made up of plants that persisted from former wet savannas on the deltas of which these terraces are remains. Certain of the savanna plants have a tremendous tolerance for water-logging and desiccation.

The stabilizing function of the vegetation is, in this type of dry-land area, not as spectacular as in the following two, but still the vegetation is probably responsible for the persistence of these terrace remnants. Erosion would doubtless have destroyed them long since if the surface were not protected by vegetation. The type of soil differs with the type of vegetation clothing the surface.

6. Natural levees:

In the distributaries the water in the centre of the channel flows faster than that at the sides. Consequently more sediment is dropped at the sides than in the centre, and the bottom tends to build up along the sides while the centre is kept

scoured clean and even deepens. As the incipient natural levees thus formed are left dry during low water in the dry season, the propagules of mangroves and other plants gain a foothold. At high water the resulting vegetation, though small and sparse, slows down the water still more and causes the deposition of more silt, building up the levee. Further silt deposition takes place during each flood season, and further establishment of vegetation during each dry season. As the level of the strip of land becomes higher, flooding may become less frequent. The composition of the vegetation changes as dry-land conditions become more prevalent. Swamp species give way to terrestrial plants. A riparian forest is formed, made up of trees well adapted to land with a rather high permanent water table. This forest, of course, carries on the usual processes of enriching the soil with organic matter and providing root channels for percolation of water, and during the now less frequent floods, brings about increased silt deposition. Its more striking function, however, is in binding the unconsolidated sediments together by its mat of roots and enabling them to resist rapid erosion during floods, thus tending to maintain the established channels of the distributaries and the integrity of the levees. Of course this is not completely effective and when channels become so blocked with silt and sand bars that they cannot carry the water, floods frequently breach the levees and inundate the intervening basins, and often succeed in altering the courses of the distributaries, or splitting them into two. This may result in abandoning the old courses and leaving undisturbed the levees lining them with their forests. The layer of leaf litter on the surface of the levees protects the soil from erosion from rain and those levees are consequently relatively long-lived features of the delta landscape. They are marked by different, often taller, strips of forest from the adjacent swamps.

On the concave sides of meanders in the distributaries the levees frequently show concentric bands of vegetation of somewhat different character, often younger toward the channel. This results from accretion of younger levee material as the current cuts into the opposite levee and drops more silt on the concave side. The vegetation at once tends of occupy and stabilize these new sediments, producing the banded appearance because of its lesser age on the newer surfaces.

7. Sand ridges:

Along the seaward margins of deltas where the sea is at all rough, beaches are formed and sand piled up in the form of beach ridges. Offshore bars may form and move shoreward under normal or storm wave action, until they are piled against the beach ridges and become part of them, either forming a broader ridge or a parallel series of ridges. Eventually narrow sand flats are formed, parallel with the shore. These ridges and flats tend to invade and cover the marshes or swamps or to protect them from wave erosion, or both.

The sand is very soon covered by a considerable assortment of beach plants - grasses with deep rhizomes and roots, various creepers that root at the nodes and thus form a mat anchored to the sand, and firmly rooted herbs and shrubs that tend to form a low scrub vegetation, often very dense. The sand of these beaches and ridges is very susceptible to movement by wind, as well as water. The vegetation not only tends to resist this erosion very effectively, but even reverses the process by stopping wind-blown or water-carried sand and adding it to the surface of the ridge, often to the extent of forming small stabilized dunes. The plants making up this sort of vegetation have the ability to stand burial of their lower stems while the tips continue to grow and keep above the rising surface of the sand. Dead parts

of these plants become incorporated into the sand, starting the process of soil formation. Trees, in the Old World especially Casuarina equisetifolia, tend to occupy these ridges, usually starting while there is still bare sand or only grass, and although slow-growing, they gradually overtop the scrub and form a very characteristic strand forest. This stabilizes the sand substratum still further.

The deltas often grow out beyond such stabilized beach ridges. Mangrove swamps, especially tend to form in the shallow water in front of them if the turbulence is not too strong. The ridges, then, are left isolated in the swamps, and other ridges may form well out in front of the old ones, and the same processes are repeated, the vegetation in each case stabilizing the sand and collecting more of it.

Such sand ridges, at least in Old World deltas, are often cleared and planted to coconuts. Those surrounded by swamp tend to be very satisfactory, but those just back of open beaches less so. When the forest and scrub on beach ridges are cleared, beach erosion, both by wind and waves is likely to ensue and the sand is scattered into the swamps. Leaving an intact strip of vegetation just back of the beach will go a good way toward preventing this erosion.

Except for interference by man, and occasional natural fires, the vegetation of sand ridges is likely to persist and develop until it is destroyed by hurricanes or other storms. If a storm is severe enough it is able to destroy any vegetation. Even so, natural vegetation affords the most effective protection against storms. The plants have evolved in these situations and have developed very effective defence against all but the most devastating storms. And these are the ones that destroy even the most resistant works of man in such situations, also.

Summary: Deltas are land constructed of generally loose, fine sediments, saturated with water, and inherently unstable. Even while still submerged these tend to be covered with rooted aquatic vegetation, which has some stabilizing effect. As soon as the sedimentary deposits are built to where they are exposed at low water, emergent aquatic, and even terrestrial plants gain a foothold. As these increase and form either a swamp or marsh vegetation, or on more continuously exposed land, a mat of grass and creepers or a sand-binding scrub, they bring about a marked stabilization of the sediments. Their dead parts also contribute to the organic content of the sediments themselves. In the interiors of sandy deltas these plant parts form deep peat deposits. The delta thus forms an ecosystem that is in a state of dynamic equilibrium between the very diverse forces of deposition and destruction by river currents and ocean waves, as well as wind and storms, and the tendency of plants to colonize and stabilize all land surfaces, submerged or emerged, and even the surface of the water, and to add organic matter to the sediments and soils thus formed. The natural vegetation of the various situations in deltas is a very effective protection of these unconsolidated land forms against erosion of all types, as well as providing enormous surfaces for friction to slow down wind and water and increase the deposition of their loads of sediments, thus building up the deltas.