USE OF THE COTTONWOOD IN AN INVESTIGATION OF THE RECENT HISTORY OF A FLOOD PLAIN

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ABSTRACT. From an extensive coring and ring count of cottonwood trees along the Little Missouri River of western North Dakota, a contour map was made of the age of the floodplain forest in a 1½ mile section of valley. The age distribution of cottonwoods, observations on the ecology of the floodplain vegetation, and in particular the sandbar colonizing habits of the cottonwood indicate that the germination and growth of the cottonwood is intricately related to the discharge of the river, movement of the channel, and development of the flood plain.

The cottonwood forests of the Little Missouri valley are composed of a series of even-aged bands of trees which show an orderly increase in age upvalley and away from the channel. Each forest band is apparently the result of the rise of a sapling thicket on a riverside sandbar, and thus the forest is a living record of the recent migration of the channel.

On the basis of the age-area distribution of the floodplain cottonwoods, a model has been constructed to describe channel migration and sediment transport. On the average, every century the reach of river studied redistributes a volume of sediment equal to the total available in the valley, by undercutting of banks and deposition on point bars and flooded surfaces. Deposition on a unit of valley floor decreases exponentially with time due to the progressive increase in elevation brought about by the deposition. The volume of sediment eroded from channel banks was found to be roughly 1.8 million cubic feet per year per mile of valley.

Evidence from the buried stems of cottonwoods, although scanty, indicates that the channel has been within a few feet of its present elevation during the past 150 years. Complex topography of the valley floor, including terrace-like forms and inset fills, may be explained entirely by the modern processes presently at work in the valley. Because of rapid channel migration it is improbable that any valley floor deposits above low water are as old as the end of the Wisconsin.

INTRODUCTION

Although it is common knowledge that the ground patterns of floodplain forests like the one illustrated herein (pl. 1) are somehow related to movement of the channel of the river whose valley they occupy, very little is known of the details of the relationship. And except for a few boulder surveys and painted-pebble studies, details of sediment transport are known only inasmuch as they can be determined from point measurements at gaging stations. Standard measurements reveal only how much sediment is being transported at a given time, not where it came from, how long it was in transit, or what percentage of time the average particle spends at rest in the deposits of the flood plain. The present study, a blend of ecology and geomorphology, attempts to illuminate some of these details by examining the growth of the floodplain forest and its relationship to the river.

Field work was carried out during the summers of 1964 and 1965 in the valley of the Little Missouri River, in western North Dakota.
View of the Little Missouri, showing the typical division of the valley floor into 2 levels: the low flood plain, occupied only by cottonwood saplings and annual weeds, and the high flood plain, on which the mature cottonwood forests occur. The scarp which separates the two levels throughout most of the valley may be seen just forward of the forest on the left. Note the open grassy floor of the forest and the bands or elongate clumps of trees interspersed with meadow. On the point of low flood plain to the right of the forest is a band of sapling trees 10 to 15 years old.

Most of the data was obtained during the 1965 season when work was done in the North Unit of the Theodore Roosevelt National Memorial Park, 15 miles south of Watford City, North Dakota (fig. 1). The area studied, a 1 1/2-mile length of valley at the south end of the North Unit, was picked because of its good forest cover, the abundant roots and buried stems of trees exposed in the river banks, and the nearness of the Watford City gaging station, 10 miles downstream. The area, being in a national park, had been protected from the axe of the lumberman for several decades. Sporadic lumbering and ranching prior to 1940 do not appear to have damaged the forest in the study area.

Ages of the trees were obtained by ring count from cores taken with a Swedish increment borer, and elevations on the valley floor were determined by tape and Brunton pocket transit. From the data thus obtained the age of the floodplain forest was mapped, and an analysis made of the meandering of the river channel and the turnover of sediment in the valley.

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**DESCRIPTION OF THE AREA**

The river.—The Little Missouri River rises in northeastern Wyoming and flows northward through western North Dakota, joining the Missouri in the Garrison Reservoir 50 miles north of Dickinson, North Dakota. Through western North Dakota, the Little Missouri valley is cut from 200 to 500 feet below the general surface of the surrounding prairie. Less than a mile wide at the floor, it is bounded by steep walls of bedrock and floored by alluvium of undetermined depth, consisting mainly of sand and silt with scattered lenses of gravel. The boundary of the study area shown on the map, figure 6, is drawn at the first outcrop of bedrock at the valley wall. Higher on the valley sides are the remnants of a rock cut terrace (Schmitz, ms, level no. 3).

Above the Watford City gaging station, located on the bridge of U. S. Highway 85, 15 miles south of Watford City, the Little Missouri drains 8490 square miles (McCabe and Crosby, 1959). It has a mean flow of 573 cubic feet per second (cfs), most of which is provided by snowmelt in the spring. During the drier months of July and August flow commonly diminishes to a trickle and has been known to cease altogether. Often during the winter when the river is frozen, no flow is recorded. It is a shallow, perpetually muddy river, with a gradient of 4½ feet per mile (Petter, ms). The bed material is largely sand and silt, with some gravel up to an inch or two in diameter. According to observers at the Medora gage, the bed may scour to depths of 8 feet during floods. Suspended load sampled at Medora from 1946 through 1951 averaged 3.7 million tons per year.

According to some of the local residents and personal observation on one occasion of moderate flow, the channel is quite unstable laterally and may undercut large areas of the valley floor at a rapid pace, especially during spring floods when ice jams are common. The channel width averages 300 feet; the remainder of the valley floor is composed of a series of flat or gently inclined surfaces, so that the bottomland
rises away from the river in a set of low steps. The valley floor may be divided roughly into three categories: (1) low floodplain and riverside bars, 0 to 8 feet above low water, (2) high flood plain, 8 to 17 feet, and (3) alluvial fans of local drainages, 15 to 50 feet. These surfaces are distinguished by marked differences in surface morphology and vegetation.

Because of the complex topographical and depositional features of the valley, no strictly morphological definition of the “flood plain” is possible. Likewise a genetic definition is unacceptable because all the processes working to mold the valley appear to have been operating throughout the valley up to the present time, although at varying relative intensities locally. In this report the term “flood plain” will be used to denote that part of the valley floor over which overbank sedimentation is more influential in moulding topography than deposition by the extending alluvial fans of local drainages. These areas are generally distinguished by conspicuous meander scrolls and cottonwood stands and are generally less than 17 feet above low water.

**Bedrock.**—The bedrock exposed in the area is the Tongue River Formation of the Fort Union Group, of Paleocene age (Laird, 1950). It is poorly cemented tan and buff shale, sand, and silt, with beds of lignite up to 15 feet thick and abundant beds of bentonite. The Pleistocene trenching of the river and its tributaries into this soft rock has produced spectacular badlands which extend up to 10 miles laterally on either side of the main valley (Laird, 1950). The easily eroded slopes of this barren topography supply an abundance of local sediment to the valley.

**ECOLOGY OF THE FLOODPLAIN FORESTS**

Since the investigation of the valley floor involves the use of age data from the cottonwood trees, it is necessary to discuss in some detail the growth and life history of these trees and their relationship to the rest of the valley bottom flora, the sediment, and the river. Except for Dietz (1952), Lindsey and others (1961), and the brief observations of Shull (1922, 1944), little attention has been paid to the vegetational aspects of floodplain development. The peculiar relationship of the cottonwood to its environment is of prime importance to the present study and is the basis for the claims made of the value of this species as an indicator of channel movement and floodplain age.

**Cottonwood physiology.**—Growth rings of trees are often used to determine the minimum age of forests or deposits. Ring-porous wood is preferred for this kind of work, since it has more clearly defined growth rings. Cottonwood is diffuse-porous; not only are its rings difficult to read, but since little research has been conducted into the growth of diffuse-porous plants, it is not altogether certain whether the rings visible in the wood are annual in origin.

The rings of the cottonwood counted and used in this paper as the basis of age determinations are believed to have been produced by annual growth for the following reasons: Research with ring-porous species indicate that forest interior trees have what is termed a “com-
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placent" ring series, influenced relatively little by climate (Fritts, 1965). Ring sequences from trees in this environment cannot be correlated with neighboring trees but are more likely to be produced annually than those from areas of more climatic stress. Stress environments tend to produce a high percentage of double or absent rings. All attempts at ring width correlation among cottonwoods and even between cores from the same cottonwoods in the study area failed. This fact, together with the existence of lush forest vegetation including Elm and Box Elder, indicates that climatic stress is low in the Little Missouri valley.

Several groves or bands of trees were cored extensively, and it was found that the ages determined by ring count differed by no more than 10 percent within each grove, although tree diameters and heights varied by as much as a factor of 5. Therefore, microenvironmental factors appear to have little effect on the number of rings produced per year.

Ages determined from coring young trees agree well with historical events recorded in aerial photographs, such as channel contraction and migration, and the creation of the two oxbows which are being silted in and forested. Therefore false rings and absent rings, if they occur in the cores taken, cancel each other out fairly well, so that roughly one growth ring per year is produced, at least in the more vigorous younger trees. Data is not sufficient for this kind of analysis for trees older than 100 years, but it is probable that ring counts of more than 100 are underestimates of true age, if anything. In this report, all ring counts are considered accurate estimates of the age of the tree trunk within 10 percent of their value.

Cottonwood establishment.—The Plains Cottonwood, *Populus sargentii*, is the principal pioneer species of the Little Missouri flood plain. Together with several species of willow (*Salix sps.*) and a number of annuals, it is the first plant to inhabit the point bars and other barren sandy deposits near the channel and frequently inundated. Muddier areas are usually dominated by willow, but plants of this genus, being shorter lived, rarely survive to participate in the mature floodplain forest and consequently are of minor importance to this study.

Sandbars near the channel, 5 to 6 feet above the low water level, constitute the only environtment where the seedlings of the cottonwood are abundant at the present time. Occasional seedlings are seen in roadside ditches and on areas of similar artificially cleared moist soil, but the riverside bars seem to be the only common natural environment offering the conditions required by the cottonwood for germination and survival.

As described by Read (1958) the conditions required by *P. sargentii* are: denuded or disturbed sand or coarse soil, usually a river bar; initial absence of competition from other species; and full sunlight with an abundant and stable supply of ground water near the surface. Over most of the valley floor, including that occupied by established cottonwood forests, there are not only no seedling cottonwoods but no cottonwoods differing markedly in age from those forming the forest canopy.
B. U.S. Department of Agriculture 1949 aerial survey photograph of the study area. The line A-E marks the cross section of figure 4. Except for the northern oxbow shown on (A), which was cut off in the 1950's, the present channel is much as it is in this photograph. Most of the large sandbars have retained their 1949 positions but are now covered with cottonwood thickets as the map shows.
Therefore the vast majority of the cottonwoods now inhabiting the valley must also have originated as seedlings on similar sandbars, although many older cottonwoods now occupy sites more than 15 feet above low water and hundreds of yards from the present channel.

The majority of the cottonwood forests are composed of series of arcuate bands of trees (pl. 2). The trees of any one of these lineations are of a uniform age, and the ages of the lineations are progressively younger toward the channel. These facts strongly indicate that each band began as a thicket of seedlings on a bar at the channel's edge and was then "transported" inland by the migration of the channel and the establishment of more trees on newer sandbars.

Flood-training.—When a sandbar has grown to a height of about 5 feet above low water, it becomes populated with cottonwood seedlings. Due to their low elevation and proximity to the channel, these young trees are subjected to what Lindsey and others (1961) call "chronic flood-training". Saplings less than 10 years old invariably show signs of severe flood damage (fig. 2), unless they inhabit a particularly sheltered location. Often, a cottonwood sapling will be prostrated and buried, so that its only surface expression is a clump of shoots rising vertically from the sand. Stems are usually deflected downstream roughly parallel to the channel. They may be bent by high water alone or by floating ice; the actual process was not observed. Burial of deflected stems may be either essentially simultaneous or subsequent to the bending.

Apparently only saplings are supple enough to be flood-trained and survive. Trees greater than 8 inches in diameter probably yield to the pressure of high water only by being tipped over and uprooted from the soft waterlogged alluvium and perhaps swept away altogether. No flood-training of large individuals was observed, other than a few

Fig. 2. Sketch of a flood-trained and buried cottonwood sapling which has given rise to a large clump of young trees. This example is representative of the process of flood-training as it occurs on the Little Missouri River. Downstream is to the right.
slightly tilted but still upright trees. Although the dead boles of fallen trees are numerous, it is impossible to say whether they died before or after they fell. No trees were observed pushed over in place or leaning more than 45 degrees but still alive. The trunks of trees toppled into the river and lodged on sandbars downstream were observed sprouting leafy branches. Saplings generated thusly from natural cuttings may occasionally survive once again to become mature trees but only if the parent tree trunk is lodged on a low sandbar with adequate water and sunlight, the same environment required by the seedlings.

Although the destructive effects of high water are confined almost exclusively to saplings on the low sandbars, evidence of former flood-training is present among the older trees. Whenever the subsurface parts of cottonwoods were found exposed in an undercut riverbank, the buried parts of the stem in every case were bent at 4 to 8 feet above low water, with the inclined portion of the stem deflected in a downvalley direction. Figure 3 shows several 65-year-old trees growing on a surface 14 feet above low water, which were found to be shoots radiating from a single base and root system 4 feet above low water, 10 feet below the
present surface. The original tree evidently germinated on a river bar more than 65 years ago and survived several floods by sending up new shoots from prostrated stems. Since that time, the local surface of the valley has been elevated 10 feet by overbank deposition, although the river channel has not aggraded.

The direction of deflection of the buried stems of figure 3 is not in the direction of the present flow of the river but is parallel to the trend of the forest band of which they are a part (pl. 2-B near the cross section A-E). This trend is downvalley but 30 degrees to the left of the present channel direction. Since the parallelism of banding and flood-training was noted in most of the exhumed trees observed, both the direction of flood-training and the ground pattern of the forest may be taken as representing past direction of flow.

The deflected stems of tree 4-C (fig. 3) range in elevation from 4 to 7 feet above low water. From figure 3 it is clear that the tree has been flood-trained at least twice. The diameters of the deflected stems range from 1 to 3 inches indicating that no great amount of time elapsed between flood-trainings. The 3-foot elevation range in flood-training must represent a "zone of chronic flood-training", that range in elevations within which cottonwood saplings are universally damaged by floods. The elevations within which the stems of tree 4-C, as well as all the other exhumed stems observed in the study area, were flood-trained roughly coincides with the 5 to 6 feet elevation at which modern flood-training is taking place. Thus it appears that the frequency of floods at this height has been constant in the recent past, and therefore the bed elevation and discharge characteristics have probably not changed appreciably.

The elevation at which flood-training occurs corresponds roughly with the median height of the annual peak discharge. As computed from the 20 years of runoff records at the Watford City gage (McCabe and Crosby, 1959), the 5-foot level (8 ft., gage height) is inundated on the average every 2 years. The yearly peak discharge almost invariably occurs during the spring and often in May and June, when the cottonwoods are seeding. Thus besides its role in flood-training, high flow is probably influential in distributing the seeds of the cottonwood. Ultimately, however, the lower limit of the distribution of the cottonwood must be determined by the limits of its physiological tolerance to submergence.

Tree 4-C is the only one of the seven exhumed trees found in the study area in which the original base of the seedling tree was completely preserved. Other exhumed cottonwoods showed short sections of bent stem, but their first beginnings had long since died and decayed. The death of the original seedling and sapling stems of these trees, the depth of usual burial and the scarcity of natural exposure, plus the natural difficulty of dating the buried stems when they can be found, precludes the possibility of determining the actual date of germination of the flood-plain cottonwoods. Coring of the above ground trunk reveals only that
time at which the tree attained the height at which it was cored subsequent to its latest flood-training.

**Maturing of the forest.**—The floor of the young forest or sapling thicket is inhabited by annuals, mainly clover, but in older forests the annuals are replaced by perennial grasses and shrubs. There are no saplings or seedlings in the understory: the established cottonwood forest does not reseed itself. Old trees may occasionally regenerate by producing suckers which eventually replace the original trunk. This phenomenon was observed only rarely and always in old and thin forests where a large percentage of sunlight penetrates the canopy.

When the forest has reached the age of 30 to 60 years, other species of trees begin to appear and to replace the cottonwoods as the latter age and die. In the order of their abundance these successional species are: Green Ash, *Fraxinus pennsylvanica var. lanceolata* Sarg.; Rocky Mountain Juniper, *Juniperus scopulorum* Sarg.; American Elm, *Ulmus americana* L.; and Box Elder, *Acer negundo* L. Few forests were found completely devoid of cottonwoods, however. Even in the oldest forests some relicts of this species are present, sometimes attaining a diameter breast high of 3 feet.

Only rarely was a cottonwood found associated with older trees of another species or markedly different in age from nearby cottonwoods. Trees of such anomalous ages were usually discovered on close inspection to have been produced vegetatively as suckers or root sprouts from preexisting trees. This observation further confirms the strict pioneering role of the cottonwood in the floodplain forest.

**SEDIMENTATION**

*Relationship of trees to floodplain sediment.*—The cross section in figure 4 illustrates the relationship of the cottonwoods to the floodplain sediments and the way in which the flood plain is built up above the low water level. The section is in the south end of the study area, shown by the line A-E plate 2-B, where a straight reach of the river has undercut the bank leaving the sediment exposed in a vertical scarp. Exposed in the riverbank are the exhumed roots and stems of several cottonwoods. Enough cottonwoods are present to give a good idea of the age of various parts of the deposit.

The structure of the sediment indicates that the deposit originated by point bar accretion and overbank deposition behind a migrating channel. Bedding of the deposit dips down valley, in the direction of declining tree ages. Sediment near the surface of the flood plain, above 10 feet, is usually, although not always, finer and more horizontally bedded than the basal deposits, although there is nothing that could be called a stratigraphic boundary between point bar and overbank flood deposits. Presumably the strike of these dipping beds is parallel to the lineation in the forest and thus parallel to the channel at the time of most of the deposition, but this is not known for certain due to the two-dimensional nature of the exposures. The ages of the trees clearly
Fig. 4. A cross section of floodplain sediment and forest along the line A-E in plate 2-B.

show that at the 5 foot level, where they germinated and were flood-trained, sediment is progressively younger downvalley.

Bars with swales behind them, several of which occur in the cross section in figure 4, are common features of the present topography. The cross section also shows at the lower levels, several buried swales, which are no longer represented at the surface. It is unknown whether these features arise principally from flood scouring behind already vegetated sandbars, as is suggested by Dietz (1952), or from relatively heavier sedimentation on the bars due to plant cover or relative proximity to the channel. No conclusive stratigraphic evidence of scouring was found. However generated, scroll topography appears early in the development of the flood plain. After the cottonwood forest has matured and the flood plain has been elevated to 8 to 10 feet, the ridges and swales are progressively subdued by blanket deposition.
Deposition on the higher levels of the flood plain, however slowly it progresses, appears to proceed uninterrupted by the episodes of local scouring observed on flood plains of eastern rivers (Sigafoos, 1964). This is probably one of the factors that produce the relatively rapid rate of increase in floodplain elevation observed in the study area.

Time-related elevation.—The lower curve, using the left-hand scale of elevation, of figure 5 shows the relationship between elevation and age of the flood plain in the study area. The data points are also shown in figure 5. The elevation with respect to low water was determined by tape and levelling by Brunton Compass, and the age determined from the cottonwoods occupying the surface. As elevations were taken as close as possible to the riverbank, however, the measurements may exaggerate the true average elevation of the surface because of the presence of natural levees near the channel. Although levees are seldom obvious, often the drainage of the surfaces trends away from the channel, indicating a slight slope in that direction. The error introduced by the levee effect should be slight, however, due to the care exercised in selecting the data points.

No cottonwoods were found on ground higher than 17 feet. Although there is a substantial scatter of points, the data are fairly well represented by a curve whose equation is

\[ h = 5.5t^{(1/6)} \]  \( (A) \)

where \( t \) is the age of the trees (time) in years, and \( h \) is the elevation of the surface in feet. Equation (A) is graphed in figure 5 along with a hypothetical floodplain elevation curve derived by Wolman and Leopold (1957) for the Brandywine Creek at Chadds Ford, Pa., from flood fre-

![Fig. 5. Elevation of the flood plain as a function of age. The upper curve was derived theoretically by Wolman and Leopold (1957) for the Brandywine; the lower curve is derived empirically in this paper from measurements made on the Little Missouri.](image-url)
frequency data. The form of the Wolman-Leopold curve did not conform to the floodplain history of the Brandywine, and this fact was used to cast doubt on the theory of continued alluviation of a floodplain surface by overbank deposition. However, when the elevation scale of this curve is expanded, it fits the data from the Little Missouri very well and diverges from equation (A) only for values of t greater than 250, for which there are no data on the Little Missouri. The concurrence of the forms of these two curves suggests that continued overbank deposition may be more important in building the flood plains of alluvial rivers like the Little Missouri than of streams like the Brandywine.

The form of the curve is that expected of a depositional surface: faster sedimentation on lower, younger areas, slower on higher, older areas. For simplicity, the curve was made to pass through the origin, although strictly following the cottonwood ages, the elevation at time zero is on the order of 5 feet.

From the evidence presented above, it appears that the growth of the flood plain and its cottonwoods are closely related. The older trees occur on the higher levels because sedimentation has continued longer in these areas than in regions of younger forests. The cottonwood germinates and survives because the river has thrown up a place for it. The deposition of sediment is then aided by the braking action of the stems and leaves on the sediment-laden water, as described by Dietz (1952). Evidently, while low and near the channel, cottonwood saplings are so frequently prostrated by high water that they cannot attain the stature of trees. As deposition continues to raise their ground level out of reach of the most frequent floods, and as the channel migrates away, reducing the hazard of even high floods, a time comes when intervals between flood-training are long enough to allow the saplings to grow to such a size that they can no longer be bent by the pressure of water or ice. Henceforth they will withstand all floods or be uprooted and destroyed. Sedimentation may continue indefinitely but at a waning rate around the trunks of the growing trees until the migrating channel once more impinges on the area and its burden of sediment and forest are swept away to lay the scene for a new cycle.

AGE OF THE VALLEY FLOOR

Definition.—The age of a part of the valley as used in this report is the length of time since last it was a riverside sand bar and is roughly equal to the age determined from coring the cottonwood trees inhabiting it. The ring count is not the true age of the tree but establishes the time at which the present stem attained the height above low water at which it was cored (10-15 ft.), after the last time the tree was knocked down by a flood. Because of the rapid growth of the cottonwood, the discrepancy between the date of the latest flood-training and the coring date should be negligible compared to the 25-year interval used in mapping. Ten-foot high cottonwoods were observed to be about 4 to 5 years old. Thus the coring date establishes the time of the cessation
of absolute domination of the cottonwoods by the river, the real "birth" of the floodplain forest.

**Mapping the floodplain forest.**—From the age data obtained by coring representative cottonwoods a contour map was made of the age of the floodplain forest. The map, figure 6, was made by plotting the ages of the trees cored on a base map of the area and contouring them with 25-year contour lines or “isochrones”. The base map was made from the 1958 aerial photograph of the study area, with corrections for recent channel movement. The absolute area of the valley bottom, 14 million square feet per linear mile of valley, was computed from the 660 ft/in. scale of the aerial photographs from which the working maps were made. Such a scale determination was judged accurate enough for the present study.

Wherever the concentration of data was great enough, the isochrones were found to parallel the banding of the forest. In areas of scanty data,
Isochrones were drawn to parallel the bands, since in all the cases treated, the forest bands were found to be of uniform age, even where diameters of trees varied considerably. Isochrones were extended to the valley wall over unforested areas in order to assign the entire valley to an age group. Although increasing the possibility of error in determining the area-age relationship, this procedure insures that the derived relationship is influenced as little as possible by selective deforestation which may have occurred as the result of lumbering activities or local deposition on alluvial fans. Therefore the forest-age map may be interpreted as a map of "valley age" and used to determine the recent history of channel migration and floodplain construction.

From the age map the former position of the channel at any time during the last 200 years may be determined by using the isochrone of the time desired as the upvalley riverbank and sketching in the parallel downvalley bank and the intervening gaps. The accuracy of this channel boundary determination declines with increasing age, as the trees available for dating become fewer.

The floodplain cottonwoods record not only the progress of lateral accretion but also of bank erosion. It is the combination of these two factors that is used in the following section to derive a rate of channel migration.

**Rate of Channel Migration**

The following discussion is an attempt to show how age data from the floodplain forest may be used to determine details of channel migration and sediment transport which are not otherwise obvious. It is entirely possible, however, that the data is inadequate to support some of the conclusions drawn, since the statistical sample is very small. The study area is barely two meanders in length. Moreover the fact that the forest age is usually not a continuum from younger to older but is composed of discreet even-aged bands of trees (presumably related to individual floods) adds to the confusion, since for the purposes of the following discussion, the channel migration must be averaged over time and treated as if it were a continuous process. In actuality, not only is the rate of overall channel migration highly variable, but the two channel banks migrate somewhat independently, as channel width fluctuates. Another source of error may be the fact that the largest flood on record occurred only 20 years ago and involved substantial channel widening. Subsequent floodplain construction within the 1947 flood channel may have biased the data. The following calculations are crude at best and are only included to indicate the wealth of information contained in the floodplain forest.

*Exponential decay of area.*—Early in the course of field work it was noted that less area is occupied by older forests than by younger forests. To test this observation, the area between each isochrone on the map was measured by planimeter, and the areas within each 25-year increment summed. These areas are plotted on a log scale against time, as a
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Fig. 7. Area decay curve, equation (B), and the data histogram, expressing the area of the flood plain as a function of age.

The histogram in figure 7. The histogram is approximated by an exponential curve whose equation is

$$100 \ln (\alpha) = 264 - t$$  \hspace{1cm} (B)

where $t$ is time or age in years, and $\alpha$ is the area per mile of valley of that age in $10^4$ square feet/year. It is reasonable to assume that the greater area occupied by progressively younger forests is not the result of any change in the rate of migration of the channel and of point bar formation but rather reflects the destruction of preexisting forest by channel migration subsequent to its formation. The longer a tree lives, the greater are its cumulative chances of being undercut and swept away by the river. Thus, if the area pioneered by seedling trees per unit time is constant (from the constant channel migration assumed above), and this area is acquired by the indiscriminate destruction of existing forests of varying age, older forests must naturally be less plentiful than younger.

Equation (B) is an exponential curve, similar to those that describe radioactive decay; hence my use of the term “decay”. On the average, valley area of any age is decreasing exponentially, with a certain half-life. The half-life calculated by solving equation (B) for $t_1 - t_0 = T \frac{1}{2}$ when $\alpha (t_1) = \alpha (t_0)$ is 69 years. Equation (B) is the simplest curve that fits the data, and for which the area under it,

$$\int_0^\infty \alpha d(t) = 14 \times 10^6 \text{ ft}^2$$  \hspace{1cm} (C)

is equal to the total area per mile of the river valley (minus 1958 channel area).
Rate of area destruction.—The time derivative of equation (B) yields the rate of change of the initial area, \( a \), through time.
\[
\frac{da}{dt} = -\left(1/100\right) 14\left[ e^{(-t/100)} \right]
\]
(D)

or:
\[
\frac{da}{dt} = \frac{-a}{100}
\]
(E)

it is clear that \( \frac{da}{dt} \) is not dependent on age but is constant for any given \( a \). If we let \( a \) equal A, the total valley area (which is assumed to be constant) we see that:
\[
\frac{dA}{dt} = -\frac{A}{100}
\]
\[
= -14 \times 10^4 \text{ ft}^2/\text{yr}
\]
(F)

Note that \( \frac{dA}{dt} = -\alpha (a) \) from equation (B) (see fig. 7); that is, area destruction by channel migration is balanced by area creation as point bars. This is the result of assuming that the valley area (minus channel area) is constant, that is, the channel does not change in area through time. Such an assumption appears to be approximately correct (± 50 percent) for periods of 25 years on the Little Missouri, although the work of Schumm and Lichty (1963) indicates that channel width may vary tremendously over 25-year periods.

The constancy of channel migration \( \frac{dA}{dt} \) follows only from the initial assumption of the constant rate of channel migration and does not prove that the initial assumption is correct. Although the rate of channel migration does vary from year to year, it is hoped that the assumed constant rate of channel migration is reasonably correct for the 25-year interval used in tabulating the data and essentially correct over longer periods of time.

Volume of erosion.—The volume of sediment in the valley above the low water mark may be calculated by multiplying area as a function of time by elevation as a function of time and integrating over time (see fig. 8).

\[
V = \int_0^\infty a(t) h(t) \, dt
\]
(G)

where \( V \) is the volume of sediment per mile of valley above low water in cubic feet. Computed in this way, \( V \) is equal to 180 million cubic feet.

Fig. 8. The volume \( V \) of sediment in the valley above low water \( (h = 0) \) may be calculated as the integral over time \( t \) of valley area \( a \) multiplied by elevation \( h \), by the method of slices. The function \( V = \int_0^\infty f(t) dt \) is finite since \( a h \) declines to zero at both \( t = 0 \) and \( t = \infty \) and is continuous between these points. \( a \) and \( h \) are from equations (B) and (A), respectively. The function may be evaluated by means of the Gamma function.
Substituting the \( \frac{da}{dt} \) of equation (E) for \( a \) in equation (G):

\[
V_e = \int_0^\infty (-1/100) \alpha(t)h(t)dt
\]

\[
= V/(-100) = 1.8 \times 10^6 \text{ ft}^3/\text{yr}
\]

where \( V_e \) is the rate of bank erosion per mile of valley, yields a rate of erosion of 1.8 million cubic feet per year.

**MORPHOLOGY OF THE FLOOD PLAIN**

*Agents of deposition.*—In the foregoing discussion no attempt was made to differentiate between point bar and overbank deposits. Since these two types of deposits cannot be distinguished readily in a cross section of the flood plain, the significance of the distinction is felt to be unimportant. In this report these two “forms” of sedimentation are treated as but two aspects of one uniform and continuous process, floodplain sedimentation.

Another distinct form of sedimentation is at work in the valley of the Little Missouri, however, which is important in considerations of the overall sediment budget and floodplain morphology. The flooding of surfaces, especially those near the valley wall, with locally derived sediment from the barren slopes of the badlands builds alluvial fans which may in a remarkably short time extend half way across the valley and stand at an elevation of 50 feet above low water at the valley wall. This type of deposit is distinguished from the true floodplain sediment by its massive poorly bedded texture, conspicuous vertical jointing, and the distinct horizontal banding common in the local alluviums of the region.

The surfaces of the alluvial fans are typically smooth and uniformly sloping away from the apex. They are vegetated with sagebrush (*Artemisia cana*) and coarse grasses. Very rarely an alluvial fan will be mature enough to have developed a fanhead trench. Most gullied fans are the result of encroachment of the migrating river channel which initiates headward eroding dissection in the tributaries.

The fan just north of the southern oxbow, left center plate 2-B, covers roughly 1/10 of a square mile and is one of the largest observed, although it was built by two small streams which drain about 1/4 square mile. Half the fan is built over a portion of flood plain mapped as younger than 250 years (fig. 6). This data, together with a rough estimate of 1/6 centimeter per year erosion in the local badlands, leads to the conclusion that the entire fan, and therefore any fan within the valley, could have been built well within a span of 1000 years. Thus it is evident that rapid sedimentation cannot be expected to cease even when the valley floor has been raised to a level that virtually precludes its being flooded by the river.

*Split-level flood plain*—The division of the flood plain into two areas of differing elevation and vegetation is not an arbitrary one. The
valley floor is composed of two distinct levels separated by a cut scarp from 5 to 10 feet high which can be followed along most of the valley in North Dakota (pl. 1). This distinction of levels is so striking that previous students of the region (Laird, 1960; Schmitz, ms; and Petter, ms) have confined the Little Missouri flood plain to the lower level and labeled the higher one as a post-Wisconsin terrace (Schmitz, ms, level no. 2), the result of isostatic rebound following the retreat of the latest continental ice sheet.

Evidence accumulated during the present study questions the validity of such an early date for level 2 and the use of the term “terrace” to describe it. It is composed exclusively of alluvium on which no appreciable soil has developed. It stands 10 to 20 feet above low water, within the zone of occasional to frequent flooding. Although it is barren of artifacts and such datable material, the cottonwoods with which it is richly clothed attest to an age of less than 300 years. In fact, the surface whose cross section appears in figure 4 and which has been shown to be from 35 to more than 65 years in age is mapped by Schmitz (ms) as level 2. Using the generally accepted genetic definition of “terrace” as a flood plain abandoned by the downcutting of the river channel, Schmitz’s level 2 cannot be so designated. Evidence from exhumed cottonwood stems indicates that the riverbed elevation has remained reasonably stable during the last 150 years, and certainly within this span of time there has been no climatic change or shift in base level sufficient to produce degradation on the order of even 10 feet. Therefore in this report the distinction of these two levels is made by the descriptive terms “high flood plain” and “low flood plain”.

It cannot be denied, however, that the two levels of the flood plain are of different ages. The low flood plain is nowhere found occupied by cottonwoods older than 15 years and is largely inhabited by seedlings under 10 years of age. The high flood plain, on the other hand, rarely bears cottonwoods younger than 35 years in the North Unit and in the South Unit is apparently populated by cottonwoods only 50 or older. Although this hiatus in tree ages and elevation levels is not reflected by any discontinuity in the floodplain elevation curve (see fig. 5), its evidence appears in the scarcity of points plotted between the elevations of 7 and 10 feet. Evidently something occurred 15 to 30 years ago that either interrupted the cottonwood establishment sandbar accretion process or partially destroyed previously developed low-lying areas of the flood plain without seriously altering the absolute elevation of the riverbed.

Examination of water supply records for the Little Missouri reveal that on the 25th of March, 1947, the river crested at 24.0 feet (21 feet above low water) at the Watford City gage. This is the largest flood on record not only at Watford City where continuous records have been kept since 1935 but also at Medora, 50 miles up river, where records have been kept on and off since 1903. From the flood curves of McCabe and Crosby (1959), the flood of 1947 appears to be a 30 to 50 year event.
Runoff was estimated at 110,000 cfs. The flood of 1947 was followed by a 60,000 cfs discharge in April of 1950, which reached a gage height of 21.5 feet. The highest flood since that time has been one of 18,900 cfs on March 22, 1960. From examination of the aerial photographs, before and after (pl. 2-A, -B), it is evident that the flood of 1947 caused considerable widening of the channel, probably wiping out stands of young cottonwoods on either side of the former channel and pushing the riverbanks back to the scarp that now separates the flood-plain levels. Since then, or more likely, since the flood of 1950, the channel has been gradually shrinking to its former size, leaving the sandbars and cottonwood thickets of the low flood plain between itself and its 1947 flood banks. The series of diagrams in figure 9 illustrates how split-level flood-

![Diagram 1](image1.png)

**Symbols:**
- **Scour**
- **Fill**

**Fig. 9.** A hypothetical sequence of events showing the probable development of the Little Missouri channel.
1. A channel of average width is developed during a period of normal peak discharges.
2. The channel expands to accommodate extraordinary flow; sediment removed from channel banks may be deposited either overbank or in the bottom of the channel causing minor temporary channel aggradation.
3. Subsequent smaller flows favor construction of new flood plain by abandoning areas of the high-flood channel. These post-flood deposits are inset below the older flood plain. Material for floodplain construction is derived from channel bottom and banks.
4. Ultimately the terraced topography generated by channel expansion and contraction will be obliterated by further deposition and channel migration or a subsequent channel expansion.
plain topography may be produced by an extraordinary hydrographic event. Abiding by Colby’s (1964) law of continuity, floodplain sediment is shifted from place to place, but the total volume represented by the cross sectional area is kept constant, since no significant net addition or loss of sediment is expected during the short time involved. Although a ten-fold variation in the width of some channels is possible (Schumm and Lichty, 1963), such catastrophic changes do not appear to have occurred on the Little Missouri since 1880, when photographs taken of the channel at Medora show a width much the same as today’s. The 1947 flood appears to have increased the channel area by no more than 50 percent. Small scale fluctuations in channel width are very likely the principal agents in producing the even-aged bands of trees observed in the floodplain forest. A more accurate and thorough study similar to the present one could probably relate individual bands of trees to discreet hydrographic events.

CONCLUSIONS

Erosion, deposition, and channel migration, at both the trunk stream and tributary level, are operating in the valley of the Little Missouri at a rate that does not seem to have been appreciated by previous investigators. The continuous alluviation of flat and gently sloping surfaces in the valley bottom coupled with the continual migration of the channel and its sporadic flood-expansion is the only mechanism needed to explain the topography of the floor of the Little Missouri valley. Terrace-like topography may be formed by channel expansion and subsequent construction of a new floodplain inset within the flood channel. Local cat-step topography, a common feature of the valley, may be formed by repeated partial destruction of alluvial fans by lateral channel movement. Although downcutting by the Little Missouri may have occurred and is probably progressing at present although at a rate much slower than that of the processes cited above, it is not needed to account for the features observed. The only direct evidence of vertical channel stability indicates that during very recent times the river bed elevation has not changed appreciably.

In the absence of fossil or archaeological evidence nothing can be said of the age of alluvial fan remnants except that they are older than the deposits which are inset below them. It has been shown that deposition on these fans may raise the level of the valley floor to 50 feet above low water in less than 1000 years. Considering the rapid rate of migration of the channel and the fact that none of these alluvial deposits were observed to be buttressed by bedrock, it is improbable that any valley floor deposits above low water are as old as the end of the Wisconsin.

REFERENCES

in an investigation of the Recent history of a flood plain


