SCIENCE

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THE DRIFT OF PUBLIC discussion in England, not only among scientists, but also among athletes and others interested in physical training, seems to be against the acceptance of Professor Roy's defence of stays and corsets, at the recent meeting of the British Association. Some of the leading journals of London were instant in their approval of Professor Roy's theories; but where they have done so, immediate protests have come from their readers. *The Spectator*, for instance, in a recent number, after quoting Professor Roy's assertion that the desire for waist-belts is instructive, and has been displayed by all athletes, and persons of whom exertion is required, since the beginning of history, adds, "It will be observed that this argument, which is certainly true of all runners, Asiatic or European, applies to men equally with women, though men gird themselves only to meet special calls upon their strength." To this a recent graduate from Cambridge, where he was distinguished as a runner and long-distance bicycle-rider, protests that neither runners nor experts upon the wheel, at that university, ever used, or showed a desire to use, tight waist-belts. On the contrary, it was their custom to gird themselves as loosely as possible in order to allow free movement of the diaphragm. If rowers even wear waist-belts, they are so loose as to cause no interference with the freest movements of all the muscles of the body. It is probable that the habit of "girding up the loins" preparatory to physical exertion originated in Oriental countries, where in ancient times, and now as well, the peculiar form of the prevailing costume made it necessary in order to secure free movement of the limbs. A custom once established, needs no further explanation. It may survive long after there is any reason for it. The Hittites wore peaked-toed, turned-up shoes thousands of years after their ancestors had come from the mountains of the north, where the form of their snow-shoes suggested the peculiar fashion; and the daily life of every people is full of instances that might be cited. Nobody to day places restraint upon any of his organs if he desires to excel in feats of strength or speed. He may wear a waist-belt, but it is never so tight, as has already been remarked as to rowers, as to interfere with the free play of the muscles.

THE VERY ABLE PAPER on hydraulic degradation, by Director J. W. Powell, published elsewhere in this issue of *Science*, is the result — it would not be safe to say 'the final result' — of more than a dozen years of study and observation upon the subject. Former publications have simply indicated the direction in which this investigation was proceeding, and announced some of the conclusions reached. This is a comprehensive, brief, pointed, and easily understood exposition of the whole subject. *Science* congratulates itself upon being the first journal of its class, or of any class, to present this admirable paper to its readers. Major Powell is understood to invite comment, criticism, and discussion of the paper, and *Science* will gladly open its columns to communications on the subject.

THE APPROACHING RESIGNATION of Dr. John B. Hamilton, Surgeon-General of the Marine Hospital Service, to accept the editorship of the *Journal of the American Medical Association*, adds another to the frequent examples of the difficulty of retaining the bright men of science in the public service. During the last ten years Dr. Hamilton, by his energy and intimate knowledge of the service, has been able to carry out many reforms that could not otherwise have been effected. One very important one is the examination of pilots for color blindness, the establishment of new hospitals, the perfecting of the hospital regulations, which amounted to a thorough reorganization of the service and its general advancement, until, as *Colburn's United Service* (London) has declared, it is "the gem of the mercantile marine of the world." The means of preventing the spread of epidemics have been so simplified by Dr. Hamilton that most places subject to epidemic visitations have practically adopted the methods brought into use in this country by him. Dr. Hamilton's remarkable energy will soon make its effect felt in the pages of the *Journal*. Nothing is slow or dull that he has to do with, not even a medical journal. He will force others to quote from him, instead of making the *Journal*, as too many similar publications now are, a judicious selection of extracts from the exchanges. His Washington friends, of whom there are many, for he is personally very popular, will regret the loss of his society, but rejoice at his promotion.

THE LAWS OF HYDRAULIC DEGRADATION.[1]

THE lands of the earth are degraded by water, by ice, and by winds; hence in discussing geological degradation it becomes necessary to recognize hydraulic degradation, glacial degradation, and æolian degradation.

In hydraulic degradation three methods may be distinguished. 1. The surface of the land is disintegrated by various methods and washed away by rains and melted snows. The rains gather into streams, as brooks, creeks, and rivers, and transport the disintegrated rock from one region to another. This general surface degradation may be called 'erosion.' 2. During the process of this transportation the streams carve channels for themselves, and this channel-cutting may be called 'corrasion.' 3. By erosion, and also by corrasion, cliffs are produced, and these cliffs are broken down by gravity. This method of degradation may be called 'sapping.'

Thus there are three methods of hydraulic degradation, — erosion, corrasion, and sapping.

There are three processes involved in erosion: (*a*) the rocks are disintegrated; (*b*) the disintegrated material is transported in water; (*c*) in order to be transported in water the material must be loaded. In like manner, there are three processes in corrasion, — disintegration, loading, and transportation. In sapping there are but two processes, disintegration and falling.

In erosion and corrasion the material which is transported may be called the 'load.' The load is transported by two methods, a portion floats with the water, and another portion is driven along the bottom. The water in which the load floats is the 'vehicle' of transportation. Gravity is the force of transportation, and acts alike on the water and on the load. In the same sense that the water furnishes its own moving force, through its inherent gravity, so the floating load furnishes its own moving or transporting force through its inherent gravity. Vehicle and floating load alike are moved by gravity. The vehicle can move without the floating load, but the floating load cannot move without the vehicle; that is, the water is the agency of flotation for the load.

The floating load is in general of greater specific gravity than the water, and while floating, it falls to the bottom and comes to rest, and the progress down-stream of the floating load ends. The excursion which each particle will make from the time it is loaded to the time it is deposited depends upon four conditions: First, specific gravity. If the specific gravity is greater, the particle is deposited sooner; if the specific gravity is less, the particle is carried

[1] A paper read before the National Academy of Sciences at its meeting in New Haven, November, 1888.

farther. Second, degree of comminution. If the particle is larger, it will fall sooner; if the particle is smaller, it will be carried farther, for the smaller the particle the greater the supporting surface in proportion to its volume. Third, the velocity of the water. If the velocity is decreased, the excursion of the particle will be shortened; if the velocity is increased, the excursion of the particle will be lengthened. Fourth, the depth of the water. If the water is shallow, the floating particle will sooner reach the bottom; if the water is deeper, the particle will be carried farther before it strikes the bottom. In this subject, therefore, we have to consider the specific gravity of the load, the comminution of the load, the velocity of the water, and the depth of the water.

As the water runs down the channel, it may roll sediment along the bottom. This is the driven load. Such sediment is moved by the impact of the water from above. But in order to do this the materials on the bottom of the water must present up-stream surfaces on which impact may act; that is, the bottom of the channel must present heterogeneity of surface. This heterogeneity may be of such a nature that the passing water may by impact lift the particles from the bottom so that they will be transported in the vehicle by their own gravity. To the extent that materials are rolled along the bottom by impact, the energy of the water is utilized in transportation; but to the extent that transportation is accomplished by flotation, the gravity of the particles themselves is the entire force of transportation. Whatever is driven is transported by the energy of the water; whatever floats is transported by its own inherent gravity. This statement is made fully, because it is fundamental, and because the principles involved have been neglected and serious error has arisen therefrom.

The particles floating in a stream collide, and there arises therefrom inter-particle friction, but if in the collision between two particles one is retarded, the other must be accelerated. If the particles are broken or ground by the process, work is done, and the energy involved must be derived from the total energy of the moving water and load. Some energy, therefore, must be lost by it, but the disintegration arising therefrom promotes transportation, as the smaller particles make longer excursions. Heat is also developed and dissipated, but perhaps the quantities involved are unworthy of consideration.

There is a degree of comminution that so approximates molecular disintegration that some geologists and chemists believe that a *quasi* or *pseudo* combination between the water and the load results therefrom: if this be the case the character of the fluid is changed and the degree of fluidity is diminished. Here, again, it may be possible that the quantities involved are so small that they may be neglected.

The volume of water remaining the same, if the velocity of the water is increased, the depth of the water is diminished. Therefore the excursion of the particle will be lengthened by the increase of velocity, but shortened by the decrease of depth, and the one compensates the other. On the other hand, to increase the velocity of a stream enables it to drive larger particles; and this ability increases with the sixth power of the velocity.

The load increases the volume of the stream to the amount measured by its own volume, and the load increases the mass of the stream to the amount of its own mass; and as the load is of higher specific gravity than the water, the mass is increased at a higher rate than the volume. As load increases volume, it thereby increases velocity; and as load still further increases mass, it still further increases the effective energy of gravity.

In order that transportation by flotation may begin, the detritus must be loaded in the water, and when it sinks to the bottom it must be reloaded that flotation may be continued. In erosion, loading is primarily effected by the impact of raindrops. This loading is continued, and reloading is accomplished by the flow of the water over the surface through its impact against obstructions, and thus the wash of the surface is carried into the stream. But the load in the water sinks when, if the declivity is sufficient, it will be driven, but if the declivity is insufficient, conditions for its reloading must be produced. The driven load often becomes floating load when the water plunges over great declivities, but the chief method of reloading is by lateral corrasion: this arises in the case of deposits which are built up until they become portions of the banks of a stream and are subsequently attacked by the stream and carried away. Reloading is therefore chiefly accomplished by the process of lateral corrasion.

As the load is of greater specific gravity than the water, all load is over-load in the sense that the load must be deposited because the water is unable to permanently hold it in suspension. An extreme condition of load may be reached, which is sometimes exhibited in nature, in which the particles are so crowded that they cannot move freely in suspension; that is, they are in part held in suspension by the water and in part supported in position by one another, and still the particles may be so fine that they will slowly move down stream: in this case the water moves faster than the particles, and is strained through them at varying degrees. Thus partial hydraulic suspension may exist. At the one extremity the suspension may be so nearly perfect that the load is scarcely retarded thereby. At the other extremity the movement of the load may be wholly stopped and the water will be strained through it. Under such conditions streams may disappear from the surface and run wholly underground, and may re-appear when the accumulated sands have been passed. The accumulated sands may be of such an extent as to absorb all the water and hold it until it evaporates. Streams that thus empty into dry valleys and sand plains are abundant in arid regions.

The friction of pure water is so slight that where the formations are hard, corrasion cannot be accomplished thereby (all processes of solution are here neglected); but where the formation is incoherent, corrasion may progress through the impact of the water against the more or less disintegrated particles lying at the surface of the bottom and banks or on the 'wetted perimeter.' In this case the particles must present surfaces up stream, against which the flowing waters may act. The surface of the bottom and banks must be heterogeneous. Such disintegration must be accomplished by some instrument, and this is the load which passes along the channel in course of transportation; and it may be affirmed, that, other things being equal, the greater the load the greater the corrasion, and the less the load the less the corrasion. Again, the banks of the stream may be disintegrated by sapping, and loaded on the water by gravity, and the rate of lateral corrasion will be greatly increased thereby. But corrasion furnishes additional load, and it may be further affirmed that the greater the corrasion the greater the load, and the less the corrasion the less the load.

Rain is discharged from the surface of the land by flowing in the direction of greatest declivity, and as multiform heterogeneous and opposing declivities meet, the line of junction becomes the channel. A stream may thus have a line of maximum depth. If the channel is straight and homogeneous the line of maximum depth is the central line of the stream, which in many cases may be a broad zone; but it is deflected, now to one side and now to the other, by curvature and by a multiplicity of other conditions. The instrument of corrasion is the load, and chiefly the driven load which is drawn toward the line of maximum depth down the opposite declivities of the wetted perimeter by gravity, and thus corrasion is more or less concentrated along the line of maximum depth. Finally, the line of maximum depth is the line of greatest velocity, where impact is at a maximum. Hence it may be affirmed that in vertical corrasion the line of maximum depth is the line of maximum corrasion.

The geological formations into which channels are cut are greatly varied in constitution: they may be granite, basalt, limestone, sandstone, clay, alluvium, etc. Many degrees of hardness and coherence are presented in these varying materials. The beds themselves are not co-extensive with the land, but are always limited by the conditions of their production. Every such formation is a comparatively small bed of sand, gravel, clay, limestone, granite, etc., as the case may be, and the bed itself is variable in structure, as in thickness, hardness, and general constitution, through many degrees.

Geological formations are primarily horizontal, but subsequently they may be tilted by diastrophic agencies, so that some beds are horizontal, some are inclined at varying degrees, and others are vertical. Where in its course a stream passes from bed to bed, the conditions of corrasion are changed; the harder bed corrades with more difficulty, the softer bed with less. Where the beds are vertical, this change along the course is at a maximum; where the beds are horizontal the stream slowly passes from one bed to another by reason of its declivity, and when the dip of a formation coincides with the declivity of a stream, the change which arises in passing from one formation to another is reduced to a minimum.

Heterogeneity of terrain has an important effect upon corrasion. Hard beds are corraded with difficulty, soft beds with ease. By this means the channel is broken into sections or reaches, now shorter, now longer, with the varying heterogeneity of the terrain, so that soft beds present reaches of lower declivity and hard beds reaches of higher declivity. The low-declivity reaches are expanded and the high-declivity reaches are contracted. Where the changes are more abrupt the declivity becomes more abrupt, so that the stream may be made to plunge in a part of its course and to flow gently in another part. The efficiency of corrasion is greater in the softer reaches, but the corrading power of the stream is increased with declivity, and thus the corrading power is concentrated on the harder reaches.

Under the conditions so briefly set forth, the smallest stream has a more or less heterogeneous terrain, and a great river like the Mississippi possesses a terrain of indescribable heterogeneity.

As maximum corrasion is along the line of miximum flow, progressive deepening of channel produces progressive narrowing of the channel; but this tendency is counteracted in various ways. The narrowing of the channel is checked by the instability of the banks. If the banks are greatly coherent, long-continued corrasion may result in the formation of deep cañons. As cohesion becomes less, the banks fall into the stream and the channel is widened; and when the terrain is composed of disintegrated materials the channel is widened until the banks have the normal slope. If the terrain is permeable to water, the material creeps into the channel and the slope is still further reduced. Quicksands that become saturated to the level of the stream, flow out, and excessive widening results therefrom. In the progressive lateral corrasion of an alluvial bank by the impact of the stream which is turned against it, wetting secures disintegration, and the banks progressively fall into the water. When the wetted perimeter — which is that portion of the channel surface covered by water — is below the channel perimeter, sapping results, and the load is still further increased. Given sufficient time, indurated banks assume the normal slope. Alluvial banks speedily assume this condition through the agencies which, considered together, may be called 'weathering;' and through the ever-recurring wash of rains the slope is ever diminished. In like manner, the most indurated banks — as of basalt, granite, or limestone — are reduced to low slopes. The stream corrading vertically through indurated rocks steadily increases its vertical banks below, while the weathering steadily decreases them above; so that the height of the precipitous portion of the banks is the residual of opposing agencies.

Corrasion is greatly modified by the declivity of the stream. This declivity may be so great that no portion of the load is deposited along its course. All the load is transported by flotation or driving. Under these circumstances, if the terrain of the channel is sufficiently coherent, the corrasion will be wholly vertical, and its rate will increase with the declivity, as the impact of the corrading particles will be increased thereby. This vertical corrasion will produce cañons with precipitous walls until at last cliffs thus formed will be broken down by sapping. But when along the course of a stream the declivity is diminished so that any portion of the load is deposited, such deposit serves to protect the bottom of the channel and to check vertical corrasion, but at the same time the channel is choked by the material thrown down, and the waters passing down the channel are turned to one side, and lateral corrasion is inaugurated thereby. In the same manner lateral corrasion is produced by the sapping of the cliffs, as the fallen cliffs choke the channel of corrasion, and the river is thus turned against its banks, which are high walls. Lateral corrasion therefore arises from local deposition and from no other cause.

If the declivity of the stream is diminished to such an extent as to prevent vertical corrasion, whatever corrasion exists must be lateral corrasion; and here again, the greater the load the greater the deposition, and the greater the resulting corrasion.

When a river flows over a plain with declivity so low that vertical corrasion is wholly checked, it is in a condition where lateral corrasion is at a maximum under the existing circumstances. This lateral corrasion is greater as the load is greater. Other things being equal, declivity determines whether corrasion shall be vertical or lateral, through the intervention of deposition.

In vertical corrasion the load is the instrument by which the channel is abraded, and in lateral corrasion the load is still the instrument with which the work is performed, but it is used in a two-fold manner: (1) it is the agency by which the stream is turned against its banks, and (2) it is still an instrument of abrasion.

The volume of water is increased by every affluent: it is therefore progressively enlarged from source to mouth, and the conditions of corrasion and transportation are greatly modified thereby. At the junction of an affluent the volume of the stream is enlarged, and the rate of corrasion is increased, vertical or lateral, or both. If the declivity of the affluent is much greater than that of the principal stream, the affluent brings with it load too coarse to be further transported. In this manner the main river is choked, and is interrupted by a series of dams constructed by the affluents. This is especially remarkable in streams running in cañons. Where these conditions prevail, that form of the channel which is usually produced by heterogeneity of terrain — that is, by harder or softer formations — is sometimes obscured, or even obliterated, by affluent dams. The corrasion which results from increase of volume of water and sediment causes the channel below the affluent to be cut faster than the channel above. In this manner, *ceteris paribus*, a stream decreases in declivity from source to mouth, and a 'normal curvature of stream declivity' is produced thereby.

The volume of the stream is variable from time to time, as it depends upon the fall of rain and the melting of snow. This variable is great, as the flood-water volume may be many times that of the low-water volume. Increase of volume which arises in this manner manifests itself in part as an increase in cross-section and in part as an increase in velocity, and the rate both of transportation and corrasion is increased thereby. Corrasion and transportation are increased by another condition that arises simultaneously with the increase of volume. The rainfall which produces this increase also produces surface erosion. Surface erosion is intermittent, as it is caused only by the wash of rain and snow. When the storms come, the load is increased at a much higher rate than the volume of water in the stream. At low-water time the load is precipitated, and clear water flows in the stream, so that corrasion, transportation, and deposition are reduced, or even suspended. At flood time corrasion, transportation, and deposition are at a maximum. Whenever an affluent receives a local rain the volume of water is increased and the volume of load augmented at a still greater rate. When such an affluent discharges into a main stream which is slightly or not at all affected by the rainfall, the new load is at once thrown down, and the affluent dam is increased. Affluent dams are primarily formed by sudden decrease of declivity, and are greatly enlarged by local increase of volume. The effect of affluent dams is to stimulate lateral corrasion below. In a region of great declivity this is expressed in the widening of the channel; in a region of somewhat less declivity it is expressed in the enlargement of the flood-plain; and in a region of minimum declivity it is expressed in changing the position of the channel.

It has been shown that the channel of a stream is widened and narrowed by varied conditions of terrain. In soft formations it is expanded, in harder formations it is constricted. Another variable arises through the agency of affluent dams, as already explained. There is still another agency by which this heterogeneity is increased. The grand terrain of a river is subject to deformations, in such a manner that there may be upheaval in one part and subsidence in another. Subsidence alone may produce an expansion of channel at its locus, and upheaval may hold the waters back and produce expansion of the stream above the locus of displacement. By either or both of these methods the channels of great streams are largely modified, and even lakes are produced thereby. And streams are ponded by still other agencies that need not here be described. Stream-reaches expanded in this manner become areas of deposition where waters are largely discharged of load. In such cases streams are deprived of the instruments of corrasion, and corrasion is checked to the extent to which this is true. It has been seen that steep local declivities are formed by indurated geological formations and by affluent dams. The ponding of streams by diastrophic and other agencies tends to convert the rapids of such declivities into cataracts. The plunging waters checked at the foot of the declivity are loaded by the impact and thrown into gyratory movements, as currents and whirlpools, and corrasion is thus greatly intensified at that point; and when the stream above is deprived of its instrument of corrasion by ponding, the corrasion at the foot of the rapids is much more intense that at the head, and thus it is converted into a cataract. Where geological conditions for sapping are most favorable, that is, where the strata are approximately horizontal and composed of harder and softer material, the cataract condition is still further promoted. It is thus that heterogeneity of width increases heterogeneity of declivity.

When a stream deposits load, the place of deposit is governed by a great variety of conditions. First, reaches of low declivity are reaches of deposition, and in ponded reaches deposition is excessive; Second, alluvial dams are sites of deposition; Third, when a stream corrades vertically and cliff banks are sapped, the material is at once deposited; Fourth, when cliffs are formed by lateral corrasion in flood-terrains the load is carried down stream, but maximum deposition occurs at the first quiet water below; Fifth, deposition sites are often adventitious. The most common agency of this character exists in the flood-wood carried by the stream. A floating tree may lodge below a reach of great lateral corrasion at the head of a region of equilibrium, where there is no lateral corrasion, and near to one bank. The tree so lodged may gather other driftwood, and inaugurate deposition, so that a bank will be rapidly constructed and built up into an integral part of the terrain. By this agency the stream may be turned against the opposite bank, and a great river-curve with a radius of one or more miles may be established, and thus square miles of the flood-plain may be cut away through the accident of a lodging tree.

It has already been seen how increase of load transforms vertical corrasion into lateral corrasion. There are two noteworthy illustrations of this fact that may well be further explained. When the stream debouches from a mountain course of high declivity to a plain or valley course of low declivity, a part of its load is suddenly deposited, the channel is thereby choked, and vertical corrasion is transformed into lateral corrasion. The stream is thrown against one and then against the other bank, and a flaring gorge is produced with its opening to the valley side and its apex in the mountains or hills. At the same time a broad, over-placed deposit is made, called an alluvial cone or alluvial fan. In this case it will be seen that as vertical corrasion is transformed into lateral corrasion the total amount of corrasion is increased thereby.

The trunks of great streams often run in low valleys where the declivity is so slight that all corrasion is lateral. Here the load is deposited, not uniformly throughout the channel, but wherever there are reaches of quiet water. The deposition from the initial load becomes less and less down stream from place of deposit to place of deposit. At every place of deposit a bank or bar is formed, which progressively becomes an impediment to the stream and around which the stream is turned in a curve. As it is diverted from its course it strikes with force against the opposite bank, and into this bank it corrades. If the banks are but slightly coherent the stream is loaded again with new material. This is greatly increased when the banks are cut in such a manner that the method of degradation by sapping is initiated, and this sapping is itself made more efficient if there are permeable strata into which the water penetrates so as to assist in sapping. The new load taken on in this manner serves further to choke the stream as it adds to the deposits below. In this manner the stream is turned against its banks at comparatively short intervals, and every curve is increased. This agency for the increase of tortuosity is counteracted by three other conditions that arise. First, two contiguous curves in the same river may increase until they coalesce, and a cut-off is established; Second, the increasing tortuosity is increasing length, and increasing length produces decreasing declivity, and the local corrasion is diminished thereby; Third, as the river swings from bluff to bluff across its flood-plain, by lateral corrasion, it works the materials over and over again, and grinds and regrinds the materials composing the banks; so that in the general average, the alluvium of the lower reach of the flood-plain is more finely comminuted than the alluvium of the upper reach. For this reason the load which is added from time to time in the downward course of the stream is more and more comminuted. Flotation is thus promoted; that is, the particles are held in suspension longer. The effect of this is that the particles make longer excursions and therefore choke the river less, and gradually they are robbed of their power of inducing corrasion. For this reason, when all the conditions are present, rivers running through low flood-plains become less and less tortuous as they approach their outlets — a condition well illustrated by the Mississippi River between Cairo and the Gulf. This law of tortuosity is interrupted wherever a lateral stream brings coarse material into the reach subject to the law.

In a stream where corrasion is wholly vertical the deposited load is driven along the bottom and reloaded from time to time, and the channel is thus kept clear of fixed deposits; but when a lesser degree of declivity is reached, so that the deposits choke the channel and cause lateral corrasion, the several deposits remain for a time to be attacked by the stream, which shifts its channel gradually or abruptly, as the case may be. When the declivity decreases to such an extent that corrasion is wholly lateral, the deposits become more permanent. A deposit once made is protected by subsequent deposits, and the process continues until bars and banks are built up into integral parts of the alluvial terrain. By this process the stream is turned against some other portion of the terrain, and loads itself again with new material. In the vicissitudes of channel-cutting recent bars and banks may sometimes be destroyed, but very rarely. To a large degree the deposits become permanent obstructions, continually increasing, until the river is wholly turned out of its course. By this process the tortuosity is produced and the channel is made to wander back and forth through the flood-terrain. In one sense the whole flood-plain valley, or rather the channel occupied by alluvial terrain, is the channel of the stream, and is occupied in part by the river and in part by deposits.

In this connection these two laws may be formulated: (*a*) When sediment is deposited it ultimately causes other sediment to be loaded; (*b*) The wider the flood-plain in proportion to the volume of the water, the greater will be the average length of time through which each deposit remains in place.

The forces of degradation are established by nature, and in general cannot be increased or diminished by man, and he can only control their operation to a limited degree. All of the forces in hydraulic degradation are of vast magnitude, and are far in excess of the powers actually utilized in the production of results, and when man deals with them he deals only with conditions. To make this clear to the mind, some illustrations may be useful. The following may serve for this purpose. The flood-plain valley of the Mississippi from Cairo to the jetties is about 550 miles in length and about 49 miles in breadth; that is, it has an area of about 27,000 square miles. If this flood-terrain be estimated to have an average depth of 50 feet, it would give a geological formation of about 250 cubic miles, which is wholly alluvial.

The forces of erosion are chiefly found in the precipitation of rain and snow from the heavens, and in the changes of the temperature from hour to hour and from season to season. Now let us suppose that all these forces could be utilized in the erosion of the described Mississippi flood-terrain, as they are sometimes utilized in bad-land hills, then the rate of erosion would be enormously accelerated. To get a clearer conception of these conditions, suppose that the whole flood-terrain were built into a system of hills having the normal slope of loose earth, and that between the hills there existed a ramification of streams, as rivers, creeks, brooks, and rills, and that the whole region was sufficiently elevated above the sea to give these streams a rapid flow, and that the rainfall of the region remains the same as at present, and that there be no protection from vegetation or other agencies, — then the present rainfall would erode away the described flood-terrain in less than five decades. Such conditions are sometimes found in nature, though rarely.

Now let there be built up in the mind a possible rate of corrasion when the conditions for the highest rate are at a maximum. The Mississippi River has been known to cut its banks at the rate of a mile a month, and yet the river was not utilized to the extent of its power; in fact, but a modicum of its corrading energy was brought into play. Using still the flood-terrain as above described, let it be supposed that the river is turned against it in such a manner that the whole mechanical energy of the stream is directed against it, and suppose further that as fast as the banks are torn down by the impact of the water and the sapping of the banks the material is promptly carried away through the agency of great declivity, then the whole terrain would be carried away in less than ten years.

Next, let the rate of transportation under maximum conditions be illustrated, and still let the described flood-terrain be used for this purpose. Suppose that the terrain could be loaded upon the Mississippi in such a manner that the waters are constantly supplied to their utmost capacity. Now it has been observed in Utah, and again in Colorado in the case of certain bad-land streams, that under most favorable conditions water is capable of transporting its own volume of load. The Mississippi River annually discharges into the Gulf an average of one million cubic feet per second. If this volume of water were loaded to its utmost capacity, as described above, the flood-terrain of the Mississippi would be discharged into the Gulf in one year.

The rate of corrasion is subject to many interdependent variable conditions, Only the laws of the first order have been presented. There is still a great number of conditions of a second order to be considered; but they do not in any material way vitiate the laws already stated. The facts and principles that have been presented are those which the engineer must use in planning and constructing irrigation works. They are also of importance in dealing with the regimen of rivers for the purpose of improving navigation, and for the still more important purpose of protecting flood-plains from overflow. It is proposed here to call attention to some of the engineering methods which have been used to control rivers for the protection of flood-plains. Those selected for mention in this manner are as follows.

The banks of the stream may be protected from lateral corrasion by revetment, but such protection will be sufficient only to the extent to which it is applied; for thorough protection both banks must be revetted throughout the whole length of the flood-plain reach. And further, the revetment must be carried below the level of possible vertical corrasion or the revetment will be undermined. By this method the channel is protected from the choking which arises from the deposition of materials brought in from upper reaches, lateral tributaries, and local erosion. In a bank-protected channel along a flood-plain reach there is a constant tendency to distribute the obstructing deposits evenly along the bottom, as the lower declivities are sites of deposits and the higher declivities present conditions of increased vertical corrasion. In a river with uniform channel and uniform volume of water the deposition is uniformly diminished from head to foot, and such a stream builds up its channel until a degree of declivity is reached sufficient to carry away all the supply of load. If the declivity is more than sufficient to carry away the load supply, vertical corrasion is inaugurated and the channel is deepened. If the declivity is insufficient to carry away the supply of load, the deposit of sediment will build up the channel, and destructive floods will be increased thereby. Revetment, therefore, is efficient only on the condition that the declivity is exactly sufficient to carry away the load and to produce no further corrasion; for if vertical corrasion be increased, the revetment will be undermined and destroyed, and if vertical corrasion is insufficient, deposits will be made and floods will result. The practical problem, therefore, is to decide whether the declivity is or is not sufficient to preserve the channel. This problem is always solved by nature, and its solution is made perfectly plain. If the declivity of the flood-plain reach is sufficient to preserve the channel, the channel will be preserved, and there will be no lateral corrasion. Every flood-terrain is such because the channel of the stream has an insufficient declivity for its own protection. The very fact that corrasion is wholly lateral is in itself an absolute demonstration that the declivity of the stream is insufficient for the protection of the channel. This arises from the fact that the load once deposited remains, as the channel does not present conditions for its reloading: revetment, therefore, is necessarily futile, except for local and temporary purposes.

If portions of the banks of a channel are revetted, the only result arising therefrom is to change the locus of lateral corrasion; for, the total deposits remaining the same, the total lateral corrasion will remain the same. If the whole channel is revetted, the whole channel will be built up thereby, and ever a greater volume of water will be distributed over the flood-plain, until the channel is entirely filled at its head, or built up to such a declivity that vertical corrasion will be sufficient to preserve the channel.

There are four other methods that have been presented by engineers and geologists still worthy of consideration, as they are more or less efficient, either separately or conjointly. These are as follows.

1. The channel of the stream may have its banks and bars removed, and it may be deepened by river ploughs. To be efficient, the clearing of the channel of its deposited obstructions must be complete. The effect of clearing a lower reach is not extended to an upper reach, but the effect of clearing an upper reach is to increase the obstructions of the lower. For this reason the channel must be cleared its entire length throughout the region to be protected from floods at one effort.

2. The channel of the river may be shortened. By this method the declivity of the stream will be increased, the velocity of the current increased, and the waters more rapidly discharged. At the same time the channel of the stream will be deepened progressively from the foot to the head of the reach, where the stream runs through alluvial formations; but wherever the stream has its bed in indurated rocks the progress of stream deepening will be retarded.

The shortening of the channel may be accomplished by two methods.

a. By establishing a nearer outlet.

b. By utilizing and promoting cut-off reaches.

3. The headwaters and tributaries may be impounded in reservoirs at flood time and held until low water, and the volume through the year may thus be more or less equalized.

4. The headwaters and tributaries of a river may have their waters drawn off into settling basins, and thus they may be caused to discharge the sediment they carry, which is the material which forms the deposits and chokes the channel, and also the instrument of lateral corrasion.

It is manifest that the storage of water and the discharge of sediment may be accomplished by the same agency.

It is the purpose here merely to mention the principal efficient methods of controlling rivers in their flood-plain reaches. Every river presents problems more or less peculiar to itself, and the application to special cases of the laws which have been set forth is one of great interest and of profound importance.

J. W. POWELL.

COMMERCIAL GEOGRAPHY.

The Care of our Forests.

IN the annual report of the Department of Agriculture, B. E. Fernow, chief of the forestry division, dwells most emphatically upon the necessity of adopting a sound policy regarding our forests. His interesting report is accompanied by a map showing the distribution of forests in the Rocky Mountains, where they serve the important purpose of regulating the flow of springs and streams. Mr. Fernow's weighty arguments and urgent demands for better care of our forests ought to attract the most speedy attention of our legislators. He says, —

"It has become evident, in spite of the enormous supplies which seemed to be available, that our natural forests are being rapidly reduced, both by an increased demand and by wasteful practices; and it is now safe to say that the annual consumption of wood and wood-products is at least double the amount reproduced on our present forest area. The forest, under proper management, is capable of furnishing continuous crops, and therefore, as a source of constant supply, demands national legislation.

"It has become evident, that with the unrestrained scourge of fire and the destruction by herding, and other malpractices now prevalent, and in the absence of all rational forest management, not only is the remaining forest deteriorated in material value, but large tracts of land are converted into absolute deserts or useless bar-