CHAPTER V.

LAND SCULPTURE.

The Basin of the Colorado offers peculiar facilities for the study of the origin of topographic forms, and its marvelous sculpture has excited the interest of every observer. It has already made notable contributions to the principles of earth sculpture*, and its resources are far from exhausted. The study of the Henry Mountains has not proved entirely unfruitful, and for the sake of showing the bearing of its peculiar features upon the general subject, I shall take the liberty to restate certain principles of erosion which have been derived or enforced by the study of the Colorado Plateaus.

I.—EROSION.

The sculpture and degradation of the land are performed partly by shore-waves, partly by glaciers, partly by wind; but chiefly by rain and running water. The last mentioned agencies only will be here discussed.

The erosion which they accomplish will be considered (A) as consisting of parts, and (B) as modified by conditions.

A. PROCESSES OF EROSION.

All indurated rocks and most earths are bound together by a force of cohesion which must be overcome before they can be divided and re-

* Geology of the "Colorado Exploring Expedition", by J. S. Newberry, p. 45.

"Exploration of the Colorado River of the West", by J. W. Powell, p. 152.

"Geology of the Uinta Mountains", by J. W. Powell, p. 181.

"Explorations West of the 100th Meridian", Vol. III, Part I, by G. K. Gilbert, pp. 67 and 554.

"The Colorado Plateau Region" in American Journal of Science for August, 1876, by G. K. Gilbert.

A portion of the last paper is repeated, after modification, in the first section of this chapter.

moved. The natural processes by which the division and removal are accomplished make up erosion. They are called disintegration and transportation.

Transportation is chiefly performed by running water.

Disintegration is naturally divided into two parts. So much of it as is accomplished by running water is called corrasion, and that which is not, is called weathering.

Stated in their natural order, the three general divisions of the process of erosion are (1) *weathering*, (2) *transportation*, and (3) *corrasion*. The rocks of the general surface of the land are disintegrated by *weathering*. The material thus loosened is *transported* by streams to the ocean or other receptacle. In transit it helps to *corrade* from the channels of the streams other material, which joins with it to be transported to the same goal.

Weathering.

In weathering the chief agents of disintegration are solution, change of temperature, the beating of rain, gravity, and vegetation.

The great solvent of rocks is water, but it receives aid from some other substances of which it becomes the vehicle. These substances are chiefly products of the formation and decomposition of vegetable tissues. Some rocks are disintegrated by their complete solution, but the great majority are divided into grains by the solution of a portion; and fragmental rocks usually lose by solution the cement merely, and are thus reduced to their original incoherent condition.

The most rigid rocks are cracked by sudden changes of temperature; and the crevices thus begun are opened by the freezing of the water within them. The coherence of the more porous rocks is impaired and often destroyed by the same expansive force of freezing water.

The beating of the rain overcomes the feeble coherence of earths, and assists solution and frost by detaching the particles which they have partially loosened.

When the base of a cliff is eroded so as to remove or diminish the support of the upper part, the rock thus deprived of support is broken off in blocks by gravity. The process of which this is a part is called cliff-erosion or *sapping*.

Plants often pry apart rocks by the growth of their roots, but their chief aid to erosion is by increasing the solvent power of percolating water.

In general soft rocks weather more rapidly than hard.

Transportation.

A portion of the water of rains flows over the surface and is quickly gathered into streams. A second portion is absorbed by the earth or rock on which it falls, and after a slow underground circulation reissues in springs. Both transport the products of weathering, the latter carrying dissolved minerals and the former chiefly undissolved.

Transportation is also performed by the direct action of gravity. In sapping, the blocks which are detached by gravity are by the same agency carried to the base of the cliff.

Corrasion.

In corrasion the agents of disintegration are solution and mechanical wear. Wherever the two are combined, the superior efficiency of the latter is evident; and in all fields of rapid corrasion the part played by solution is so small that it may be disregarded.

The mechanical wear of streams is performed by the aid of hard mineral fragments which are carried along by the current. The effective force is that of the current; the tools are mud, sand, and bowlders. The most important of them is sand; it is chiefly by the impact and friction of grains of sand that the rocky beds of streams are disintegrated.

Streams of clear water corrade their beds by solution. Muddy streams act partly by solution, but chiefly by attrition.

Streams transport the combined products of corrasion and weathering. A part of the *débris* is carried in solution, and a part mechanically. The finest of the undissolved detritus is held in suspension; the coarsest is rolled along the bottom; and there is a gradation between the two modes. There is a constant comminution of all the material as it moves, and the work of transportation is thereby accelerated. Bowlders and pebbles, while they wear the stream-bed by pounding and rubbing, are worn still more rapidly themselves. Sand grains are worn and broken by the continued jostling, and their fragments join the suspended mud. Finally the detritus is all more or less dissolved by the water, the finest the most rapidly.

In brief, weathering is performed by solution; by change of temperature, including frost; by rain beating; by gravity; and by vegetation. Transportation is performed chiefly by running water. Corrasion is performed by solution, and by mechanical wear.

Corrasion is distinguished from weathering chiefly by including mechanical wear among its agencies, and the importance of the distinction will be apparent when we come to consider how greatly and peculiarly this process is affected by modifying conditions.

B. CONDITIONS CONTROLLING EROSION.

The chief conditions which affect the rapidity of erosion are (1) declivity, (2) character of rock, and (3) climate

Rate of Erosion and Declivity.

In general *erosion is most rapid where the slope is steepest;* but weathering, transportation, and corrasion are affected in different ways and in different degrees.

With increase of slope goes increase in the velocity of running water, and with that goes increase in its power to transport undissolved detritus.

The ability of a stream to corrade by solution is not notably enhanced by great velocity; but its ability to corrade by mechanical wear keeps pace with its ability to transport, or may even increase more rapidly. For not only does the bottom receive more blows in proportion as the quantity of transient detritus increases, but the blows acquire greater force from the accelerated current, and from the greater size of the moving fragments. It is necessary however to distinguish the ability to corrade from the rate of corrasion, which will be seen further on to depend largely on other conditions.

Weathering is not directly influenced by slope, but it is reached indirectly through transportation. Solution and frost, the chief agents of rock decay, are both retarded by the excessive accumulation of disintegrated rock. Frost action ceases altogether at a few feet below the surface, and solution gradually decreases as the zone of its activity descends and the circulation on which it depends becomes more sluggish. Hence the rapid removal of the products of weathering stimulates its action, and especially that portion of its action which depends upon frost. If however the power of transportation is so great as to remove completely the products of weathering, the work of disintegration is thereby checked; for the soil which weathering tends to accumulate is a reservoir to catch rain as it reaches the earth and store it up for the work of solution and frost, instead of letting it run off at once unused.

Sapping is directly favored by great declivity.

In brief, a steep declivity favors transportation and thereby favors corrasion. The rapid, but partial, transportation of weathered rock accelerates weathering; but the complete removal of its products retards weathering.

Rate of Erosion and Rock Texture.

Other things being equal, *erosion is most rapid when the eroded rock offers least resistance;* but the rocks which are most favorable to one portion of the process of erosion do not necessarily stand in the same relation to the others. Disintegration by solution depends in large part on the solubility of the rocks, but it proceeds most rapidly with those fragmental rocks of which the cement is soluble, and of which the texture is open. Disintegration by frost is most rapid in rocks which absorb a large percentage of water and are feebly coherent. Disintegration by mechanical wear is most rapid in soft rocks.

Transportation is most favored by those rocks which yield by disintegration the most finely comminuted *débris.*

Rate of Erosion and Climate.

The influence of climate upon erosion is less easy to formulate. The direct influences of temperature and rainfall are comparatively simple, but their indirect influence through vegetation is complex, and is in part opposed to the direct.

Temperature affects erosion chiefly by its changes. Where the range of temperature includes the freezing point of water, frost contributes its powerful aid to weathering; and it is only where changes are great and sudden that rocks are cracked by their unequal expansion or contraction.

All the processes of erosion are affected directly by the amount of rainfall, and by its distribution through the year. All are accelerated by its increase and retarded by its diminution. When it is concentrated in one part of the year at the expense of the remainder, transportation and corrasion are accelerated, and weathering is retarded.

Weathering is favored by abundance of moisture. Frost accomplishes most when the rocks are saturated; and solution when there is the freest subterranean circulation. But when the annual rainfall is concentrated into a limited season, a larger share of the water fails to penetrate, and the gain from temporary flooding does not compensate for the checking of all solution by a long dry season.

Transportation is favored by increasing water supply as greatly as by increasing declivity. When the volume of a stream increases, it becomes at the same time more rapid, and its transporting capacity gains by the increment to velocity as well as by the increment to volume. Hence the increase in power of transportation is more than proportional to the increase of volume.

It is due to this fact chiefly that the transportation of a stream which is subject to floods is greater than it would be if its total water supply were evenly distributed in time.

The indirect influence of rainfall and temperature, by means of vegetation, has different laws. Vegetation is intimately related to water supply. There is little or none where the annual precipitation is small, and it is profuse where the latter is great—especially where the temperature is at the same time high. In proportion as vegetation is profuse the solvent power of percolating water is increased, and on the other hand the ground is sheltered from the mechanical action of rains and rills. The removal of disintegrated rock is greatly impeded by the conservative power of roots and fallen leaves, and a soil is thus preserved. Transportation is retarded. Weathering by solution is accelerated up to a certain point, but in the end it suffers by the clogging of transportation. The work of frost is nearly stopped as soon as the depth of soil exceeds the limit of frost action. The force of rain drops is expended on foliage. Moreover a deep soil acts as a distributing reservoir for the water of rains, and tends to equalize the flow of streams.

Hence the general effect of vegetation is to retard erosion; and since the direct effect of great rainfall is the acceleration of erosion, it results that its direct and indirect tendencies are in opposite directions.

In arid regions of which the declivities are sufficient to give thorough drainage, the absence of vegetation is accompanied by absence of soil. When a shower falls, nearly all the water runs off from the bare rock, and the little that is absorbed is rapidly reduced by evaporation. Solution becomes a slow process for lack of a continuous supply of water, and frost accomplishes its work only when it closely follows the infrequent rain. Thus weathering is retarded. Transportation has its work so concentrated by the quick gathering of showers into floods, as to compensate, in part at least, for the smallness of the total rainfall from which they derive their power.

Hence in regions of small rainfall, surface degradation is usually limited by the slow rate of disintegration; while in regions of great rainfall it is limited by the rate of transportation. There is probably an intermediate condition with moderate rainfall, in which a rate of disintegration greater than that of an arid climate is balanced by a more rapid transportation than consists with a very moist climate, and in which the rate of degradation attains its maximum.

Over nearly the whole of the earth's surface there is a soil, and wherever this exists we know that the conditions are more favorable to weathering than to transportation. Hence it is true in general that the conditions which limit transportation are those which limit the general degradation of the surface.

To understand the manner in which this limit is reached it is necessary to look at the process by which the work is accomplished.

Transportation and Comminution.

A stream of water flowing down its bed expends an amount of energy that is measured by the quantity of water and the vertical distance through which it descends. If there were no friction of the water upon its channel the velocity of the current would continually increase; but if, as is the usual case, there is no increase of velocity, then the whole of the energy is consumed in friction. The friction produces inequalities in the motion of the water, and especially induces subsidiary currents more or less oblique to the general onward movement. Some of these subsidiary currents have an upward tendency, and by them is performed the chief work of transportation. They lift small particles from the bottom and hold them in suspension while they move forward with the general current. The finest particles sink most slowly and are carried farthest before they fall. Larger ones are barely lifted, and are dropped at once. Still larger are only half lifted; that is, they are lifted on the side of the current and rolled over without quitting the bottom. And finally there is a limit to the power of every current, and the largest fragments of its bed are not moved at all.

There is a definite relation between the velocity of a current and the size of the largest bowlder it will roll. It has been shown by Hopkins that the weight of the bowlder is proportioned to the sixth power of the velocity. It is easily shown also that the weight of a suspended particle is proportioned to the sixth power of the velocity of the upward current that will prevent its sinking. But it must not be inferred that the total load of detritus that a stream will transport bears any such relation to the rapidity of its current. The true inference is, that the velocity determines the size-limit of the detritus that a stream can move by rolling, or can hold in suspension.

Every particle which a stream lifts and sustains is a draft upon its energy, and the measure of the draft is the weight (weighed in water) of the particle, multiplied by the distance it would sink in still water in the time during which it is suspended. If for the sake of simplicity we suppose the whole load of a stream to be of uniform particles, then the measure of the energy consumed in their transportation is their total weight multiplied by the distance one of them would sink in the time occupied in their transportation. Since fine particles sink more slowly than coarse, the same consumption of energy will convey a greater load of fine than of coarse.

Again, the energy of a clear stream is entirely consumed in the friction of flow; and the friction bears a direct relation to its velocity. But if detritus be added to the water, then a portion of its energy is diverted to the transportation of the load; and this is done at the expense of the friction of flow, and hence at the expense of velocity. As the energy expended in transportation increases, the velocity diminishes. If the detritus be composed of uniform particles, then we may also say that as the load increases the velocity diminishes. But the diminishing velocity will finally reach a point at which it can barely transport particles of the given size, and when this point is attained, the stream has its maximum load of detritus of the given size. But fine detritus requires less velocity for its transportation than coarse, and will not so soon reduce the current to the limit of its efficiency. A greater percentage of the total energy of the stream can hence be employed by fine detritus than by coarse.

(It should be explained that the friction of flow is in itself a complex affair. The water in contact with the bottom and walls of the channel develops friction by flowing past them, and that which is farther away by flowing past that which is near. The inequality of motion gives rise to cross currents and there is a friction of these upon each other. The ratio or coefficient of friction of water against the substance of the bed, the coefficient of friction of water against water, or the viscosity of water, and the form of the bed, all conspire to determine the resistance of flow and together make up what may be called the coefficient of the friction of flow. The friction depends on its coefficient and on the velocity.)

Thus the capacity of a stream for transportation is enhanced by comminution in two ways. Fine detritus, on the one hand, consumes less energy for the transportation of the same weight, and on the other, it can utilize a greater portion of the stream's energy.

It follows, as a corollary, that the velocity of a fully loaded stream depends *(ceteris paribus)* on the comminution of the material of the load. When a stream has its maximum load of fine detritus, its velocity will be less than when carrying its maximum load of coarse detritus; and the greater load corresponds to the less velocity.

It follows also that a stream which is supplied with heterogeneous *débris* will select the finest. If the finest is sufficient in quantity the current will be so checked by it that the coarser cannot be moved. If the finest is not sufficient the next grade will be taken, and so on.

Transportation and Declivity.

To consider now the relation of declivity to transportation we will assume all other conditions to be constant. Let us suppose that two streams have the same length, the same quantity of water, flow over beds of the same character, and are supplied to their full capacities with detritus of the same kind; but differ in the total amount of fall. Their declivities or rates of fall are proportional to their falls. Since the energy of a stream is measured by the product of its volume and its fall, the relative energies of the two streams are proportional to their falls, and hence proportional to their declivities. The velocities of the two streams, depending, as we have seen above, on the character of the detritus which loads them, are the same; and hence the same amount of energy is consumed by each in the friction of flow. And since the energy which each stream expends in transportation is the residual after deducting what it spends in friction from its total energy, it is evident that the stream with the greater declivity will not merely have the greater energy, but will expend a less percentage of it in friction and a greater percentage in transportation.

Hence declivity favors transportation in a degree that is greater than its simple ratio.

There are two elements of which no account is taken in the preceding discussion, but which need to be mentioned to prevent misapprehension, although they detract in no way from the conclusions.

The first is the addition which the transported detritus makes to the energy of the stream. A stream of water charged with detritus is at once a compound and an unstable fluid. It has been treated merely as an unstable fluid requiring a constant expenditure of energy to maintain its constitution; but looking at it as a compound fluid, it is plain that the energy it develops by its descent is greater than the energy pertaining to the water alone, in the precise ratio of the mass of the mixture to the mass of the simple water.

The second element is the addition which the detritus makes to the friction of flow. The coefficient of friction of the compound stream upon its bottom will always be greater than that of the simple stream of water, and the coefficient of internal friction or the viscosity will be greater than that of pure water, and hence for the same velocity a greater amount of energy will be consumed.

It may be noted in passing, that the energy which is consumed in the friction of the detritus on the stream bed, accomplishes as part of its work the mechanical corrasion of the bed.

Transportation and Quantity of Water.

A stream's friction of flow depends mainly on the character of the bed, on the area of the surface of contact, and on the velocity of the current. When the other elements are constant, the friction varies approximately with the area of contact. The area of contact depends on the length and form of the channel, and on the quantity of water. For streams of the same length and same form of cross-section, but differing in size of cross-section, the area of contact varies directly as the square root of the quantity of water. Hence, *ceteris paribus*, the friction of a stream on its bed is proportioned to the square root of the quantity of water. But as stated above, the total energy of a stream is proportioned directly to the quantity of water; and the total energy is equal to the energy spent in friction, plus the energy spent in transportation. Whence it follows that if a stream change its quantity of water without changing its velocity or other accidents, the total energy will change at the same rate as the quantity of water; the energy spent in friction will change at a less rate, and the energy remaining for transportation will change at a greater rate.

Hence increase in quantity of water favors transportation in a degree that is greater than its simple ratio.

It follows as a corollary that the running water which carries the *débris* of a district loses power by subdivision toward its sources; and that, unless there is a compensating increment of declivity, the tributaries of a river will fail to supply it with the full load it is able to carry.

It is noteworthy also that the obstruction which vegetation opposes to transportation is especially effective in that it is applied at the infinitesimal sources of streams, where the force of the running water is least.

A stream which can transport *débris* of a given size, may be said to be *competent* to such *débris*. Since the maximum particles which streams are able to move are proportioned to the sixth powers of their velocities, competence depends on velocity. Velocity, in turn, depends on declivity and volume, and (inversely) on load.

In brief, the capacity of a stream for transportation is greater for fine *débris* than for coarse.

Its capacity for the transportation of a given kind of *débris* is enlarged in more than simple ratio by increase of declivity; and it is enlarged in more than simple ratio by increase of volume.

The competence of a stream for the transport of *débris* of a given fineness, is limited by a corresponding velocity.

The *rate* of transportation of *débris* of a given fineness may equal the capacity of the transporting stream, or it may be less. When it is less, it is always from the insufficiency of supply. The supply furnished by weathering is never available unless the degree of fineness of the *débris* brings it within the competence of the stream at the point of supply.

The chief point of supply is at the very head of the flowing water. The rain which falls on material that has been disintegrated by weathering, begins after it has saturated the immediate surface to flow off. But it forms a very thin sheet; its friction is great; its velocity is small; and it is competent to pick up only particles of exceeding fineness. If the material is heterogeneous, it discriminates and leaves the coarser particles. As the sheet moves on it becomes deeper and soon begins to gather itself into rills. As the deepening and concentration of water progresses, either its *capacity* increases and the load of fine particles is augmented, or, if fine particles are not in sufficient force, its *competence* increases, and larger ones are lifted. In either case the load is augmented, and as rill joins rill it steadily grows, until the accumulated water finally passes beyond the zone of disintegrated material.

The particles which the feeble initial currents are not competent to move, have to wait either until they are subdivided by the agencies of weathering, or until the deepening of the channels of the rills so far increases the declivities that the currents acquire the requisite velocity, or until some fiercer storm floods the ground with a deeper sheet of water.

Thus rate of transportation, as well as capacity for transportation, is favored by fineness of *débris*, by declivity, and by quantity of water. It is opposed chiefly by vegetation, which holds together that which is loosened by weathering, and shields it from the agent of transportation in the very place where that agent is weakest.

When the current of a stream gradually diminishes in its course—as for example in approaching the ocean—the capacity for transportation also diminishes; and so soon as the capacity becomes less than the load, precipitation begins—the coarser particles being deposited first.

Corrasion and Transportation.

Where a stream has all the load of a given degree of comminution which it is capable of carrying, the entire energy of the descending water and load is consumed in the translation of the water and load and there is none applied to corrasion. If it has an excess of load its velocity is thereby diminished so as to lessen its competence and a portion is dropped. If it has less than a full load it is in condition to receive more and it corrades its bottom.

A fully loaded stream is on the verge between corrasion and deposition. As will be explained in another place, it may wear the walls of its channel, but its wear of one wall will be accompanied by an addition to the opposite wall.

The work of transportation may thus monopolize a stream to the exclusion of corrasion, or the two works may be carried forward at the same time.

Corrasion and Declivity.

The rapidity of mechanical corrasion depends on the hardness, size, and number of the transient fragments, on the hardness of the rock-bed, and on the velocity of the stream. The blows which the moving fragments deal upon the stream-bed are hard in proportion as the fragments are large and the current is swift. They are most effective when the fragments are hard and the bed-rock is soft. They are more numerous and harder upon the bottom of the channel than upon the sides because of the constant tendency of the particles to sink in water. Their number is increased up to a certain limit by the increase of the load of the stream; but when the fragments become greatly crowded at the bottom of a stream their force is partially spent among themselves, and the bed-rock is in the same degree protected. For this reason, and because increase of load causes retardation of current, it is probable that the maximum work of corrasion is performed when the load is far within the transporting capacity.

The element of velocity is of double importance since it determines not only the speed, but to a great extent the size of the pestles which grind the rocks. The coefficients upon which it in turn depends, namely, declivity and quantity of water, have the same importance in corrasion that they have in transportation.

Let us suppose that a stream endowed with a constant volume of water, is at some point continuously supplied with as great a load as it is capable of carrying. For so great a distance as its velocity remains the same, it will neither corrade (downward) nor deposit, but will leave the grade of its bed unchanged. But if in its progress it reaches a place where a less declivity of bed gives a diminished velocity, its capacity for transportation will become less than the load and part of the load will be deposited. Or if in its progress it reaches a place where a greater declivity of bed gives an increased velocity, the capacity for transportation will become greater than the load and there will be corrasion of the bed. In this way a stream which has a supply of *débris* equal to its capacity, tends to build up the gentler slopes of its bed and cut away the steeper. It tends to establish a single, uniform grade.

Let us now suppose that the stream after having obliterated all the inequalities of the grade of its bed loses nearly the whole of its load. Its velocity is at once accelerated and vertical corrasion begins through its whole length. Since the stream has the same declivity and consequently the same velocity at all points, its capacity for corrasion is everywhere the same. Its rate of corrasion however will depend on the character of its bed. Where the rock is hard corrasion will be less rapid than where it is soft, and there will result inequalities of grade. But so soon as there is inequality of grade there is inequality of velocity, and inequality of capacity for corrasion; and where hard rocks have produced declivities, there the capacity for corrasion will be increased. The differentiation will proceed until the capacity for corrasion is everywhere proportioned to the resistance, and no further,—that is, until there is an equilibrium of action.

In general, we may say that a stream tends to equalize its work in all parts of its course. Its power inheres in its fall, and each foot of fall has the same power. When its work is to corrade and the resistance is unequal, it concentrates its energy where the resistance is great by crowding many feet of descent into a small space, and diffuses it where the resistance is small by using but a small fall in a long distance. When its work is to transport, the resistance is constant and the fall is evenly distributed by a uniform grade. When its work includes both transportation and corrasion, as in the usual case, its grades are somewhat unequal; and the inequality is greatest when the load is least.

It is to be remarked that in the case of most streams it is the flood stage which determines the grades of the channel. The load of detritus is usually greatest during the highest floods, and power is conferred so rapidly with increase of quantity of water, that in any event the influence of the stream during its high stage will overpower any influence which may have been exerted at a low stage. That relation of transportation to corrasion which subsists when the water is high will determine the grades of the water-way.

Declivity and Quantity of Water.

The conclusions reached in regard to the relations of corrasion and declivity depend on the assumption that the volume of the stream is the same throughout its whole course, and they consequently apply directly to such portions only of streams as are not increased by tributaries. A simple modification will include the more general case of branching streams.

Let us suppose that two equal streams which join, have the same declivity, and are both fully loaded with detritus of the same kind. If the channel down which they flow after union has also the same declivity, then the joint stream will have a greater velocity than its branches, its capacity for transportation will be more than adequate for the joint load, and it will corrade its bottom. By its corrasion it will diminish the declivity of its bed, and consequently its velocity and capacity for transportation, until its capacity is equal to the total capacity of its tributaries. When an equilibrium of action is reached, the declivity of the main stream will be less than the declivities of its branches. This result does not depend on the assumed equality of the branches, nor upon their number. It is equally true that in any river system which is fully supplied with material for transportation and which has attained a condition of equal action, the declivity of the smaller streams is greater than that of the larger.

Let us further suppose that two equal streams which join, are only partially loaded, and are corrading at a common rate a common rock. If the channel down which they flow after union is in the same rock and has the same declivity, then the joint river will have a greater velocity, and will corrade more rapidly than its branches. By its more rapid corrasion it will diminish the declivity of its bed, until as before there is an equilibrium of action,—the branch having a greater declivity than the main. This result also is independent of the number and equality of the branches; and it is equally true that in any river system which traverses and corrades rock of equal resistance throughout, and which has reached a condition of equal action, the declivity of the smaller streams is greater than that of the larger.

In general we may say that, *ceteris paribus, declivity bears an inverse relation to quantity of water.*

(There is an apparent exception to this law, which is specially noteworthy in the sculpture of bad-lands, and will be described in another place).