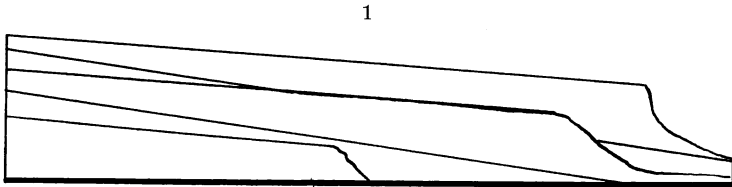


ART. XLII.—*Aggraded Terraces of the Rio Grande*; by  
CHARLES R. KEYES.

THE Rio Grande is probably the most remarkably terraced drainage-way in the world. Bordering the stream is an extensive succession of high-level mesas that constitute the most striking feature of the great valley's surface relief.

These escarpmented plains, or mesas, inclining strongly towards the river, are abruptly cut off as they near the banks of the stream. The different series of terraces are at levels 20 to 250 or 300 feet above the flood-plain. The areal shape of the plains is roughly that of a parallelogram, very long in proportion to the width, the longer axis disposed at right angles to the stream. Viewed from the side, the relationships of several mesas is as represented in diagram below (fig. 1):



Relationship of Rio Grande mesas.

In their wide extent, in their marked inclination towards the river, in their isolated character, and in their smooth and even surface, these high-lying plains present notable accentuations of physiographic expression that are rarely recognizable outside of the semi-arid regions. These elevated plains of the broad river valley have long attracted the attention of travelers. Many have been the explanations of their origin. No solution of their genesis has yet appeared that is at all satisfactory, or that takes into account the unusual climatic conditions of the region, and the novel geologic agencies at work.

The Rio Grande is one of the great rivers of the American continent. It is as long as the Mississippi. Unlike the case of the latter stream, it has, for a long river, a very high gradient. For the first thousand miles, from its headwaters, the average fall is over five feet to the mile. In times of flood, when the snows are melting in the mountains, the waters are almost of torrential nature. At other times, as in the months of July and August, the stream is often very nearly dry, although there is always a strong underflow beneath the sandy bottom.

After leaving the headwaters region, a distance of perhaps

300 miles, the Rio Grande receives no lateral augmentation from perennial tributaries in a distance of nearly one thousand miles, or nearly to the mouth of the Rio Pecos in Texas. Through most of this part of its course the river-bed is 1,000 to 2,500 feet below the level of the bolson plains lying on either side of the great valley.

Physiographically the Rio Grande has had a complex origin. That portion of its course which lies in New Mexico is largely antecedent in character. Other parts may be consequent. Climatic conditions with which most of us are not very familiar are chiefly responsible for many of the bold and unusual relief effects that characterize the region through which the Rio Grande flows. The valley mesas, or table-plains, are among the most instructive of all of these topographic features.

Being a stream of such high gradient, with an average fall, as already stated, for its 300 miles in New Mexico of over five feet to the mile, its corradng powers are little short of marvelous and its carrying capacity amazing. During the dry season of the year the waters of this stream are greatly overburdened with sediments and the channels rapidly silt up. In late years, since most of the water has been taken out for irrigation purposes, the silting-up process has become a very serious matter. Many localities show clearly that within the last dozen years the deposition has filled up the valley to heights of 20 to 30 feet.

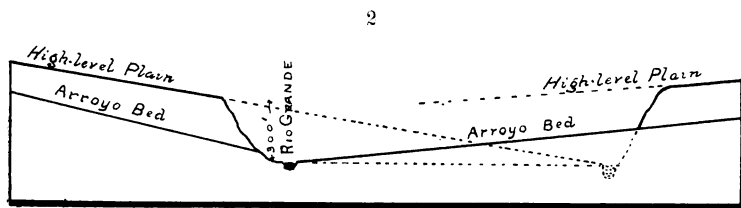
As already mentioned, no lateral drainage of a perennial nature is received by the Rio Grande within the borders of New Mexico. All increase of the grand stream from the sides takes place only during brief periods of very heavy rainfall. The side waters are then torrential. At other seasons of the year these tributaries are true arroyos, or dry creeks, as their Spanish title signifies. These arroyos have very steep gradients, often two to four and even five per cent.

In the mountain ranges on either side of the valley of the great stream the arroyos occupy deep canyons. In this part of their courses the channels are being rapidly cut deeper and deeper into the indurated bed-rocks. After emerging from the mountains these lateral drainage-ways are as pronouncedly constructive in character as they were destructive before.

Into the broad Rio Grande valley the side arroyos pour vast quantities of coarse mountain waste. The alluvial fans which are formed become confluent. On either side of the river broad plains several miles wide are built up; and these are inclined strongly towards the channel of the master stream. Were the river free from meandering, these plains on each side would doubtless become continuous and even.

In the course of its wide meandering the stream cuts rapidly

into its banks on the convex side of its broad swings. In a distance of two or three miles lateral change of channel a cliff 100 to 200 feet in height may be formed. Arroyos entering the river from the bowed side quickly shorten their paths, assume new and higher gradients, and scoop out canyons in the old fans. Thus, between the adjacent arroyo-courses there is left a high-level terrace, or mesa, bordering the main water-way. On the opposite side of the bow the arroyos lengthen their courses, lower their gradients, and build out new extensions of their fan-plains to the water's edge. This phenomenon is best shown in diagram, by an actual section across the Rio Grande at Socorro (fig. 2).



High-level plains of the Rio Grande, at Socorro.

The processes described are repeated again and again, along the entire course of the river. As a final result there are found sloping terraces at many different levels. The effects are apparently as unique as they are striking. Closer inquiry clearly shows that the same relief effects exist along the streams in more humid regions: only in the last named cases the characteristic phenomena are all but totally obscured because here destructive processes are far more active than the constructive. In the semi-arid districts the gradation conditions are reversed.

The typical characters of the high-level plains along the Rio Grande are well displayed at many points. At El Paso, at Rincon, at Socorro, at Albuquerque and at San Felipe they are finely shown. Near the last named place another interesting factor comes into play. At different times during the latest geologic epoch great basalt-flows have moved down the plains towards the river. These have preserved the surfaces of the old mesas at different levels. In some instances the river has quite recently cut through the lava-cap, as represented below (fig. 3).

The best description of these high-level terraces is given by Herrick.\* Although they were thought by this writer to be striking enough to deserve the distinguishing title of clino-plains, he did not even hint at their real origin.

\* American Geologist, vol. xxxiii, p. 376, 1904.

A more recent description of what appears to be a very similar phenomenon, but upon a miniature scale and in the humid region of Vermont, is that of Fisher.\* This account is important in this connection in showing that the general features are also recognizable beyond the arid districts.

The original surface of the line of bolson plains, through which the Rio Grande now treads its way, appears to be from 700 to 1000 feet above the present bed of the stream. At the

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Basalt flows cut by the Rio Grande at San Felipe.

present time there are remaining only few traces of these old bolson surfaces. Most of these remnants have been preserved only on account of being covered by extensive lava sheets. The Albuquerque volcanoes and basalt sheets, six miles west of the city, on the divide between the Rio Grande and the Rio Puerco, seem to rest on the old bolson surface. The basalt fields near Santa Fe have similar relations. The elevated plain, southwest of Socorro, also appears to belong to the same class. Farther south at Paraje, at old Fort Selden and at El Paso, the same remnantal levels are noted. All of these mesas are to be carefully distinguished from the so-called clinopains of the Rio Grande valley proper, that are seldom found rising more than 200 to 300 feet above the water-level in that stream.

There is still another class of plains which might be easily taken for terraces bordering the Rio Grande, that should be clearly separated from all the others. These may be in a sense regarded as lake-benches. They are due to the damming of the river for a brief period. Evidences are abundant indicating that the Rio Grande has been in very recent times and at various points dammed by the crossing of volcanic flows. At old Fort Selden, at San Acacia above Socorro, at Algodones above Albuquerque, at the White-Rock canyon west of Santa Fe and at the Black canyon south of San Antonio, basalt-flows have covered the course of the river and produced a temporary choking up of its waters. These barriers thrown across the river were from 200 to 500 feet in height.

\*Proc. Boston Soc. Nat. Hist., vol. xxxiii, pp. 942, 1906.

Under the conditions now existing it would be expected that such dams would leave conspicuous traces of the existence of the lakes. Such, however, does not appear to have been the case. At least, the lakes were so ephemeral in character that they left no evidences of distinct beach-levels, or elevated lines of delta-fans. It may be that the fans were confluent in such cases, and that the entire areas of the high plains, as those existing above the White Rock canyon, at Rincon, and above the mountain barrier at El Paso, represent these temporary lake deposits.

Notwithstanding the turbid character of the river waters and the prodigious quantities of coarse materials carried by the swiftly flowing stream, any lake that may have been formed must have quickly disappeared through the cutting of the dam or holding barrier. Even with some extraneous accumulations of sediments the local gradient was soon lowered, and the great influx of coarse sands and gravels from the lateral arroyos must have rapidly destroyed all traces of the lake beds and moulded them into new aggradation surfaces. In any case it would be exceedingly difficult to differentiate these plains of old lake-basins from ancient arroyo fillings. Moreover, the plains aggraded by the arroyos extend, at the distal and more elevated side, very much higher than would be possible for lake beds to do. If any deposits of the last mentioned class were formed, they would be quickly destroyed, or so disguised as to be almost unrecognizable.

When the barriers finally disappeared, enabling the river to recover its original lower level and to renew its old meanderings, the gradients of the lower courses of the arroyos were greatly increased, and the high aggradation-plains were cut by canyons more or less parallel to one another. This may be the explanation of certain local series of close-set, parallel canyons found at such places as in the Pajarito Park district west of Santa Fe.

Many erroneous notions are entertained regarding the history of the Rio Grande. Travelers unaccustomed to the novel effects of the workings of the geologic agencies in the arid and semi-arid regions are prone to explain everything in terms of their native humid heaths. As a result much that is fanciful has been indulged in. With the exception of W. J. McGee even the trained geologists, who have traveled through the region, seem to have entirely overlooked the two most vigorous geologic processes of the arid regions—the eolian and the planorosive, the latter more widely known among the dwellers of those regions as sheet-flood erosion. Both are practically unknown to people living in those parts of the world where there are abundant rains. They give rise to phenomena the

explanation of which present great difficulties by the other and more familiar agencies.

There appears to be much misconception regarding the composition of the deposits which go to make up the aggraded plains of the Rio Grande and other large rivers of the Southwest. The substructure is almost invariably spoken of as gravel. This seems hardly correct. To be sure, the entire surface of the plains might easily be mistaken for exposures of gravel-beds. Closer inspection clearly shows that by far the greater part of such deposits is made up of clay, called by the Mexicans adobe. In this adobe there are commonly a few small pebbles. For the most part the most gravelly surface when turned by the plow gives a loamy soil, such as is possessed by the prairies of the Mississippi valley, except the color. There are some gravel-beds, but on careful examination they are found to be very limited and to represent gravel-trains of former arroyo-courses. They are sharply defined gravel streams traversing the old fans.

Over most of the arid regions the winds blow away the fine soil at the surface until there is left a layer of closely set pebbles which act as a protection to the further action of this kind. The fact that the plains deposits are largely adobe instead of coarser materials, as one would naturally expect from surface appearances and from long experience in humid regions, is at first very surprising. That the deposits in question are composed chiefly of fine clays is due mainly to the effects of planorosion, or flood-sheet erosion as it is termed by McGee. The deposits of this vigorous geologic process are principally clays rather than sands and gravels. This is probably an explanation for most of the extensive so-called Tertiary and Quaternary "lake-deposits" of many portions of the West. Planorosion is peculiar to arid regions. It is neither fluvial, nor lacustrine, nor maritime in nature, but sheet-flood erosion in its strictest sense, modified by eolian influences during dry times.