Geomorphology of the Southern Great Plains in Relation to Livestock Production[1]

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Twelve years ago the American Society of Range Management was founded "to foster advancement in the science and art of grazing land management and to promote progress in conservation and greatest sustained use of forage and soil resources." A general knowledge of the basic principles of geology, and an awareness of both past and present results of geological processes can aid the fulfillment of the aims of this Society.

Geology may be defined simply as the study of the Earth. Geomorphology is the study of the land forms which together constitute the surface of the earth, and the processes which first developed and are now modifying these surface features. It is on this surface that range management is undertaken and it is the characteristics of this surface, together with geological materials underlying this surface, which in large measure determine the details of management endeavors and, perhaps, their success or failure.

Boundaries

The southern part of the Great Plains has distinct landform boundaries on three sides. The northern boundary is placed at the prominent north-facing Pine Ridge escarpment in northwestern Nebraska and southern South Dakota. The western boundary coincides with the foothills of the Rocky Mountains and the Sacramento Mountains. The southern edge is clearly marked by the readily recognizable though somewhat irregular southern escarpment of the Edwards Plateau.

In contrast to these distinct limits, the eastern boundary of the Great Plains is vague and indistinct and many definitions have been proposed in the literature. Proposals include the arbitrary use of a specified contour of elevation, such as the 1500-foot or 2000-foot line; the general line of change from eastern, humid region brown soils (pedalfers) to western, arid region black soils with lime carbonate or caliche layers (pedocals); the 20-inch rainfall line; or the general line of change from eastern prairie tall grass to western plains short grass.

None of these suggested boundary criteria is entirely satisfactory. Meridians or contours may cross areas of marked dissimilarity and, of course, are not visible on the ground. The change in character of soils takes place across a transition zone of considerable width. The rainfall line varies markedly over periods of years and causes similar variation in the grasslands.

Geomorphologists define the eastern boundary of the Great Plains by location of a low east-facing escarpment which, although discontinuous, is present along most of the distance from South Dakota to Texas. In central Nebraska it is located at the Loess Breaks. In northern Kansas it is marked by the eastern margin of the Smoky Hills and the Kearny Hills. In southern Kansas the topographic break is called the Red Hills. In Oklahoma it is the Gypsum Hills, and in the Texas Panhandle it is the eastern edge of the Llano Estacado. In many places it is also spoken of as the Break of the Plains.

Geologic Development

The geologic history of the Great Plains extends back through time for hundreds of millions of years. During periods

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so far distant that their details are vague, rocks were formed which are of a very complex nature. Some were originally hot molten material rising from far beneath the surface of the earth. Others were formed in ancient oceans which existed where mountains and high plains are now present. The original forms of these rocks have been highly modified during the ensuing time. They are not exposed at the surface in the Great Plains, but are known from well records and from exposures in nearby areas, especially the Rocky Mountains.

Much more recently in geologic history, between 50 to 500 million years ago, the general Great Plains area was covered with shallow ocean waters in which there accumulated deposits of mud, sand, and gravel. These materials have since been hardened into layers of limestone, shale, sandstone, and conglomerate. Some of these layers are exposed in the southern part of the Great Plains, especially in the region of the Edwards Plateau and in the Pecos and Raton sections. Elsewhere, well records show that these layers are present beneath a cover of younger rocks.

Approximately 50 million years ago, near the end of a unit of time known as the Cretaceous Period, because so much chalk was deposited then, there began a gigantic upheaval of rocks along the western margin of the Great Plains area. As a result, great mountains were formed. These have been called the ancestral Rocky Mountains to indicate that they were in the same general location as the present Rockies but the details of peaks and canyons, ranges and intermontaine basins were not exactly the same then as they are now. At the same time, the Great Plains region was gently raised above sea level and became dry land.

The new mountains were at once attacked by erosion. Physical and mechanical processes began to break up the newly exposed rocks and the resulting detritus was carried away by newly formed stream systems. Major streams flowing across the Great Plains area began cutting into the former ocean floor and, as valleys were developed and deepened, tributary streams dissected the surrounding flatlands. As a result the whole region became a hilly terrain with relief of several hundreds of feet.

There then occurred a change in the activity of streams crossing the plains area from the western mountains. Probably because the climate became more arid, stream power diminished and deposition began to exceed erosion and transportation. Waste from the destruction of the mountains was carried onto plains by floods, but so much of the water was lost by evaporation and disappearance underground that flow was not sufficient to carry this debris across the plains to the Mississippi River and thence to the Gulf of Mexico. Most of the material was deposited en route.

Stream channels rapidly became choked so that the water was forced to spread laterally and find new channels. Valley floors became covered with increasing thicknesses of silt, sand, and gravel left by the heavily loaded streams. As the former valleys were filled to higher and higher levels the streams wandered greater distances to each side. Deposition spread until not only were valleys completely filled and divides covered, but even the hills began to disappear beneath the rising cover. Ultimately only the tops of a few of the highest hills remained exposed above the plain. The High Plains section of western Kansas and eastern Colorado is a part of this depositional surface which has been only slightly modified since it was formed. It originally extended over most if not all of the Great Plains area.

The accumulated alluvium was thickest where it filled former valleys and thinnest over buried hilltops and ridges. Maximum thickness along the western margin was about 600 feet. The cover thinned to a feather edge toward the east. Because the deposit was formed by many streams flowing in numerous channels which changed position frequently, the internal characteristics of stratification and grain size are highly variable over short distances both horizontally and vertically.

Again there was a reversal of stream activity and erosion once more became dominant in the Great Plains area. Major streams flowing across the High Plains section from the west were able to erode deep valleys into the debris cover. This cover was completely removed and older bedrock exposed on the Edwards and Stockton Plateaus. In the Central Texas, Pecos, and Raton sections erosion has cut deeply into the older bedrock to produce canyons and mesas.

The dominance of erosional processes has continued to the present, but not without interruptions and minor reversals at some localities. Most major valleys and many tributaries have gravel terraces tens or hundreds of feet above present drainage levels, indicative of pauses in the downcutting of the streams. Also present are debris-filled segments of former stream courses or deep accumulations of alluvium below modern streams, indicative of short-lived episodes of deposition.

Near the end of Great Plains history severe climate change to a wetter and colder regime caused the formation of great masses of glacial ice in central

Canada. Some of this ice flowed southward until it reached the edge of the Great Plains in eastern Nebraska. Variations in the volume of streams directly associated with the ice undoubtedly caused formation of many of the valley-side terraces. A drier interval permitted accumulation of a vast area of dune sand and loess in central Nebraska.

Applications to Range Management

Now for the practical aspects of this subject, the applications which translate into dollars and cents in range management. How does geology contribute to the basis for livestock production in the Great Plains? Stated in a nutshell, the present environment of the Great Plains is to a very large extent the product of the geologic and geomorphic history of the area. The patterns of major topographic features, the presence and distribution of various kinds of bedrock and surficial materials, and the occurrence of ground water are the resultants of many geologic events which occurred through long spans of geologic time. Many factors interact in a highly complex fashion.

Before correct procedures of range management can be applied, certain environmental requirements must be satisfied. Basic necessities for the profitable production of livestock are water, forage, and land areas suitable for range use.

Primary controls of large-scale rainfall distribution are the great wind belts and pressure systems of the world. Secondary control of very considerable importance is exerted by major aspects of location and land forms. The Great Plains occupy a continental interior site. Moisture-laden winds must travel long distances to reach the area, and usually lose their water en route. Furthermore, the Great Plains lie in a rain shadow in the lee of the Rocky Mountains. Cyclonic air masses travelling in a prevailing eastward direction lose most of their moisture content on the western side of the mountains. Dry air descending onto the plains tends to cause evaporation of water already on the land rather than precipitation of additional supplies.

The existence of a vast plains area east of high mountains has been determined by the geologic history of the region. The mountains are present because that part of the land area was subjected to great upheavals by geologic forces and strong rocks thus raised to the surface have resisted the levelling effects of erosion since the upheaval took place. The plains area was not thus raised.

In the Great Plains area the amount of rainfall increases from west to east. The amount is essentially constant in a south to north direction, but the effectiveness of the precipitation increases northward as mean annual temperature and evaporation rates decrease. Throughout the area, however, the amount of rainfall is deficient for what are termed normal or humid region methods and products of agriculture. Problems of land use are therefore closely linked to the availability of water.

All water comes directly or indirectly from condensation of water vapor into particles which are precipitated onto the land. During and after every storm, some water runs off in streams; some water seeps into the ground where it may be used by plants, may enter a subsurface storage zone, or may percolate slowly through minute open spaces until it reappears at the ground surface somewhere else; and some water returns directly to the atmosphere by evaporation.

The amount of moisture present both in the atmosphere and in the soil at a given locality will have a strong effect on the kind of soil being formed and the rate at which it is developed. All soil is formed by the break-up and modification of previously existing parent material. In most instances the parent material is the local bedrock; sometimes gravel or other debris transported from another area is the parent material. The soil-forming or weathering processes can be subdivided into two groups—those which cause mechanical changes in the parent material (freezing and thawing, heating and cooling, wedging by plant roots, expansion as a result of chemical change), and those which cause chemical changes in the parent material (oxidation, hydration, carbonation, solution).

In every area several weathering processes will be active simultaneously. The type and characteristics of the resulting soil will depend on the balance between the processes involved, plus factors of vegetation, erosion, and the nature of the parent material. Texture, structure, and depth of soils are characteristics which are of critical influence on the ability of the soils to absorb, hold, and release water for plant use, and their ability to resist erosion.

The amount of precipitation and its distribution throughout the year will in large measure determine the kinds of plants which are able to grow in a given area. These plants are in turn important indirectly because they influence the kinds of soil being developed and the kinds and rates of erosion. They are, of course, of direct importance as possible forage for range animals.

The amount and distribution of the precipitation also exerts considerable direct control on the kinds of erosion processes modifying the landscape, the way in which these processes affect the various types of bedrock present, and the rates at which these changes will take place. In some areas badlands have developed and the land is not usable for range. In other areas fine flat or gently-sloping land is eminently suitable for range use.

The most essential primary use of water on the range is for livestock consumption. In only a few favored areas of the Great Plains is it possible to find reliable sources of water at the surface. Some perennial trunk streams bring water from the more humid climate of the mountains to the west only to lose much of it through evaporation or percolation into porous subsurface materials. Streams originating on the plains are generally intermittent and not dependable. Permanent flow can be achieved by these streams only after their valley floors have been eroded sufficiently deep to tap underground sources of water. In general, this occurs only in the easternmost parts of the plains.

In most parts of the Great Plains supplies of ground water must be developed. Successful development necessitates at least a general knowledge of the geological principles which control its occurrence and availability.

All ground water originally was precipitated onto the surface of the earth from the atmosphere. If this precipitated moisture is to be able to enter subsurface materials, open spaces must be present. The percentage by volume of open space in soil or rock is the porosity. If the moisture is to be able to move from one subsurface spot to another—into a well, for instance—the open spaces must be interconnected. A measure of the degree of interconnectedness of the open spaces is the capacity of the material for permitting the movement of fluid through it. This is the permeability.

There is a great range in the porosity and permeability of geological materials. In general, gravel and sand are highly porous and permeable and therefore are important sources of water and are known as aquifers. Silt and clay may have moderately high porosities, but their permeabilities are low and little if any water can be obtained from them. They are aquicludes.

Bedrock bodies formed by the cementation of loose particles show similar contrast. Conglomerate and sandstone usually constitute good aquifers; shale is usually impermeable and so is an aquiclude. Solid limestone often has a low porosity and permeability, but it is frequently cracked and cut by solution channels which produce a secondary permeability.

Water which moves toward the bottom of an inclined aquifer surrounded by impermeable material is subjected to an increasing head or pressure. If the aquifer is tapped by a well, artesian flow will occur and the water will rise toward or even to the surface without pumping. This is, of course, a very desirable situation economically.

Underground supplies of water in the Great Plains are found both at depth and near the surface. The deep water is generally in a sandstone or conglomerate, having entered such a rock body either where it was exposed at the land surface in the more humid mountain region to the west, or where it was exposed in the bed of a large stream within the plains area itself. The so-called Dakota sandstone is the most famous aquifer in the plains, although it is not productive everywhere that it is present. Also of great local importance are supplies of artesian water contained in porous strata in the Roswell basin.

The internal characteristics of the vast alluvial mantle present in the High Plains and elsewhere were determined by the vagaries of the depositing streams and are, therefore, highly variable. Discontinuous sheets and lenses of highly permeable sand or gravel are mixed indiscriminately with less permeable masses of the dominant silt. Thicknesses of the total deposit and of individual members vary widely and impermeable layers or zones of lime caliche accumulation further complicate the situation. As a result even closely spaced wells may find water at quite different depths and in different amounts.

Shallow accumulations of water may also be present in sand and gravels underlying the present stream beds, in coarse debris filling remnants of the valleys or previously existing streams, in porous stream deposits remaining as terraces on the sides of present valleys, or in deposits left by glaciers which invaded the northeastern corner of the plains region.

Water entering a thick body of permeable material will tend to move downward until it encounters an impermeable barrier. It will then percolate laterally to some point of escape. Therefore, wherever erosion has cut the land surface through a permeable body and into an impermeable layer beneath, springs and seepage zones are common at the base of the permeable bed. These may be an important source of water for local use of range animals.

The growth of good forage depends to a great extent on favorable rainfall and temperature conditions. Also necessary, however, are favorable soil and a flat land environment not subject to rapid erosion. Both of these factors are the product of geological processes.

In the Great Plains suitable range land is present almost everywhere. In fact, some of the land is almost too good. It attracts those interested in the tillage of wheat or other crops and may be withdrawn from available range. Only where stream erosion is producing cliffed areas and badlands is grazing markedly inhibited. The situation may be especially unfavorable where outcropping rocks consist of resistant strata alternating with weak layers. The weak material is rapidly removed by weathering and erosion and the resistant rocks uphold vertical or near-vertical walls cut by intricate systems of narrow and irregular gullies and arroyos. This occurence is outstanding along the breaks of the Llano Estacado and Edwards Plateau, in the mesalands of the Pecos section, and in some localities along the eastern Break of the Plains.

Summary

The present physical environment of the Great Plains is largely the product of past geologic and geomorphic events. An understanding of the processes involved helps to explain the occurrences of different kinds of soils, land forms of various aspects, and ground water supplies. The actual pattern is far more intricate than broad generalizations suggest. Even a single range-land unit may well contain different soils, different land forms, different water supplies, and therefore require different range management practices.