GEOMORPHOLOGY OF THE LOWER AND MIDDLE PART OF THE WHITE RIVER BASIN, SOUTH DAKOTA

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ABSTRACT

The landscape of the White River Basin has been created by slow wind and water erosion that occasionally has been accelerated. Downcutting of the White River formed three distinct terrace levels and possibly a fourth, the Nebraskan-age Medicine Root gravels.

Downcutting has occurred first in the lower part of each valley so the landscape age generally increases progressively away from the mouth of the White River. Isolated volcanic ash beds in local eolian sediments probably are remnants of ash falls in the Great Plains that occurred from 0.6 to 2.5 mybp. Thus, the maximum landscape age must be Pleistocene. Prevailing winds have formed deflation basins and a NW-SE aligned tributary drainage pattern, particularly in the lower part of the basin with Pierre shale bedrock. In the upper part of the basin, the resistant Tertiary bedrock prevents streams from changing their channels as eolian sediment is deposited in unaligned channels. Valleys in the Tertiary bedrock have undergone or are undergoing post-Pleistocene alluviation and subsequent dissection of this fill.

INTRODUCTION

The ancestral White River originated during the late Tertiary or early Pleistocene Period. The upper reaches extended into the Black Hills where chert from the Minnelusa Formation and other resistant siliceous units occur. Eroded by streams and deposited in gravel, beautifully banded specimens of these siliceous nodules are locally called Fairburn agates. These agates are found frequently along the middle reaches of the river but not to the north in the Bad River basin. The White River tributaries, captured by the headward advance of the Cheyenne River peripheral to the southern Black Hills, must have drained the southern Black Hills. The White River may have been located slightly to the south of its present east-west channel (Figure 1) at least during the time the Medicine Root gravels were deposited (Harksen, 1966, Harksen and McDonald, 1969). These gravels were ". . . believed to be Nebraskan in age . . ." (Harksen and McDonald, 1969, p. 54), and extend discontinuously from Cuny Table to a gravel-capped hill 70 miles east in Mellette County. Cuny Table also has a vol-

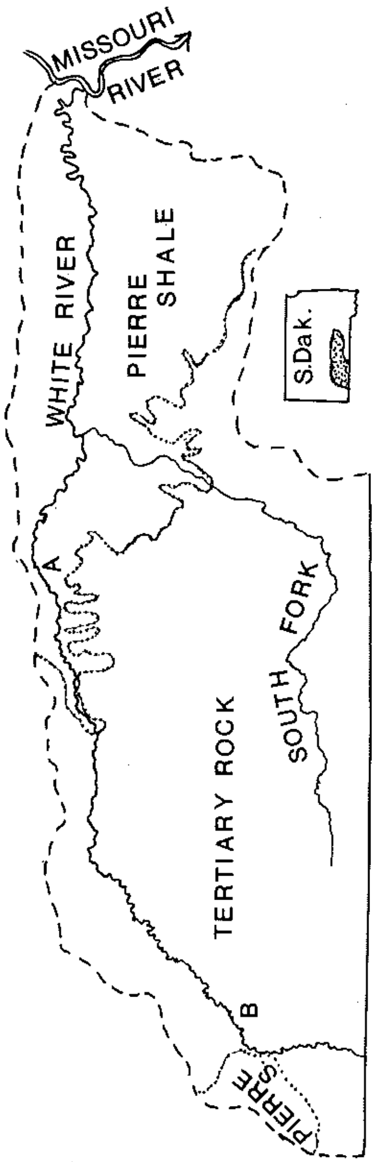

Figure 1. The White River drainage basin in South Dakota has three terrace levels that have been studied from the Missouri River to Point A. A mammoth skeleton has been found in alluvium at Point B.

canic ash layer that tentatively was called Pearlette ash, which is several ash deposits ranging in age from 0.6 ± 0.1 to 1.9 ± 0.1 mybp (Naeser et al., 1973) or up to 2.5 mybp (Hallburg, 1980).

The White River may have changed its course in response to an uplifting of the Siouxana Arch and the Chadron-Cambridge Arch system (Stanley and Wayne, 1972). At an earlier time, the interfluve to the north was the continental divide separating drainage systems flowing to the Gulf of Mexico and the Hudson Bay (Flint, 1955). Uplift of the arch system after the early glaciations may have forced the White River to flow along the ancestral channel into eastern South Dakota (Lemke et al., 1965) rather than to the south marginal to the glaciated area. Entrenchment of the Missouri River probably occurred during the Illinoian (Warren, 1952) or the early Wisconsin (White, 1964a) glaciations.

Pierre shale (Searight, 1937; Crandell, 1950) is the most extensive exposed bedrock in the eastern part of the basin, and Tertiary-age rocks are dominant in the western and southern part but Pierre shale is exposed discontinuously along the entire length of the White River in South Dakota. Tertiary bedrock caps some hills or buttes along the Missouri River trench. A Pliocene quartzite of the Bijou formation caps Medicine Butte (Agnew, 1958) and the Iona Hills (Baldwin and Baker, 1952). Presumably, the Tertiary-age beds were continuous across the basin at one time.

Some glacial drift occurs along the Missouri River in the White River basin. Although the drift was included tentatively with the Wisconsin drifts (Flint, 1955), a Kansan or Nebraskan age would be more consistent with the drift distribution in Nebraska. If the ice thickness was enough to cause the Kansan and Nebraskan glaciers to advance farther west in Nebraska than the Wisconsin glaciers (Reed et al., 1965), it is illogical to assume they did not do so in South Dakota. An older age for the drift and an increased time for erosion would help to explain why meltwater channels marginal to the glacial boundary have been destroyed by erosion and are not evident today. In addition, Holocene erosion of the land surface has occurred so that no landscape age difference is evident between the glaciated and non-glaciated Pierre shale areas. Thus, the glacial erratics and drift that occur may be erosional remnants of an early Pleistocene glaciation.

TERRACES

Three well-defined high terraces border the White River in the middle reaches of the stream (Caddes, 1947). They are about 200, 300 and 350 feet (61, 91, and 107 m) above the present channel (White, 1964a). The landscape has been graded to each level except where there was an older adjacent area that was capped by gravel or by resistant Tertiary-age rock. These terraces are of Pleistocene age because Warren (1952) reported gravel, fifty feet higher in elevation than the 350-foot terrace which contained Kansan or post-Kansan fossils. Harksen (1966) considered that the Medicine Root gravels were Nebraskan in age and they lie above the three White River Terraces. Thus, the three terraces must be Pleistocene in age. The relationship of these terraces to terraces or terrace-like features studied a few miles from the mouth of the White River by Kahil (1970) are not clear. Some of these terrace-like features may have originated when the Missouri Trench was inundated by glacial meltwater.

The 200-foot terrace, which was reported from the Missouri River trench to the confluence with the Little (South Fork) White River (White, 1964a) is easily discernible another 40 or 50 miles upstream. In addition, the terrace surface extends up tributary valleys. The equivalent terrace can be traced up Cottonwood Creek, a tributary of the White River located a few miles upstream from the confluence with the Little White River (Figure 1). This terrace decreases in height, relative to the stream, toward the headwater, where it merges with the present flood-plain (White, 1964a). Lower lying terraces in the creek valley are paired in some cases but they do not appear to extend up and down the valley. Possibly they are paired remnants left during the headward advance of the downcutting. Light-colored, relatively unweathered alluvium on the surface of low lying terraces along some sections of the creek probably were deposited in lakes created by ice dams. A local resident indicated about 1950 that an ice dam, 15 to 20 feet high, had formed a large pond that extended up the valley several miles. Gravel and cobbles from the channel were ice-rafted up onto the terraces submerged by the pond during a sudden spring thaw accompanied by a warm rain.

Obviously, the 200-foot terrace equivalent on Cottonwood Creek has progressively younger surficial alluvium from the mouth to the upper reaches. Thus, only tentative conclusions can be made about soil age on the terrace unless the terraces have been studied in detail. Drainageway tributaries of Cottonwood Creek are more deeply incised in the lower part of the valley than in the upper part. These V-shaped tributaries in the upper reaches rapidly change into drainageways lacking definite channels. The landscape with the small indistinct drainageways is essentially the one which correlates to the 200-foot (61 m) terrace system of the White River.

The 200-foot (61 m) terrace level also decreases in relative height upstream along the White River. Identification of a terrace level becomes more difficult upstream because terrace-like areas with resistant Tertiary bedrocks, with or without gravel caps, become more numerous. The 200, 300 and 350 foot (61, 91, and 107 m) terraces probably merge. These terraces have not been systematically studied in the upper reaches of the White River.

WATER EROSION OF INTERFLUVES

Soils derived from Pierre shale are slowly permeable so that runoff is rapid from high intensity rainfall. The shale or mudstone weathers rapidly, first to loose platy fragments and second to a clay rich soil. Shrinking and swelling of the clay as it dries and wets (White, 1962) causes mass movement that rounds the hills. Water erosion of these slopes brings about a slow reduction of the surface as a unit except where the area has a protective cap of gravel or the shale has a rather continuous layer of concretions. Steep slopes commonly occur below these caps and they have loose shale fragments at a shallow depth. These slopes recede by parallel slope retreat and by gullies so that mass movement is not a dominant process.

Parallel slope retreat is the dominant process for landscape reduction in the area with badlands formed from Tertiary bedrock (Smith, 1958). Even in the fine-textured Chadron beds, parallel slope retreat is dominant until weathering is sufficient for the clay to shrink and swell with changes in the water content (Schumm, 1956). Characteristically the Badlands consist of cliffs with either nearly barren areas that slope gradually away from them or that have accumulated alluvium washed from the cliff. Frequently the landscape consists of butte-like hills with accordant summits that gradually become a continuous surface as the distance from the river increases. Ward (1922) discussed an upper and lower Prairie in the White River Badlands. The higher surface may have formed initially when it was graded to the 300-or 350-foot terrace or even the Medicine Root gravel deposits. Erosion of the badland walls or cliffs around buttes is controlled by the weathering rate of the resistant beds and their ability to resist slumping when softer underlying beds are eroded.

WIND EROSION OF INTERFLUVES

Interfluves of tributaries of the White River in the Pierre shale area are oriented NW-SE in the prevailing wind direction (Flint, 1955, p. 157). Russell (1929) suggested that aligned drainage systems were superposed on the landscape after sand dunes migrated across the area. Wind drifting of soil into drainage channels that are not aligned NW-SE occurs following prairie fires and probably following droughts (White, 1961). This process causes the landscape to develop so that runoff would be to the aligned drainageways. Rahn and Frazee (1974) suggested the alignment could be caused by erosion along NW-SE trending faults or joints that occur east of the Black Hills. However, a fault trends SW-NE (Steece, 1964) rather than in the direction the streams are aligned in the eastern part of the area. Streams with erosive capacities that are larger than the amount of eolian sediment brought into them are not aligned in prevailing wind direction. This is particularly true in the Tertiary rock area where indurated strata prevent a rapid change in a stream's direction. Any eolian fill is eroded before it can change the stream's direction.

Areas of sand may develop NW-SE oriented dunes (Harksen, 1967) but oriented dune-ridges are usually inextensive in length and have irregular slopes that progressively are smoother as they become older. Upland sand dunes frequently have migrated from sandy stream flood plains or terraces. Most terrace areas from which the sand has been blown have a gravelly subsoil that is covered by 60 to 75 cm of sand. Surprisingly, the sand is not completely removed from the gravel. Deep-rooted grasses on sand dunes with poorly developed soils do not develop a dense sod to protect the sand from wind erosion. Possibly, these plants are able to compete with sod-forming grasses (White, 1971) until the sand layer becomes less than 60 to 75 cm thick.

Sand is more completely blown from soils derived from Pierre shale or Tertiary shales and siltstone than from areas with gravelly substrata. Bedrock areas, across which sand dunes have migrated recently, may have 10 to 20 cm of sand, but in areas from which the dune has migrated hundreds of years ago, little if any sand remains. Wind erosion following prairie fires probably has gradually removed the sand from these areas which normally do not have a continuous sod cover to reduce wind erosion. Sand dunes downwind from these areas usually contain more clay and silt than the dunes that are associated with terraces.

Landscapes derived from Pierre shale frequently contain blowout-like depressions (Crandell, 1958). Some of these areas have clay-rich dunes that contain rounded shale and gypsum fragments (White, 1973). Winds apparently eroded partially weathered, sand-sized shale fragments exposed by gully erosion. Blowouts in the shale range from these that have formed recently (Flint, 1955, White, 1973) to those that probably formed during the Pleistocene. Small depressions, 5 to 10 meters across in clay soils, may be caused by wide desiccation cracks (White, 1972 a, b) that undergo slumping and filling. These depressions have characteristics of those created as buffalo wallows in more sandy soils (Harksen, 1968b).

Buffalo probably increased erosion along areas where trails were formed. Harksen (1968b) reported that some interfluves in South Dakota were crossed by paths caused by buffalo. Clayton (1975) in North Dakota concluded buffalo trails had a significant effect on erosion by both wind and water. A rancher in NW South Dakota reported the range in the late 1800's had NW-SE bands of range with sparse or no short grasses. He had concluded the short grasses were destroyed by trampling as buffalo migrated annually to the north and back south.

Buttes and dissected terraces with escarpments frequently are capped by cliff dunes (White, 1960) which are eolian materials eroded either from the cliff or the lower lying area beside the escarpment. Most cliff dunes are loess (Harksen, 1968a) if the cliff is composed of siltstone or silty sediment. A few clay-textured dunes occur above cliffs composed of loose sand-size shale fragments. One area examined (SE ¼ Sec. 10, T. 41 N., R 30 W., Mellette County, S. D.) had a dune above a small gully that had eroded the top of the escarpment. This dune blocked the headward advance of the gully. For this reason, alignment of streams in the prevailing wind direction by wind erosion of a gully in an escarpment (Beaty, 1975) seems not to be applicable to South Dakota conditions (Rahn, 1976).

POST-PLEISTOCENE EROSION

Many intermittent streams or drainageways have V-shaped channels that were formed after the area was homesteaded. These gullies may not be a part of a normal erosion cycle. After prairie fire damage was reduced, the average grass cover increased and, presumably, less sediment was eroded from slopes into the drainageways. Water collecting in the drainageways was not loaded with sediment and thus could flow with a greater velocity and cause the gully erosion (White and Lewis, 1967).

Sediment on slopes must have been relatively stable during the last part of the late Wisconsin glaciation in eastern South Dakota. Possibly, the slopes were forested. Spruce forests remained in eastern South Dakota and in North Dakota until about 10,000 to 11,000 years ago (Watts and Bright, 1968; McAndrews et al., 1967). A mammoth skeleton was found a few miles from the White River some 175 miles upstream from the Missouri River (Hannus, 1980). It was near the base of a butte composed of valley fill that rested on the Chadron formation. The mammoth-bearing layer in the fill had fossil aquatic species and probably was the stream channel at that time (White, 1980). Because the site is located where the valley bifurcates, colluvial-alluvial sedimentation must have forced the two streams to combine upstream in the valley rather than to join farther downstream as they do today. Runoff would be greater from the landscape on the outside of the "Y" formed by the joining of the two channels than from the inside or top of the "Y." Thus, the channels should have flowed along the outside edges of the valley and joined farther downstream if they were actively eroding their valleys. This is the case today. Humic material capping the skeleton is 10,670 ± 300 C^{14} years old.

(Teledyne Isotopes No. I-11,710, personal communication, L. A. Hannus, 1982). Thus, the valley fill accumulated after this time.

The butte with the mammoth skeleton has about 8 m of alluvial fill which was rapidly dissected by a channel that cut nearly to the base and then refilled. Apparently filling of the valley kept the channel near the middle of the valley so that a slight change in the stream's hydrology would permit it to erode rapidly and then refill rapidly. A change in the base level of the valley due to a change in the elevation of the White River channel would take a considerable length of time, but soil zones were not found. Thus, the brief erosion cycle must have been caused by a climatic pulsation, possibly to a more humid climate.

McAndrews et al. (1967) suggested widespread aridity from about 10,000 to 4,000 years ago, when prairie was more extensive. The main filling of the valley apparently occurred during this interval. Since that time, erosion has been dominant but with intermittent periods of alluviation. Charcoal from two hearths buried by alluvium in the valley were 785 ± 80 and 845 ± 155 C^{14} years old. (Teledyne Isotopes Nos. I-11,582 and I-11,583, personal communication, L. A. Hannus, 1982). This alluvium has been removed by erosion except for butte-like remnants. Harksen (1974) collected charcoal from two hearths in valley fill near Scenic, South Dakota. The charcoal was dated as 2,350 ± 180 and 780 ± 130 C^{14} years BP. The younger charcoal came from a lower position in the fill than the older charcoal. The older fill was partially eroded before the younger hearth was constructed and then the valley was refilled with about four feet more alluvium after which a soil zone formed and subsequently two more feet of alluvium was deposted. The valley fill is undergoing dissection today. Hamilton (1967), in western North Dakota badlands, suggested that 9 to 12 cm of alluvium could accumulate each year, which is compatible with a rate reported in Brice (1966) for southwestern Nebraska. Brice also reported alluviation and erosion events that are compatible with those in South Dakota.

SOIL LANDSCAPE AGES

Most, if not all, of the landscape in the White River basin must have originated in the Quaternary. If Harksen and MacDonald (1969) are correct that the Medicine Root gravels are early Nebraskan in age, then most of the landscape must be Kansan or younger because these gravels occur on parts of the landscape that are higher than the adjacent parts more recently exposed by erosion. The lack of volcanic ash of the Pearlette group, except at a few places, can be explained by having it removed by erosion. In addition, Pearlette ash group ages range from 0.6 to 2.5 mybp which would span the Nebraskan, Kansan and possibly part of the Illinoian glacial stages. Thus, most of the landscape must be younger than Nebraskan or even the Illinoian stages. Presumably the gently rolling landscape in the upper part of the basin bordering Nebraska is physiographically oldest, but this area has considerable evidence of wind erosion so that the soils may be forming in sediment deposited or weathered from bedrock at a relatively recent date.

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