SOIL CYCLING AND TEXTURE DIFFERENTIATION IN WAVY GILGAI

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INTRODUCTION

Gilgai microrelief on slopes consists of narrow microridges, 5 to 10 cm high and a meter or so wide, which are separated by 2- to 5-meter wide microvalleys. These small ridges and valleys, called wavy gilgai, are oriented parallel to the steepest slope gradient (White and Agnew, 1968). On landscapes lacking a slope the microrelief usually consists of microknolls and microdepressions and is called normal gilgai.

Gilgai forms in clay soils which develop subsoil desiccation cracks during droughts. Soil material from upper soil horizons either falls downward in the crack or swells downward as the dry soil is moistened (White and Bonestell, 1960; White and Agnew, 1968). When the dry subsoil is moistened, it can not swell back into the filled crack space so that it flows upward at certain points to form the microrelief high. In the formation of gilgai microrelief, soil moves downward in certain areas and the subsoil is displaced laterally and then upward to form the microrelief ridges or knolls. Microvalley and microridge soils have distinct texture differences, particularly if the area is on a slope that has an upper steeper part formed in coarse-textured materials. The development of the texture differences in wavy-gilgai soils will be discussed.

Descriptions of wavy gilgai soils and the sampling areas.

Wavy gilgai soils from three areas were sampled. At one location, a weakly developed soil formed from relatively unweathered shale was also sampled for comparison.

Area–I soils (600 ft. S., 420 ft. W. center, sec. 24, T. 42N., R.32W. Mellette County) are derived from Tertiary-age (Chadron?) shale or mudstone on a 5 percent slope. Soils on higher slopes are also formed from the shale. The microridge crests are about 3 m apart and are 5 to 15 cm higher than the center of the microvalley.

Area–II soils (SE1/4, SE1/4, sec. 31, T.43N., R.27W., Mellette County) are derived partly from Pierre shale and partly from a sandy gravel which was eroded from a steep slope that lies above the area. The gilgai is on 30-m-long 8-percent footslope approximately 50 m below the gravelly terrace sediment so that

erosion products from the upper slope are transported into the wavy gilgai area. The microridge crests are 250 to 300 cm apart and are about 10 cm higher than the center of the microvalley.

Area–III (near the center of NW1/4, sec. 16, T.42N., R. 26W., Mellette County) is similar to Area II except the gilgai is on the middle part of a long slope and the gravelly terrace sediment is some 100 m away and is less steep. Thus the slopes in Area III are more stable than those in Area II and less coarse-textured material is eroded across the gilgaied soils. Soils in Area III probably are much older than those in Area I and at least as old as those in Area II. Microridge crests in Area III are about 3.5 m apart and 10 to 15 cm higher than the microvalleys.

Thirty meters away at the same elevation on the slope, a non-gilgaied Lakoma soil was sampled for comparison purposes. The soil is weakly developed and is formed in less disintegrated Pierre shale than the adjacent gilgaied soils. The gilgaied soils of Areas II and III would be phases of the Opal soils while those in Area I would be phases of the Larvie or Metre clay soils.

Soils in the microridge have thinner dark-colored surface layers than the adjacent microvalley soils. The microridge soils usually are calcareous at the surface and contain less organic matter than the microvalley soils, which usually are noncalcareous to a depth of at least 15 to 30 cm. Gilgai microvalley soils with a thick noncalcareous upper layer usually are associated with a microridge soil that has narrow seams of calcareous subsoil in an otherwise moderately dark-colored surface layer. These light-colored seams appear to be more strongly weathered than the calcareous material of the microridges when found with microvalley soils that are calcareous at a shallow depth. Thus some wavy gilgai areas have effectively younger soils with less weathering than the soils in other gilgai areas.

METHODS

The particle-size analyses were by the pipette method (Day, 1965) on a salt-and organic-matter-free sample which was dispersed with sodium hexametaphosphate. In addition, a second set of samples from the gilgai soils of Area III were treated to remove carbonates (Jackson, 1956) prior to the particle-size analyses. Total nitrogen was determined by the Kjeldahl procedure. A glass-electrode-equipped pH meter was used for the pH's of a 1:1 soil: water mixture.

RESULTS AND DISCUSSION

Microvalley-soil surfaces have less clay than the adjacent microridge surfaces (Fig. 1 and Table 1). As the microridge develops, its surface layer is eroded into the microvalley. The coarse material tends to remain in the microvalley while part of the clay stays in the runoff and is carried downslope and out of the gilgai area. The retained coarse material becomes the surface of the microvalley. Area I consists of weakly developed gilgai soils formed from a shale or mudstone which has little coarse material so that the surface texture is similar in the two gilgai soils (Fig. 1). In contrast, the gilgai of Area II formed where the clay subsoil was mantled by coarse-textured material so the microridge and microvalley surfaces have similar sand contents (Fig. 1). As should be expected, the microridge surfaces have slightly more clay than the microvalley surfaces. Some small areas of the microridges had calcareous clay at the surface where the coarse-textured mantle had been displaced by subsoil material. Therefore, the movement of subsoil up to the microridge surface in Area II is a localized process and occurs sporadically along the microridge. Area III is similar to Area II except a coarse-textured mantle probably did not occur on the slope as the gilgai microrelief developed.

Texture differences between the microvalley and microridge soils may be partly determined by the sediment which collects in the microvalleys from runoff from higher slopes. Runoff from the steep coarse-textured slope above the gilgaied slope in Area II may add material to the microvalleys. If this did occur, the texture of the microvalley and microridge surfaces possibly were affected, but evidence for this is lacking. Area II soils have more difference in texture than is known for any other gilgaied soils.

THE CYCLING PROCESS

As coarse-textured material collects in the microvalley, either from up slope or from the microridge, the subsoil clay is displaced toward the microridge and subsequently up toward the surface. Microvalley-soil textures in the surface and subsurface layers do not seem to be important in the formation of wavy gilgai. They range from clay to sandy loam while the lower subsoil is always fine textured. The upper-subsoil and surface-soil layers of the microvalley apparently act as a "wall" or barrier to keep the microridge material from slumping. Surface soil gradually settles into cracks in the microvalley and displaces the lower subsoil toward the microridge subsoil. Subsoil of the microridge is displaced upward in this process. Thus soil material in wavy gilgai could conceivably be carried in a never ending cycle from the microvalley surface into the subsoil, then into the microridge subsoil, back to the microridge surface and back to the microvalley.

Some microridges contain pebbles with long axis oriented vertically in the direction the subsoil moves upward. These pebbles are swept upward in the flow and are left as a residue on the microridge surfaces after the finer material has been removed by erosion. Variations in the texture of the soils in wavy gilgai may reflect the present stage of the cycle. In Area I, some coarse material has been cycled to the microvalley surface or left as an erosional lag; in Area II, the microvalley has accumulated much coarse material; and in Area III coarse material apparently has accumulated in the lower subsoil (Fig. 1) of the microridge.

Particle-sizes found in the Area III gilgaied-soil samples after the carbonates were removed (Table I) are similar to those reported in Figure 1. The sand in the carbonate-free samples was fractionated into five sizes. Comparable layers in the microridge and microvalley soils of Area III had comparable quantities of each sand size if differences in the total sand content of the layer are considered. No sorting of the sand apparently has occurred in the cycling process. The larger sand content in the lower part of the microridge soil in comparison to the microvalley soil could be either a residue left behind after the clays moved upward toward the surface or a pocket of sand-rich material pushed from the microvalley subsoil into the microridge subsoil. Sand and coarse-silt contents of the Lakoma soil (Fig. 1) are low. The Lakoma soil has the same layer of the Pierre shale for parent material as the Area III gilgaied soils. Approximate clay contents of the microridge soil can be calculated from the clay of the shale parent material by considering the sand and coarse silt of the microridge soil as being dilutents. Some clay in the lower part of the Lakoma soil does not appear in the clay size because it is bound into silt-size fragments of the shale. The large clay content in the 20 to 40 cm layer of the Lakoma soil probably results from the weathering of these shale fragments.

Some of the texture differences of the two soils in a gilgai area may be caused by differences in the degree of weathering and soil development. Clay moves or weathers from the surface layer and tends to accumulate in the subsurface layer as a soil becomes older (Fig. 1, Area III). Thus the microvalley soil of Area III is effectively older than the microridge soil which consists of younger material pushed upward from the subsoil. The soil-organic-matter content, as measured by the total nitrogen content (Table I), is higher in the microvalley soil than in the microridge soil and indicates a relative age difference. In addition, the carbonate content is inversely related to the nitrogen content and is high in the upper layers of the microridge soil where weathering has been less than in the microvalley soils. Thus, cycling of material in gilgaied soils becomes more evident as the soil becomes older. Gilgai formed from young soils (Fig. 1, Area I) have little difference between the two soils. The carbonates are near or at the surface of both soils and there are small quantities of organic matter, particularly in the microridges (Table II).

SUMMARY

Wavy gilgai microrelief consists of parallel microvalleys and microridges that run up and down slopes in the direction of the steepest gradient. The microridge is composed of subsoil material which was forced upward when it was displaced as soil in the microvalleys moves downward in subsoil desiccation cracks. Soil, including coarse-textured material, can move downward in the microvalley and upward in the microridge. This cycling is a slow process which can cause marked differences between the microvalley and microridge soils.

LITERATURE CITED

White, E.M. and A.F. Agnew. 1968. Contemporary formation of patterned ground by soils in South Dakota. Geol. Soc. Amer. Bull. 79:941-944.

White, E.M. and R.G. Bonestell. 1960. Some gilgaied soils in South Dakota. Soil Sci. Soc. Amer. Proc. 24:305-309.

Day, P.R. 1965. Particle fractionation and particle-size analysis. Methods of Soil Analysis. Agronomy 9:545-567.

Jackson, M. L. 1956. Soil Chemical Analysis – Advanced course. Published by the author, Department of Soils, Univ. of Wisc., Madison, Wisc.

Table 1. Particle sizes on carbonate-free basis and the total nitrogen.

Depth	Particles				Sand Fractions (mm)[1]					Total Nitrogen
	<2μ	2-20μ	20-50μ	>50μ	.05-.1	.1-.25	.25-.5	.5-1.	1-2	
cm		%					%			%
Area III	Microvalley soil									
0-5	29.0	18.0	19.5	33.5	3.9	9.1	8.5	8.9	2.1	.22
5-20	45.7	14.3	12.4	27.6	2.7	7.9	7.4	7.6	1.9	.16
20-41	59.0	12.1	7.9	21.0	1.8	5.9	5.7	5.8	1.4	.15
41-56	52.6	15.5	8.7	23.2	1.9	5.8	6.3	7.2	1.3	.10
56-71	51.1	15.7	7.6	25.6	1.9	6.7	7.6	8.1	1.6	.08
71-86	50.8	15.4	7.5	26.3	1.2	6.1	7.8	9.1	1.3	.06
Area III	Microridge soil									
0-5	45.3	13.1	11.2	30.4	2.7	9.6	8.6	7.2	2.0	.21
5-15	48.8	11.5	9.0	30.7	2.6	9.4	9.3	8.1	1.4	.15
15-30	49.3	11.6	9.0	30.1	2.3	8.8	8.9	8.5	1.4	.11
30-46	46.1	12.9	8.3	32.7	2.5	9.2	9.5	9.6	1.7	.09
46-71	46.0	10.9	7.7	36.5	2.4	9.5	10.1	10.7	2.4	.08
71-81	44.1	12.4	1.1	42.4	2.4	11.2	13.2	13.8	1.8	.06

[1] Sum may be different than for 50 total

Table 2. Carbonate content of the soil profiles.

Area	Microvalley Depth cm	Microvalley $CaCO_3$ Content[1]	Microridge Depth cm	Microridge $CaCO_3$ Content
Area I	0-5	N (6.9)[2]	0-8	L (8.1)[2]
	5-46	N (7.7)	8-23	M (8.3)
	46-64	M (8.3)	23-46	H (8.2)
	64-74	H (8.5)	46-81	H (8.3)
Area II	0-8	N	0-3	N
	8-41	N	3-15	N
	41-61	N	15-20	N
	61-86	N	20-41	H
	86-94	H	41-64	H
Area III	0-5	N	0-15	H
	5-20	N	5-15	H
	20-41	N	15-30	H
	41-56	M	30-46	H
	56-71	H	46-71	H
	71-86	H	71-81	H

[1] N-None, L - Low, M - Median, and H - High.

[2] pH of 1:1 soil:water mixture.

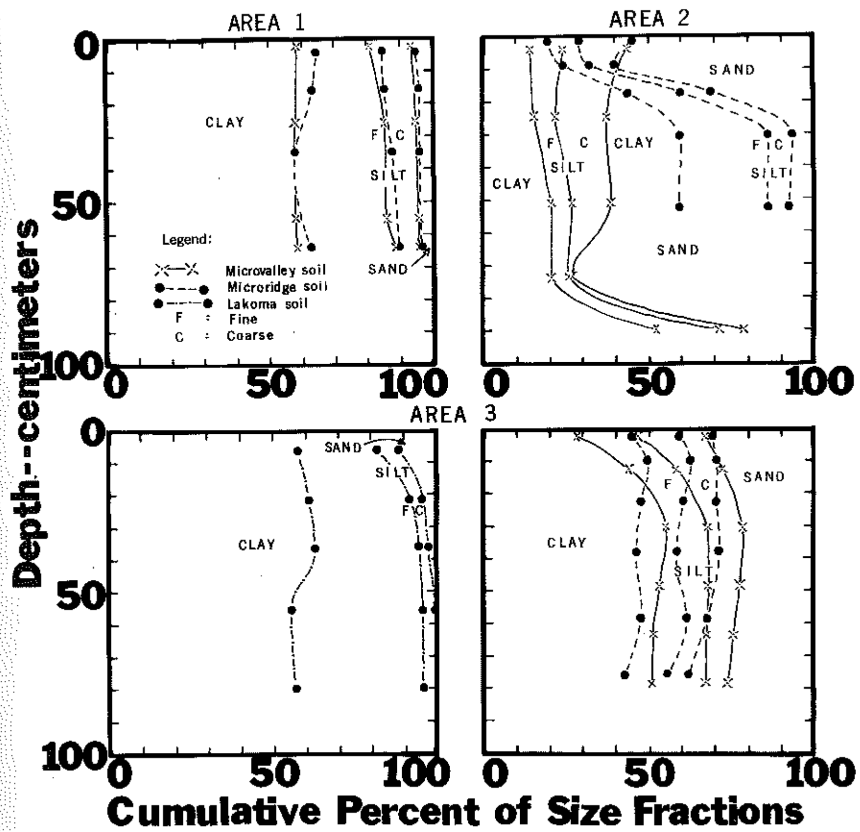

Figure 1. Particle size analyses of the soils. The particle diameters for clay, fine silt, coarse silt, and sand are, respectively, $<2\mu$, $2-20\mu$, $20-50\mu$, and 50μ – 2 mm.