Evaluation of Soil Mineralogy and Associated Properties of Soils Derived from Eocene-age Sediments in Western North Dakota

J.A. Heilig[1], J.C. Kempenich[1], M.G. Ulmer[1], P.W. Benedict[1], T.M. Champa[1] and E.C. Murphy[2]

[1]USDA-Natural Resources Conservation Service
[2]North Dakota Geological Survey

Introduction:

The Rolling Soft Shale Plain (MLRA 54) in southwest North Dakota is underlain by sedimentary bedrock. Most of this material is of Cretaceous and Paleocene age (Sentinel Butte Formation) (Figure 1) and have subdued colors (Bluemle, 2000). However, the bright-colored clayey and sandy layers deposited above the Sentinel Butte Formation characterize the Golden Valley Formation (Figure 2). These vivid white, yellow, orange, and purple layers were deposited by streams and rivers in late Paleocene and early Eocene time, between 50 and 60 million years ago (Figures 3 & 4). The Golden Valley Formation is made up of two members. The upper member, called the Camels Butte Member, consists of sandstone lenses interspersed with finer-grained material. The lower layer is the Bear Den Member, with soils derived from kaolinitic mudstone and claystone (Murphy, 2002). Soils derived from the Bear Den Member are of limited extent (approximately 30,000 hectares), but have unusual soil mineralogy, morphology, and chemical properties that make them unique in the northern Great Plains. They are scattered throughout western North Dakota (Figure 5).

PERIOD	EPOCH	AGE (Millions of years)	EVENT OR FORMATION DEPOSITED	BIOLOGICAL EVENTS
QUATERNARY	PLEISTOCENE	0 to 2	Erosion and badlands cutting Glaciation near Missouri River	Human cultures; extinction of many large mammals; early man; increasing herbs, decreasing trees
TERTIARY	PLIOCENE	2 to 5	Erosion	Abundant mammals; spread of grasslands
	MIOCENE	5 to 24	Arikaree Fm. in some places EROSION	Increase of mammals; development of grasses; reduction of forests.
	OLIGOCENE	24 to 37	White River Fm. in some places EROSION	Flint modern mammals; worldwide tropical forests
	EOCENE	37 to 54	Golden Valley Fm. in some places EROSION	Archaic mammals; abundant flowering plants.
	PALEOCENE	54 to 65	Sentinel Butte Fm. Tongue River Fm. EROSION	Evolutionary "explosion" of mammals; modernization of flowery plants; coal deposited.
LATE CRETACEOUS		65 and older	Hell Creek Fm. Fox Hills Fm. Pierre Fm.	Decease of reptiles, climax of dinosaurs; early birds; rise of flowering plants; decrease of conifers.

Figure 1. Geological time scale depicting events that have occurred in southwest North Dakota. The formations listed here are all found at the surface. (Bluemle, 1980)

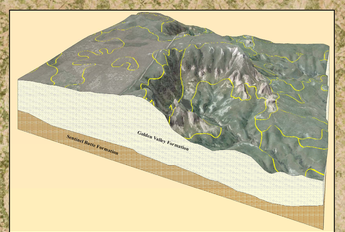

Figure 2. Three-dimensional diagram showing soil delineations and Golden Valley outcrop on a residual upland landscape in northern Billings County, North Dakota

Figure 3. Vivid colors highlight this Golden Valley outcrop in the Little Badlands near South Heart, North Dakota - *Photo by Jeanne Heilig, NRCS*

Figure 4. Bright white Golden Valley outcrop near Grassy Butte, North Dakota *Photo by Todd Solem, NRCS*

Landscape/Soils:

Landscape and landform development are similar throughout MLRA 54 (Figures 6 & 7), but the sediments that comprise the Bear Den Member of the Golden Valley Formation have undergone more intense and extended weathering than sediments from surrounding geological materials. The Lefor soils (Fine-loamy, mixed, semi active, frigid Typic Argiustolls) are typical upland soils that developed in the soft stratified mudstone of the Golden Valley Formation (Figures 8 & 9). The soils that developed from the Golden Valley Formation usually show well-developed horizons and structure (Figures 8 & 10), but are significantly different in mineralogy, soil chemical properties, fertility, and productivity from the soils that developed from the Sentinel Butte Formation.

Geological Formations Underlying Southwest North Dakota

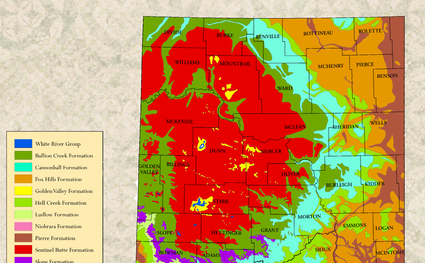

Figure 5. Geological formations from which the parent materials for the soils in southwest North Dakota are derived

Figure 8. Typical pedon of Lefor fine sandy loam. *Photo by Michael Ulmer, NRCS*

Figure 9. Typical Lefor fine sandy loam landscape in the Golden Valley Formation in southwestern North Dakota. Used as rangeland for grazing, but many areas are also used for cropland. *Photo by Jeanne Heilig, NRCS*

Figure 6. Typical Belfield-Daglum silt loams landscape in the Golden Valley Formation *Photo by John Kempenich, NRCS*

Figure 7. Typical Belfield-Daglum silt loams landscape in the Sentinel Butte Formation *Photo by DougWysocki, NSSC*

Figure 10. Typical pedon of Belfield silty clay loam. *Photo by Jeanne Heilig NRCS*

Tables 1 & 2—Comparison of selected soil physical and chemical properties of Typic Argiustolls in the Sentinel Butte and Golden Valley Formations

Table 1.
Comparison of mineralogy and selected soil properties (fine-loamy

	Sentinel Butte Formation – Yegen Fine-loamy, mixed, superactive, frigid Typic Argiustolls				Golden Valley Formation – Lefor Fine-loamy, mixed, semiactive, frigid Typic Argiustolls					
Horizon Designation	Ap	Bt	Btk	Cr	Ap	BE	Bt	Btk	BCy	Cr
Depth (cm)	0-18	18-64	64-135	135-152	0-15	15-25	25-61	61-97	97-125	125-152
Organic Carbon Percent (OC)	1.0	0.6	0.3	0.3	0.9	0.4	0.4	0.1	0.05	0.01
Cation Exchange Capacity (CEC) (meq/100 g soil) *NH_4 extraction method at pH 7.0*	**13.4**	**14.9**	**12.8**	**11.1**	**10.0**	**7.1**	**8.3**	**5.8**	**5.1**	**4.8**
CEC / Clay Ratio	0.95	0.90	0.82	0.79	0.67	0.42	0.29	0.22	0.21	0.28
1500 kPa H_2O / Clay Ratio	0.54	0.48	0.48	0.44	0.44	0.35	0.30	0.35	0.37	0.40
Linear Extensibility (LE) *COLE * horizon thickness (cm)*	0.32	0.97	0.88	0.17	0.21	0.11	0.86	0.36	0.27	0.12
pH *1:1 dry soil – distilled water solution*	6.3	6.8	7.8	8.0	5.4	5.2	6.3	8.1	7.9	7.8
Clay Mineralogy[1] *Each horizon*	MT VR MI	MT VR MI	MT VR MI	MT VR MI	KK MI	KK MI	KK MI	KK MI	KK MI	KK MI
Mineralogy Class *Each horizon*	mixed	mixed	mixed	mixed	mixed	mixed	mixed	mixed	mixed	mixed
Activity Class *Each horizon*	Super active	Super active	Super active	Super active	Semi active	Semi active	Semi active	Semi active	Semi active	Semi active

[1] MT = montmorillonite MI = mica VR = vermiculite KK = kaolinite

Table 2.
Comparison of mineralogy and selected soil properties (fine texture)

	Sentinel Butte Formation – Belfield[1] Fine, smectitic, frigid Typic Argiustolls						Golden Valley Formation - Belfield[1] Fine-mixed, semiactive, frigid Typic Argiustolls					
Horizon Designation	Ap	BE	Bt	Btk	Bk	BCky	Ap	BE	Bt	Btk	2BC	2BCy
Depth (cm)	0-23	23-28	28-61	61-79	79-135	135-152	0-16	16-43	43-107	107-125	125-156	156-186
Organic Carbon Percent (OC)	2.2	1.4	1.0	0.8	0.7	0.7	1.7	1.0	0.3	0.3	0.2	0.1
Cation Exchange Capacity (CEC) (meq/100 g soil) *NH_4 extraction method at pH 7.0*	**18.4**	**16.7**	**23.6**	**19.8**	**17.8**	**18.5**	**9.8**	**10.3**	**10.5**	**8.0**	**4.3**	**4.8**
CEC / Clay Ratio	0.68	0.55	0.59	0.48	0.51	0.54	0.42	0.41	0.31	0.30	0.26	0.24
1500 kPa H_2O / Clay Ratio	0.43	0.36	0.36	0.37	0.38	0.40	0.36	0.33	0.30	0.32	0.34	0.38
Linear Extensibility (LE) *COLE * horizon thickness (cm)*	0.45	0.10	3.30	1.94	1.40	0.29	0.29	0.16	2.43	0.50	------	------
pH *1:1 dry soil – distilled water solution*	5.8	6.2	7.3	7.9	8.3	8.3	4.2	5.6	7.1	8.1	8.3	7.6
Clay Mineralogy[2] *Each horizon*	MT	MT	MT	MT	MT	MT	KK MI	KK MI	KK MI	KK MI	KK MI	KK
Mineralogy Class *Each horizon*	smectitic	smectitic	smectitic	smectitic	smectitic	smectitic	mixed	mixed	mixed	mixed	mixed	kaolinitic
Activity Class *Each horizon*	Super active	Super active	Super active	Super active	Super active	Super active	Semi active	Semi active	Semi active	Semi active	Semi active	Semi active

[1] Soils are outside the range of the Belfield series because of low SARs.
[2]MT = montmorillonite MI = mica KK = kaolinite

Soil mineralogy and selected soil chemical and physical properties were evaluated and summarized to compare soils developed from Golden Valley and Sentinel Butte Formations (Tables 1 & 2). Data indicates the dominant soils from this area would classify as Argiustolls or Haplustolls, with mixed mineralogy. However, the activity class of the soils derived from the Golden Valley Formation is semi active or active rather than superactive. Cation exchange capacity, linear extensibility, pH, and organic carbon values are lower in the soils that developed in the Golden Valley sediments than similar surrounding soils that developed from the Sentinel Butte formation.

Detailed mineralogy was available for each of the evaluated soils, but clay mineralogy was also estimated using the ratio of CEC to clay and the ratio of 1500 kPa water to clay. The ratio of CEC to clay ranged from 0.2 to 0.5 for the Golden Valley soils, indicating kaolinitic or mixed mineralogy. In contrast, the ratio of CEC to clay ranged from 0.5 to 0.9 for the Sentinel Butte soils, indicating mixed or smectitic mineralogy. The ratio of 1500 kPa water to clay was generally less than 0.35 in the soils derived from the Golden Valley formation, while this ratio was greater than 0.35 in the high activity clays that developed in the Sentinel Butte Formation.

Conclusion:

The unique characteristics and soil properties of the soils derived from the Bear Den Member of the Golden Valley Formation make it necessary to correctly identify, classify, and delineate in order to develop appropriate interpretations and management practices. These soils with their unusual mineralogy will require additional evaluation and investigation during the update of MLRA 54.

Citations:

Bluemle, John P. 2000. The Face of North Dakota, Third Edition, Educational Series 26, North Dakota Geological Survey.

Murphy, Edward. 2002. Mineral Resources of North Dakota: Clay, North Dakota Geological Survey.