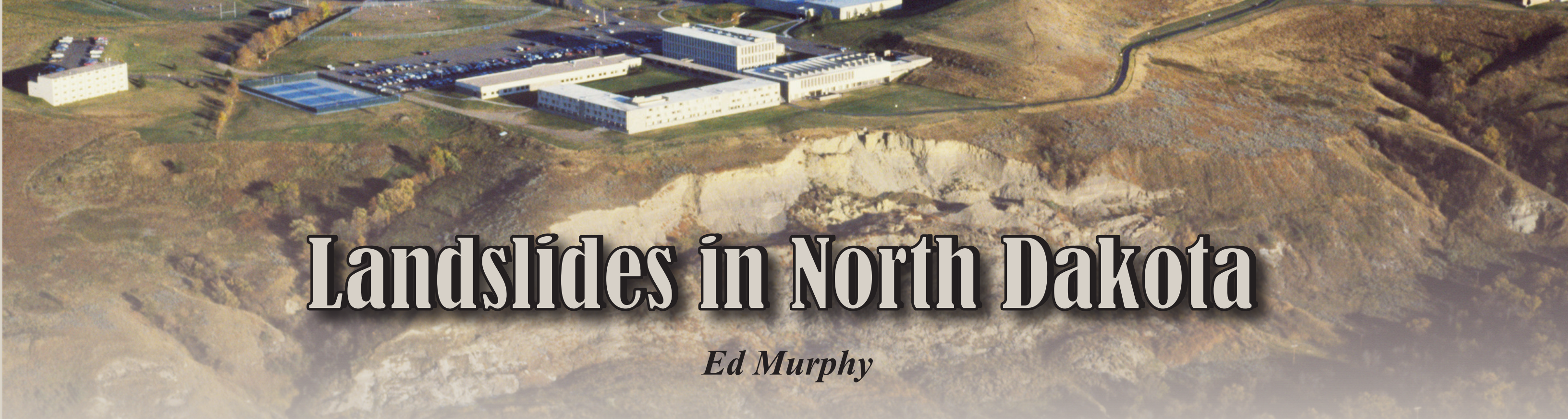

Landslides in North Dakota

Ed Murphy

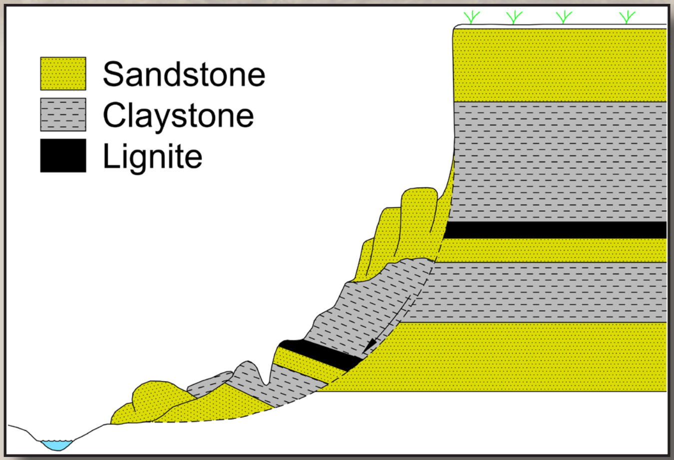

Figure 1. A cross-sectional view of a rotational slump in Tertiary rocks in North Dakota. In a rotational slump the beds within the body of the slide will be rotated back towards the slope. However, chunks of rock typically break off within the slide and may be flat-lying or tilted in a different direction.

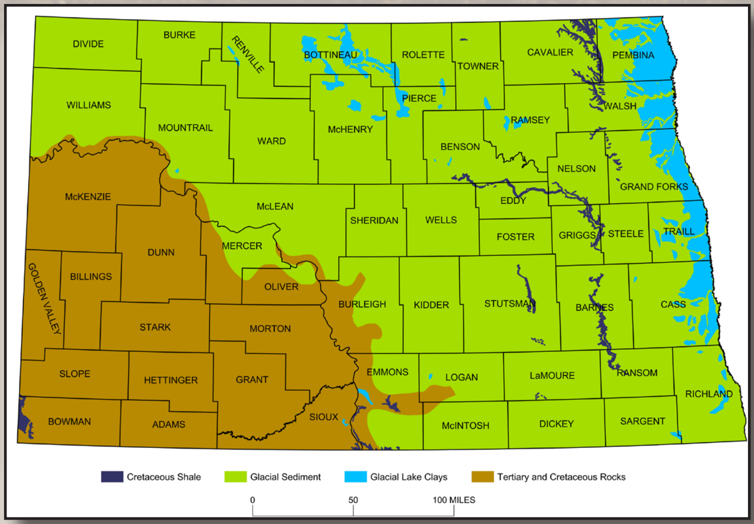

Figure 2. General groupings of the surface rocks and sediments in North Dakota.

Introduction

Landslides cause billions of dollars in damages in the United States each year (Highland, 2006). Annually, landslide damages in North Dakota can reach into the millions of dollars. The vast majority of rocks and sediment at or near the surface in North Dakota are relatively soft so a good rule of thumb is the longer and steeper the slope the more unstable it will be (figs. 1-3). For that reason, the relatively steep river valleys are one of the areas in the state susceptible to landslides. In addition, the badlands topography and buttes in western North Dakota are also prone to slope failure. The vast majority of landslides in North Dakota are categorized as rotational slumps (fig. 1).

Figure 3. A series of landslides along 76th Avenue South in Fargo. One of the disturbed areas (1) extends for 500 feet and is up to 100 feet wide. The scarp of another landslide (120 x 160 feet in area) is visible midway between the two homes on the right (2). Nine homes had to be abandoned in this area due to slope stability problems including the home situated between 1 and 2. Photograph from GoogleEarth dated April 2014, looking south/southwest.

The Surface Rocks and Sediments of North Dakota

The near surface rocks and sediments of North Dakota can be grouped into

Background Photo: *A landslide below the University of Mary. Photo taken September, 1987. The slope was later repaired.*

four general categories: 1) glacial lake clays, 2) glacial sediments, 3) alternating layers of Tertiary or Cretaceous age rocks, and 4) Cretaceous shales (fig. 2). The clays that were deposited by glacial Lake Agassiz in the Red River Valley and glacial Lake Souris in north-central North Dakota can be very unstable (fig. 3). There are a number of small landslides along the Red River Valley that contain evidence of flow (Schwert, 2006). The glacial sediments across much of the state are primarily till, an unsorted mixture of sand, silt, and clay containing rocks ranging in size from pebbles to cobbles to boulders. Whereas most landslides in till are rotational slumps, till in steep, non-vegetated slopes is susceptible to toppling. Till in North Dakota often contains vertical joints or fractures. When till is present in steep outcrops, blocks of this glacial sediment tend to break off in chunks along these joints and roll or topple down the slope (fig. 4).

Figure 4. Jointed till in the scarp of a landslide north of the BNSF railroad tracks southwest of Williston. The slope below was littered with blocks of till that had toppled down the slope. I was investigating this slope in 1996 when the vibrations from a passing freight train caused a 6 x 8 foot block of till to topple from the scarp in the background.

Figure 5. US Highway 85 crosses the Long X Bridge over the Little Missouri River Badlands just south of the North Unit of the Theodore Roosevelt National Park. All of the rocks in this photograph, except for those along the north rim, are part of landslides (Murphy, 2004). Photograph taken looking north.

The Tertiary and Cretaceous rocks of North Dakota (Fox Hills to Arikaree Formations) are comprised of alternating beds of claystone, mudstone, siltstone, sandstone, lignite, and clinker (the latter two lithologies are restricted to the coal-bearing formations). These poorly to moderately indurated rocks are prone to slumping along steep slopes and the majority of North Dakota's landslides occur within this grouping. The area of most concentrated and persistent landslides occurs along the Little Missouri River Valley from a point just west of the North Unit of the Theodore Roosevelt National Park east to the mouth of the Little Missouri River. Landslides along the Little Missouri River Valley significantly increase in size and number in this area owing to the redirection of the Little Missouri River by glaciers approximately 600,000 years ago. The north-flowing ancestral Little Missouri River was forced to the east, out of a north-trending valley now occupied by Bowline, Red Wing, Cherry, and Tobacco Garden creeks, and quickly eroded a new channel creating over-steepened slopes that are very susceptible to slope failure (fig. 5). The well-cemented sandstone or clinker that form the caprock of buttes in western North Dakota are prone to both slumping and toppling (see cover).

The Pierre Formation is only present at the surface in a few relatively small areas in southwestern, south-central, southeastern, and northeastern North Dakota. Yet because of the relative instability of this shale, some of the largest landslides or landslide complexes in the state occur within rocks of the Pierre Formation (fig. 6).

Landslide Frequency and Occurrence

Although landslides can occur without any appreciable warning, it is common for precursors of wide-scale failure to develop at a site. Concentric cracks often develop along the top or edge of the slope as well as bowing or bulging within the slope as a result of smaller scale failure. Occasionally bent tree trunks will document how a living tree adjusted to being moved downslope. Landslides often reflect moisture conditions. Landslides in North Dakota tend to be more frequent during wet years, especially if those have been preceded by a series of dry years. Desiccation cracks can form during dry years that can act as a conduit for precipitation infiltrating into the subsurface during wet years.

The year 2011 was a particularly bad year for landslides in western North Dakota. It was the sixth wettest over a span of 65 years (1949-2014) for the Medora monitoring station and was part of an increasing moisture trend following 2005, the driest year on record at Medora. The North Dakota Department of Transportation had to contend with six major landslides that had impacted travel on five roadways (Highways 8, 22, 73, 85, and 1804). There were at least five other landslides affecting either township or county roads in McKenzie County alone (Donovan, 2011).

Aerial Photography and LiDAR Interpretation

Landslides have characteristic features that are visible at the surface. These include longitudinal and transverse cracks, longitudinal and transverse ridges, displaced vegetation, springs, a vertical and barren slope ranging from a few feet to tens of feet in height at the top of the slope (known as the scarp), and a rounded or jumbled mixture of rock at the base of the slope that marks the terminus of the slide (referred to as the toe). Even with all of these surface characteristics, all but the smallest landslides are best mapped off of aerial photography or LiDAR images.

We use aerial photographs in stereopairs so we can evaluate the image in 3D. The US Department of Agriculture aerial photographs that we evaluate for landslides and other features were typically flown during the growing season so leaves are on the trees. Although there is not an overabundance of trees in North Dakota, they do tend to congregate along river valleys and other areas of steep topography where the leaf canopy can obscure the underlying slope. As a result, we often look for changes in canopy height or other vegetative changes as potential indicators of unstable slopes. Landslides may result in fewer or no trees because they were transported down slope and have not been able to re-establish on the steepened slope. Conversely, landslides may contain more trees than the adjacent slopes owing to an increase in near-surface moisture resulting from water ponded

Figure 6. A landslide complex along the Oahe Reservoir five miles north of the South Dakota border. The prominent scarp across the reservoir consists of rocks of the Fox Hills Formation and the body of the slide is in shale of the Pierre Formation. This landslide complex covers nearly 600 acres. Photo looking northeast.

Figure 7. Trees are aligned in depressions on the surface of a landslide complex along the south valley of the Little Missouri River in McKenzie County. This landslide complex is characterized by a well-vegetated undulating surface, is a half mile wide, three miles long, and covers a total area of about 1,000 acres.

within a broken, jagged slope or where slope failure has exposed springs. In these types of settings, the trees or vegetation often line up parallel to the edge of the slope (fig. 7).

The Geological Survey just recently began using LiDAR to identify unstable slopes. LiDAR is a valuable tool to evaluate slope conditions because it sees through the trees and vegetation thus exposing the morphology of the underlying slope.

Geological Survey Landslide Identification Program

The North Dakota Geological Survey began a landslide mapping program in 2003. To date we have mapped nearly 11 million acres in North Dakota (25% of the state) and have identified 11,077 landslides (fig. 8). These

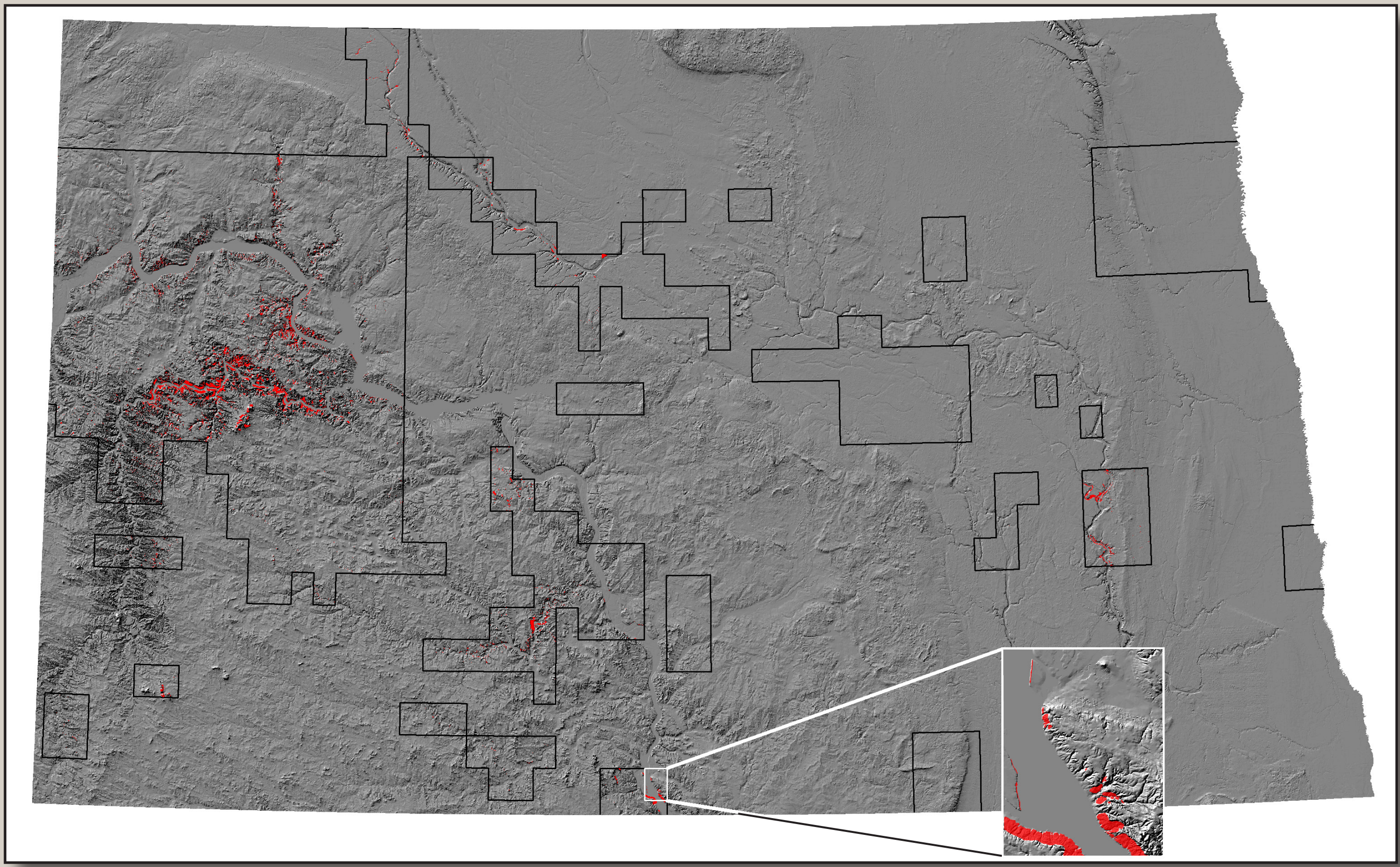

Figure 8. Landslides in North Dakota on a shaded relief base map. The 11,000 individual landslides are shown in red. The Fort Yates SE Quadrangle is enlarged to show more detail (outlined in white). The landslides photographed in Figure 6 are in the southeast corner of this quad. To date, one fourth of the state has been mapped for landslides (areas mapped are outlined in black).

landslides cover a combined area of 116,500 acres. While landslides in North Dakota average 10 acres in size, the largest we have identified to date covers 1,724 acres in the Little Missouri River Valley in Dunn County. In addition to that stretch of the Little Missouri River Valley, there are stretches along the Heart River in Morton County and the Pembina River in Cavalier County where landslides are hundreds of acres in size. In those areas, it is difficult to cross a valley with a road, pipeline, or transmission line without encountering landslides. Most of these landslides are well vegetated, appear relatively stable, and are likely hundreds, if not thousands, of years old.

Much of the landslide identification effort has been to route infrastructure away from unstable slopes. In North Dakota, that has primarily meant roads, pipelines, transmission lines, and buildings. More recently, we have been prioritizing the landslide identification areas to stay ahead of the siting of wind farms throughout the state. Wind turbines are typically placed in areas of elevated topography to take advantage of prevailing wind patterns. These settings are often plateaus, buttes, hills, or escarpments and the slopes of those features may be prone to failure (fig. 9). We have been identifying areas of slope failure so that these turbines can be set back a safe distance from the edge. As with any slope, trimming back the base or adding infrastructure (weight) at the top may be enough to create slope stability problems. Without a geologic map identifying where landslide-prone slopes occur, it is difficult to recognize slopes to be avoided.

Figure 9. Newly installed wind turbines situated on a plateau in western Morton County.

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