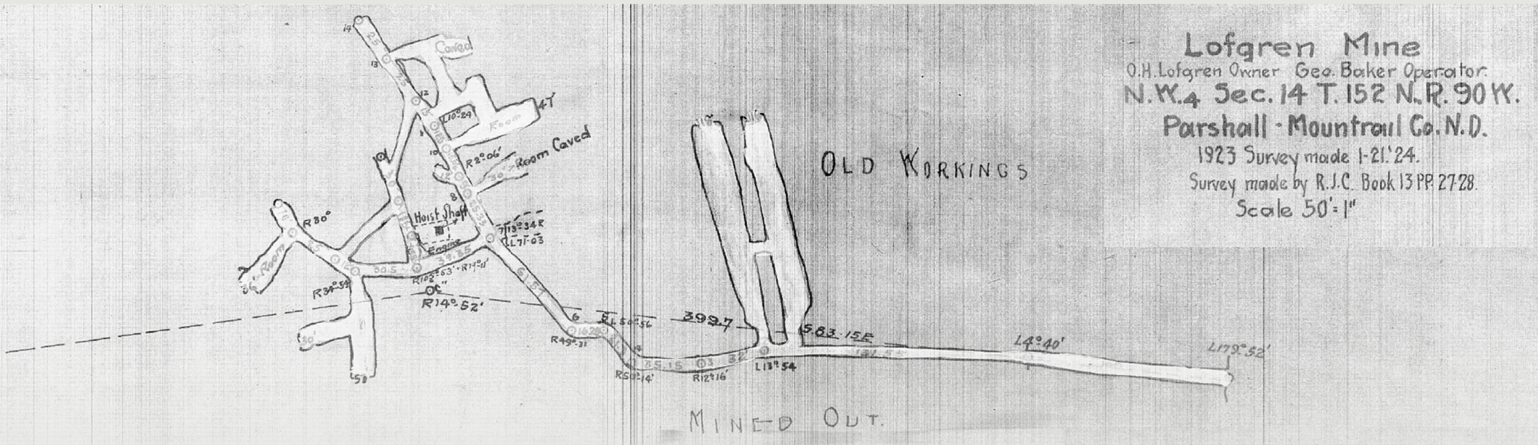

Undermined Ground

Levi D. Moxness

Introduction

Sinkholes are often featured on the national news and have a way of gripping the imagination when they occur. After watching seemingly bottomless voids appear without warning in a backyard to swallow a garden shed, one cannot help but wonder whether you, too, are currently sitting on the delicate roof of an enormous cavern of unknown origins. Fortunately, the settings in which these hazards can occur is actually quite limited. The most common type of sinkhole occurs in states like Florida and Kentucky, which contain significant areas underlain by limestone in the near subsurface. These carbonate rocks are naturally dissolved by groundwater over time, creating caverns prone to collapse if the water table falls. North Dakota does not contain thick carbonate rocks near the surface, but sinkholes do occur in the western half of the state (fig. 1). This type of subsidence can usually be attributed to the collapse of abandoned underground lignite mines.

Figure 1. A five-foot-deep sinkhole caused by underground mining near Haynes in southern Adams County. The void visible along the back wall of the sinkhole represents the adjacent portion of the mine collapse working its way to the surface. The roof above it will soon collapse. NDGS photo by Ed Murphy in the 1980s, prior to reclamation of the site by the North Dakota Public Service Commission.

North Dakota's Lignite Legacy

North Dakota produced nearly 30 million tons of lignite in 2018. That tonnage is produced from five surface mines (the Freedom Mine, Beulah Mine, Center Mine, Falkirk Mine, and Coyote Creek Mine). These large surface mines, with mined-out areas carefully reclaimed, have been standard practice for the North Dakota lignite industry for several decades. The early history of lignite mining in the state was much different, however, involving hundreds of underground mines excavated and abandoned prior to 1966.

Large-scale mining of lignite in western North Dakota began soon after the arrival of the first European settlers, many of whom heated their homes with coal-fired stoves. The first commercial lignite mine in what would become the state of North Dakota opened in Morton County in 1873 near the town of Sims. The early underground workings doubled as a military fortification for the miners, who faced attacks by the local Sioux despite the presence of the US Army led by Lieutenant Colonel George A. Custer. Coal was in high demand to power railroad and steamboat traffic, and at least 72 additional mines opened in North Dakota by 1900 (Oihus, 1983).

By 1940, as many as 320 mines were active in the state (Dahlberg et al., 1984). Over the next few decades, as fuel oil and natural gas became more popular for residential heating, lignite production shifted toward supplying fuel for electrical power plants. With the development of large earth-moving equipment, large surface mines adjacent to power plants became the most commercially viable setting for lignite production. As a result, most of the state's smaller lignite mines were abandoned. No state or federal requirements for reclamation existed for the countless mining companies that operated and dissolved in North Dakota before the Surface Mining Control and Reclamation Act of 1977, and the abandoned mines became a public concern. As the mines aged, collapses and the resulting sinkholes became increasingly common. These features were especially alarming when they occurred near roadways, residential neighborhoods, utilities, and other infrastructure.

Most underground mines in North Dakota utilized the room and pillar mining method, where rectangular "rooms" were excavated and "pillars" of lignite were left to support the overburden (fig. 2). NDGS geologist Leonard P. Dove noted that underground mines used little to no timbering for support, and even the pillars were often removed as the last step in mining out an area (Dove, 1925). He observed that the rooms began caving almost immediately, and that sinkholes at the surface were rendering the land "essentially useless for farming" as early as the 1920s.

A Growing Inventory of Collapses

A 1980 compilation found at least 616 abandoned mine sites in North Dakota, an estimation that quickly grew to over 2000 as additional collapse features appeared, and new sites were discovered (Wald and Beechie, 1996). The Abandoned Mine Lands (AML) Division of the North Dakota Public Service Commission has worked since 1981 to stabilize and reclaim the most hazardous of these mines by pumping pressurized grout into old mine shafts and filling sinkholes at the surface. Exploratory drilling and the compilation of historic mine maps have added greatly to the AML inventory (fig. 3). Historical records are often non-comprehensive, however, and the vast number of sites scattered across the state means that verification is a momentous undertaking.

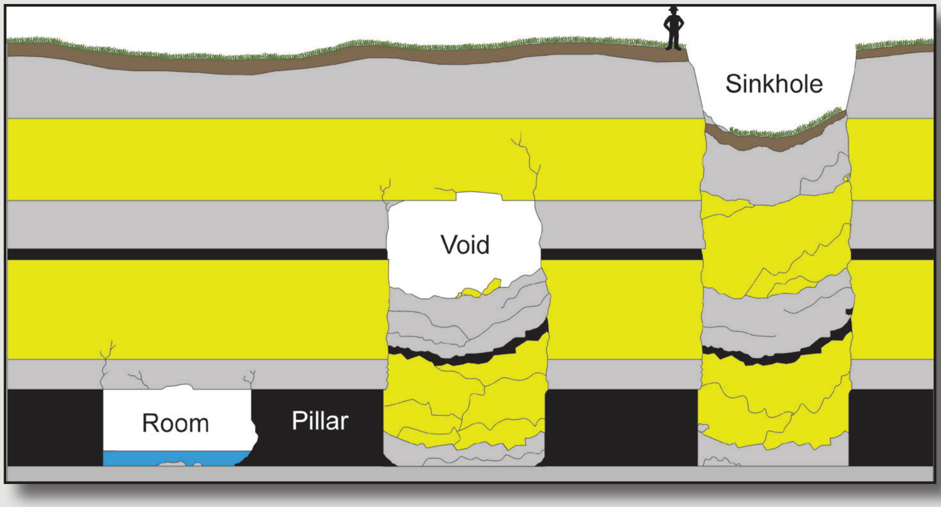

Figure 2. A simplified cross-section of an abandoned underground lignite mine in different stages of collapse. Lignite (black) in the Fort Union Group is typically interbedded with sandstone (yellow) and mudstones (gray). These weak sedimentary units are usually poorly consolidated and eventually collapse when undermined.

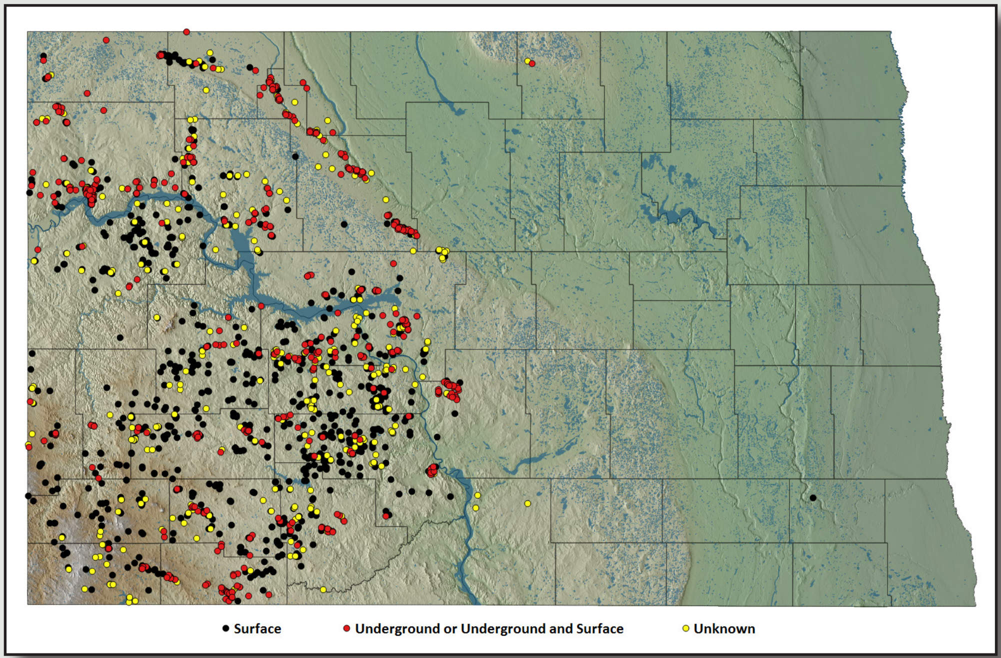

Figure 3. The approximate location of known or recorded abandoned mines in North Dakota. Most of these are former lignite mines, including underground or partially underground mines (red), surface-only mines (black), and mines for which a record exists but details are unknown (yellow). North Dakota Public Service Commission data available via the North Dakota GIS Hub Data Portal.

The North Dakota Geological Survey (NDGS) identifies areas of unstable ground through its landslide mapping program. The mapping process involves the visual identification of failed slopes by reviewing historical and contemporary aerial photography, satellite imagery, and, more recently, LiDAR data (Moxness, 2019). Available since 2018 for all of western North Dakota, bare-earth imagery produced from high-resolution LiDAR strips away visual clutter like vegetation cover and land use variations. In addition to highlighting landslides, subsidence caused by collapsing underground mines is often clearly expressed on LiDAR imagery (fig. 4). The surface expression of these collapse features is distinct from other types of subsidence associated with lignite, such as overburden subsidence caused when thick coal seams burn underground (fig. 5).

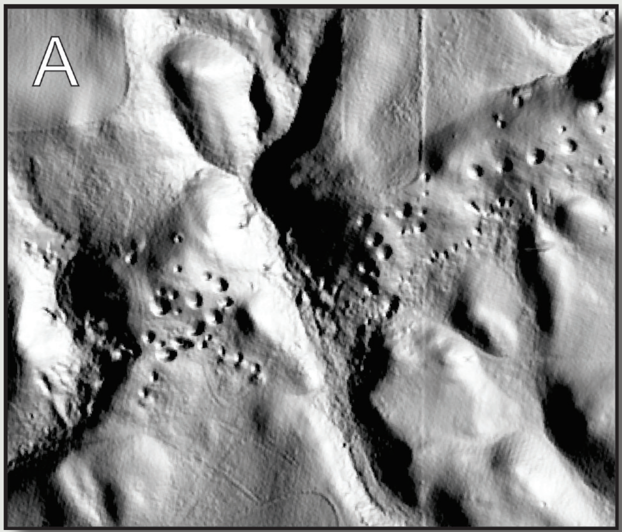

Figure 4. Sinkholes produced by collapsed underground lignite mines near Alkabo in Divide County. The larger sinkholes measure over 50 feet in diameter. The collapses are clearly expressed as circular depressions on bare-earth LiDAR imagery (A) and visible to varying degrees on Google satellite imagery (B).

Figure 5. A shaded-relief DEM produced from LiDAR of Burning Coal Vein Campground in Slope County. The 15-foot-thick Harmon lignite bed burned here for several decades. As the lignite burned away, the volume loss caused the sedimentary bedrock above it to collapse, giving it a "wrinkled" surface expression (arrow).

The NDGS includes areas of unstable ground undermined by abandoned mines on its landslide map series. AML areas will be broadly delineated based on the expression of collapse features at the surface. Although remotely mapping these features at the surface can't provide the subsurface detail needed for reclamation or predictive models, it can provide an additional dataset for the countless mines that are currently just points in an inventory. For hazards as seemingly indiscriminate as sinkholes, the more precisely we can delineate the impacted areas, the easier we can all sleep.

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