“Mudlumps” in the Red River Valley

By Lorraine A. Manz

Mudlump: *A diapiric sedimentary structure that forms a small short-lived island, some 4000 square meters in area, near the mouth of a major distributary of the Mississippi River; it consists of a broad mound or swelling of silt or thick plastic clay that stands 2 to 4 m above sea level. It is created by the loading of rapidly deposited delta-front sands upon lighter-weight prodelta clays, causing the clays to be intruded or thrust upward into and through the overlying sandbar deposits. (AGI Glossary of Geology, 5th edition)*

Introduction

While mapping near the community of Minto in the northern Red River Valley a few years ago, I came across a freshly dug roadside drainage ditch. The excavation was fairly shallow, but deep enough to expose a few feet of yellowish-gray, thinly bedded and laminated offshore lake sediment of the Sherack Formation that underlies most of the topsoil in this part of the valley. Heavy rain earlier in the week had erased any impressions left by the backhoe and smoothed the bottom of the ditch to an almost-level surface that I noticed was disturbed by a number of low, roughly circular, mound-like extrusions of a light yellowish-brown clay (fig. 1). Ranging in size from a few inches to about two feet in diameter, and no more than an inch or two high, for want of a better description, they looked a lot like cow pies.

Figure 1. Mounded clay extrusion in a freshly dug ditch near Minto in Walsh County. The floor of the ditch was perforated by dozens of these features that ranged from a few inches to about two feet in diameter. This is one of the larger mounds. When I revisited this site a year later, the ditch was already overgrown with reeds and other vegetation.

The “Johnstown ditch”

In 1970, a large drainage ditch (County Ditch 19) was excavated alongside a roughly 5-mile stretch of Grand Forks County Road 1, a few miles east of the community of Johnstown. Its eastern end terminated at a second ditch (County Ditch 12) running perpendicular to it along 23rd Street NE. Soon afterwards, the embankments of both ditches began to slump, particularly on the side next to the road, and efforts to repair them only led to more slumping. The problem caught the attention of former UND geology professor Lee Clayton who, as a field exercise, would send his graduate students out to the “Johnstown ditch” from time to time to figure out what was going on. Once in a while, if the bottom of the ditch was exposed, they too would observe low, pancake-like extrusions scattered across its surface. Clayton (unpub. Data, 1970) referred to the features as “injection anticlines” and was surprised to discover that instead of consisting of lake sediment as he’d expected, they were, in fact, made of a very clayey till.

A fundamental problem

The clay-rich sediments that underlie the Red River Valley of North Dakota and Minnesota were deposited in the deep, offshore waters of glacial Lake Agassiz – a vast proglacial lake that formed as meltwater pooled along the margins of the Laurentide Ice Sheet as it receded northwards at the end of the last ice age. The clays contain large amounts of smectite – the general name for one of several groups of clay minerals capable of absorbing exceptionally large volumes of water. Increasing the moisture content of fine-grained (silt and clay) sediment compromises its engineering properties by acting as a lubricant, and this is reflected in the low unconfined compressive strength and loadbearing capacity that characterize the Agassiz lake clays. Without the support of caissons or pilings anchored to more robust geologic units like till or bedrock, bridges, large buildings and other heavy structures built on such poor foundations are at risk of failure.

Most of the engineering concerns in the Red River Valley are associated with the Sherack and Brenna Formations, and the Huot Member of the Forest River Formation.

The Sherack Formation (fig. 2A) is the surface unit throughout most of the Red River Valley and consists of about 15 to 30 feet of laminated clay, silt, and sand (Harris and others, 2020). It is primarily clay and silt in the central part of the valley but becomes progressively sandier towards its eastern and western margins. As an engineering unit, the Sherack is relatively competent and will generally tolerate low-load structures such as houses and parking lots reasonably well – provided the underlying Brenna Formation remains confined in the subsurface.

The Brenna Formation is in the subsurface along the axis of the Red River Valley (fig. 2B) and is unconformably overlain by the Sherack Formation. With clay contents typically exceeding those of most other Lake Agassiz sediments, the Brenna's engineering properties and affinity for water mean that the Brenna is an exceptionally weak engineering unit, especially north of the Edinburg moraine where it is 70 to 95 percent clay (Arndt, 1977). The Brenna's shortcomings as a foundation material are well-known, notorious even (Schwert, 2003; Anderson, 2005). Moreover, its high plasticity and tendency to flow in response to shear stress means that, unconfined, the Brenna is a common cause of slope failure – a recurrent problem along the banks of the Red River and its tributaries, and more than one county drainage ditch.

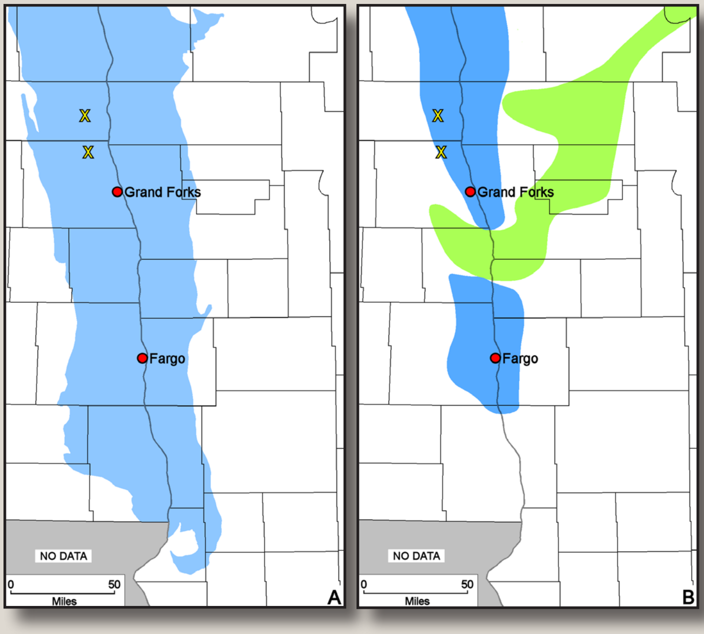

Figure 2. (A) Approximate distribution of the Sherack Formation in the Red River Valley of North Dakota and Minnesota. Yellow X's on both maps mark the approximate locations of the "Minto" and "Johnstown" ditches. Modified from Harris and others, 2020. **(B)** Approximate distribution of the Brenna Formation (blue) and the Huot Member of the Forest River Formation (green) in the Red River Valley of North Dakota and Minnesota. The regional extent of the Huot west of the Red River is unclear owing to a lack of reliable data. Clayton's observations imply that it continues at least as far as northern Grand Forks County, but this has never been verified. Modified from Harris and others, 2020.

The Huot Member of the Forest River Formation (fig.2B) is an unusually clay-rich till unit. Averaging about 70 percent clay (Harris and others, 2020), it is derived from reworked lake sediment that was deposited along the southern margin of a glacier as it flowed into Lake Agassiz during the last major readvance of the Laurentide Ice Sheet into the Red River Valley. The Huot is unconformably overlain by the Sherack Formation, and conformably overlain by the Brenna Formation, which it closely resembles in terms of its general appearance and engineering characteristics. Like the Brenna, therefore, the Huot is a weak stratigraphic unit that is prone to slumping and flow. Clayton's description of the till in the "injection anticlines" suggests it was probably the Huot. He would not have been familiar with this nomenclature at the time because the till was not described and formally defined as a stratigraphic unit until four years later (Harris and others, 1974, 2020).

Causes and effects of slope failure

Wherever there is topographic relief, large or small, gravity is always working to level it. Figure 3 shows an object resting on a sloping surface. The vertical gravitational force (g) acting on it can be divided into two components: one parallel to, and one perpendicular or normal to the slope. The parallel force (gp) represents shear stress – the driving forces trying to move the object downhill. The normal force (gn) represents shear strength – the forces resisting that movement, which include the frictional force between the object and the surface, and the internal cohesion, friction, and resistance to shear of the object itself. If the resisting forces are greater than the driving forces (gn > gp) the object stays where it is, but if the driving forces are greater than the resisting forces (gp > gn), the object will move downhill. In other words, slope failure happens when the shear stress gravitational component (gp) exceeds the combined normal component and the shear strength of the material the slope is made of (gn). In engineering geology the ratio of these resisting forces to driving forces may be expressed as a factor of safety (FoS) where:

$$\text{FoS} = \frac{\text{resisting force (shear strength)}}{\text{driving force (shear stress)}}$$

An FoS greater than 1 denotes slope stability, with failure occurring at or near unity. Values less than 1 practically guarantee slope failure, so clearly anything that increases shear stress, lowers shear strength or both is a potential problem. Some of the prerequisites that may lead to such conditions in the Red River Valley (weak lithologies, structural overload, and high water content) have already been touched on, to which must be added another important cause of slope instability, which is the oversteepening of slopes or removal of lateral support by erosion and human activity.

Slope failure in the Red River Valley takes place in several ways (Schwert, 2003), but the issues with the Johnstown ditch and its side-drainages, and the curious features in the ditch near Minto are mainly associated with just two main processes: slumping and flow.

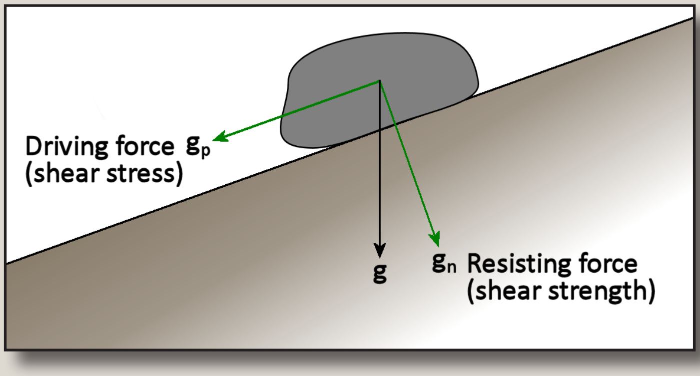

Figure 3. The vertical gravitational force (g) acting on an object resting on a slope can be divided into two components: one parallel to, and one perpendicular or normal to the slope. The parallel force (gp) represents shear stress – the driving forces trying to move the object downhill. The normal force (gn) represents shear strength – the forces resisting that movement, which include the frictional force between the object and the surface, and the internal cohesion, friction, and resistance to shear of the object itself.

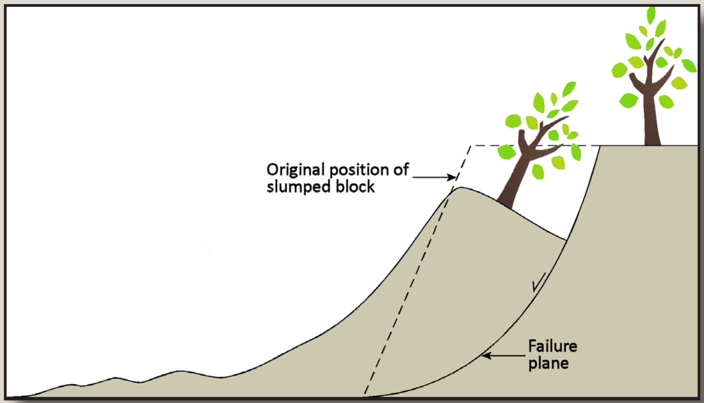

Figure 4. Rotational slumping. A cohesive block of material slides along a well-defined, curved plane of failure. The displaced block undergoes a backward rotation as it moves downslope.

Slumping is a common type of slope failure that occurs throughout North Dakota wherever clayey sediments and bedrock are exposed and gradients are steep. Added weight and/or water-saturated ground often aggravate the process. Slumping involves the downward rotary movement of a cohesive block of material along a well-defined, concave-up plane of failure (fig. 4). The rotated slump blocks are easily recognized by their backward-tilting surface features – trees, utility poles, or fence posts, for example. Most of the bank failures along the Red River are slumps.

Less common in the Red River Valley is another form of slumping in which the slump block drops almost vertically (fig. 5). According to Schwert (2003) this type of slope failure appears to be caused by the lateral flow of unconfined weak (low shear strength) clays, primarily Brenna or Huot material, from beneath the overlying, more competent Sherack Formation sediments into an adjacent stream channel or manmade excavation. Like rotational slumping it is exacerbated by increased loading and wet conditions. The effect is a bit like squeezing toothpaste out of a tube.

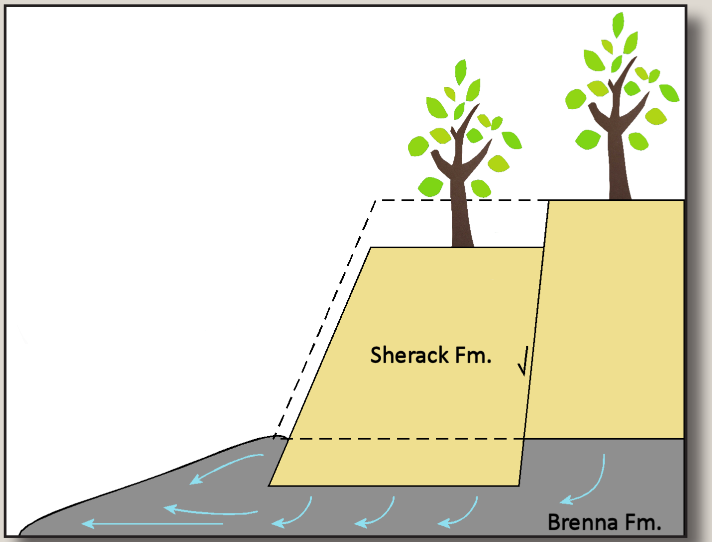

Figure 5. Vertical slumping caused by lateral plastic flow of unconfined weak sediment (Brenna Formation) in response to stress (the weight of the overlying Sherack Formation). Blue arrows indicate the direction of flow. The dashed line has the same meaning as in figure 4.

The persistent instability of the Johnstown ditch is due in part to its unfortunate location. The ditch was constructed in a part of Grand Forks County where the Sherack Formation is relatively thin (Arndt, 1977). I am unsure whether or not the excavation actually cut into the underlying till, but it doesn't really matter because the outcome was going to be the same. The removal of overburden and lateral support with the opening up of the channel, and the weight of nearby County Road 1 bearing down on it, meant that failure of the ditch's sloping roadside embankment was inevitable.

Slumping along the Johnstown ditch became a recurring problem that was eventually mitigated for a time until North Dakota entered a wet cycle in 1993. It is still an issue, and particularly troublesome is the 1-mile stretch of County Ditch 12 immediately north of County Road 1 where it joins ditch 19 (fig. 6). Here, frequent slumping has forced the relocation of the adjacent gravel road, and embankment gradients have been reduced from 6:1 to 2:1 in an attempt to mitigate the situation (R. Axvig, personal commun., 2021).

"Mudlumping"

Slope failure does not explain the mound-like features I described at the beginning of this article. The ditch near Minto had been recently dug, it was relatively shallow, and the roadside embankment seemed to be intact. Nevertheless, the appearance of these curious structures indicates that conditions in and around the ditch are not entirely stable.

Given the location (fig. 2B), the most likely origin of the mounds is the Brenna Formation and its propensity to flow. Clayton believed as much about the origin of his "injection mounds" except they were formed in till rather than lake sediment. Although not as deep as the Johnstown ditch (11 feet), the setting in the one near Minto was essentially the same: unconfined weak sediment

Figure 6. Slumping along Grand Forks County Ditch 12 just north of where it joins ditch 19 (bottom left) near County Road 1.

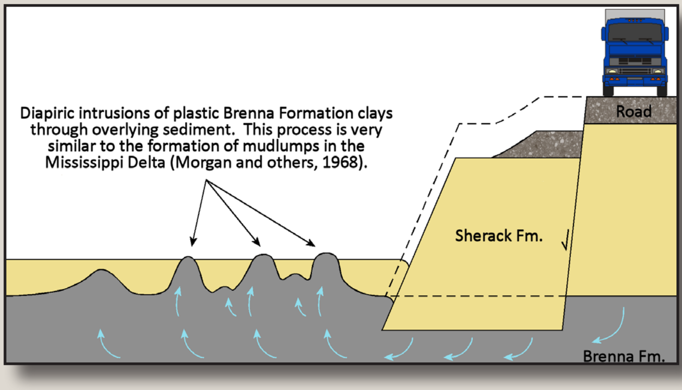

Figure 7. "Mudlumping" on a small scale: the diapiric intrusion of weak, plastic clay (Brenna Formation) into and through overlying, more competent sediment (Sherack Formation) as a result of overloading. Like other forms of slope failure in the Red River Valley, this problem is often aggravated by additional stress from the weight of nearby roads, buildings, and other human activity. Blue arrows indicate the direction of flow. The dashed line has the same meaning as in figure 4.

adjacent to a surface laden with the weight of a road, which in this case, had been raised several feet as a precaution against seasonal flooding, or perhaps in repair of damage from earlier slope failures. In addition, several heavy downpours in the weeks preceding the mounds' discovery had made the ground in the area very wet.

The excavation of the ditch evidently did not expose the unit underlying the Sherack, although the contact between them was probably not more than a few feet below its base. After so much rain, the combined weight of undisturbed sedimentary material and the gravel road above it became too much for the underlying water-saturated clay and it began to flow toward the ditch. Following the path of least resistance, once there, it was forced upward, breaking the surface wherever the overlying sediment was weakest (fig. 7) much like the mudlumps on the Mississippi Delta, only much smaller (Morgan and others, 1968).

Readers familiar with the Brenna Formation will know that it is typically described as grayish brown to very dark gray, even black, in color when wet (Arndt, 1977; Harris and others, 2020), yet the mounds were light yellowish brown, which suggests oxidation. Evidence of oxidation was observed in the upper 10-11 inches of the Brenna Formation in cores from the Fargo area (Liu and others, 2014) but not at the type and reference sections in Grand Forks and Oslo, MN (Harris and others, 2020). Compaction ridges associated with the West Fargo Member of the Poplar River Formation, which was deposited during the low-water Moorhead Phase of Lake Agassiz (12.6 to 10.6 thousand years ago) and which unconformably overlies the Brenna, are common in central Grand Forks and Walsh Counties, including the areas around Minto, and Johnstown, and their presence is strongly indicative of subaerial exposure. There are none within a few miles of the Red River in, and north of Grand Forks in the deeper part of the basin, where lake water may have persisted throughout the Moorhead Phase, leaving the submerged sediment unaltered.

Acknowledgements
My grateful thanks to Grand Forks County Engineer Nick West and former NRCS soil scientist Rich Axvig, who were able to provide compelling evidence that the "Johnstown ditch" and Legal Drain (County Ditch) Number 19 are one and the same. Also for sharing their thoughts and recollections regarding the troublesome history of Johnstown's county drains. (Final note: Just before this article went to press, I came across several references to the Johnstown ditch in one of Lee Clayton's field notebooks and was able to confirm its identity, although he also included part of County Ditch 12 in his definition.)

References

Anderson, F.J., 2005, A highlight of engineering geologic issues in Fargo, North Dakota: North Dakota Geological Survey Newsletter, v. 32, no. 1, p. 24-26.

Arndt, B.M., 1977, Stratigraphy of offshore sediment Lake Agassiz – North Dakota: North Dakota Geological Survey, Report of Investigation 60, 58 p., 3 pls.

Harris, K.L., Manz, L.A., and Lusardi, B.A., 2020, Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota – an update: North Dakota Geological Survey Miscellaneous Series 95, 249 p.

Harris, K.L., Moran, S.R., and Clayton, Lee, 1974, Late Quaternary stratigraphic nomenclature, Red River Valley, North Dakota and Minnesota: North Dakota Geological Survey Miscellaneous Series 52, 47 p.

Liu, Xiuju, Fischer, T.G., Lepper, K., and Lowell, T.V., 2014, Geochemical characteristics of glacial Lake Agassiz sediments and new ages for the Moorhead Phase at Fargo, North Dakota, USA: Canadian Journal of Earth Sciences, v. 51, p.850-861. Doi: 10.1139/cjes-2014-0039.

Morgan, J.P., Coleman, J.M., and Gagliano, S.M., 1968, Mudlumps – diapiric structures in Mississippi Delta sediments, in Braunstein, J., and O'Brien, G.D., eds., Diapirism and Diapirs: Tulsa, Okla., American Association of Petroleum Geologists Memoir 8, p. 145-161.

Schwert, D.P., 2003, A geologist's perspective on the Red River of the North – history, geography, and planning/management issues: Proceedings 1st International Water Conference, Red River Basin Institute, Moorhead, MN.