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ORIGINAL ARTICLE

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A highlight of environmental and engineering geology in Fargo, North Dakota, USA

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Abstract Several unfavorable environmental and engineering geologic conditions exist in Fargo, North Dakota. Dominantly, the behavior of smectitic clays within the proglacial Lake Agassiz sediments of the Sherack and Brenna Formations creates subsoil instability beneath engineered structures in the Fargo area and slope instability within cutbank meanders of the Red River of the North. Unfavorable engineering geologic conditions encountered include: the elastic deformation of clayey glaciolacustrine soils, shrink-swell properties, inadequate bearing capacities, and mass movements. These conditions are responsible for structural failures including the Fargo Grain Elevator in 1955 and the Northern Pacific railroad grade. Bank failures along the Red River are common due to the inherent instability of Brenna Formation smectitic clays which are subject to plastic deformation in the subsurface, with resultant block failure of overlying Sherack Formation. Recent alluvial sediments due to typical fluvial action and the continued seasonal saturation of cutbank meanders within the floodplain also add to soil instability.

Keywords Clay soils · Foundation failure · Glacial lake agassiz · Sherack formation · Brenna formation · Smectite · Fargo · Red River Valley · North Dakota · USA

Introduction

The application of geology to the supporting factors of engineered works is the sub-discipline of geology known as engineering geology. Engineering geologists in some form or fashion have most likely been around since ancient times. Many of the engineered and constructed works of the ancient world are located on generally good natural sites and appear to take local geological conditions into consideration.

Some of the earliest types of works likely to have been studied by engineering geologists include the construction of tunnels for water transport and the construction of the Roman highway (Kiersch 1991). Today, most engineering geologists are well versed in soil and rock mechanics, issues relating to slope stability, aggregate resource exploration and characterization, and groundwater resource identification, development, and protection. Environmental geology issues, both historical and recent, in Fargo, North Dakota must be dealt with and a brief discussion follows (Fig. 1).

Environmental geological overview of the Fargo Area

The City of Fargo is within the Red River Valley adjacent to the Red River of the North which drains the majority of northeastern and eastern North Dakota. Its sister city, Moorhead, Minnesota, continues the urban footprint to the east and comprises the largest metropolitan region in the state (Fig. 2).

The surficial geology (defined here as the near surface sediments most encountered during the construction of engineered works) in the Fargo area is characterized by

Fig. 1 Failure of engineered fill soils on the eastern ramp of the Business HWY94 overpass just west of the City of West Fargo after recent heavy precipitation in the area during the Fall of 2004

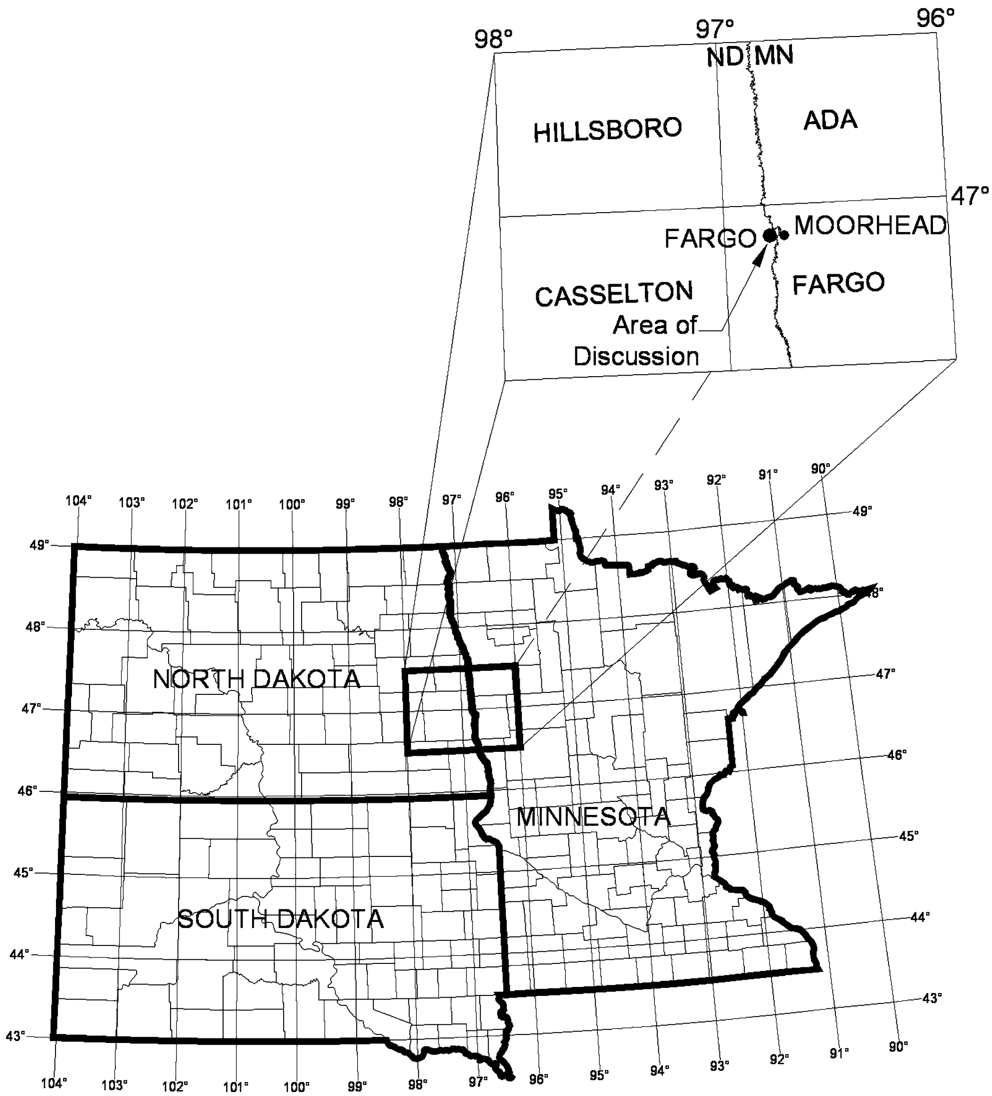


Fig. 2 The City of Fargo is located along the southern border of the states of North Dakota and Minnesota in the Upper Midwestern US that is created by the Red River of the North

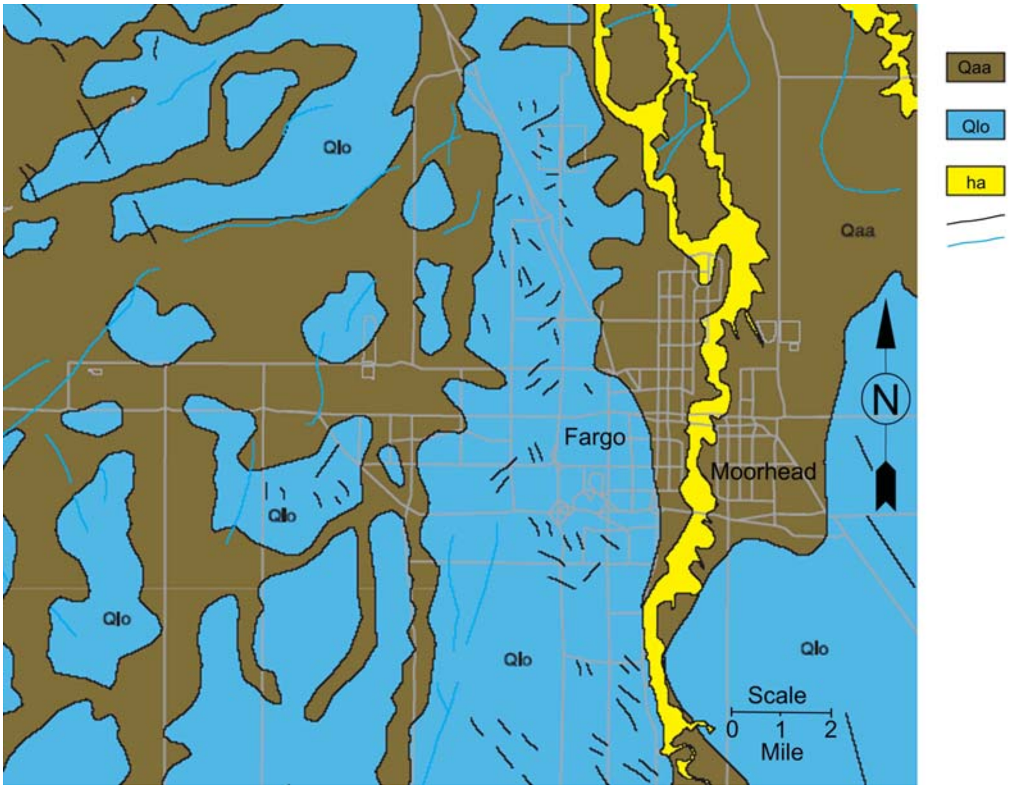


Fig. 3 Generalized lithostratigraphic geologic map of the Fargo area depicting the distribution of surficial sediments in the southern Red River Valley. Unit Qaa consists of overbank sediments associated with ancient river systems draining the Lake Agassiz floodplain. Unit Qlo consists of offshore glaciolacustrine silts and clays of the Sherack and Brenna Formations (Harris et al. 1974). Unit Ha consists of Holocene age alluvium and channel sediments deposited within the Red River floodplain and along tributary drainages. Ice drag marks (*linear black lines*) and compaction ridges (*linear blue-gray lines*) are also shown. Modified from Harris et al. (2005)

a relatively uniform blanket of glacial lake sediments deposited during the onset of Glacial Lake Agassiz around 11,000 years before present (bp) (Fig. 3) and alluvial sediments that mantle the lake silts and clays throughout the southern Red River Valley.

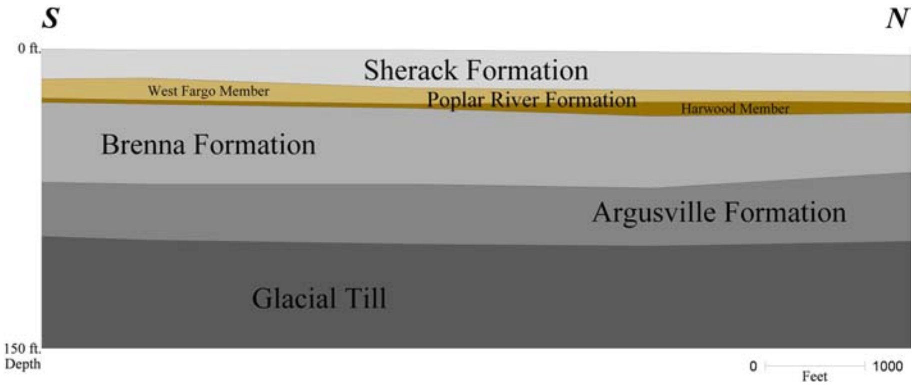
The sediments that underlie the Fargo area consist dominantly of glacial lake silts, sands, and clays (and gradational combinations of each) that reach depths of up to 46 m below the land surface (bls). The Red River of the North incises this relatively featureless plain and periodically delivers a healthy amount of overbank fines to the area during seasonal flooding events (Fig. 4a, b). Sediments underlying the Fargo area that are arguably of greatest concern consist of glaciolacustrine silts, clays, and silty clays of the Sherack and Brenna Formations (Harris et al. 1974). In the Fargo area these sediments are generally found to depths slightly greater than 31 m. The generalized stratigraphy of these units (Fig. 5) is somewhat regular with 6 m of yellow-brown laminated silty clays of the Sherack Formation (Fig. 6) underlain by approximately 24 m of gray, fat clays of the Brenna Formation (Fig. 7) (Schwert 2003). Sandwiched between these units are the West Fargo and Harwood Members of the Poplar River Formation (Harris and others 1974; Arndt 1977). Due to the fact that these glaciolacustrine sediments contain high amounts of smectitic or ‘‘swelling’’ clays in their overall mineralogy these sediments present many difficulties when structural loads are applied due to their inherent ability to take up water within their mineralogical framework with a resultant loss of strength.

Examples of engineering geologic issues in the Fargo area

For the most part, the engineering geologic problems that exist in the Fargo area are the result of the interaction between constructed engineered works and the underlying ‘‘load -bearing’’ sediments. The presence or absence of water within these sediments serves to create two major engineering geologic challenges within the valley: soil stablility issues related to the construction of surface engineered works and slope stability issues re-

Fig. 4 a View to the north along North Elm Street in Fargo. High water levels in the Red River encroaching upon and in many cases shutting down convenient local transportation routes and providing for increased cutbank meander instability and erosion through seasonal saturation of the entire cutbank meander as shown Fig. 4b in this southern view of North Elm Street during recent flooding in the Summer of 2005

Fig. 5 Generalized south to north geologic cross section of near surface glaciolacustrine and subglacial sediments present beneath the greater Fargo area



lated to failures within cutbank meanders along the Red River of the North along the North Dakota border with Minnesota.

Previous workers (Moran 1972; Arndt 1974; Schwert 1997, 2003) have documented several significant engineering geologic conditions throughout the Red River Valley. Some examples are the elastic deformation of clayey glaciolacustrine soils, shrink-swell properties, inadequate bearing capacity, and mass movements.

Elastic deformation of clay-rich soils has been documented throughout the Red River Valley. Under certain cases of loading and unloading, such as in the construction, use, and subsequent failure of the Fargo grain elevator in 1955 (Fig. 8), soils beneath the structure deform in response to the increased load upon them, resulting in an adverse structural effect. Upon removal of the load, these materials restore to their previous condition.

Volumetric expansion of clayey rich soils under differing moisture conditions has also been documented. During significantly wet periods, subsurface soils increase in their capacity to accept water into their mineralogical framework, with a resultant loss of bearing capacity. Conversely, during periods of drought the

Fig. 6 Outcrop of Sherack Formation along a tributary drainage of the Red River of the North just north of the City of Fargo showing the well developed laminae of silts and clays deposited in the offshore depositional environment of Glacial Lake Agassiz and subvertical fracturing developed within this unit at the outcrop

Fig. 7 Brenna Formation slickensided clay uncovered at the City of Fargo, North Dakota landfill during excavations for new waste cell construction. The Brenna Formation was formally named and described by Harris et al. (1974) and is recognized at depth throughout the near surface throughout the Red River Valley and has been well discussed by Schwert (1997, 2003) (Image by Schwert)

Fig. 8 View of the collapsed Fargo Grain Elevator after subsurface soil failure in 1955. (Image from the Institute for Regional Studies, North Dakota State University, Fargo, North Dakota)

Fig. 9 View to the south along the eastern bank of the Red River depicting earthflow, soil slumping, and bank failure near residential developments in north Fargo. Note the subvertical orientation of trees and presence of developing scarps in the foreground

opposite occurs, resulting in overall volumetric reduction of material. Taken in concert, these changes in soil volume over time have the cumulative effect of destroying the underlying foundation stability.

Many structural failures have occurred due to the inherent weakness of clay-rich soils in the Red River Valley and their inability to accept uniform or non-uniform loads. Three significant failures noted include the Transcona Elevator in Winnipeg, Manitoba (Peck and Bryant 1953), the Fargo Grain Elevator in 1955 (Nordlund and Deere 1970), and the failure of the Northern Pacific railroad grade, best chronicled by Schwert (1997).

These types of failures have occurred simply by the overloading of unstable foundation soils in the subsurface, which deformed through an increase in load with a resultant decrease in effective stress and increase in pore water pressure with further expansion of materials around the structures (much like placing a brick in a box of mud). The solution has been to drive supporting structures through the glacial lake sediments into the more stable underlying subglacial sediments.

Mass movements of unstable soils within the Fargo area have also been extensively documented by Harris (2003) and Schwert (2003).

Failures of materials within cutbank meanders along the banks of the Red River are persistent and common and are related to the inherent instability of underlying Brenna Formation sediments which undergo plastic deformation in the subsurface with the resultant block failure of overlying Sherack and recent alluvial sediments and repeated seasonal flooding (Figs. 9, 10).

If surrounding geology is ignored in the construction of engineered works, then that geology will most certainly assert its influence on any engineered structures.

Current investigations

The common factors in the majority of the engineering geologic problems that are encountered in the Fargo area are the result of the inherent physical properties of the Glacial Lake Agassiz offshore sediments and the underlying stratigraphic relationships of these materials. Problem areas must be identified prior to site utilization and other areas with more favorable geologic conditions considered. However, when the geologic condition is pervasive and is common across a large pre-existing urbanized area (Arndt and Moran 1974) it may be possible to engineer around the problem, or more

Fig. 10 View to the southwest of failed cutbank along a meander of the Red River north of Fargo, North Dakota. Note the presence of a well defined failure scarp and coherent vegetated slump block with subvertically orientated trees. Portions of the upper Sherack Formation are visible along the cutbank

appropriately in the case of Fargo; through it, as this may be more economical than finding new sites.

Currently, environmental and engineering geologists from the North Dakota Geological Survey and North Dakota State University, in addition to many others, are engaged in detailed geologic mapping studies and public education efforts to enhance and develop the public's understanding of the existing geological conditions in the Fargo area. Many of the products created from these investigations, such as detailed geologic and derivative maps, will serve as the primary database for environmental and engineering geological investigations conducted within the Fargo area in the future.

The engineering geology of the glaciolacustrine deposits of the Sherack and Brenna Formations in the vicinity of the Fargo area and their physical and engineering properties, stratigraphic relationships and environmental geological characteristics are understood.

How these materials vary spatially, both in two and three dimensions, is not yet fully documented. This work will continue.

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