Geomorphology and Interpreted Surficial Geology of the South Fork of the Crow River Watershed

The Crow River watershed (North and South Fork) contributes between 16 to 53% of the sediment load to the Mississippi River at Anoka with only 4 – 20% of the total flow (Crow River Diagnostic Study Report, 2005). It exports suspended sediment to the Mississippi River in large enough quantities to affect the drinking-water-treatment system for Minneapolis and St. Paul, which have intakes located immediately downstream of the confluence with the Crow (Arnston, 2007). The South Fork of the Crow River is the higher sediment loader in the watershed and this may be in part because its geology is more like watersheds of the Minnesota River than those in the upper Mississippi watershed. The goal of this mapping project was to better map the distribution of glacial parent material within the watershed to increase our understanding of why the South Fork of the Crow River is so turbid. A map of the entire watershed is required for this rather than simply an inventory of eroding stream banks because the latter is only one of several mechanisms that contribute to the suspended sediment load (silt and clay) of a stream. Any location in the watershed can potentially be contributing sediment to the stream network if there is unconsolidated silt and clay at or near the surface; a mechanism to dislodge it (e.g. rain, wind, bioturbation, tillage); and a way to move it to the stream (e.g. flowing water, wind, bioturbation, gravity).

This map of the *Geomorphology and Interpreted Surficial Geology of the South Fork of the Crow River Watershed* emphasizes the glacial landforms, the processes which formed them and the interpreted distribution of all surface sediment in the watershed. Sediment and topographic variability controlled the way that the land was initially used by European settlers and drove the way it was later modified in order to overcome obstacles to cultivation. Increased sediment loads in other, nearby, agriculturally dominated watersheds have been interpreted to be a consequence of such land uses and modifications (e.g. Engstrom and Swain, 1986; Knox, 2001; Brigham et al., 2001; Magdalene, 2004). This map was constructed as a first step in understanding which parts of the landscape are sources for fine-grained sediment. A companion study on the radionuclide geochemistry of the suspended sediment will apportion the sediment load to shallow and deep sources in the landscape and make the mechanisms of sediment delivery and possibly the storage of the sediment in transit more apparent (Schottler et al., in prep.). Preliminary estimates suggest that roughly half of the sediment load is derived from shallow sources that are exposed to the radioisotopes in rainwater. The other half of the load is not exposed to these radioisotopes in rain so derives from deeper erosion of glacial sediment or from stream banks that have been storing sediment for a few decades. When the final results of the geochemical work are available, these two studies will illuminate areas in the landscape to focus on in order to reduce sediment loading.

Stream and soil development and their effects on land use

By comparing landscapes created during different glaciations in Minnesota (Wright, 1972), one can see that it takes on order of hundreds of thousands of years for stream networks in the southeast to evolve to a point where there is negligible standing water on a landscape. Two different geomorphic processes occur: 1) the bogs, lakes and other low areas common in a glacial landscape are gradually filled with sediment and organic detritus; and 2) the stream network grows headward, increasing its number of branches, and ultimately reaching the remaining undrained areas. In this way the area contributing surface runoff in a watershed gradually increases over time. If a markedly lower percentage of precipitation falling on the watershed is stored as standing water or infiltrated into the deeper groundwater, a common response is an increase in the average annual stream discharge. Stream geomorphic attributes depend on many factors, but a likely consequence of increased discharge is an increase in some combination of cross-sectional area, slope and velocity of the affected river reach in order to accommodate higher flow. Details would depend on site specific factors such as geology and vegetation.

Areas mapped as Holocene Alluvium (unit Ha) on this map represent the deposits of naturally formed Holocene and modern streams that have been adjusting to precipitation and groundwater flow since the end of the last glaciation in this area. They do not delineate a branched, dendritic network because they are relatively young and for the most part, the trunk streams follow the course of former glacial meltwater streams (unit **Qsm**). Glacial channel locations were commonly strongly influenced by the presence of ice in the landscape, in many places circumscribing an arcuate path around the former ice front (unit **Qtm** marks moraines formed at ice margins; unit **Qsm** marks meltwater stream locations; see northwest portion of map for clearest example of ice marginal streams circumscribing an ice front marked by a moraine; then consider the northeast-trending, subparallel, upper reaches of Buffalo Creek and the South Fork of the Crow River—they outline more extensive positions of the same ice lobe. Where the rivers turn southeast they mark where the proglacial streams were forced to loop around the margin of another ice lobe). In other places the streams inherited a course dictated by the presence of an ice-surface low that persisted as streams on top of the ice were gently lowered to the ground as the ice thinned. In these locations, the modern streams are flanked by low hills of disorganized stream sediment (where units **Qcss** and **Qsm** are in close association in southwest portion of map). In still other regions, tunnels that formed beneath the ice left significant troughs that are now commonly occupied by the linear, south-, southwest- and southeast- trending in the middle of the mapped area. Subglacial water in these tunnels flowed uphill and to the south owing to the pressure of the ice. Today they are areas where water ponds or, if crossed by modern streams, the water slows. So in many places in this landscape, the main branches of Buffalo Creek and the South Fork of the Crow are not in the most logical places of maximum gradient. They have inherited and pieced together reaches of different origin and have sections with low gradients, relatively sluggish flow and broad floodplains.

Glaciated landscapes have newly constructed, irregular topography (sometimes called hummocky) so typically have many depressions that are not linked by stream networks. At the time of European settlement, these depressions were locations of shallow lakes and wetlands (Marschner, 1974). Many parts of this watershed have a black organic upper soil horizon that develops in grasslands (mollic epipedon) over 20 inches thick (e.g. Glencoe, with the related Canisteo, Harps and Nicollet soils). These soils formed over the course of the Holocene (approximately the last 10,000 years of non-glacial climate) on poorly drained flat areas or in shallow depressions with predominantly glacial till parent material (units **Qt, Qth, Qtm, Qtw, Qtwd, Qlsm**).

Most of the landscape away from the stream channels is now fairly well drained and many of the shallow lakes and wetlands are gone (Taffen, 1998).

The low gradient and relatively low permeability of the parent materials made artificial drainage practices essential for farmers to get into the fields early enough in the spring, ensure a timely harvest in the fall and expand the area available for row crops. The installation of artificial drainage networks represents a substantial extension of the drainage in a very brief interval of time from a geologic perspective. It now taps into previously isolated depressions, straightens and deepens low-sloping glacial channels and dries slow-draining, low-relief areas, substantially reducing places where water and thereby sediment are stored on the upland part of the landscape (See Sancoki, 1998 for a map of the drainage network that also identifies the judicial ditches and stream extensions). This has potentially altered the balance between erosion and deposition everywhere downstream of the changes. One could argue that the modern rivers created only very small parts of their own channels—glaciation imposed the initial configuration on them and humans have done much of the rest.

Artificial drainage is common in all of the low-relief, agriculturally developed parts of Minnesota and Iowa in the area underlain by loamy Des Moines lobe till (typically greater than 65% silt and clay). The storm flow, annual baseflow and minimum flow of similar streams in Iowa have commonly increased significantly over the second half of the 20th century. The increase is more than can be accounted for by increases in precipitation over this period and is attributed to artificial drainage and other farm practices as well as increased incision and widening of streams, allowing them to intercept more shallow groundwater (Schilling and Libra, 2003, Zhang and Schilling, 2006; Schilling and Helmers, 2008).

The South Fork of the Crow River watershed differs from most other southern Minnesota watersheds in containing an aerially extensive, relatively unconsolidated surficial unit dominated by silt and clay. This may play a key role in the suspended sediment supply to the river. The unit overlies the tills in this watershed and although clearly attributed to a lake in places (laminated silt with clay and fine sand) it grades into a silty diamicton that resembles the till but is much easier to drill and dig into (unit **Qlsm**). This unit can be up to 10 m thick, is thickest in low-lying areas, and is interpreted as resulting from the temporary ponding of glacial meltwater on stagnating ice, as is described further below.

Silt is inherently not as cohesive as clay and material deposited in a lake or on top of ice does not become over-consolidated like till which, when deposited beneath the glacial load can be drained of its pore water and concurrently compacted. The Chippewa River watershed and the Le Sueur River watershed have similar, relatively unconsolidated silt-and-clay dominated surficial units, deposited in Glacial Lake Benson and Minnesota, respectively.

Glacial History

All of the sediment in this area was originally imported by streaming (fast-moving) ice that originated in an ice shed that covered southern Saskatchewan, Manitoba and northwest Minnesota and was part of the Laurentide ice sheet. Separate tributary ice streams from this ice shed formed what was considered a simple outlet glacier—the Des Moines lobe. However, because the ice originated in different ice streams and because the geology of the glacier bed varied, subtle differences in the matrix texture and rock-fragment content of the till—the unsorted, direct deposit of the ice—can be used to infer the different and source areas and the evolution of the ice shed over time (Jennings et al., 2008).

The tills at the surface in this watershed were deposited by two ice streams (units **Qt** and **Qth);** these ice streams flowed side by side but were dynamically independent.

The southern junction of the ice streams creates the subtle, broad linear highland that is the southern boundary of the watershed and is marked by much smaller pockets of sand and gravel expressed as whiter areas in the airphoto image (unit **Qcss**). The ice-surface low would have been created where increased friction along the shear zone enhanced melting and the sand and gravel patches are interpreted as the sedimentary evidence of supraglacial meltwater.

The more northerly of the two ice streams (unit **Qt**) thinned and stagnated first. This created a lower ice-covered area with active ice to the south that started to invade it. Floodwater originating in the highlands of the Alexandria moraine to the north coursed through the low area of stagnant ice and the water could not drain as it was blocked on all sides. Coarse-textured ridges of fluvial sediment filled crevasses (unit **Qccs)** and the area was scoured (unit **Qtwc**).
Eventually, a widespread drape of silty, loose till-like sediment was deposited as the ice wasted (unit **Qlsm).**

After deglaciation, modification of the sediment and landscape occurred as modern streams evolved and as isolated depressions filled with organics (unit **Hp**) and sediment (unit **Hl**) deposited in lakes, ponds and bogs Over the moderating climate of the Holocene (last 10,000 years) the surface deposits have been chemically and physically altered by slow, soil-forming processes and more recently by human modification.

Map construction

The map units in the *Geomorphology and Interpreted Surficial Geology of the South Fork of the Crow River Watershed* were constructed by interpreting early spring, stereo-pair, aerial photographs, taken in 1977-78 (1:80,000) and 1968 (1:90,000) and compiling these interpretations on 1:24,000 United States Geological Survey topographic maps. Field work was conducted between fall 2006 and summer 2008. Most exposures were located by driving the study area on section-line roads at an average of every two miles. Exposures consisted mainly of short-lived artificial excavations including road cuts, construction sites and gravel pits. Natural exposures along Buffalo Creek (downstream of Brownton) and the South Fork of the Crow River (from Lester Prairie to Watertown) were accessed by canoe.

In some cases, landscapes and outcrops were photographed, sometimes in addition to being sampled. The photos are meant to allow the map-user to better visualize land use and sediment types in the watershed. Units were compiled on a mylar overlay of a 30-m digital elevation model (DEM) at a scale of 1:100,000. This line work was scanned, cleaned and converted to polygons. Polygons were assigned a unit label based on field observations, air-photo interpretations, soil information from NRCS soil surveys for the counties in the watershed, and an unpublished generalized soil geomorphic map (R. Paulson) that covered all of south central Minnesota.

The attribute table for *Field Observations* was populated with a code that indicates the type of sample (oc = an outcrop; g = giddings probe or soil boring; grab is a sample from various depths), whether a photo is linked to the point (ph = photo); and a unique identifier. The unique identifier links the attribute table to an excel spreadsheet where sediment texture, grain counts and notes are stored. For soil borings and extensive exposures, there may multiple samples taken at different depths linked to a single point. This information can be accessed by setting *Field Observations* as a selectable layer and then clicking on a point.

The samples and observations described above were supplemented with soil boring and outcrop information from McLeod County, an MGS mapping project that was underway concurrently (Lusardi and Jennings, 2009). These data are in a separate point file and also contain a code for the type of sample (GD = giddings probe or soil boring; HS = hand sample) and a unique identifier that serves as a link to an external spreadsheet.

References

Arnston, Allen, 2007. Estimated and measured traveltime for the Crow River Watershed, Minnesota: U.S. Geological Survey Scientific Investigations Report 2007-5138, 12 p.

Brigham, M.E., McCullough, C.J., and Wilkinson, P., 2001. Analysis of suspended-sediment concentrations and radioisotope levels in the Wild Rice River Basin, northwestern Minnesota, 1973-98. U. S. Geological Survey Water Resources Report 01-4192, 21 pages.

Crow River Watershed Organization, 2005. Crow River Diagnostic Study Report Summary, January 2005, 22 pages.

Engstrom, D.E., Swain, E.B., 1986. The chemistry of lake sediments in time and space. Hydrobiologia v. 143, 37-44.

Harris, K. L., 1998. Computer Assisted Lithostratigraphy. *In* Patterson, C.J. and Wright, H.E. Jr., eds, Contributions to Quaternary studies in Minnesota: Minnesota Geological Survey Report of Investigations 49, p. 179-192.

Jennings, C.E., Lusardi, B.A. and Harris, K.L, 2008. Multiple, discrete till sheets created in differently sourced ice streams are deposited in the Des Moines lobe, USA, Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract C23B-03.

Knox, J.C., 2001. Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. Catena, 42 (2-4), p. 193-224.

Lusardi, B. A. and Jennings, C. E., 2009. Surficial Geology of McLeod County, Minnesota, 1:100,000 Minnesota Geological Survey County Atlas Series, C-20 part A.

Magdalene, S. C. C., 2004. From field to stream: rapid runoff through agricultureal tile drainage within the Minnesota River basin. Univ.of Minn.PhD thesis.

Marschner F.J., 1974. The original vegetation of Minnesota, compiled from U.S. General Land Office Survey notes by Francis J. Marschner, 1:500,000. Redrafted from the original by P.J. Burwell and S.J. Haas under the direction of M.L. Heinselman. St. Paul: North Central Forest Experiment Station, United States Department of Agriculture.

Sanocki, C.A., 1998. Physical characteristics of stream subbasins in the South Fork of the Crow River basin, south-central Minnesota. USGS Open-File Report 98-20, 11p, and map, scale 1:126,720.

Schilling, K.E. and Libra, R.D., 2003. Increased baseflow in Iowa over the second half of the 20th century. Journal of the American Water Resources Association, 39 (4), 851-860.

Schilling, K.E., and Helmers, M., 2008. Effects of subsurface drainage tiles on streamflow in Iowa agricultural watersheds: Exploratory hydrograph anaylsis. Hydrological Processes 22, p. 4497-4506.

Schottler, S., Engstrom, D.E. and Blumentritt, D. in prep. Suspended Sediment Source Apportionment in the South Fork of the Crow River.

Taffen, Steven J., 1998. Managing Minnesota's drainage system. Minnesota Agricultural Economist 692, Spring 1998, p. 1, 3-7.

United States Department of Agriculture, Natural Resources Conservation Services, Soil Survey of McLeod County, 2005.

Wright, H.E. Jr., 1972. Physiography of Minnesota. *In* P.K. Sims and G.B Morey, eds, Geology of Minnesota: A Centennial Volume. p. 561-578. Minnesota Geological Survey, St. Paul, Minnesota.

Zhang, Y.-K. and Schilling, K.E., 2006. Increasing streamflow and baseflow in Mississippi River since the1940's: Effect of land use change. Journal of Hydrology v. 324, p. 412-22.

Map Legend

QUATERNARY

Ha Pebbly sand to silt deposited in laterally continuous horizontal layers by modern streams in channels and floodplains. Many modern streams re-occupy glacial channels so unit may be coarser in places owing to reworking of glacial stream sediment. Also includes areas of decomposing organic material and fine sand, silt and clay deposited by slack water.

Hl Silt to clay with sand and organics near shore. Deposited in ponded water in modern or drained lakes.

Hp Partially to fully decomposed organic matter infilling shallow water bodies such as seasonal or ephemeral ponds, lakes (typically growing from the shore into deeper water), along low-gradient modern and glacial streams and in depressions in the landscape. The irregular topography of glaciated landscapes, especially where ice stagnated, creates many isolated depressions that seasonally held standing water as a result of the low infiltration capacity of the loamy glacial sediment.

Sediment associated with the northwest-source Des Moines lobe ice—Deposits contain various amounts of gray siliceous shale fragments. Color of glacial sediment is typically yellow-brown where oxidized and dark gray where unoxidized. Sorted sediment has the color associated with the dominant grain size (dark gray for clay, light gray to pale yellow for silt, pale gray to pale yellowish white for sand).

Qt Unsorted deposit with a loam matrix and clasts of gravel (diamicton); compact. Till deposited beneath active ice.

Qth Unsorted deposit with a loam matrix and clasts of gravel (diamicton). In areas of highest relief and where interspersed with unit **Qliw**, (eastern portion of map) not as compact as elsewhere. Interpreted as originating in an unstable layer on unevenly down-wasting ice and may be sorted in places as a result of resedimentation. Supraglacial till assigned to the Heiberg phase of the Des Moines lobe.

Qliw Silt and clay layers, bedded sand, and loamy, vaguely bedded glacial sediment; interpreted as lake and debris flow deposits confined within growing holes in stagnant ice surface resulting in flat-topped, circular hills. Ice-walled-lake plain deposits.

Qtm Ridge of poorly sorted glacial sediment (diamicton); interpreted as demarcating margin of active ice and formed by a combination of ice-marginal processes such as meltout of a basal debris layer, thrusting, and debris flows. Some areas mapped as moraine may have inherited their form from an earlier topographic high.

Qts Unsorted deposit with a sandy loam matrix with clasts of gravel (diamicton); interpreted as the result of incorporation by active ice of shallowly buried sand in the high relief area of the Alexandria moraine by Des Moines lobe ice.

Qtw Unsorted deposit of loamy glacial sediment with gravel clasts (diamicton); surface expression is subdued and commonly streamlined. Interpreted as having been washed by water and having the potential to be capped with a coarse lag resulting from the removal of finer particles by water and a drape of fine sediment deposited by waning flows.

Qsm Sand and gravel in channels oriented down-gradient from and around interpreted former ice margins. Interpreted as glacial melt water stream sediment. Most aggregate mines in the watershed occur in this unit.

Qcss Poorly sorted gravel and sand intercalated with loamy poorly sorted glacial sediment (diamicton); in places fines up to silt; confined to narrow, low ridges. Interpreted to have been deposited in crevasses or low areas on the ice surface by running water and gravity. Those areas aligned with glacial stream sediment (unit **Qsm**) were most likely ice-supported (supraglacial) streams that occupied a low in the ice surface related to enhanced melting in a broad shear zone (southwest corner of the map). In the middle portion of the map, the more prominent ridges associated with **Qtwc** occur in a broad zone interpreted as resulting from a sheet flood that moved through, across, and/or beneath stagnant, crevassed ice in the area. Also includes small areas interpreted as subglacial tunnel deposits (eskers).

Qtwc Broad area of scoured and streamlined glacial sediment (diamicton), related to

Qcss but without the prominent, oriented ridges. Interpreted as having been washed by a sheet flood that moved from the highlands of the Alexandria moraine to the southeast. Water may have flowed on top of, through or beneath the ice. Subsequent ponding of floodwater deposited unit **Qlsm,** described below.

Qtwd Silt-draped glacial sediment (diamicton) forming a gentle slope in the northwest area of map that emanates from the Alexandria moraine. This may be one location where water flowed into the low, stagnant-ice covered area.

Qlsm Unsorted, poorly consolidated deposit with matrix of silt loam to clay loam to loam with some gravel (diamicton); located primarily in low-lying areas over a broad portion of the watershed; characterized by unusually thick organic soil development. Interpreted as the result of waning floodwaters and stagnating ice. Postdates units **Qcss** and **Qtwc** and may drape them in places as well as all underlying glacial sediment. Flood waters emanated from the northwest in the area of the Alexandria moraine and efficient drainage was impeded by higher ice to the south and east.

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