Spatial variation in till texture and clay mineralogy across the Saginaw Lobe terrain, Great Lakes region, USA

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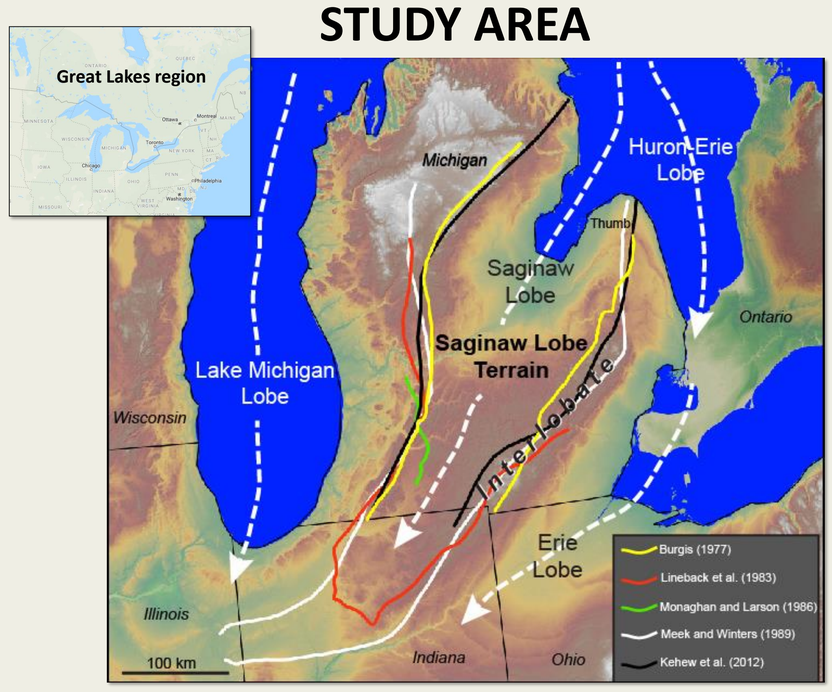
Abstract

We present a spatial/mapping approach to the study of the glacial history of the Saginaw lobe of the Laurentide Ice Sheet. The Saginaw Lobe flowed into southern Michigan, USA, forming modern-day Saginaw Bay and leaving behind a series of small moraines in down-ice locations. Upon its retreat – and likely also during its advance – a large proglacial lake (Glacial Lake Saginaw) formed in the northeastern margins of the "Saginaw terrain". The Saginaw lobe advanced to the southwest, out of this lake basin and onto thinly mantled, sandstone and shale bedrock. Although the Late Pleistocene deglacial chronology of this lobe has been generally assumed for decades, few numerical ages exist that could help constrain a better defined timeline. Indeed, as luminescence ages slowly emerge for terrain of the Saginaw Lobe and nearby areas, it seems clear that the lobe retreated from the region considerably earlier than is generally assumed, adding to the potential for large areas of ponded water in proglacial settings, all of which are as yet unmapped.

In this project, we sampled tills on uplands across the terrain of the Saginaw Lobe, avoiding outwash plains. In all, we obtained 334 samples of calcareous till, by bucket auger. Sample locations were sited generally uniformly across >20,000 km^2. Additionally, we recovered 17 samples of lacustrine clay from two areas on the former lakebed of Glacial Lake Saginaw. Grain-size analyses on these samples, by laser diffraction, revealed that the majority of the samples are texturally bimodal, with a mode in the clay-fine silt fraction and one in the very fine to medium sand fractions. Samples with a larger "fine" mode were typically in locations that were either (1) immediately down-ice from what would have been ponded by Glacial Lake Saginaw as the ice advanced into the region, and (2) areas which would have been trapped between the Saginaw ice and the large, preexisting West Branch Moraine. Down-ice, along the lobe axis, tills become sandier, which we attribute to the increasing influence of sandstone bedrock, as well as increasing distance from the clay source (the lakebed).

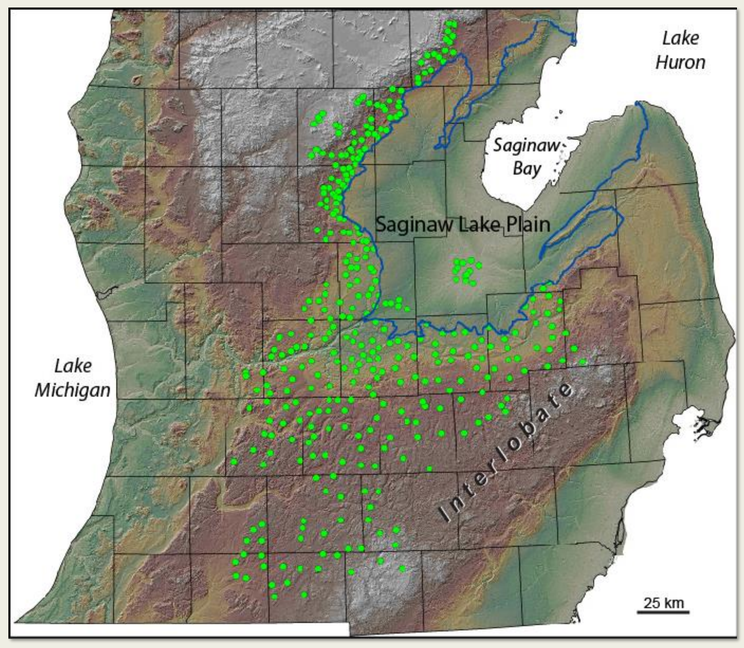
Our data highlight the spatial variability that can exist within a till sheet that, until now, was considered to have been comprised almost entirely of loam-textured till. Maps and grouping algorithms in ArcGIS helped us to identify natural groupings of these till textures, and in so doing, better elucidate the workings of the Saginaw Lobe as it advanced onto, and receeded from, southern Michigan.

STUDY AREA



The southern Great Lakes region, USA, showing the general flowpaths of the major glacial lobes, and previously defined boundaries of the Saginaw Lobe terrain.

SAMPLE DISTRIBUTION



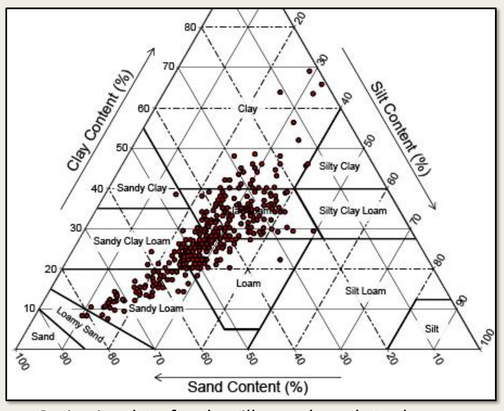
Locations of all 347 samples, and the uppermost shoreline of Glacial Lake Saginaw. In all, we examined 336 till samples from across the Saginaw Till Plain, and 17 samples of lacustrine sediment from the Saginaw Lake Plain.

METHODS

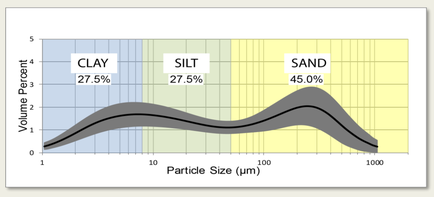
We sampled calcareous tills by bucket auger. Particle size analysis was performed by laser diffractometry. Texture data were examined for outliers, using ESRI's Cluster and Outlier Analysis (Anselin Local Moran's I). Only six samples were eliminated in this manner; the tills are remarkably uniform, texturally, across the landscape. The remaining 330 till and 17 lacustrine sediment samples were then analyzed in a Grouping Analysis, as a way to find natural groups across the Saginaw terrain. We used nine variables in the Grouping Analysis, to provide the widest array of data, and thus, obtain the greatest potential for discrimination: clay, clay + fine silt, clay + medium silt, clay + silt, silt, fine sand, medium sand, fine sand + medium sand, and (fine sand + medium sand)/clay. We set the spatial constraint method as k nearest neighbors, and used the default Euclidean distance method, with eight neighbors. We began by running the Grouping Analysis on the full data set, allowing it to determine the optimal number of groups. After examining the data, we removed the group with the lowest standard deviation from further analysis. The tool was then run again on the remaining data, and the process was repeated until the data were unable to be partitioned into groups that were interpretable. Two representative samples from each of the six groups were examined for clay mineral analysis, using traditional X-ray diffarction methods. These two samples were (1) located near the geographic center of its group, and (2) had clay and silt contents that are both within 3% of the group mean.

----- RESULTS AND INTERPRETATIONS -----

1. Textures/colors



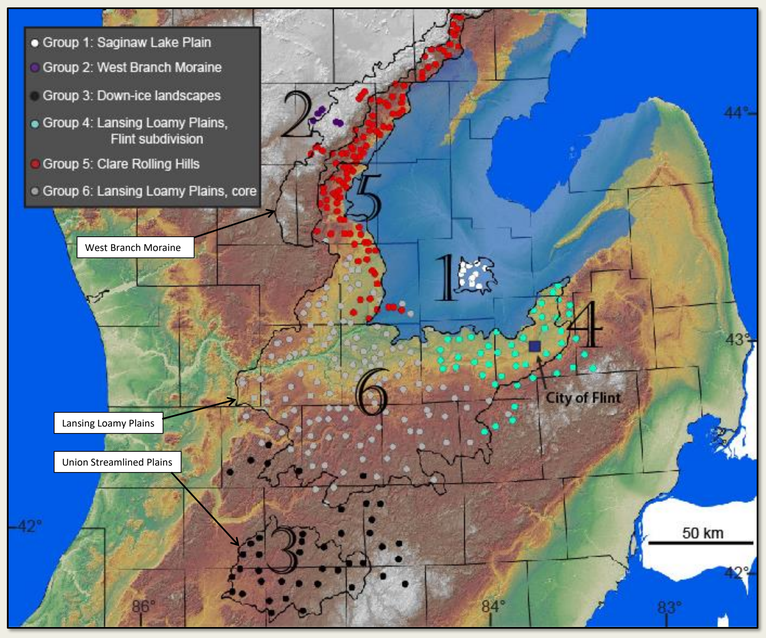
Grain size data for the till samples, plotted on a standard NRCS textural triangle.



Mean grain size data for the 330 till samples, with an envelope of +/- one standard deviation.

Saginaw Lobe tills are calcareous and loamy. Typical colors are 10YR 4/4 and 4/3 (dark yellowish brown and brown, respectively). Carbonate masses and coatings are common on ped faces, typically 10YR 6/1 and 6/2 (gray and light brownish gray). Clay loam, loam and sandy clay loam textures are most common; the mean overall, and the most common, texture is clay loam. Most tills have a bimodal grain size distributions, which we interpret as a mixture of lacustrine clays and outwash sands, both of which form in proglacial sedimentary environments.

2. Natural Groups

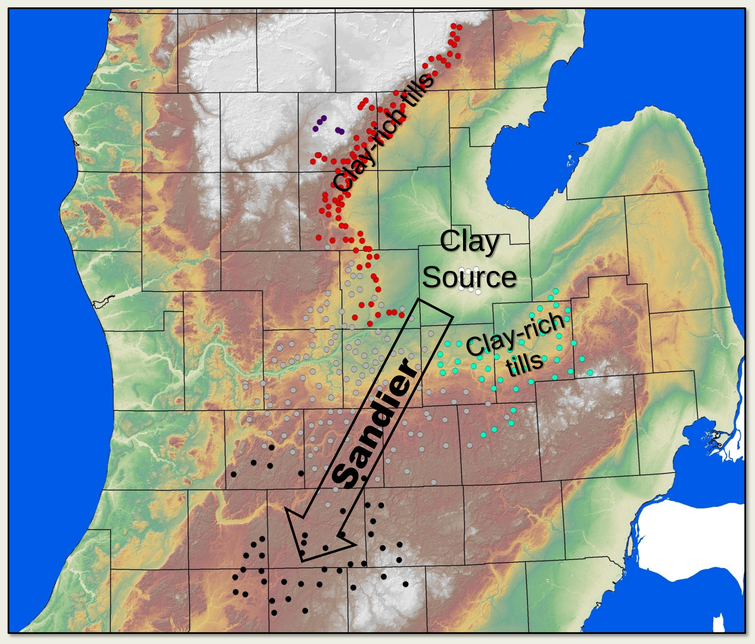


Map of the six natural groups that were produced by the Grouping Analysis, on a background showing some of the physiographic regions of Schaetzl et al. (2013).

The Grouping Analysis produced six natural groups across the Saginaw Lobe terrain, each with distinct mean textures:
(1) Saginaw Lake Plain (clay)
(2) West Branch Moraine (sandy loam)
(3) Down-ice Landscapes (sandy loam)
(4) Lansing Loamy Plains, Flint subdivision (clay loam)
(5) Clare Rolling Hills (clay loam)
(6) Lansing Loamy Plains, core (sandy clay loam)

Sediments in all six groups have generally similar clay mineralogies: illite (38% ± 7.5%), kaolinite + chlorite (29% ± 11%) and vermiculite + chlorite (33% ± 7.3%) [mean values].

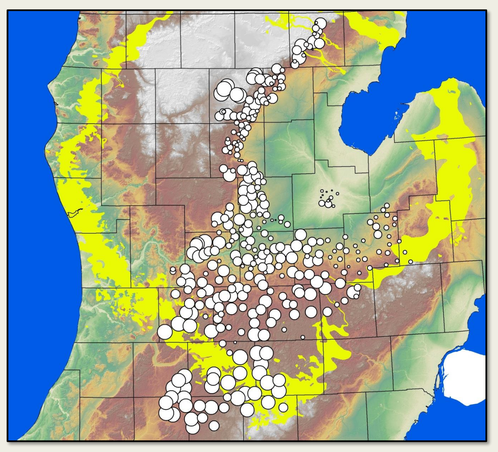
3. Explaining Till Textures



Tills get increasingly sandy down-ice, along the Lobe axis, as well as within the West Branch Moraine. We attribute this to mixing of sandstone bedrock, which underlies the central part of the lobe (see Figure, right). Tills may have been originally very clay-rich, as the Saginaw Lobe dredged up lake clay from ancestral Glacial Lake Saginaw.

Tills are the most clay-rich on the flanks of the lobe, which we attribute to mixing of lake sediment from as-yet unknown proglacial lakes in this area. Both of these "flanking" till groups (4 and 5) lie immediately inside of uplands, and down-ice of the lake plain.

Thus, the spatial variation of the tills is best explained by a mixing model.



Sand contents of the till samples, shown as graduated circles. Values range from 0.5 to 82.1% sand. Yellow areas show the extent of the Marshall Sandstone bedrock unit.

Conclusions

Across the Saginaw Lobe terrain, tills have similar colors and clay mineralogy, suggestive of a broadly similar geologic history. Most of the tills are bimodal in grain size, with clay-fine silt and sand modes. They have little of the coarser silt and very fine sand fractions, typically seen in tills dominated by crushing and abrasion in a basal traction zone in bedrock terrains. Therefore, we believe that a mixing model best explains till genesis and spatial variation here, i.e., textural variations occur primarily due to differing mixtures of clay-fine silt (lacustrine sediment) and (ii) sands (outwash). The generally illite-rich composition of clays across the terrain indicate that the tills have a common source of fine sediment: lacustrine sediment from an older Glacial Lake Saginaw, one formed as the MIS 2 ice advanced into the region. In effect, the advancing Saginaw Lobe dredged up its own lacustrine clays and silts, depositing them down-ice as clay-rich tills.

Along the axis of the Lobe, tills get sandier down-ice because the ice likely entrained and transported both (i) sandstone bedrock and (ii) proglacial sands from fans, kame deltas and outwash surfaces, especially for sites in the southern part of the terrain where the landscape slopes away from the ice. Lake clays from up-ice locations became diluted by increasing amounts of sand scoured from bedrock and pre-existing glacigenic sediments. Down-ice, the tills are very sandy but even here they also have distinct clay-fine silt modes. Slightly increased kaolinite contents down-ice also support a mixing model of till genesis here.

Tills are most clay-rich in Groups 4 and 5, which lie between an upland and the lake plain. We suggest that the advancing ice here had an as-yet unknown proglacial lake, which had its own lake sediment. The Saginaw Lobe dredged up these fine sediments, causing the tills here, on the flanks of the lobe, to be finer-textured.

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