Late Wisconsin Permafrost Conditions as Evidenced by Patterned Ground in the Saginaw Lowlands, Eastern-Central Lower Michigan

MICHIGAN STATE UNIVERSITY

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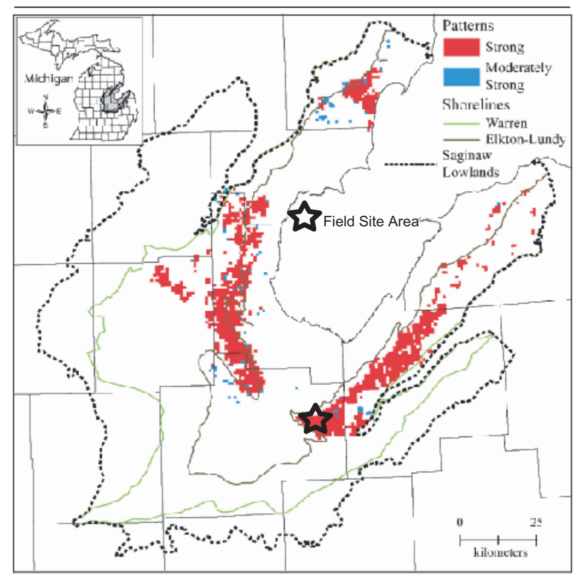
Introduction

Patterned ground has been reported in all states that border Michigan and in Ontario, Canada. Patterned ground was first recognized in Michigan by Brunnschweiler (1969) and Tillema (1972), who confined his study to a relatively small area (~194 km²) in the west-central part of the Saginaw Lowlands. Lusch (1982) mapped the non-sorted patterned ground (c.f. Washburn 1956) across a much larger area (>900 km²) within the Saginaw Lowlands, making it the second most extensive area of documented, contiguous patterned ground in the North American Central Lowlands, behind that mapped in central Illinois (Johnson 1990).

The patterned ground has been attributed to thermal-contraction cracking of paleo-permafrost (Tillema 1972; Lusch 1982). Our hypothesis was that allochthonous sand had filled the thermal-contraction cracks, and thus the locations of those cracks could be identified by the contrast between the sand and the largely fine-grained texture of the regional soils. The specific objectives of this study were to re-examine the extent and nature of the patterned ground throughout the Saginaw Lowlands (11,656 km²) using (1) georeferenced digital data not previously available, (2) geophysical characterization of the subsurface, and (3) detailed pedological studies of the polygons.

Location of Saginaw Lowlands, Warren- and Elkton-Phase Shorelines, Field Site Area, and mapped extent of patterened ground.



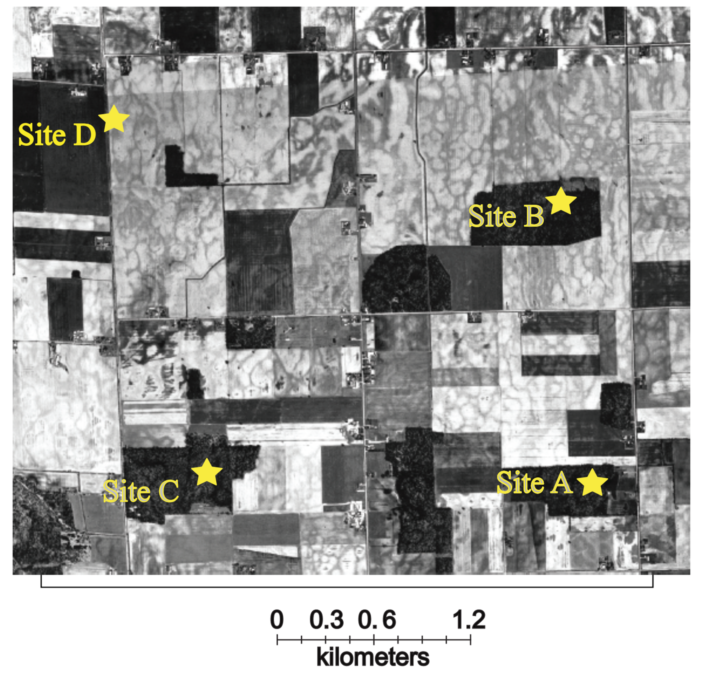
Methods

Four study sites were selected for detailed characterization using electrical resistivity (ER) methods, soil descriptions, and grain-size analyses of auger-hole samples.

Electrical resistivity (ER) methods, which measure the resistance of earth materials to electrical current flow, were used to identify and image lateral variations in soil properties associated with patterned ground in the study area. Material resistivity is inversely proportional to the soil moisture content and clay percentage.

In this study, we employed constant spread traverses (CSTs) and multi-electrode arrays using Dipole-dipole and Wenner electrode configurations (Reynolds, 1997). The Wenner configuration is most sensitive to vertical variations in electrical resistivity, while the Dipole-dipole configuration is especially sensitive to laterally discontinuous or vertical features. CSTs do not provide depth information and were used as a fast exploratory tool.

Site Map



GIS mapping

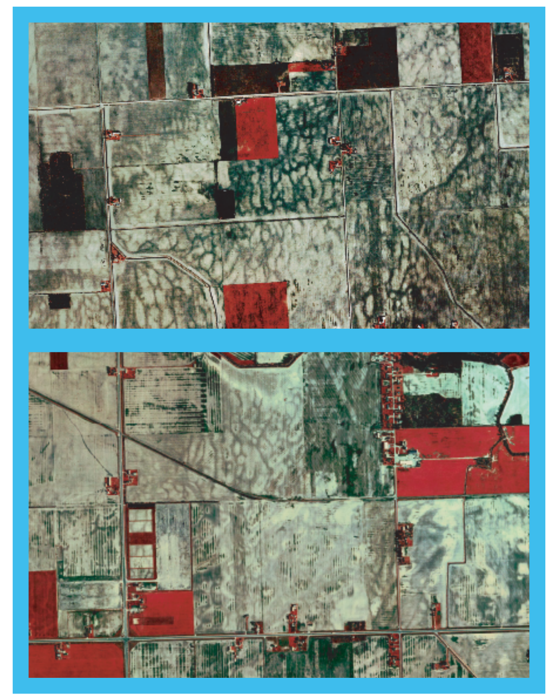
The closed-net polygons patterned ground features present in the Saginaw Lowlands allow them to be identified using aerial photography under some soil conditions. The higher elevation of polygon interiors causes lower soil moisture contents and a higher reflectance than polygon boundaries. In order to map the extent of patterned ground aerial photography (digital orthophoto quads (DOQs) taken in March and April of 1997 through 2000) from the National Aerial Photography Program was used. Approximately 1020 km² was mapped, approximately 1/10 of the study area, as having presence of patterned ground.

To describe the polygon dimensions, 750 well-defined polygons were selected in Arc GIS. The lengths of the long and short axes of each polygon was measured in Arc GIS and used to calculate their ellipsoidal areas and orientations. This analysis indicated that polygons had areas ranging from 0.71 ha to 1.30 ha, and had long axes oriented between 0° and 357°.

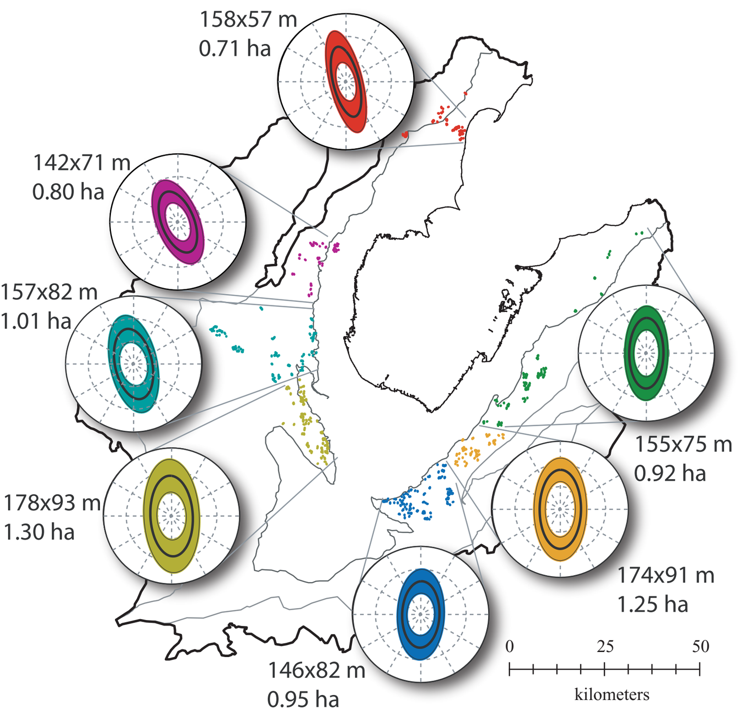
DOQs showing examples of good patterns (A) and moderate patterns (B).

A

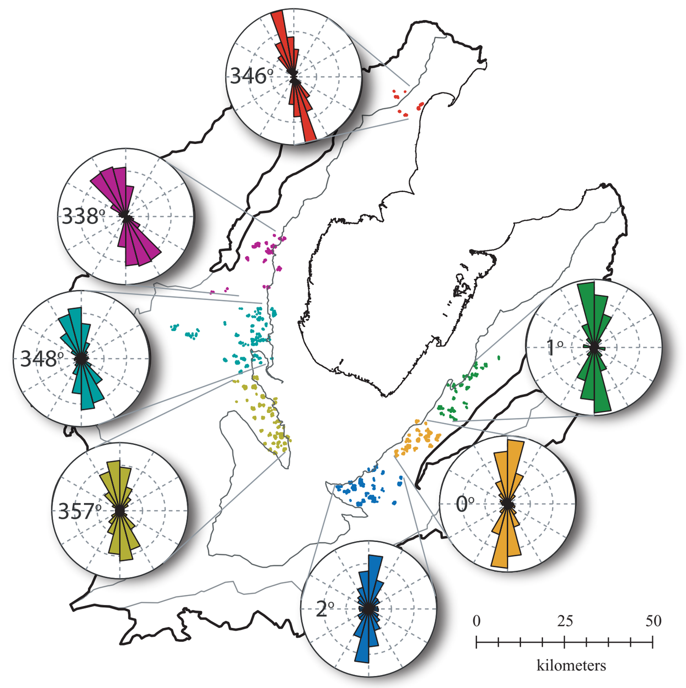
B



Mean sizes (middle black line) plus one standard deviation (shaded ellipse), grouped into seven geographic clusters.



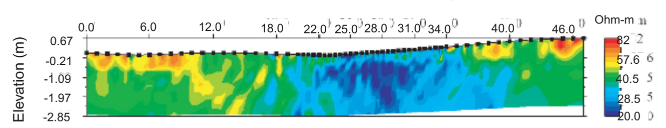
Mean orientations of patterned ground polygons grouped into seven geographic clusters.



Site A

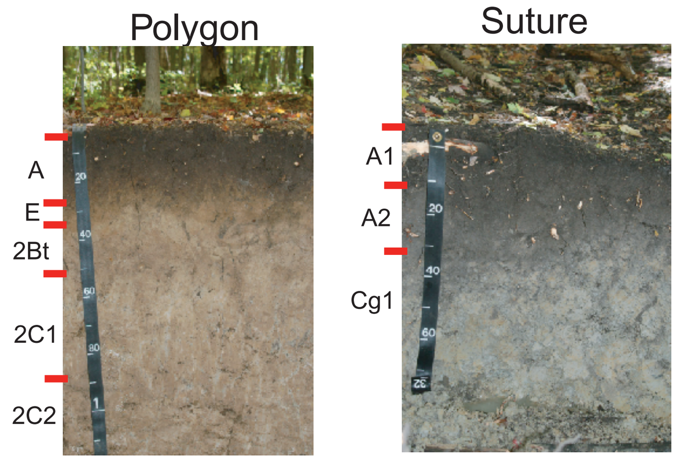
Survey Type: Dipole-Dipole and Wenner
Electrode Separation: 1m with 0.5 m separation between 20.5 and 34 m.

ER data profile for Site A



ER data collected at Site A showed high resistivity values in the polygon centers and a low resistivity body in the polygon suture. Since no significant textural difference between polygon centers and suture was detected, the resistivity difference is interpreted to result from a larger moisture content in the suture.

Polygon / Suture



Polygon:

Horizon	Depth (cm)	Coarse Fragments (>2 mm) (%vol)	Texture Class
A	0-23	2.0	fSL
E	23-32	2.0	fSL
2Bt	32-54	2.0	SiL
2C1	54-87	5.0	SiL
2C2	87+	5.0	SiL

Suture:

Horizon	Depth (cm)	Coarse Fragments (>2 mm) (%vol)	Texture Class
A1	0-11	2.0	SiL
A2	11-25	2.0	SiL
Cg1	25-94	2.0	SiL
2Cg2	94+	5.0	SiL

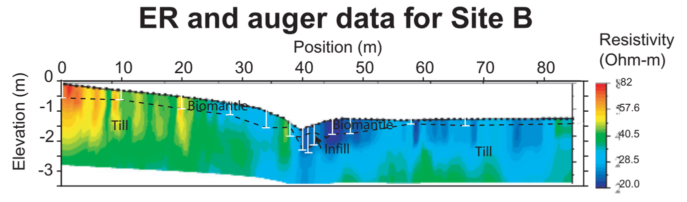
SiL=silt loam, fSL=fine sandy loam

Site B

Survey Type: Dipole-Dipole and Wenner

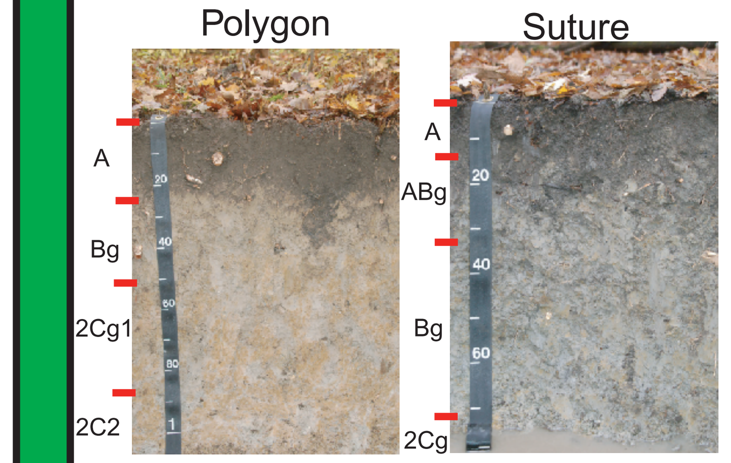
Electrode Separation: 1m for the whole survey

ER and auger data for Site B



ER data show low resistivity values for the polygon suture, while the two polygon centers are characterized by both low and high resistivity. The difference between polygon centers may be a result of topography variations, with the driest conditions and thus highest resistivity for the highest elevation.

Polygon / Suture



Polygon:

Horizon	Depth (cm)	Coarse Fragments (>2 mm) (%vol)	Texture Class
A	0-25	0.0	SL
Bg	25-51	2.0	fSL
2Cg1	51-86	5.0	SiL
2C2	86+	5.0	SiL

Suture:

Horizon	Depth (cm)	Coarse Fragments (>2 mm) (%vol)	Texture Class
A	0-13	0.0	SiL
ABg	13-27	0.0	SiL
Bg	27-71	0.0	SiL
2Cg	71+	5.0	SiL

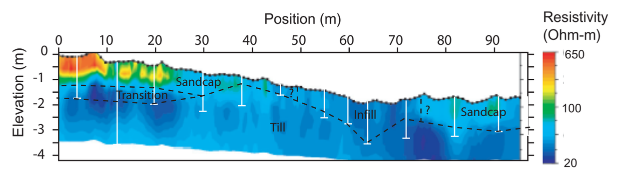
SiL=silt loam, fSL=fine sandy loam, SL=sandy loam

Site C

Survey Type: Dipole-Dipole and Wenner

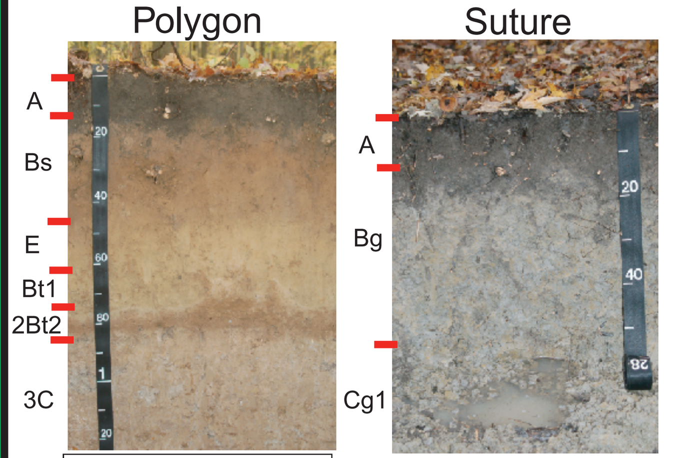
Electrode Separation: 1m for the whole survey

ER and auger data for Site C



A sand cap of ~80cm thick was present in the polygon centers, which resulted in high resistivity values. The textural difference between polygon centers and suture, where the sand cap was absent, resulted in large resistivity differences.

Polygon / Suture



Polygon:

Horizon	Depth (cm)	Coarse Fragments (>2 mm) (%vol)	Texture Class
A	0-15	0.0	fSL
Bs	15-46	0.0	fSL
E	46-61	0.0	LfS
Bt1	61-73	0.0	LfS
2Bt2	73-82	7.0	cSL
3C	82+	5.0	SiL

Suture:

Horizon	Depth (cm)	Coarse Fragments (>2 mm) (vol%)	Texture Class
A	0-14	0.0	SiL
Bg	14-56	0.0	SiL
Cg1	56-90	N/A	SiL
2Cg2	90-105	N/A	SiL
2Cg3	105+	N/A	fSL

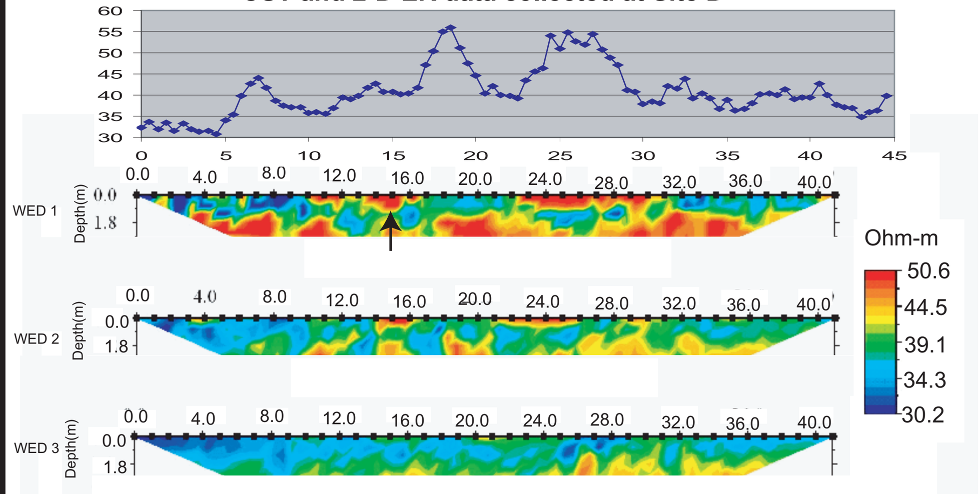
SL=silt loam, fSL=fine sandy loam, cSL=coarse sandy loam, LfS= loamy fine sand

Site D

Survey Type: Dipole-Dipole and Wenner

Electrode Separation: 1m for the whole survey

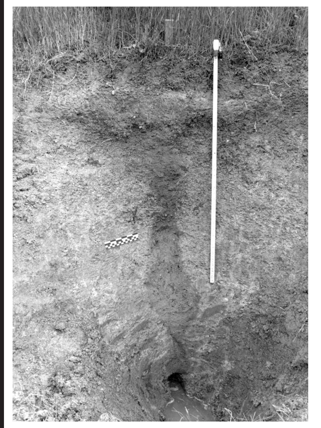
CST and 2-D ER data collected at Site D



At this site, multiple ER data sets were obtained after Constant Spread Traverse measurements identified several high resistive bodies at the location of a previously identified ice-wedge cast (Lusch 1982). Augering data confirmed the presence of sand in an otherwise loamy matrix.

The multi-electrode ER data identified the presence of a high resistive body of shallow and discontinuous nature. The generally high resistivity values for profile WED 1 are due to its proximity to the ditch, which drains the soil.

A soil pit demonstrated the presence of a shallow bowl-like structure at the location of the high resistive bodies in the ER data. The dimensions of the thermokarst feature was markedly different than the permafrost ice wedge cast identified by Lusch (1982) for a nearby location.



Feature interpreted as an Ice Wedge Cast by Lusch (1982), left, and sandy bowl-like structure found at Site D, below.

Discussion

A total of 1020 km² of patterned ground was mapped in the Saginaw Lowlands. The sorted reticulate nets are composed of polygons with an average size of ~1 ha. The orientation of the polygons shows no correlation with the slope of the land surface.

The patterned ground is primarily found between the Glacial Lake Warren and Elkton shorelines. Based on their position, the formation of the patterned ground was likely constrained to the period between Lake Warren (14.8 k cal. yrs) and Lake Elkton (14.3 k cal. yrs).

Electrical resistivity methods were successfully used to characterize the polygon centers and swales. Observed resistivity differences resulted from soil moisture changes for Sites A and B, and from textural differences for Site C.

Soil pits showed strong differences between polygon centers and swales. Except for Site C, where a sand cap was present, texture was comparable. This suggests that differences in soil formation primarily result from oxidation/reduction state.

At Site D, complementary methods confirmed the presence of a sandy bowl structure. This structure, close to the location of a thermokarst crack found in a previous study, however, was discontinuous.

Evidence from all Sites points to thermokarst erosion, rather than ice-wedge replacement, as the process of formation of the relict permafrost features in the Saginaw Lowlands.

References

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MSU Hydrogeology Lab