Preliminary Results of a Ground Penetrating Radar Survey on Two Aeolian Dunes : Implications of Climate Change for Northwest Michigan, USA

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Abstract

Ground penetrating radar (GPR) was used in the investigation of two interior (non-coastal) aeolian (wind-blown) sand dunes. The purpose of the research is to regionally expand upon previous results which investigated Holocene climate change in eastern Northern Michigan which began in 2005 led by the United States Geological Survey. The study area lies in the Huron Mountains, located in the eastern region of Northern Michigan about 60 km northwest of Marquette. The specific study location is approximately 2-3 km southwest of Ives Lake. Four GPR transects were run in a grid across one dune along two transects on the other. The pulseEKKO 100 and 1000 GPR systems using antennae frequencies of 100, 200, and 225 MHz were used to investigate the dunes' subsurface layering. Laser leveling was used throughout the length of each GPR transect in order to topographically correct the profiles for elevation change.

Through the preliminary interpretation of the processed GPR reflection profiles of the subsurface stratigraphy the feature can be more thoroughly interpreted as an aeolian dune. With the stratigraphy revealed by GPR and previous research suggesting the dune to be Holocene (ca. 10,000 to 8,000 years old) in age along with the inherent criteria necessary for dune formation (wind, sand, and low amounts of vegetation cover) one can hypothesize that climate change, significant enough to alter the landscape from being conducive to dune formation to being fully forested, affected this area of Northern Michigan during the Holocene.

Introduction

Climate change is an important issue facing the world today. It's not a new phenomenon though; fluctuating climate change has affected the world throughout history (Lawrimore, 2003). The conducted research is in support of a larger project led by the United States Geological Survey (USGS) which began in 2005 to investigate Holocene climate change in Upper Michigan through optical stimulated luminescence (OSL) age dating of interior (non-coastal) aeolian (wind-blown) sand dunes. A sand dune is "mound, hill or ridge of windblown sand, either bare or variously covered by vegetation, capable of movement from place to place through the development of a slipface, but always retaining its own characteristic shape for an extended period of time" (David, 1977). The presence and activity of non-coastal sand dunes in Upper Michigan is tied strongly to climate and vegetation cover (ground cover). Necessary conditions for dune formation include low vegetation (ground) cover percentage (<30%), sufficient winds to transport sand, and an abundant supply of sand to be reworked into dunes (Wasson and Nanninga, 1986). The last time period of widespread dune activity in eastern Upper Michigan was 8 to 10 ka (thousand years ago) based on 65 OSL dating ages from samples over a 12,000 km^2 area (Loope et al., 2012).

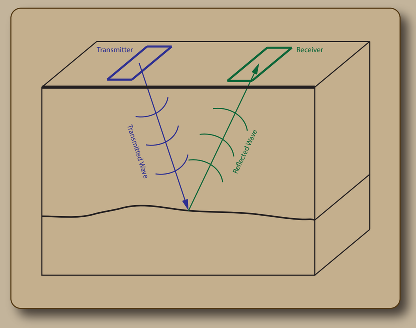
The specific goal of this research is to establish, using ground penetrating radar (GPR), that two landforms selected through interpretation of area maps can be identified as aeolian sand dunes. Through the identification of these formations as sand dunes along with applying the conditions necessary for dune formation, it is possible to expand the spatial extent of dry climate in the Great Lakes region during the early Holocene (8 to 10 ka).

Methods

The primary method of investigation for this research was GPR, which uses electromagnetic (EM) radio waves that are essentially the same as the radio waves a car antenna receives from a broadcasting radio station. The EM waves are radiated from a transmitter that pulses a signal into the ground. The waves are then diffracted, refracted, and most importantly reflected. The reflected signals are sent back toward the surface where they are measured by a receiver unit, amplified, and digitized by the computer and software that is used to record the measurements (Figure 1) (Meyers et al., 1996). PulseEKKO 100 and 1000 GPR systems were used to collect profiles for this research. Both 100 MHz and 200 MHz frequencies were used in a stepped method of data collection where the transmitter and receiver antennae are moved individually in desired increments (.25m for 100 MHz, .1m for 200 MHz) along a survey tape at constant distance from one another (1m for 100 MHz, .5m for 200 MHz). Topcon laser leveling survey equipment was used to collect topographic data that was then used to geometrically correct the reflection profiles. The data from the GPR transects and laser leveling was then loaded into Sensors and Software GPR programs for processing, visualization, plotting, and interpretation.

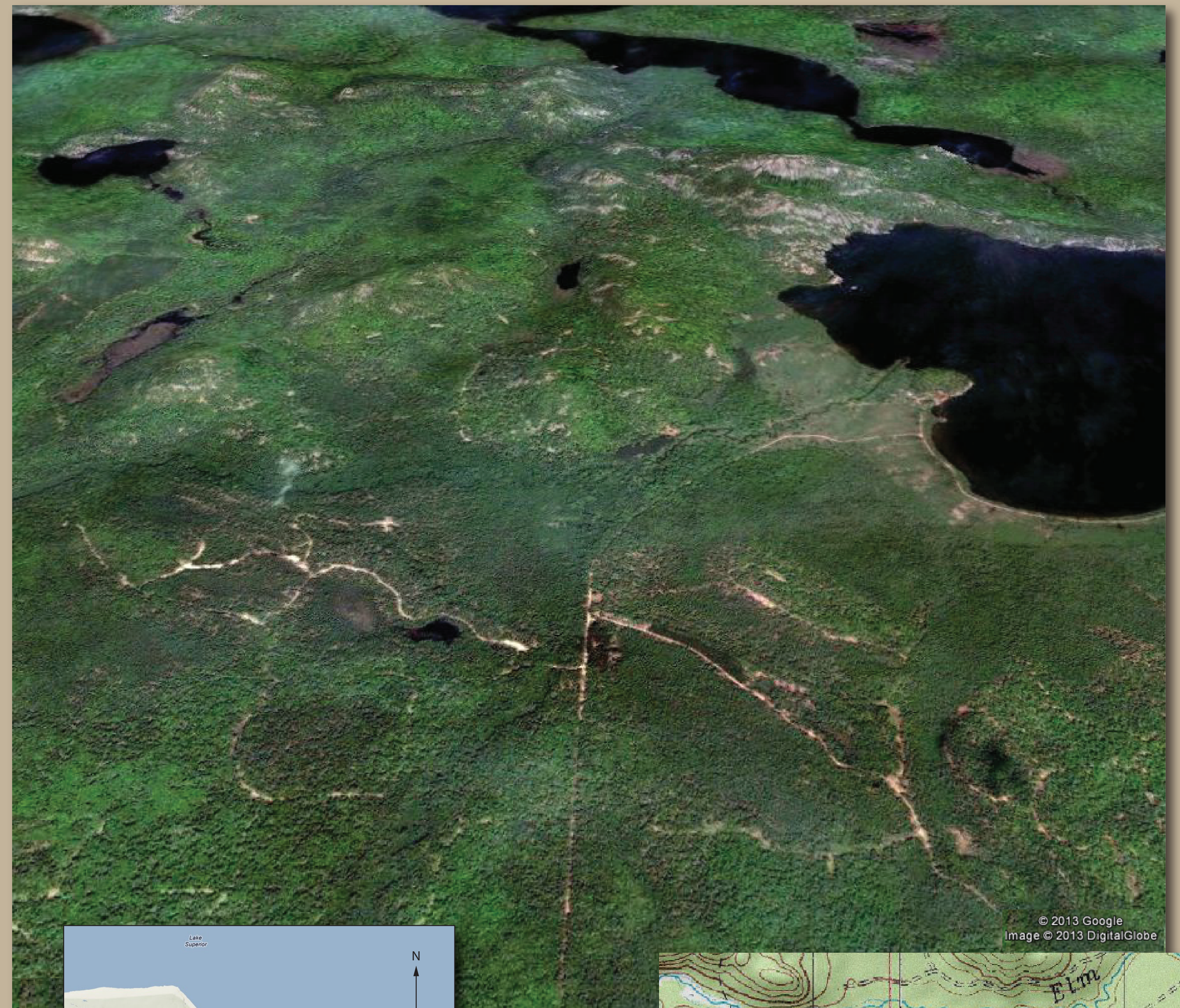
Laser leveling equipment used for topographical correction

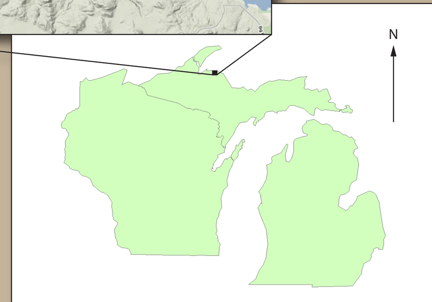
The GPR transmitter and receiver being used on the leeward slope of the Chicken House dune. View to the northwest.

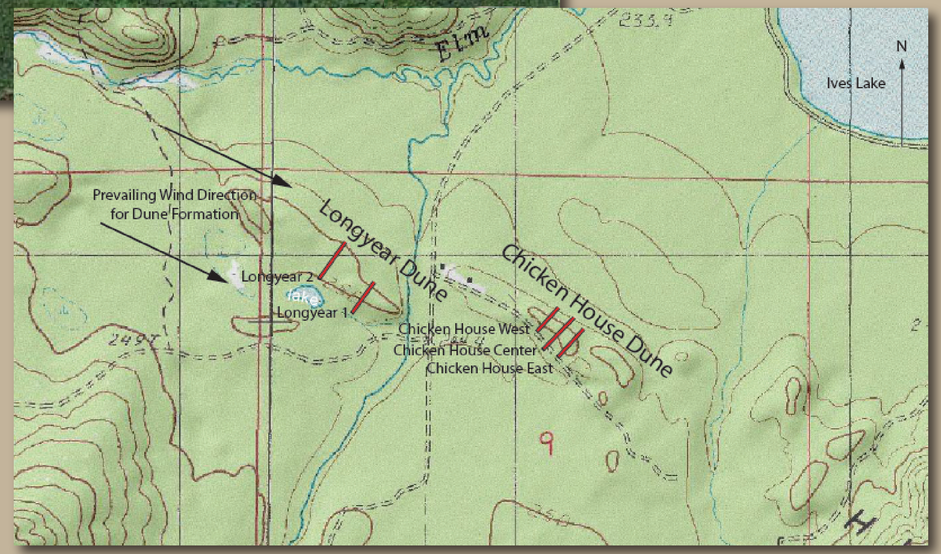


A diagram of how the electromagnetic wave is transmitted and reflected by a GPR unit.

Location

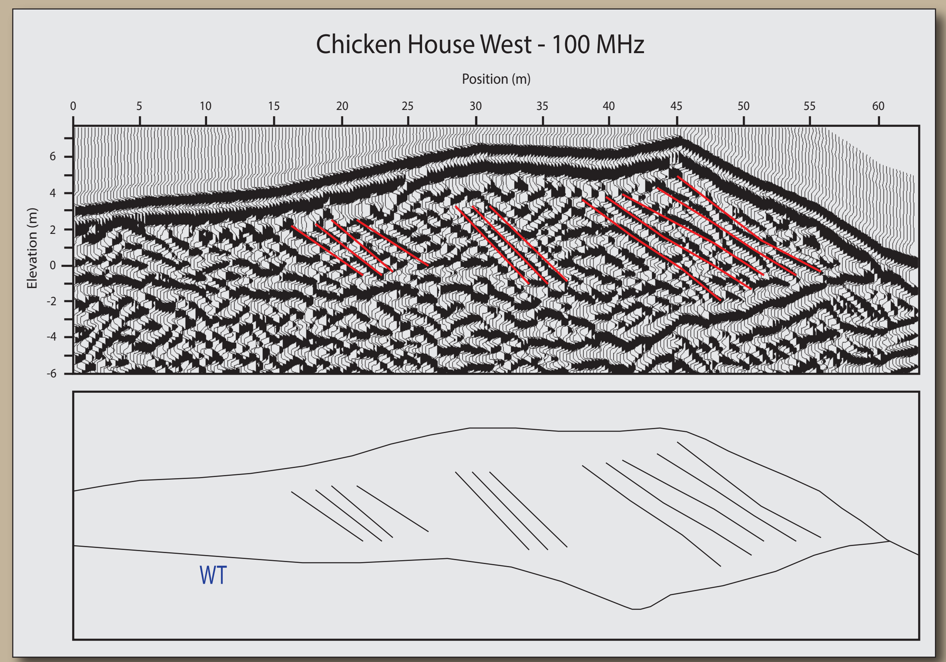




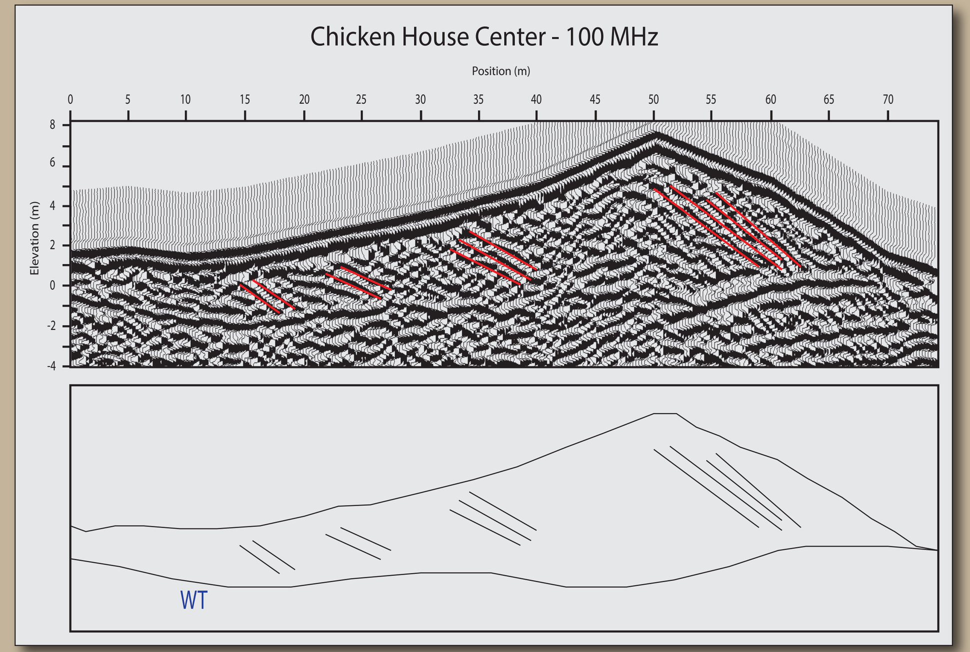


The study site is within the Huron Mountains about 60 km northwest of Marquette and about 2-3 km southwest of Ives Lake. A topographic map shows the locations of the GPR transects within the study area in red (lower right).

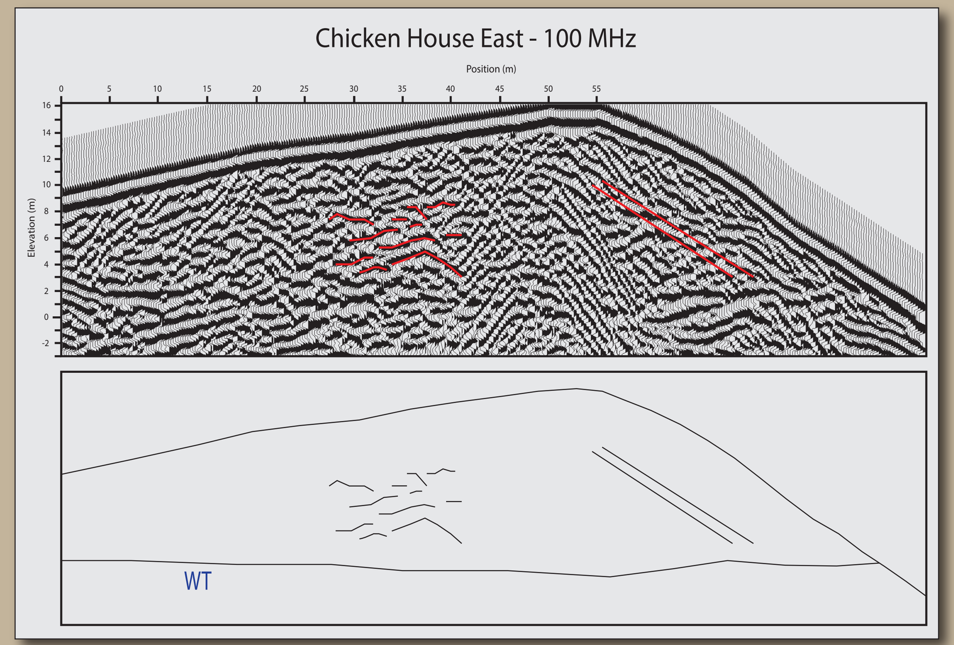
Results



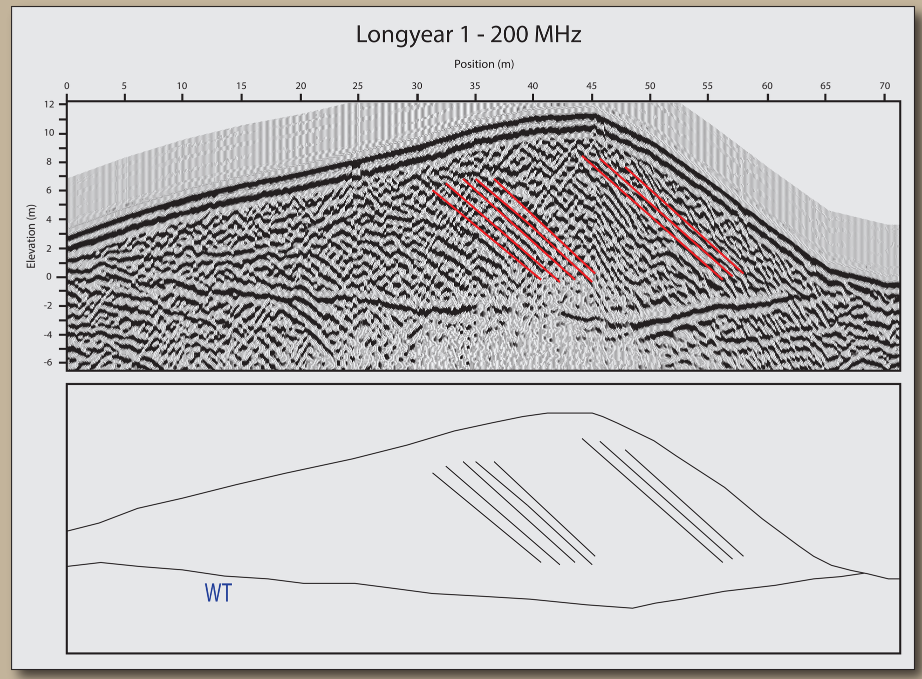
The western most of three GPR transects collected perpendicular to the orientation of the Chicken House dune. The transect runs from the southwest (left) to the northeast (right). A 100 MHz frequency was used to produce the reflection profile (top). Below the reflection profile is an outline of the dune with the interpretation of the stratigraphy imaged by the GPR inside the outline. The bottom line of the trace (bottom) shows the presence of the water table (WT). The dip in the water table is due to topographical correction and the existence of changing velocities the EM wave encounters as it travels through the ground. Each of the red lines traced over the reflection profile indicate points of interest, in this case showing prior slipfaces of the dune that have since been buried by the migration of the dune.



The center GPR transect collected on the Chicken House dune. This reflection profile (top) was also created using a frequency of 100 MHz. The interpretation of the reflection profile (bottom) highlights the nature of the stratigraphy contained within the dune. Again there is a clear representation of prior slipfaces created through the migration of the dune.



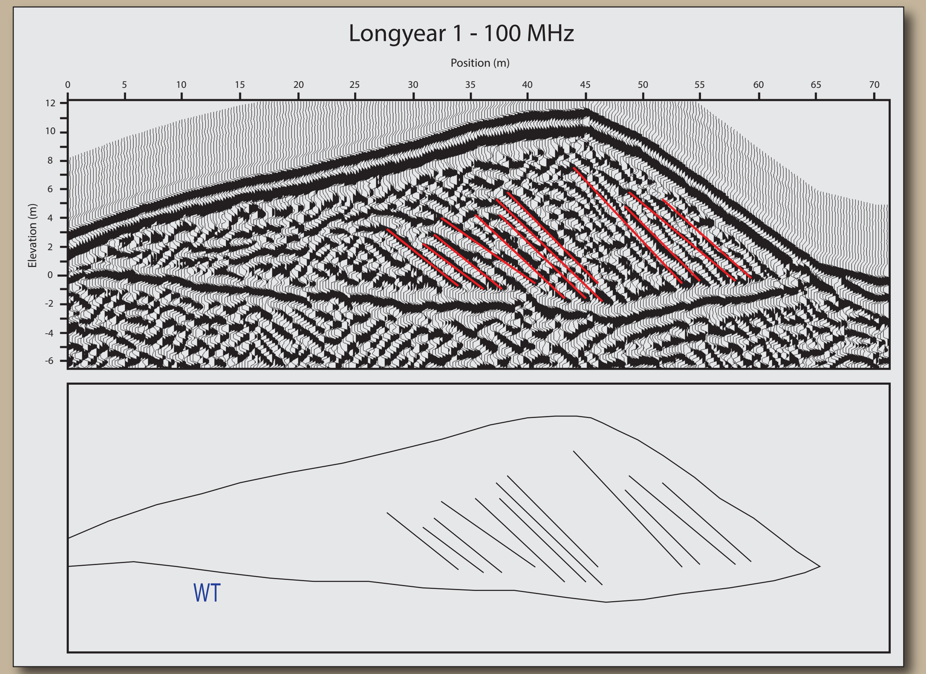
The eastern most GPR transect collected on the Chicken House dune. The reflection profile (top) was again created using the 100 MHz frequency antenna and receiver. The interpretation of the stratigraphy (bottom) for this transect differs from the center and west transect in some areas. While there is still significant evidence for prior slipfaces similar to the center and west transects, the east transect shows significantly more horizontal layering especially to the southwest (left). This is due to the orientation of the transect in regard to the morphology of the dune as it migrated across the landscape where the primary direction of movement was southeast (toward the viewer).



The eastern most of two GPR transects that were taken perpendicular to the orientation of the Longyear dune. The reflection profile (top) was created using a 200 MHz frequency antenna and receiver. There is clear evidence of prior dune slipfaces throughout the internal stratigraphy, with a few prominent sections highlighted in red and transferred to the trace (bottom).

The center transect of the Chicken House dune. View to the northeast, at the base of the dune looking up the stoss slope.

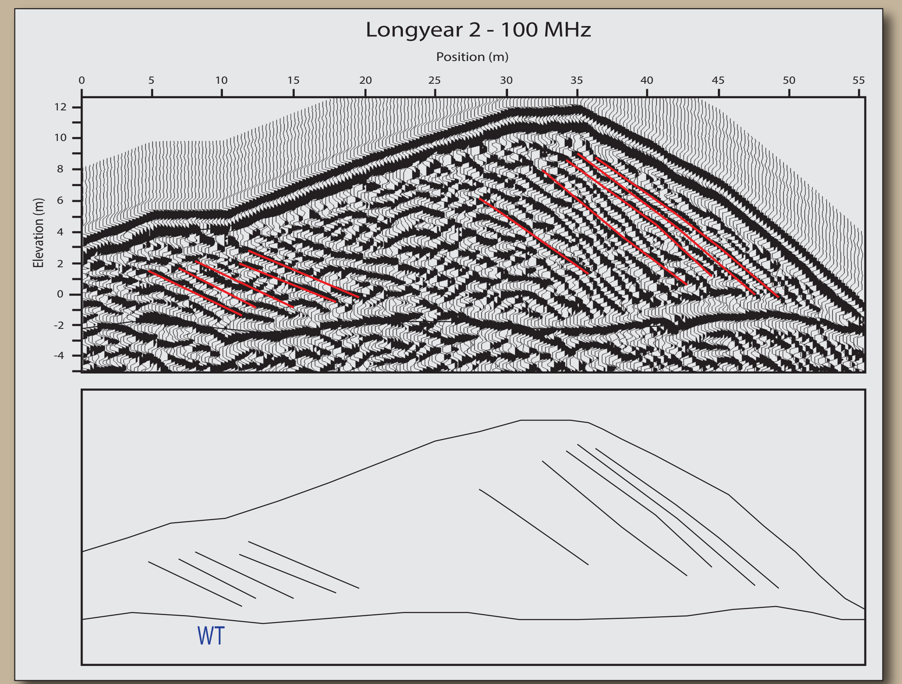
The crest of the Longyear dune, the slipface is located to the left. View to the east.



The same Longyear 1 transect as the profile to the left, but this reflection profile (top) was created using 100 MHz equipment instead of the 200 MHz. The reflection profile and the trace below show the same prominence of prior slipfaces, just with lower resolution compared to the 200 MHz.

At the base of the Chicken House Dune. View from southeast to northwest.

The eastern transect of the Longyear dune. Looking down the stoss slope, view to the southwest.



The western most of the two GPR transects collected on the Longyear dune. The reflection profile (top) and the trace (bottom) show virtually the same indicators as the eastern transect. More strong evidence for prior slipfaces is present.

Discussion

The interpretation of the GPR reflection profiles collected on the Chicken House and Longyear formations show that they are sand dunes that have been stabilized with vegetation cover. The first indicator is the cross sectional shape of the formations which are consistent with the shape of a dune, with a gradual windward slope leading to a crest and then down a slipface at an angle near the angle of repose (around 30°). The cross sectional shape is not enough to positively conclude that both formations are dunes though. To get a better idea of the processes involved in the building of the formations, GPR was used to image the subsurface stratigraphy (layering) contained within. Interpretation of the reflection profiles shows that there is significant evidence of the type of layering that would be found in a sand dune that has migrated through the landscape over time. As the dune migrates, sand is blown up the windward (stoss) slope. The grains would then build up on the crest of the dune.

Over time there will be a buildup of sand grains on the crest of the dune to the capacity that it can no longer support itself. The buildup will then slump down the existing slipface, effectively creating a new slipface (David, 1977). Below is a generalized diagram of how this process works to create the stratigraphy seen in the GPR reflection profiles of the Chicken House and Longyear dunes. Each of the GPR transects collected on the dunes show very similar stratigraphy to one another and are all consistent with the idea of a migrating dune creating new slipfaces over time. The profile that differs the most from the others is the Chicken House East transect. Near the current slipface, extending into the dune, there is still strong evidence for prior slipfaces. But the further into the dune and away from the slipface, the more horizontal the stratigraphy becomes. This is due to the transect be positioned parallel along the small arm that runs perpendicular to the rest of the dune. This means the transect is essentially looking in the opposite direction of the others with respect to the way the dune was formed, showing a different aspect of the dune's stratigraphy.

The Chicken House dune and Longyear dune were concluded to be dunes, which leads to the conclusion that there must have been a dryer climate in the study area than that of the current humid continental in order for the dunes to form. But what type of dune are the two and where did the wind that created them come from? By looking at the bird's eye view of the Chicken House dune presented in the elevation model (below), the dune shows an arm extending perpendicular to its majority at its southeast end. This formation is consistent with the description and illustration of the fish-hook dune (David, 1977). It may also be a parabolic dune where one of the arms was removed by an undetermined erosional process. As for the wind direction, W to NW is the likely direction when considering the classification of the dune along with the presence of a sand supply to the dunes' W and NW (soils map below).

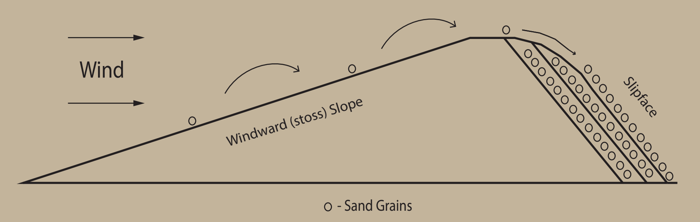
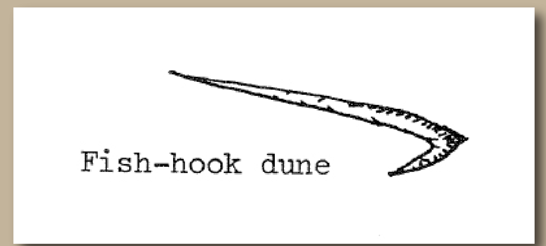
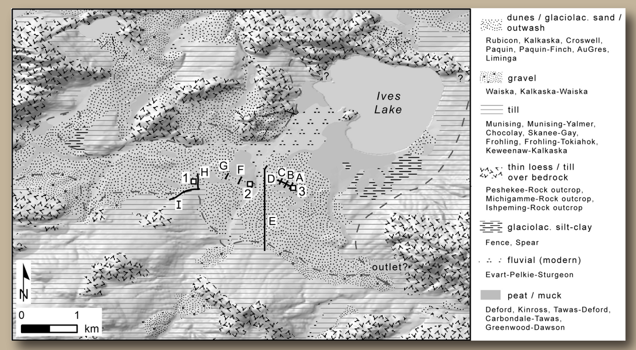


Diagram of a sand dune and how it is formed. Wind blows grains of sand up the windward (stoss) slope and then the grains build up on the leeward slope creating a slipface. Slipfaces are continually created as wind causes the dune to migrate.

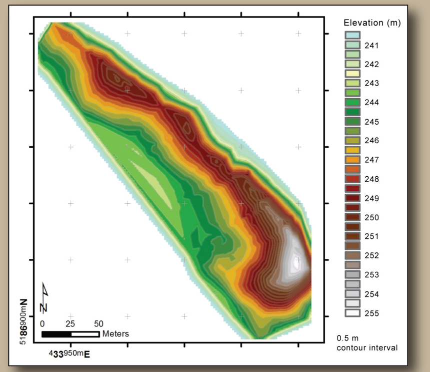
Example of a solidified sand dune outside of Zion National Park in Utah. The stratigraphy that occurs within a dune can be clearly seen here, with the red lines highlighting a few of the many slipfaces that have occured over time.



A fish-hook dune formation classification. (David, 1977)



A map of the soil types occuring within the study area in the Huron Mountains. (Henry Loope)



Elevation model of the Chicken House dune. Points collected using a Total Station. (Henry Loope)

Summary

GPR research was conducted within the Huron Mountains located in the Upper Peninsula of Michigan to classify two formations as sand dunes that have become stabilized with vegetation since they were active tens of thousands of years ago. Reflection profiles collected were where they were merged with the elevation data collected using laser level surveying equipment. Through working with the data to create the best, most accurate looking portrayal of the subsurface stratigraphy it was possible to identify layering patters consistent with the layering one would expect to find within a sand dune, namely a progression of slipfaces that have been buried by a succession of new slipfaces created by the migration of the dune. Once the Chicken House and Longyear dunes were sufficiently identified as being dunes, the elevation model for the Chicken House dune was used along with a topographic map and a soils map of the area to synthesize that the dominant direction of wind creating these dunes must have been from the W to NW. Establishing that these formations are indeed dunes leads to the conclusion that there must have been a dryer climate present in the area than that of the current one in order for there to be proper conditions for the dunes to form.

Acknowledgements

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