Using LiDAR for mapping coastal geomorphological changes due to historical mining tailings migrating along the Lake Superior shore at Grand Traverse Bay, MI

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History
Remnant stamp mill
Gay, MI stamp mill operated from 1900-1932

Lake Superior

Sluiceway to carry stamp sand waste material

View to the East
• 1938

Approximately 15.8MMT (69.3%) of original 22.5MMT still in original pile at Gay

Note migration of stamp sand to “Coal dock”

Traverse River Breakwall

Stamp mill

2km
Oblique aerial photo – Gay, MI stamp sands - 2017

Village of Gay, MI

Lake Superior

View to North
Looking north along Grand Traverse shoreline (north of breakwall, about 1960)

Pre-stamp sand encroachment
Stamp sand measurement transects

From Rasmussen, et al., 2002
Stamp sand widths 1938-2017 by transect number

Blues and greens = earlier dates
Reds = latest dates

Source pile
Coal dock
Trough
Buffalo Reef
Breakwall
Impacts
Stamp sand overtopping
Traverse River Breakwall (July, 2018)
Drone image courtesy C. Brooks
Stamp sand encroachment onto cobble field of Buffalo Reef spawning area
View to SW, beach face south of Coal Dock

2016
View to SE (from residences) toward Lake Superior (north of breakwall)
South of breakwall, view to SE
Sediments
Stamp sand from Gay

Stamp sand just south of Gay

Stamp sand from breakwall
Slime clay (green mineral = epidote)

Lens cap for scale = 77mm diameter
Photo taken at Gay source pile
Natural beach sand south of breakwall
Suspended slime clay.
View to east from stamp sand beach

June 17, 2014 Landsat Thematic Mapper

Plume of suspended Slime clay sediment
% Stamp Sand Offshore Gradient – Ponar sampling

Coal dock

Traverse River

Buffalo Reef

0 Ponar sample locations (Kerfoot)
LiDAR
Bathymetric LiDAR principles

Five LiDAR acquisitions at Grand Traverse Bay (2008, 10, 11, 13, 16) USACE and NOAA

In the clear water of Lake Superior, reflectance pulses returned from depths to ~25m
LiDAR images (shaded relief)
Significant features at Grand Traverse Bay

- Offshore bars of stamp sand
- Trough
- Shoreline Stamp sand
- Traverse River
- Original Pile
- Buffalo Reef
- Coal Dock
- Trough

NOAA LiDAR 2010
2008 to 2016 Terrestrial Stamp Sand Extent Change Detection

Extent of the Gay Stamp Sand coastline change from 2008 to 2016 displayed on 2016 NAIP orthoimagery. Shoreline area gain displayed in green, loss in red, and unchanged in grey. Area of significant change locations displayed in hectares and volume in teragrams of stamp sands. It is important to note that locations of constant area stamp sand extent does not necessarily correspond to a constant volume of stamp sands. The constant area lost 0.94 Tg of stamp sands from 2008 to 2016.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Area (ha)</th>
<th>Percent Loss from 2008 to 2016 (%)</th>
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</thead>
<tbody>
<tr>
<td>Gay Pile</td>
<td>2008</td>
<td>31</td>
<td>21%</td>
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<tr>
<td></td>
<td>2016</td>
<td>25</td>
<td></td>
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<tr>
<td>Shoreline: South of Coal Dock</td>
<td>2008</td>
<td>41</td>
<td>2%</td>
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<tr>
<td></td>
<td>2016</td>
<td>40</td>
<td></td>
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<tr>
<td>Shoreline: Between Gay Pile and Coal Dock</td>
<td>2008</td>
<td>95</td>
<td>3%</td>
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<tr>
<td></td>
<td>2016</td>
<td>92</td>
<td></td>
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</table>
Mass Eroded From Pile & Deposited On Beach

Estimated 2080+ before all stamp sand eroded from original pile at Gay
a. Stamp sand migration of offshore bars

b. Profile of offshore bar change

LiDAR change detection of migrating offshore bars (stamp sand)

Kerfoot, Brooks, Sayers, Schuchman)
Bathymetric change derived from 2008 & 2016 LiDAR

Kerfoot, Brooks, Sayers, Schuchman)
LiDAR-derived estimate of stamp sand thickness (2010)

Thicknes of the stamp sand (from the bedrock to the top in meters)

- 0.0 - 1.9
- 1.9 - 2.4
- 2.4 - 2.9
- 2.9 - 3.4
- 3.4 - 4.0
- 4.0 - 4.4
- 4.4 - 4.9
- 4.9 - 5.6
- 5.6 - 6.3
- 6.3 - 7.1
- 7.1 - 8.2
- 8.2 - 9.6
- 9.6 - 12.0
- 12.0 - 15.5
- 15.5 - 23.7

Kerfoot, Brooks, Sayers, Schuchman)
Geomorphology
LiDAR relief image of stamp sand beach with rhythmic beach cusps

8-25% slope over 50m distance
Berm crest to base of breaker zone
5m vertical change

Cross shore profiles were created to compare stamp sand vs. natural sand beach/littoral zones (next slides)
2016 LiDAR cross shore profile - (stamp sand beach) North of breakwall

2.7m depth / 25m horizontal = 0.108 slope
2016 LiDAR cross shore profile – (natural sand beach)
South of breakwall

1.7m depth / 45m horizontal = 0.038 slope
Comparison of beach & littoral geomorphology on LiDAR painted relief images

South of breakwall

- Rhythmic inner bar
- Low-slope outer bar
- Natural Sand

North of breakwall

- Steep-slope lacks bar
- Stamp Sand
Possible bed-surf mechanism
South of breakwall

A mechanism for the generation of wave-driven rhythmic patterns in the surf zone, October 2000

Figure 4. Topographic perturbation and flow pattern ($k = 3.0, r = 0.5, N = 0.01, \gamma = 0.02$, and $\alpha(0) - 0.1$). Shoals are white, and deeper areas are shaded. The shoreline is at $x = 0.0$ and the breaking at $x = 1.0$. 
Waves and beach processes (effect of slope)
Fig. 5. Beachface processes: E–F’ — Evolution of beachface slope and dominant sand grain size as a response to changes in wave height in the range 1–2 m; E–F — Evolution of beachface slope at constant sand grain size; F’–G — Beachface slope restoration as the result of supply of coarser sediment. F’–H — Wave height reduction as the result of formation of an immersed sand bar.
Just south of breakwall (natural sand beach) 10/10/18
Just south of breakwall (stamp sand beach) 10/10/18
Historically high lake levels coupled with exceptional wave heights during October, 2017 storm
Result: Steep stamp sand beach face allowed waves to overtop beach crest

The view to SE on 10-27-17 from residential deck just north of breakwall

Stamp sand “normal shoreline” 100m away
Storm waves (10/17/17) flooded across 100m beach width
To roadway behind residences
Stamp sand beach & Lake Superior is to the left
10-25-17 View toward Lake Superior (about 135m away).
Septic drain field filter fabric exposed by scouring flood of wave water
Natural sand beach.

Post Oct. 2017 storm
South of breakwall
View to south.

Insignificant impact.
Conclusions

• Five LiDAR acquisitions from 2008-2016
• Provided quantitative tool for
  – Migration rate and loss/gain measurements
    • Width
    • Mass
  – Mapping encroachment on critical spawning area
  – Measurements of beach/littoral morphological changes
    • Wave dynamics changes caused by stamp sand
    • Deleterious effects of coastal geomorphic changes
  – Prediction of future migration & change
To learn more, please visit

https://mtri.org/stampsands.html

or

http://www.geo.mtu.edu/KeweenawGeoheritage/
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