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Paleoclimate of Inland Dunes: Linking OSL Dates to Dune Activation & Climate Change

David Vogel

Paleoclimate of Inland Dunes: Linking OSL Dates from Northern Wisconsin to Dune Activation & Climate Change

David A. Vogel, Dr. Nelson R. Ham
Geology Discipline, St. Norbert College, De Pere, WI 54115

INTRODUCTION

Inland sand dunes are prevalent throughout the Great Lakes region, and specifically in northeastern Wisconsin[1,7]. Today, most of these dunes are inactive, preserved as parabolic dunes- crescentic dunes with trailing arms stabilized by vegetation[4]. Parabolic dunes have been established as a proxy for paleoclimate conditions of inland environments, reflecting local prevailing winds and regional circulation systems through their orientation[9], and aridity and vegetation through their stabilization process[10]. Additionally, optically-stimulated luminescence (OSL) dating techniques allow recognition of spans of eolian activity[8]. However, while dunes in northeastern Wisconsin are known to be associated with exposed glacial lake sediment from the Wisconsin Glaciation, they lack established dates of activity or paleoclimate reconstructions, leaving a gap in regional understandings of post-glacial conditions. Preliminary analysis of unpublished ages of sand dunes in this area indicates activity several thousand years after glacial lake drainage, suggesting they instead reflect climatic changes other than lake sediment exposure. Recent meta-analysis of inland dunes validate use of parabolic dunes as paleoclimate proxies, demonstrating alignment between OSL dating of dunes and regional shifts in temperature and aridity[10], with more recent dates into the 21st century well-supported by parallel ecological studies[3].

This study seeks to establish what trends in parabolic dune orientation or prevailing wind direction exist, and how their spatial variation could relate to OSL date distributions. Furthermore, we seek to relate the timing of dune stabilization with regional and global models of past climate change and extrapolate this to both records of Dust Bowl eolian activity in the 1930s[3], as well as possible future reactivation according to ongoing climate change models[11].

We hypothesize that dunes found in northeast Wisconsin would generally align with models of regional post-glacial climate that significantly differ from current wind, temperature and aridity conditions, and also provide constraints for future reactivation. To investigate, dune crests, orientation bisectors and previously-unpublished OSL dates were mapped, modeled statistically, and related to literature timing and conditions of dune stabilization.

METHODS

- **Sampling Locations –** Ocoto County has several prominent dune fields (divided into clusters A, B and C), from which unpublished OSL dates have been collected in previous years, along with readily available high-resolution LiDAR and hillshade imagery for analysis in Esri ArcGIS Pro (*Fig. 1*)
- **OSL Dating –** Collection of dune cores at night, quartz grains then stimulated with diodes to release energy trapped in crystalline defects accumulated during burial, producing light emissions measured with an image intensifier and equated to a standard dose rate accumulated over some span of time. Yields tabulated dates of last exposure (stabilization) and uncertainty (*Fig. 2*).
- **Experimental Design –** Mapped fields of parabolic dune crests were bisected with vectors indicating direction of orientation (*Figs. 3A-C*), analyzed in clusters with Stereonet 11 to yield orientation roses (*Figs. 3D-F*) and an opposite mean vector indicating the origin of prevailing winds. OSL dates from said fields are mapped to spatially illustrate dune timing.
- **Statistical Analysis –** OSL dates and uncertainties are plotted in R in an empirical distribution function and distribution curve by thousands of years ago (ka) (*Fig. 4*).

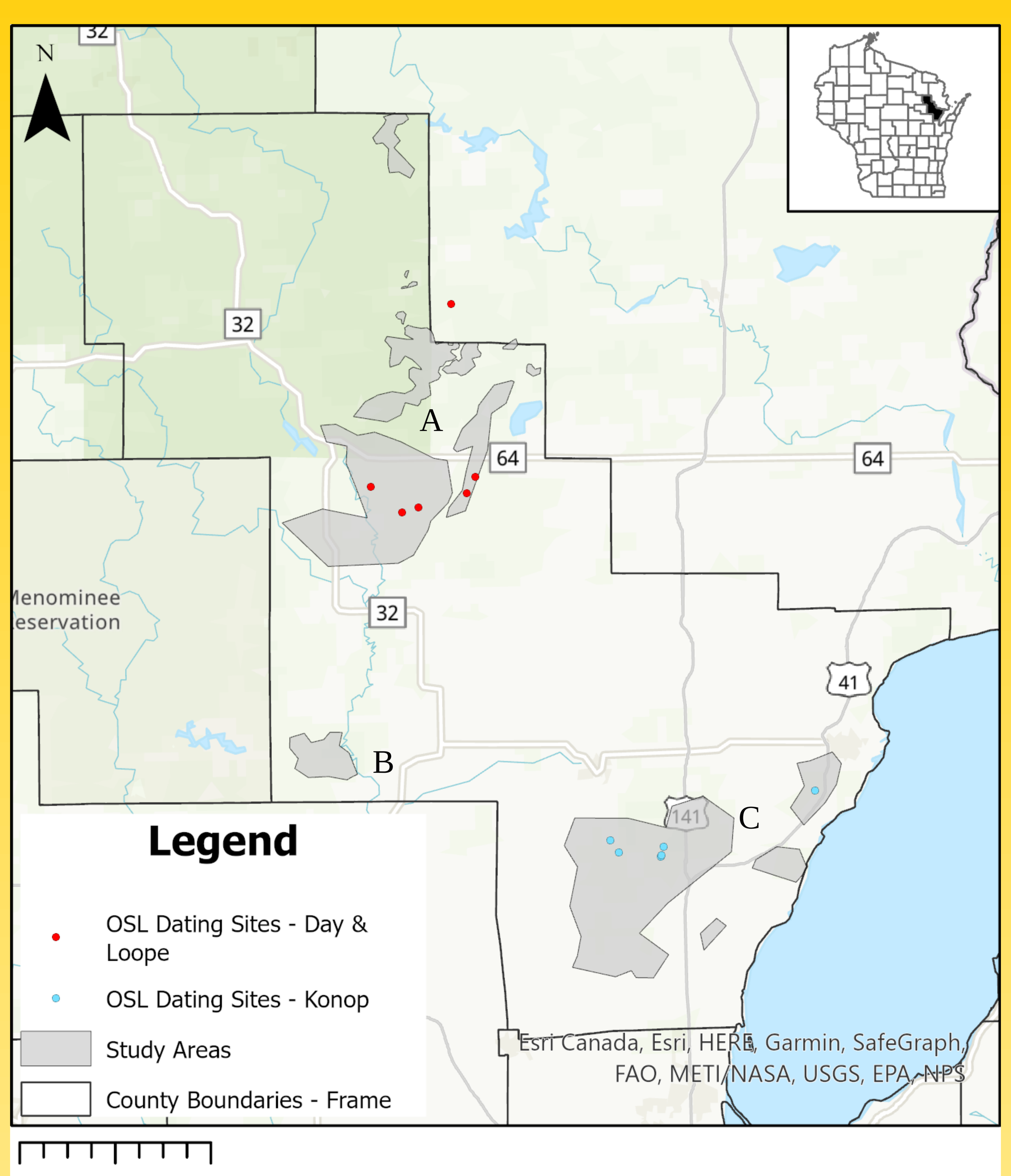


Fig. 1 (*left*) – Oconto County, with dune field study areas in grey and grouped into middle (A), southern (B), and southeastern (C) fields, and OSL dating sites colored by origins (red for Day[2] or Loope[7], blue for Konop[6])

Fig. 2 (*below*) – Tabulated OSL dates with associated dune fields, ages and uncertainties in kilo annum (thousands of years BP).

Source	Field	Age (ka)	σ (± ka)
Konop	Southeast	8.75	0.42
Konop	Southeast	10.3	0.5
Konop	Southeast	10.4	0.5
Konop	Southeast	10.5	0.6
Konop	Southeast	10.8	0.5
Konop	Southeast	10.7	0.6
Konop	Southeast	9.98	0.63
Konop	Southeast	11.8	0.8
Day	Middle	8.59	0.40
Day	Middle	8.44	0.44
Day	Middle	9.03	0.43
Day	Middle	9.65	0.46
Day	Middle	9.65	0.47
Day	Middle	9.35	0.42
Day	Middle	10.1	0.50
Loope	Middle	9.50	0.70
Loope	Middle	10.30	0.50
Loope	Middle	5.90	0.60

RESULTS

- **Parabolic dune orientation found to average to SE with generally unimodal distributions**
  - Mean vectors opposite dune orientation indicate paleocurrents from the northwest to have prevailed
  - Southeastern field has bimodal distribution, accounting for a minor eastern region of south-southwestern dunes near Green Bay shore
  - Northern study area vastly inconsistent with regional trend, omitted from analyses for reexamination
- **OSL dates primarily fall around Preboreal stage of Holocene, indicating activity and stabilization after draining of post-glacial lakes**
  - Distribution of dates peaks just over 10 ka, slight bias towards younger end (~9 ka)
  - Potentially anomalous shallow core date (5.90 ± 0.60 ka) noted in middle field, well outside of dominant timing

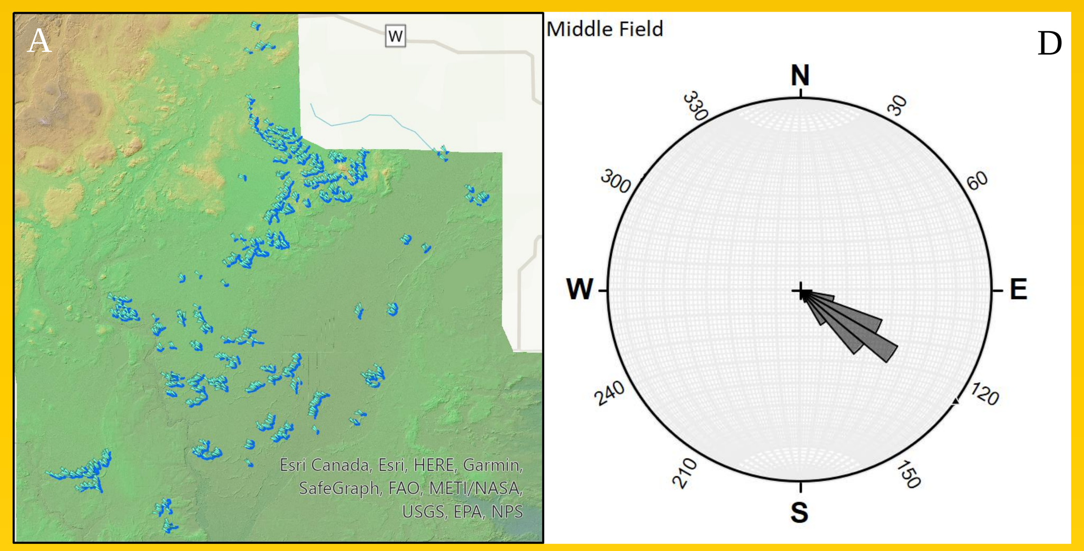


Fig. 3A – Middle field dune crests and bisectors (n = 772)
Fig. 3D – Middle field dune orientation rose with unimodal distribution, with azimuthal mean orientation vector (125.8) and prevailing wind vector (305.8)

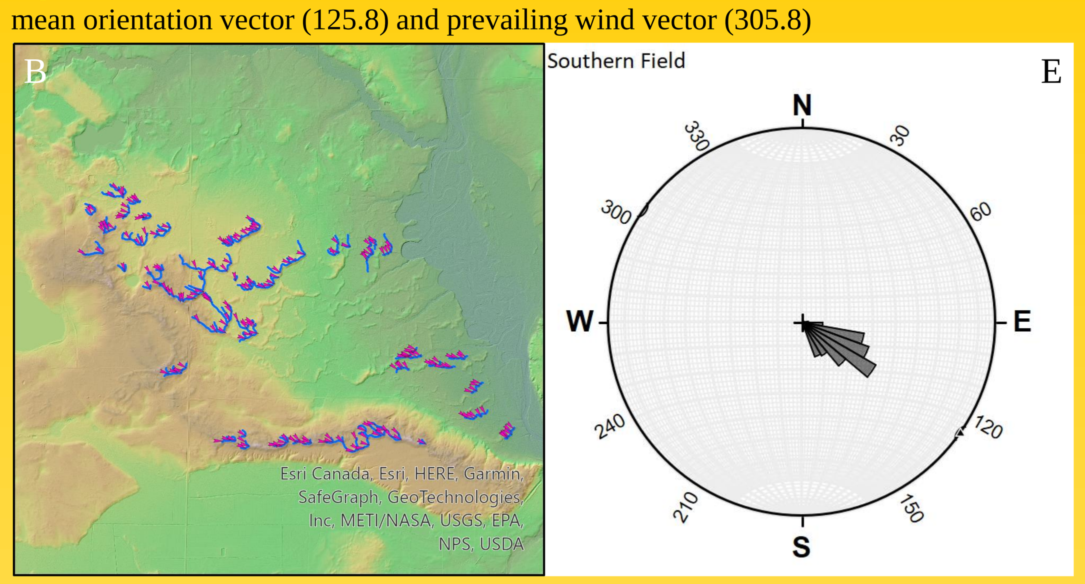


Fig. 3B – Southern field dune crests and bisectors (n = 193)
Fig. 3E – Southern field dune orientation rose with unimodal distribution, with azimuthal mean orientation vector (125.1) and prevailing wind vector (305.1)

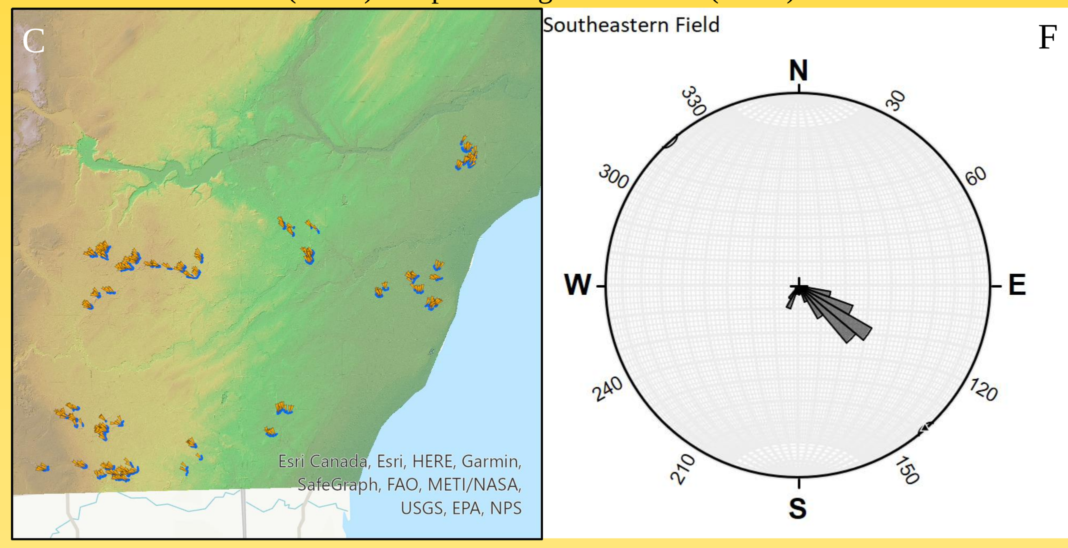


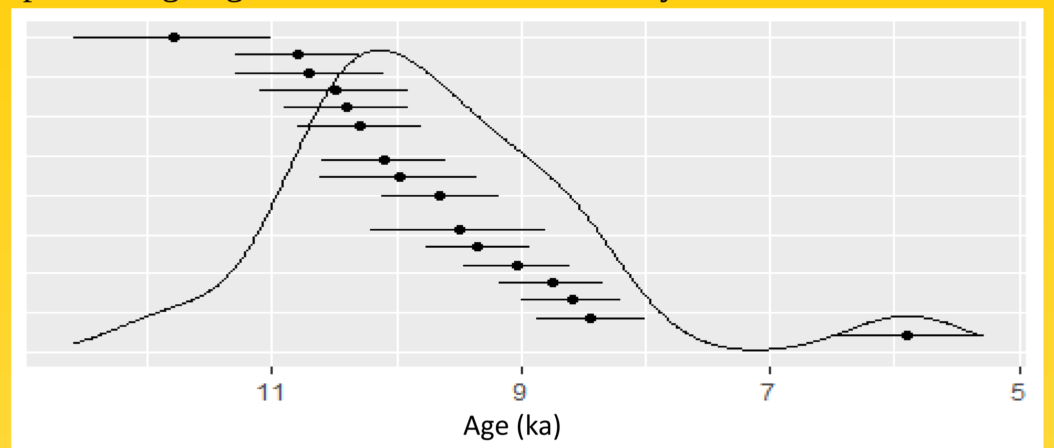
Fig. 3C – Southeastern field dune crests and bisectors (n = 431)
Fig. 3F – Southeastern field dune orientation rose with bimodal distribution, with azimuthal mean orientation vector (138.4) and prevailing wind vector (318.4)

CONCLUSIONS

- **Timing verifies dune activity came after glacial lake abandonment**
  - Activity of glaciolacustrine sand dune clustered within single primary period relating to drought-driven water table changes seen in upper Great Lakes[7]
  - Separation of inland dunes from Wisconsin Glaciation physically and temporally makes exposure of lacustrine sediment and influence of glaciers on paleoclimate unfeasible as drivers of activity[8]
- **Paleoclimate aligns with regional literature, and differs from the present**
  - Similarly-dated dunes correspond with gaps in pollen/vegetation records from cool, dry Preboreal conditions when forests opened, host to northwesterly winds around the Great Lakes[1,7]
  - Modern currently are southwesterly on average (~perpendicular), with minor January to April modern winds closest to past trends[5]; dominance of past currents seen in dunes indicate significant changes in climate and resultant air circulation systems
- **Concentrated period of activation driven by regionally dry climate post-Younger Dryas**
  - Younger Dryas cooling and aridity associated with OSL dates from Great Lakes region saw similar reactivation with persistence into Preboreal[1,7], implying sensitivity of the region's dunes to climate changes and role of supplementary drivers to forest/vegetation opening required[8]
- **Later Holocene reactivation of dunes sparsely evidenced, but possible**
  - Shallow sample could be OSL error as suspected in other studies[8], but could also indicate later reactivation into the recent past strongly evidenced elsewhere by tree-ring and lakebed analyses[1,3]
- **Findings somewhat restricted to localized interpretation, but consistent in results**
  - Mapping of complex compound parabolic dunes – using trailing arms, wind/leeward slope topographies
  - Limited to single county, low number of OSL dates (n = 18); realistic study scope, OSL cost constraints
- **Future dune activity feasible within current models**
  - The 1930s Dust Bowl and other comparable drought-driven events has been observed initiate inland dune activity, potentially accounting for dates significantly post-dating the Younger Dryas event[3,10]
  - Dust Bowl conditions are thought to have neared aridity, water table and vegetation failure conditions for widespread regional dune activation[3]; current WICCI projections of climate change anticipate increased air and water temperature, regular extreme weather events, decreasingly consistent precipitation and longer summer droughts linked with past activity[7], and could see vegetation failure and current shifts to drive new dune behaviors and alter stabilized dune ecosystems within the next ~40 years[11]
- **Multiple options for future expansion, refinement and reexamination of study**
  - Continued mapping of crests and bisectors, OSL dating could improve statistical certainty
  - Integrating soil type maps – possible locations of other dune remnants matching fine to medium sandy soils, similarly susceptible to activation
  - Review northern field 'dunes' – arrangement and preliminary soil examination more consistent with eskers, but trailing arms and stoss/lee slope differences noted
  - Monitor dune behavior in Oconto County for shallow reactivations
  - Integrate mapped dunes into forest management, preserving vegetation-stabilized dune ecosystems

Fig. 3A-F (*left*) – Dune field areas with mapped crests and bisectors (A-C), and resultant orientation rose and paleocurrent vectors (D-F)

Fig.4 (*right*) – Oconto County OSL dates from Konop[6], Day[2], and Loope[7] studies arranged in an empirical distribution curve, points indicating dates and bars their uncertainties, with a superimposed distribution curve indicating how dates are grouped temporally



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