Reinterpretation of the Proterozoic (?) Devils Island Sandstone, Keweenawan Rift, Northern Wisconsin

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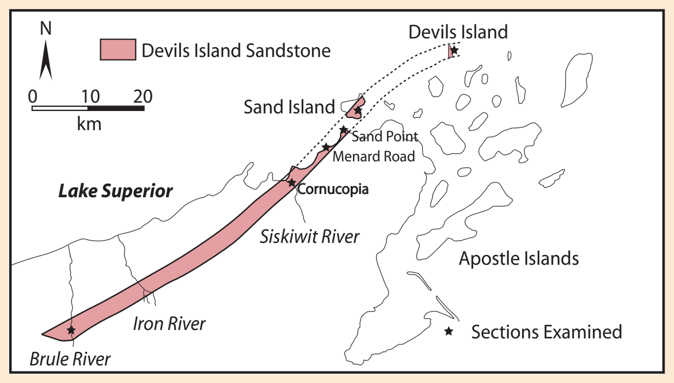
Purpose

The Proterozoic Devils Island Sandstone of Northern Wisconsin is currently interpreted as a nearshore lacustrine deposit formed in the Keweenawan rift (Adamson, 1997). This same interpretation had been given the correlable Hinckley Sandstone in eastern Minnesota (Tryhorn and Ojakangas, 1972) until recent study showed that it represents a braided stream, dune, and interdune depositional environment (Johnson et al., 2001). The purpose of this project is to determine whether the environment of deposition of the Devils Island Sandstone also needs reinterpretation.

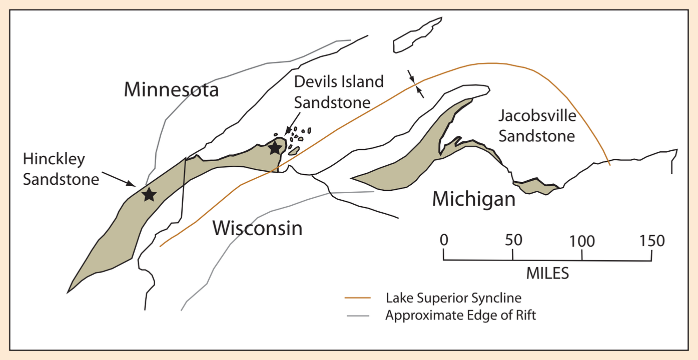
Location and Geologic Setting

The Devils Island Sandstone is exposed in Northern Wisconsin along coastal cliffs on the shore of Lake Superior from Sand Point to Menard Road on the mainland as well as in cliffs along the eastern shore of Sand Island and nearly all of Devils Island. Other mainland exposures can be found in segments of the channels of the Brule, Iron and Siskiwit Rivers.



Map showing outcrop locations, modified from Adamson, 1997

The Devils Island Sandstone is a formation within the Proterozoic Bayfield Group. It is believed to have been deposited in the late stage of the Keweenawan Rift, a failed continental rift spanning from Kansas to Lake Superior. Of the predominanty feldspathic Bayfield Group, the Devils Island Sandstone, a quartz arenite, contains the most mature sediment.



Map showing extent of the Bayfield Group and its corrable units in Minnesota and Michigan as well as the axis of Lake Superior Syncline, modified from Wolff and Huber, 1973 and Anderson and McKay, 1997.

Trace Fossil Description

Trace fossils have been found in beds of the silty planar facies at one locality. Trace fossils are preserved in six slabs and include both epichnal and hypichnal preservation. These include two categories of trace fossils: centimeter-scale and millimeter-scale traces. Asymmetric ripples are also preserved on the bottom side of one of the trace-fossil-bearing slabs. These ripples have varying wavelengths from 5.5–6.0 cm and ripple heights from 2–3mm and are composed of fine-grained sand containing no silt.

Centimeter–scale trace fossils
The trace fossils preserved are gently curved to sinuous. Some exhibit Y-branched segments (Fig. 1) at angles between 30 and 50 degrees. Segments range from 0.3–1.0 cm in diameter and to 13 cm long, although in certain locations the traces are as short as 1cm long. Sinuosity varies from localized curves that bend up to 90 degrees within a relatively straight trace (Fig. 2), to regions where traces turn 180 degrees within 2–3 cm (Fig. 3). Traces commonly cross over similar traces without disturbing the underlying trace. Grain size along the surface of the trace is very fine-grained sand to silt, with the internal structure composed primarily of fine-grained sand.

In cross-section, the traces form a discrete structure separated from the underlying sediment by a dark, very fine-grained sand to silty lamination (Fig. 4). The underlying laminae are depressed directly beneath the trace. Traces range in height from 1-2 mm.
One trace appears to have a tripartite structure (Fig. 3) in plan view. A few traces also display faint ridges crossing the width of the trace (Fig.5). This suggests a burrow back-fill structure.

Millimeter-scale traces
The second type of trace fossil is 1.0–1.5 mm wide and up to 25 mm long (Fig. 3). These form gently curved patterns in plan view. Traces have Y-branches at angles between 50–120 degrees and cross over the large-diameter trace fossils . These mm-scale trace fossils are too small to distinguish any internal structure in hand sample.

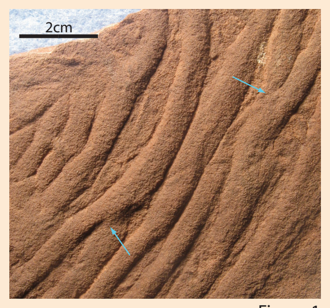


Figure 1
Arrows point toward Y-Branching in cm-scale trace fossils.

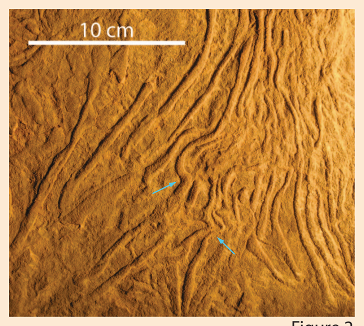


Figure 2
Arrows point to abruptly bent or curved portions of cm-scale trace fossils

Blue arrow points toward region where trace fossil bends 180 degrees
Green arrow points to trace fossil with tripartite structure
Orange arrows point to mm-scale trace fossils
Figure 3

Arrows point towards dark silt laminae and depressions below cm-scale trace fossil, shown in cross-sectional view
Figure 4

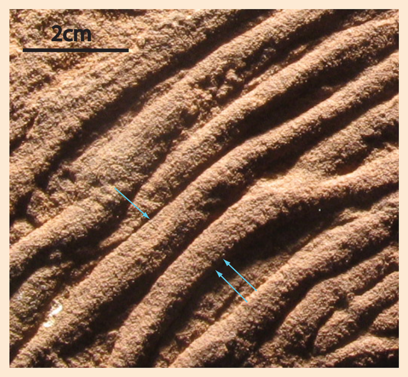


Figure 5
Arrows point to ridges crossing width of trace fossil, suggesting a burrow back-fill structure

Discussion

The Devils Island Sandstone was deposited within a rift valley containing braided streams, eolian dunes, periodically flooded interdune flats, and one or more lakes. In this dynamic environment stream channels were shifting, dunes were migrating, and lake levels fluctuated. Stream or lake water episodically flooded the surrounding flats and interdune areas.

Four facies in the Devils Island Sandstone, tangential cross-strata (eolian dunes), trough cross-strata (braided streams), sandy planar beds (sand flats and interdune flats), and convolute bedding (soft-sediment deformation) are similar to facies observed in the Hinckley Sandstone. A similar interpretation of the depositional environment, eolian to fluvial, reflects this. This interpretation is also in agreement with Nuhfer and Dalles (1987) who proposed that sand flats, streams, and ponds created the Devils Island Sandstone. Paleocurrent measurements within the trough cross-strata facies in the Hinckley Sandstone consistently indicate flow to the SE whereas in the Devils Island Sandstone a northeasterly flow direction is more predominant. It appears that streams in the Hinckley Sandstone flowed towards the axis of the Keweenawan Rift, suggesting a rift marginal position, whereas streams within the Devils Island Sandstone flowed more parallel to the rift axis, representing a location on or near the center of the rift.

The discovery of traces of multicellular organisms raises a question about the age of the Devils Island Sandstone. As a rift deposit, this unit has been assumed to be mid-Proterozoic in age. Such trace fossils are rare in sediments older than late Proterozoic. Therefore, these traces could be a rare example of mid-Proterozoic multicellular life. Conversely, the presence of trace fossils could suggest a late Proterozoic age for the Devils Island Sandstone.

Conclusion

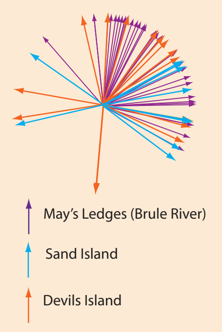
The purpose of this project was to determine whether the most recent interpretation of the depositional environment of the Devils Island Sandstone was accurate after the depositional environment of the correlable Hinckley Sandstone was revised.
Five different facies have been recognized:
- Tangential Cross-Strata = Eolian dune northeasterly migration direction.
- Trough Cross-Strata = Fluvial environment, dominant flow towards the north and east.
- Sandy Planar Beds = Periodic flooding of sand flats and interdune areas.
- Silt-Bearing Planar Beds = Lacustrine environment with fluctuating lake levels.
- Convolute Bedding = Rapid deposition, primarily by dunes, on a saturated substrate.

-Both the Devils Island Sandstone and the Hinckley Sandstone were deposited in a similar dune/braided stream environment. The Devils Island Sandstone also included lakes.
-The Devils Island Sandstone, with lakes and rift-parallel streams, was deposited near the rift axis.
-The Hinckley Sandstone, with rift-normal streams, was deposited near the rift margin.
- Presence of trace fossils within the Devils Island Sandstone indicates the presence of multicellular organisms suggesting a late Proterozoic or younger age for the Devils Island Sandstone.

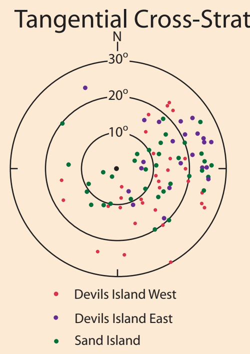
Additional Work:
1) A more detailed description of the smaller-scale tangential cross-strata, without definitive eolian features, is necessary in the development of a complete depositional model for this facies.
2) Further study of the traces and examination of thin sections taken from trace fossil-bearing rock to gain more information on the nature of organisms during this time.

Facies Identified

Paleocurrent flow directions in trough cross-strata inferred from trough and cross-strata orientations



Orientation and Inclination of Tangential Cross-Strata



Tangential Cross-Strata (Eolian dune)
Sets are 30 to 150cm thick and form large, curved sets in plan view, which can span over 10m. Grain size varies from fine- to medium-grained sand. Climbing adhesion ripple structures occur in packages up to 7cm thick within cross-strata. Ripple forms, crinkly laminations, and mm-scale laminations are common in toesets. Locally, wedge-shaped, cm-scale strata downlap onto these laminated toesets. Cross-strata dip predominantly to the northeast and east.

Trough Cross-Strata (Braided streams)
Trough cross-strata occur in beds ranging from 1 to 4dm thick, and bed thickness can vary laterally as trough cross-strata locally scour into underlying strata. Individual troughs can be 40cm to one meter in width and 15 to 20cm thick. Grain size ranges from fine- to coarse-grained sand with granules and pebbles locally, especially along bounding sur faces. Overall grain size is coarser and more poorly sorted than all the other facies. Fine-grained sand rip-up clasts that parallel strata are common, and typically range in size from 0.5 to 2cm. Ripple forms up to 3cm in amplitude cap trough cross-strata beds. Trough cross-strata orientations indicate a paleocurrent diredction range primarily to the north to southeast with predominant directions varying by locality.

Sandy Planar Beds (Sand flats and interdune areas that are periodically flooded)
Sandy planar beds contain mm- to cm-scale beds of fine- to medium-grained sand. Subaqueous ripples, predominantly asymmetrical, are common and indicate a variety of flow directions. Climbing adhesion ripple structures, mm-scale planar laminations and crinkly laminations are common. In plan view, some bedding-plane surfaces appear irregular and bumpy. Locally there are sets of cross-strata up to 20cm thick. At some localities, these planar beds may be traced laterally into tangential cross-strata toe-sets.

Silt-Bearing Planar Beds (Lake with fluctuating lake levels)
The silt-bearing planar-bedded facies contains laterally continuous beds with subaqueous ripples and mudcracks. This facies is generally more poorly sorted than the sandy planar beds. Two subfacies can be distinguished:
- *Silty planar beds* form laterally continuous, thinly laminated fining-upward sequences with mm- to cm-scale (typically thinner than 1cm) sand-silt couplets with rippled to ir regular silty capping laminae. Grain size ranges from silt to medium-grained sand. Locally, tool marks and horizons with mudcracks are present. This subfacies is recessive in outcrop and is laterally continuous except where it is cut out by overlying strata. At one locality, trace fossils were found.
- *Sandy-silty planar beds* are similar to the silty planar beds in that they both contain sand-silt couplets, but these beds have comparatively thicker fining-upward sand-silt couplets (typically 1 to 3cm thick). Grain size also shows more variability, ranging from silt to coarse-grained sand. High-angle cross-strata occur in sandy lenses 2 to 30cm thick with rip-up clasts. This subfacies also has a much higher ratio of sand to silt compared to the silty planar beds. Climbing ripple structures and mudcracks can also be found. Laterally, this facies can grade into the finer grained silty planar subfacies.

Convolute Strata (Soft-sediment deformation triggered by rapid deposition on a saturated substrate)
Several different forms of soft-sediment deformation are present in the Devils Island Sandstone. These include local fluidized zones where strata are broken and upturned, centimeter-scale faults, and small-scale folds. This facies occurs locally within the tangential cross-strata facies and to a lesser extent within trough cross-strata. In addition there are convolute beds with nearly entirely deformed strata that range from 1 to 2.5m thick. Grain size in these beds is most commonly lower to upper fine-grained sand. Outcrops of this facies on eastern Sand Island and Devils Island form resistant, laterally continuous ledges.

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