Piscine Trace Fossils from Late Wisconsinan Glacial Varves, New England, USA

Stratigraphic, Paleoecologic and Paleobiogeographic Implications

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Introduction

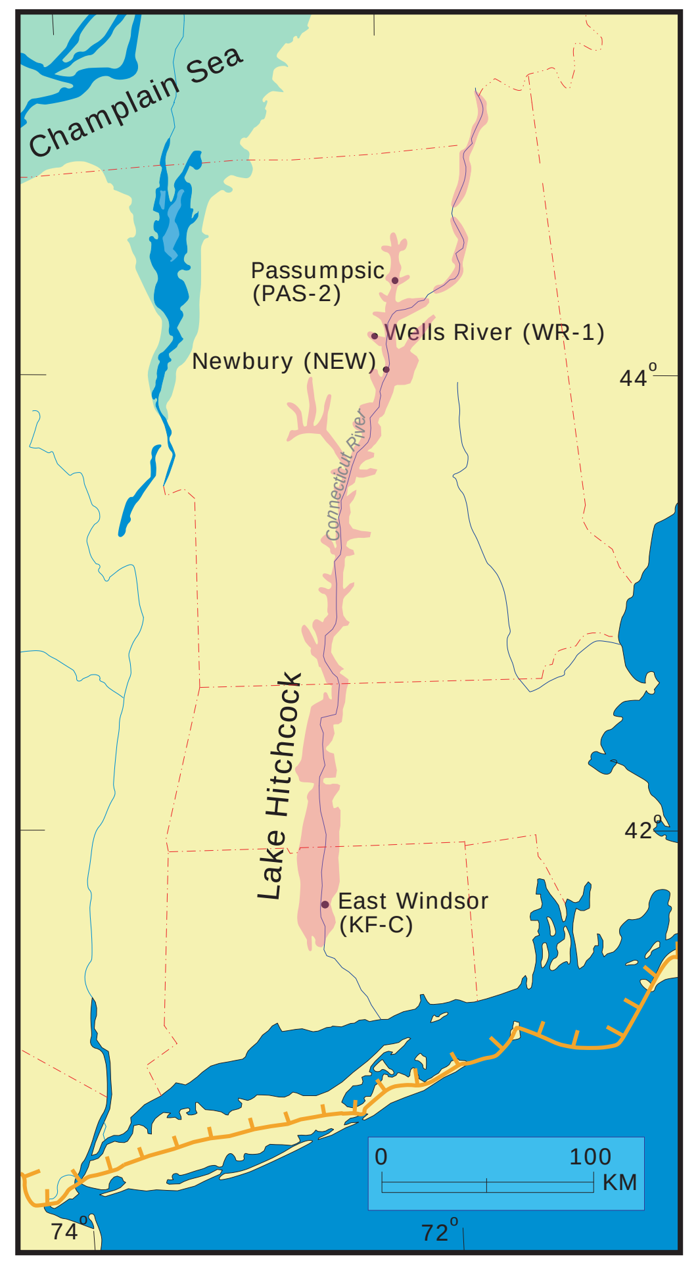

Figure 1. Map of New England showing locations of four study sites. Pink outline = extent of glacial Lake Hitchcock and successive lakes in the Connecticut Valley, light blue shading = extent of Champlain Sea, orange hatched line = terminal postion of the Laurentide ice sheet in New England.

Founding Fish

The timing of postglacial reinvasion of New England drainages by fish is a complex problem.

- No confirmed piscine body fossils have been found in New England glaciolacustrine sediments.
- Molecular genetic data do not yield detailed information on dispersal pathways and rates of fish migration.
- A deglacial history of channel switching, lake impoundment and drainage events, and postglacial isostatic rebound further complicates attempts to model regional postglacial reinvasion by fish.

Trace fossils produced by fish from New England provide new information on the precise location of early postglacial invaders in the Connecticut Valley.

- Reconnaisance at four sites exposing varved glaciolacustrine sediment revealed the presence of fish in glacial Lake Hitchcock and successive Connecticut Valley lakes (late Wisconsinan) through impressions and trails made in lake floor substrates.
- New trace fossil sites are in the north-central Connecticut, Passumpsic, and Wells River valleys of northern Vermont and in the southern Connecticut Valley at East Windsor, Connecticut (Fig. 1).

Late Wisconsinan Refugia

Glacial refugia are areas of land that were ice-free and capable of supporting life while the majority of the present land surface in New England was ice covered.

- During the last glaciation, sea level was about 125 m lower than today, exposing areas of high relief offshore from the current North American coastline (Fig. 2).
- The Georges Bank refugium, known to have supported large land mammals during the last ice age, was located just offshore from the modern New England coastline (Fig.2).
- Many of the freshwater fish that now inhabit the lakes and rivers of New England survived here as well.
- As glaciers began to recede, re-exposing freshwater drainages, fish migrated inland from a few major refugia (Fig. 2, red arrows).

Figure 2. Map showing the locations of exposed offshore landmasses during the last glaciation and during the period of postglacial isostatic uplift. Modified from Schmidt, 1986.

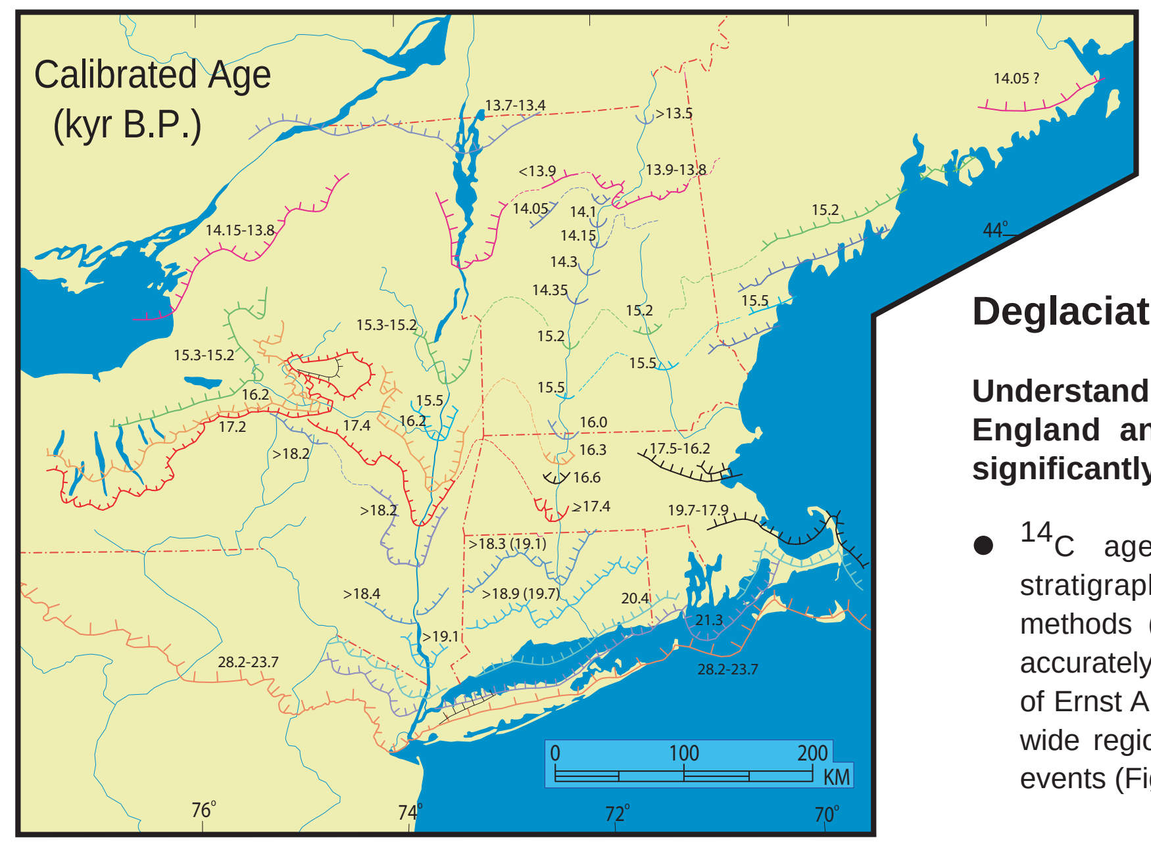

Figure 3. Map showing the deglaciation chronology of New England and neighboring states. Successive ice margins are indicated by colored hatched lines. Numbers indicate calibrated ages of ice margin positions in thousands of years BP (see Ridge, 2004).

Deglaciation of New England

Understanding of the deglacial chronology of New England and neighboring states has improved significantly over the last two decades (Fig. 3).

- ^{14}C ages of plant fossils and paleomagnetic stratigraphy from varves, and modern calibration methods (Fig. 4) have made it possible to correlate accurately the New England Varve Chronology (NEVC) of Ernst Antevs (1922, 1928) with varve records from a wide region and to apply numerical ages to deglacial events (Fig. 3).
- This new high-precision correlation of varve records allows a more detailed reconstruction of glacial lake history and ice recession with respect to a calibrated (~calendar year) time scale (Figs. 3 and 4; Ridge, 2004).

Methods

Figure 5. Clockwise from left: Digging vertically into steep banks; bedding plane in the process of being cleared; a cleared bedding plane ready for investigation.

Excavation

During the study of varve sections at NEW and PAS-2 in the 1997 and 1999 field seasons, large trace fossils were discovered and photographed.

- Excavations were made at KF-C, PAS-2 and WR-1 during the summer of 2004 in search of more fossil material.
- Outcrops of varved lake sediment were excavated in order to provide broad bedding plane exposures.

Recovery

Trace fossils were photographed and were collected in blocks or preserved as casts on site.

- Casting materials were a quick-setting plastic known commercially as SMOOTH-CAST 300 and a quick-setting silicone rubber known as OOMOO 25.
- Casting of the traces is critical given the unconsolidated and fragile nature of the damp sediment that disintegrates upon drying.
- In order to locate the trace fossils within the varve chronology, 2- or 3-inch PVC cores were driven into the sediment and the location of each trace fossil horizon was recorded relative to the cores.

Figure 6. Clockwise from top left: 3 inch PVC cores were driven into previously unknown outcrops (K-F Brickyard, East Windsor, CT); preparation for casting an excavated block, a ring of clay was molded around the area of interest; a quick-setting plastic casting compound was poured onto the specimens; small control cores were used to locate trace fossils precisely within the section.

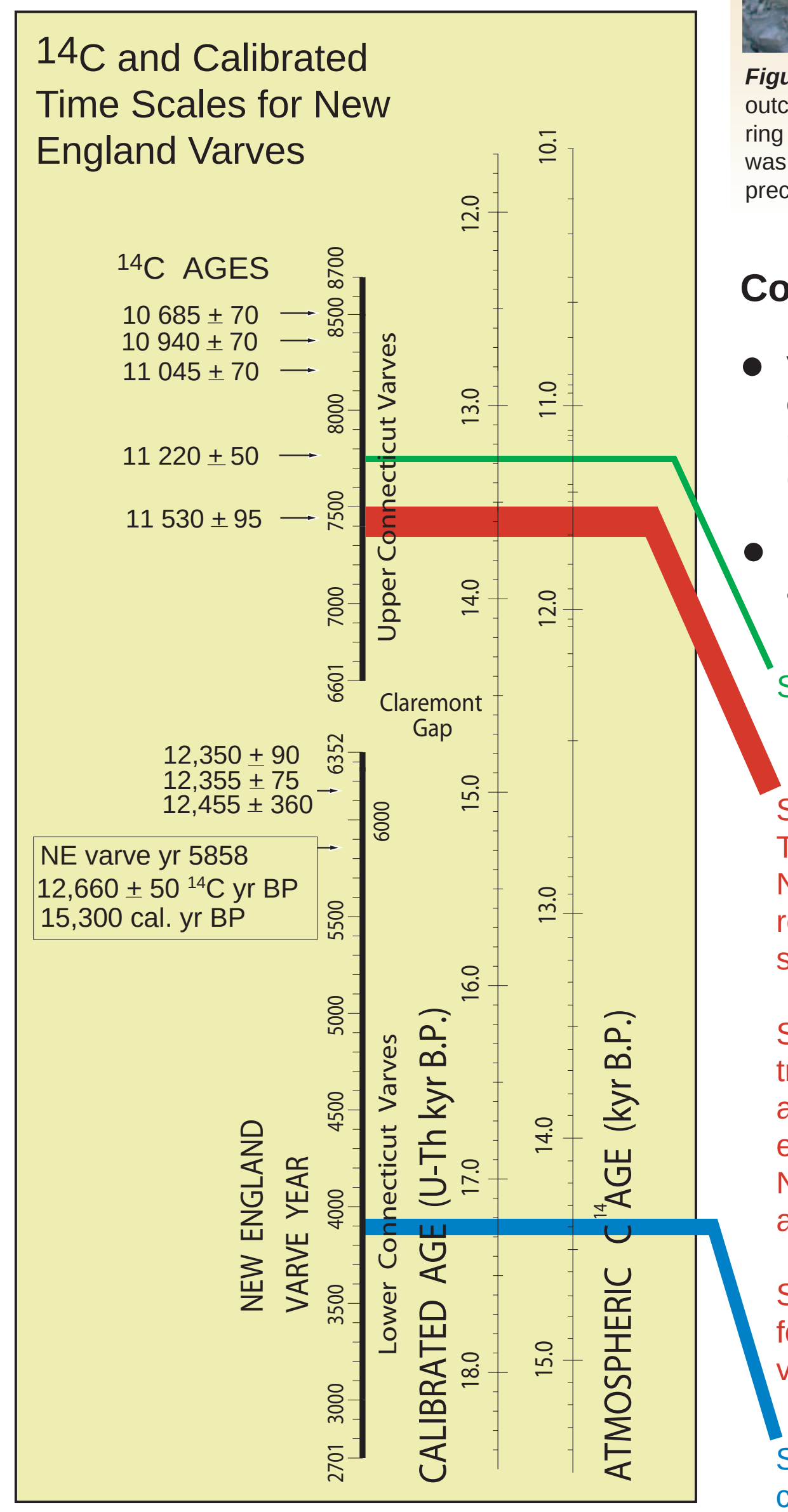

Figure 4. Atmospheric ^{14}C and calibrated (U-Th) time scales applied to the New England Varve Chronology based on the calibration of ^{14}C ages of plant fossils in varves of known number. CALIB 4.3 (Stuiver et al., 1998; Stuiver and Reimer, 1993) was used to calibrate ^{14}C ages.

Core Matching and Stratigraphy

- Varve cores collected in 2004 were cut, measured, and matched to overlapping sequences of 3-inch PVC cores that had been collected in previous years and matched to the New England Varve Chronology (NEVC) at each site.
- Horizons containing trace fossils of vertebrate origin were placed in time according to their position in the NEVC.

Site PAS-2: Type 1 traces were found in NE varves 7752-7763.

Site PAS-2: Type 1 traces were found in NE varves 7410-7418. Type 1 trace fossils originally photographed in 1999 occurred in NE varves 7350-7370. A reconnaissance search in 2004 revealed abundant Type 2 trace fossils in NE varve 7360 of the same sequence.

Site WR-1: The Wells River varve sections, which occur in a tributary embayment, are more difficult to match with the NEVC and can only be placed using horizons that depict basin-wide events. Type 1 traces were found in varves that correspond to NE 7475-7485. A lower trace fossil horizon, which contains abundant Type 2 traces, occurs in NE varves 7359-7362.

Site NEW: A horizon containing Type 1 and 2 trace fossils was found and photographed in 1997 while excavating New England varves (NE) 7307-7443.

Site KF-C: Type 2 trace fossils were discovered at a brickyard clay pit in Connecticut after the abstract for this poster was submitted. Varve cores collected at this site have not yet been measured but preliminary paleomagnetic data from the section indicate the traces are in NE varves 3850-3950.

Trace Fossils

Type 1 - *Undichna* isp.

Large, wave-shaped trails occur throughout the Vermont varve sections

- These are preserved as negative epireliefs or as positive hyporeliefs.
- Thickness of the trail varies along its length, thickening or thinning near crests and troughs (eg., Fig. 7B).
- Trails are commonly composed of sets of two or three out-of-phase waves, each having a different amplitude (eg., Fig. 7A, C, D).

Conform to the ichnogenus *Undichna*

- Type 1 traces are interpreted as trails made by fish swimming at substrate-level, such that one or more fins are in contact with the substrate.
- Body waves produced by the fish as it propels itself are incised into the sediment surface by caudal, anal, and pelvic or pectoral fins.
- Preliminary anlaysis of fin placement and swimming mode in several specimens indicates that multiple fish could be responsible for the different types of *Undichna* trails.

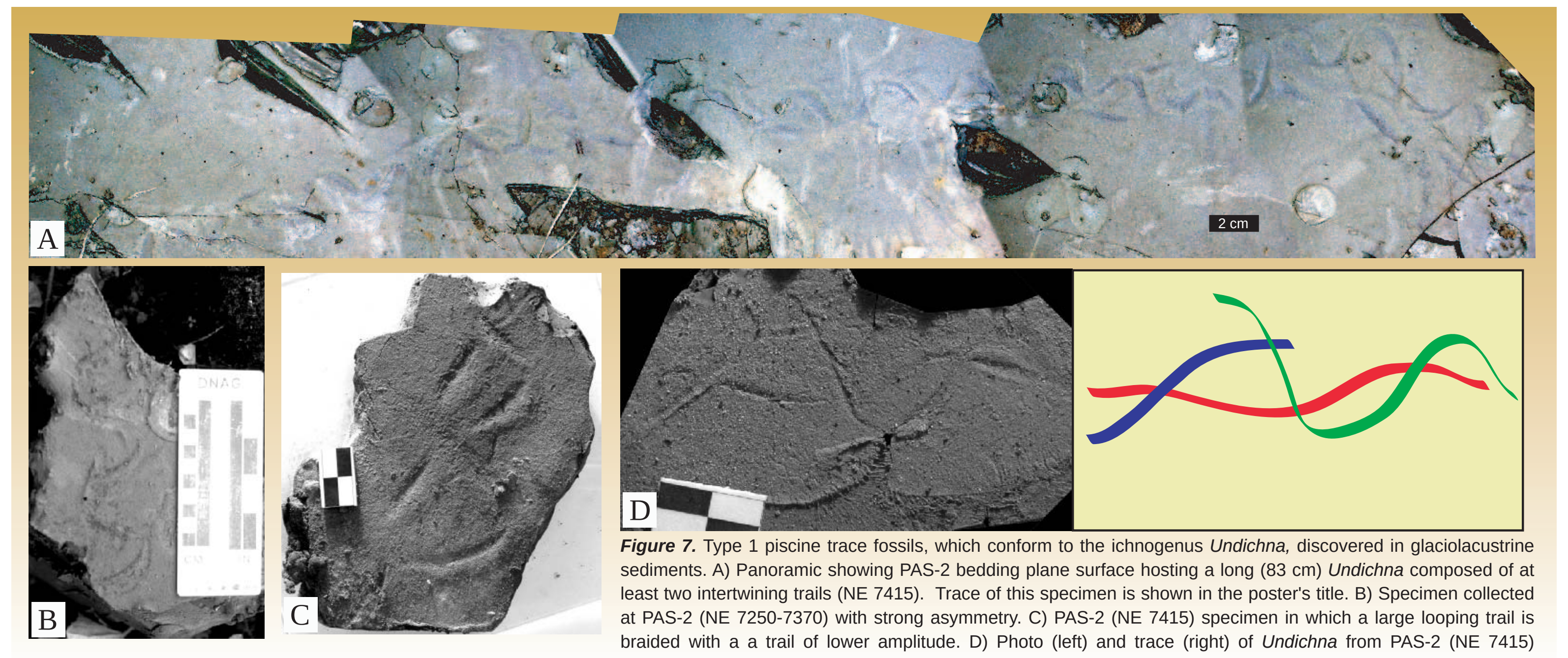

Figure 7. Type 1 piscine trace fossils, which conform to the ichnogenus *Undichna,* discovered in glaciolacustrine sediments. A) Panoramic showing PAS-2 bedding plane surface hosting a long (83 cm) *Undichna* composed of at least two intertwining trails (NE 7415). Trace of this specimen is shown in the poster's title. B) Specimen collected at PAS-2 (NE 7250-7370) with strong asymmetry. C) PAS-2 (NE 7415) specimen in which a large looping trail is braided with a a trail of lower amplitude. D) Photo (left) and trace (right) of *Undichna* from PAS-2 (NE 7415) specimen showing 3 intertwined, overlapping trails.

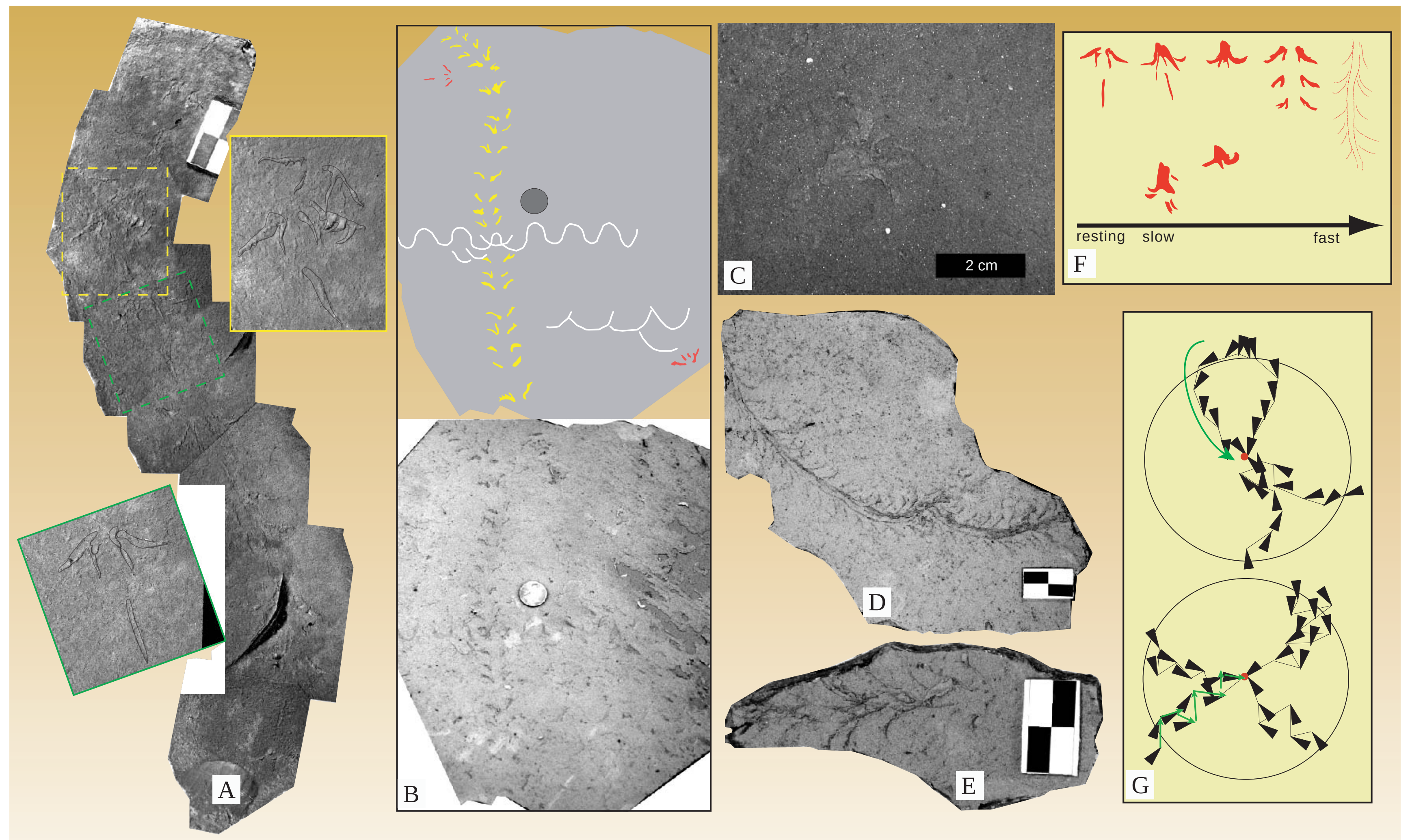

Figure 8. Type 2 trace fossils from glaciolacustrine sediments that represent behaviors of freshwater sculpin. A) Plastic cast of a series of body impressions from PAS-2 (NE 7360). Upper enlargement shows a turning movement of fish with associated striations made by pectoral fin rays. Lower enlargement shows a well-preserved whole ventral impression. B) Photo (below) and tracing (above) of bedding plane (at NEW (NE 7307-7443) with Type 1 and Type 2 trace fossils. Note resting traces (isolated full body impression in red). C) Cephalic imprints are common at PAS-2 (NE 7360). Note the wide, triangular shape of the head and lateral pectoral and pelvic fin impressions. These may represent the act of feeding in the substrate. D) Smooth arc-like trails at WR-1 (NE 7359-7362) made during rapid movement of fish. E) Zig-zag trails (same horizon as in D) which show alternating directions of head movement. F) Altogether different Type 2 traces can be viewed as a continuum from resting to rapid movement all made by the same type of fish. G) Two common approach strategies used by sculpins when locating prey (red dot).

Type 2 - Small Repeated Impressions

At all sites, a small singular or repeated impression with a consistent morphology was discovered.

- Type 2 is a bilaterally symmetrical trace composed of two pairs of linear or curvilinear imprints diverging to the posterior and occasionally, a longer median imprint at the posterior (Fig. 8A).
- Outer pair of imprints may show up to 3 parallel striations extending toward the posterior (Fig. 8A, B).
- Always preserved on bedding planes as negative epireliefs or positive hyporeliefs.

The basic morphology of the trace indicates a bilaterally symmetrical trace-maker with at least two pairs of laterally-arranged appendages.

- The Type 2 traces conform well to the proportions of the freshwater sculpin body plan (Fig. 9) and those parts of the sculpin that would be in contact with the substrate.
- Freshwater sculpins are demersal fish (lacking a swim bladder), often found at rest on the substrate, and move only when provoked or when ambushing prey.
- Forward motion is primarily achieved by a rapid "hopping" movement that utilizes the large flexible pectoral fins.
- A continuum of resting to rapid locomotion behaviors are represented by Type 2 trace fossils (Fig. 8F).
- Smooth arcs (Fig. 8D) and zig-zag imprints (Fig. 8E) resemble sculpin feeding strategies that have been noted in experiments dealing with the positioning of the lateral line system in relation to prey location (Fig. 8G, green arrows show path of one sculpin).

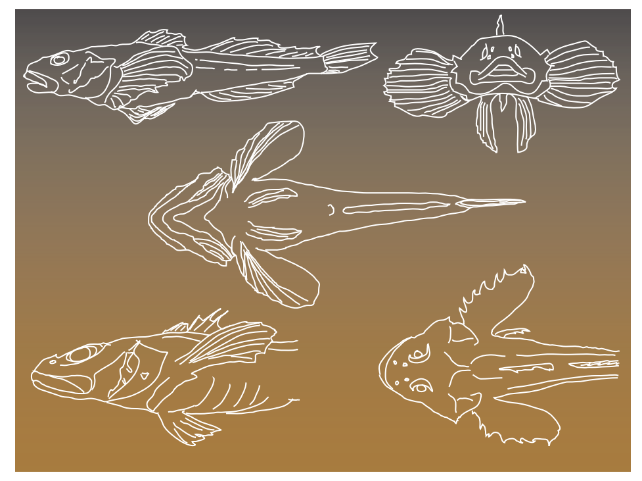

Figure 9. The probable trace-maker of Type 2 piscine trace fossils in this study: a freshwater sculpin. Figure shows a generalized morphology drawn from images of preserved specimens. Total length of full specimen in center (ventral view) is about 7 cm.

Implications

Paleoecologic Implications

Our ecological picture of Lake Hitchcock was previously one of very low diversity, and invertebrate-dominated due to a lack of vertebrate fossil evidence. The addition of these new piscine traces to the growing body of invertebrate traces provides a more complete picture of lake bottom ecology in the late Wisconsinan of New England. Freshwater sculpins inhabit the lake floor for their entire adult life, feeding on insect larvae, crustaceans, oligochaetes, other small fish, and fish eggs. Including this dynamic benthic predator in the overall picture of lake ecology expands the possibilities for companion species. An active and abundant fly larvae and/or worm population, represented by abundant *Cochlichnus* burrows, may have supported the sculpin populations.

The larger fish represented by the *Undichna* trails may have been preying upon the sculpin populations, but were not necessarily primary benthic fish themselves. If benthopelagic and pelagic fish predators inhabited Lake Hitchcock as well, it follows that a richer prey fish population than indicated by the trace fossil evidence may have existed.

It is also interesting to note that deep water species of sculpins are highly preferential with respect to water temperature. For breeding in particular, sculpins that live in deep lakes are known to prefer water between 5-10^{o}C (Scott and Crossman, 1973). Further investigation may lead to the ability to count rays of the pelvic fin of some well-preserved trace fossils, which would allow for species-level identification and refinement of paleoecologic interpretations.

Stratigraphic Implications: Possible Sculpin Horizons?

Both types of trace fossils were found at the three sites in Vermont. *Undichna* was found throughout each of the three sections, but the repeated impressions and moving traces of the freshwater sculpin were found only at certain horizons within each section. A "sculpin horizon" was accurately predicted between sections PAS-2 and WR-1 (varve year 7360). Sculpin trace fossils are abundant within these horizons and have not been found elsewhere. As a stratigraphic marker this could be a useful tool, but a more exhaustive search needs to be performed at each section in order to confirm the presence/absence of sculpin traces. It may be that "sculpin horizons" represent temperatures and depths that were preferable to the fish, and may help reconstruct, with better resolution, the history of the lake.

Paleobiogeographic Implications

Freshwater fish that now inhabit the drainages of New England must have utilized the extensive areas exposed during times of lower sea level. Some component species of New England fish populations resemble the populations of the Atlantic Coastal Plain. Other components resemble populations to the north--relict Arctic Charr (*Salvelinus alpinus*), Lake Trout (*Salvelinus namaycush*), Slimy Sculpin (*Cottus cognatus*), Deepwater Sculpin (*Myoxocephalus thompsoni*) and Burbot (*Lota lota*) in northeastern U.S. lakes being good examples. Fishes with northern affinities probably thrived in refugia from the Grand Banks in the north to Georges Bank in the south. Georges Bank could have acted as a regional center for fish distribution into Lake Connecticut (Fig. 2) and subsequently into Lake Hitchcock and other lakes of the Connecticut Valley (Fig. 1). It is clear from the new trace fossil evidence combined with high-resolution stratigraphy that these northern forms were among the first to venture into the newly deglaciated landscapes of New England.

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