

Introduction to Reassessing the role of meltwater processes during Quaternary glaciations

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The seven papers presented in this special issue of *Quaternary Science Reviews* were presented as posters in session 42 at the XVI INQUA Congress held in Reno, NV August 2003. Glacial meltwater is the unifying theme for these papers. Meltwater is a crucial component of both modern and ancient glacial systems and is known to affect processes of glacier motion, glacial sediment entrainment, sub-, en- and proglacial sediment transport and deposition. The study of meltwater processes, landforms and sedimentary successions provides better palaeoglaciological reconstructions including insight into palaeoflow magnitude and frequency. Growing recognition of the importance of large meltwater fluxes to the oceans as triggers of climate change continues to make meltwater a key topic for Quaternary research.

The important role of meltwater encompass a wide range of topics, including the measurement of meltwater temperatures at artesian vents at the margins of Icelandic glaciers (Tweed et al., 2005); consideration of meltwater as an erosional agent within landscape development (Munro-Stasiuk et al., 2005); and meltwater as a possible driver of climate change (Rayburn et al., 2005). Two papers based on fieldwork in Iceland are presented first, followed by 5 papers that reconstruct palaeoglacial environments from the USA. The later are presented in geographic order, from west to east.

Temperature measurements of meltwater from Icelandic glaciers by Tweed et al. (2005) provide instrumental data for supercooled water conditions. Data was collected from meltwater draining the terminal overdeepenings of Skeiðarárjökull, Skaftafellsjökull and Svínafellsjökull, all of which are retreating. Thermistors were lowered into turbid artesian vents for periods of <1–4 h. Meltwater temperatures were often below atmospheric freezing point indicating the operation of the glaciohydraulic supercooling process. Frazil ice and anchor ice terraces were commonly observed around vents. Sediment trapped in the latticework of frazil ice was also observed, highlighting the importance of supercooling for debris entrainment in modern glaciers, as well as for reconstructing glacial environments from past ice ages.

Alho et al. (2005) examine the large-scale characteristics and impacts of Iceland's largest jökulhlaup system that drains the northern margin of Vatnajökull ice cap. The largest Holocene jökulhlaup along the upper reaches of the Jökulsá á Fjöllum River is reconstructed by Alho et al. (2005) to have had a peak discharge of ~0.9 Sv. Using satellite imagery, digital elevation data and hydraulic modelling within a GIS, palaeohydraulic variables are reconstructed including Froude numbers of up to 1.4, velocities of 1–19 ms⁻¹, and stream powers of 46,000 Wm⁻². Jökulsá á Fjöllum jökulhlaups occupied a very irregular channel topography characterized both by relatively wide and shallow channels and bedrock gorges. Geomorphological evidence of the flood consists of scoured lava surfaces, streamlined erosional hills, large boulder fields, and expansion bars

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downstream of gorges. Erosional processes such as hydraulic plucking, abrasion and cavitation operated effectively in constricted reaches where flow velocities and depths generated intense erosion producing potholes and cataracts within a scabland topography. By using a GIS methodology, site-specific analysis of landforms and sediments and their associated hydraulic variables offers a dynamic approach to understand catastrophic processes associated with jökulhlaups.

The next three papers examine the important role meltwater played in the evolution of the glacial landscape in southeastern and south-central Michigan, USA. Beginning in the west, [Kehew et al. \(2005\)](#) use geomorphology and stratigraphy to explain a complex glacial landscape. They describe the advance and retreat of the Lake Michigan Lobe of the Laurentide Ice Sheet to its furthest east position, and then recessional positions as the lobe recessed back into the Michigan basin. A sediment-landform assemblage approach is used to describe the evidence for proglacial glaciectonic activity, marginal stagnation and subglacial meltwater events. The Valparaiso Moraine, long considered a recessional moraine is now described as an upland, complete with a small field of drumlins underlain by a veneer of till resting on up to 30 m of lacustrine sediment. Numerous continuous rotosonic cores down to bedrock on the uplands and recessional moraines provide a new insight on the composition of these large landforms. Fast flow, perhaps associated with a surge is reconstructed for the Lake Michigan Lobe as it advanced uphill to its maximum position. Trapped proglacial water bodies are indicated by lacustrine sediment. Deformed lacustrine deposits with sand, overlain by till indicate ice decoupling from the bed, and high subglacial pore water pressures. [Kehew et al. \(2005\)](#) suggested that parts of the Lake Michigan lobe acted like an ice stream.

The next paper by [Kozłowski et al. \(2005\)](#) focuses on the evolution of the large Central Kalamazoo River Valley (CKRV). The CKRV is anomalously large compared to upstream and downstream sections, and passes through a large end moraine. Continuous rotosonic cores, γ -ray logs and other geophysical methodologies indicate that repeating units of boulder gravels are the lowermost sediments at the base of the valley fill within the channel. A series of tunnel channels associated with the Saginaw Lobe to the northeast of the CKRV, many with eskers and reversed slopes that cross modern drainage divides, end where the CKRV begins. It is hypothesized that the flow that formed these tunnel channels, also formed the CKRV. The meltwater path from the CKRV is traced westward to Lake Michigan. Along its pathway evidence for flow deceleration with concomitant fan construction, and channel incision into inter-morainal lowlands is described. The reconstructed flow has implications for regional deglaciation of the ice

lobes in southern Michigan. The Lake Michigan Lobe must have receded to allow the meltwater to enter glacial Lake Chicago in the Michigan Basin. In addition, the outburst flooding is thought to have occurred when the adjacent Saginaw Lobe to the east was at its Kalamazoo position.

The tunnel channels at the head of the CKRV make up some of the western-most ones associated with the Saginaw Lobe. The tunnel channels have a radial pattern across south-central Michigan and are discussed in the paper by [Fisher et al. \(2005a\)](#). In this paper at least two generations of tunnel channels are observed, with an older set oriented north–south and a younger set oriented northeast–southwest. A small swarm of drumlins in the area crosscut the older tunnel channels and are parallel with the younger tunnel channels. The younger tunnel channel set appears to end at the Sturgis Moraine, which has large outwash fans on its distal side. This area had been previously recognized as a large head of outwash, which extends southwest across northern Indiana and into northeastern Illinois. Tunnel channels and drumlins were mapped across upland ridges that had been originally mapped as end moraines. [Fisher et al. \(2005a\)](#) argue that because drumlins and tunnel channels with out fans are found proximal to, across, and distal to the upland ridges, that the upland ridges cannot be recessional moraines. Some outwash fans and kames partially bury some of the tunnel channels and drumlins, but are superimposed on the upland ridges, and record ice recession. The importance of recognizing and mapping tunnel channels appears to be very important for understanding glacial landscape evolution in southern Michigan.

Perhaps one of the best examples of glacial grooves in the world can be found on Kellys Island in Lake Erie, USA. Originally, the origin of such grooves was associated with glacial abrasion by debris-rich ice. In the paper by [Munro-Stasiuk et al. \(2005\)](#) this formative mechanism is challenged. On the island, only 1 large groove remains as a result of limestone quarrying over the past century. The large groove 10 m wide, 110 m long, and 3 m deep is covered with s-forms including: linear erosion forms, cavettos, sichelwannen, comma forms, plunging forms, potholes, muschelbrusche, and spindle flutes. The authors argue that erosional forms within the groove are the product of pressurized subglacial water, but whether the flow was confined to anastomosing N-channels or as a broader sheetflow is unknown. Parallel grooves mapped from other islands around Kelleys Island, and from the lake bottom using side-scan sonar images suggest a broader flow than in localized N-channels.

The last paper by [Rayburn et al. \(2005\)](#) focuses on a timely issue involving routing of glacial meltwater to the oceans from retreating ice sheets and proglacial lakes, and its possible impact on past climate change. The

authors suggest that drainage from the Great Lakes basins down the Hudson River Valley released initially 0.1–0.2 Sv before a steady-state discharge of ~ 0.056 Sv. Importantly, based on new ^{14}C dates, these flows preceded opening of the Champlain Sea by about 150–300 years and coincided with the beginning of the Younger Dryas cold period. With the opening of eastern outlets from Lake Agassiz at the beginning of the Younger Dryas currently being questioned (Fisher et al., 2005b), alternative mechanisms, or meltwater sources to disrupt the thermohaline circulation in the North Atlantic are important.

This collection of papers has dealt with meltwater flow acting over a range of spatial and temporal scales to influence both modern ice-marginal and proglacial environments as well as a range of palaeo-environments. Although recent advances in our understanding of modern meltwater processes have provided useful models for interpreting the sedimentary record, further work is needed to identify, should they exist, appropriate modern analogues for large-scale meltwater fluxes beneath former ice sheets.

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