Geotechnical and sedimentary evidence of late glacial ice dynamics in southern Lake Vättern

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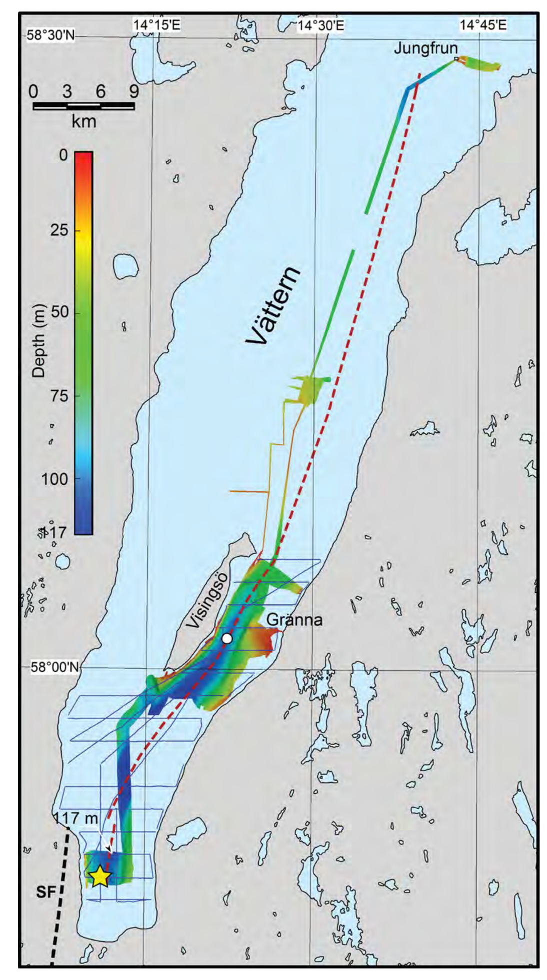
Abstract

In the Autumn of 2012, five closely spaced boreholes were drilled in southern Lake Vättern, recovering a 75 meter late Pleistocene to Holocene sedimentary record. At ~55 meters below the lake floor shear strength and high-resolution bulk density measurements indicate the presence of an unconformity in the glacial clay and silt sediments. Incremental load consolidation tests reveal a pre-consolidation pressure for the underlying sediments of between 1100-1400 kPa. This is ~800 kPa more than the current in-situ effective stress, and indicates either substantial erosion (the removal of 100-150 meters of sediment), or consolidation under a large grounded ice mass (sitting 90-110 m above paleo-sea level). Glaciotectonic deformation in underlying sediments supports the interpretation of a grounded ice mass. Decimeter scale interbedded clays and silts in surrounding sediments also suggest an ice proximal location. In the ~30 m of overlying glacial clays, there is no further evidence for grounded ice. However, changes in the thickness of the interbedded sediments, and the frequency of dropstones, may suggest a re-advance, possibly associated with the Younger Dryas. Further chronological constraints from the sedimentary record will place these observations more firmly in the context of regional glacial dynamics.



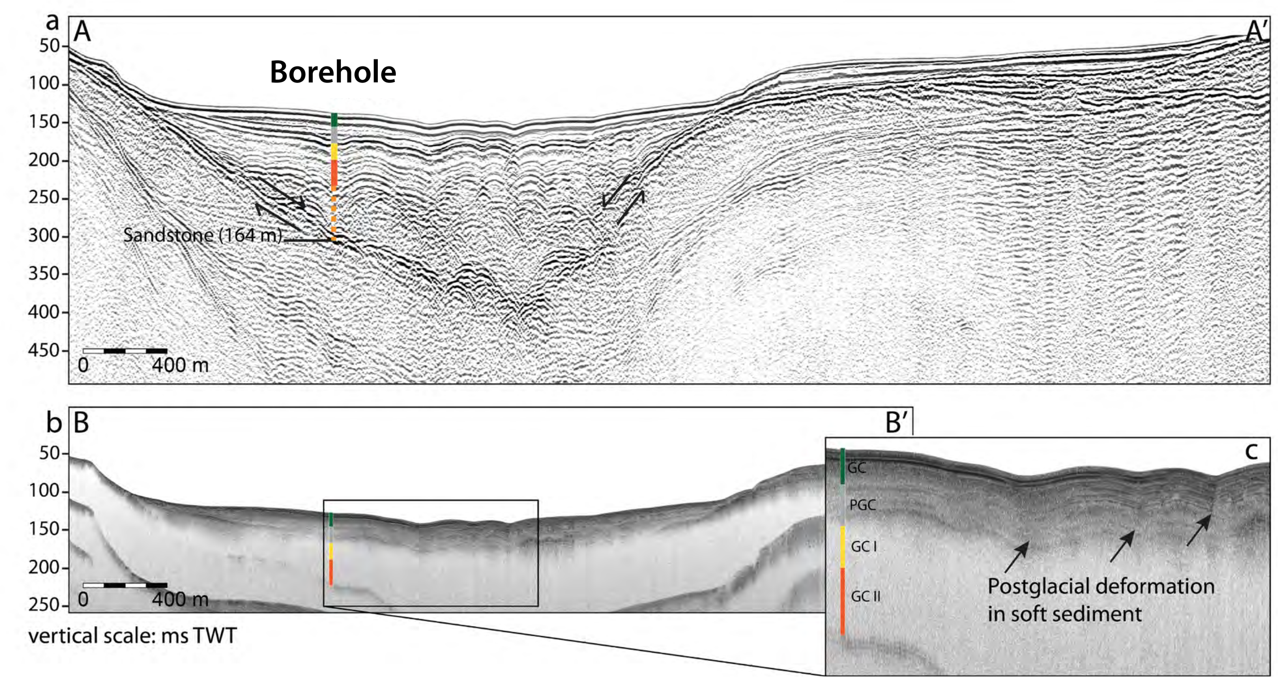
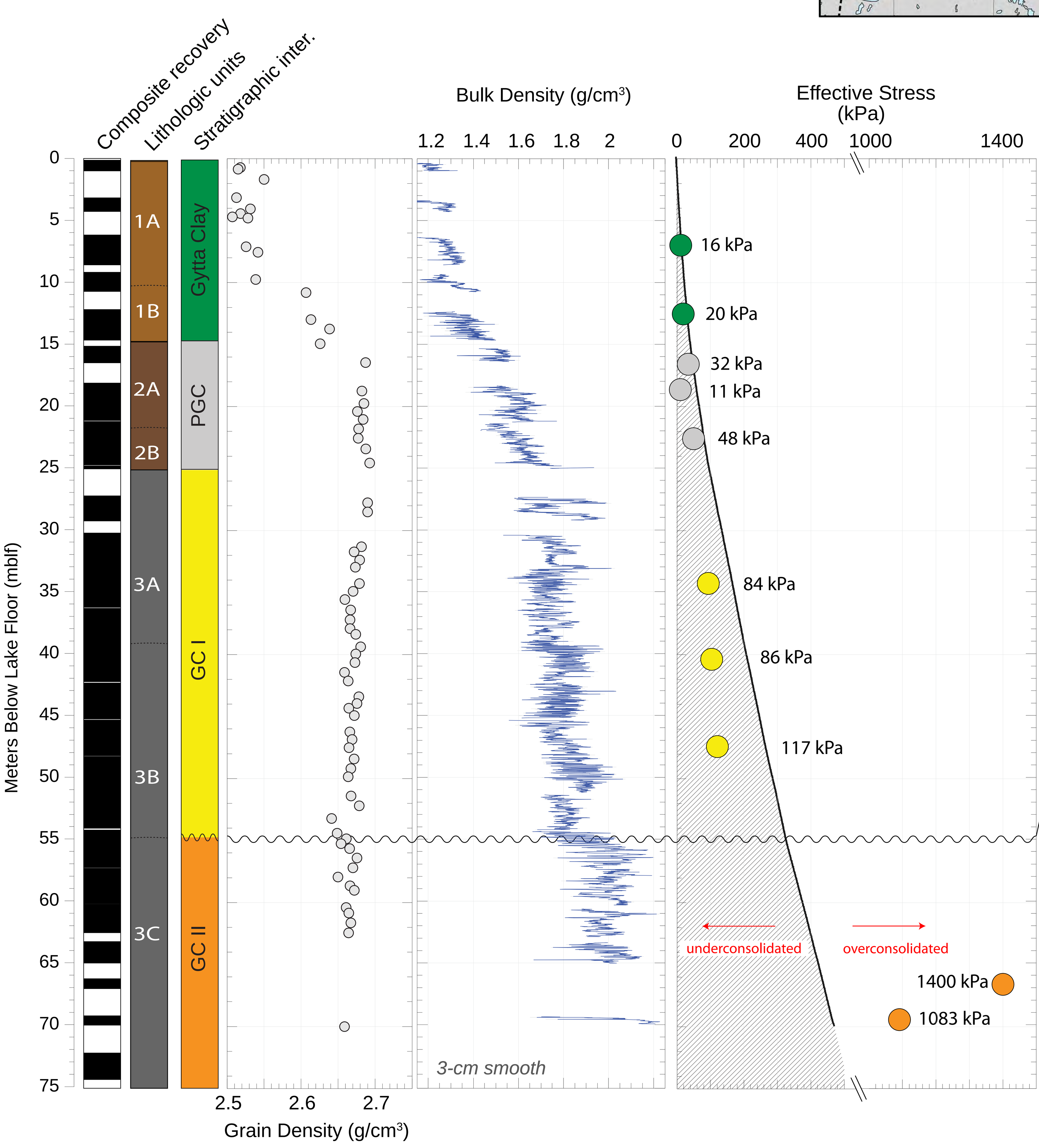


Figure 2: Seismic reflection profile (top) and subbottom profile (bottom) across the graben in the southern part of the Lake. Location of the drilling site is marked in the profiles and includes a preliminary interpretation of the stratigraphic units. (GC II=Glacial Clay Unit II; GC=Glacial Clay Unit I; PGC=Post-Glacial Clay; GC=Gyttja Clay).

Figure 1. Location of the drilling site in Southern Lake Vättern (star) overlain on recently collected bathymetry and tracklines where seismic data was collected.



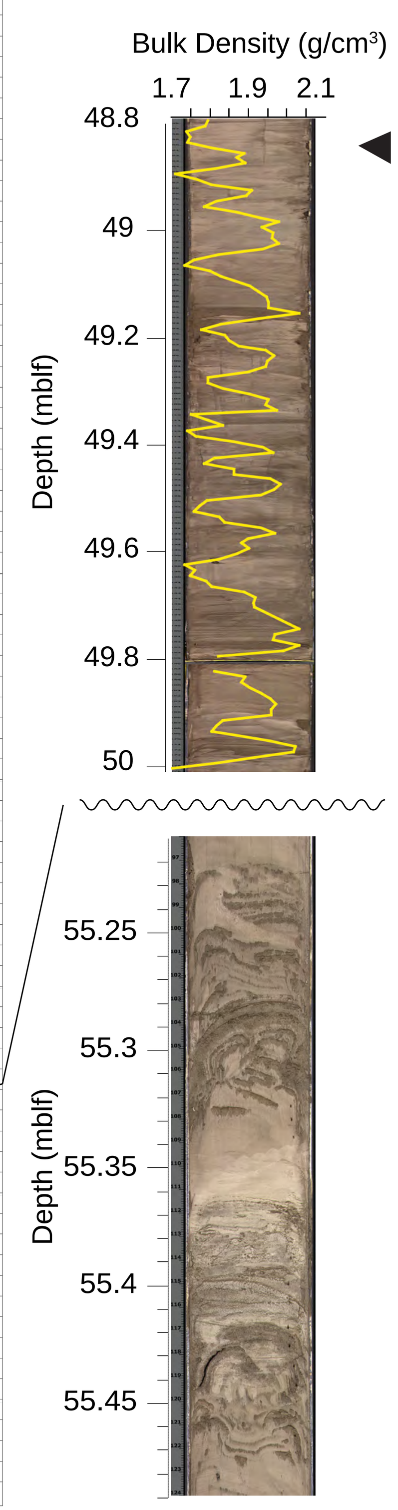


Figure 4. Bottom: Digital image of sediments below 55 mblf where clear signs of glaciotectonic deformation exist. **Top:** Above 55 mblf, there is no sign of glaciotectonism in the sediments from GC I. Instead they exhibit well preserved centimeter to decimeter scale intervals of dark-brown slightly coarser layers. These are captured by the MSCL bulk density measurements.

Figure 5. MSCL bulk density and XRF-scanning Ca/Ti ratios over a10 m interval from the base of GC I. The same cyclic sedimentary units (*varves?*) shown in ***Figure 4*** are preserved throughout much of GC I. Intervals of darker, slightly more coarse sediment have higher bulk density (blue), and also exhibit higher Ca/Ti ratios (red). In addition to radiocarbon dating and pollen stratigraphy, these cycles may provide a way to advance the age model for the drilled sequence.

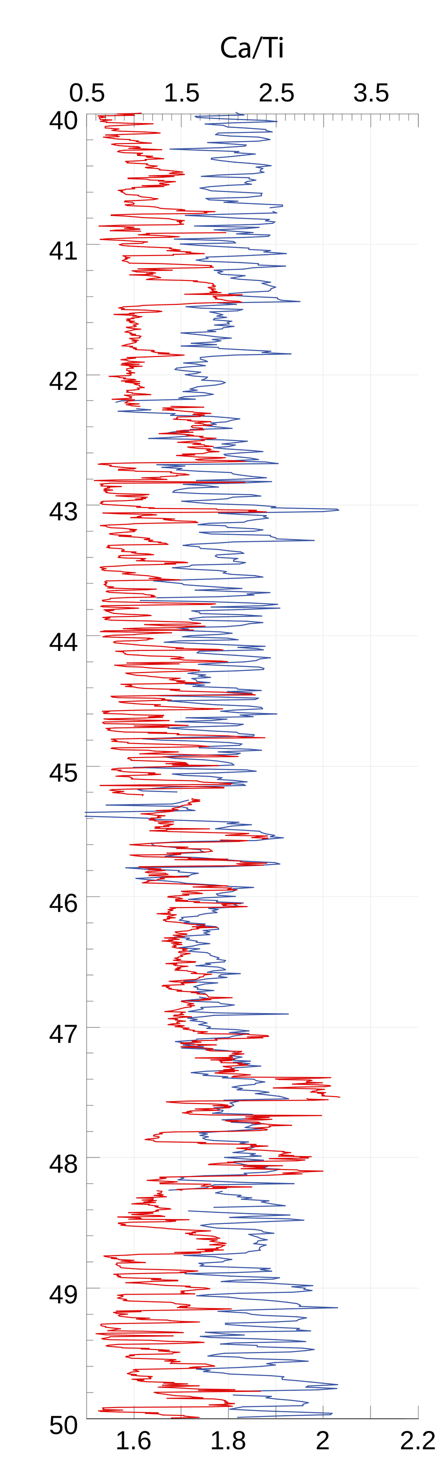


Figure 3. A: Cummulative recovery from drilling in the 5 boreholes. **B**: Lithologic units identified by visual core descriptions and physical property measurements. **C**: Preliminary interpretation of the the corresponding stratigraphic units. **D**: Discrete sample analyses of sediment grain density. **E**: High-resolution multi-sensor core logging measurements (MSCL) of bulk density. Shown is the composite profile generated by splicing material from the 5 boreholes. The increase in bulk density that occurs across the GC I & II boundary is not associated with a change in grain density. **F**: Solid line indicates the estimated in-situ effective stress (calculated from the MSCL bulk density data). Large circles denote depths where consolidation tests were performed. The preconsolidation pressure (the maximum past stress) derived from the consolidation tests is shown in relation to the current in-situ effective stress. Samples from GC I, PGC and Gyttia Clay appear normally to underconsolidated, while smpes from GC II are both heavily overconsolidated. Results from individual test are shown in ***Figure 6***. Evidence of glaciotectonic deformation in the recovered sediments suggests that the overconsolidation is a result of glacial loading (***Figure 4***).

Consolidation Test Results and Preconsolidation Pressures

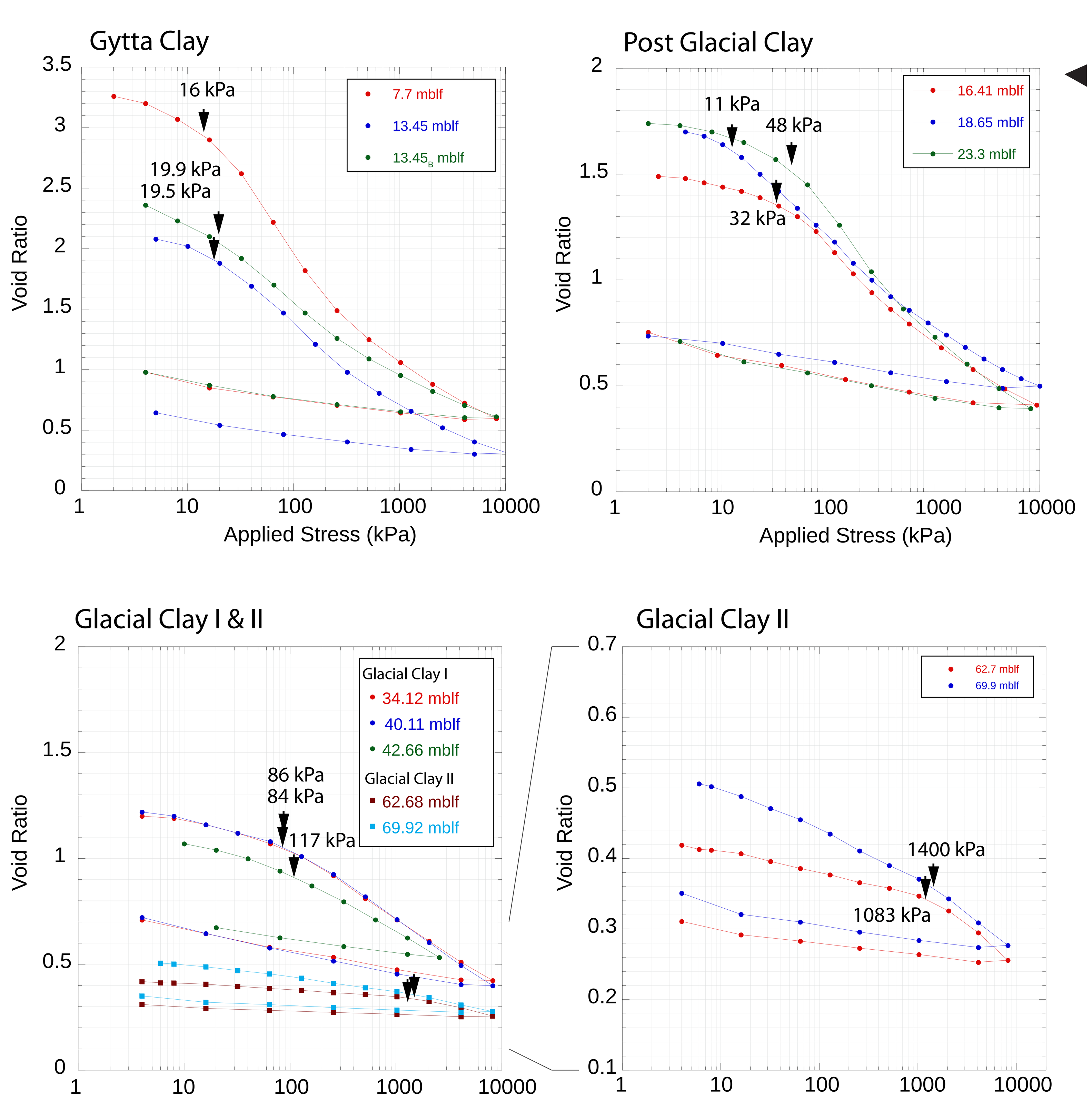


Figure 6. Consolidation results presented as void ratio vs. logarithm of effective stress (applied load). Samples were incramentally loaded up to a maximum10,200 kPa, before being unloaded. The duration of each step was determined by the time taken to reach the end of primary consolidation. This was evaluated in real time by the controlling software, however, a minimum step time of 120 minutes was set, and a maximum of 24 hours. Test results are presented separatley for the Gyttia clay, PGC and GC units. The first break, or inflection point in the consolidation curve, indicates the change from recompression to virgin compression. This occurs at the pre-consolidation pressure, or the maximum past effective stress that the sample has experienced. In normally consolidated sediments, the pre-consolidation pressure should equal the in-situ effective stress under hydrostatic pore pressure conditions. Pre-consolidation pressures were determined graphically using Casagrande's (1939) method.

Figure 7. Automated incremental load and constant rate of strain consolidation system at IGV, Stockholm University. Manufactured by Geocomp Corporation, Acton, MA, USA. The load frame has a 44 kN (10,000 lbf) capacity, allowing applied loads of up to 20 MPa on standard 5 cm diameter (2 cm thick) samples. This equates to in-situ pressures at burial depths of > 2 km below the seafloor.

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