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# Pingo remnants as recorders of Late Weichselian climate and environmental change

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Pingos are known from present day permafrost regions in Alaska, Canada and Siberia and occur under conditions with sufficient groundwater, leading to the formation of ice lenses.

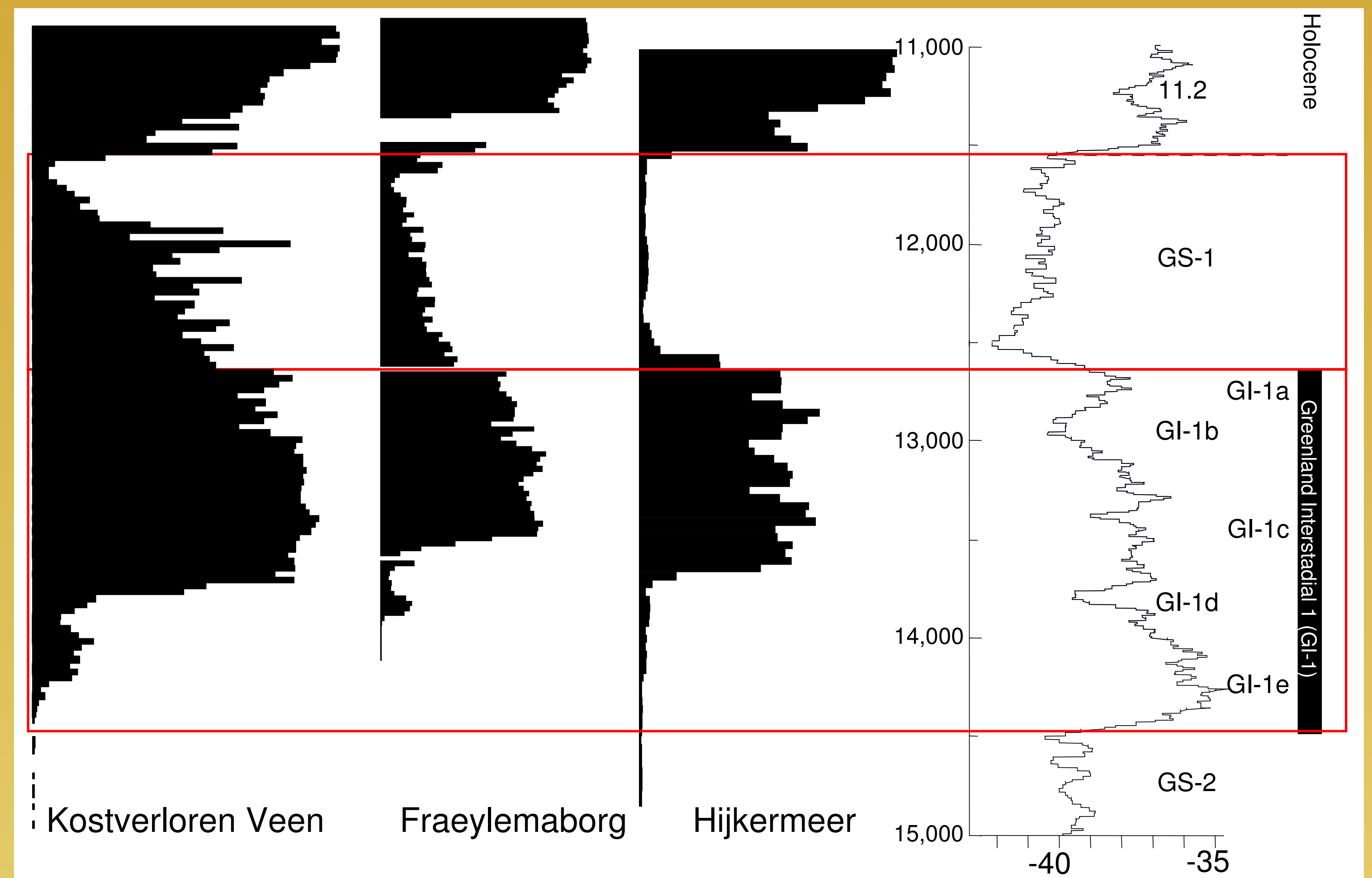
In the Netherlands, the remains of hundreds of pingos have been recognised over the last decades, especially after the development of high-resolution digital elevation models. These pingos presumably originated as a result of hydrostatic pressure, under conditions of discontinuous permafrost during the cold Weichselian Pleniglacial. As temperature rose at the onset of the Lateglacial interstadial (GI-1, round ca. 12,500 <sup>14</sup>C BP or 14,700 cal BP), permafrost most likely started to disappear from that time onward resulting in the development of pingo remnants – isolated depressions with or without a rampart.

The presence of these pingo remnants with a diameter of 50 to 300 meters and in depth varying between 5 meters in the southern Netherlands to 20 meters in the northern Netherlands indicates a minimum thickness of permafrost in the order of those values.

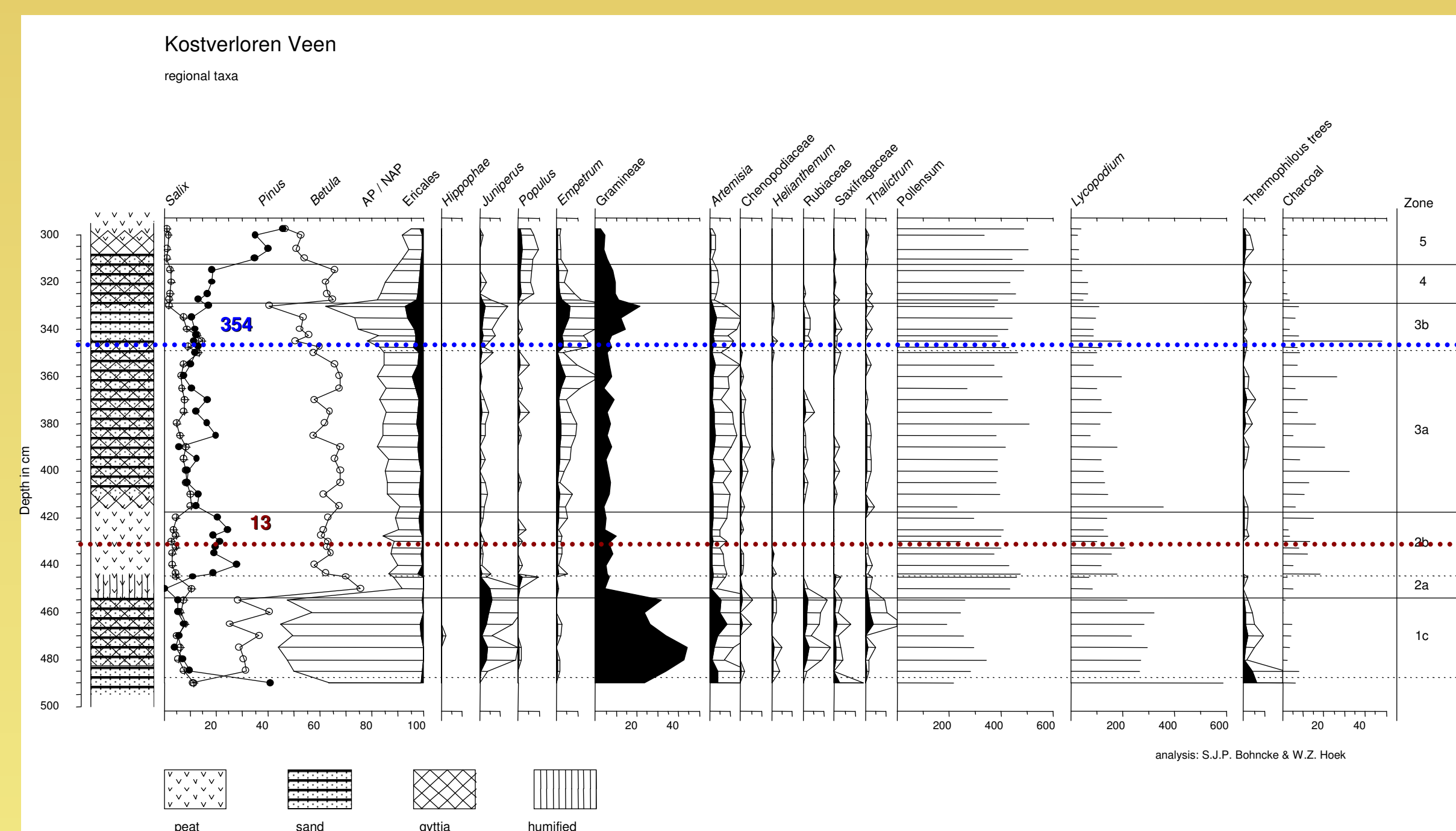
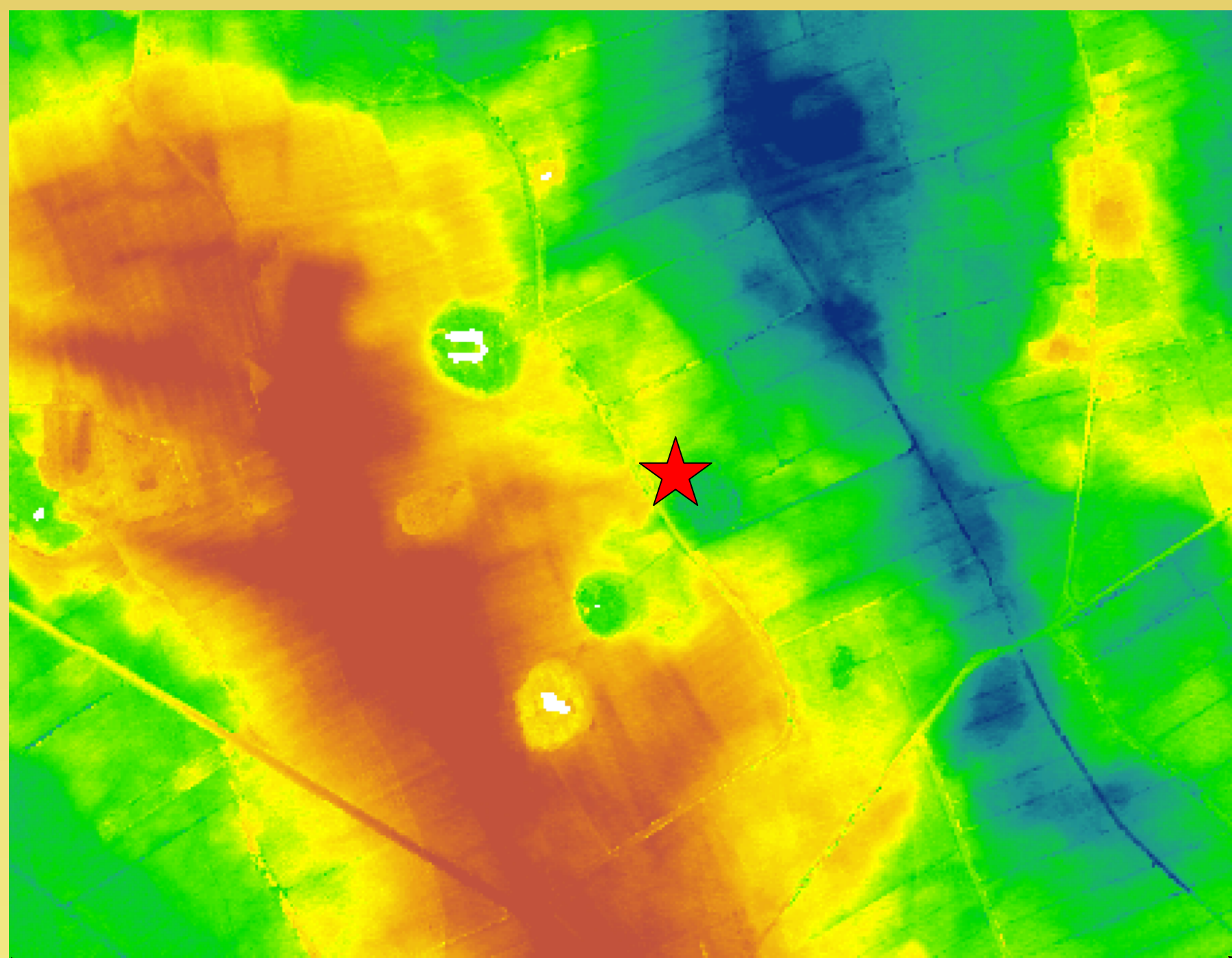
← Present day pingo near Tuktoyaktuk, Mackenzie Delta, Canada (above), and the Mekelermeer pingo remnant in the N-Netherlands (below).

→ Loss on Ignition results from 3 Pingo sites in the northern Netherlands and comparison with Greenland NGRIP ice core oxygen isotope record.

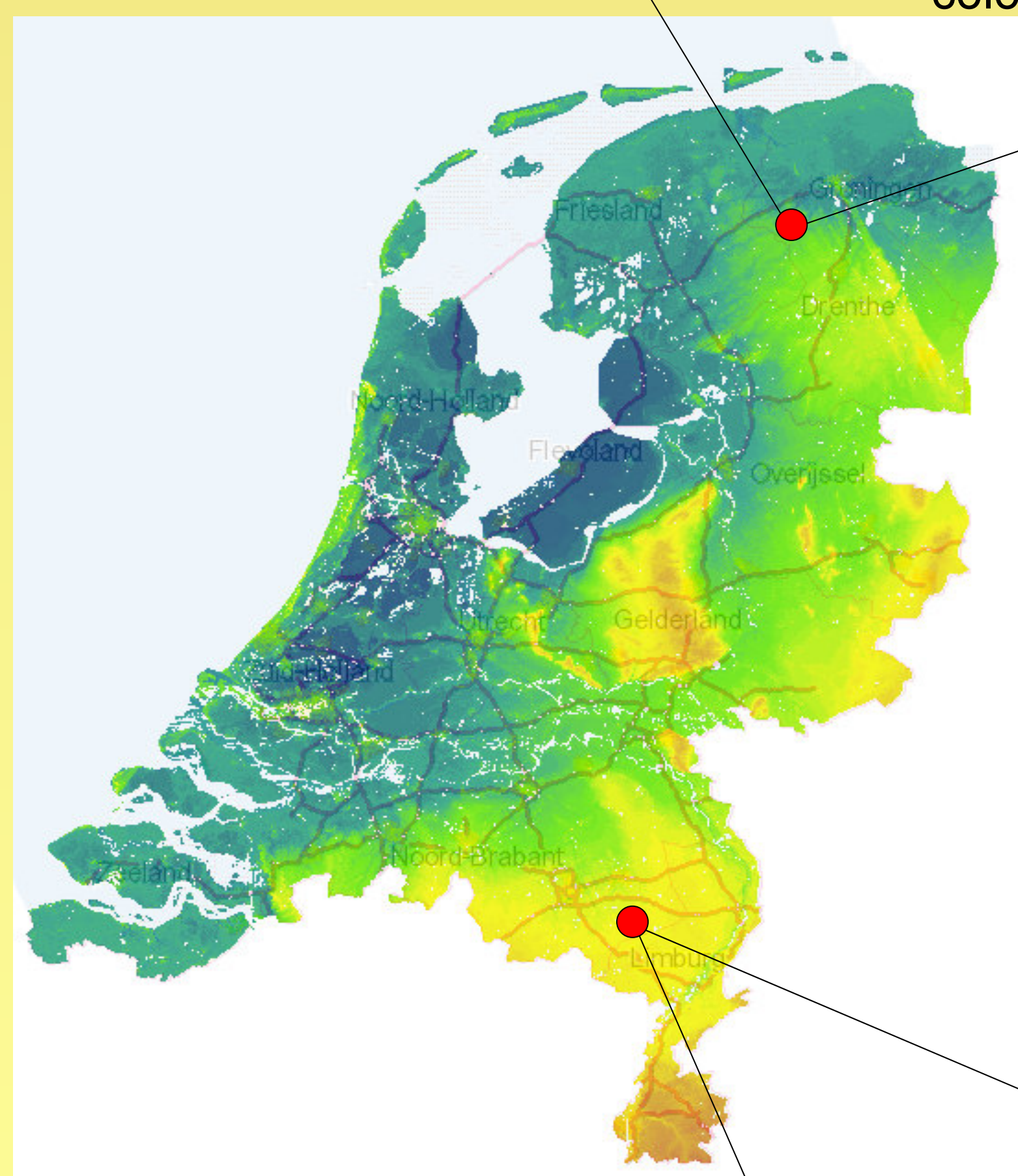
Melting of the permafrost layer that was several meters thick presumably lasted several hundreds of years. Implications for the disappearance of permafrost during the Lateglacial in The Netherlands are given by the basal organic infilling of pingo remnants, dated to begin between 12,500 and 11,900 <sup>14</sup>C BP. In the closed depressions, peat or gyttja could be formed collecting pollen, aeolian sand, tephra, and other aerosols. Chironomids and aquatics lived in these lakes and their remains are deposited in discrete layers and can be used to estimate past climate. Some of these depressions are filled with calcareous gyttja, implying that hydrostatic pressure and groundwater exfiltration continued after the decay of the ice-body. The fills of clusters of pingo remnants that are closely together can be used to estimate variation within and between the basins.



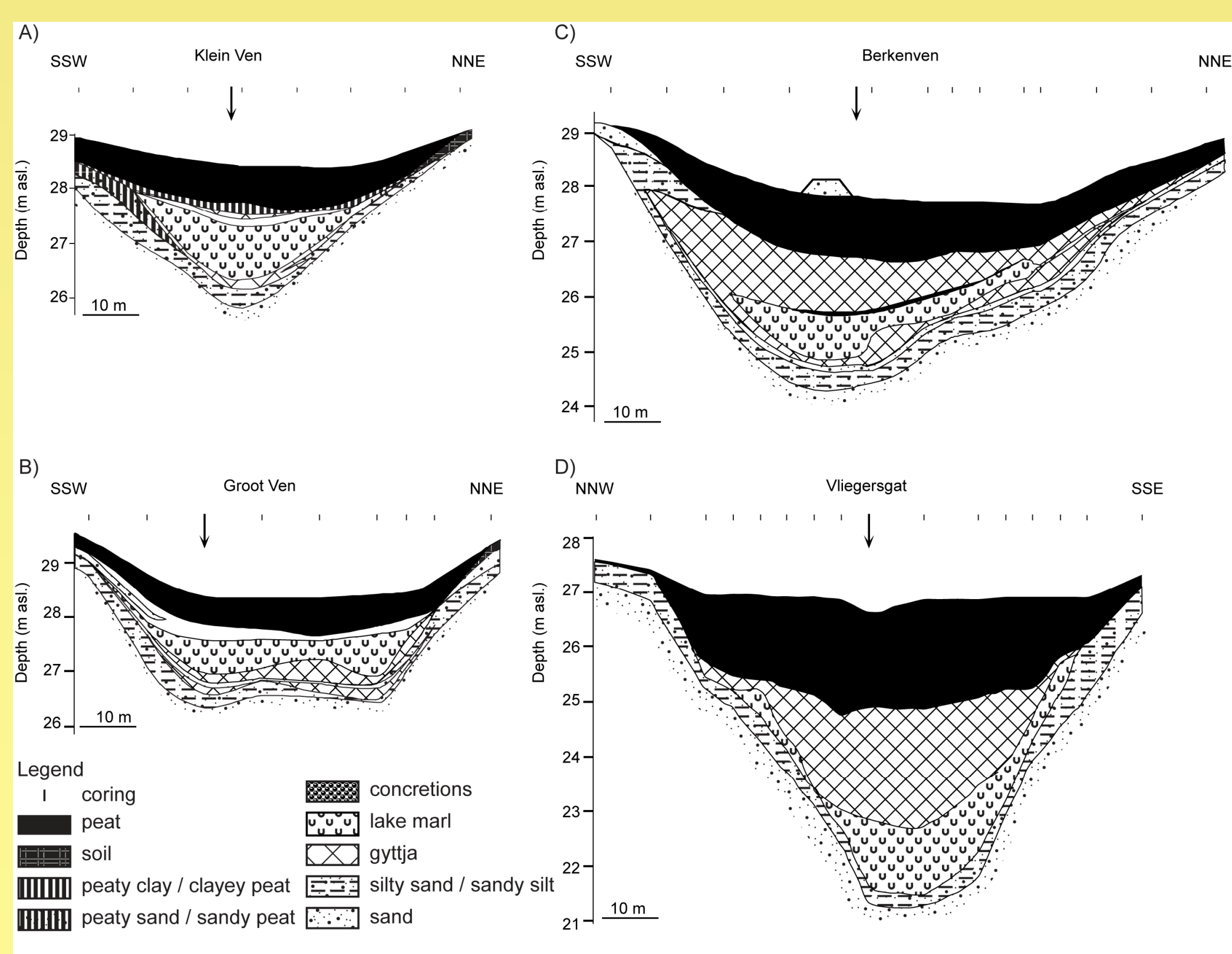
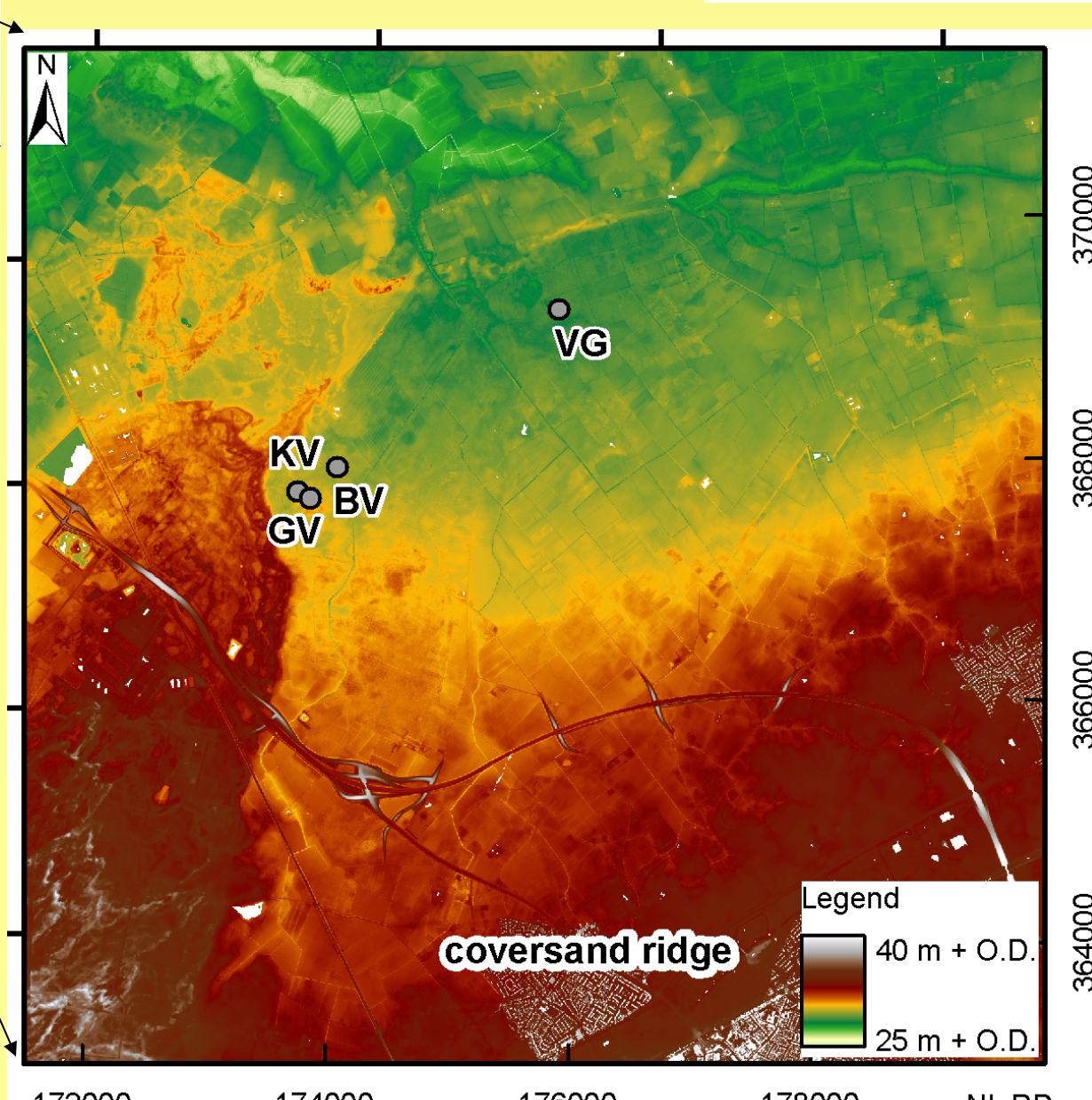
## Kostverloren Veen



↑ Pollen diagram and presence of microtephra in Kostverloren Veen. (after Davies et al., 2005)

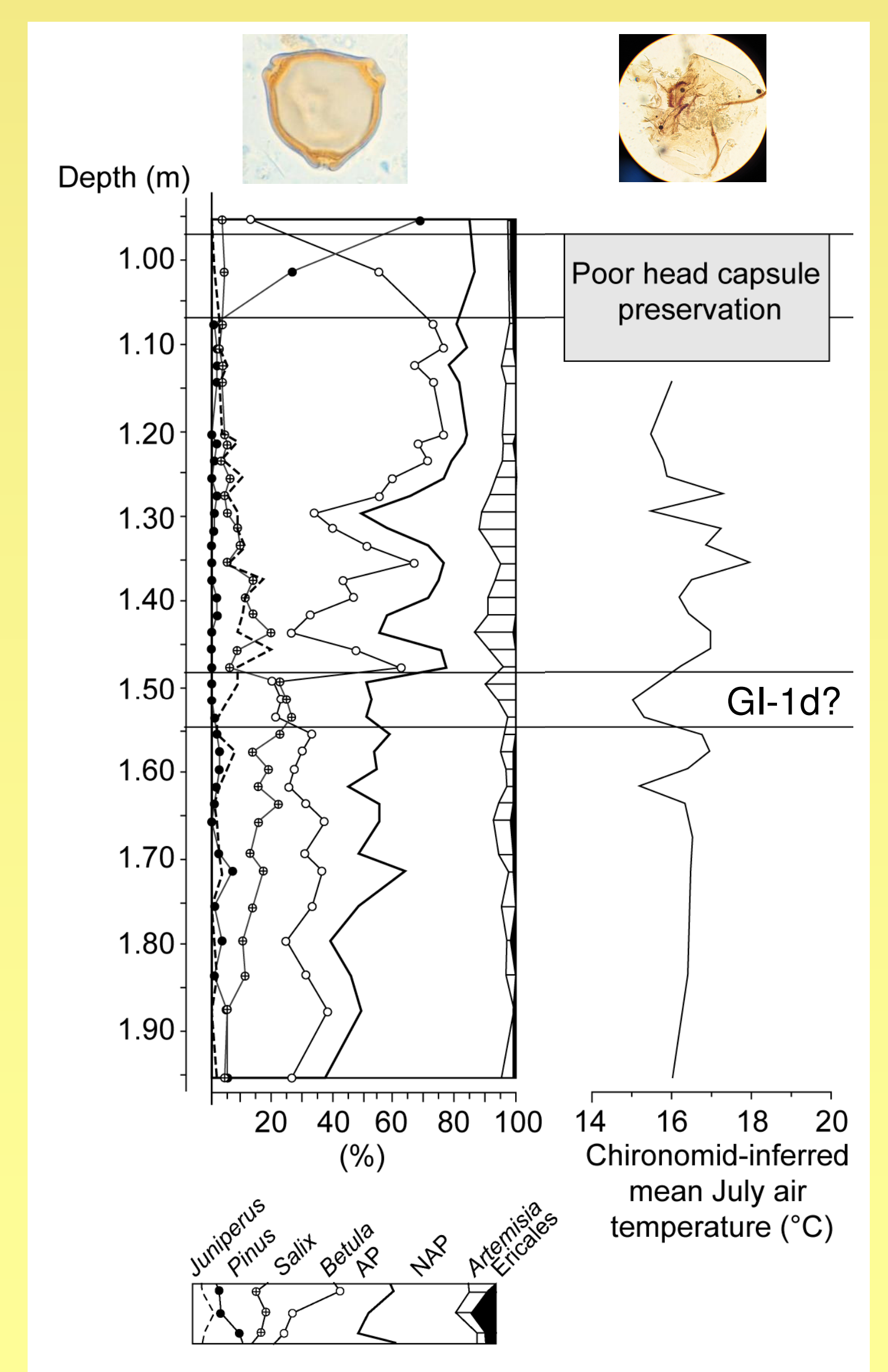


## Weerterbos



↑ Infill Weerterbos pingo remnants.

→ Lateglacial Interstadial pollen record and chironomid-inferred mean July air temperatures Klein Ven. (Van Asch et al., in preparation)



Because pingo remnants in the Netherlands act as closed systems without inflow, contamination is regarded negligible and therefore their fills form a unique record of climatic and environmental change since the last deglaciation.