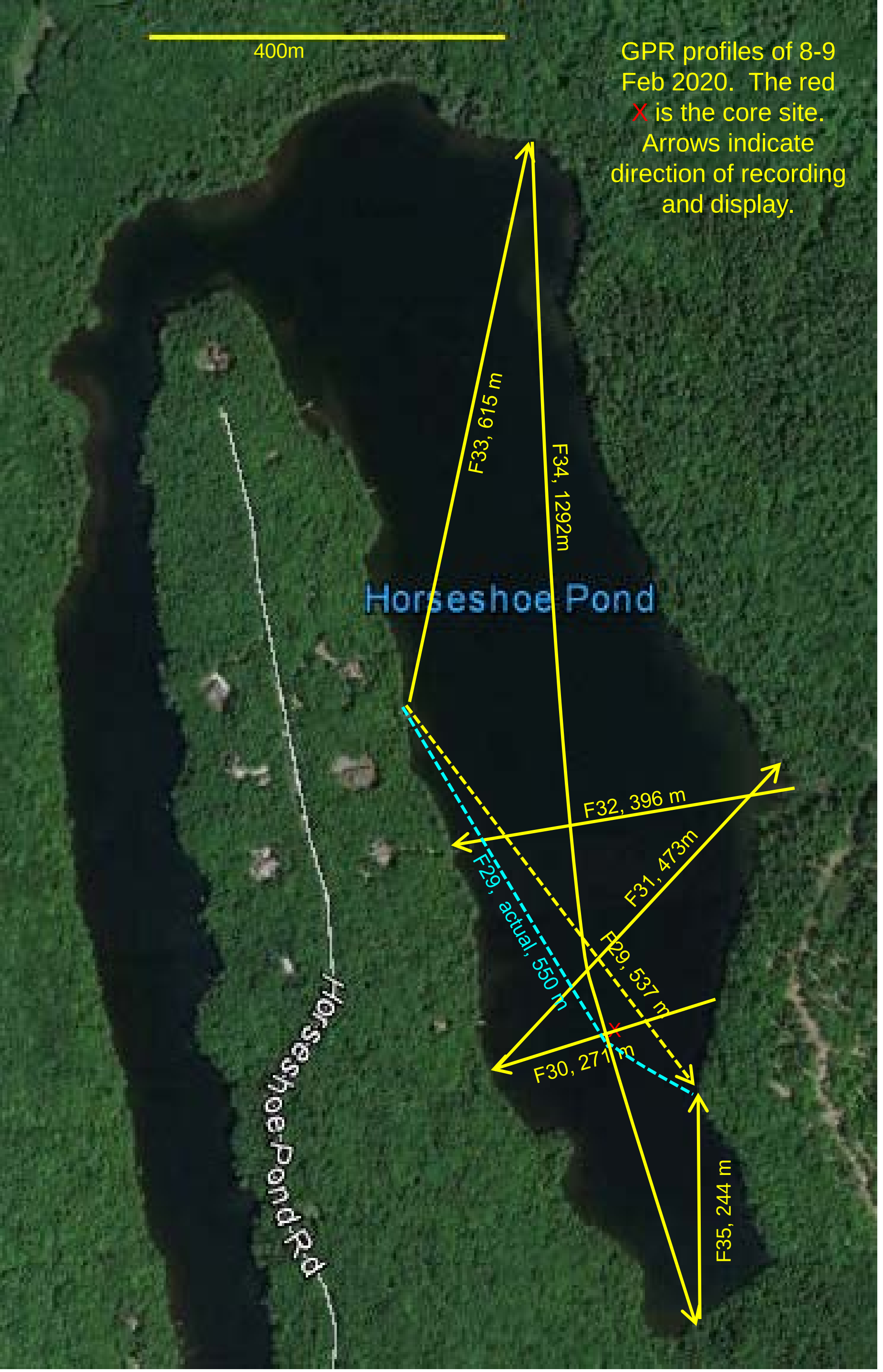

Horseshoe Pond Ground-penetrating radar (GPR) profiles of 8-9 February 2020

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I recorded GPR profiles on Horseshoe Pond on February 8, 9, 2020. I used a 42 W 100 MHz GSSI transceiver antenna (Manufacturer's suggested peak radiated power and pulse center frequency) dragged slowly by hand (about 1 m/sec) or by snowmobile (about 5 m/sec). The actual center frequency for the bottom and subbottom reflections varied between 60 and 80 MHz. I used a GSSI SIR 3000 control unit and recorded 2048 16-bit samples per trace. Five transects were reasonably straight, while two slightly curved around the core site. Dragging and towing were at constant speed; my experience with which I have found positional errors at about 3 m or less. The profiles are vertically exaggerated to emphasize subtle features. The lake water is surely of extremely low conductivity, which allowed exceptional signal penetration. I used a nonlinear intensity grey scale, except where noted, to bring out all reflections.

Reflection horizon basics: I annotated the profiles. The geological units are gyttja (organic–rich silts) with embedded cm-size sandy layers, till (unstratified mix of clay-silt-sand-to boulders), and possible debris flows or slumps. The sandy layers, are relatively dense deposits of clay to sand, and with relatively low water content. *All stratification, meaning event horizons, is caused by reflections from interfaces, primarily those between the water bottom and the top of the gyttja, between the gyttja matrix and its embedded sandy layers, and between gyttja and till.* I see little evidence of bedrock. More exactly, differences in water content, and therefore density, cause reflections because water so strongly determines wave speed. Water wave speed is about1.5 time slower than in silty saturated gyttja, and at least 2 times slower than in the dense sandy layers.

Influence of storms: To understand the stratigraphy is to understand the effects of storms. *Frequent yearly storms* resuspend clays and silts that constantly accumulate on slopes less than 6 m deep. Statistically then, most silts and clays end up in the deeper basins,. However, because of turbidites they can also mound on rises, as you will see here. More rarely, *severe storms* and sometimes earthquakes, cause turbidity currents and their deposits, the sandy turbidites layers. About 50 such severe events have happened in New England over the last 10,000 years. A turbidity current is an underwater avalanche of turbulent suspended sediment moving a few meters/second. Off the continental shelf they can be 100 m high, propagate 200 km, leave dense armoring deposits or scour the bottom. They do the same in lakes but at much smaller scales. Most importantly they carry sand to deeper parts of lakes. Most turbidites in New England lakes were launched by severe storms, but any likely slumps(slide # 5) suggests earthquakes or ice quakes.

Horseshoe Pond: Frequent yearly storms and turbidites are well represented in these profiles because: 1) there is no or little accumulation on some slopes, which is where frequent storms resuspend and retransport silts, and where turbidity currents are fastest. 2) The mounding beneath rises (slide #3) is caused by turbidite armoring of the gyttja deposited over the last turbidite. 3) Most unconformities appear at the bottom of slopes, where hydraulic jumps (turbulent changes in wave speed) occur and are known to launch (secondary) turbidity currents. These are erosional unconformities, where a turbidity current eroded existing strata. 4) There are isolated horizons, which were likely caused by turbidity current "heads," which are short lengths of turbulence that abruptly dropped their loads. In some profiles faint horizons extend from them, which are from the remaining clay–fine sand content that kept on propagating and usually constitute the stratification within basin gyttja (e.g., slide #5). 5) In the first reference I cite, I correlated my horizons with core strata at two ponds in New England, one of which I give later.

Did I find anything new and interesting?: Yes. **1)** Core site gyttja is at least 7 m thick and beneath 12 m of water. This exceptional signal penetration can be improved. **2)** The identifiable till surface beneath the gyttja would allow an assessment of how much sediment has eroded into this pond since deglaciation. **3)** The core site suggests that the original lake bottom may be quite deep; at least 62 feet just to till. All profiles suggest a deep channel possibly down the center of the lake and then bifurcating around a till pile along F31 (slide #2). The bedrock surrounding the pond is granite (lower half of HP) and interbedded sandstone and limestone (upper half), both of which were easily eroded by ice sheet movement, a process known as overdeepening. Thus the main lobe of Horseshoe Pond may be a mini-landlocked fjord, like the Finger Lakes. So may the many other elongated N-S oriented lakes in the area. I doubt I'm the first to surmise this. **4)** Slide #8 shows another excellent core site in the northern half of HP

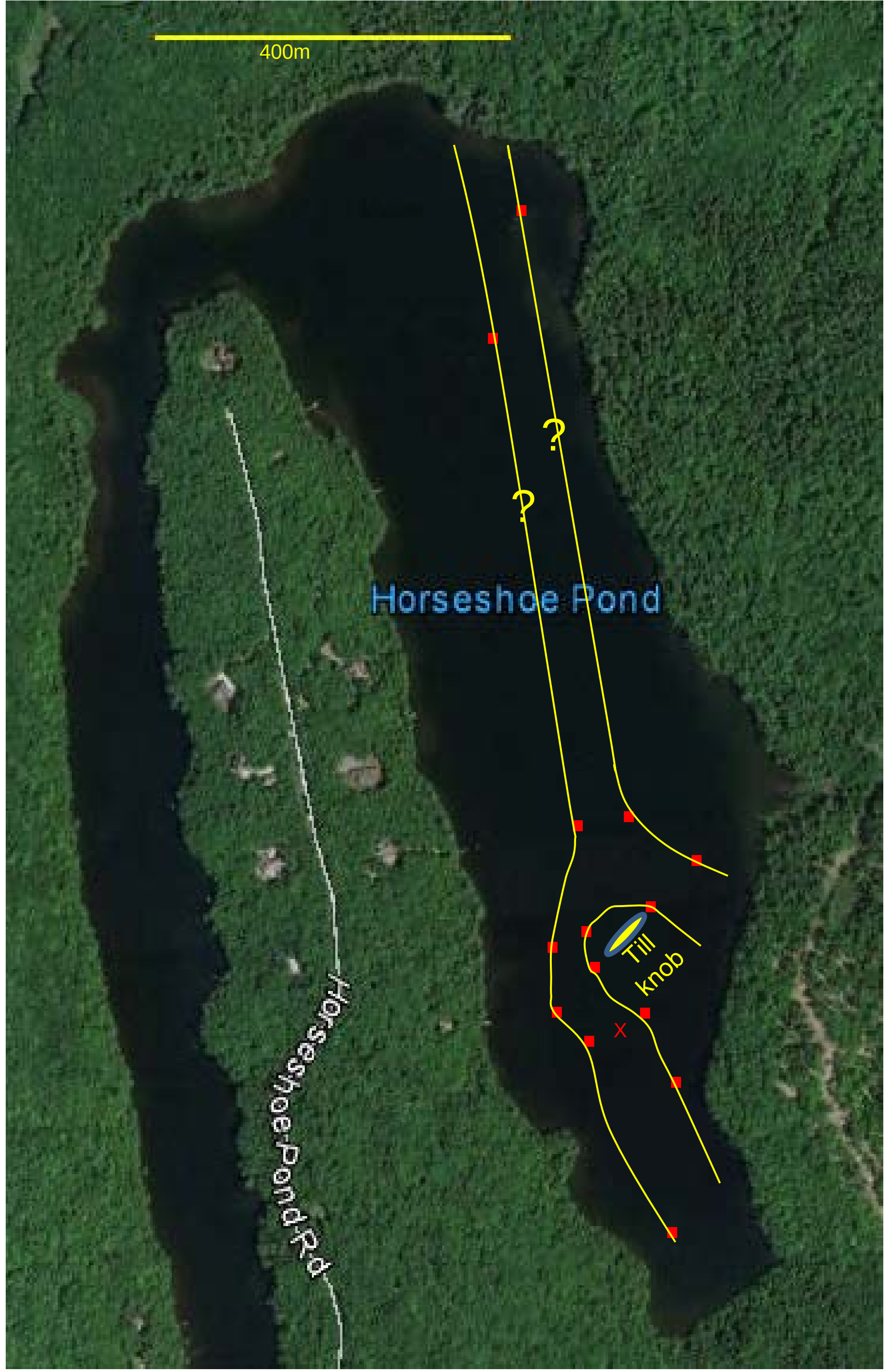
To probe deeper?: There are four approaches. 1) get a deep core and find the water content versus depth. If water content decreases in deep gyttja, which it might, then my calibrated subbottom depths are to shallow! 2) Profile again in summer with a canoe and electric motor. I think there is less energy lost to ice reflections when on open water.. See the last slide for comparison with a much deeper lake profiled using a 19 foot canoe with the antenna in the middle. 3) Use a lower frequency antenna, which is available and will require some testing. 4) Await development by the GSSI of a 100 MHz antenna with a much higher scan rate than I used. This would allow far greater stacking than I now do. Stacking cancels out random noise (a bane of surveys) and reinforces coherent signals. Note that acoustic signals will not penetrate gyttja.

References

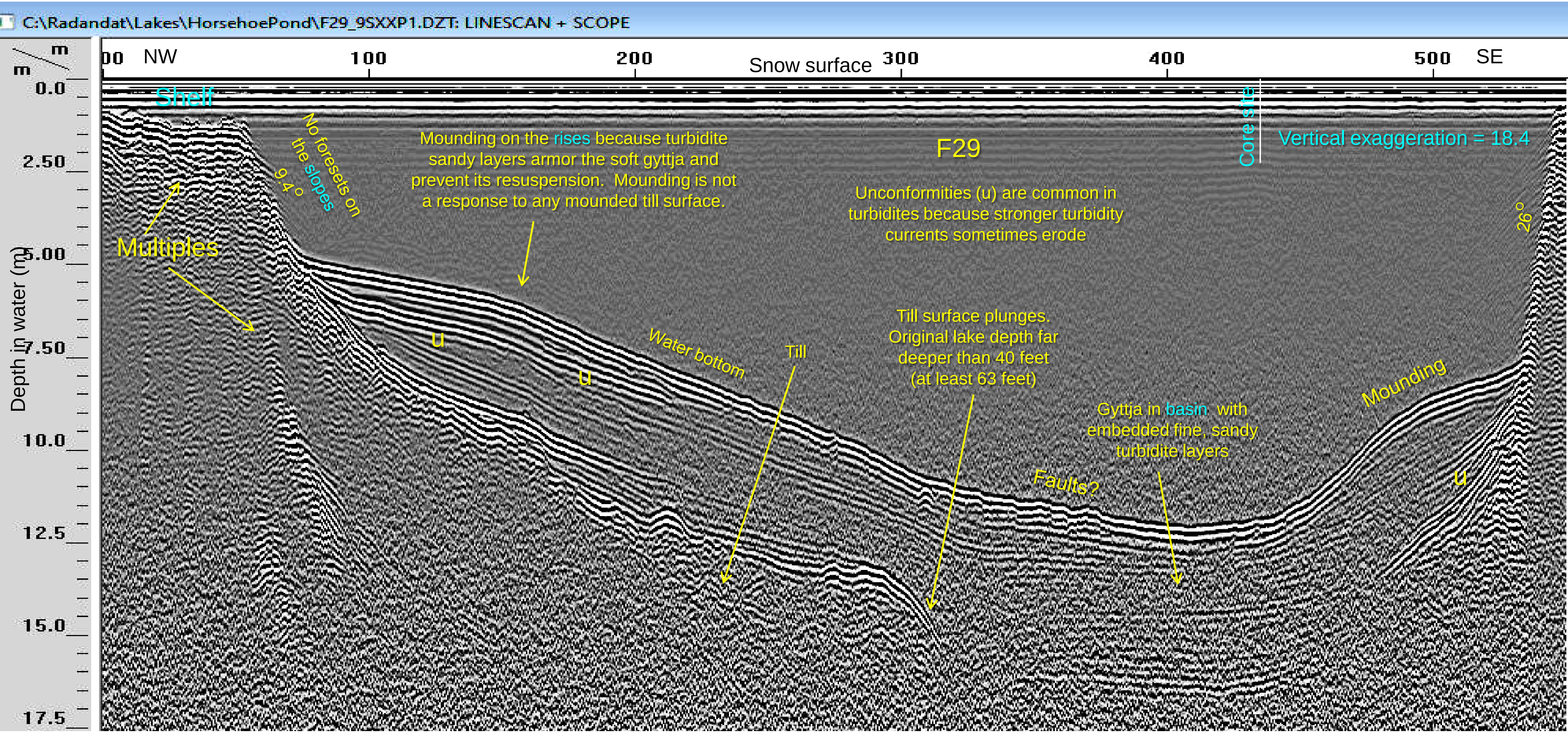
Arcone, S. A., 2018, Sedimentary architecture beneath lakes subjected to storms: control by turbidity current bypass and turbidite armouring, interpreted from ground-penetrating radar images. *Sedimentology*, **65**, 1413–1446. doi: 10.1111/sed.12429.

Arcone, S. A., S. Campbell and Pfeffer, T., 2014, GPR profiles of glacial till, and its transition to Bedrock: Interpretation of water content, depth and signal loss from diffractions, *J. Envir. Eng. Geophys.*, **19**(4), 207–228, doi: 10.2113/JEEG19.4.207

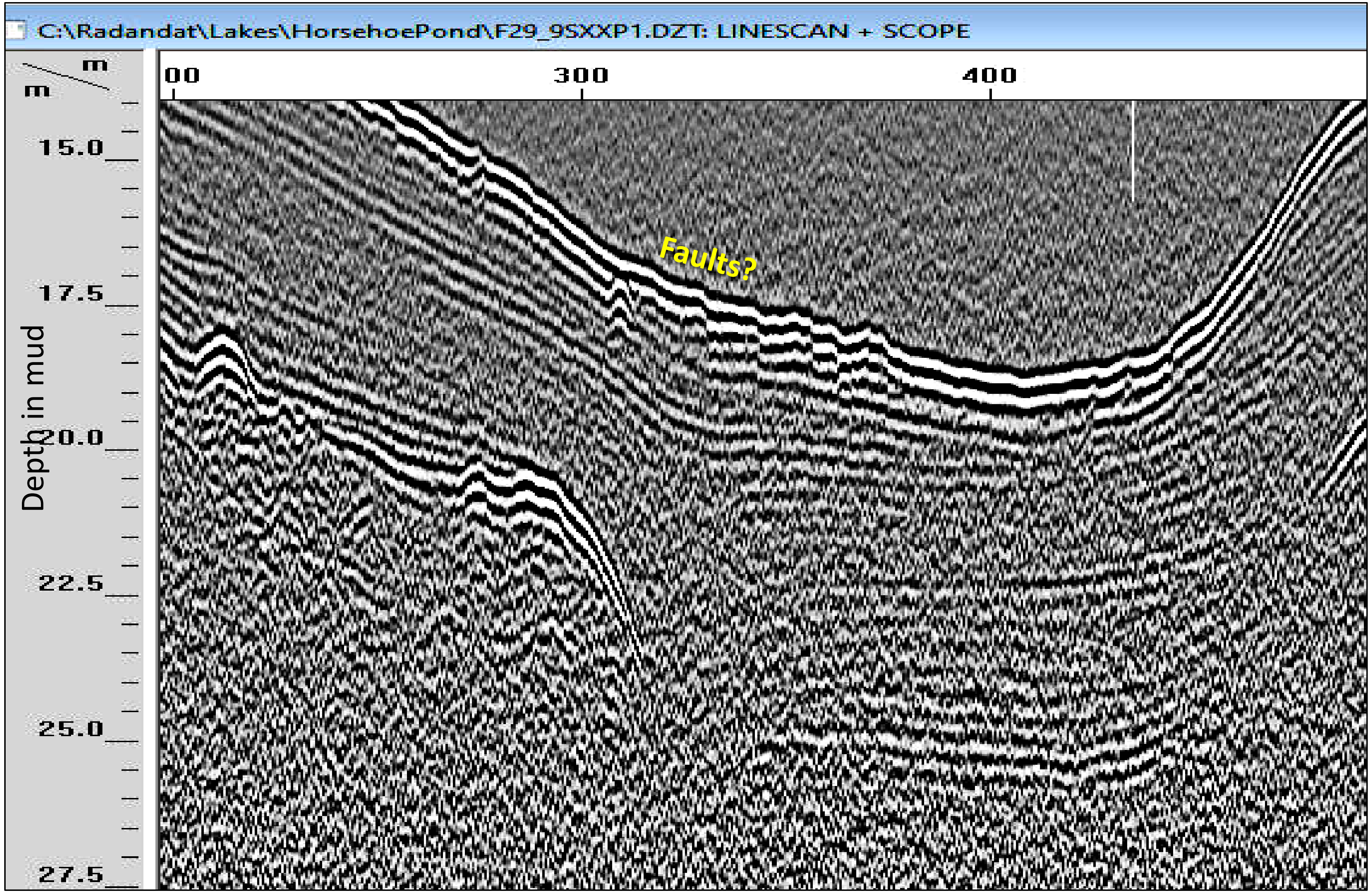
Rough, speculative idea of a possible deep channel, based on 6/7 profiles. Many other lakes in this area are similar. The till left behind could be more than 22,0oo years old, when the Laurentide Ice Sheet advanced over New England. The gyttja above the till is at least 14600 years old but with an insignificant amount of organics until about 11,700 years ago.



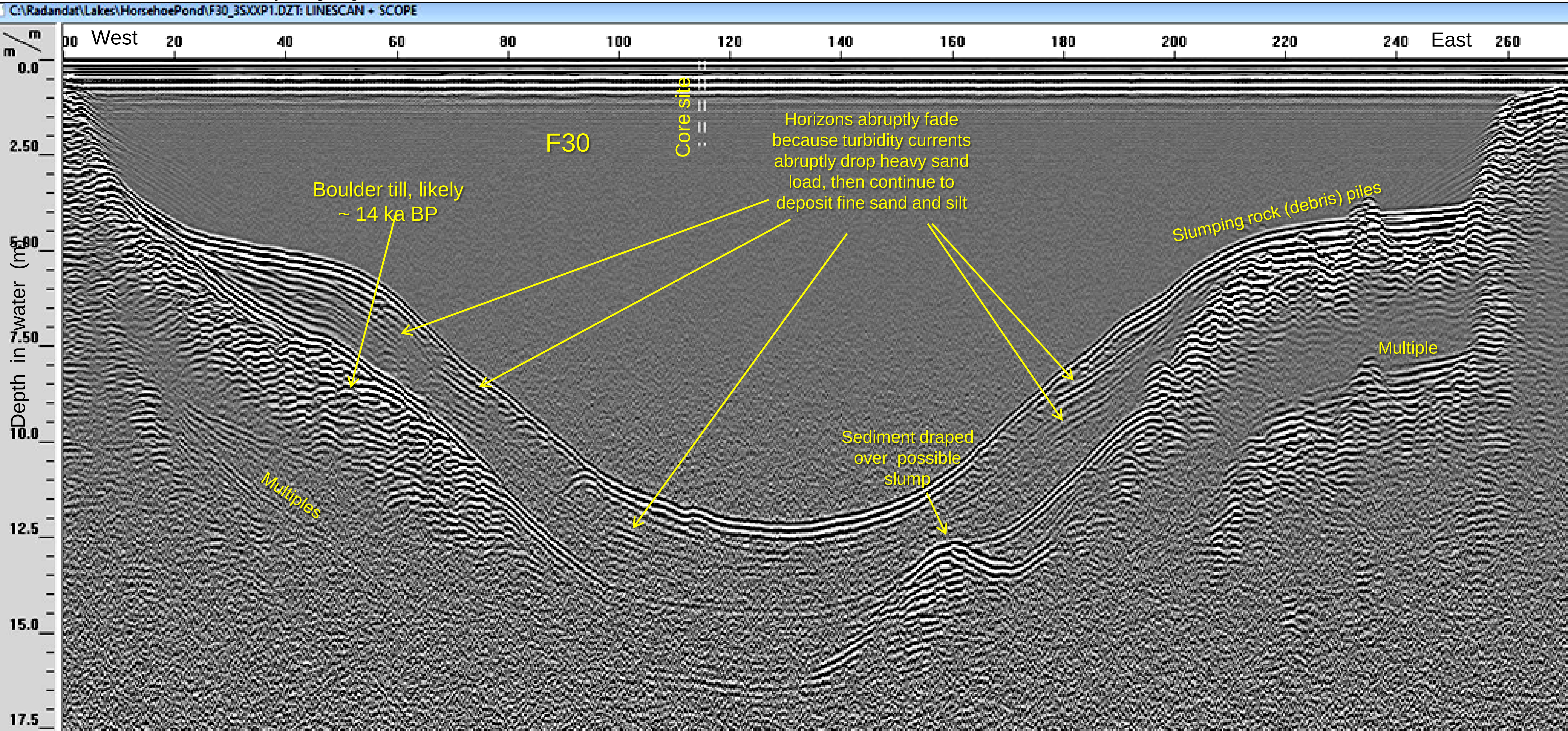
This profile slightly curved around the core site. The straight line distance between start and end was 537 m. I estimate the actual distance traveled was 550 m

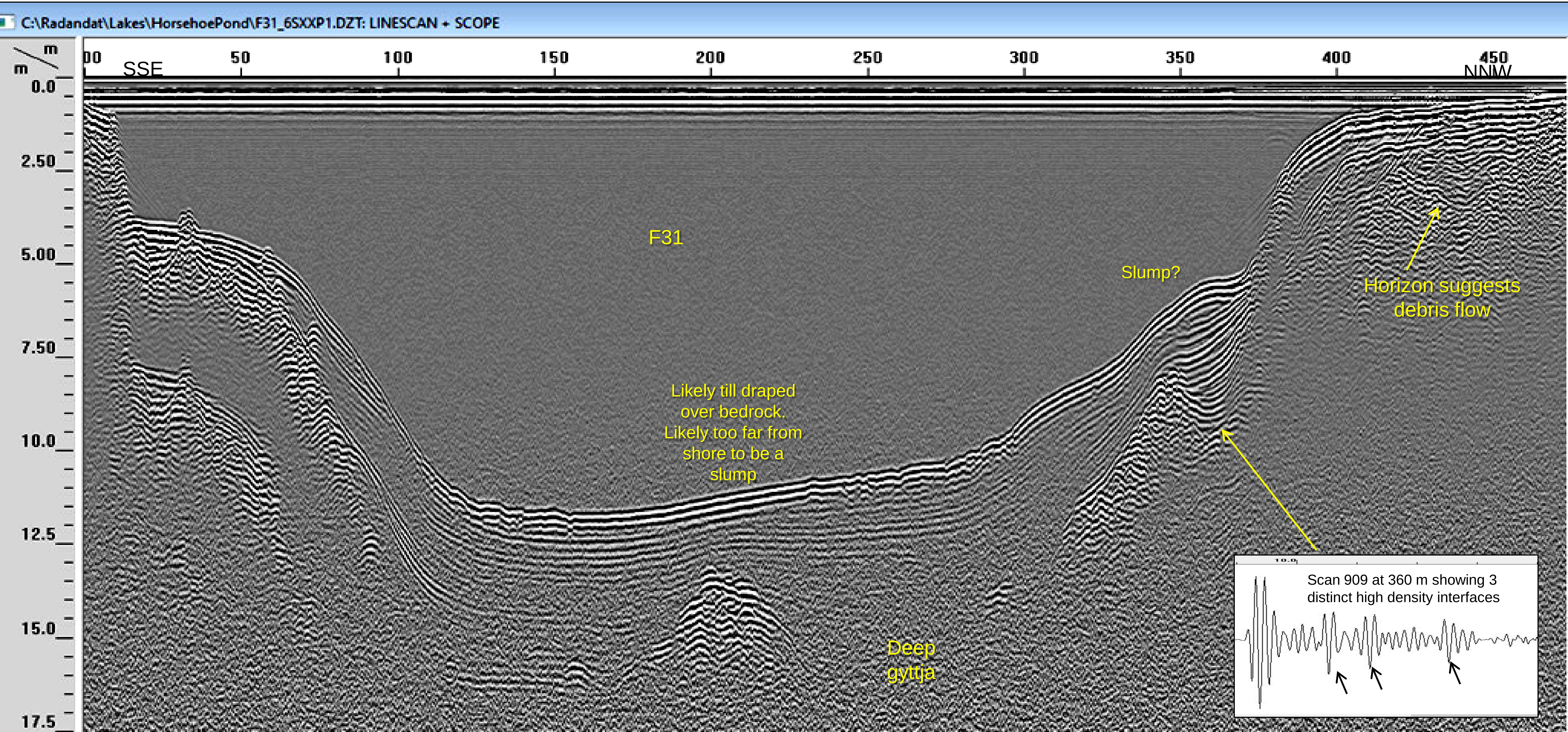


Detail of basin stratigraphy. About 7 m of subbottom penetration.



This profile went right by the core site. The depth is 39.1 feet. This a perfect site for a deep core that could transcend the organics, go through till and hit bedrock. This lake looks like an ancient Fjord gouged out of bedrock.

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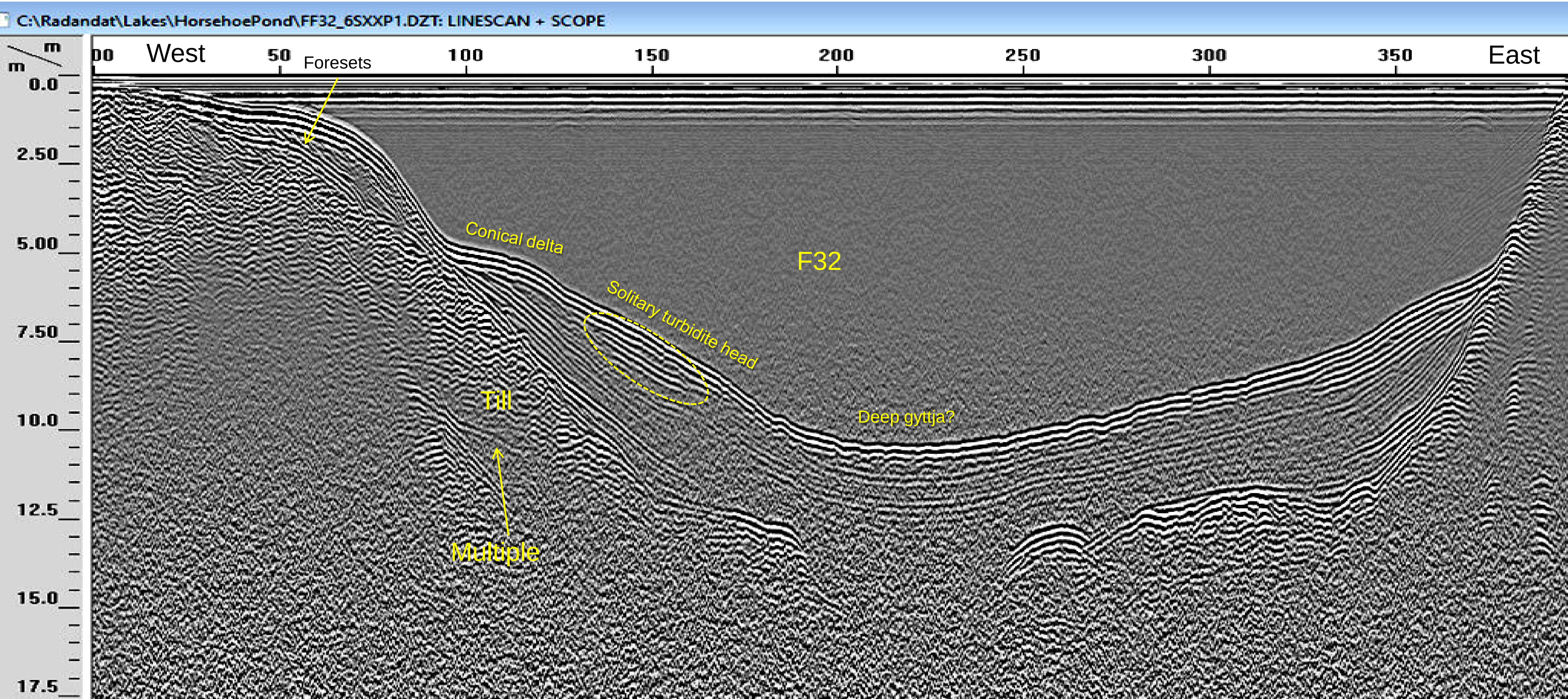
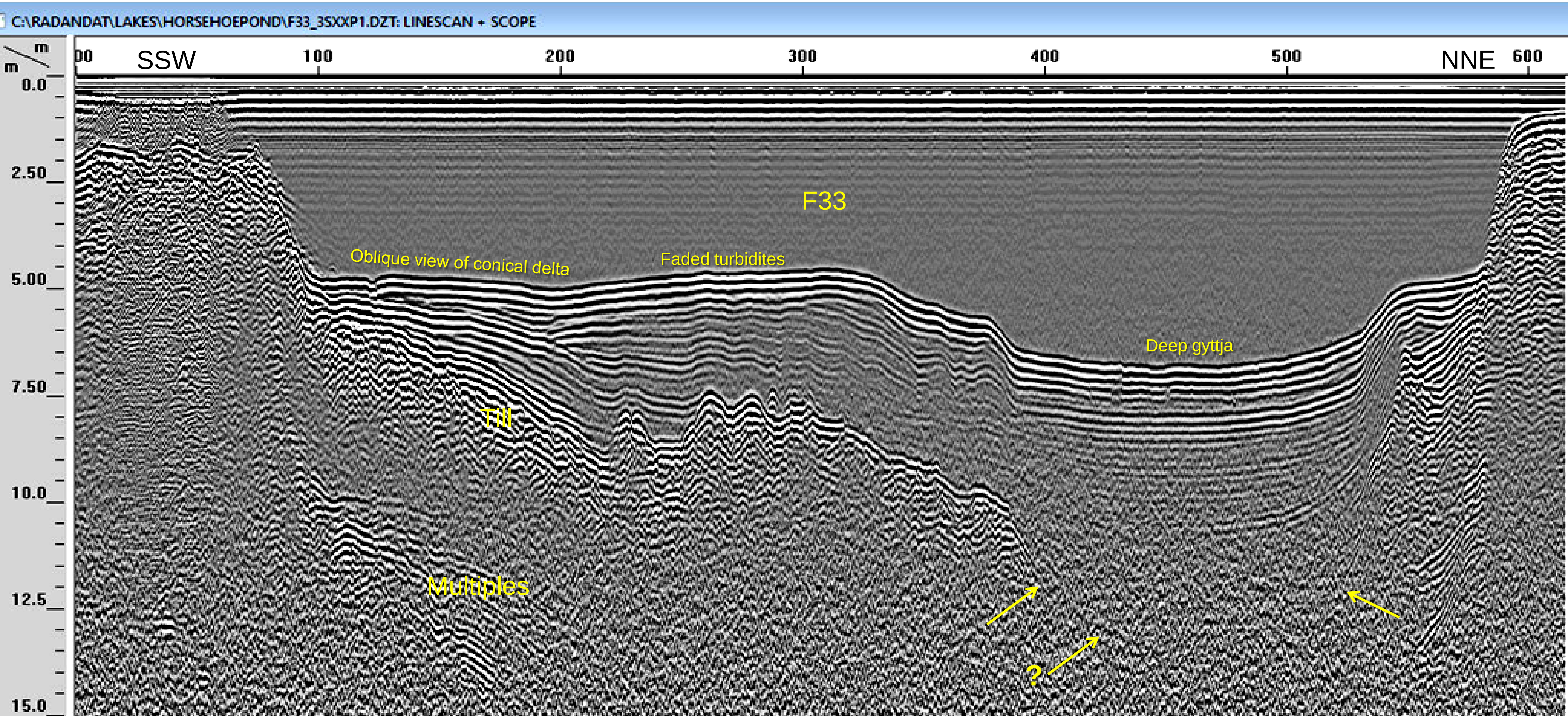
F31
Slump?
Horizon suggests
debris flow
Likely till draped
over bedrock.
Likely too far from
shore to be a
slump
Deep
gyttja
Scan 909 at 360 m showing 3
distinct high density interfaces

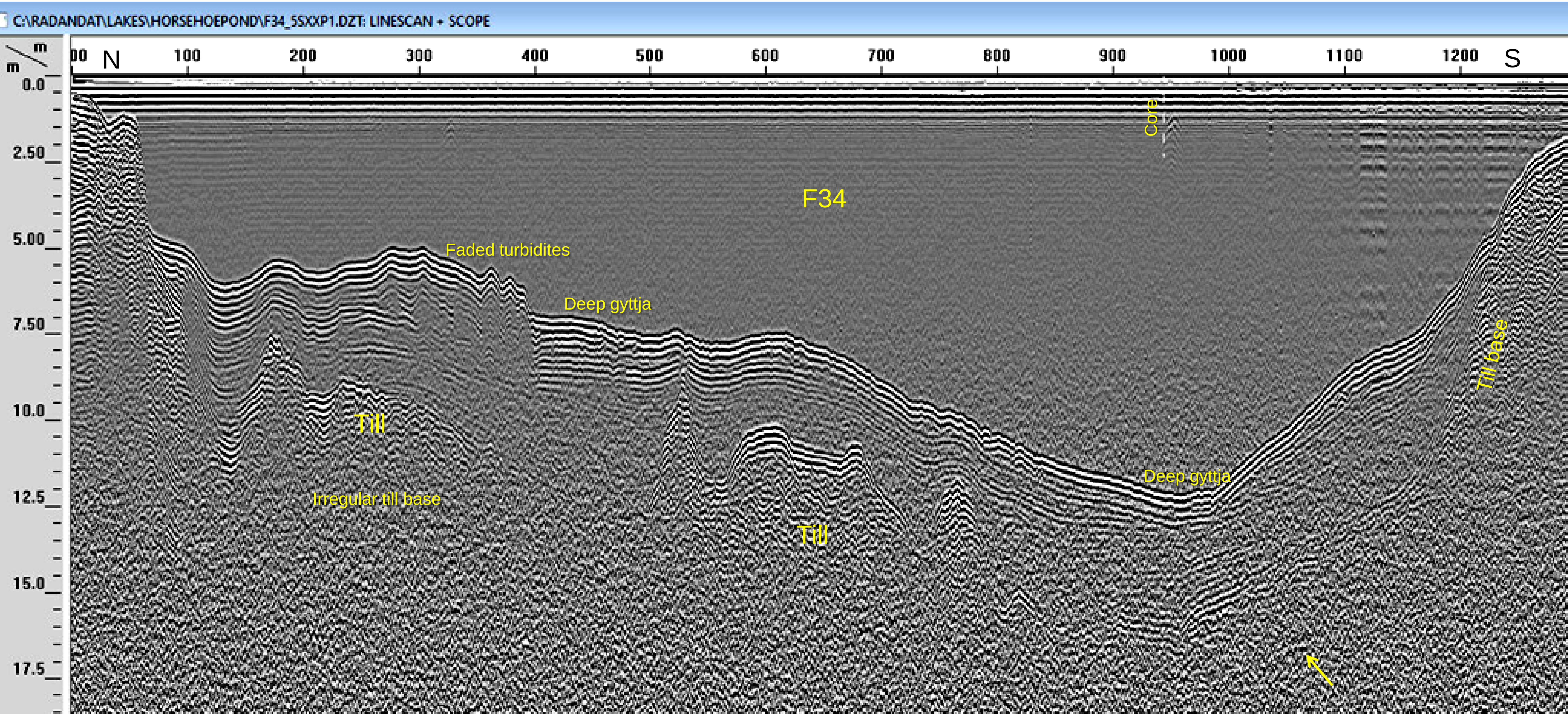
This profile started in a west side cove. The dipping foresets form a Gilbert delta, which results from progressive deposition of sand and gravel. The conical delta at the slope bottom is where hydraulic jumps caused erosion, unconformities and new turbidity currents. Like the previous profiles, there is an ancient channel down the center of this lake, and it seems to be a mini-Fjord caused by bedrock erosion. The isolated horizon was caused by a solitary pulse of turbidity that stopped abruptly.



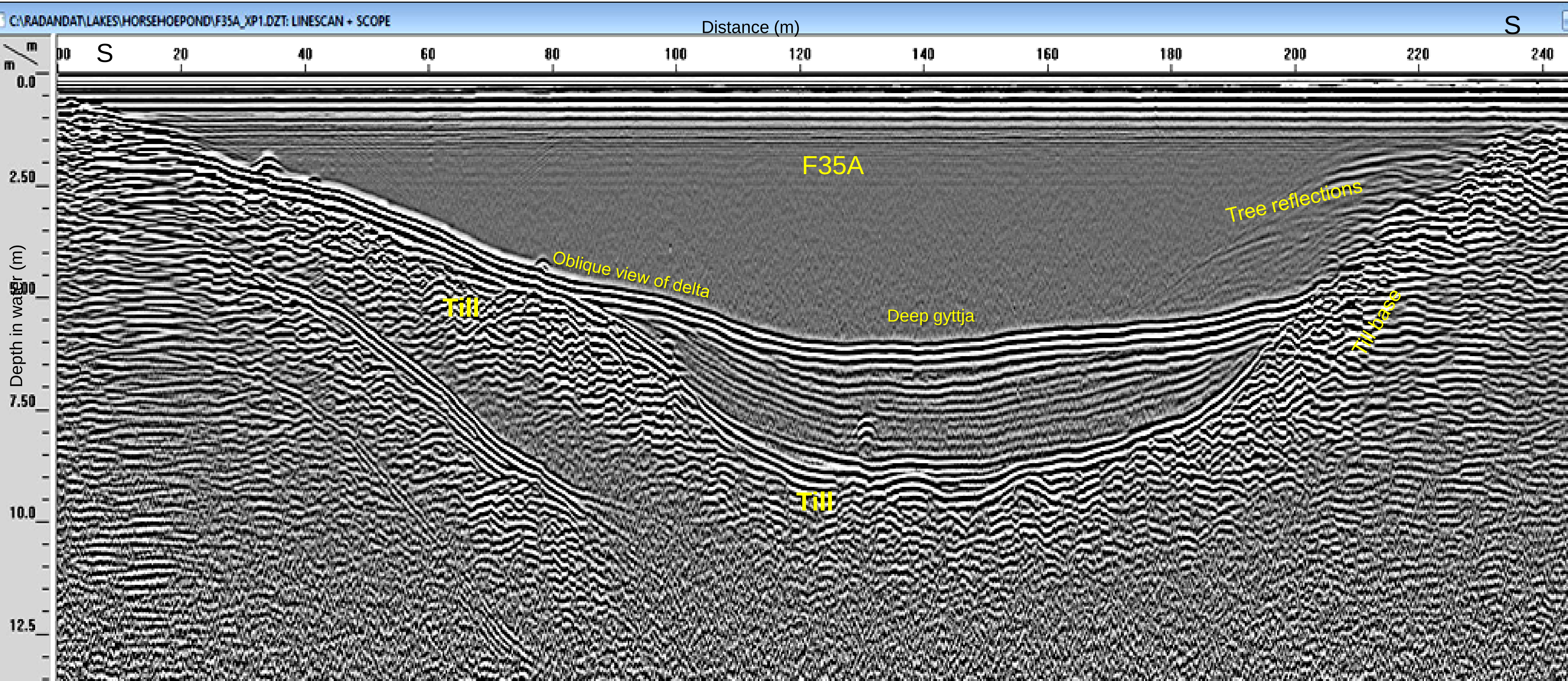
This profile started at our origin on the east side, at 327 Horseshoe Pond Road dock. It ended at a beaver dam on the north side. As on the south side there is a channel of deep sedimentation where the water is only about 6 m deep and a possible second core site. The arrows indicate possible plunging till horizons.



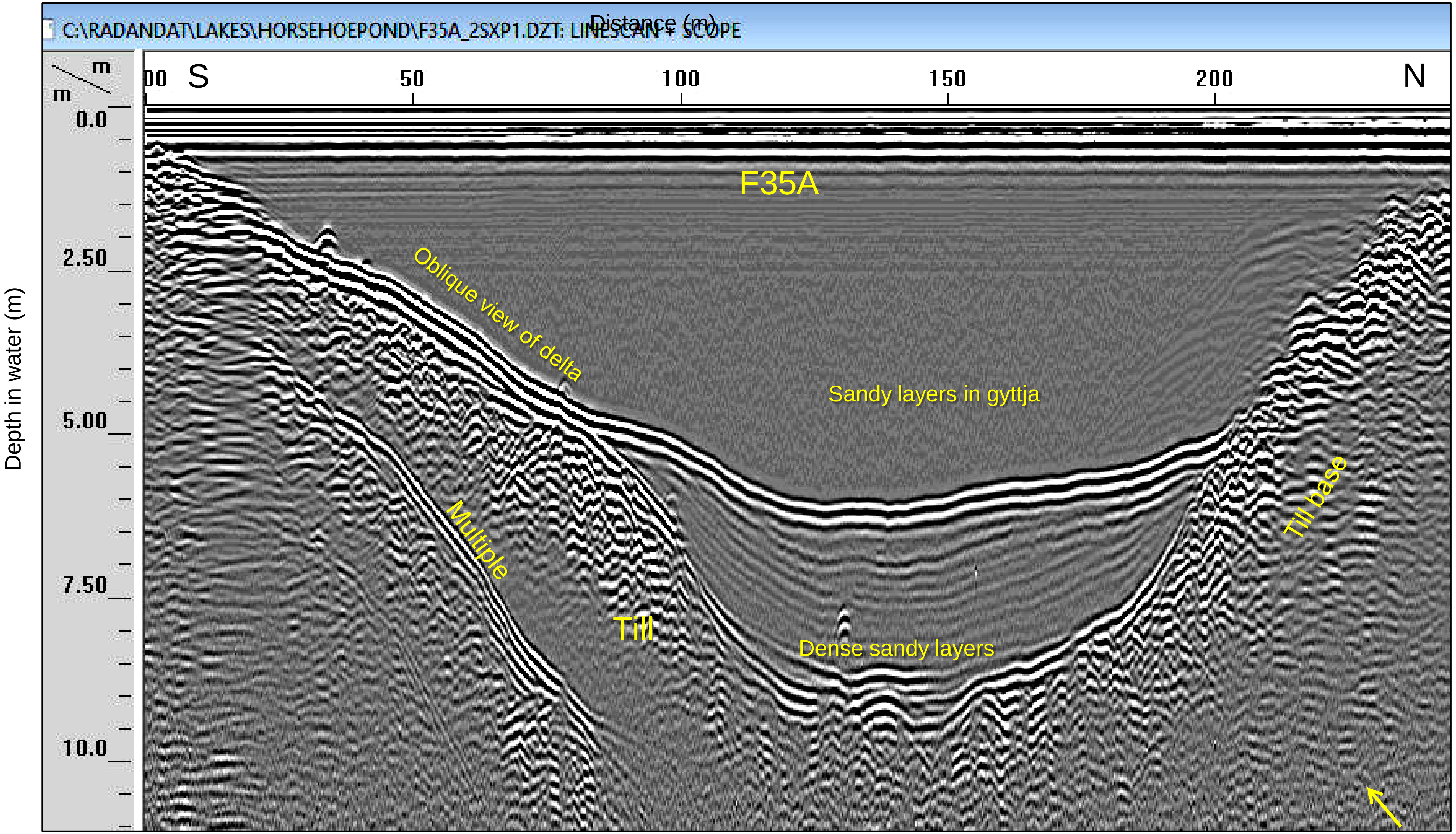
This profile started at the beaver dam on the north end's east side. It traveled near the core site (vertical dashed line) and then cuved slightly toward the south shore. It shows an irregular till base. Arrow at lower right indicates possible deep horizon.



This profile started at the south end and ended at the same point as did F29. Water depth is less than 6 m and the north slope is less than 5 m. There aren't strata along the northern slope , which means silts have been washed away and there was no coarse sand or gravel. The south slope near surface is stratified and so is likely medium to coarse sands and gravels.

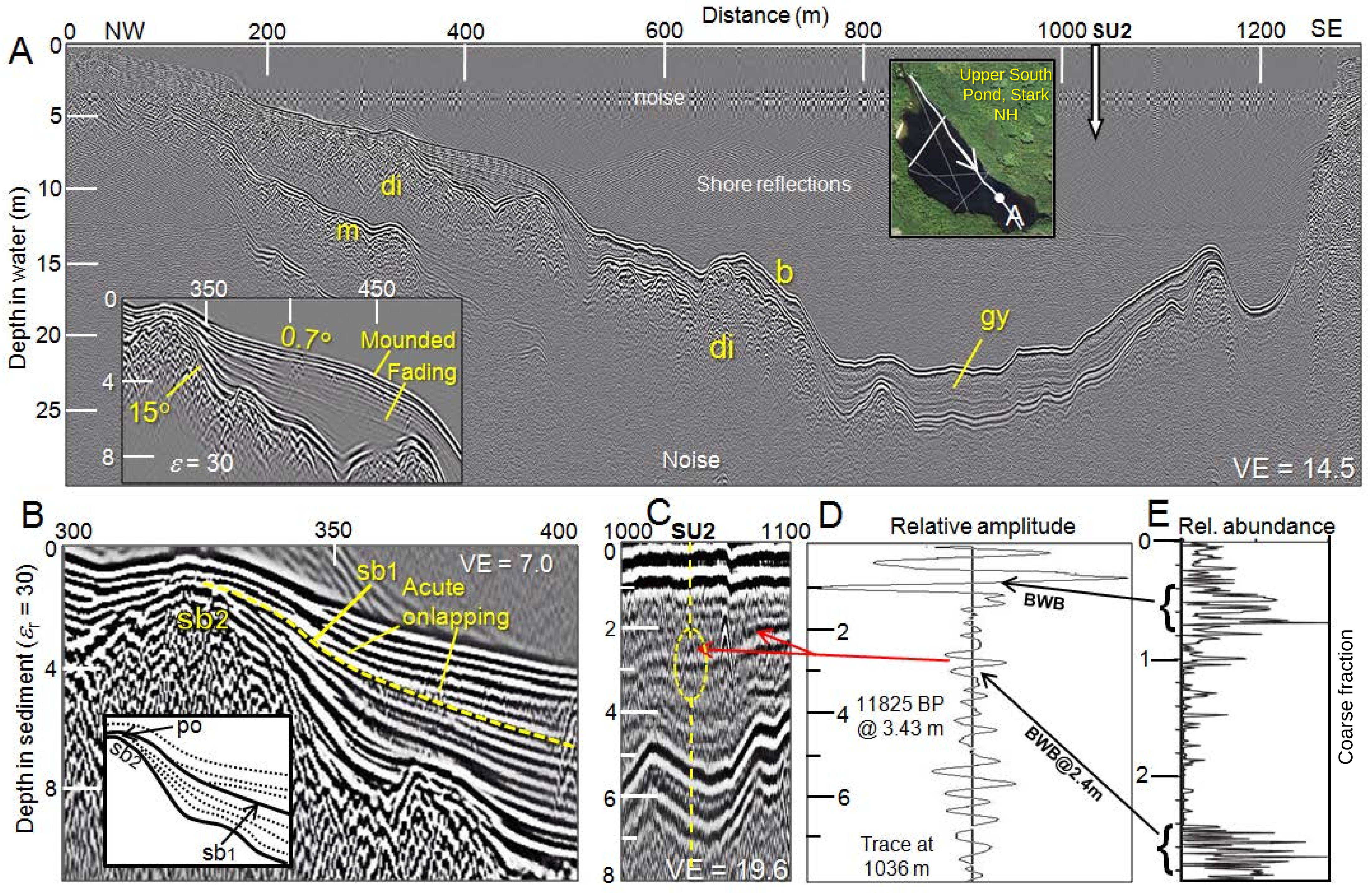


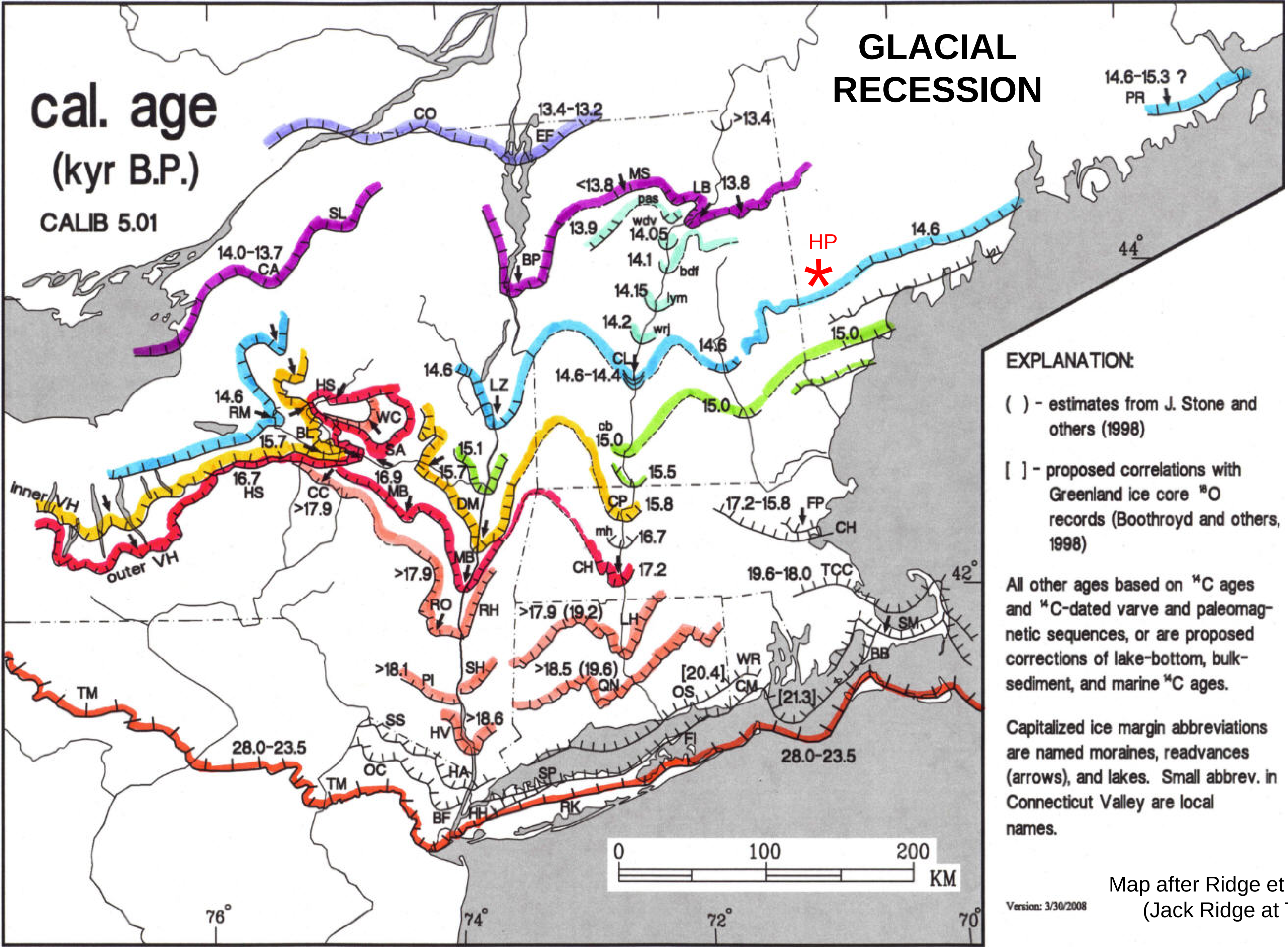
This is a different version of the previous profile in which the amplitude format is linear, meaning the grey scale intensity is proportional to the amplitude. Consequently the strongest reflectors stand out. Here the surface and a layer of likely dense sandy silt along the till are strongest



For comparison and likely similar age dating, this is a NNW-SSE 100 MHz profile from Upper South Pond in Stark, NH, with some dates from a core that might be similar to Horseshoe Pond. The labels are b (water bottom), di (diamicton, or till), gy (gyttja), m (multiple reflection), po (pinchout), and sb (sediment bypass, meaning the turbidity current did not erode). The maximum water depth is 20 m, beneath which are at least 6 m of sediment over till.

At lower right there are two radar horizons that correlate with an abundance of coarse sediments, the lower one at 2.4 m sediment depth (inside dashed circle) being more distinct. A raw date of 11825 years BP (before present) was obtained from gyttja at 3.43 m depth. The corrected date @ 3.43 m should be 13614–13040 BP. There is a faint horizon at 3.8 m that might be the correlating horizons because this core location might not be exact. The deepest horizon is more than 6 m deep, suggesting that this profile represents events that occurred far earlier than 13ka BP when the area was glaciated. Glacier recession at this latitude and place is dated at about 14 ka BP.





This map shows approximate dates when ice receded. Horseshoe Pond (HP) is near the 14,600 years before present contour. This suggests that the previous profile had about 2.5 m of subglacial deposits. For sure the till was laid down when the ice sheet advanced, over 22,000 years ago.

Map after Ridge et al., 2012
(Jack Ridge at Tufts)