GPR imaging of the internal structure of modern migrating dunes, Napeague, NY

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INTRODUCTION

By using ground penetrating radar we have been able to examine the internal structure of modern migrating dunes located in eastern Long Island. These eolian dunes, located in Napeague, NY, are a unique and stunning formation, and can be seen actively overrunning parts of a forest. Parts of the dune system are actively migrating at high rate while others have been stabilized by vegetation. Preliminary GPR in both active and stabilized dunes reveals fine scale internal dune structure, including foreset beds. Our preliminary results show that in addition to such internal dune structure, the GPR images several trees that have been completely consumed by the dune. Below the base of the dune, the water table and pre-dune sedimentary layers, as well as apparent erosional surfaces, have also been imaged.

Long Island has two remarkable examples of parabolic dunes, the Grandifolia Dunes of the north shore which formed proglacially in the latest Pleistocene, and the modern Walking Dunes on the south fork (figure 1). In the past the study of the internal structure of such dunes required damaging excavation. Due to the sensitive ecological setting which these dunes reside, it is important to study them with as little environmental impact as possible. Fortunately, the development of non-intrusive techniques such as ground penetrating radar (GPR) for imaging the subsurface, have made it possible to study such sensitive locations in great detail.

Figure 1. *Map of eastern Long Island (after Engelbright et al.,2000] indicating the locations of the Napeague dune fields, as well as the Grandifolia Pleistocene parabolic dunes.*

The Walking Dunes of Napeague, NY (figure 2) are a modern migrating system, composed of three parabolic dunes ranging from 10 to 25 meters in height (Black, 1996). Sediments eroded from the adjacent headlands which comprise the dunes are first carried into the Napeague Harbor by costal currents and are deposited as a series of offshore ridges, which are then transported to the beach by wave action. Eolian processes move the sediments from the beach face landward where ultimately the dunes are formed. As the dunes grow they migrate landward in a southeasterly direction, a result of the prevailing winds from the northwest which carry the sediments and shape the parabolic dunes (figure 3). Dune migration continues at a rapid rate, until new dunes are formed. Newer dunes which alter the wind flow, as well as countervailing winds from the Atlantic, slow the rate migration, and eventually the dune becomes stabilized by the inset of vegetation (Black, 1996).

Figure 2: *200 MHz GPR survey being conducted on Dune 3w, Walking Dunes, Napeague, NY. Note that the sand is encroaching upon forest, with the tops of trees soon to be overrun by the dune.*

The ecologically fragile setting of the Walking Dunes made GPR an ideal method for studying the internal structure of the dunes. Not only is GPR non-intrusive which preserves the dunes, but it is also a powerful tool which can provide very clear resolution at shallow depths as well as deep with in and below the dune. The different antenna configurations of the GPR make it very versatile in its ability to resolve small scale or large scale features, at varying depths. For the Walking Dunes, 200 MHz and 500 MHz antennas were used. The high frequency 500 MHz antenna was chosen because of its high resolution at shallow depths, ideal for observing dune slip surfaces, and limbs of buried trees. The 200 MHz antenna was chosen because its lower frequency was ideal for imaging at depths beyond the reach of the 500 MHz antenna. The 200 MHz antenna has sufficient resolution to image dune slip surfaces, but can image deep enough to see the water table, and in some cases sedimentary horizons predating the dune. With either antenna configuration, another feature of the GPR is the ability to create 2D as well as 3D data plots, depending on how the data are collected. Closely spaced parallel lines of data collection will allow for 3D imaging, the surface of both dunes is well suited for the 2D and 3D survey.

The fine slip surfaces of the eolian dunes, which we are able to observe with the GPR, give rise to another question about the dunes which is essential to understanding how the GPR creates a subsurface

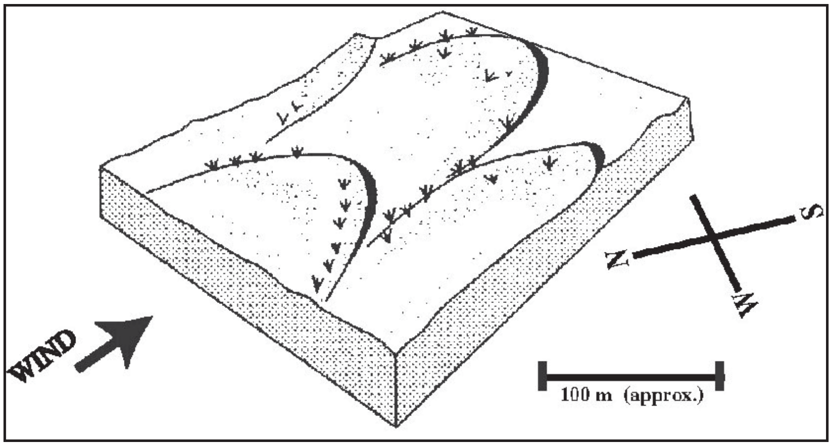

Figure 3**:** *Schematic diagram of parabolic dunes,after McKee (1979). In the case of the walking dunes, the NW prevailing winds result in the parabola shaped dunes directed to the SE.*

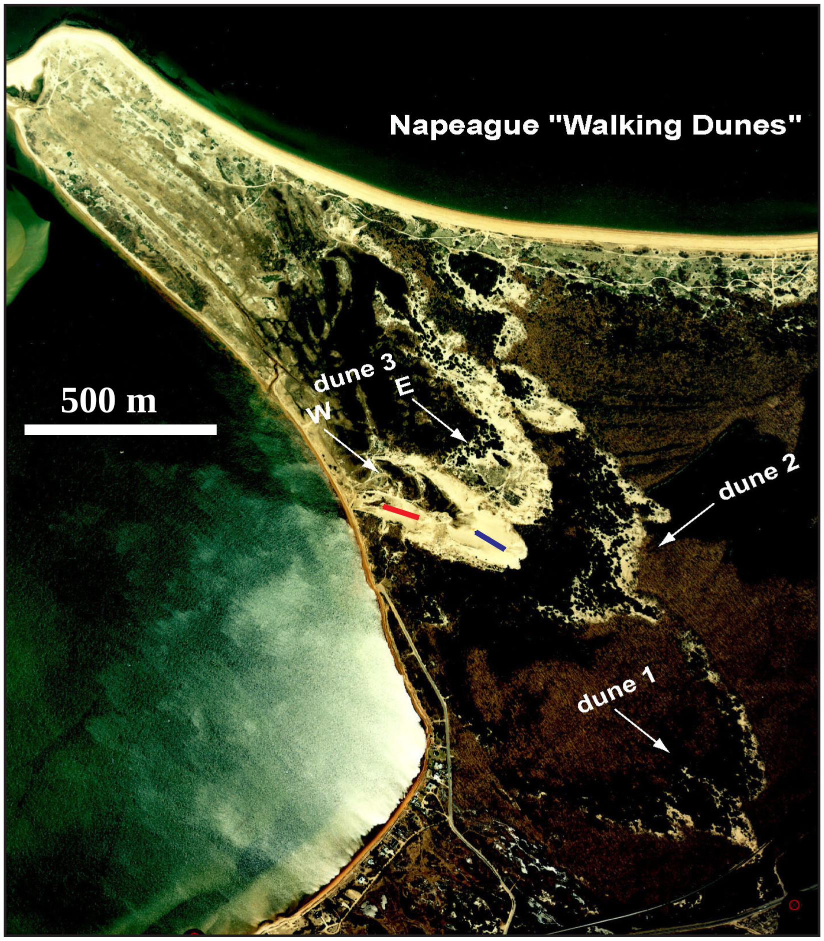

Figure 4*: Aerial Image of Walking Dunes. Our primary GPR lines are from separate parts of the dune 3W. The radargram in fig. 8, indicated by the red line on this aerial image, was collected on a younger, 'small dune' forming on the western limb of dune 3W. The data from the 'big dune' (fig. 9) were collected within the main part of dune 3w (blue line). Note that the older dunes (1 and 2) are stabilized by vegetation.*

image. Why can we see these slip surfaces? If the dune were in fact 100% pure homogenous sand, no reflectors would be present; the GPR would not be able to produce images revealing the internal structure. The radar waves would simply pass right through any slip surfaces, unable to recognize them. We have found in other GPR surveys along nearby beach environments that very thin layers of mafic minerals in the sand are responsible for producing the very well defined reflection surfaces in the dunes visible to radar by creating an impedance contrast which the GPR images very clearly. This relatively minor component of the dunes greatly enhances the effectiveness of imaging of them using GPR.

PRELIMINARY RESULTS

Although the focus of this study is the "big dune," (figure 4), initial studies and GPR data collection were carried out on the "small dune" (figure 4). Initial GPR surveys along the small dune have revealed internal dune structure in both 2D and 3D. In the 'small dune' the slip surfaces of the dune front as well as some other reflectors, possibly tree limbs, can be clearly seen in a 500 MHz line (figure 5). The data in figure 5 can be misleading. It is important to note the vertical exaggeration of the radargram, making the slip surfaces *appear* to dip much more steeply then they actually do. A more accurate representation of the slip surfaces is shown in figure 6, without vertical exaggeration, it can be clearly seen that the slip surfaces dip at a much shallower degree, about 10 degrees. These dips are consistent with exposed slip surfaces, visible near the crest of the dune just to the side of the radar survey (figure 7). High frequency 500 MHz GPR surveys allowed us image in very high resolution the first four meters below the dune. Additional surveys were performed using a 200 MHz antenna which can image at greater depths (due to its longer wavelength), yet still has high enough resolution to detect the internal dune structure.

A 200 MHz radar survey was run from the crest of the dune, and extended past the base of the dune (figure 8). This lower frequency antenna with greater penetration facilitated in imaging the subsurface at greater depths, revealing several important reflectors. In this topography-corrected radargram, some of these reflectors are roughly horizontal, while others dip NNW (to the right of the radargram), near the surface of the dune, the slip surfaces can be seen, just as in figure 5. At about 225ns a prominent horizontal reflector was identified to be the water table, this was confirmed by an additional radar line intersecting the

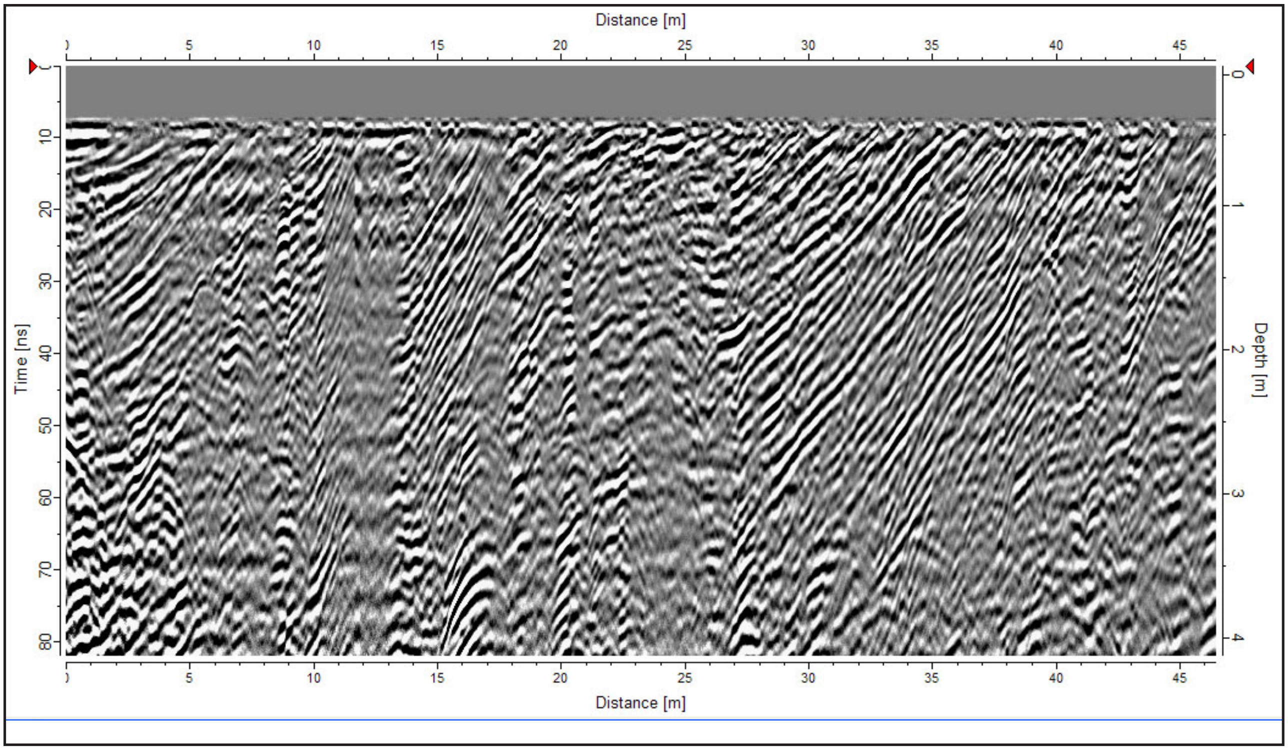

Figure 5*: 500 MHz radargram from crest of the dune (at left) northwestward into the blowout, with no topographic correction applied. The left (SE)end of this line is actually 7.5 m higher than the right (NW) end. The vertical exaggeration is roughly 5:1. Note the strong reflectors dipping to the left, particularly pronounced in the ranges, 0-6m, 13-20m, and 28-43m. These are interpreted to be sand slip surfaces that formed on teh advancing leeward surface of the dune. They appear close to horizontal in short cross lines (NW to SE), so their true dip with respect to the horizontal is roughly 10 degrees to the SE. Some of the gaps in the continuity of these dipping reflectors near 7, 12, 23 and 45 m may represent true changes in the nature of the slip surfaces due to complexity in the history of dune growth and migration. Most, however, are likely artifacts due to shallow zones of high impedence that effectively limiti radar transmission to greater depths.*

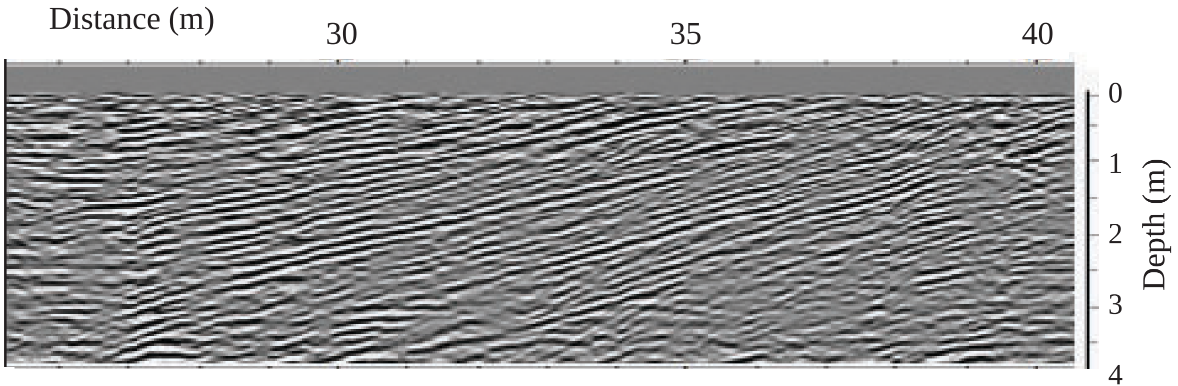

***Figure 6**: A portion of figure 5, rescaled to eliminate vertical exaggeration. Note that the slip surfaces (which look steep in figure 5) are actually quite shallow. Note also the extremely close spacing (as little as 10 cm) of the layering detected by the radar. Both here and in fig. 5, note that these surfaces are subparallel, but ocasionally show slight angular mismatches. interpreted to reflect evolution of wind direction or position within the evolving dune.*

***Figure 7**: Slip surfaces exposed by wind erosion on crest of ‘big dune’, the main part of dune 3W. Height is approximately 5 feet (1.6 m).*

main dune line and a marsh adjacent to the dune, in which we followed the horizontal reflector to the surface where the ground was visibly saturated. While on the dune surface, we confirmed the water table depth by hand auguring down to it. The depth which it was reached corresponds to the depth on the radargram. In addition, the water was found to be fresh which explains why there is good radar transmission through that depth. Conversely, salty water has very high radar impedance effectively ending GPR penetration. In this highly permeable sand, the water table slope is expected to be very small. Knowing this, we can refine our estimate of radar velocity by making sure that the water table appears essentially horizontal on the radargram. Radar wave velocity is determined by observing the nature of the hyperbola shaped point reflectors, usually caused by cobbles. Although for the most part the dune is homogeneous sand, we are fortunate because in this rare example, the dune is actively overrunning trees, which provide us a good source of hyperbola reflections reflections to gauge velocity.

Similar results to those obtained in the small dune were obtained in the main part of dune 3 W (figure 9) using a 200 MHz antenna. We concentrated on using the 200 MHz antenna, results in the small

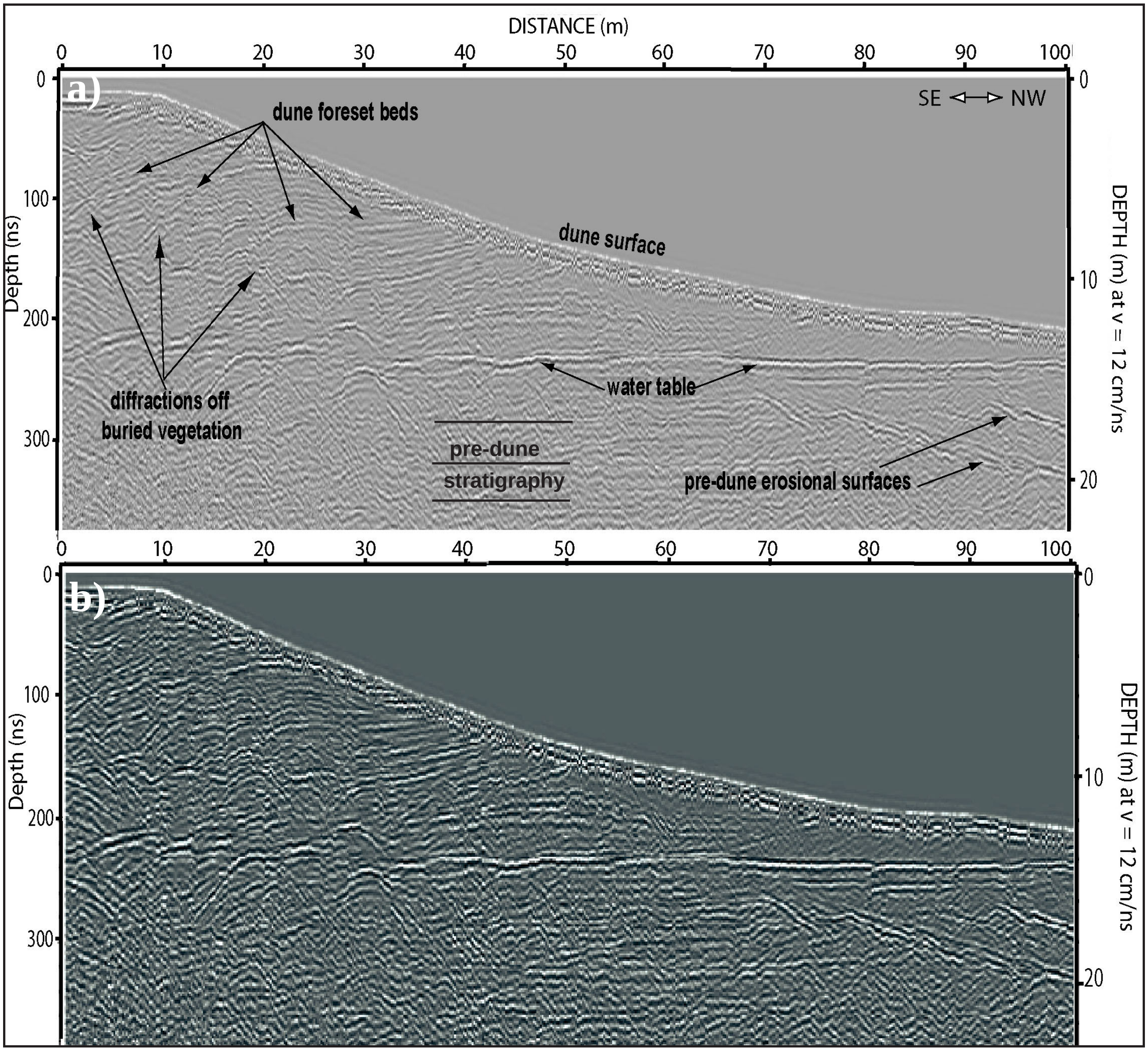

Figure 8: *200 MHz radargram of the 'small dune', indicated in figure 4 by the red line. Part (a) indicates our interpretation of the main features of the radargram, shown unmarked in (b). A topographic correction has been applied with an assumed velocity of 12 cm/ns, based upon fits to the shapes of reflection hyperbolas (from buried trees) and the known depth to the water table at a hand auger site at the 86 m mark on the radargram. Based upon observations there, and on a crossing radar line (not shown here), the bright reflector 14m below the crest of the dune is confirmed to be water table. There are two apparent erosional surfaces at right, dipping to the right (toward Napeague Bay). Note that one of them clearly cuts off the subhorizontal pre-dune stratigraphy. Several bright hyperbolic features within the dune result from diffractions, almost certainly off of buried trees.*

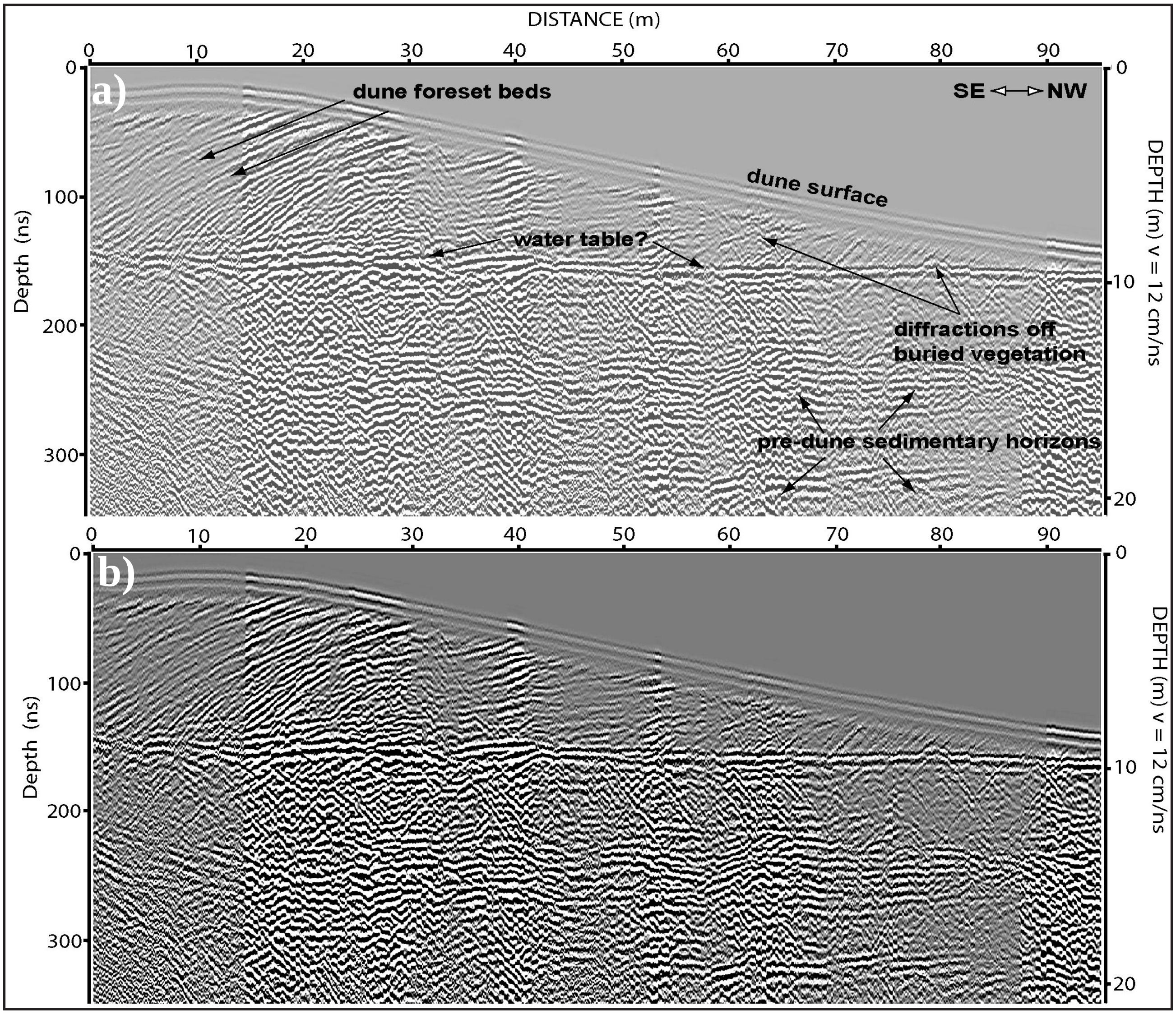

Figure 9: 200 MHz radargram of the 'big dune', indicated in figure 4 by the blue line. Part (a) indicates our interpretation of the main features of the radargram, show unmarked in (b). A topographic correction has been applied with an assumed radar velocity of 12 cm/ns, based upon fits to the shapes of reflection hyperbolas, this velocity estimate matches that of the 'small dune' (figure 8) as expected in this very homogenous region. Vertical exageration is roughly 2:1 within the dune, and probably closer to 3:1 below the water table, because the velocity there is undoubtedly less than above the water table. Note that the well-developed pre-dune stratigraphy is at most weakly folded, unlike the sediments in the nearby Hither Hills. They may be post-glacial in age or, perhaps, glacial sediments from below the zone deformed by the glacier. Also note that slip surfaces in the dune create many strong and continuous reflectors, though fewer (at a typical spacing of about 50cm) than resolved with the 500 MHz antenna (figure 5).

dune (figure 8) showed that it provided sufficient resolution to see the slip surfaces of the dune, while also having the ability to image at the greater depths encountered in dune 3 W which is much larger and taller. Initial data collection on dune 3 W using a 200 MHz antenna has revealed internal dune structure as well as other important reflectors (figure 9). Complexity in the shape of the slip surfaces in parts of the dune suggest possible complexity in the growth of the dune. The overall progression of the dune is clear, as previous slip surfaces were eroded their sand transported to the front of the dune by eolian processes. Thus, the slip surfaces near the surface toward the right side of figure 9 were once at the base of the advancing dune front. Just as in the small dune, there is evidence of the dune over running trees in the radargram, as well as a prominent reflector of the forest floor, and a reflector which is probably but not yet confirmed to be the water table.

IN SUMMARY

The Walking Dunes have proven to be remarkably good radar targets, producing clear imaging of many slip surfaces, and other notable reflectors such as the water table and over-run trees. The presence of the water table and trees is significant, as they provide important constraints on radar velocity, which is important in interpreting the data. Radargrams show the classic dune internal structure, consistent with growth under the prevailing winds in this region. In addition to the clear imaging of slip surfaces which give insight to the manner of dune growth and migration (rate, direction, reword and include), there is also evidence of erosional events preceding the dune which may yield insight to the geomorphology of the regions past. GPR has proven to be a powerful tool for exploring the internal structure of eolian dunes, both for its versatility and ability to collect large amounts of data fairly rapidly, as well as it is a non intrusive method which allows us to study these sites with out destroying them.

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