Is Bald Hill the Hill of a Hill-hole Pair?

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Introduction

The purpose of this research is to test whether the Bald Hill complex, located in Farmingville, Long Island, which is part of the Ronkonkoma Moraine, is a glaciotectonic feature, possibly the hill in a hill-hole pair. Hill-hole pairs have formerly been recognized on Long Island in the Selden Hill complex, situated a short distance northwest of the Bald Hill complex (Tvelia, 2011).

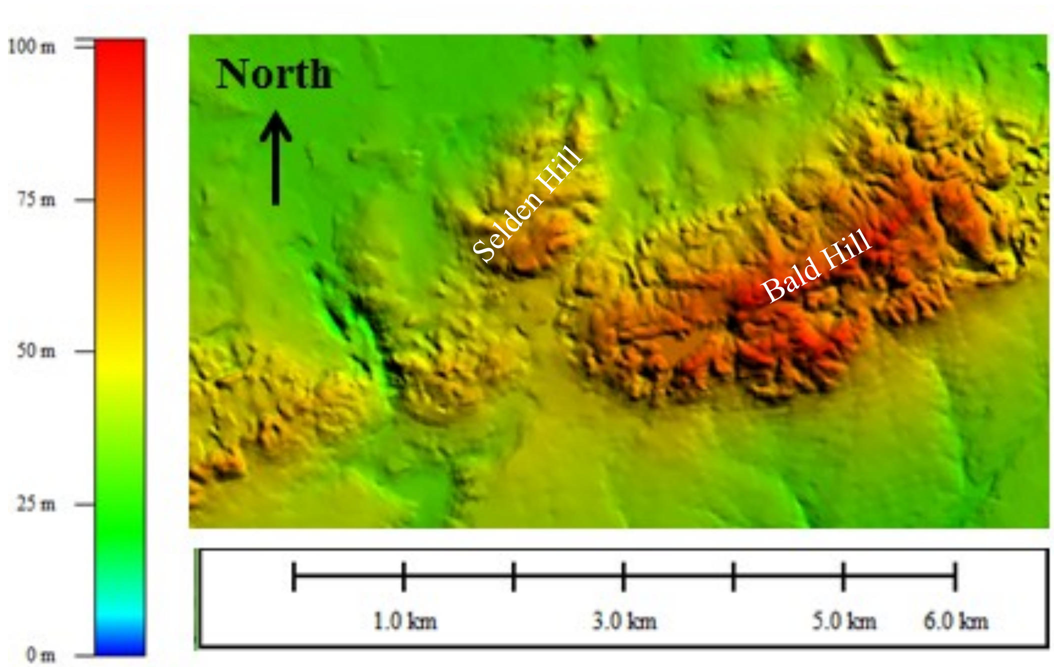
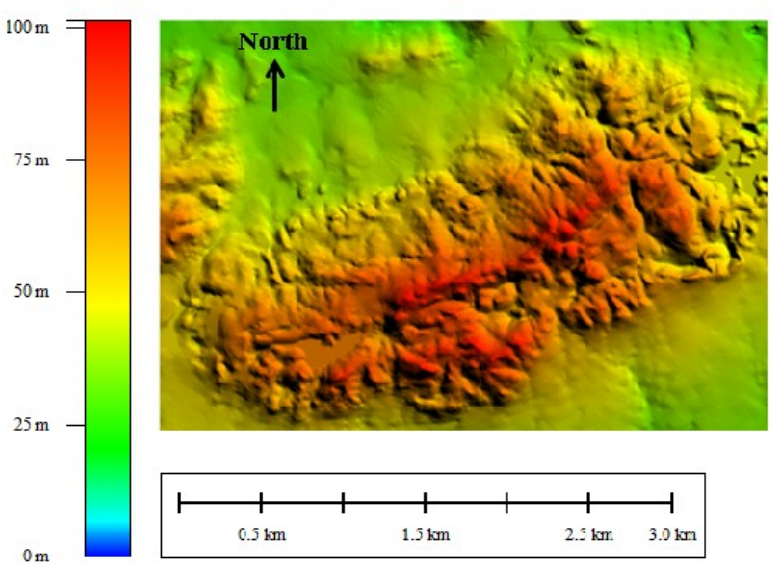


Figure 1: Digital Elevation Map of the Ronkonkoma Moraine

Figure 1 shows both the Bald Hill complex and the Selden Hill complex. Tvelia (2011) used ground penetrating radar (GPR) to find folds and faults supporting his hypothesis that the Selden Hill complex is a glaciotectonic feature. The Selden Hill complex has multiple glacial ridges which are curved and concave on the upglacier side (Tvelia, 2011). The Bald Hill complex has similar topographic features (Figure 2).



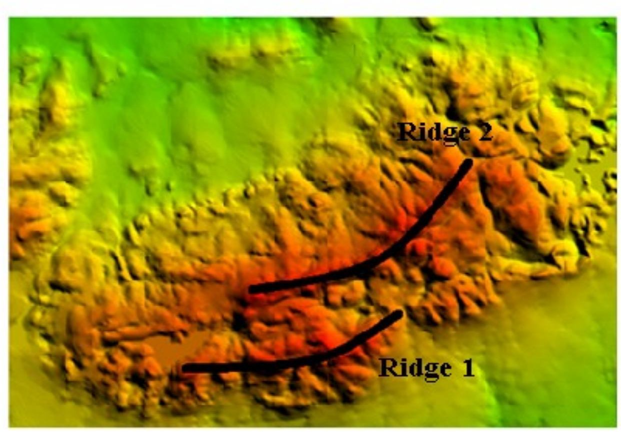


Figure 2: Multiple ridges concave in the upglacier direction on Bald Hill.

Bluemle and Clayton (1984) define a hill-hole pair as "a discrete hill of ice-thrust material, often slightly crumpled, situated a short distance downglacier from a depression of similar size and shape". According to Bluemle and Clayton (1984), features of hill-hole pairs include:

1.Arcuate or crescentic outline of hill; concave on the upglacier (proximal) side, convex in the downglacier (distal) direction.
2.Multiple, subparallel, narrow ridges separated by equally narrow valleys following the overall arcuate trend of the hill.
3.Asymmetrical cross profile of hill; higher with steeper slopes on convex (distal) side, lower with gentler slopes on concave (proximal) side.
4.*Topographic depression on concave (upglacier) side of hill; area and shape of depression approximately equal to that of hill.*

Another indicator of a glaciotectonics can be found when looking a the subsurface. The typical structure consists of "parallel valleys and ridges eroded from folded and thrust-faulted strata" (Aber, 1988). The most effective way to do so is by using GPR. The tectonics in the ridges should resemble that of a fault-propagating fold (Figure 3) because the material was pushed up and ahead of the advancing glacier. Thrusts within a fault-propagating fold travel along zones of weaknesses and "occurs when a propagating thrust fault loses slip and terminates upsection by transferring its shortening to a fold developing at its tip" (Mitra, 1990). As shown in Figure 4, the glacier thrust the material as it advanced and created a hill with fault-propagating folds. At some point, the glacier receded and the hole left behind eventually is filled with water, forming a lake.

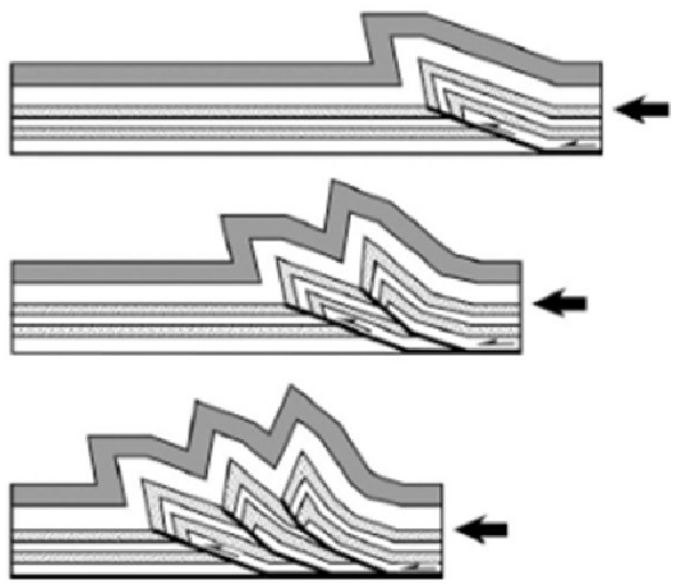


Figure 3: Evolution of a stacked set of fault-propagating folds

Modified from Poblet and Lisle (2011)

The hill in a hill-hole pair is associated with a hole of similar volume, located near it. However, for Bald Hill, the hole was likely filled in because no hole is visible. This situation is not unusual and can be found in northeastern Poland and Belarus (Aber, 2007). A cross section (Figure 5) produced by Smolensky *et. al.* (1989) shows a hole situated just north of the Selden and Bald Hill complexes filled with Upper Glacial sediment. (Tvelia, 2011). If it is the hole of the hill-hole pair, it could be the source of the Bald Hill complex.

However, Criscuola (2010) studied a well log (S58761) for the same hole that Smolensky (1989) studied. He was not convinced that the hole was filled in by Upper Glacial sediment, shown in the cross section (Figure 5). He suggests that he sees Magothy sediment at that level, which would suggest that there was no hole in the Magothy.

In this study, GPR will be used, similar to that used by Tvelia (2011), to look for folds and faults below the surface of the Bald Hill complex. If folds and faults are found, anticlines are expected to be found along the ridges. Glacial till (boulders and cobbles) should exist at the surface and at depth. This evidence will suggest that the Bald Hill complex was formed by a glaciotectonic process. Till found at the surface would show that the glacier overrode the area.

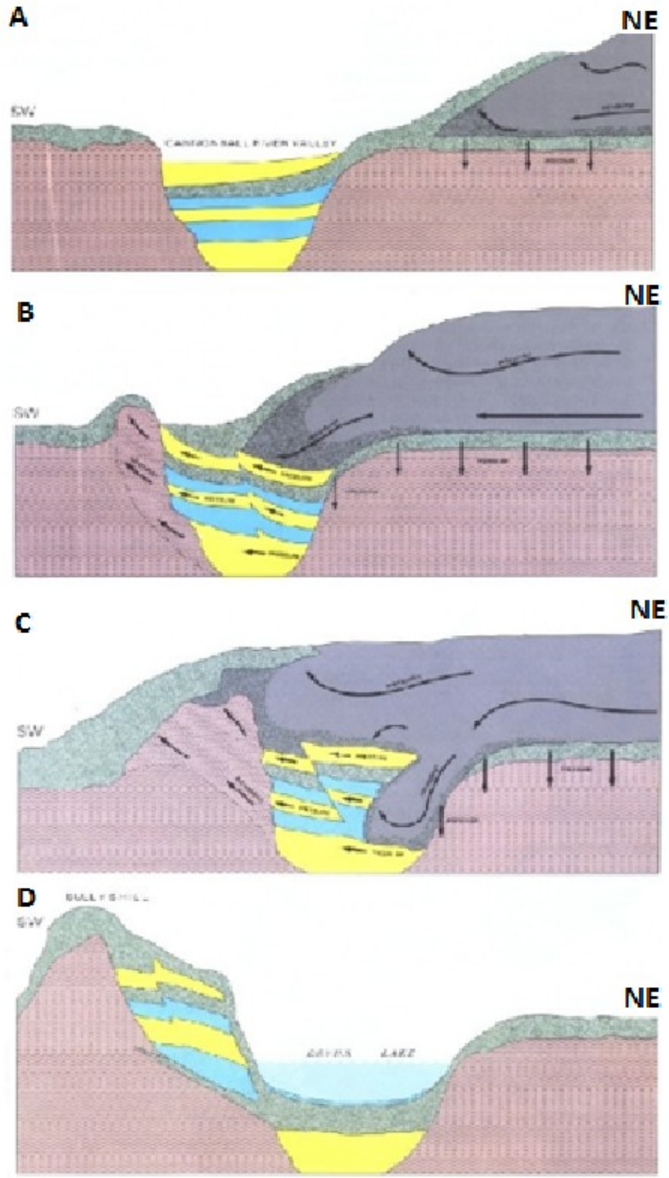


Figure 4: Shows the formation of a hill-hole pair in Devil's Lake, North Dakota

http://nd.water.usgs.gov/devilslake/science/geology.html#formation

Methods

The Digital Elevation Model (DEM) for the Patchogue quadrangle (hh54), from the Cornell University Geospatial Information Repository (CUGIR) viewed in Global Mapper was used to evaluate the topography of the Bald Hill region. To determine the exact location of the geomorphic features, a map with street names was superimposed on the DEM (Figure 6). A path in Bald Hill was evaluated with ground penetrating radar (Figure 7). The path follows a trail through the woods starting from the extension of Edgewood Avenue. The GPR lines travel from the South to the North and starts at 40°50'13" N, 73° 01'28"W.

Analyzing the subsurface features with GPR can play a significant role in understanding the glaciotectonics of an area (see for example Tvelia, 2007). GPR is used to detect boulders, stratigraphy and structure using high-frequency electromagnetic waves. Till layers can be distinguished as cobbles and boulders, which appear as hyperbolas in the radiogram. This is an innovative way to analyze the structural patterns at significant depths up to 15 meters in order to interpret the tectonics. The data is processed in a manner similar to that used in seismology. Both 200 MHz and 100 MHz antennas were used but the 200 MHz radiogram provided the best information for the study. The 100 MHz antenna shows overall trends beneath the surface but the 200MHz antenna has a better resolution.

Dr. Daniel Davis of Stony Brook University processed the data using Reflexw, to make it easier to interpret. Once processed, the topo-correction was made with leveling along the first 270 meters on the southern end of the path and Light Detection and Ranging (LIDAR) data from the Suffolk County Department of Information Technology for the northern 466 meters.

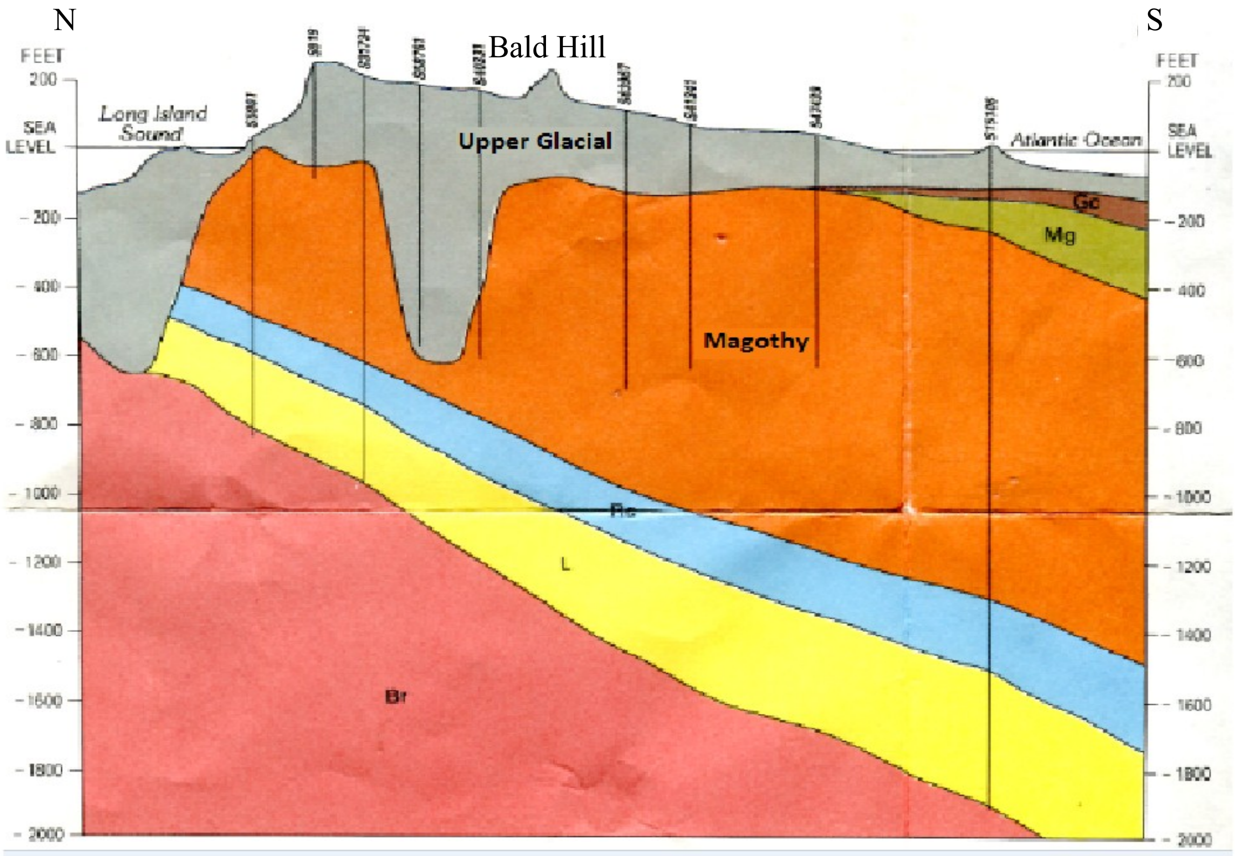


Figure 5: Cross section of Long Island from the north to the south through Bald Hill shows a large hole in the Magothy Formation just to the north of Bald Hill (Smolensky *et. al.,*1989).

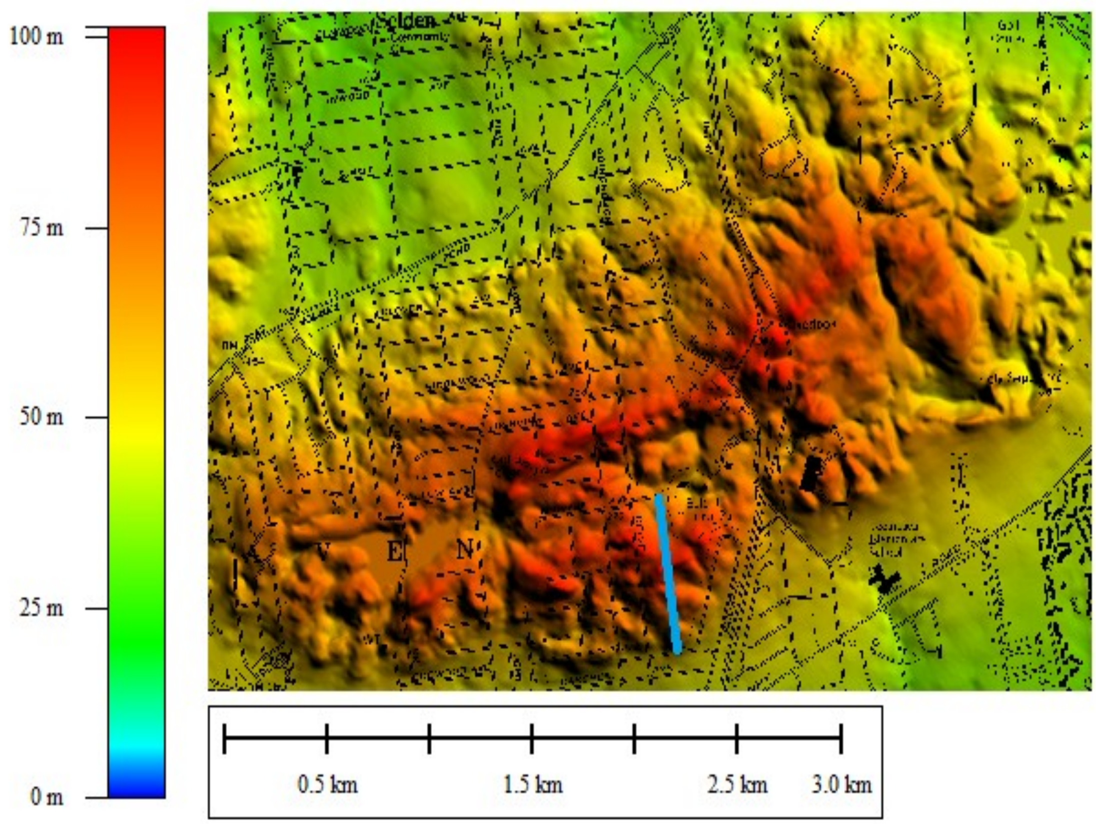


Figure 6: A map with street names superimposed on the DEM. The blue line shows the path along which the GPR data were collected.

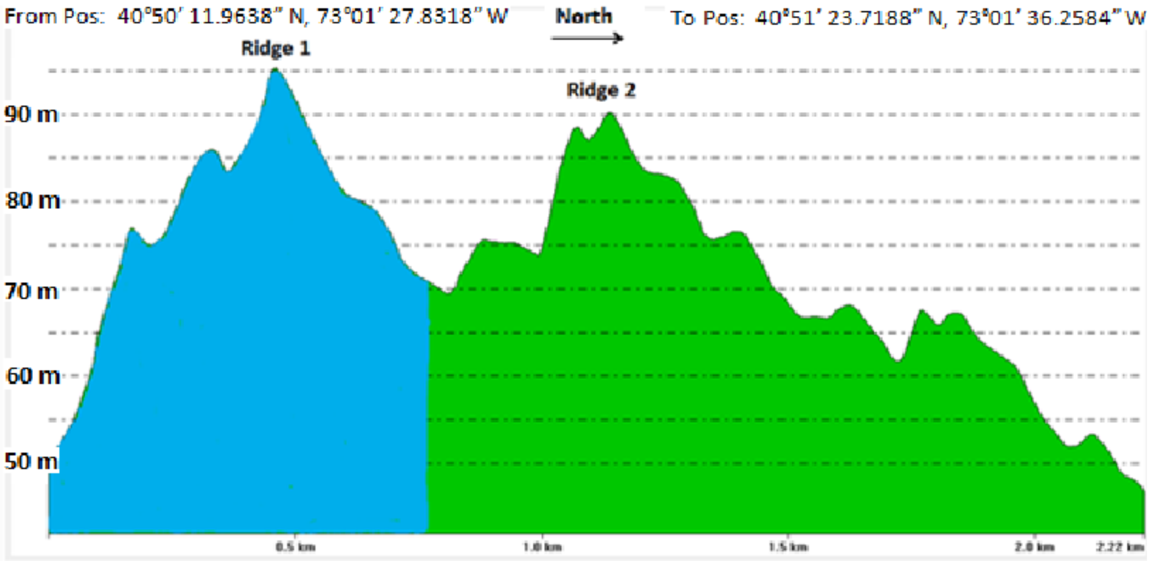


Figure 7: Cross section on the path from figure 6 showing the two prominent ridges. The blue area is the region GPR data was retrieved from.

Results

This study was over several ridges in the Bald Hill complex starting from the south (see Figures 2 and 7). All data was analyzed with the 200 MHz radiogram. The first ridge is about 114 meters from the starting point and reaches an elevation of 77 meters. The second ridge is at 260 meters from the starting point and reaches an elevation of 86 meters. The third ridge (labeled "Ridge 1" in Figures 2 and 7) is located 380 meters from the starting point with an elevation of 95 meters. Figure 8 shows the three ridges, labeled "Ridge A", "Ridge B", and "Ridge C", respectively.

Cobbles and boulders are evident within the 200 MHz radiogram which indicates that till is present at the surface and at depth. The occurrence of till shows that the glacier traveled over the complex. Cobbles and boulders can be distinguished as hyperbolas on the radiogram (see Figure 9). Finding till is more effective on the data that has not been topo-corrected because it is the only way to distinctly see the cobbles and boulders as hyperbolas. Cobbles are abundant at the surface 20 meters from the starting point, and between 610 and 700 meters from the starting point. Cobbles are also present near the summit of the ridge located at about 380 meters from the starting point. Between 70 and 150 meters from the starting point, cobbles reach depths of about 4 meters. Boulders can be mapped when the radius of the hyperbola has to be increased in order to fit the structure. Boulders are evident between 160 and 190 meters from the starting point and reach depths of 8 meters below the surface. Boulders are also present around 715 meters from the starting point and reach depths of about 9 meters below the surface.

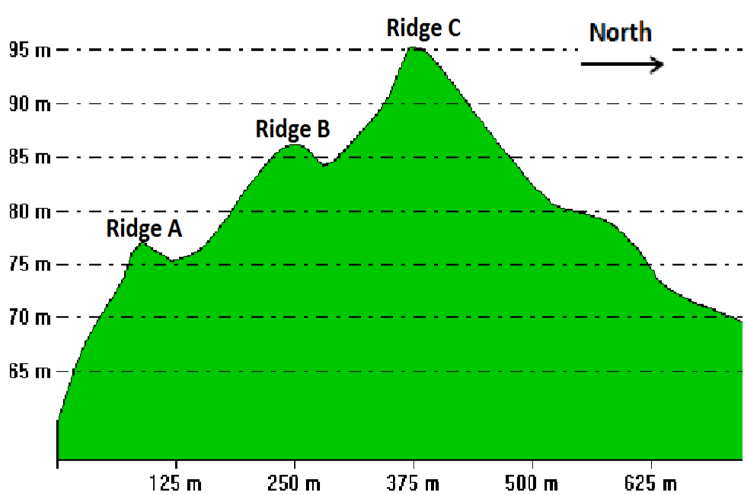


Figure 8: Cross section of the path in the Bald Hill complex that GPR data was collected from.

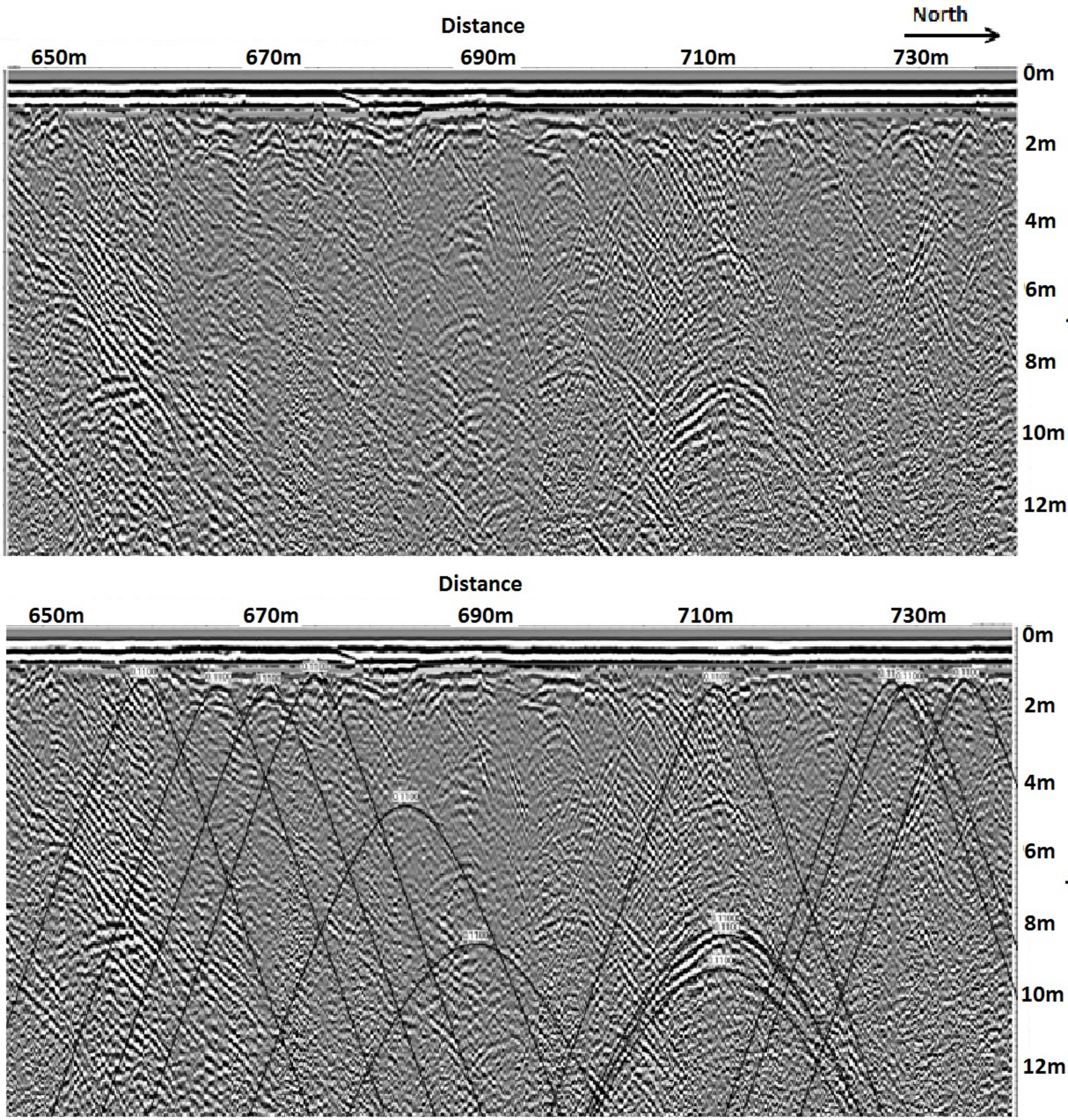


Figure 9: 200 MHz radiogram (not topographically corrected) showing hyperbolas in positions where possible cobbles and boulders are present.

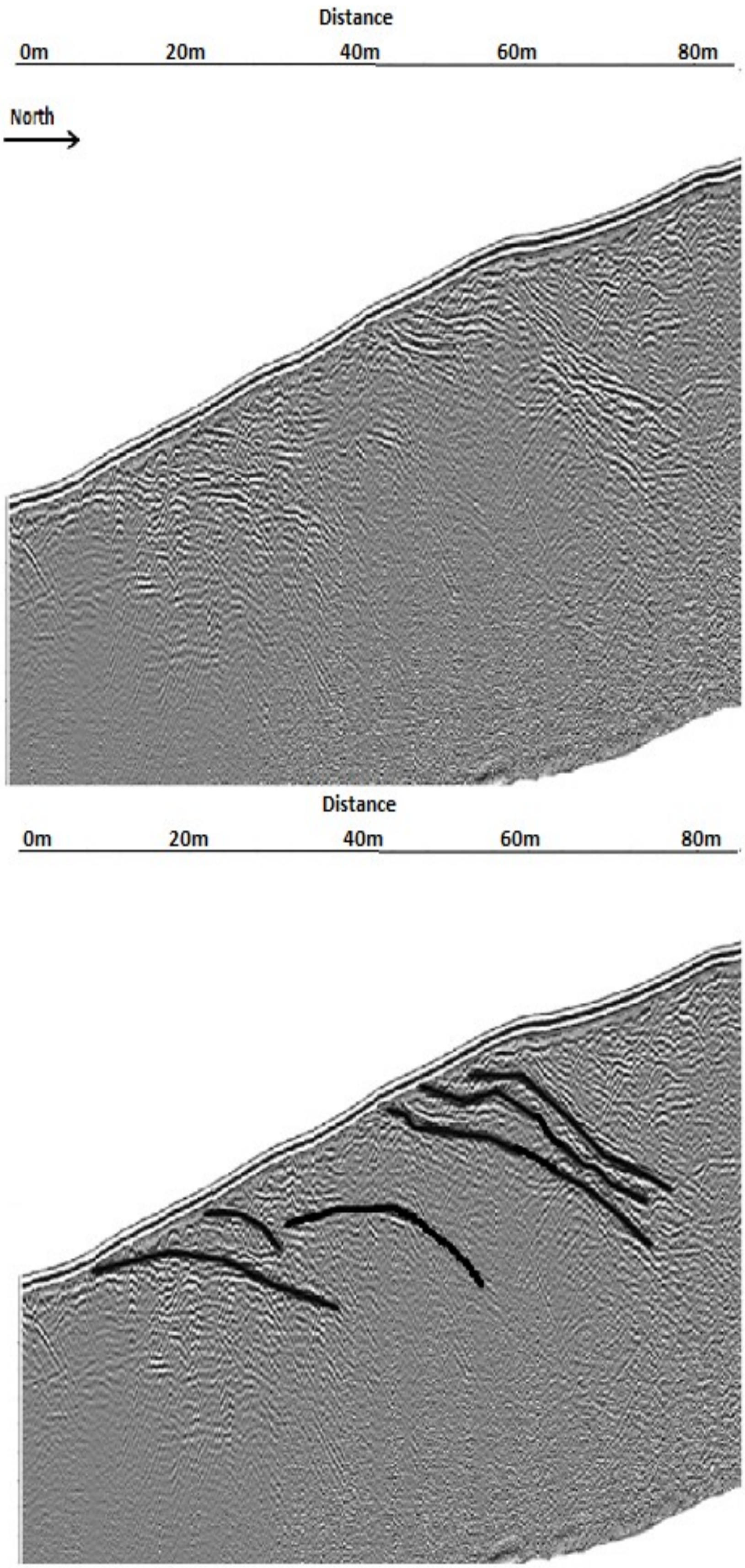


Figure 10: 200 MHz radiogram (topographically corrected) showing slightly folded and dipping beds located 20 meters from the starting point. Truncated beds reaching depths of about 13 meters, are located 60 meters from the starting point.

Folds and dipping beds are evident throughout the 200 MHz radiogram and in many areas tend to roughly mimic the topography. Slightly folded and dipping beds that reach the surface are present at 20 meters from the starting point (Figure 10). Truncated beds reaching depths of about 13 meters are present at a distance of 60 meters from the starting point (Figure 10). Between 160 and 200 meters from the starting point, there is a small fold representing a northern limb of an anticline dipping roughly 18° to the north (Figure 11). This fold reaches depths of about 12 meters. The fold mimics a small hill, suggesting that the fold axis is near the crest of the hill. Folds reaching depths of 18 meters dip approximately 28° to the north between 220 and 260 meters from the starting point (Figure 12).

These folds, located around the limb of a larger anticline, follow the topography of the second small ridge. At the summit, around 260 meters from the starting point, dipping beds that parallel the topography and dip in the same angle as the folds are present (Figure 12). From 360 to 450 meters from the starting point, dipping beds and folds are present, dipping about 25° to the north (Figure 13). Slightly dipping beds and folds parallel the topography of the northern part of the hill from 540 to 610 meters from the starting point (Figure 14). Very steep beds dipping 54° to the north are present from 620 to 670 meters from the starting point (Figure 15).

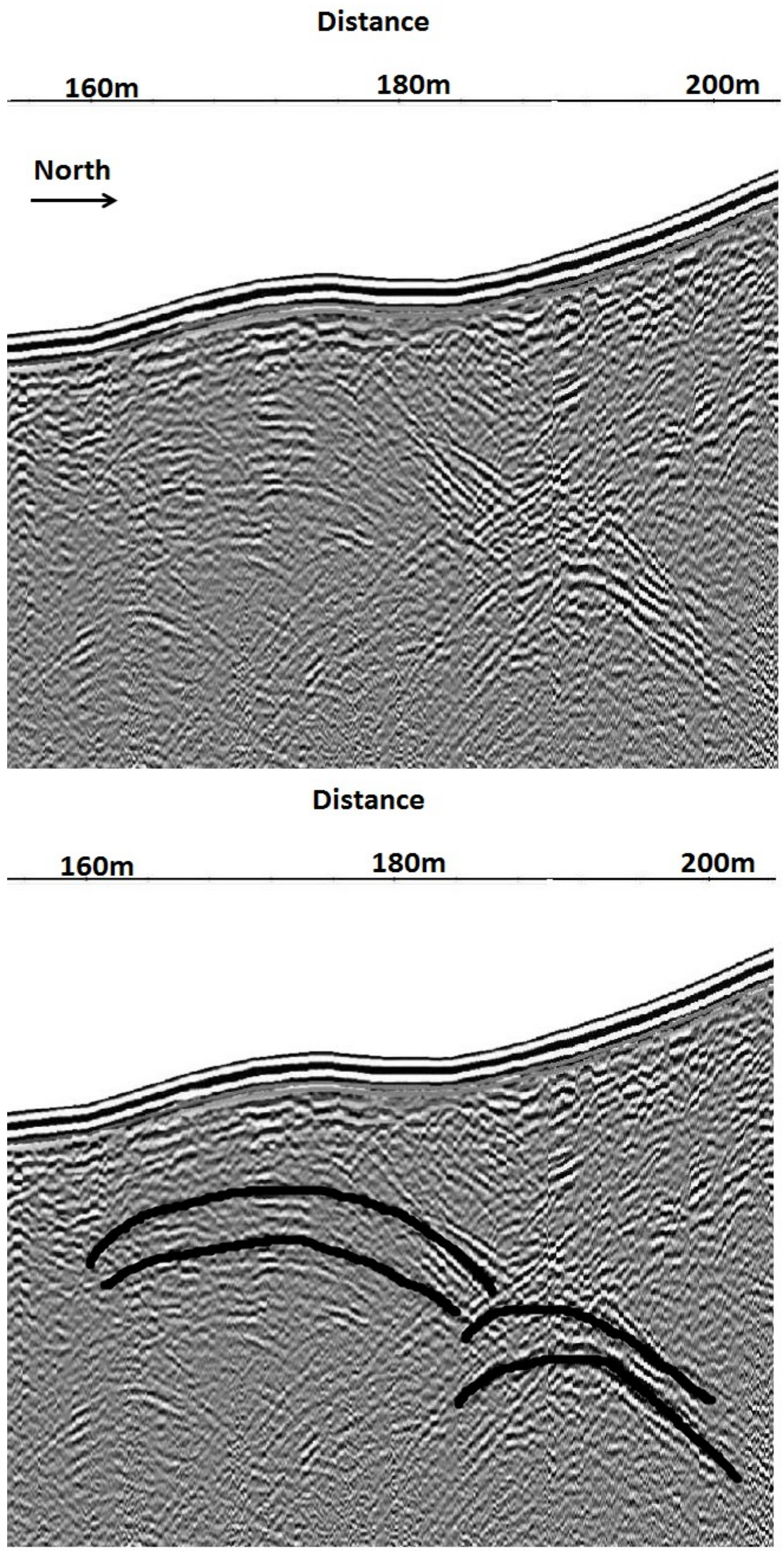


Figure 11: 200 MHz radiogram showing small folds from 160 to 200 meters from the starting point. These are not diffraction hyperbolas as determined by an attempt to fit to hyperbolae on non-topo corrected radiograms.

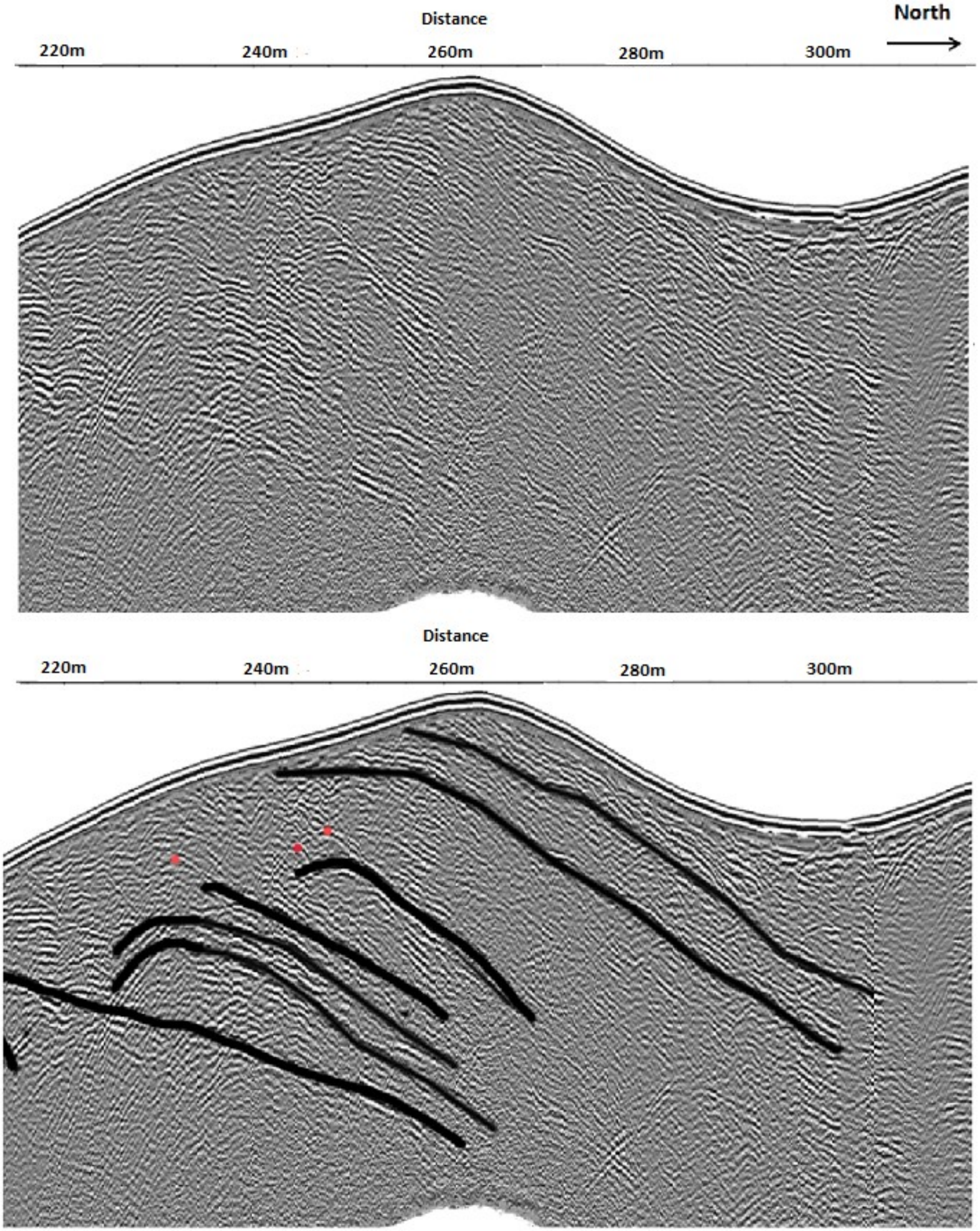


Figure 12: 200 MHz radiogram showing folds reaching depths of 18 meters between 220 and 260 meters from the starting point. Some of the cobbles are shown in red.

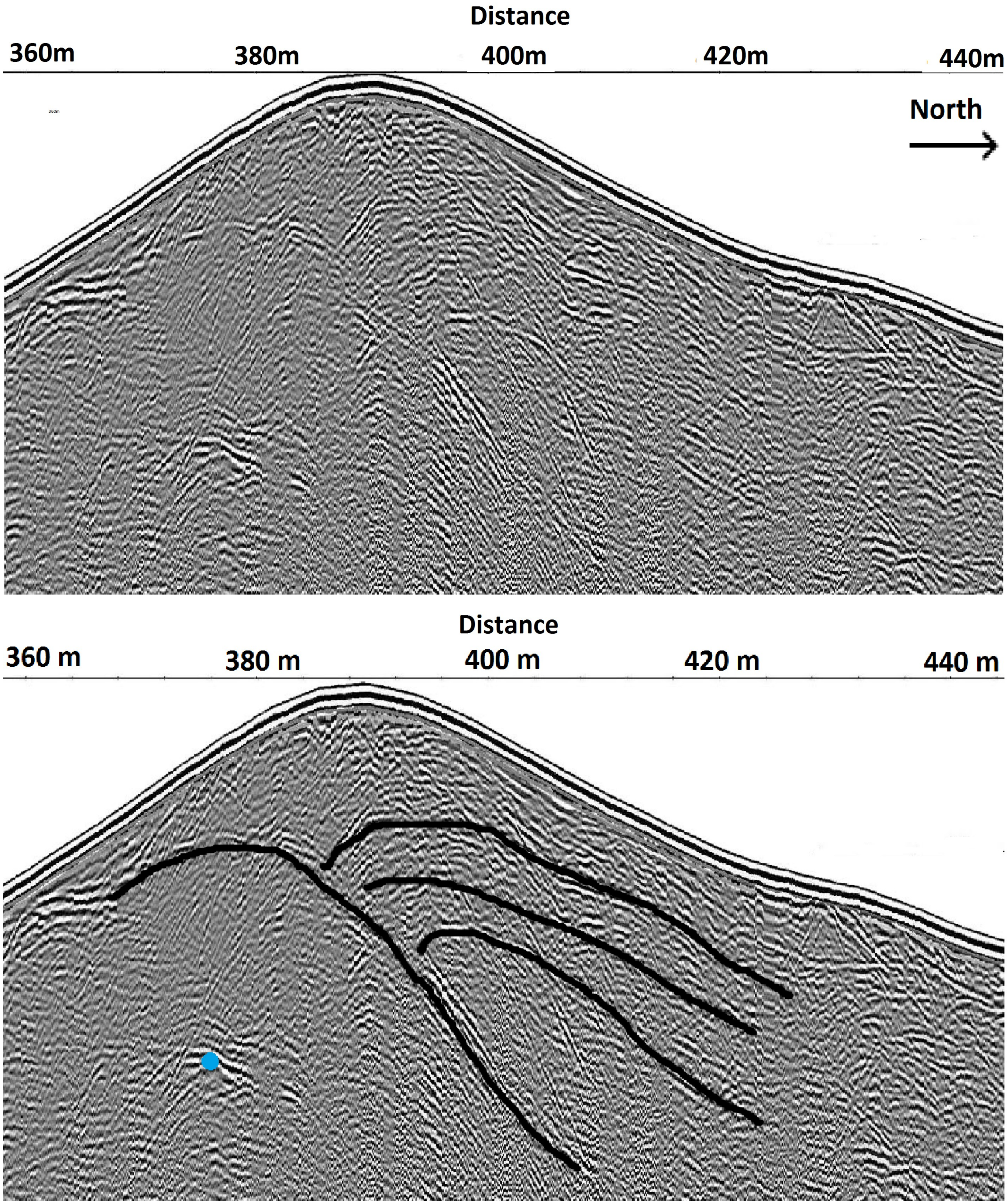


Figure 13: 200 MHz GPR radiogram showing dipping beds and folds from 360 to 450 meters from the starting point. A possible cobble is shown as a blue dot. Hyperbola fitting before topo correction show that the key layers indicated are layers and not boulders.

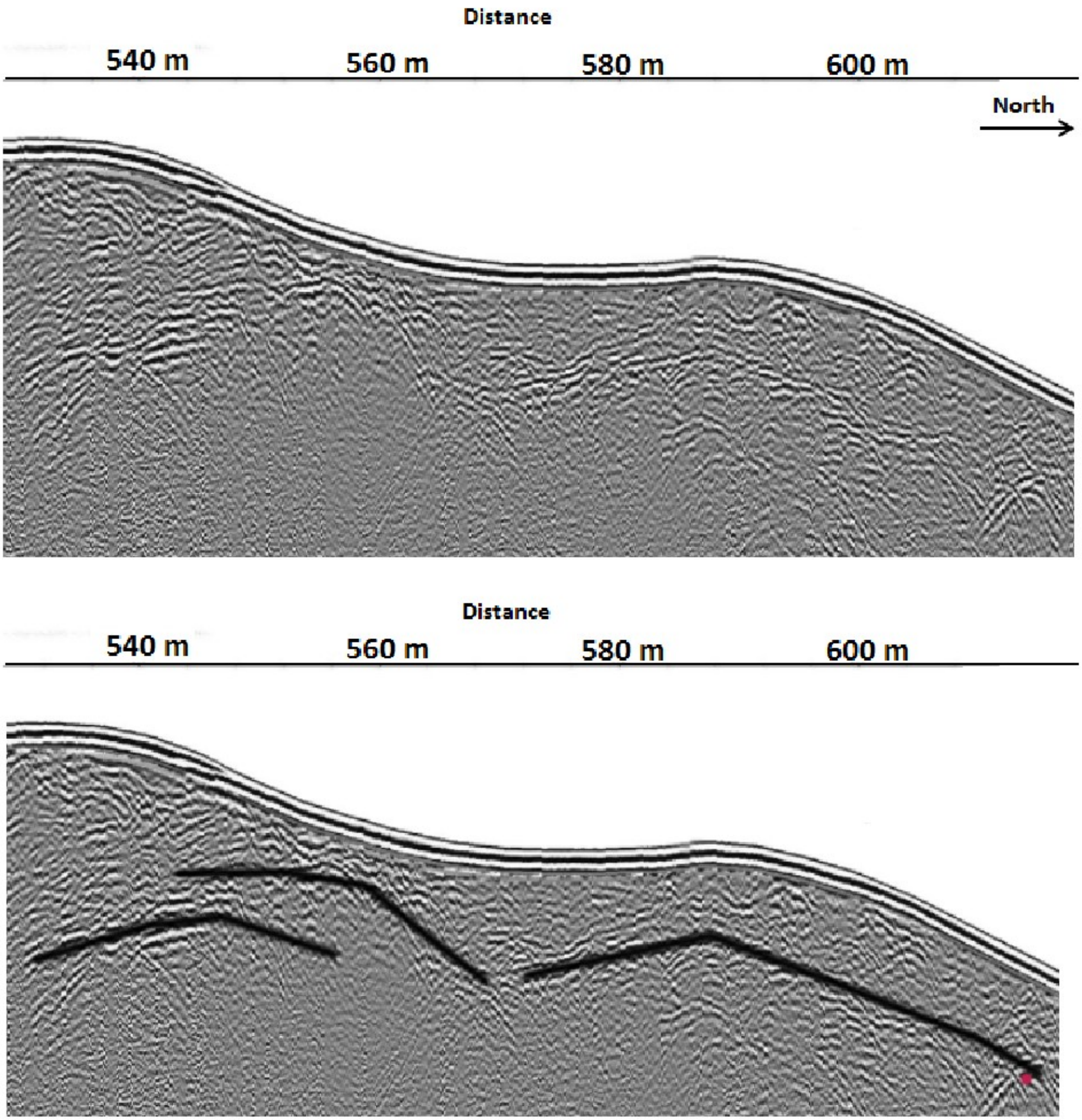


Figure 14: 200 MHz radiogram showing slightly dipping beds and folds that roughly follow topography from 540 to 610 meters from the starting point. A cobble is shown as a red dot.

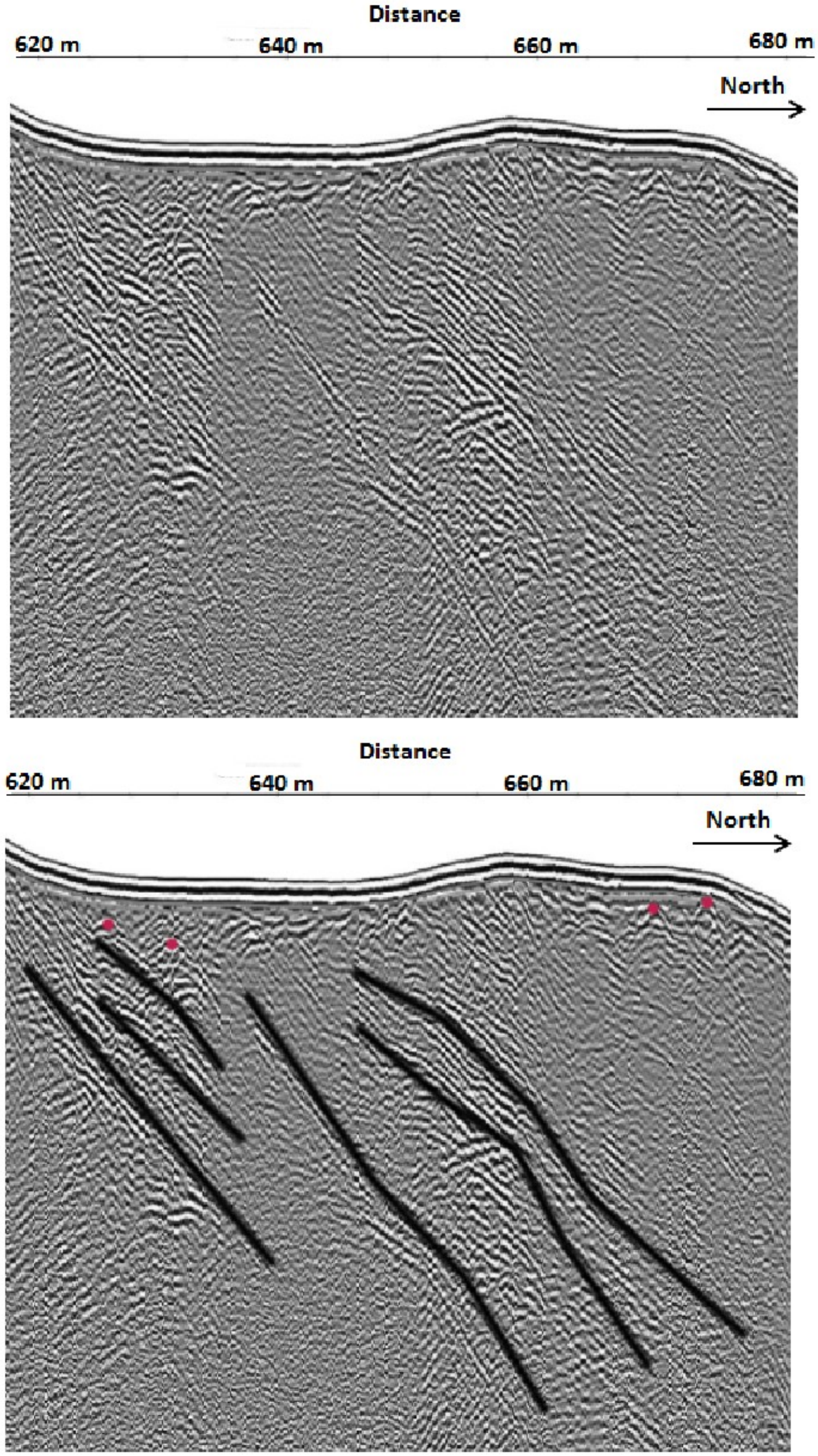


Figure 15: 200 MHz radiogram showing steeply sipping beds from 620 to 670 meters from the starting point. Cobbles are shown as red dots.

Interpretation

When studying the Bald Hill complex, it is important to compare the characteristics, both above and below the surface, to the hill of a hill-hole pair. The features of a typical hill-hole pair can be seen in the Bald Hill complex.

1. *Arcuate or crescentic outline of hill; concave on the upglacier (proximal) side, convex in the downglacier (distal) direction.* When looking at the region in map view, the outlines of the hills are concave on the northern side and convex on the southern side. This corresponds to the direction of the glacial advance (see Figure 2).
2. *Multiple, subparallel, narrow ridges separated by equally narrow valleys following the overall arcuate trend of the hill.* There are multiple ridges visible in map view, which are parallel to each other and follow the arcuate trend of the hill (see Figure 2).
3. *Asymmetrical cross profile of hill; higher with steeper slopes on convex (distal) side, lower with gentler slopes on concave (proximal) side.* When looking at the side profile of the complex, the two major ridges have steeper slopes on the convex side and gentle slopes on the concave side. This is particularly evident in ridge 2 (Figure 7).
4. *Topographic depression on concave (upglacier) side of hill; area and shape of depression approximately equal to that of hill.* In the Bald Hill complex, the hole of the hill-hole pair is not visible. The cross section (Figure 5) of Long Island shows a hole that has been filled in with Upper Glacial sediment that could possibly be associated with the Bald Hill Complex (Smolensky, 1990). However, there is controversy surrounding this issue because Criscuola (2010) studied a well log (S58761) that is located in the hole and believes it is Magothy sediments rather than Upper Glacial.

GPR data shows folds and dipping beds that parallel the topography throughout the radiogram (Figure 16). When looking at the subsurface, if it is an ice shove feature, ridges and their associated fault-propagating folds are present. In the GPR radiograms folds are present, but the associated faults are not seen, but the fold geometries indicate where the faults would likely be located.

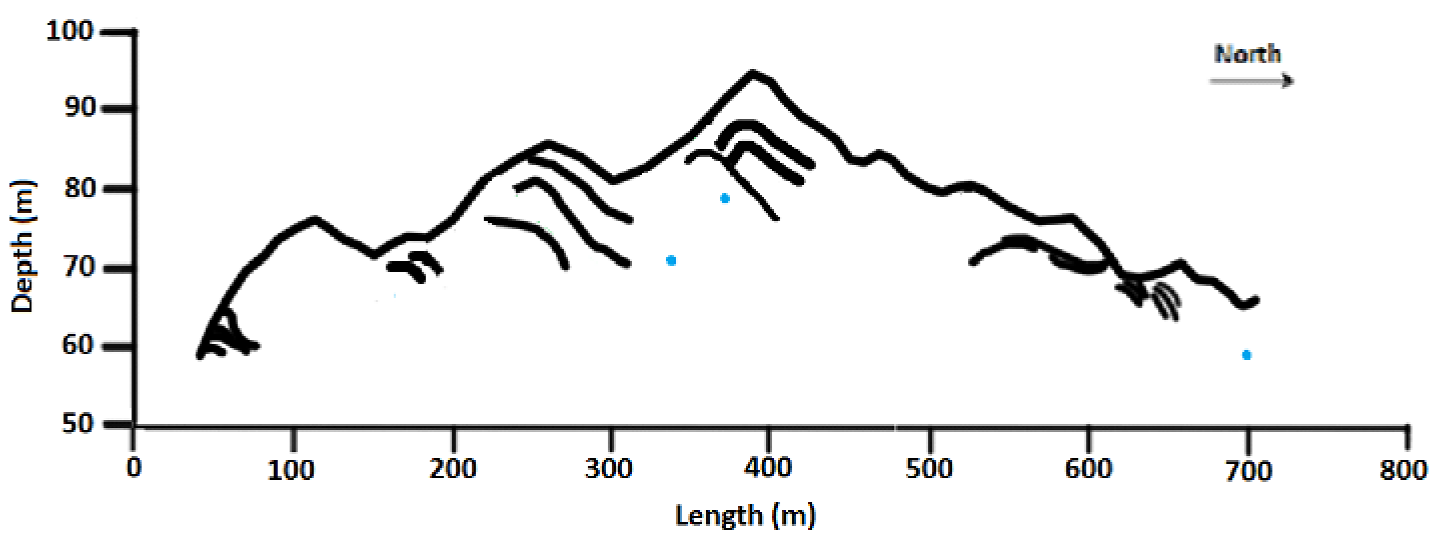


Figure 16: An interpretation of the features on the path based on the GPR radiogram from 0 to 720 meters. Dipping beds and folds are shown as black lines and boulders are shown as blue dots.

Folds that roughly follow the topography are evident on both the second ridge (Figure 12) and the third ridge (Figure 13). As the bedding layers were thrust up by the glacier, the ridges and the associated folding formed simultaneously. Folds are truncated at the surface around 60m (Figure 10) and 260m (Figure 12) from the starting point. Aber (2007) states that it is common for the hills to undergo erosion and be reduced in size. Folds that have been eroded from the top are also seen in the Ashley Schiff Park Preserve (Tingue *et al*, 2004)

The presence of till, (cobbles and boulders), exists at different depths in the radiogram. This suggests that the material that was pushed up was previously covered by a glacier. The glacier went over the top because till was also found at the surface. Figure 17 shows the advance of the glacier that deposited till on the surface of the folds.

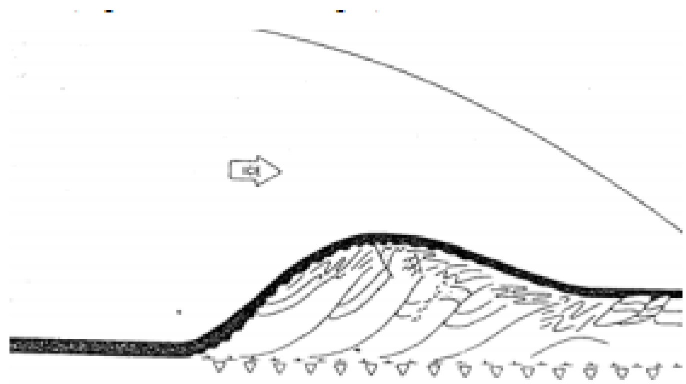


Figure 17: Erosion of the top of the hill as the glacier traveled over. Till over the surface is represented by the thick black line.

This research shows that glaciotectonics are present beneath the surface of the region, which suggests that this could be a combination of hill-hole pairs rather than a continuous moraine. The term "moraine" has been typically defined as a depositional feature resting on the surface. Fuller (1914) describes Bald Hill as a "confluent cone", which is a product of the discharge of glacial streams that produce deposits unified into a ridge. The tectonics present suggest that this hill complex is glacial tectonic feature and not a depositional feature as was previously thought.

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