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Natural Resources Conservation Service

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Subject: Stratigraphic investigations with ground-penetrating radar (GPR) at Wrightsville Beach and Arapahoe Ridge, North Carolina; 22 to 26 January 1995.

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Purpose:
To use GPR to investigate and characterize subsurface stratification at Wrightsville Beach in New Hanover County, and along the Arapahoe sand ridge in Pamlico and Beaufort counties. The radar profiles will be used to chart and characterize stratigraphic layers and to help interpret the evolution of these landforms.

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Activities:
On 23 and 24 January, GPR surveys were conducted at Wrightsville Beach in New Hanover County. Multiple, subparallel traverses using different scanning times were conducted with GPR along each side of Wrightsville Beach (each about 4.4 miles). In addition, several shore-normal transects were conducted along some east-west roads. Survey activities were completed at Wrightsville Beach on the morning of 24 January.

During the afternoon of 24 January, calibration trials were completed on several sections of the Arapahoe sand ridge in Pamlico County. During the morning of 25 January, about 16.2 miles of continuous radar profiles were obtained along Route 306 from Grantsboro to Bonnerton in Pamlico and Beaufort counties. This traverse was conducted along and parallel with the crest of the Arapahoe sand ridge. During the afternoon of 25 January, transects were conducted along several east-west roads which were normal to the long axis of the ridge. On 26 January, two representative traverses were rerun for the purpose of processing and inclusion in this report. On the afternoon of 26 January, multiple traverses were conducted along the top of a cut bank to a sand pit. The purpose of these traverses were to estimate the velocity of signal propagation and dielectric constant of the sandy soil materials.

Ground-penetrating radar:

Background:

Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. The use and operation of GPR have been discussed by Morey (1974), Doolittle (1987), and Daniels and others (1988). This system operates by transmitting short pulses of electromagnetic energy into the ground from an antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the transmitting antenna. Whenever a pulse contacts an interface separating layers of differing electromagnetic properties, a portion of the energy is reflected back to the receiving antenna. The receiving unit amplifies and samples the reflected energy and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms are displayed on a thermal recorder or are stored on an internal disk drive for future playback and/or post-processing.

Ground-penetrating radar techniques have been used to provide high resolution stratigraphic profiles of offshore (Pratt and Miall, 1993) coastal (Smith and Jol, 1992, Meyers and others, 1994, van Heteren and others, 1994); deltaic (Jol and Smith, 1992); and lacustrine (Jol and others, 1994) deposits. In these studies, radar profiles were used to study the stratigraphy and evolution of these features. Scanning times varied with environments and ranged from 145 to 335 nanoseconds (ns). In each of these studies, results varied with depositional environment. In the study conducted by van Heteren and others (1994), a SIR System-3 radar unit with a 120 mHz was used. In this study, which was conducted along a number of barrier beaches and spits in New England, GPR was used to study the evolution of these features and to determine locations for subsequent vibracore observations. These authors provided a summary of characteristic radar signatures for several depositional environments. The other studies were conducted in Canada, Utah, and Washington with pulseEKKO radar systems. These studies used lower frequency antennas but achieved comparable depths of observation.

Equipment:

The radar unit used in this study was the Subsurface Interface Radar (SIR) System-2 manufactured by Geophysical Survey Systems, Inc. (GSSI).* The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. Radar profiles were plotted on a model GS-608P thermal plotter/printer. The system was powered by a 12-volt vehicular battery. The model 3110 (120 mHz) antenna with a model 705DA transceiver was used in this investigation. A lower frequency, model 3207 (100 mHz) was available, but not used during this study. As most transects were conducted over paved or gravel roads and the model

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* Trade names are used to provide specific information. Their mention does not constitute endorsement.

3207 lacked runners, the antenna would have suffered prohibitive wear on these coarse surfaces.

The radar profiles included in this report have been processed through RADAN software. Processing was limited to signal stacking, horizontal scaling, compression, terrain correction, customizing color transform and color tables, and annotations. The scales along the left-hand border of the included radar profiles (enclosed envelope, sheets 1 to 3) represent two-way travel time and are in nanoseconds.

Interpretations:

A. The radar profile -
Reflected radar waveforms were plotted on thermal sensitive paper in a raster-scan, thermal plotter/printer. Through a thermo-chemical reaction, radar images are developed as the thermal sensitive paper is moved under a fixed thermal printhead. The intensity of these images are dependent upon the amplitude of the reflected signals.

Figure 1 is an example of a radar profile. The horizontal scale represents units of distance traveled along an antenna traverse. This scale is dependent upon the speed of antenna advance along a traverse line and the rate of paper advance through the thermal plotter. The vertical scale is a time or depth scale which is based on the velocity of signal propagation.

The four basic components of a radar profile have been identified in Figure 1. These components are the start of scan pulse (A), inherent antenna noise (B), surface image (C), and subsurface interface images (D). Each of these components, with the exception of the start of scan pulse, is generally displayed as a group of dark bands. The number of bands can be limited by high rates of signal attenuation or superimposed signals. These bands limit the ability of GPR to discriminate closely spaced interfaces. The dark bands occur at both positive and negative signal amplitudes. The narrow white band(s) separating the darker bands represent the neutral or zero crossing between positive and negative signal amplitudes.

The start of scan image (see A in Fig. 1) results from direct feed-through of transmitted pulses into the receiver section of the antenna. Though a source of unwanted clutter, the start of scan pulse is often used as a time reference line.

Reflections unique to each of the system's antennas are the first series of multiple bands on radar profiles. Generally the width of these bands increases with decreasing antenna frequency or signal filtration. These reflection (see B in Fig. 1) are a source of unwanted noise on radar profiles.

The surface image (see C in Fig. 1) represents the ground surface. Below the image of the surface reflection are images from subsurface interfaces (see D in Fig. 1). Interfaces can be categorized as being either plane or point reflectors. Most soil horizons and geologic strata appear as a series of continuous, parallel bands similar to those appearing in Figure 1. Features that produce these reflections are referred to as "plane reflectors." Small objects such as rocks, roots, or buried cultural features can produce a hyperbolic pattern similar to the feature

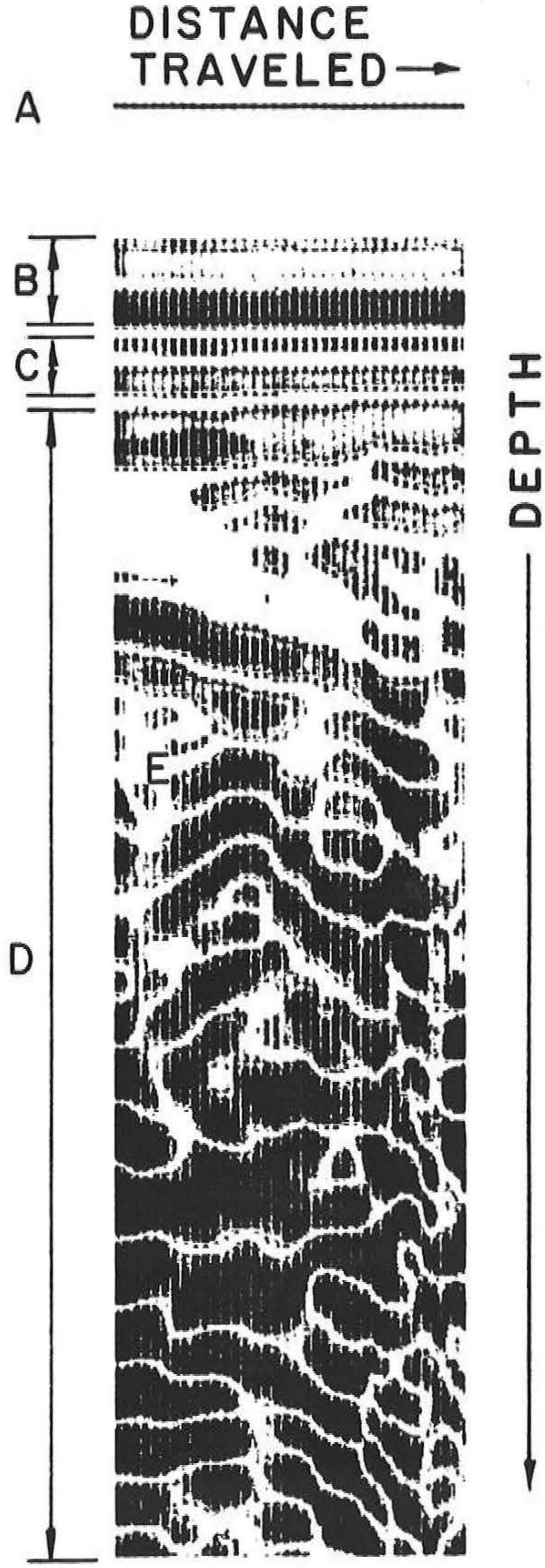


FIGURE 1
RADAR PROFILE

appearing (weakly expressed) to the right of E in Figure 1. Features that produce these reflections are referred to as "point reflectors."

B. Calibration -
Generally, for most investigations, soil auger or coring data as well as exposures and observation pits are used to verify interpretations and confirm the depths to known reflectors. These data are used to determine the depth scale(s). However, in this study, few observations and no deep corings were made to confirm interpretations or observation depths.

The GPR is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g. soil horizon, stratigraphic layer) and back. In order to convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationship among depth (d), two-way, pulse travel time (t), and velocity of propagation (v) are described in the following equation:

$$v = 2d/t$$

The velocity of propagation is primarily effected by the dielectric constant (e) of the profiled material(s) according to the equation:

$$e = (c/v)^2$$

where c is the velocity of propagation in a vacuum (0.3 m/s). The amount and physical state (temperature) of water has the greatest effect on the dielectric constant of a material. Tabled values are available that approximate the dielectric constant of some materials (Morey, 1974; Petroy, 1994). However, as discussed by Daniels and others (1988), these values are approximations.

Calibration trials were conducted at each of the two principal sites using different scanning times. The objectives of these trials were to determine the dielectric constant and velocity of propagation of electromagnetic energy through surface soil layers, establish crude depth scale(s), and optimize control and recording settings.

During calibration trials, multiple traverses were conducted with the 120 mHz antenna. Considerations of desired versus achievable depths of observation and the resolution of subsurface features influenced the selection of scanning times. The 120 mHz appeared to provided reasonable depths of observation. Scanning time used in this investigation varied from 110 to 370 ns. A scanning rate of 32 scans/sec was used in these trials and in all subsequent field work.

At each principal site, based on known depths to buried reflectors, a velocity of propagation and a depth scale were estimated for the surface soil layers. Reflectors, buried at depths of 50 cm on Wrightsville Beach and 95 cm on Arapahoe ridge, were distinguishable on radar profiles. Figure 1 is a radar profile taken in a borrow pit on the Arapahoe ridge in an area of Tarboro loamy sand, 0 to 5 percent slopes. Tarboro is a member of the mixed, thermic Typic Udipsamments family. In Figure 1, the reflection (hyperbolic pattern) from a buried metallic reflector is evident to the immediate right of "E." This profile was recorded using a 120 mHz antenna with a scanning time of 110 ns. Based on the round-trip travel time to this reflector, the velocity of propagation was estimated to be 0.067 m/ns. The dielectric constant was estimated to be 4.7. The estimated dielectric constant is within the range specified by Morey (1974) for dry sands (4 to 6).

As the reflectors were buried at depths of less than 1 m, estimated velocities of propagation and dielectric constants were appropriate for only the surface layers in areas of excessively drained, sandy soils. As radar traverses crossed several soils and numerous subsurface layers or facies of variable compositions, no single value is appropriate for either the dielectric constant or velocity of propagation. However, as a large proportion of the traverses were conducted in areas having sandy materials and relatively shallow depths to water tables, the dielectric constant and velocity of propagation for saturated sands (30 and 0.055 m/ns, respectively) can be used to obtain a conservative or ballpark estimate of the maximum depth of observation. Based on these values, scanning times of 210 and 240 ns would provide maximum observation depths of about 5.8 and 6.6 m, respectively.

Because of the high electrical conductivities of the beach sands at Wrightsville Beach, the maximum observation depth was reduced. Depths of observation were greatest on the higher-lying portions of dunes. In most areas below an elevation of about 5 feet, observation depths were less than 1.5 m. Along Arapahoe ridge, observation depths exceeded 6.6 m except along toe slope areas where the sand ridge merged with finer textured and more conductive materials.

C. Performance -
Ground-penetrating radars do not perform equally in all soils. The maximum observation depth of GPR is, to a large degree, determined by the conductivity of the soil and geologic materials. Materials having high electrical conductivities rapidly dissipate the radar's energy and restrict observation depths. The principal factors influencing the conductivity of soils and geologic materials to electromagnetic radiation are: (i) degree of water saturation, (ii) amount and type of salts in solution, and (iii) the amount and type of clay.

Electromagnetic conductivity is essentially an electrolytic process which takes place through moisture filled pores. As water-filled porosity is increased, the velocity of signal propagation is reduced and the rate of signal attenuation is increased. As the degree of water saturation increases, the observation depth of the radar is restricted.

Electrical conductivity is directly related to the concentration of dissolved salts in the soil solution. Ions absorbed to clay particles can undergo exchange reactions with ions in the solution and thereby contribute to the electrical conductivity of soils and geologic materials. The concentration of ions in solution is dependent upon the clay minerals present, the relative proportion of ions on exchange sites, the degree of water filled porosity, the pH of the solution, and the nature of the ions in solution. Depth of observation is less than 25 cm in salt water or on most foreshore (intertidal) areas.

Soil texture (clay content) and mineralogy strongly influence the performance of GPR. The maximum observation depth of GPR increases as the clay content decreases and the proportion of low activity clays increases. Generally, observation depths are 5 to 25 meters in coarse textured soils, 2 to 5 meters in moderately-coarse textured soils, 1 to 2 meters in moderately-fine textured soils, and less than 0.5 to 1.5 meters in fine textured soils. As discussed earlier, these observation depths become less as the concentration of soluble salts in solution and the exchange activities of clays increase. Along the Arapahoe ridge, finer-textured soil materials on toe slope areas, and thin bands or strata of finer textured materials restrict observations depths.

The amount of energy reflected back to an antenna from a subsurface interface is a function of the dielectric gradient existing between the adjoining materials. The greater or more abrupt the difference in dielectric properties, the greater the amount of energy reflected back to the antenna, and the more intense will be the amplitude of the image recorded on the radar profile.

The radar profiles contained reflections from numerous, often segmented stratigraphic layers. These layers varied laterally in expression. On some radar profiles, reflections from these layers were poorly expressed or partially masked by adjacent strata. The radar detects but does not identify subsurface interfaces. In areas where subsurface layers are numerous or segmented, a large number of auger or coring observations would be required to satisfactorily interpret the radar profiles.

Discussion:

General:

Radar profiles were obtained from the two study sites. It is hoped that these profiles will provide a better understanding into the internal structure and evolution of the selected landforms. In addition, these profiles can guide future exploratory observations on these landforms. Hopefully, with time, sufficient experience and ground-truth verifications, many of the graphic signatures appearing on these profiles can be used to help characterize the stratigraphy and evolution of barrier island units.

This study was the first opportunity that I had to operate the SIR System-2 unit. This opportunity was not without some difficulties. I forgot to bring the remote marker. Difficulties were encountered in establishing the correct settings on the thermal plotter. Engineers at Geophysical Survey System, Inc., have mistakenly programmed a reversed grey-scale (high amplitude reflections were printed as white rather than black) into SIR System-2 units. This "reversed" grey-scale is improper and has complicated the establishment of acceptable settings on the thermal plotter. As a consequence, the interpretability of the radar profiles developed on the thermal plotter has been reduced. A program modification is being developed by GSSI which will correct this error.

The included radar profiles were selected from the taped data. These profiles were processed through RADAN software to improve interpretations and to illustrate some of the major stratigraphic features using a more appropriate grey-scale. The general location and trend of some subsurface interfaces have been approximated with dark lines. These lines have been drawn to emphasize the location, extent, and stratigraphic characteristics of some, but not all, subsurface layers.

While the depths of observation were more restricted than anticipated, much information can be gleaned from the radar profiles. With sufficient ground-truth observations, these profiles may help to improve interpretations of these landforms and stratigraphic units.

Wrightsville Beach:
Wrightsville Beach is a barrier island. Maximum elevation and relief are about 4.6 m. The island was mapped as Newhan fine sand (Weaver, 1977). Newhan is a member of the mixed, thermic Typic Udipsamments. This excessively drained soil is on dunes. Because of the sensitive nature of these relatively unstable habitats, and limited accessibility, only the lower side slopes of dunes could be traversed with GPR. Most radar traverses were conducted on lower-lying backshore areas of coastal beaches and urban areas. Because of high electrical conductivities, foreshore areas were prohibitive to GPR. Foreshore areas are partially covered by salt water during high tides and are washed and rewashed by waves.

The upper profile on Sheet 1 is from a traverse conducted along a shore-parallel street on the southern, west side of Wrightsville Beach. The traverse was conducted in a southerly direction (north is to the left). As most radar profiles obtained at Wrightsville Beach were exceedingly depth restricted and generally of poor quality, the profile appearing in the upper part of Sheet 1 is not considered to be representative.

Discontinuous soil horizons and/or strata appear across the upper part of the profile (see "A," Sheet 1, upper profile). These features may represent fill materials used in urban development and/or interfaces separating major storm deposits.

Because of the high levels of signal amplification needed to penetrate the relatively conductive beach deposits, unwanted background noise in the form of parallel, horizontal bands are apparent at "B." These bands are caused by signal reverberation or "ringing." Another form of background noise is the strong, multiple bands in the lower part of the profile (see "C"). These bands are known as double return echoes.

Numerous point reflectors, identified by their hyperbolic patterns can be seen in this profile. These reflections most likely represent buried utility lines, pipes, or other artifacts. If metallic, these reflectors produced reverberated signals similar to those apparent at "D."

A major subsurface interface is apparent to the left of "E." Its irregular and non-parallel configuration suggests a former erosional surface, possibly a former tidal inlet. Multiple sets of dipping interfaces (see "F" in Sheet 1, upper profile) suggest foreset progradation. As these interfaces dip towards the south, their shape, orientation, and stratigraphic relationships suggest a southerly movement of materials.

As the vertical scale is exaggerated, the dip of these interfaces can not be determined directly from the radar profiles. The inclination can only be determined with an appropriate depth scale (requires ground truth verification at several observation points) and a horizontal distance scale between known observation points. While several researchers (Jol and Smith, 1992; Jol and others, 1994; Smith and Jol, 1992) have reported angles of inclination for similar interfaces, it is unclear whether these angles were measured directly from the radar profiles (an incorrect procedure) or were calculated.

High rates of signal attenuation restricted observation depths and weakened reflections from subsurface interfaces (see "H" in Sheet 1, upper). Along Wrightsville Beach, attenuation was principally associated with the concentrations of soluble salts.

In the upper profile on Sheet 1, an eolian sand dune was crossed at "G." Because of increased elevations and depths to salt water, observation depths increased on most dunes. Interfaces within the upper part of the dune (see "G") probably reflect successions of wind blown deposits. Beneath these interfaces, multiple sets of dipping interfaces suggest foreset progradation.

Arapahoe Ridge:
The investigated sand ridge has been referred to as the Minnesott ridge (DuBar et al., 1974) and the Arapahoe ridge (Daniels et al., 1977). These researchers have interpreted this feature as being a portion of a former barrier system (DuBar et al., 1974) and as a former storm beach ridge (Daniels et al., 1977). The east slope of this ridge is known as the Suffolk scarp, a shoreline feature of the Pamlico sea. The base of this scarp is at an elevation of about 5.8 m. This scarp separates the Talbot from the Pamlico surfaces (Daniels et al., 1977).

The Arapahoe sand ridge, located between the Pamlico and Neuse rivers, is about 43.5 km long and about 0.8 to 1.6 km wide. Maximum relief along this linear ridge is about 6.1 m. Along the axis of the ridge, about 4.6 to 6.1 m of sands have been estimated to overly the Talbot morphostratigraphic unit (Daniels et al., 1977). These authors describe the contact with the Talbot unit as abrupt, often with observable increases in clay, silt, and/or organic materials.

The radar profiles selected for inclusion in this report are from the portion of the Arapahoe sand ridge shown in Daniels and Hammer (1992). Sheet 1 (lower profile) is a processed radar profile collected along a 3.2 km portion of North Carolina 306. This profile was collected along the portion of NC 306 shown in Figure 6.22 of Daniels and Hammer (1992). Sheet 2 (upper profile) is a processed radar profile collected along county road 1201 from the junction with NC 306 to the base of the Suffolk scarp (see Figure 6.22 in Daniels and Hammer, 1992). Sheet 2 (lower profile) and Sheet 3 (upper and lower profiles) are processed radar profiles collected along county road 1927. These profiles provide a continuous cross-section of the Arapahoe ridge from its western to eastern toe slope areas.

Highway 306 -
The lower profile on Sheet 1 is from a 3.2 km, south to north traverse conducted along Route 306 from near the community of Sandhill to Bennett (see Figure 6.22 in Daniels and Hammer, 1992). The traverse was conducted in a northerly direction (south is to the left). Relative distances (in meter) have been approximated across the upper part of this profile.

Reflections from a soil horizon appear across the upper part of this profile (see "A"). The irregular depth to this interface may reflect the wavy topography of the soil horizon, slight differences in surface elevation, or both. The dominant soils along this traverse were Leon and Tomahawk. Leon is a member of the sandy, siliceous, thermic Aeric Haplaquods family. Tomahawk is a member of the loamy, siliceous, thermic

Arenic Hapludults family. Both soils have spodic horizons. It is probable that the interface ("A") represents the spodic horizon.

Multiple sets of dipping interfaces (see "B" in Sheet 1, lower) suggest foreset progradation. As these interfaces dip toward the south, their shape, orientation, and stratigraphic relationships suggest a southern migration of materials.

Several bands of unwanted background noise are apparent in this profile. Because of the high levels of signal amplification, horizontal bands of unwanted background noise are apparent at "C." These bands are caused by the reverberation of reflected signals or "ringing."

Two major subsurface interfaces are apparent below "D." These interfaces appear to have irregular, highly oblique configurations. However, considering the excessive vertical exaggeration in this profile, these interfaces are believed to consist of nearly level, alternating interfaces.

Near "E," several poorly expressed, irregularly shaped, segmented interfaces are apparent. Collectively, these interfaces provide a unique and recognizable radar signature. These interfaces may comprise a distinct stratigraphic unit or sequence of layers. The poor expression of these layers may be a reflection of the "very poor preservation of bedding" in exposures of the sands of the Arapahoe ridge noted by Daniels and others (1977).

County Road 1201-

GPR Survey:

The upper profile on Sheet 2 is a processed radar profile collected along county road 1201 from the base of the Suffolk scarp to the junction with NC 306 (see Figure 6.22 in Daniels and Hammer, 1992). This radar profile has been compressed and terrain corrected. The traverse was conducted in an east-west direction (east is to the left). The short vertical lines appearing at the top of the profile represent equally-spaced (30.5 m) observation points. Distances (in meter) were measured with a tape. Relative elevations (for terrain correction) were measured with a level and stadia rod.

The eastern 305 m portion of this traverse was conducted away from the base of the Suffolk scarp. Soils in this portion of the traverse were members of the Stockade (fine-loamy, mixed, thermic Typic Umbraqualfs) and Wasda (fine-loamy, mixed, thermic Histic Humaquepts) series. These nearly level, very poorly drained soils have attenuating, loamy subsoil. In these soils (see "A") observation depths were restricted to the upper part of the soil profile. In addition, the depth of observation was restricted and the amplitude of subsurface interfaces reduced near "D." Thin layers of finer textured soil materials, seepages and/or contaminants are possible factors producing these higher rates of signal attenuation.

Accumulations of slope debris are evident at "B." These reflections represent multiple layers of materials washed down the road from higher lying slope positions.

Near "C"(on Sheet 2, upper), multiple sets of superimposed, parallel interfaces dip gently towards the east and suggest possible foreshore facies formed in an intertidal area. Along the scarp, several subsurface interfaces are apparent below "E." These interfaces appear to consist of alternating beds which are inclined towards and intercepts the scarp. To the left of "F," these interfaces appear to be truncated by a more steeply inclined interface. Near "F," an area of no signal return is evident. This area may consist of uniform (and therefore non-reflecting) materials or more attenuating materials which weaken the amplitudes of the reflected signals.

Beneath the crest of the Suffolk scarp (between observations points 0 to 61 m), subsurface interfaces appear to be horizontal and consist of multiple, parallel layers (see "G" on Sheet 2, upper profile).

A major subsurface interface has been marked across the lower portion of this radar profile (see line above "H" on Sheet 2, upper profile). This layer appears to be composed of more highly attenuating materials, as few reflections are evident below this interface. This interface may represent the buried soil materials and the Talbot morphostratigraphic unit discussed by Daniels and others (1977).

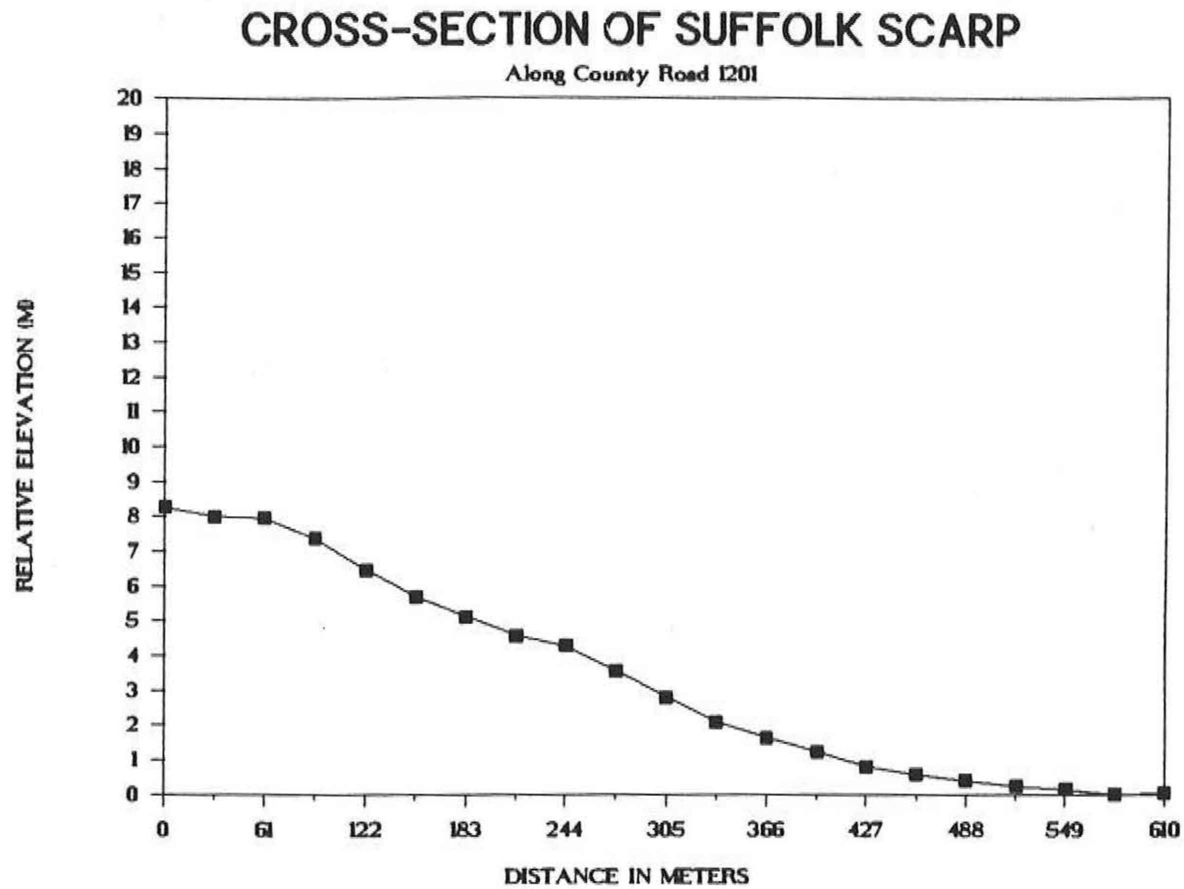
EM Survey:
A traverse was made with an EM34-3 meter along County Road 1201. At each of the equally spaced observation flags, measurements were taken with an EM34-3 meter in both the horizontal and vertical dipole modes.

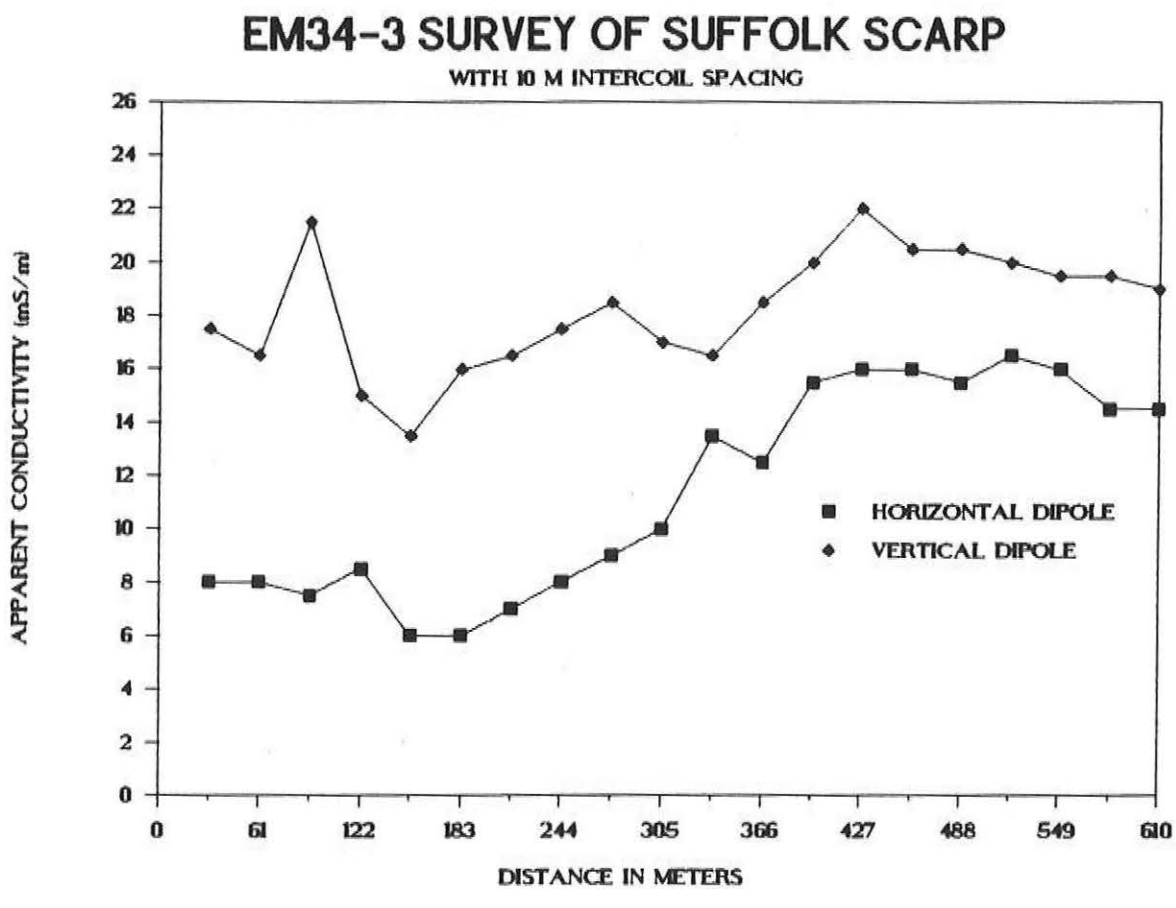
Figure 2 records variations in apparent conductivity with depth, location, and relative surface elevations along this line. The relatively high values of apparent conductivity on lower-lying slope components help to explain the comparatively poor performance of GPR on these positions.

In a most general way, Figures 2 shows that an inverse relationship exists between apparent conductivity and elevation. Higher-lying, summit and shoulder positions of the Suffolk scarp tend to have lower values of apparent conductivity than the lower-lying footslope and toeslope positions.

It was presumed that the EM data would reflect changes in moisture and clay contents, which are related to topographic position and the underlying stratigraphy. At each observation point, values of apparent conductivity increased with increasing observation depth (horizontal dipole orientation < than vertical dipole orientation). It was presumed that the measurements obtained in the vertical dipole orientation (integrates values over depths of 0 to 15 m) would be influenced by both the coarse-textured deposits of the Arapahoe sand ridge and the underlying finer-textured deposits of the Talbot morphostratigraphic unit. Measurements obtained in the horizontal dipole orientation (integrates values over depths of 0 to 7.5 m) would be principally influenced by the coarse-textured deposits of the Arapahoe sand ridge except on lower-lying foot and toeslope positions where finer-textured materials were closer to the surface.

County Road 1927-
The lower profile on Sheet 2 and the two profiles on Sheet 3 are from a single radar traverse conducted along a portion of county road 1927. This traverse began near the western margin of the Arapahoe sand ridge and extended eastward to the toe of the Suffolk scarp. Because of the


CROSS-SECTION OF SUFFOLK SCARP
Along County Road 1201
RELATIVE ELEVATION (M)
DISTANCE IN METERS
0
61
122
183
244
305
366
427
488
549
610


EM34-3 SURVEY OF SUFFOLK SCARP
WITH 10 M INTERCOIL SPACING
APPARENT CONDUCTIVITY (mS/m)
HORIZONTAL DIPOLE
VERTICAL DIPOLE
DISTANCE IN METERS
0
61
122
183
244
305
366
427
488
549
610

length of this traverse (1891 m), the radar profile had to be divided into three portions. Each profile was compressed and terrain corrected. The traverse and each profile extend in a west to east direction (west is to the left). On each profile, the short vertical lines appearing at the top of the profile represent equally-spaced (30.5 m) observation points. Distances (in meter) were measured with a tape. Relative elevations (for terrain correction) were measured with a level and stadia rod.

The western 90 m section of this traverse (see Sheet 2, lower profile) was conducted along the western edge of the Arapahoe sand ridge in an area of moderately attenuating soils and soil materials. Subsurface reflections from this portion of the traverse are attenuated, of low amplitudes, and depth restricted. However, within this portion of the traverse, a subsurface interface ("A") can be traced eastward about 360 m beneath the sand ridge. This interface may represent the contact of the sand ridge with the Talbot morphostratigraphic unit discussed by Daniels and others (1977).

On Sheet 2 (lower profile), reflections from several westward-dipping interfaces are apparent near "B." These low angle interfaces dip landward (toward the west) and may represent the migration of former foreshore ridges or storm surge facies. Overlying these westward dipping interfaces are several interfaces with more or less horizontal, parallel configurations (near "C" on Sheet 2, lower profile; and "D" on Sheet 3, upper profile). These interfaces occur beneath the higher-lying backslope and summit positions of the Arapahoe sand ridge. In places, these nearly horizontal interfaces are more segmented and variable in expression (near "A" on Sheet 3, upper profile). It is suspected that in many areas, these nearly horizontal interfaces overlie at varying depths a more uneven interface (near "D" on Sheet 2, lower profile; below "B" on sheet 3, upper profile). This relationship suggests the preferential filling of a former erosional surface. In other places, the nearly horizontal interfaces appear to overlie interfaces that dip landward (towards the west) and have a more uneven or wavy topography (near "C" on Sheet 3, upper profile).

The Suffolk scarp forms the east face of the Arapahoe sand ridge. Along the backslope of this scarp, interfaces appear indistinct, are highly segmented, and have a chaotic configuration (near "A," Sheet 3, lower profile). On lower-lying backslope and footslope positions, subsurface interfaces resume a nearly horizontal configuration (near "B" on Sheet 3, lower). However, these strata appear to be broken by several low-angle planes (near "C" on Sheet 3, lower profile).

The interfaces above "D" on the lower profile of Sheet 3 are believed to represent a major stratigraphic boundary. This stratigraphic boundary consist of several closely spaced and superimposed, high-amplitude interfaces. These interfaces appear to be composed of moderately attenuating materials, as few reflections are evident below these interfaces. These interfaces may represent buried organic and mineral soil layers, and the Talbot morphostratigraphic unit discussed by Daniels and others (1977).

Along the toe of the Suffolk scarp, several relatively shallow interfaces appear to dip gently shoreward (see E and "H" on Sheet 3, lower profile). These interfaces may represent foreshore facies. These weakly expressed, gently dipping interfaces rest unconformably on the layer suspected of being the Talbot morphostratigraphic unit. Beyond the Suffolk scarp, depths of observation become more restricted as a result of the presence of finer-textured materials nearer to the soil surface.

Results:

1. Ground-penetrating radar techniques can be used effectively on eolian sand dunes and higher-lying backshore areas of coastal beaches. The relatively high electrical conductivities of salt and brackish waters restrict the depths of observation on most lower-lying back barrier marshes, lagoons, and foreshore areas of coastal beaches. In these areas the use of GPR for soil and stratigraphic investigations is considered inappropriate. For any radar antenna, the actual depths of observation depths will depend on the depth to brackish or salt water and the amount of fines in the sediments.

2. All radar profiles were turned over to Robert Thieler and Andrew Brill of the Geology Department of Duke University for use in their research. In addition all radar profiles have been stored on tapes and will be maintained in my office. The examples provided in this report are highly interpretative and for general guidance only. Persons more familiar with coastal environments and stratigraphic facies should analyze and help interpret the radar profiles. Ground-truth corings are needed and are essential to confirm interpretations.

3. Upon request and with advanced notice, select portions of the radar profiles can be processed and made available.

4. It is hope that with time and further experiences, characteristic signatures appearing on radar profiles can be used to assess the stratigraphy and evolution of coastal environments.

It was my pleasure to work with the research assistants from Duke University and the NRCS staff in North Carolina. I hope that the co-operative spirit which pervaded this study will be extended into other field investigations.

With kind regards

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