Chapter 2
Ground-penetrating Radar

Abstract Ground-penetrating radar is a near-surface geophysical method that reflects radar waves from buried interfaces in the ground and produces two and three-dimensional images of buried geological and anthropogenic units. When many thousands or hundreds of thousands of reflections are displayed in two-dimensional vertical slices, profiles of these units can be made and interpreted much like viewing layers in the wall of a trench. When many hundreds of profiles are collected within a grid of closely spaced two-dimensional slices, horizontal maps of the reflective units as defined by the amplitude of the waves produced can be constructed. Those amplitude maps can show geological changes over broad areas such as where certain soils or strata are found, and also the human-produced features on and within those units. An interpretation of what is producing amplitude-defined features visible in map form is possible by analyzing the individual two-dimensional reflection profiles and that interpretation can be used to understand broad areas of study.

2.1 Introduction to Ground-penetrating Radar

Ground-penetrating radar is an active method, transmitting radar waves into the ground, and then recording waves that are received back at the surface. The variables that are measured in this method are elapsed time between sending and receiving a wave, amplitude of the recorded waves, and also data about the frequencies of the waves that are recorded (Conyers 2013). Waves are generated in the ground at interfaces between sediment layers, soils or other features. When many thousands of these wave arrivals are recorded along two-dimensional transects (or in some new methods three-dimensional arrays) accurate depths of visible features and stratigraphy can be produced. The geometry of visualized units, and to some extent the types of materials that have generated reflections in the ground can also be determined. The power of the integrative method of GPR and magnetic information comes by allowing the magnetics to help inform and understand more about aspects of the units visible in three-dimensions with GPR and vice versa (Fig. 2.1).

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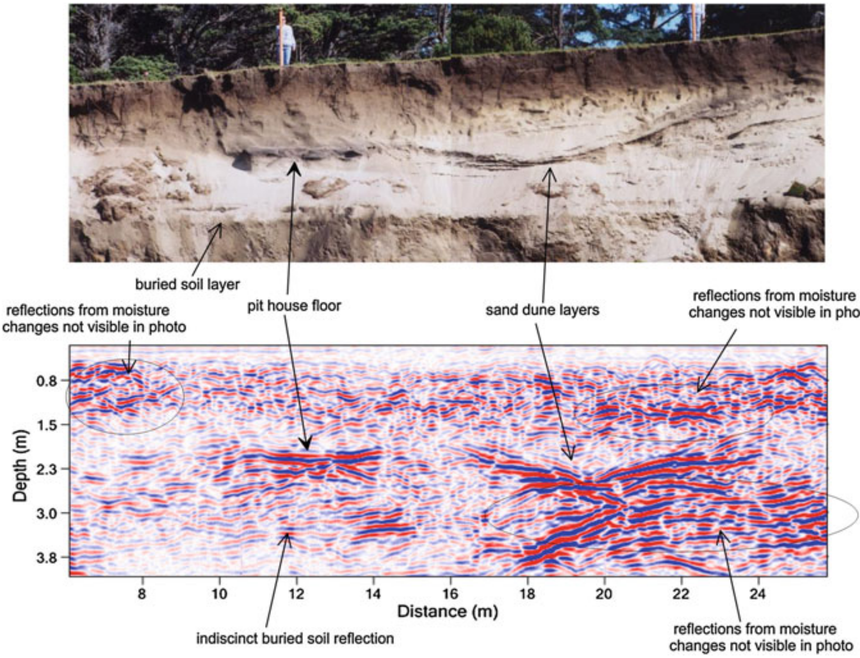

Fig. 2.1 Comparison of units visible in an outcrop with radar reflections seen in profile, along a sea cliff in coastal Oregon, USA

The GPR method transmits radar (electromagnetic waves) energy into the ground and then measures the elapsed time and amplitude of reflected waves as they are received back at the ground surface (Fig. 2.1). Many thousands or hundreds of thousands of reflected waves are collected along the transects of antennas as they are moved along the ground surface to produce reflection profiles of buried layers and features analogous to viewing profiles in excavation trenches (Fig. 2.1). When many reflection profiles are collected in a grid, three-dimensional images of buried materials in the ground can be constructed (Conyers 2013: 166). Ground-penetrating radar therefore has the unique ability to not just produce images of both geological and archaeological units in the ground, but to do so in three-dimensions (Conyers 2012: 20).

Ground-penetrating radar's ability to produce two and three-dimensional images of soils and sediments within depths that are usually of importance for archaeology (a few centimeters to 3-4 meters burial at most) means that complex images of geological materials associated with archaeological deposits is possible. While some archaeological thinking views the geological matrix of a site as a volume of material that must be removed and discarded to get to the important artifacts and features of interest, most recognize that there is important information to be gained by studying these matrix units (Davidson and Shackley 1976; Waters 1992: 15). It was this appreciation that geology and stratigraphy can't be divorced from archaeological research and therefore an analysis of ancient landscapes and environments that gives GPR great utility (Conyers 2016). This cross-disciplinary focus between GPR, magnetics, excavations and an understanding of the geology gives the methods discussed here an ability to study buried and other wise invisible ancient landscapes.

2.2 The GPR Method

Ground-penetrating radar data are acquired by reflecting pulses of radar energy produced from a surface antenna (Fig. 2.2), which generates waves of various wavelengths that propagate downward. They spread as they move into the ground in a cone-shaped geometry that is a function of the physical and chemical properties of the materials through which they pass (Conyers 2013: 47). As these waves move through the ground they are reflected from buried objects, archaeological features and stratigraphic bedding surfaces. The reflected waves then return to the ground surface to be detected and recorded at a receiving antenna, which is paired with the transmitting antenna. The two-way travel times of the waves moving through the ground are measured at the receiving antenna and their arrivals recorded in elapsed time of travel, measured in nanoseconds (ns). As the propagating radar waves pass through various materials in the ground their velocity will also change, depending on the physical and chemical properties of the material through which they are traveling (Conyers 2013: 107). If the constituent differences at interfaces of materials occur abruptly the radar waves' propagating velocity will also change when they pass across the contacts. When this occurs a reflected wave is generated that can move back to the ground surface from the reflection interface. Not all radar waves will travel back to the ground surface at a reflection interface and some energy will continue to propagate deeper in the ground to be reflected again from more deeply buried interfaces, until all the energy finally dissipates with depth. Only the reflected energy that travels back to the surface antenna is recorded and visible for interpretation as some is lost as it moves away from the antennas after reflection.

Reflections generated from radar waves propagating in the ground are created at interfaces where differing composition of materials are in contact along a boundary, and are different enough so that the velocity of moving waves that intersect the interface changes abruptly (Conyers 2013: 27). An example of a composition change that affects velocity in this way might be where a clay unit is overlain by a sand bed (Fig. 2.3). Some other possible scenarios that may or may not generate reflections are also shown in Fig. 2.3. The amplitude of the received waves back at the surface is directly proportional to the change in the speed of the radar waves as they intersect the buried interface, with the greater the velocity change, the larger the reflected wave amplitude. Each abrupt velocity change in a complexly layered area will theoretically create a reflected wave (Conyers 2013: 28). In contrast a gradational change in materials over some distance where there is no abrupt velocity change would not produce a reflection. Velocity changes are almost wholly

Fig. 2.2 A GSSI SIR-3000 GPR system with a 400 MHz antenna and survey wheel

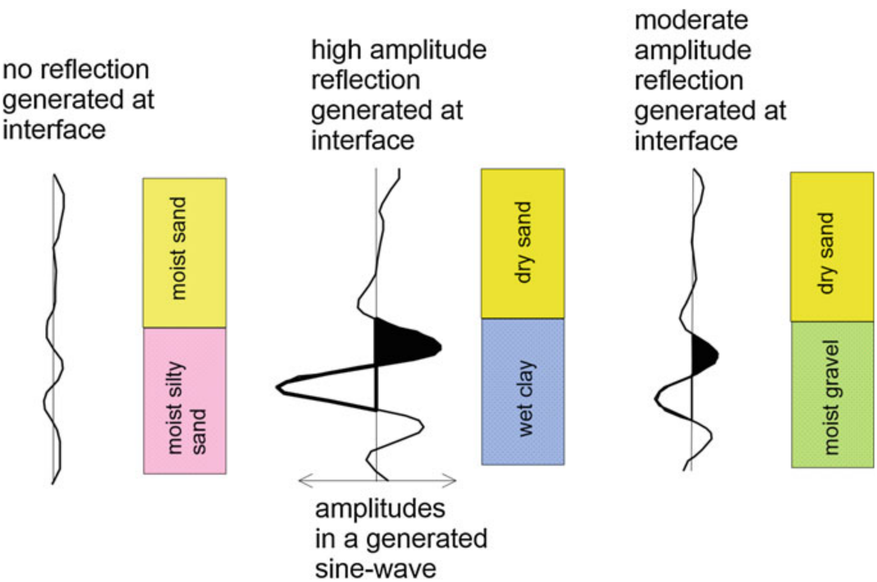

Fig. 2.3 Comparison of reflected radar wave amplitudes depending on the differences in materials along a contact

a function of the amount of retained water in the different buried materials (Conyers 2012: 36). The more interstitial water, the slower the waves will move. For instance wet clay has a very high percentage of water, and will greatly slow radar waves. Dry sand or silt will allow radar wave transmission at a very high velocity. An interface between these two very different velocity units would create a very high amplitude radar wave reflection.

Reflection profiles are the basic interpretive tool for GPR and are created as radar antennas move along the ground surface transmitting waves downward into the ground. A sequential stacking of many hundreds of reflections (termed traces) consisting of reflected waves from different depths in the ground is then produced (Fig. 2.4). Each trace is recorded at a discrete position along an antenna transect, and the display of all these sequentially is used to produce a two-dimensional vertical slice in the ground (Fig. 2.5). Profiles of reflections are the standard images used for many complex stratigraphic interpretations of buried materials in the ground, which is often employed for ancient landscape analysis. These will be used throughout this book, as they can be used to identify and understand geological layers as well as archaeological components within those geological packages. When that information can be studied with the aid of magnetic information that is helpful in determining composition, a great deal can be learned about buried materials in the ground.

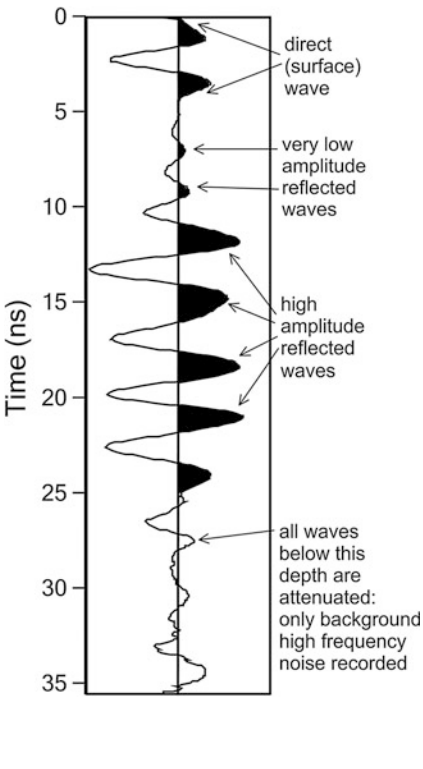

Fig. 2.4 One GPR trace showing amplitudes and attenuation over the time-window

Many reflection profiles collected in a grid can also be processed together in order to produce individual maps of various depth slices in the ground (Fig. 2.5). Often this is quite beneficial in visualizing large areas of ground, and has become the basic image used by many for GPR interpretation (Conyers 2012, 2013). In this amplitude slice-map method all two-dimensional reflection profiles are re-sampled within user-defined depths, and the relative amplitudes of reflected waves located at those depths are then plotted, interpolated and gridded to produce a defined number of horizontal slices in the ground. These are often the images used by many in data

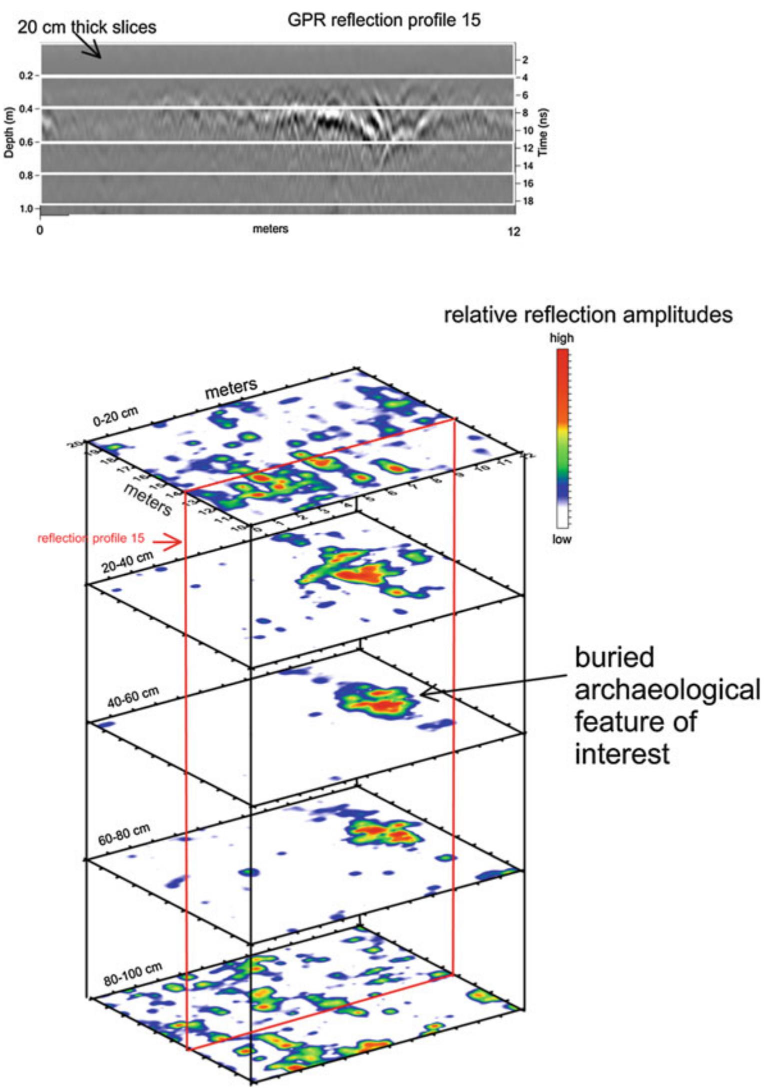

Fig. 2.5 The production of GPR images from collected traces, which are stacked together to produce reflection profiles, and then re-sampled to create amplitude slice-maps with depth

fusion analyses, where depth-slices are directly compared to maps generated from other geophysical methods. The method outlined in this book is to evaluate the individual profiles from which the maps were created first in order to understand what is creating the mapped features in each slice (Conyers 2016). Then once the genesis of all the reflections in the maps are understood, a more complete merging of maps from different depths in the ground can be used in an interpretation.

References

Conyers LB (2012) Interpreting Ground-penetrating radar for archaeology. Taylor and Francis Group, New York, Routledge

Conyers LB (2013) Ground-penetrating radar for archaeology, 3rd edn. Rowman and Littlefield Publishers, Alta Mira Press, Latham, Maryland

Conyers LB (2016) Ground-penetrating radar for geoarchaeology. Wiley-Blackwell Publishers, London

Davidson DA, Shackley ML (1976) Geoarchaeology: earth science and the past. Westview Press, Boulder

Waters MR (1992) Principles of geoarchaeology: a North American perspective. University of Arizona Press, Tucson

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