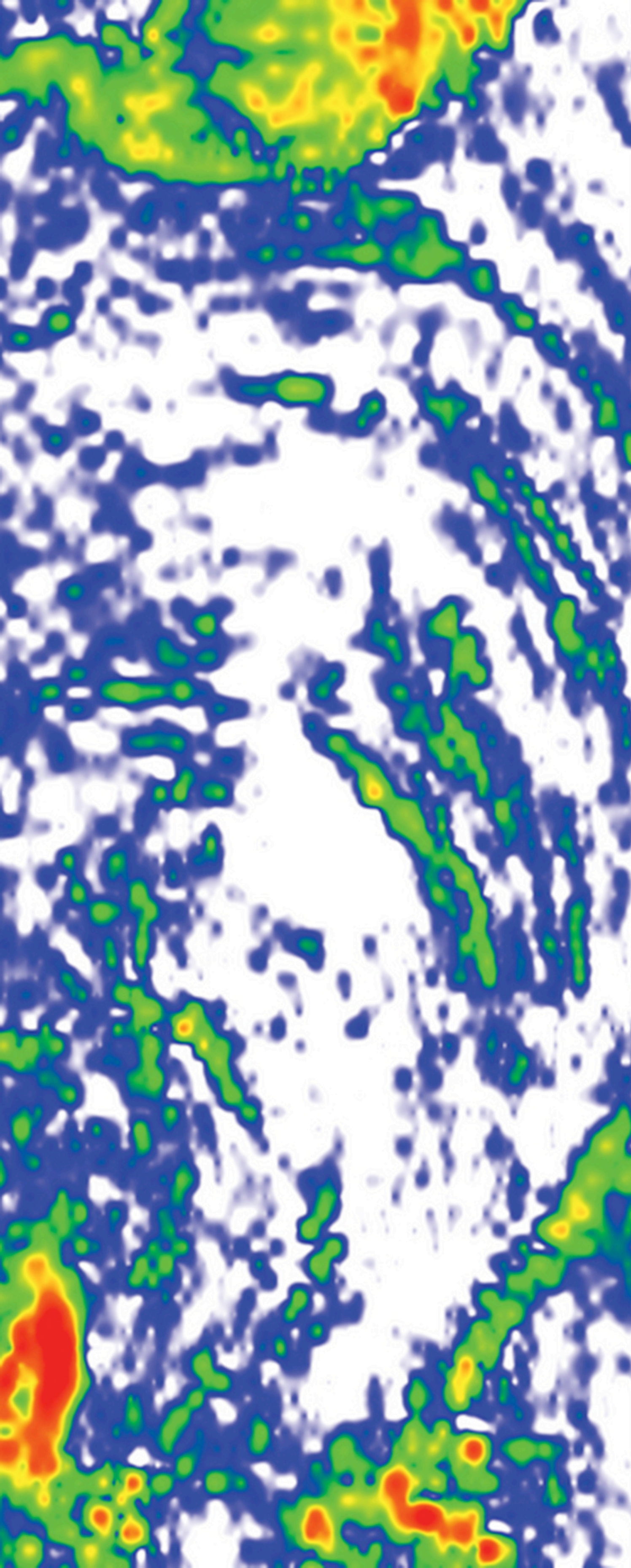

New Analytical Methods in Earth and Environmental Science

GROUND-PENETRATING RADAR FOR GEOARCHAEOLOGY

Lawrence B. Conyers

WILEY Blackwell

GROUND-PENETRATING RADAR FOR GEOARCHAEOLOGY

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GROUND-PENETRATING RADAR FOR GEOARCHAEOLOGY

LAWRENCE B. CONYERS

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Registered Office
John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

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Library of Congress Cataloging-in-Publication Data

Conyers, Lawrence B., author.
Ground-penetrating radar for geoarchaeology / Lawrence B. Conyers.
pages cm
Includes bibliographical references and index.
ISBN 978-1-118-94994-8 (cloth)
1. Ground penetrating radar. 2. Archaeological geology. I. Title.
TK6592.G7C66 2016
930.1028–dc23

2015020391

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover image: Amplitude slice map across a sand dune sequence from coastal Brazil showing occupational surfaces on the bottom, cross-beds within the dunes in the middle, and highly reflective inter-dune sediments at the top © Lawrence Conyers

Set in 9.5/11.5pt Minion by SPi Global, Pondicherry, India

1 2016

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About the Author

Lawrence B. Conyers is a professor of anthropology at the University of Denver, Colorado. He received a Bachelor of Science degree in geology from Oregon State University and a Master of Science degree from Arizona State University. He holds both M.A. and Ph.D. degrees in anthropology from the University of Colorado, Boulder. Before turning his attention to ground-penetrating radar and other near-surface geophysics for archaeological mapping, he spent 17 years in petroleum exploration and development where he worked with seismic geophysical prospecting. His GPR research is conducted throughout the United States and at many sites throughout the world.

Acknowledgments

I am fortunate very early in my professional life to have worked with excellent geophysicists who helped me along with seismic reflection interpretation during the years I was in the petroleum business. Randy Ray, Phil Howell, and Bill Miller were all instrumental in my early growth in the subject. Bill Miller actually showed me the very first GPR profile sometime in the 1980s when GPR was very new to both of us. I remember talking to him about how we could immediately appreciate ways this new device could be interpreted in much the same way as seismic reflection. As it turned out, many of the original GPR processing programs were taken directly from seismic work, so it was natural to fall right into GPR. I was gladdened to see in the research for this book that my professor of geophysics in graduate school back in the 1970s, Bill Sauck, has now started to do GPR research, and I have cited a recent publication by him and one of his graduate students in Chapter 6. When I was in graduate school I was also fortunate to have Payson Sheets as an advisor, who thinks like a geologist and geophysicist as well as an archaeologist. While studying with Payson I was very lucky to also be advised on soils and geomorphology by Peter Birkeland, who was instrumental in getting me to think about near-surface sediments and soils in ways that were directly applicable to GPR and archaeology. None of my work with GPR could have been accomplished without the intelligent collaboration and loyal friendship of two true geniuses of GPR research, Jeff Lucius and Dean Goodman.

Early on in my academic career I was encouraged to pursue GPR and geoarchaeology research at the University of Denver, even though many of my colleagues in the Anthropology Department considered these subjects to be perhaps a little "too scientific" or at least very esoteric. They were always encouraging and supportive, and with other geological friends across campus in the Geography Department, Don Sullivan and Mike Daniels, I had my own "team" of collaborators to work with on a number of great projects, some of which are used as examples in this book.

Many other collaborators in projects around the world have been always easy to work with and tolerated much trial and error on my part within the framework of their own research. All were great colleagues, and most of the examples provided here would not have come about without their generous and supportive collaboration.

My many students, both graduate and undergraduate, did much of the hard work in data collection. They asked all the right questions to keep me on track, and provided many of the obvious answers when I was flummoxed by complex datasets. A list of these many wonderful coworkers, collaborators, students, and colleagues who helped provide the data, insights, and hard work necessary to provide the examples for this book includes, but is not limited to, Melissa Agnew, Peter Arceo, John Arthur, Tiago Attore, Andrew Bauman, Robert Bauman, Leigh-Ann Bedal, Mike Benedetti, Lucia Bermejo, Nuno Bicho, Federica Boschi, Tamara Bray, Charles Bristow, Richard Buckley, Carmen Buttler, Scott Byram, Maria Caffrey, James Conyers, Anika Cook, Lauren Couey, Matthew Curtis, Mike Daniels, Mike Disilets, Kristin Elliott, Eileen Ernenwein, Paul Fish, Suzanne Fish, Nicole Fulton, Matt Golsch, Dean Goodman, Jonathan Haws, John Hildebrand, Maren Hopkins, Sally Horn, Gary Huckleberry, Harry Jol, Christina Klein, Michele Koons, Jeff Lucius, Harold Luebke, Cody Main, Corey Malcolm, Ana Isabel Ortega Martinez, Ian Moffat, Jeremy Moss, Dani Nadel, Steve Nash, Samantha Nemecek, Matt Pailes, Lisa Piscopo, Hannah Polston, Yossi Salmon, Payson Sheets, Zach Starke, Jennie Sturm, Don Sullivan, Mary-Jean Sutton, Tiffany Tchakirides, Victor Thompson, Chet Walker, Lynley Wallis, Katrina Waechter, and Sean Wiggins.

1 Introduction to Ground-penetrating Radar in Geoarchaeology Studies

Abstract: Geology and archaeology have long been integrated as a way to understand site formation processes, place artifacts within an environmental context, and as a way to study ancient people within the landscapes where they worked and lived. An analysis of sedimentary environments has long been necessary in this endeavor, but is often constrained by a lack of excavations, exposures, and other data to study areas in a three-dimensional way. Ground-penetrating radar (GPR) has unique three-dimensional abilities to place ancient people into an environmental context by integrating both archaeological and geological information within the buried context of a site over wider areas that is usually possible. The GPR method can accomplish this because it is based on the analysis of reflections produced from the interfaces and layers of geological units in the ground that are then studied three dimensionally. When this is done, robust analyses of buried geological and archaeological materials can be done for subsurface areas not visible at the surface in order to generate more holistic analyses of geoarchaeological studies.

Keywords: environmental context, sedimentary environments, three-dimensional analysis, buried materials and strata, stratigraphy, reflection generation, environmental reconstruction

Introduction

There has been a long period of collaboration between geologists and archaeologists, as it is impossible to separate the geological record from archaeological materials preserved within sediments and soils. These cross-disciplinary geoarchaeology studies involved stratigraphic analysis, environmental reconstructions, site selection for future excavations, and an analysis of site preservation and postabandonment processes (Butzer 1971; Rapp and Hill 2006). More recently, these types of collaborative geological and archaeological studies have included landscape analysis that places people within an often complex and changing environment (Bruno and Thomas 2008; Constante et al. 2010; Stern 2008). The inclusion of geophysical analysis within geological and archaeological studies has occurred more recently and is beginning to make an impact in many research projects (Campana and Piro 2008; Kvamme 2003) as buried deposits can be studied and integrated with more limited excavations and exposures. These geophysical studies for the most part employ magnetics, electromagnetic induction and electrical resistivity, and ground-penetrating radar (GPR). The use of these types of geophysical methods allows

Ground-penetrating Radar for Geoarchaeology, First Edition. Lawrence B. Conyers.

a more complete and broader aerial analysis of complex buried (and otherwise invisible) archaeological and geological materials than was possible in the past (Johnson 2006).

This book is devoted to one of these geophysical methods, GPR, and especially the integration of its unique imaging properties to measure and display materials in the ground along with geological and archaeological data. The GPR method transmits **radar** (electromagnetic waves) energy into the ground and then measures the elapsed time and strength of reflected waves as they are received back at the ground surface (**Figure 1.1**). 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 (**Figure 1.2**). When many reflection profiles are collected in a grid, three-dimensional images of buried materials in the ground can be constructed (Conyers 2013, p. 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, p. 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 m 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, most recognize that there is important information to be gained by studying it (Davidson and Shackley 1976; Waters 1992, p. 15). It is this appreciation that geology cannot be divorced from archaeological research that forms the basis for the field of geoarchaeology. This cross-disciplinary focus can become even more important when GPR is integrated with the other datasets to project important information from the visible areas in outcrops or excavations into the invisible and still buried areas of a site.

Often much of what can be seen in GPR profiles and three-dimensional **amplitude maps** is more geological than archaeological, and there can often be confusion as to what is anthropogenic in origin, or instead the geological matrix (Conyers 2012, p. 19). Successful

Figure 1.1 Collecting GPR profiles with a GSSI SIR-3000 control system and 270 MHz antennas.

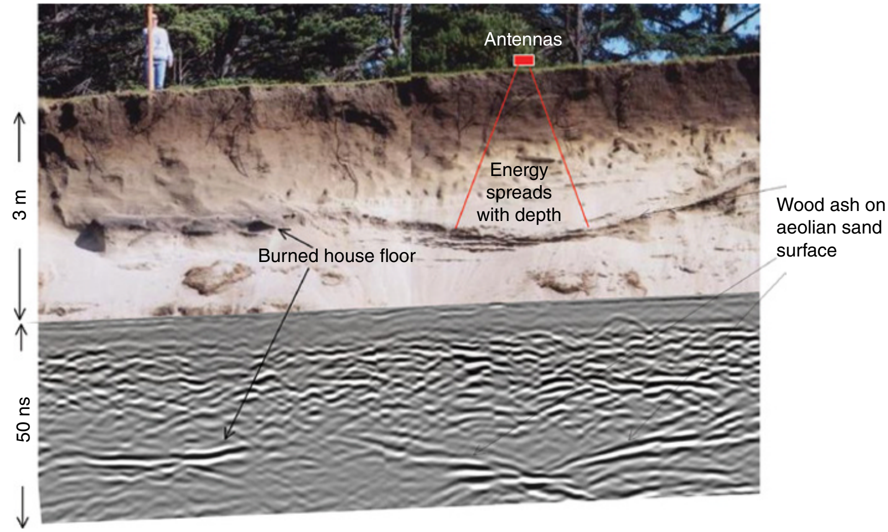

Figure 1.2 Comparison of a 400 MHz reflection profile collected within a 50 ns time window to a 3 m thick outcrop of cross-bedded aeolian dune sands with a burned house floor. Reflection energy spreads from the surface transmission antenna, creating an average of reflections received back at the ground surface from subsurface interfaces. From Conyers (2012). © Left Coast Press, Inc.

differentiation of the two, and an interpretation of radar **reflections** derived from all the units in the ground, is therefore crucial. As most archaeological sites are the result of burial and preservation by geological forces and processes, the various features in the ground that have been modified and altered by physical and chemical forces must be understood. This can be difficult even when exposures are visible to the human eye, but especially challenging when various buried features are visible but not necessarily understood in GPR images. The application of GPR to both geological and archaeological features and their interpretation within standard GPR-processed images is the goal of this book.

Scales and Applications of Geoarchaeological Studies with GPR

Geoarchaeological studies range in scale from very small scale analysis of micromorphology of soils and sediments using the microscope to large landscapes covering huge tracts of land (Goldberg et al. 2001; Rapp and Hill 2006). The GPR method of acquisition and data processing methods has very specific resolutions at measurable depths, which necessitates that it be employed within a middle-range of the usual standard geoarchaeology studies. These scales of study typically involve a few hectares aerial extent at most, with depth of analysis of 3–4 m and feature resolution usually larger than about 20 cm in the maximum extent. There are some notable examples of very large data sets recently collected by **multiple array systems** towed by motorized vehicles that can study many tens or even hundreds of hectares (Gaffney et al. 2012; Trinks et al. 2010) but these are still relatively rare. Within the scope of most geoarchaeological applications (French 2003, p. 6), and with most of the examples presented here, the study area may be on the order of a few hundreds of square meters in dimension to depths of about 6–7 m.

Geological analysis within the context of archaeology, which can be expanded on and broadened using GPR, can be used to study landscape evolution (Ricklis and Blum 1997) where settlement changes are a function of environmental fluctuations. Specifically, GPR datasets can define fluvial units that are the product of erosion and redeposition (Behrensmeyer and Hill 1998) and associated soil units, which are a function of landscape stability over many centuries (Birkeland 1999; Ferring 2001; Holliday 2001). An analysis of these geological units using an integration of stratigraphic units (Shackley 1975) with GPR datasets (Conyers 2009), within a dynamic landscape will also allow for the study of site formation processes (Schiffer 1972).

Studies that are expanded beyond site formation processes can show the effects of humans on a landscape and their adaptation to environmental change over time (Campana and Piro 2008). This is done by focusing on the geological matrix of a site first, defining depositional environments and changes in those environments laterally and vertically over time. The archaeological record is then placed within this context to understand human adaptation to and modification of their environment. This definition and understanding of environments is one of the key foci in GPR integration with geoarchaeology. This book will provide examples of various common environments discernable in GPR data sets, and then place human activities within those contexts.

The important geological packages of sediments and associated geological units that can be studied and analyzed with GPR are most of the terrestrial depositional environments (such as rivers, floodplains, sand dunes, beaches and other coastal environments), bedrock features that were part of an erosional landscape and later buried, and soil horizons that were living surfaces providing some degree of stability in the past. These types of buried features must usually be defined first in excavations and outcrops, and then projected into areas where they are buried and invisible except by using GPR techniques.

A key to understanding past environments is to first define the general stratigraphy of buried units and understand how those units are visible in common GPR images. This is not always as straightforward as would be hoped, as the varying chemical and physical properties of buried materials sometimes allows reflection of radar waves, and at other times does not. Depth of energy penetration, radar wave attenuation, the spreading of transmitted radar waves as they travel in the ground, and a variety of other variables relating to radar wave properties can often confuse and mislead some interpreters. Often these problems are solvable, and many examples regarding resolution, depth of analysis, and interpretation of the results of data processing are included. For the most part the larger scale geological units, and sometimes their associated sedimentary structures, are readily visible with GPR, and these can readily define specific ancient environments. When GPR interpretations are enhanced with subsurface information derived from augering, cores, and small scale excavations, a three-dimensional analysis of broad landscape features and past environments is usually possible. Facies analysis of larger scale geological units can then be integrated with anthropogenic features and sometimes associated soils to place humans within ancient and historical landscapes.

Basics of the GPR Method

Ground-penetrating radar data are acquired by reflecting pulses of radar energy produced from a surface antenna, which generates waves of various wavelengths that propagate downward (**Figure 1.1**). They spread as they move into the ground in a cone (**Figure 1.2**), which is a function of the physical and chemical properties of the