BONEBEDS

Genesis, Analysis, and Paleobiological Significance

Edited by
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and Anthony R. Fiorillo

The University of Chicago Press
Chicago and London

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The University of Chicago Press, Chicago 60637
The University of Chicago Press, Ltd., London

Printed in the United States of America

16 15 14 13 12 11 10 09 08 07 1 2 3 4 5

ISBN-13: 978-0-226-72370-9 (cloth)
ISBN-13: 978-0-226-72371-6 (paper)
ISBN-10: 0-226-72370-4 (cloth)
ISBN-10: 0-226-72371-2 (paper)

Library of Congress Cataloging-in-Publication Data

Bonebeds : genesis, analysis, and paleobiological significance / edited by Raymond R. Rogers, David A. Eberth, and Anthony R. Fiorillo.
p. cm.
Includes bibliographical references and index.
ISBN-13: 978-0-226-72370-9 (cloth : alk. paper)
ISBN-13: 978-0-226-72371-6 (pbk. : alk. paper)
ISBN-10: 0-226-72370-4 (cloth : alk. paper)
ISBN-10: 0-226-72371-2 (pbk. : alk. paper) 1. Vertebrates, Fossil. 2. Paleontological excavations. 3. Paleobiology. I. Rogers, Raymond R. II. Eberth, David A. III. Fiorillo, Anthony R.
QE841.B675 2007
560—dc22

2007003767

♾ The paper used in this publication meets the minimum requirements of the American National Standard for Information Sciences—Permanence of Paper for Printed Library Materials, ANSI Z39.48-1992.

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PREFACE

Bonebeds rank among the more notable features of the fossil record, and they tend to conjure up visions of expansive, densely packed animal graveyards rife with the scent of ancient catastrophe. Perhaps comparable visualizations gripped William Buckland, an early bonebed researcher, as he studied mammalian skeletal debris in 1821 from Kirkdale Cave, a Pleistocene locality in Yorkshire. Buckland pored over the amassed fossils and associated sediments and astutely concluded that the concentration of bones resulted from the activity of hyenas, with eventual burial of the skeletal remains by a diluvial flood event. Shortly thereafter, Sir Roderick Murchison published his classic description of the Silurian System, which included the first report of the widespread marine Ludlow Bonebed. Other workers soon followed the trail to the bones, working the Triassic fissure fills in the Bristol region and the Jurassic bone deposits of Lyme Regis, among other localities in and around the United Kingdom. The quest for bones soon extended throughout much of Europe and beyond, and by the beginning of the twentieth century a diverse array of fantastic bonebeds had been discovered and described from localities around the world. Today, thousands of bonebeds are known from Phanerozoic sedimentary rocks on every continent.

While the classic view of bonebeds as areally extensive deposits of bone heaped upon bone is still commonly held and, in fact, quite accurate in at least some spectacular cases (e.g., the classic Agate Springs mammal bonebed in the Miocene of Nebraska), it does not reflect the full spectrum

of bone concentrations, and it is not a suitable basis for a working definition. Indeed, we struggled to clarify the precise meaning of the term "bonebed" as we wrote our respective chapters, and the reader is warned that some of the chapters provide slightly different versions of what exactly constitutes a bonebed (e.g., the 5% criterion of Behrensmeyer [Chapter 2] vs. the "greater than background" perspective of Eberth et al. [Chapter 3]). Nevertheless, we did reach general agreement on a basic definition that, while downplaying the dramatic side, serves to effectively characterize a bonebed (see Appendix 1 in Chapter 2 for a comparison of terms and definitions). The two most important criteria that distinguish a bonebed from other vertebrate occurrences are (1) whether a site (e.g., cave, bog, hollowed-out tree stump, etc.) or sedimentary stratum preserves the hardparts of only one individual (*not* a bonebed) or the hardparts of more than one individual in close spatial proximity (a bonebed), and (2) whether a site or stratum preserves hardparts in an abundance greater than the associated or "background" facies. The operational meaning of "close spatial proximity" varies with the context: consider, for example, the variable spatial scales of a tadpole bonebed and a sauropod bonebed (both are known from the rock record). Similarly, the relative abundance of bone in a bonebed can vary dramatically and is probably best judged by the individual researcher from a qualitative comparison with other fossil sites. The key point is that, in our opinion, any vertebrate locality that preserves the hardparts of two or more individuals in close association begs both careful scrutiny and, in most cases, an explanation that accommodates more than the singular demise of a lone individual.

In regard to indication of multi-individual mortality, we recognize that the vast majority of bonebeds documented in the literature do convincingly preserve the remains of two or more dead animals. In fact, we maintain that it is the very prospect of concentrated multi-individual mortality that piques the interest of bonebed researchers, be they taphonomists interested in reconstructing ancient death events or paleobiologists engaged in morphological or evolutionary studies. That said, we also recognize the possibility that some concentrations of vertebrate hardparts, such as sharktooth lags embedded in marine strata, can develop due to processes entirely unrelated to localized mortality (sharks shed great numbers of teeth during life, and physical processes on the sea floor can concentrate them).

In *Bonebeds: Genesis, Analysis, and Paleobiological Significance*, we have attempted to distill the paleontological significance of bonebeds through a series of core papers that address current theoretical and practical treatments of bonebeds and their data. Our primary objectives are to (1) provide the reader with workable definitions and a framework for the

consideration of bonebeds, and (2) supply the reader with an up-to-date compendium of current techniques of data collection and analysis with a specific focus on bonebeds. This edited compilation is not intended to be a comprehensive historical account of bonebed studies, and while we recognize that there is perhaps a rich historical story to be told, we have purposely kept the focus on a selection of more contemporary scientific issues. The chapters emphasize sites known from the rock record (true beds in a sedimentary basin sense), and this reflects the experiences and predominant interests of the authors. This emphasis is not meant to imply that cave-hosted bone accumulations are not bonebeds-*they most certainly are*! However, there are already several fine books and detailed professional reports devoted to the study and interpretation of bone accumulations preserved in caves. Finally, in a preemptive effort to avoid confusion, readers are alerted at the outset that throughout the book the term "bonebed" is often used synonymously with terms such as “skeletal concentration,” “vertebrate accumulation,” and “bone assemblage.” It is also important to note that the term “assemblage” is frequently used to refer to subsets of bones recovered from a bonebed or a formation. For example, a bonebed researcher might refer to the "mammal assemblage" derived from a multitaxic bonebed that also yields the remains of fish and amphibians.

The first half of *Bonebeds: Genesis, Analysis, and Paleobiological Significance* delves into conceptual and interpretive aspects of the bonebed record. Chapter 1 considers bonebeds from a formative perspective, and an intuitive process-based classification is proposed that differentiates among various biogenic bone accumulation scenarios and physically generated concentrations. Chapter 1 draws upon numerous examples of modern phenomena in both terrestrial and marine settings that yield localized concentrations of vertebrate hardparts. A database approach to the study of bonebeds is developed in Chapters 2 and 3. Chapter 2 explores the Evolution of Terrestrial Ecosystems (ETE) Bonebed Database to provide an overview of bonebeds through time, with a focus on large-scale trends in taxonomic composition, ecological representation (carnivores vs. herbivores), and taphonomic quality (e.g., temporal trends in articulation patterns). The ETE Bonebed Database can be viewed online at www.press.uchicago.edu/books/rogers/. Chapter 3 utilizes a second “bonebeds database” (partially overlapping with the ETE Bonebed Database, available here in print form and online at the URL given above) to further elucidate patterns of origin and occurrence with specific reference to research biases and common facies associations. Both of these database-driven contributions examine terminology and classification. In

Chapter 4, bonebed datasets are reviewed in relation to paleobiology, with an emphasis on species characterization, paleobehavior, and paleocommunity reconstruction.

The second half of *Bonebeds* emphasizes practical approaches and serves as a "how-to" guide to the study of bonebeds. In Chapter 5, the reader is guided through preliminary site assessment, excavation and mapping techniques, and the collection of both geological and taphonomic data. Chapter 6 tackles bonebeds from a numerical perspective and probes the various quantitative methods that can be applied to bonebed assemblages. Protocols for counting specimens, evaluating taphonomic equivalence, comparing species richness among sites, estimating taxonomic abundance, and assessing faunal change (using bonebeds) are discussed, and multiple examples are provided. Chapters 7 and 8 provide a detailed review of the geochemistry of fossil bone and explore the phenomenon of fossilization in relation to vertebrate hardparts. Chapter 7 outlines specific examples of the utility of rare earth element concentrations in addressing bonebed-related questions (e.g., degrees of spatiotemporal mixing) and concludes with a useful primer on the analysis of trace metals in fossil bone. Chapter 8 tackles the topic of stable isotopes in relation to bonebeds and provides numerous examples of studies that utilize bonebed assemblages to address broad paleoenvironmental questions.

We envisage *Bonebeds: Genesis, Analysis, and Paleobiological Significance* as a useful resource for seasoned researchers, students, and amateurs interested in issues that pertain to vertebrate paleontology, archeology, paleoecology, and sedimentary geology. Through this book we demonstrate that bonebeds are a tremendous resource for the paleobiologist, geologist, and archeologist, and that the future of bonebed research is bright. We are confident that careful practice, in combination with new tools and methodologies, will lead to new and unique insights into the history of the vertebrates. Indeed, this seems destined to happen as new bonebeds are discovered and announced on a seemingly daily basis, and as classic bonebed localities are revisited and reinterpreted by a new generation of bonebed researchers with fresh eyes, innovative tools, and provocative new questions.