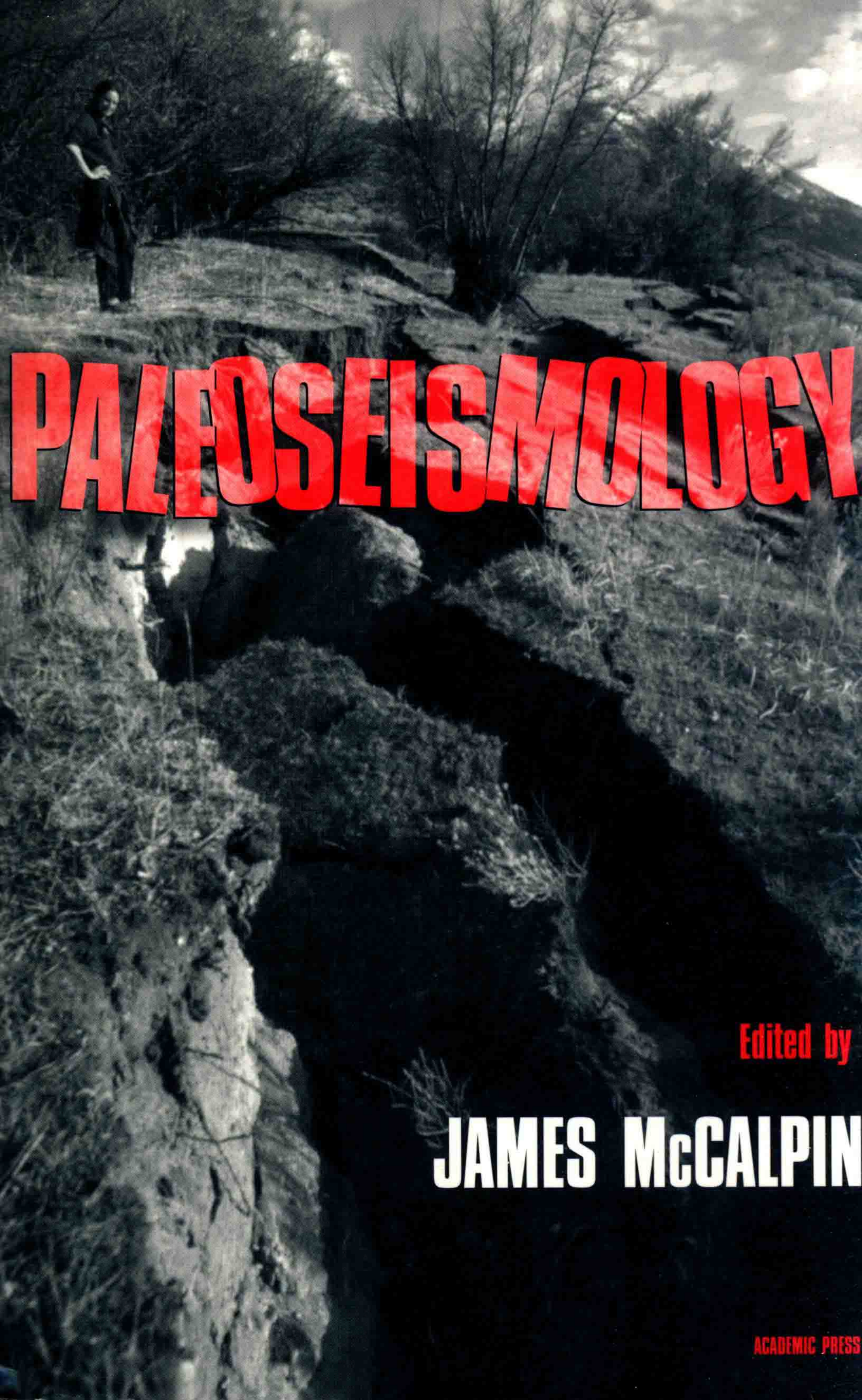

PALEOSEISMOLOGY

Edited by

JAMES McCALPIN

ACADEMIC PRESS

Paleoseismology

Edited by

James P. McCalpin
GEO-HAZ CONSULTING, INC.
ESTES PARK, COLORADO

ACADEMIC PRESS
An Imprint of Elsevier
San Diego New York Boston London
Sydney Tokyo Toronto

Front cover photograph: Surface fault rupture caused by the 28 October 1983 Borah Peak, Idaho (USA), earthquake. This small section of the fault north of Rock Creek ruptured fine-grained, moist, cohesive alluvium and formed a 2 m-high monocline. Tensional stretching of the monoclinal crest created the prominent open fissures. The editor's gracious wife (height 1.8 m) provides a scale. Photo courtesy of James McCalpin.

This book is printed on acid-free paper. ♾

Academic Press
An Imprint of Elsevier
525 B Street, Suite 1900, San Diego, California 92101-4495, USA
http://www.apnet.com

Academic Press
24-28 Oval Road, London NW1 7DX, UK
http://www.hbuk.co.uk/ap/

Library of Congress Catalog Card Number: 96-2096
ISBN-13: 978-0-12-481826-2
ISBN-10: 0-12-481826-9

PRINTED IN THE UNITED STATES OF AMERICA
06 07 08 09 EB 9 8 7 6 5 4 3 2

Paleoseismology

This is Volume 62 in the
INTERNATIONAL GEOPHYSICS SERIES
A series of monographs and textbooks
Edited by RENATA DMOWSKA and JAMES R. HOLTON

A complete list of books in this series appears at the end of this volume.

The rupture trace of the 1983 M_s 7.3 Borah Peak, Idaho earthquake (Lost River fault zone) approximately 50 m north of the Doublesprings Pass Road, is dominated by a 15-m-wide graben. One year after the rupture, a 3-4-m-deep, 45-m-long trench (left and lower center) was excavated across the fault trace to identify and characterize paleoearthquakes; note persons in trench at far left for scale. The sense and amount of 1983 displacements at this location closely mimicked those of the previous earthquake (ca. 5000–6000 years ago), suggesting characteristic earthquake behavior at this location (see Chapter 9). Photograph taken in April 1985, 17 months after the rupture. The log of this trench is shown in Schwartz and Crone, 1985.

Contributors

Numbers in parentheses indicate page numbers on which authors' contributions begin.

Gary A. Carver (183) Department of Geology, Humboldt State University, Arcata, California 95521. E-mail: gac1@axe.humboldt.edu

William R. Hackett (147) WRH Associates, 2880 E. Naniloa Circle, Salt Lake City, Utah 84117. E-mail: wrhackett@aol.com

Suzette M. Jackson (147) Lockheed Idaho Technologies Co., P.O. Box 1625, MS 2107, Idaho Falls, Idaho 83415. E-mail: msj@inel.gov

Randall Jibson (397) U.S. Geological Survey, Box 25046, MS 966, Denver Federal Center, Denver, Colorado 80225. E-mail: jibson@gldvxa.cr.usgs.gov

James P. McCalpin (1, 33, 85, 183, 271, 439) GEO-HAZ Consulting, Inc., P.O. Box 1377, 1221 Graves Ave., Estes Park, Colorado 80517. E-mail: mccalpin@geohaz.com.

Alan R. Nelson (1) U.S. Geological Survey, Box 25046, MS 966, Denver Federal Center, Denver, Colorado 80225. E-mail: anelson@gldvxa.cr.usgs.gov

Stephen F. Obermeier (331) U.S. Geological Survey, National Center, Reston, Virginia 20192. E-mail: sobermei@usgs.gov

Thomas K. Rockwell (271) Department of Geological Sciences, San Diego State University, San Diego, California 92182. E-mail: trockwel@geology.sdsu.edu

Richard P. Smith (147) Lockheed Idaho Technologies Company, P.O. Box 1625, MS 2107, Idaho Falls, Idaho 83415. E-mail: rps3@inel.gov

Ray J. Weldon II (271) Department of Geological Sciences, Cascade Hall, University of Oregon, Eugene, Oregon 97403. E-mail: ray@neotec.uoregon.edu

Preface

A clear sign of the youth of paleoseismology has been the lack of a comprehensive book on this rapidly developing field of research. This book is designed to meet this need for an overview volume, one that outlines the concepts behind and techniques used in current investigations. Books by Wallace (1986), Vita-Finzi (1986), and particularly Crone and Omdahl (1987) partly filled this need in the late 1980s. In many ways this book is an outgrowth of Crone and Omdahl's volume, which summarized the "Directions in Paleoseismology" conference convened by the U.S. Geological Survey. The scope of paleoseismology has expanded so rapidly in the past decade, however, that even full-time paleoseismologists have difficulty maintaining an awareness of important developments throughout the specialty. A parallel development is that paleoseismologists, many of whom had previously worked in relative isolation within their respective countries, began to collaborate in the late 1980s. There is also an increasing awareness of the value of collaboration with specialists in structural geology, geodesy, and seismology for solving paleoseismic problems (Wallace, 1986; Weldon, 1991). Such timely collaboration makes it easier for us to provide a broader perspective on many aspects of paleoseismology than would have been possible a decade ago. This book appears at a time in the development of paleoseismology when some techniques have become routine and some concepts widely accepted, but when many other aspects of the field are still rapidly evolving (Vittori *et al.*, 1991).

Much of the emphasis throughout the book is on techniques and case histories, for two reasons. First, as in other field sciences, the techniques of field data collection greatly influence the final interpretation of phenomena. In our view, some current differences in field techniques used by different research groups have contributed to differences in seismotectonic models that rely heavily on paleoseismic data. For example, the models of characteristic earthquakes and fault segmentation (Wesnousky *et al.*, 1984; Schwartz and Coppersmith, 1984; Schwartz and Sibson, 1989a) currently in vogue in the United States have been partly justified by paleoseismic data collected in trench exposures of normal and strike-slip faults. In Russia, paleoseismic reconstruction relies heavily on slope failure phenomena (see Chapter 8) and the faults themselves are rarely trenched (Solonenko, 1977; Nikonov, 1988a, 1995). Perhaps as a result of this more indirect approach, the temporal and spatial occurrence of large paleoearthquakes in Russia has been interpreted as more random. In a parallel example, the study of paleoliquefaction in unconsolidated deposits in the United States (by geologists and civil engineers) has focused on developing criteria to distinguish coseismic liquefaction features from similar features of nonseismic origin, and on characterizing the responsible paleoearthquake. In European studies of "seismites" in semiconsolidated rocks of Cenozoic and Mesozoic age (by stratigraphers and sedimentologists), sediment deformation is often merely assumed to be seismic in origin, but rarely is this proven or related to any particular fault. These examples suggest that, at this stage in the development of paleoseismology, paleoseismologists would probably benefit from a global-scale discussion and standardization of terminology and field techniques.

The second reason for an emphasis on techniques is that all chapter authors are active field researchers in paleoseismology, and each has helped to develop some of the techniques described. In particular, we emphasize the need to integrate geomorphic and stratigraphic studies of paleoearthquake evidence, by correlating landforms and processes in deformation zones to their corresponding depositional environments and stratigraphy.

The book is aimed primarily at a graduate to professional level audience in geology, geography, or geophysics, although we assume some familiarity with geomorphology (physical geography) and Quaternary geology. Throughout the book, we try to keep in mind the needs of practitioners who collect and interpret paleoseismic data. Other scientists, engineers, and planners who use paleoseismic data in engineering design or land-use planning may find the overview chapters (1 and 2) and the summary of Chapter 9 most useful.

I acknowledge the assistance of many colleagues who shared their knowledge of paleoseismology. In particular, I thank the reviewers of various parts and drafts of the book, many of whom have at least as broad a perspective on paleoseismology as we do. These include T. K. Rockwell, A. J. Crone, S. L. Wesnousky, R. C. Bucknam, S. L. Obermeier, and S. Pezzopane (Chapter 1), A. R. Nelson (Chapter 2), D. A. Ostenaa and M. Hemphill-Haley (Chapter 3), T. Parsons and J. Zollweg (Chapter 4), J. D. Sims and R. Campbell (Chapter 7), and R. L. Schuster (Chapter 8). Fanchen Kong, V. S. Khromovskikh, and Yoko Ota provided historical perspectives on the development of paleoseismology in China, Russia, and Japan, respectively. In addition A. R. Nelson reviewed much of the book and upgraded its content and exposition to a high standard. Dan and Sue Doylen of Master Graphics (Estes Park, Colorado) provided expert assistance in preparing the figures. Finally, I gratefully acknowledge a decade of support from the U.S. Geological Survey's National Earthquake Hazards Reduction Program, without which my research, and many of the concepts and techniques reported in this book, never would have been developed.

James P. McCalpin
Estes Park, Colorado

Acknowledgments

Thanks are due to the following publishers and professional societies for permission to reproduce copyright material.

A. A. Balkema Publishers: Fig. 2.9
American Association for the Advancement of Science: Figs. 6.21, 6.23
American Association of Petroleum Geologists, Pacific Section: Figs. 5.7, 5.36
American Geophysical Union: Figs. 2.5, 2.16, 3.24, 3.25, 4.5, 5.21, 5.26, 6.10, 6.31, 9.10, 9.18
American Society of Civil Engineers: Fig. 7.28
Annales Tectonicae: Fig. 9.9
Association of Engineering Geologists: Figs. 2.20, 2.23
Blackwell Scientific Publishing Company: Figs. 5.5, 7.3
Brigham Young University: Fig. 2.3
Cambridge University Press: Fig. 9.14
Colorado School of Mines Press: Figs. 3.14, 3.15, 3.28
Earthquake Engineering Research Institute: Fig. 5.28
Elsevier Publishing Company B.V.: Fig. 2.13
Geological Society of America: Figs. 3.11, 3.12, 3.19, 9.10, All © the authors.
Humboldt State University: Fig. 5.27
INQUA Neotectonics Commission: Fig. 2.4
John Wiley & Sons: Fig. 6.4
Journal of Geography (Japan): Fig. 2.11
Macmillan Journals Ltd.: Fig. 5.29
National Academy Press (USA): Figs. 1.1, 5.17, 5.18, 5.20, 6.16, 9.1
New Mexico Geological Society: Fig. 3.18
Oregon Division of Geology and Mineral Resources: Fig. 5.39
Pergamon Press: Fig. 9.15
Royal Society of New Zealand: Fig. 6.7
Seismological Society of America: Figs. 3.7, 3.10, 3.29, 5.12, 9.2, 9.3
Seismological Society of Japan: Fig. 6.15
Society for Sedimentary Geology: Fig. 3.20
Springer-Verlag Publishers: Fig. 5.35

Symposium on Engineering Geology and Geotechnical Engineering: Fig. 2.6
University of Chicago: Fig. 5.22
University of Washington: Figs. 6.32, 6.33
Utah Geological Survey: Figs. 2.12, 2.14, 2.15, 2.18, 2.22
Yale University: Fig. 5.2

Contents

Chapter 7 Using Liquefaction-Induced Features for Paleoseismic Analysis

Stephen F. Obermeier

Chapter 8 Using Landslides for Paleoseismic Analysis

Randall W. Jibson