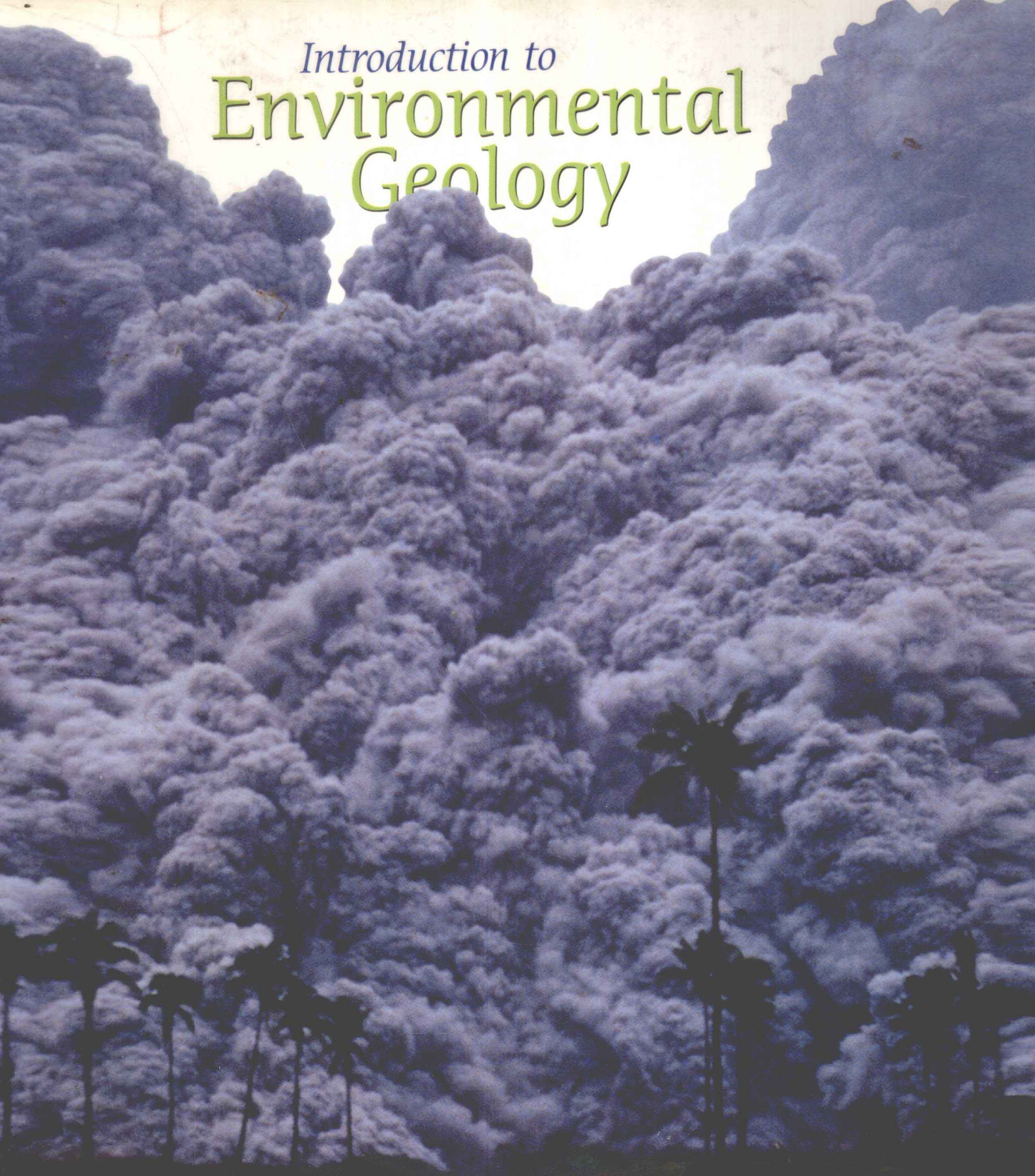
Introduction to Environmental Geology



Edward A. Keller

INTRODUCTION TO ENVIRONMENTAL GEOLOGY

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Brief Contents

For brother Denny and sister Kate,
with thanks for being there and bringing love
and understanding to our lives,
our families, and others you came to know.

PREFACE

Earth's dynamic and changing environment comprises one of the most compelling and exciting areas of study. Now is a particularly interesting time to study the environment from a geologic perspective because, as the human population increases and the use of resources grows, we may be on a collision course with the natural support systems that provide water, air, soil, and other resources we depend on. As a result, it is our responsibility to learn as much as possible about our planet, with the objective to solve environmental problems.

Environmental geology is the application of geologic information to the entire spectrum of interactions between people and the physical environment. During a course in environmental geology, you will develop an understanding of how geology interacts with major environmental problems facing people and society. This is the essence of *Introduction to Environmental Geology*. To this end, this book concentrates on several major goals:

- Introduce you to the basic concepts and principles of physical and environmental geology, focusing on earth materials and processes.
- Provide you with sufficient information concerning natural hazards and the geologic environment so that you will be a more informed citizen. You will be better prepared to make decisions concerning where you live and how society responds to natural hazards and catastrophes such as earthquakes, volcanic eruptions, and flooding.
- Help you develop an understanding of relationships between natural resources and pollution. We seek, find, and use resources and, as a result, may pollute our environment. Thus, it is important to know how we might minimize pollution problems.
- Help you understand the basic concepts of environmental management as they relate to the geologic environment in areas such as waste management, environmental health, global change, and environmental assessment.

After finishing your course in environmental geology, you will be better prepared to make decisions concerning where you build or buy a home, what resources you choose to utilize, and appropriate environmental actions relevant to society and Earth's ecosystems from a local to global scale. Admittedly, these are lofty ideals and some might label me as a hopelessly optimistic, naive university professor. I do believe we need to be positive about our environment and the changes that we envision for the future. We can utilize resources and live on this planet without degrading it. This is the essence of sustainability and is why I wrote this book.

Introduction to Environmental Geology is well suited to your study of environmental geology, whether you are a geology major or are taking this class as a science elective. I have organized *Introduction to Environmental Geology* to naturally flow from the introduction of fundamental principles of environmental science and geology, to more specific information concerning how Earth works, to natural processes and hazards, to understanding natural resources and their management, with the objective of minimizing environmental degradation. We end with a detailed discussion of global change, focusing on climate and some important interactions between society and the geologic environment.

Introduction to Environmental Geology consists of fourteen chapters arranged in four parts:

- Part 1 introduces philosophy and fundamental concepts, the structure of Earth and plate tectonics,

and the origin and significance of minerals and rocks. Thus, Part 1 presents fundamentals of physical geology with important environmental information necessary to understand the remainder of the text. Chapter 1 introduces some of the fundamental concepts of environmental science, with an emphasis on the geologic environment. Chapter 2 discusses the structure of Earth and the important subject of plate tectonics and how our planet works from a geologic perspective. Chapter 3 presents geologic information concerning rocks and minerals necessary for understanding environmental geology problems and solutions to those problems. In Chapter 3, we also introduce some of the fundamental principles of geology, including the law of original horizontality, the law of cross-cutting relationships, the concept of the depositional environment, the concept of the rock cycle, and the principle of magmatic differentiation.

- Part 2 addresses natural hazards, including earthquakes (Chapter 4), volcanic activity (Chapter 5), rivers and flooding (Chapter 6), landslides (Chapter 7), and coastal processes (Chapter 8). The intent is not to provide copious amounts of detailed information concerning these processes, but to focus on the basics involved and the environmental concerns of earth processes and natural hazards.
- Part 3 presents the major resources associated with the geologic environment and the subject of pollution. Important topics include water resources (Chapter 9), mineral resources (Chapter 10), energy resources (Chapter 11), and soils (Chapter 12). The focus is to present the basic principles concerning natural resources and to identify potential environmental problems and solutions.
- Part 4 is concerned with the important topics of global change, environmental management, and relationships between environment and society. Chapter 13 discusses global change with a focus on global warming and stratospheric ozone depletion. Finally, in Chapter 14, which is a "capstone," we discuss relationships between environment and society with topics such as environmental health, waste-management site selection, land-use planning, environmental law, and environmental impact analysis.

Features of the Text

This book is sensitive to the study needs of students. Each chapter is clearly structured to help you understand the material and effectively review the major concepts. To help you use the material from the book, each chapter is organized with the following study aids:

- Learning objectives that state clearly what you should be able to do upon completing the chapter.
- Selected features, called *Case History* or *A Closer Look*, are added where appropriate to help you relate topics in the text to the world around you. Examples of *A Closer Look* features include: (1) the Gaia Hypothesis (Chapter 1), which introduces the idea of evaluating Earth as a system; (2) the importance of understanding the history of a river system with respect to flooding (Chapter 6); (3) principles and processes related to Darcy's Law, wetlands, and acid mine drainage (Chapter 9); (4) relationships between plate tectonics and mineral resources (Chapter 10); (5) the process of radioactivity (Chapter 11); and (6) radon gas (Chapter 14).
- A chapter summary reinforces the major points of the chapter to help you refocus on the important subjects.
- Detailed references are supplied at the end of each chapter to provide additional readings and to give credit to the scholars who did the research reported in the chapter.
- Key terms are presented at the end of the chapters. These will help you identify the important concepts and terminology necessary to better understand the chapter.
- Review questions help with your review of important subject matter, and provide a page number where the answer may be found.
- Critical thinking questions stimulate you to think about some of the important issues in the chapters and try to relate these to your life and society.

The appendixes in *Introduction to Environmental Geology* are intended to add additional information useful in helping you understand some of the more applied aspects of environmental geology. This information may be most useful in supplementing laboratory exercises and field exercises in which you may participate. Specific topics include:

- Identification of rocks and minerals with accompanying tables and suggestions.
- Strength of rocks.
- Introduction to topographic and geologic maps with specific information concerning how to read topographic maps, construct topographic profiles, and understand geologic maps.
- Introduction to Digital Elevation Models (DEMs) and Global Positioning Satellite instrumentation (GPS).

Instructional/Learning Package

In addition to the text itself, the author and publisher have been pleased to work with a number of talented people to

produce an excellent instructional package. This package includes the traditional supplements that students and professors have come to expect from authors and publishers, as well as new kinds of components that utilize electronic media.

- *VR Excursions: Exploring Earth's Environment, Version 1.0* (0-13-096262-7) by Mike Kelly, Michael Ort, Steven Semken, and Jay Shiro Tashiro. Appropriate for use in classes on environmental science, environmental geology, physical geology, physical geography, and Earth science, this highly interactive CD-ROM gives students "access" to a variety of complex environments (a nuclear waste disposal site, a coal-fired power plant, and a solid-waste landfill site). These virtual environments are rich enough that they can be tailored to a professor's individual course goals or they can be used with the accompanying lab manual and Instructor's Manual as a turnkey method of using the computer to give students "hands-on" field experience in the environmental sciences. *VR Excursions* is available with this textbook at a significantly reduced price (Package ISBN 0-13-083400-9). Please contact your Prentice Hall representative for details.
- *World Wide Web Resources.* Students and professors will notice that each part opener features information about the World Wide Web. The World Wide Web (WWW) contains a large number of Web sites from which information may be obtained. You may need to research information while writing a term paper for your geology course, or you may be interested in obtaining further information on a particular subject, such as earthquakes or climate change, and wish to use information taken from the Web. Also, there is a trend for scientists to release the results of their research through the WWW. In order to make it easier for students to explore this vast and productive resource, this book will have a dedicated site on the WWW at **http://www.prenhall.com/keller.** This site contains numerous resources that will help students get started using the WWW as an effective informational tool.
- Foley, *Investigations in Environmental Geology, Second Edition* (0-13-857079-5). Using a hands-on, inquiry-based, problem-solving approach, this laboratory manual for environmental geology features 27 exercises based on classic and recent case histories and current events topics.
- *Geosciences on the Internet—A Student's Guide.* This unique resource gives clear step-by-step instructions to access regularly updated geoscience resources, as well as an overview of the World Wide Web. *Geosciences on the Internet* is the perfect tool to help students take advantage of the Keller Web site and the World Wide Web.
- *New York Times/Themes of the Times—The Changing Earth.* This unique newspaper supplement, updated annually, features recent articles on dynamic, geology-related articles from the pages of *The New York Times.* These articles help students make connections between the classroom and the world around them.
- *Presentation Manager.* This user-friendly navigation software enables professors to custom build multimedia presentations. *Prentice Hall Presentation Manager 3.0* contains several hundred images from the text. The CD-ROM allows professors to organize material in whatever order they choose; preview resources by chapter; search the digital library by keyword; integrate material from their hard drive, a network, or the Internet; edit lecture notes and annotate images with an overlay tool. This powerful presentation tool is available at no cost to qualified adopters of the text.
- Transparencies (0-02-363292-5). Includes 100 illustrations and photographs from the text, all enlarged for excellent classroom visibility.
- Slide Set (0-02-363293-3). A set of slides to complement both lecture and laboratory presentations.
- Instructor's Manual (0-02-363-291-7). Intended as a resource for both new and experienced teachers, this manual contains a variety of lecture outlines, additional source materials, teaching tips, and various other ideas for the classroom.

Acknowledgments

Successful completion of this book was greatly facilitated by the assistance of many individuals, companies, and agencies. In particular, I am indebted to the U.S. Geological Survey and their excellent environmental programs and publications. To authors of papers cited in this book, I offer my thanks and appreciation for their contributions. Without their work, this book could not be written. I must also thank the thoughtful people who dedicated valuable time completing reviews of chapters or the entire book. Their efforts have greatly contributed to this work. I wish to thank: Miguel A. Goni, University of South Carolina; Paul F. Hudak, University of North Texas; Anthony J. Martin, Emory University; Roderic A. Parnell, Jr., Northern Arizona University; Sam Swanson, The University of Georgia; John V. Thiruvathukal, Montclair State University; Donald J. Thompson, California University of Pennsylvania; Bruce Tiffney, University of California; Andrew H. Vassiliou, Rutgers University; and Albert Werner, Mount Holyoke College.

Special thanks goes to Tanya Atwater and William Wise for their assistance in preparing the chapters on plate tectonics, and minerals and rocks, respectively.

I am particularly indebted to my editors at Prentice Hall. Special thanks goes to my senior editor, Robert McConnin, who recently retired following an illustrious career that guided (with the will of a sherpa leading a climber up a difficult peak) many classic books to print. I greatly appreciate the assistance of Leslie Cavaliere, Joseph Sengotta, Beth Boyd, and Daniel Kaveney. Appreciation is extended to my excellent production editor, Tim Flem, who brought it all together and made valuable suggestions. Art was rendered by GeoSystems Global Corp. and Academy Artworks. Endless word processing and transcribing from tape to text was done by Ellie Dzuro, who has done so many books for me and continues to amaze me with her quality work. I thank my students, especially Molly Trecker, who worked on permissions and read, along with Jamila Rivera-Sckolnik, the entire book to help find typos and other errors that invariably sneak in at unwelcome places! Finally, I appreciate the help, encouragement, and support from my wife Valery, son James, and daughters Sarah and Jamila.

Edward A. Keller
Santa Barbara, California

Contents

CHAPTER 10

Mineral Resources 210

CHAPTER 11

Energy Resources 230

CHAPTER 12

PART 4

CHAPTER 13

CHAPTER 14

PART 1

Foundations of Environmental Geology

Chapter 1

Philosophy and Fundamental Concepts

Chapter 2

Internal Structure of Earth and Plate Tectonics

Chapter 3

Minerals and Rocks

Web Resources

Visit the following WWW sites to further explore topics presented in Part 1:

- *PBS's Savage Earth:* http://www.pbs.org/wnet/savageearth/
- *NASA's Observatorium:* http://observe.ivv.nasa.gov/nasa/earth/earth_index.shtml
- *U.S. Geological Survey Online Edition of This Dynamic Earth: The Story of Plate Tectonics:* http://pubs.usgs.gov/publications/text/dynamic.html

Further information about these and many other interesting sites can be found at this book's home page at

http://www.prenhall.com/keller

The objective of Part 1 is to present the fundamentals of physical geology and the important environmental information necessary to understand the rest of the text. Of particular importance are: 1) the fundamental concepts of environmental science, emphasizing the geologic environment; 2) the structure of Earth and, from a plate tectonics perspective, how our planet works; and 3) geologic information concerning rocks and minerals necessary to understand environmental geology problems and solutions to those problems.

Chapter 1 opens with a definition and discussion of environmental geology, followed by a short history of the universe and the origin of Earth. Of particular importance is the concept of geologic time, which is critical in evaluating the role of geologic processes and human interaction in the environment. We suggest that environmental issues result from overpopulation, urbanization, and industrialization, coupled with insufficient ethical regard for the land and inadequate institutions to cope with environmental stress.

Chapter 2 presents a brief discussion of the internal structure of Earth and a rather lengthy treatment of plate tectonics. Over periods of several tens of millions of years, the positions of the continents and the development of mountain ranges and ocean basins have dramatically changed our global environment. The patterns of ocean currents, global climate, and the distribution of living things on Earth are all, in part, a function of the processes that have constructed and maintained continents and ocean basins over geologic time.

Minerals and rocks and how they form in geologic environments is the subject of Chapter 3. Minerals and rocks provide basic resources that our society depends on for building materials to construct our homes, buildings, and other structures; the airlines, trains, cars, buses, and trucks that move people and goods around the globe; and the maintenance of our industrial economy, including everything from computers to eating utensils. The study of minerals and rocks aids in our general understanding of Earth processes at local, regional, and global levels. This is particularly important in understanding hazardous processes, including landslides and volcanic eruptions, in which properties of the rocks are intimately related to the processes and potential effects on human society.

CHAPTER 1

Philosophy and Fundamental Concepts

Learning Objectives

In this chapter we discuss and define geology and environmental geology, focusing on aspects of culture and society that are particularly significant to environmental awareness. We present some basic concepts of environmental science that provide the philosophical framework of this book. After reading this chapter, you should be prepared to discuss the following:

- Geology and environmental geology as a discipline
- Geologic time and its significance
- The scientific method
- Important factors related to the "environmental crisis"
- Increasing human population as the number one environmental problem
- The concept of sustainability
- Systems theory and changes in systems
- The concepts of environmental unity and uniformitarianism and why they are important to environmental geology

The Dolomites of the Italian Alps form spectacular scenery. Many fundamental principles of geology have resulted from studying Alpine geology. *(Edward A. Keller)*

Case History
Ducktown, Tennessee

The land surrounding Ducktown once looked more like the Painted Desert of Arizona than the lush vegetation of the Blue Ridge Mountains of the southeastern United States (Figure 1.1) (1). The story starts in 1843 with what was thought to be a gold rush that turned out to be a rush for copper. By 1855, 30 companies were transporting copper ore by mule over the mountains to a site called "Copper Basin" and to Ducktown. Huge ovens—open pits 200 m long and 30 m deep—were constructed to separate the copper from zinc, iron, and sulfur. The local hardwood forest was cut to fuel these ovens, and the tree stumps were pulled to be turned into charcoal. Eventually, every tree over an area of about 130 km^2 (an area about four times that of Manhattan Island) was removed. The ovens produced great clouds of noxious gas that were reportedly so thick that mules wore bells to keep from colliding with people and each other. The sulfur dioxide gas and particulates produced acid rain and acid dust that killed what vegetation remained. Loss of vegetation led to extensive soil erosion, leaving behind a hard mineralized rock cover resembling a desert. The scarred landscape is so large that it is one of the few human landmarks visible from space.

The devastation resulting from the Ducktown mining activity produced adverse economic and social change. Nevertheless, people in Ducktown in the 1980s remained optimistic. A sign at the entry to the town states, "Copper made us famous. Our people made us great." Revegetation started in the 1930s, and by 1970 approximately two-thirds of the area was covered with some vegetation.