Second Edition

THE HUMAN FOOTPRINT

A GLOBAL ENVIRONMENTAL HISTORY

Anthony N. Penna

WILEY Blackwell

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This second edition first published 2015

Edition history: John Wiley & Sons, Inc (1e, 2010)

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

Editorial Offices
350 Main Street, Malden, MA 02148-5020, USA
9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

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Library of Congress Cataloging-in-Publication Data

Penna, Anthony N.
The human footprint : a global environmental history / Anthony N. Penna. – Second edition.
pages cm
Includes bibliographical references and index.
ISBN 978-1-118-91246-1 (pbk.)
1. Human ecology – History. 2. Ecology – History. 3. Climatic changes – History. 4. Natural history. I. Title.
GF13.P46 2015
304.2 – dc23

2014017310

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

Cover image: Melting water streams from iceberg carved from Ilulissat Kangerlua Glacier (Jakobshavn Icefjord) in Disko Bay. © Paul Souders/Corbis

Set in 10.5/13pt Minion by Laserwords Private Limited, Chennai, India

1 2015

Dedication for the First Edition
In Memoriam

To my grandparents, whose life journeys created opportunities

Vincenzo Penna (1870–1950)
Filomena Penna (1873–1956)
Niccolo DePalma (1888–1916)
Carolina DePalma Bosco (1890–1981)
Pellegrino Bosco (1882–1963)

To my parents, who provided incentives

Anthony Penna (1907–1987)
Mary DePalma Penna (1914–2003)

Dedication for the Second Edition

To my grandchildren

Olan Anthony Turner, London, UK (2010–)
Skylar Rosalie Thieme, Philadelphia, USA (2013–)

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Acknowledgments

Many of the global challenges facing humans in the twenty-first century will require knowledge about the complexity of the planet's climate system and contextually informed understandings of our role as stewards of its fragile ecology. For educators at all levels of teaching, the task of integrating ecology and environmental history into local, regional, and national histories will become a compelling endeavor requiring flexibility, adaptation, and new knowledge. Survey courses in global environmental history and specialized national and regional environmental histories will become important dimensions of the evolving history and social science curriculum and the growing field of environmental studies.

This book is the result of two journeys; the first took place in numerous conversations with my wife-to-be, Channing, as we walked the nearly 500 mi (804 km) pilgrimage route across northern Spain, el Camino de Santiago, in September 2001. The second journey, familiar to all writers, began with the assertion that this subject is worth writing about.

From 2002 until publication in 2010, the research took me on its own journey and became a central part of each day. In writing this book, I relied on the knowledge, insight, and wisdom of many scholars in various disciplines. I also had the benefit of many colleagues who read earlier versions of single chapters, clusters of chapters, and the entire manuscript during its initial stages of development. My former teacher, colleague at Carnegie-Mellon University, and long-term friend, Irving H. Bartlett, the John F. Kennedy Professor Emeritus of American Civilization at the University of Massachusetts, Boston, remained an enthusiastic critic and supporter of this work. Irving's death in July 2006 denied us the pleasure of celebrating its publication over lunch after a marathon bike ride along the commonwealth's southeastern coast. Joel A. Tarr, the Richard S. Caliguiri University Professor at Carnegie-Mellon University, also a former teacher, a colleague, and a long-term friend, gave unselfishly of his time and knowledge as this project unfolded.

I want to thank George Dehner, Jason Eden, Martin Melosi, and Jeffrey Stine, who read earlier versions of some chapters in the first edition, and

George and Jeffrey along with Professors Qingjia Edward Wang of Rowan and Beijing Universities and Eric Vanhaute of the University of Ghent in Belgium and the many anonymous reviewers from the United States, Canada, and the United Kingdom who read the entire manuscript. Their detailed critiques helped me to refocus, revise, and rewrite.

In the first edition, I received the invaluable aid of my research assistants. David Adams and Michael Mezzano compiled the initial bibliographies while Katherine Platt, Jeanine Rees, and Eric Skidmore located materials for chapters on manufacturing, industrialization, consumption, and energy. During the final year of the project, Neysa King and Colin Sargent conducted electronic searches for photographs, charts, graphs, and maps. The fruit of their labor is found throughout this book. In addition, Colin used his advanced technical skills to turn all graphical material into electronic files and format the entire manuscript in accordance with the publisher's guidelines and in the second edition did invaluable photographic research to eliminate photographs taken from public websites and to substitute them with those possessed by verifiable owners. Elizabeth Somerset's electronic index of the first edition made the final preparation of a published index less onerous. All three contributed mightily at the end and I am in their debt. John R. McNeill read the page proofs for the first edition and identified a number of errors before the manuscript went to press. This led executive editor Peter Coveney and me to spend a day reviewing the entire manuscript making additional corrections. Once the first edition was published, I received much feedback from readers. David Burzillo, who teaches global environmental history at the Rivers School in Weston, Massachusetts, identified errors in the section on ancient history that I have corrected in this edition. Likewise, Karl Geiger, my friend and co-worker at Habitat for Humanity, Boston, provided detailed commentary on every chapter that improved the text greatly. To all of them, I owe much thanks. For the second edition, in the United Kingdom, Georgina Coleby and Hazel Harris provided much-needed management and editorial support. Without their attention to detail and their enthusiastic support, the preparation of this second edition would have become a challenge.

Undergraduate and graduate students who have enrolled in my global environmental history courses and seminars came from majors in history, political science, sociology, economics, international relations, biology, civil and environmental engineering, chemistry, and environmental studies. They brought with them knowledge and ideas that informed our ongoing conversations. Many entered these courses skeptical about the importance of historical perspective in understanding present environmental conditions. All left with a willingness to read more widely in other disciplines and with a richer, contextualized understanding of the environmental costs of human action.

For the first edition, I gained much insight from two seminars on world history. One was a joint series that began in 2007–2008 between Tufts University and Northeastern University, directed by Felipe Fernandez-Armesto at Tufts and Laura Frader at Northeastern. Sven Beckert, Harvard University, and Dominic Sachsenmaier, Duke University, directed the other, a weekend conference titled "Global History, Globally," in February 2008. Both the series and the conference provided papers, presentations, and discussions that penetrated more parochial boundaries and encouraged participants to engage in broader historical and comparative perspectives.

While deeply involved in her own creative enterprise, my wife, Channing, has remained an enthusiastic supporter of my work.

Introduction

The Nature of World History

There has been a surging interest in the field of world history as scholars attempt to cross regional and national boundaries. By weaving national biographies into world history, we engage the fragments of history by fitting them together in a coherent and meaningful whole. Herein lies one of the big intellectual challenges for world historians, namely "to transcend national frontiers, and study forces such as population movements, economic fluctuations, climatic changes, and the transfer of technologies."[1] It remains a vibrant yet contested subject not only because it disturbs the 200-year dominance of European and American national narratives and a trend of subordinating the rest of the world to a Euro-American paradigm but also because no institutional framework in the profession of historians exists for world history. As a highly successful approach to studying change over time, the nation state will remain the primary vehicle for analyzing the experiences of individual, local, and regional communities. For world historians, "exploring the connections, comparisons, and systems that help to situate historical development in larger appropriate contexts"[2] will increasingly become their domain.

Micro-historical studies that focus on vertical trends dominate the research agendas of most American and European universities. The continuing importance of specific studies will remain unchanged but recent developments in world history argue for what one historian has described as a horizontally integrative macro-history, one that described and explained interrelated historical phenomena.[3] Looking inward to describe changes in aspiring national histories and outward in an effort to make interregional connections and exchanges places less emphasis on persons and nations. As historians go about this transformation in describing world historical

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events, they attempt to decenter Europe, despite its dominance in world affairs from the beginning of industrialization through World War II.

By decentering Europe, other parts of the world come into clearer focus in the millennia before industrialization. The coal revolution released energy from the fossil remains of plants and animals, altered global material culture in the nineteenth century, and served as a point of demarcation, separating the premodern from the modern world. Additionally, world history encompasses a longer and deeper history, one that is not bounded within a Judeo-Christian framework and one in which the fossilized remains of humans allow archeologists, paleo-anthropologists, and geneticists to gain insight into the physiological development of early humans. Their diets, health, and vulnerability to disease and predation serve as windows into a deep history of humanity.[4]

The Nature of Big History

Big history attempts to place human history within the framework of the history of the universe from its beginnings to life on Earth today. In the words of Fred Spier, one of the field's primary scholars, big history "look[s] at the large-scale patterns of the major processes that have shaped our common past."[5] In *The Human Footprint*, those patterns and processes are identified in the chapter headings and subtitles as they relate to natural and human history. Fred Spier poignantly referred to

> the idea that all of us belong to one single, rather exceptional, animal species, which emerged on a rather exceptional planet somewhere in the universe; that our closest cousins are the primates; that we are, in fact, related to all life forms and that, seen from a cosmic perspective, our far cousins are the rocks, the water and even the stars.[6]

In this regard, Chapter 1 and Chapter 2 in this volume attempt to make these cosmic and human connections. The book's remaining chapters have a human focus and draw heavily on the conceptual framework pioneered by the historian David Christian, who gave this new field its name, "big history."

The Nature of World Environmental History

This world environmental history is not a comprehensive survey of human history focused on civilizations, nations, personal biographies, or events. Plenty of existing world histories accomplish this important task. This one focuses on great transformations in human history and the relationship between human history and natural history, with the emphasis on human world–natural world interrelationships. In the words of J. R. McNeill, it "concerns itself with changes in biological and physical environments, and how those changes affect human societies."[7] It approaches this challenge by reformulating prior knowledge about local, regional, and national histories and by using knowledge that integrates and interrelates these histories.

Additionally, some of the reformulation occurs by crossing disciplinary boundaries and using the research findings and new knowledge of geologists, climatologists, evolutionary biologists, archeologists, paleo-anthropologists, demographers, economists, and the social sciences as they study Earth's history, evolution, agricultural productivity, urban planning, manufacturing, industry, consumption, and energy use. Scholars across the disciplines are committed to understanding developments as they have been and are now in the real world, not as imagined constructions without a scientific basis. Each discipline, with its own perspective, contains a unique theoretical structure and proof process. In essence, scholars may study the same subject from their traditional disciplinary perspectives but arrive at different places studying the same "real world." In its own way, this book integrates great global transformations and evolutions, telescoped from planetary and human origins to modern consumption patterns and energy uses. Each effort to integrate disciplines as well as local, regional, national, and transnational histories makes the global transformations that draw on ecology and environment possible.

Earth's History and Human Origins

Because histories of humankind assume a global ecological system that made life possible and sustainable, they ignore the origins of Earth and its development over billions of years. Leaving little about Earth's history to the imagination, this book begins with an examination of the evolutionary history of our planet that made all life forms, including human life, possible and sustainable. As astronomer Carl Sagan famously said, "we are all stardust." Our bodies are made of oxygen, carbon, nitrogen, and iron, all elements synthesized in the thermonuclear explosions of stars that seeded future stars with heavier elements.[8] In its own way, as volatile as the universe, Earth's history is punctuated with massive tectonic movements that became a complex arrangement of continents.

According to many scientists, changes in the natural world provided the conditions for evolution. As Fred Spier has noted, "plate tectonics may have played a dominant part in driving biological evolution, including human evolution. Continuous shifts in the position of Earth's land masses led to changes in the ocean currents, which influenced the global climate. I see this as an example of how dominant geological and climate regimes can influence human evolution."[9]

Although the science of human genetics and evolutionary biology are rapidly changing disciplines, their ability to map genetic and biological structures offers insights into our evolutionary history. In response to geological and climate changes a million and a half years ago, *Homo erectus*, an early hominid, whose genus, *Homo*, originated in eastern Africa about 2.5 million years ago (mya) developed anatomical features more closely identifiable as modern. An increased brain size, a flatter face and jaw, a tilted pelvis for walking upright, and longer limbs distinguished *H. erectus* from its hominid predecessors.[10] Cultural changes accompanied the physiological ones. Paleo-anthropologists now believe that *H. erectus* may have numbered only 18,500 breeding individuals with offspring totaling about 30,000 when they began their migration out of Africa.[11] Our understanding of the co-evolutionary processes of Earth and of humanity enhances our growing commitment to a historical interpretation based on ecological interdependencies.

Mass Migrations and the Rise of Agriculture

A cooling climate changed the tropical habitat of *H. erectus* and initiated its migration from eastern Africa to Eurasia, a million or more years ago. With intervals of hundreds of thousands of years separating them, other migrations followed, including the migration of *Homo sapiens* out of Africa about 100,000 BP. Warming climates, retreating ice sheets, the loss of habitat

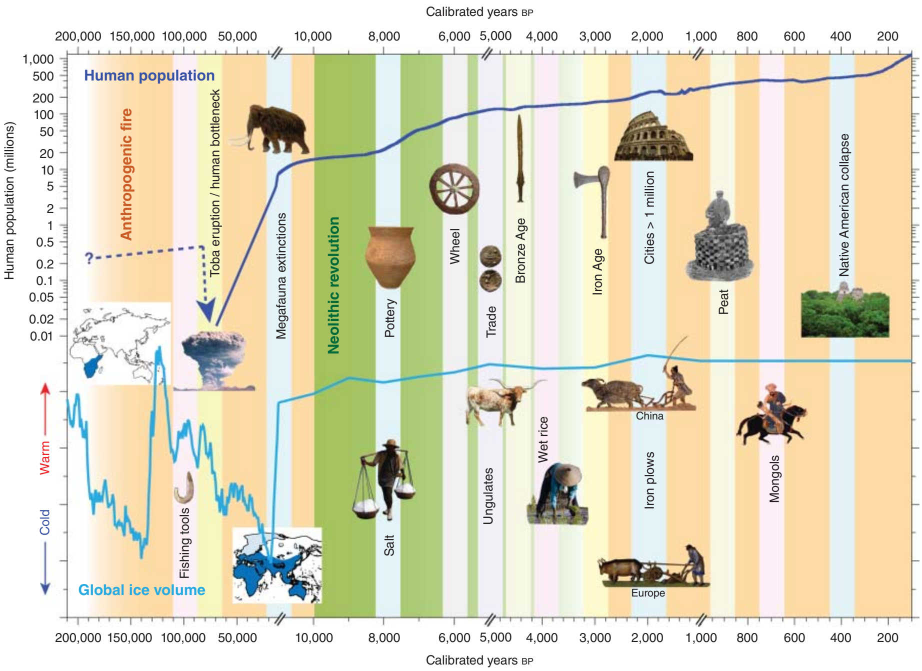

Figure I.1 Global timeline of human transformation of the terrestrial biosphere. *Source*: Erle C. Ellis et al. "Dating the Anthropocene: Towards an empirical global history of human transformation of the terrestrial biosphere," *Elementa: Science of the Anthropocene*. Courtesy of Jed O. Kaplan.

Figure I.2 Zebras grazing on the Serengeti in Botswana, August 2011.
Source: Photographed by the author.

for Ice Age megafauna such as mammoths and other large herbivores, and extreme predation by hunters and gatherers may have created a nutritional bottleneck. The mass extinction of megafauna may have caused a buildup of fuel that suggests the human use of fire to clear woodlands and increase open spaces for the spread of seeded plants. “For instance, fire-stick farming by Australian Aborigines created fine-grained landscape mosaics with greater small-animal diversity and increased hunting productivity.”[12] Extreme predation represents another early example of the human footprint on the natural world. One of its unintended consequences allowed smaller mammals to fill the ecological void left by megafauna decline.

The independent invention of agriculture in many parts of the world between 10,000 and 8000 BP may have been a response to these growing nutritional deficits. Rising carbon dioxide levels, an outcome of retreating Ice Age glaciers, made for a more robust plant life that early farmers cultivated selectively. In the opinion of Fred Spier, “the prime candidate for a global factor involved in triggering the emergence of the agricultural regime is climate change.”[13] This change ushered in a long (7,000–8,000 years) period of climate stability for the first time in 100,000 years that coincided generally with the rise of civilization, about which many historians write without much reference to the importance of climate. During the transition to a more stable climate, humans and animals became dependent on each other and on a comparatively small number of domesticated plants.

This transformation from hunting and gathering to agriculture can be described best as evolutionary, occurring in response to ecological changes beyond the control of *H. sapiens*. The costs to these early cultivators cannot be minimized, however. For millennia, agriculture demanded labor-intensive commitments from humans and their work animals. Their diminished stature and shortened lives suggest a bleak existence.

Adversity led to innovations and inventions, however. The selective breeding of plants and animals and the fabrication of tools increased productivity and led to larger settlements and villages. Many became cities with complex social, economic, and administrative hierarchies. Food surpluses released others to develop skills that increased their mobility and led to a rise in skilled crafts and monetary exchange. With a rise in human skilled capital, many cities became centers for growth and made the transition to agrarian civilizations.

The successful migration of early Eurasian farmers and their livestock spread disease among previously isolated human communities as domestication brought humans and animals into close proximity and exposed humans to animal microbes that became human pathogens. Despite increased food production, a demographic explosion failed to materialize until the twentieth century. With the population passing the seven million mark during the first decade of the twenty-first century, 6% of all humans who have ever lived are alive today. A drop in the death rate worldwide, not a rise in the birth rate, caused global populations to skyrocket. The surge did not happen because people "suddenly started breeding like rabbits: it is just that they stopped dying like flies."[14]

Early agrarian societies became a precondition to population growth, manufacturing, and industrialization. As anthropologist Alf Hornborg points out, "land improvement for the purpose of agricultural production is the main form of capital accumulation in preindustrial societies on all continents, and simultaneously one of the most tangible ways in which humans for millennia have changed their natural environments."[15] As this book points out, population growth and the ascendancy of cities became significant outgrowths of the transition to agriculture.

Population Growth and the Rise of Cities

For millions of years, infinitesimal growth rates defined the human population. One theory proposes that the eruption of Mt. Toba in Sumatra 74,000 years ago, the largest in the Quaternary (the past 2.6 million years), caused a global cooling that killed all but a few thousand members of *H. sapiens*. The evidence for this demographic collapse is written into our DNA.[16] Although more than 100 billion people have been born in the past 50,000 years, growth remained very slow for most of human history, not reaching 750 million people until early nineteenth-century industrialization.[17] The first billion was reached in those early decades and then a burst in population, unprecedented in history, took place. It took about 120 years to add another two billion. In the past 60 years the world's population rose from three billion in 1959 to four billion in 1974, five billion in 1987 and six billion in 1998. In 2011, the number of humans alive reached seven billion.[18]

In antiquity, cities became geographic centers for safety and protection, management, and the distribution of goods and services. From these responsibilities, city-states and agrarian civilizations emerged, with population densities reaching nineteenth-century levels in some centers. Uruk, an early Sumerian city, maintained a population density of as many as 60 persons per acre, with a total population estimated at between 20,000 and 30,000 in 5300 BP, a density similar to Paris, France, in the nineteenth century.[19]

Once cities broke through the artificial barriers imposed by ancient and medieval walls, horizontal low-density growth competed with vertical high-density growth for real and perceived resources. In China and Japan, for example, much of the population growth took place in rural areas after 1750, while in Europe growth occurred in mostly settled and densely populated regions between 1750 and 1850. The impact of growing populations and increasing urbanization placed considerable stress on ecosystems, including woodlands, water, and wildlife, as the ecological footprint of humans broadened and deepened.

In the modern metropolitan world, the spread of low-density living arrangements led to more energy consumption, producing vast quantities of greenhouse gases. Suburbanites purchase 85% more gasoline than those who live within 5 mi of a city center. This imbalance accounts for about six tons of carbon emissions per vehicle each year.[20] Thinking about cities as "great carbon-reduction machines," where "sidewalks are as sexy as hybrids" and in which cars last for 15 years but street grids last a century or more, may become the template for urban revitalization in the developed world and increasing urbanization in the developing world.[21]

Cities and the Rise of Manufacturing and Industry

Population growth and urbanization can be traced to the growth in manufacturing and industry, two transformations that are co-joined in this book. Manufacturing and industrialization have a long evolutionary history, punctuated by production-changing inventions. At their core, however, is the intensified use of fire, a utility discovered by *Homo ergaster* more than a million years before. As crafts and skilled trades became viable occupational categories in ancient cities, small-scale fabricating and manufacturing using open pit fires and furnaces flourished in urban workshops and in many highly decentralized rural households across Eurasia, from the Mediterranean to India and China.

Until the eighteenth- and nineteenth-century transitions from workshop to factory, the global economy concentrated on polycentric economic interactions. Asian workshops centered primarily in India and China supplied their trading partners across the world with up to 80% of their consumer goods in dyed cotton cloth, silks, and porcelain. Spices, especially pepper from Asia, seasoned the otherwise bland meals across Eurasia. The direction of these energy flows and interactions changed as Europe broke through the bottleneck created by dwindling supplies of organic energy provided by its forests. The coal revolution, extracting mineral energy by burning fossil minerals and converting water into steam, increased production. Steam engines increased economic efficiencies and separated the premodern from the modern world. As historian Harold Livesay has written, "the world of material possibilities was dramatically altered between 1780 and 1880. No previous century witnessed such changes."[22]

Industrialization replaced workshops with factories, mercantile exchange with moneyed capitalism, hand looms with power looms, and handicrafts with mass production. Steam turbines replaced steam engines in many industrial enterprises. Inventions, investments, and innovations became synonymous with wealth creation, while toiling masses flocked to cities in search of a better life. As the distance between the classes grew greater, with wealth concentrated in the hands of entrepreneurs and the owners of production, poverty became widespread.

Economic wealth creation imposed heavy environmental costs as industrial cities experienced explosive population growth during the nineteenth century that overwhelmed their ancient infrastructures. Deafening noise, the unbearable smell of rotting draft-animal carcasses, the bloody remains of slaughtered cows and pigs running in the gutters and alley-ways, and human waste from overflowing cesspools, cellars, and privy vaults were constant reminders of urban decay.

In the *longue durée*, these same wealth-creating industrial cities would become engines of progress. Pockets of poverty would remain and income would continue to be distributed unequally, but, in comparison to rural areas, an extended life expectancy would become a characteristic of living in modern twentieth-century cities. As industrialized cities became engines for the production of capital goods (e.g., iron and steel, locomotives and freight cars, cloth and finished textile goods), they also became vehicles for the growth and spread of consumer goods.

World Trade and New World Ecology

As was the case with manufacturing and industry, consuming material goods cuts a broad path across five centuries of product initiation, marketing, and replacement. Unlike industrial work, however, with its eighteenth-century origins, the patterns of commerce in consumer goods across Eurasia and among Indian Ocean trading partners extend across many centuries. The history of consumer goods, with the transformation of luxuries into commodities for large numbers of buyers, provides readers with a historical perspective into the modern world of mass consumption and its ecological effects. Its location in this book is the logical outcome of global environmental transformations in agriculture, population change, and urbanization.

The international market of exchange and its impact on the global flows of energy, people, and goods became unprecedented. The increased production of sugar and its declining price were tied directly to slave labor. Importing West African slaves to the Americas for work on sugarcane plantations not only transformed sugar consumption in the Western world but also altered human relationships for centuries into dominant and subservient categories.[23] The sun supplied the energy that transformed seeds into sugarcane and tea plants, while ships catching the trade winds brought slaves from West Africa to the West Indies and Brazil and railroad engines burning fossil coal brought both tea and sugar to consumers.[24]

J. R. McNeill has revealed how ecological interdependencies shaped geopolitical history in the American tropics. As slaves arrived in the New World in the seventeenth century to grow sugar, the slave ships brought with them the West African mosquito *Aedes aegypti*, the vector for yellow fever. Many West Africans had acquired immunity, while Europeans coming from temperate climates had not. Transformed plantation landscapes in the American tropics became breeding grounds for *A. aegypti*. Invading armies from France and England suffered greatly from outbreaks of yellow fever as they tried to defeat the Spanish in the Caribbean.[25]

Fossil Fuels and Climate Change

Energy is a ubiquitous category for which the reader can find evidence throughout this book. While the burning of fossil coal released humans from the constraints of premodern organic sources of energy (e.g., wood, biomass, and animal dung), its use began the long-term process of environmental degradation and destruction by emitting carbon, sulfur, and nitrogen oxides that reduced air quality and caused the atmosphere to warm at an alarming rate. The transition to fossil coal accelerated industrialization, after centuries in which humans had harnessed the velocity of the wind and the natural flow of water to do work. Their energy, supplemented by human labor, had powered the looms of textile mills, the saws and lathes of lumber mills, and the crushers, cutters, and grinders of ironworks. Most of these power sources and their industrial output trod lightly on the land and its water, when compared to coal-fired plants.

Coal, cheaper than wood, changed the workplace and household economy in the nineteenth century and with it the natural and built environment. Coal continues to fuel industry and generate electricity for modern households. Petroleum, natural gas, and, to a lesser extent, nuclear and biofuels are fulfilling increasing worldwide demands for energy. With automobiles becoming the ubiquitous symbols of status throughout the world, petroleum-producing countries are playing an increasingly significant role in the global economy. With rising demand for energy resources, global greenhouse emissions from all fossil fuels are contributing to rising temperatures and climate change.

Since this book begins by identifying the many ways in which geological changes created a climate system that made possible the origins of life, a concluding chapter on the world's warming climate serves to reinforce interdependencies between the natural world and human history. The Fifth Assessment Report in March 2014 of the United Nations' Intergovernmental Panel on Climate Change points out that major greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), have all increased since the approximate beginning of the industrial age in 1750 due to human activity. "Concentrations of CO_2, CH_4, and N_2O now substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years. The mean rates of increase in atmospheric concentrations over the past century are, with very high confidence, unprecedented in the last 22,000 years."[26]

The Fifth Assessment stresses that burning fossil fuels has warmed the atmosphere and the ocean and has changed the global water cycle (observed in reduced snow and ice, in a global mean sea-level rise, and in changes in some climate extremes, with droughts in some regions and floods in others). The evidence points out that humans have been the dominant cause of the observed warming since the mid-twentieth century.

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Chapter 1

An Evolving Earth

Introduction

Earth is a living, dynamic, and sometimes violent planet. Able to sustain organic life, subject to violent swings in temperature, the modern climate is the result of Earth-defining changes. These changes range from the collision of Earth's continents to the ability of its oceans to absorb solar energy as heat and reflect it as light, and to influence the intensity and flow of ocean currents. Atmospheric changes, tectonic movements, and global climate are interconnected forces that transformed Earth's history and created an environment suitable for the development of all life forms.

On a much longer timescale, scientists believe that our solar system formed because gaseous clouds of debris from older stars condensed into solid matter about 4.6 billion years ago. The formation of our solar system was but one of many significant cosmic events in the history of the universe, which most scientists agree took place about 13 billion years ago. At many trillions of degrees, a super-heated universe, smaller than the size of an atom, began expanding faster than the speed of light in its first few seconds. This was the Big Bang. The universe's background radiation is a reminder of this event and the continuing expansion of the cosmos.

For the next 300,000 years, the universe remained a super-heated entity much like the interior of the sun in our solar system. As the universe expanded and cooled, a phenomenon that continues to this day, energy and matter separated. As described by the historian David Christian:

> About 300,000 years after the big bang, all the ingredients of creation were present: time, space, energy, and the basic particles of the material universe, now mostly organized into atoms of hydrogen and helium. Since that time, nothing has really changed. The same energy and the same matter have continued to exist. All that has happened is that for the next 13 billion years these

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same ingredients have arranged themselves in different patterns, which constantly form and dissipate.[1]

By collapsing the timescales of the 13-billion-year cosmos by a factor of one billion, the Big Bang took place 13 years ago. In this scenario, Earth's first living organisms appeared about four years ago, and modern humans evolved in Africa about 50 minutes ago. The invention of agriculture and the building of cities, which you will read about in later chapters, occurred five minutes and three minutes ago, respectively.[2] Thought about in this way, the life of humans is a relatively recent addition to Earth's history. Looked at in another way, if the 10-billion-year projected life of Earth's energy system were compressed into a single year, all of written human history would be represented in less than a minute. And the twentieth century would be less than a third of a second long.

The Origins of Earth and Its Unique Atmosphere: From Hot to Cold Planet

More than 4.6 billion years ago the explosive atomic energy of mega-sized meteors created a liquid mass of molten rock of 1,800°F (980°C). This was the newly forming Earth, with an atmosphere of mostly hydrogen and helium, the main gases around the sun. During a 600-million-year period, repeated bombardments followed by the sinking of the iron cores of those meteors created the molten center of Earth. Its iron core created the planet's magnetic field, which deflected many high-energy and dangerous particles from Earth. In this very important way, it acquired and to this day possesses a protective shield.[3]

This extremely hot planet created an equally torrid atmosphere including super-heated hydrogen and helium molecules, moving so fast that they escaped Earth's gravity. The young Earth can be thought of as a massive volcanic field that created its own infant atmosphere, releasing gases: water (H_2O) as steam, carbon dioxide (CO_2), and ammonia (NH_3).[4] As large meteor strikes slowed over a period of about two billion years, however, the surface and its atmosphere changed significantly. Some scientists attribute this climatic transition to the impact of a mega-meteor, estimated to be the size of the planet Mars, that struck Earth about two billion years ago. The impact knocked it on its side, deflecting much of the sunlight that would have normally warmed the tropics. A decrease in solar radiation