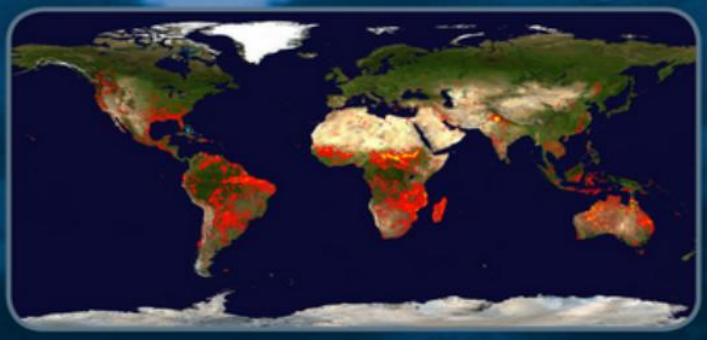

FIRE ON EARTH

An Introduction

Andrew C. Scott, David M.J.S. Bowman, William J. Bond,
Stephen J. Pyne and Martin E. Alexander

WILEY Blackwell

Contents

Fire on Earth:

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For my wife Anne, my children Rob and Katrina for their love, cheery encouragement and support and in memory of my father

John D. Scott (1917–1966)

ACS

For Fay, for her wisdom and unwavering support of my quest to discover the meaning of fire on Earth.

DMJSB

For my wife, Winifred, for her cheerful companionship and support over many years.

WJB

For Sonja – who didn't need a third time to be charmed

SJP

For my wife Heather and children Neal, Evan, Graeme and Wynne, and my parents Connie and Russ, with much love.

MEA

Preface

Earth is the only planet known to have fire. The reason is both simple and profound: fire exists because Earth is the only planet to possess life as we know it. Life created both the oxygen and the hydrocarbon fuel that combustion requires, it arranges those fuels according to processes of evolutionary selection and ecological dynamics and, in the form of humanity, it supplies the most abundant source of ignition. Fire is an expression of life on Earth and an index of life's history. Few processes are as integral, unique or ancient.

Yet, while the significance of fire can hardly be doubted, it rarely enters the discourse of relevant disciplines or appears in standard texts of geology, biology, human history, physics or global chemistry. Fifty years ago, the only organized inquiries lodged in applied contexts such as combustion engineering, urban fire services and, fitfully, forestry and range science. No journal exclusively reported on it; conferences, wholly national, might be held once a decade on how better to control it; and, even when it was examined, free-burning fire, which integrates everything around it, was narrowly confined within other disciplines. The outcome was an extraordinary disconnection. While fire was ubiquitous in various forms throughout Earth, it was absent from our formal inquiries about our world. It stood outside both science and scholarship.

Today, the literature has multiplied exponentially. Dedicated journals exist. Half a dozen international conferences might be held annually. A host of formal sciences, or programmes announcing interdisciplinary intentions, are willing to consider fire. Wildfire appears routinely in media reporting. What has not happened, however, is a synthesis of contemporary thinking that can

bring together the most powerful concepts and disciplinary voices that have interested themselves in fire. There is no global survey that can convey why planetary fire exists, how it works and why it looks the way it does today. This volume intends to redress the problem.

The text consists of four parts. The choice of themes is not arbitrary. We wanted to:

- establish the autonomy and longevity of fire on Earth;
- centre its dynamics in the living world;
- accent the critical presence of fire for humanity, and of humanity for pyrogeography;
- have fire's behaviour serve more as an integration of factors, and hence a summary, than as a putative foundation to everything else.

No volume can hope to summarize everything that has been published on the subject, or convey fire's endlessly ramified expressions in the field. We have selected those organizing themes that we believe best introduce the subject.

Each part is intended to stand alone, yet allow for connections to the others. Instead of creating an artificial synthesis, an intellectual equivalent of Esperanto, we elected to let each author speak in his own disciplinary tongue, in the hope that the gains from fluency will overcome any losses from translation. Yet, as in any collaborative venture, we have had an influence on what each of us has written and, hence, this volume must be considered as a book with five authors rather than an edited volume. The result is not an encyclopaedia, but a studied description and explanation of how fire appears to a prominent cadre of fire researchers. As each discipline organizes the whole through its own disciplinary prism, so each author speaks in his own voice.

Inevitably, there are lapses and overlaps in the particulars of the four parts. Each of us, for example, sees the

foundational fire differently. For someone interested in deep time, fire appears as an emerging property of an evolving planet – one that leaves a geologic record. For biologists, fire appears as a product of the living world – the substrate without which fire cannot exist. For a cultural historian, it appears as an informing and defining technology for humanity – a unique signature of our agency and identity. And for someone interested in fire behaviour, fire will appear as a chemical reaction shaped by its physical surroundings.

We felt it better to let each author follow his own vision and thematic arc than try to merge them into a common cauldron. In this way, each perspective:

- will understand the increasingly dominant presence of humanity differently;
- will see it as the latest in a long chronicle of fire eras;
- will see it as perturbation along all scales of Earth's biota;
- will see it as an index of humanity's changing power; or
- will see it an arena for the application of better understanding to protect ourselves from the fires we do not want and promote those we do.

Nor have we tried to describe field operations, as previous texts by some of the authors have. The reason is simple. Other technologies, notably video, can do that job much better; 30 seconds of film can convey more accurately and vividly how to scrape fireline or run a pump than 30 pages of text. We wanted to let a book do what it can do best, which is to explore our understanding of fire and our relationship to it. We have sought to explain what principles mean through ground-truthing details, selected examples and case studies.

Inevitably, we can include only a minuscule fraction of landscapes, events, information and published (and unpublished) studies. Our choices will reflect our own

judgment of what is most useful within the setting of this text, what the fashion of the times prefers and, inevitably, our own personal experiences and tastes.

We have elected to hold in-text citations to a minimum and to supplement them – again selectively – in the rosters of references and further reading attached to each of the four parts. The published literature on fire now numbers in the tens of thousands (and is expanding exponentially) and, while it is densest in the more developed world, its topics range across the planet. The authors of this text alone have a collective bibliography that includes hundreds of citations. The fire literature since the early 1960s has multiplied exponentially so, just as only a handful of examples must stand for the whole, only a tiny fraction of this literature can enter our bibliography. A master bibliography belongs online, not on printed pages.

These choices will please those members of the fire community whose work has been selected and will doubtless irk those who work has not. To the many who may feel we have slighted important sources, we plead *nolo contendere* and repeat that our purpose has not been to summarize the entire state of the literature, but to demonstrate why fire matters and how we might better understand the complex ways it intertwines with Earth and humanity. As Plutarch famously put it, the mind is not a vessel to be filled, but a fire to be kindled.

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We thank the many researchers for allowing us to use their photos and diagrams and, in some cases, make new versions for us.

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About the Authors

Professor Andrew C. Scott is internationally recognized for his work in palaeobotany, palynology, coal geology, petrology and geochemistry and for his work on the geological history of wildfire. He is currently Professor of Applied Palaeobotany and a Distinguished Research Fellow in the Department of Earth Sciences at Royal Holloway University of London, England, where he has been since 1985. Professor Scott received his bachelor's degree in geology from Bedford College, University of London, England. He studied in the Botany Department of Birkbeck College, London where he received his PhD. He received a personal professorial chair in 1996. He was awarded a D.Sc. in 2002 by the University of London for his published work. Professor Scott is a Fellow of the Geological Societies of London, America, the Royal Society of Arts, and the Higher Education Academy. He received the Gilbert H. Cady award from the Geological Society of America in 2007.

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survey, field experiments and molecular ecology. After completing his PhD in forest ecology and silviculture at the University of Tasmania in 1984, he spent two decades undertaking full time research in rainforest and savanna ecology throughout northern Australia. He received a DSc in 2002 from University of Tasmania, and has received travelling fellowships from the Australian Academy of Science, Harvard, Kyoto, Leeds and Arizona universities.

Professor William J. Bond holds the Harry Bolus Chair of Botany at the University of Cape Town. His interest in fire began while working for the Forestry Department of South Africa on understanding fynbos shrublands and how to manage them. From this beginning, he was able to forge links with researchers on fire ecology in the other Mediterranean-type ecosystems. In the 1990s, after he moved to UCT, he began working on the ecology of African savannas and the intriguing interactions of fire, large herbivores and physical forces in shaping these ecosystems. He has had the good fortune to work with colleagues in similar ecosystems elsewhere in the world helping to develop a global perspective. He has also made periodic excursions into the deep past to better understand the present. He is a Fellow of the Royal Society of South Africa and a foreign associate of the National Academy of the USA.

Professor Stephen J. Pyne is a historian and Regents Professor in the School of Life Sciences, Arizona State University, Tempe, Arizona, USA. He has written over a score of books, including fire histories of the U.S. (*Fire in America; Between Two Fires*), Canada (*Awful Splendour*), Australia (*Burning Bush*), Europe (*Vestal Fire*), and the world generally; two editions of a textbook, *Introduction to Wildland Fire*; and numerous articles about fire elsewhere in the world. Among his other interests is the history of exploration, to which he has contributed *The Ice: A Journey to Antarctica*, *How the Canyon Became Grand*, and *Voyager:*

Exploration, Space, and the Third Great Age of Discovery. He spent 18 seasons in fire management with the National Park Service. He is a MacArthur Fellow, a member of the American Academy of Arts and Sciences, and twice a fellow at the National Humanities Center.

Dr. Martin E. Alexander, a forester by training, but began specializing in wildland fire with the 1972 and 1973 fire seasons when he worked as a U.S. Forest Service hotshot crew member. He obtained his B.Sc.F. (1974) and M.Sc.F. (1979) degrees from Colorado State University and Ph.D. degree in forestry from the Australian National University (1998). Marty retired in late 2010 as a Senior Fire Behaviour Research Officer with the Canadian Forest Service stationed at the Northern Forestry Centre in Edmonton, Alberta, after nearly 35 years of public service. He presently serves as an Adjunct Professor of wildland fire science and management at the University of Alberta and Utah State University. His research and technology transfer efforts have focused on practical applications of wildland fire behaviour knowledge, including firefighter and public safety. In 2003, Dr. Alexander received the International Wildland Fire Safety Award from the International Association of Wildland Fire and the Canadian Forestry Achievement Award from the Canadian Institute of Forestry in 2010. His work has taken him to all the provinces and territories of Canada, and to many parts of the world, including the continental USA and Alaska, Australia, New Zealand, Portugal, Greece, Italy, Turkey, and Fiji.

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/scott/fireonearth

The website includes:

- Powerpoints of all figures from the book for downloading
- PDFs of all tables from the book for downloading
- PDFs of all tables from the book for downloading
- Links to key fire websites
- Links to videos and podcasts
- Additional teaching material

Part One

Fire in the Earth System

Photo

Recent research using satellite data has revolutionized our understanding on the distribution of fire on Earth. This image shows smoke plumes from Californian fires between Los Angeles and San Francisco in October 2007 billowing out over the Pacific Ocean. Red spots indicate active fires. (Image from Modis Rapid Response Project at NASA/GSFC, image 1163886).

Preface to Part One

The first part of this book is an introduction to fire that not only considers fundamentals of fire as a physical/chemical process but also includes methods for the study of fire, an appreciation of the geological history of fire and its importance in the Earth System.

For some, fire is an every day part of life; for others, it is a remote phenomenon and is unimportant; for still others, it evades consciousness altogether. This may be said not only for individuals, but also for entire subject areas where fire has yet to be given its rightful place.

In this section, we discuss the nature and occurrence of fire and illustrate ways by which it can be recognized and studied. The past ten years has seen a revolution in our perception of fire, and news of major wildfires may now be instantly broadcast through a wide range of media. In addition, the increase in the ways we can observe fire through the use of satellites and the ability to view maps of the positions of active fires – even from our mobile phones – has brought a phenomenon unfamiliar to many to the forefront of current debate on human impact on the planet.

What is less well known or appreciated is the long geological history of fire on our planet and the role that fire has played in deep time in shaping our Earth. In this section, we demonstrate the methods we can use to unravel the history of fire – not just in terms of thousands of years, but in terms of hundreds of millions of years. In only the past few years, we have begun to unravel the relationship between fire and atmospheric change, especially with oxygen in the fossil record. This has led to a reassessment of the relationship between fire and vegetation, both from an ecological as well as from an evolutionary perspective. Part One sets up, therefore, the role of fire as an Earth System process and its special role in the evolution of life on land.

Chapter 1

What is Fire?

This chapter serves as an introduction not only to Part One but also to the book as a whole. It considers many of the fundamentals of fire. We introduce here a number of concepts that are developed throughout the text and, where relevant, the chapter numbers or parts are given for reference. In addition, some areas are dealt with here because there is no space to develop them more fully within this book, as to do so would make it too long and unwieldy. Due to this, we have tried to provide a wide range of illustrative material here, as well as more extensive references for further reading.

1.1 How Fire Starts and Initially Spreads

Simply put, fire – generally called combustion – is a rapid chemical oxidative reaction that generates heat, light and produces a range of chemical products (Torero, 2013). However, in the context of vegetation fires, it is important to consider not only the range of materials that may be combusted, but also the conditions under which fire may occur and even be ignited.

It is obvious, therefore, that the basis of a fire is the nature of the fuel that will be combusted and the type of ignition source. The general principle for vegetation fires is that there is an initial high-temperature heat source. This may be produced by lightning, volcanic activity, a spark from a rock

fall or, of course, by humans. Plants contain a range of organic compounds that include cellulose, a carbohydrate that is a linear polysaccharide polymer found in many cell walls. The high initial temperature causes a breakdown of the cellulose molecule and produces a range of gaseous components that include ammonia (NH_3), carbon dioxide (CO_2) and methane (CH_4). These gases mix with atmospheric oxygen and undergo a rapid exothermic reaction – combustion. This rapid increase in heat, together with the readily available oxygen, allows the reaction to continue and a fire is started (Cochrane and Ryan, 2009). These features may be characterized by the use of a fire triangle (Figure 1.1, Fire fundamentals).

Figure 1.1 Fire triangles. The importance of different elements of fire is shown in relation to different scales, from the initial starting of a fire to the controls on fire in deep time. (This figure is compiled from a range of different authors' work including S. Pyne, M. Oritz, C. Whitlock, A. C. Scott).