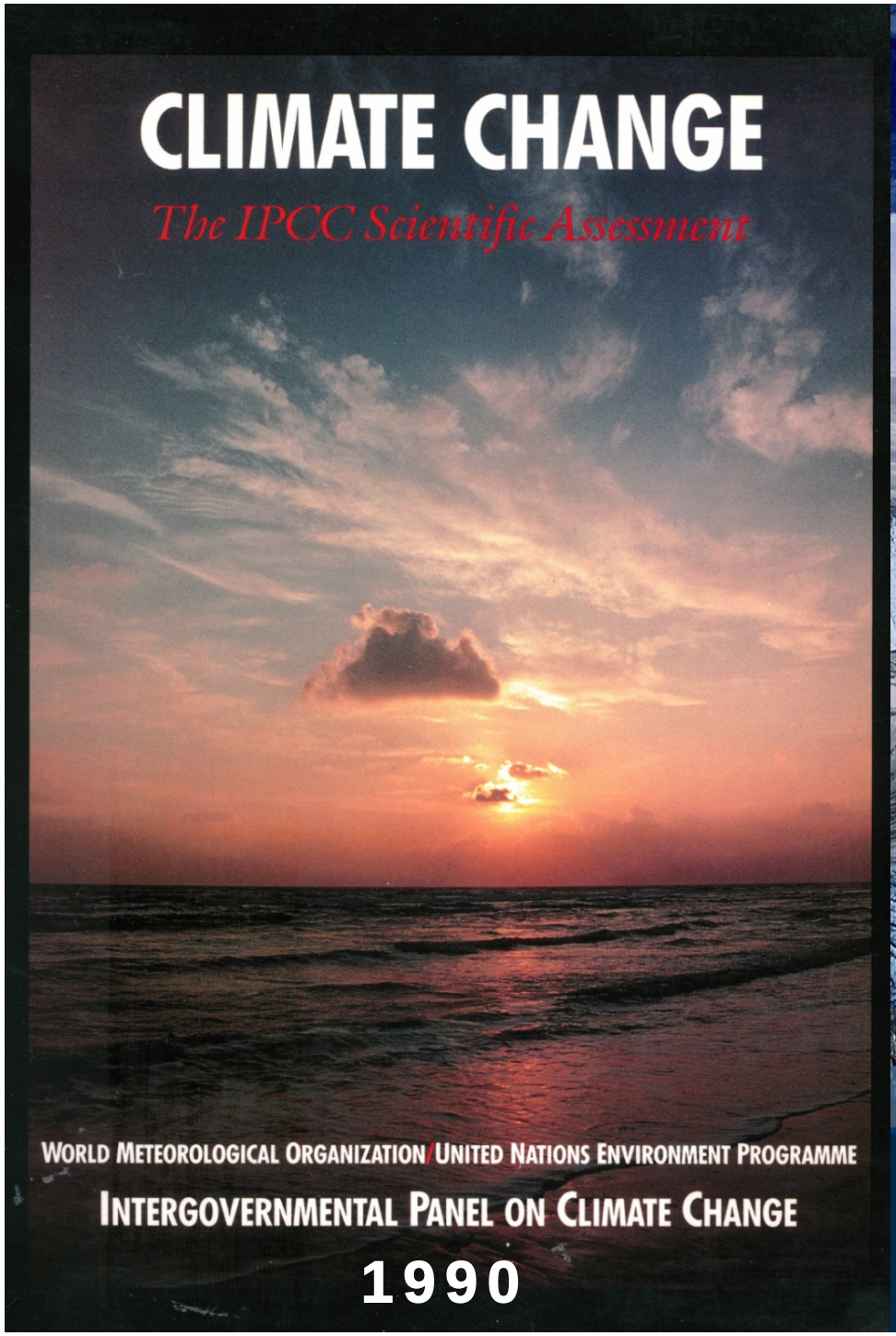
The Anthropocene is functionally and stratigraphically distinct from the Holocene

Alejandro Cearreta
(UPV/EHU, Anthropocene Working Group)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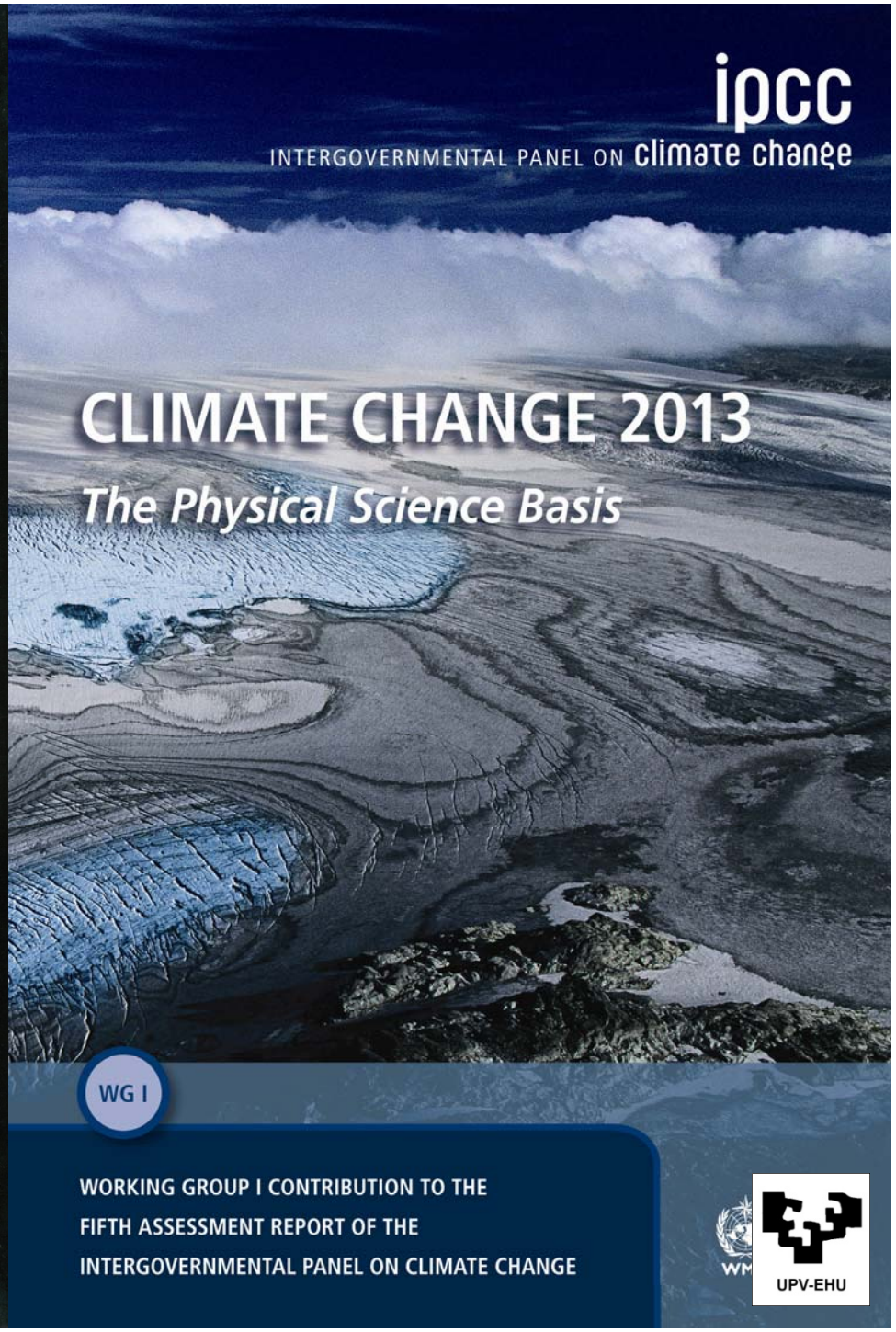
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FIFTH ASSESSMENT REPORT OF THE
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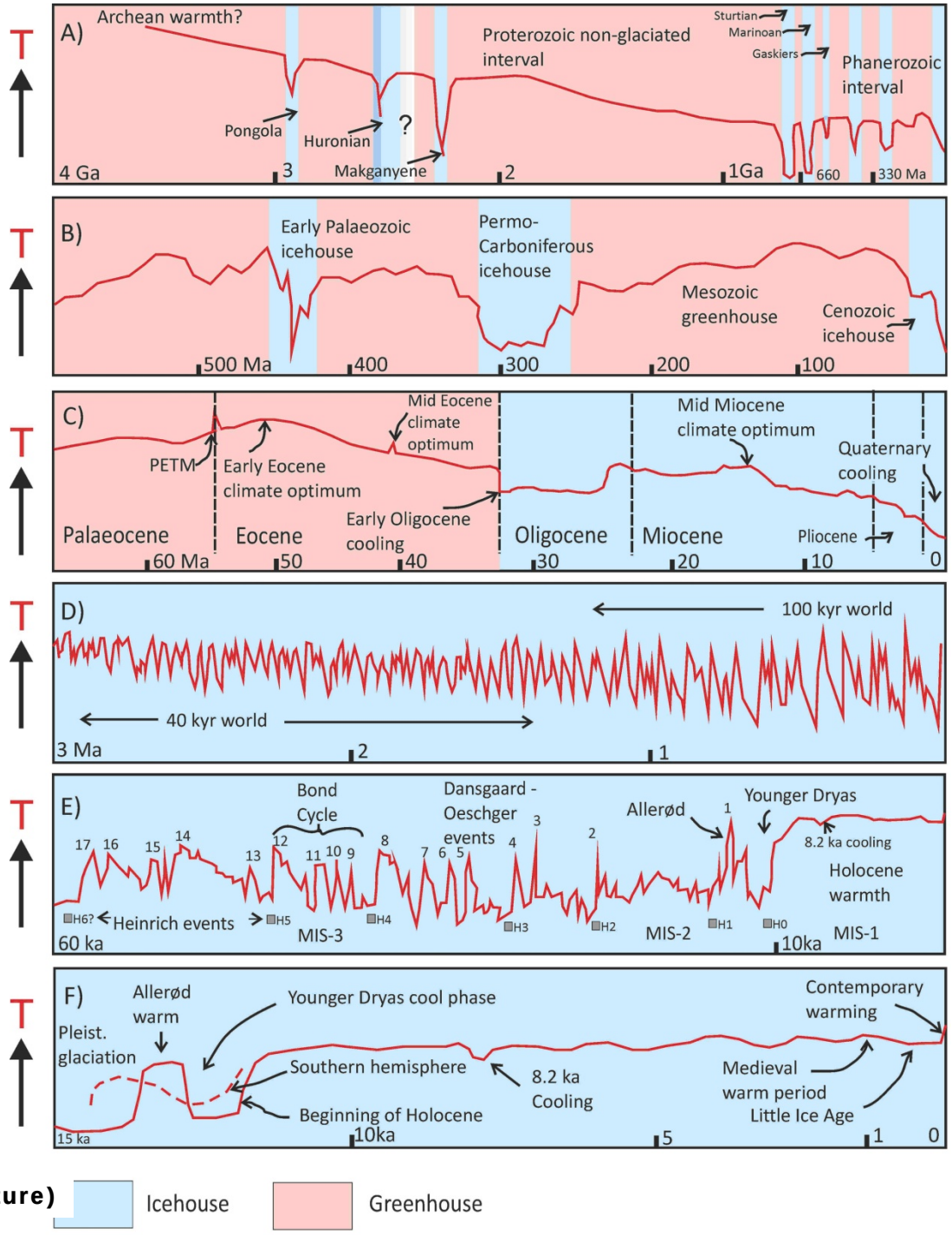

(Steffen, W. et al., 2016. Earth's Future)

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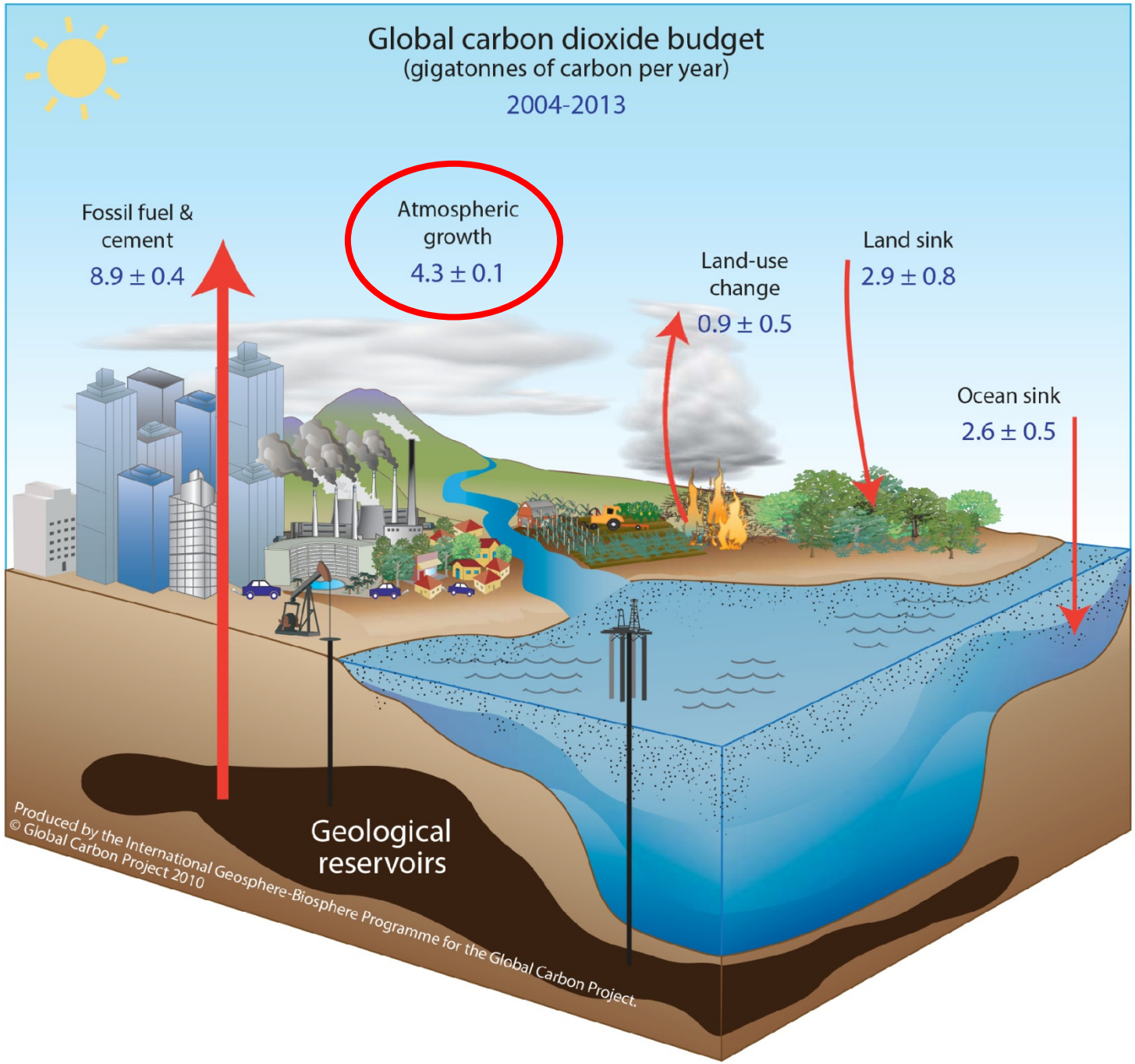
Global carbon dioxide budget
(gigatonnes of carbon per year)
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Atmospheric growth
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Land-use change
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Land sink
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Ocean sink
2.6 ± 0.5
Geological reservoirs
Produced by the International Geosphere-Biosphere Programme for the Global Carbon Project.
© Global Carbon Project 2010

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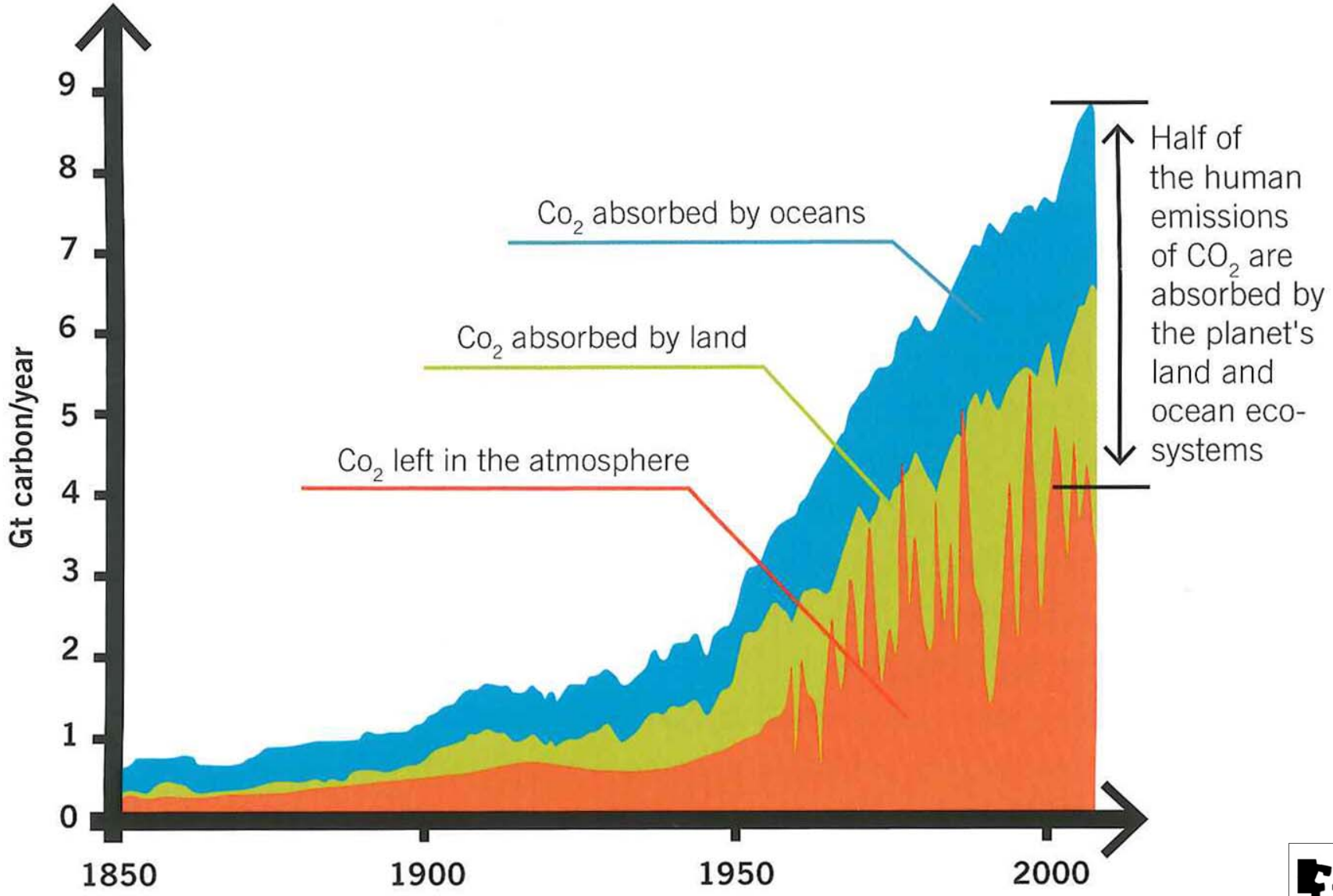
EARTH'S GREAT SERVICE TO HUMANKIND



(Rockström, J. & Klum, M., 2015. Big World, Small Planet, 207 p)

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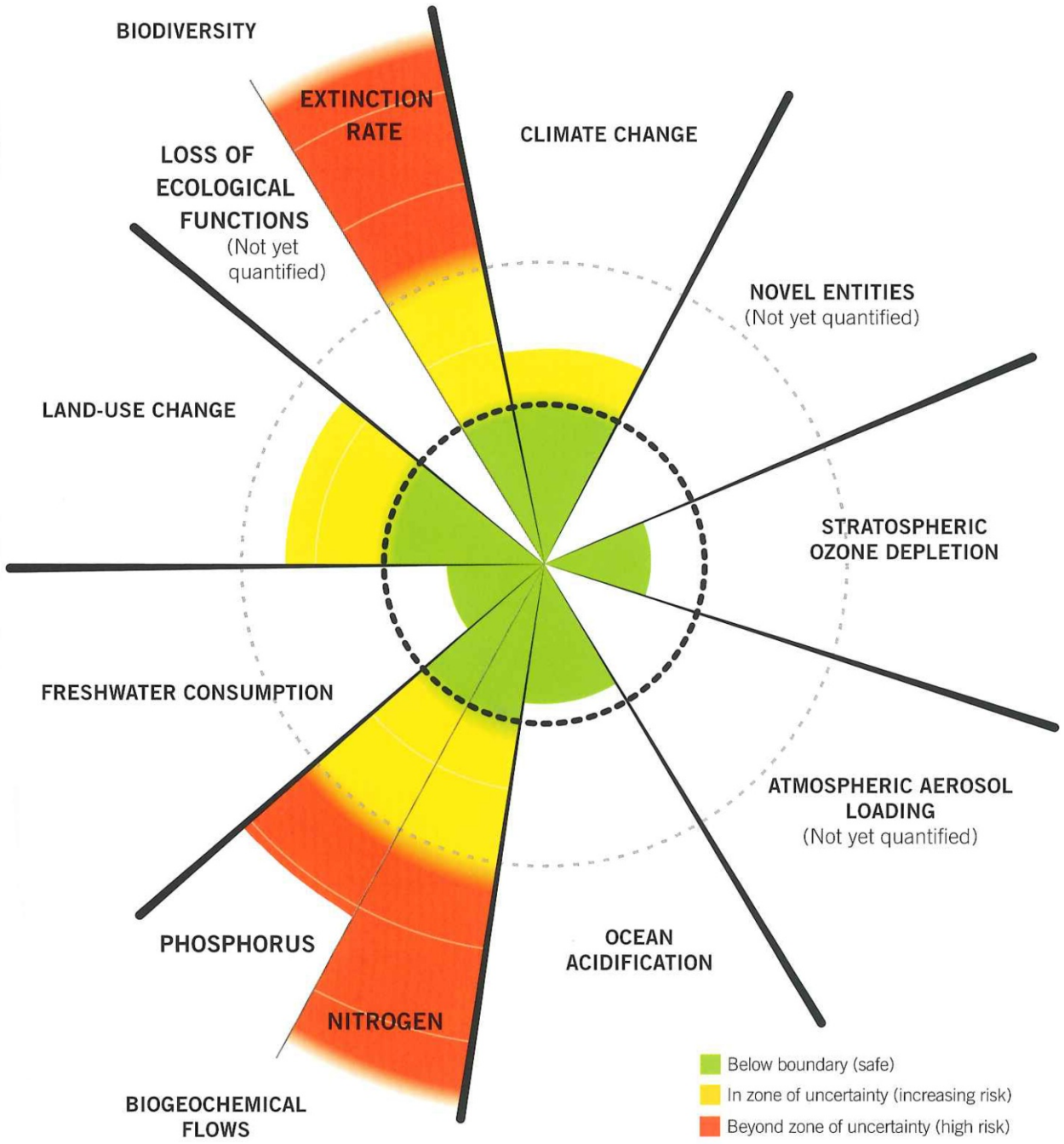

(Rockström, J. & Klum, M., 2015. Big World, Small Planet, 207 p)

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GLOBAL CHANGE NEWSLETTER

No. 41 May 2000

The International Geosphere–Biosphere Programme (IGBP): A Study of Global Change of the International Council for Science (ICSU)

The "Anthropocene"

by Paul J. Crutzen and Eugene F. Stoermer

The name Holocene ("Recent Whole")for the post-glacial geological epoch of the past ten to twelve thousand years seems to have been proposed for the first time by Sir Charles Lyell in 1833, and adopted by the International Geological Congress in Bologna in 1885 **(1)**. During the Holocene mankind's activities gradually grew into a significant geological, morphological force, as recognised early on by a number of scientists. Thus, G.P. Marsh already in 1864 published a book with the title "Man and Nature", more recently reprinted as "The Earth as Modified by Human Action" (2). Stoppani in 1873 rated mankind's activities as a "new telluric force which in power and universality may be compared to the greater forces of earth" [quoted from Clark (3)]. Stoppani already spoke of the anthropozoic era. Mankind has now inhabited or visited almost all places on Earth; he has even set foot on the moon.

The great Russian geologist V.I.Vernadsky (4) in 1926 recognized the increasing power of mankind as part of the biosphere with the following excerpt "... the direction in which the processes of evolution must proceed, namely towards increasing consciousness and thought, and forms having greater and greater influence on their surroundings". He, the French Jesuit P. Teilhard de Chardin and E. Le Roy in 1924 coined the term "noösphere", the world of thought, to mark the growing role played by mankind's brainpower and technological talents in shaping its own future and environment.

The expansion of mankind, both in numbers and per capita exploitation of Earth's resources has been astounding (5). To give a few examples: During the past 3 centuries human population increased tenfold to 6000 million, accompanied e.g. by a growth in cattle population to 1400 million (6) (about one cow per average size family). Urbanisation has even increased tenfold in the past century. In a few generations mankind is exhausting the fossil fuels that were generated over several hundred million years. The release of SO_2, globally about 160 Tg/year to the atmosphere by coal and oil burning, is at least two times larger than the sum of all natural emissions, occurring mainly as marine dimethyl-sulfide from the oceans (7); from Vitousek et al. (8) we learn that 30-50% of the land surface has been transformed by human action; more nitrogen is now fixed synthetically and applied as fertilizers in agriculture than fixed naturally in all terrestrial ecosystems; the escape into the atmosphere of NO from fossil fuel and biomass combustion likewise is larger than the natural inputs, giving rise to photochemical ozone ("smog") formation in extensive regions of the world; more than half of all accessible fresh water is used by mankind; human activity has increased the species extinction rate by thousand to ten thousand fold in the tropical rain forests (9) and several climatically important "greenhouse" gases have substantially increased in the atmosphere: CO_2 by more than 30% and CH_4 by even more than 100%. Furthermore, mankind releases many toxic substances in the environment and even some, the chlorofluorocarbon gases, which are not toxic at all, but which nevertheless have led to the Antarctic "ozone hole" and which would have destroyed much of the ozone layer if no international regulatory measures to end their production had been taken. Coastal wetlands are also affected by humans, having resulted in the loss of 50% of the world's mangroves. Finally, mechanized human predation ("fisheries") removes more than 25% of the primary production of the oceans in the upwelling regions and 35% in the temperate continental shelf regions (10). Anthropogenic effects are also well illustrated by the history of biotic communities that leave remains in lake sediments. The effects documented include modification of the geochemical cycle in large freshwater systems and occur in systems remote from primary sources (11-13).

Considering these and many other major and still growing impacts of human activities on earth and atmosphere, and at all, including global, scales, it seems to us more than appropriate to emphasize the central role of mankind in geology and ecology by proposing to use the term "anthropocene" for the current geological epoch. The impacts of current human activities will continue over long periods. According to a study by Berger and Loutre (14), because of the anthropogenic emissions of CO_2, climate may depart significantly from natural behaviour over the next 50,000 years.

To assign a more specific date to the onset of the "anthropocene" seems somewhat arbitrary, but we propose the latter part of the 18th century, although we are aware that alternative proposals can be made (some may even want to include the entire holocene). However, we choose this date because, during the past two centuries, the global effects of human activities have become clearly noticeable. This is the period when data retrieved from glacial ice cores show the beginning of a growth in the atmospheric concentrations of several "greenhouse gases", in particular CO_2 and CH_4 (7). Such a starting date also coincides with James Watt´s invention of the steam

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Informe de citas: 1.127

(de Todas las bases de datos)

Buscó: **Tema:** (Anthropocene) **...Más**

Este informe refleja las citas de los elementos origen indexados en todas las bases de datos.

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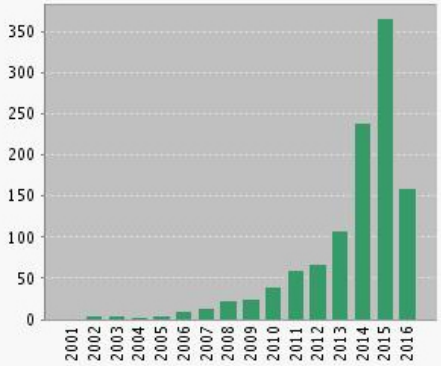

Se muestran los últimos 20 años.

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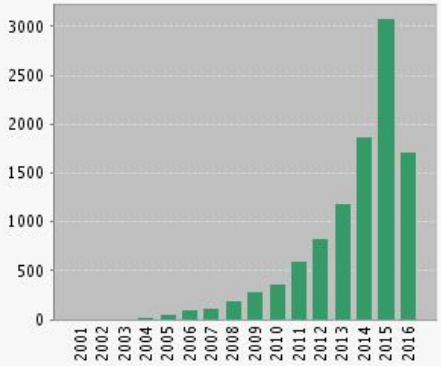

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h-index [?] :	46

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MAN AND NATURE;

OR,

PHYSICAL GEOGRAPHY

AS MODIFIED BY HUMAN ACTION.

BY

GEORGE P. MARSH.

"Not all the winds, and storms, and earthquakes, and seas, and seasons of the world, have done so much to revolutionize the earth as MAN, the power of an endless life, has done since the day he came forth upon it, and received dominion over it."—H. BUSHNELL, *Sermon on the Power of an Endless Life.*

NEW YORK:
CHARLES SCRIBNER, 124 GRAND STREET.
1864.

CORSO

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GEOLOGIA

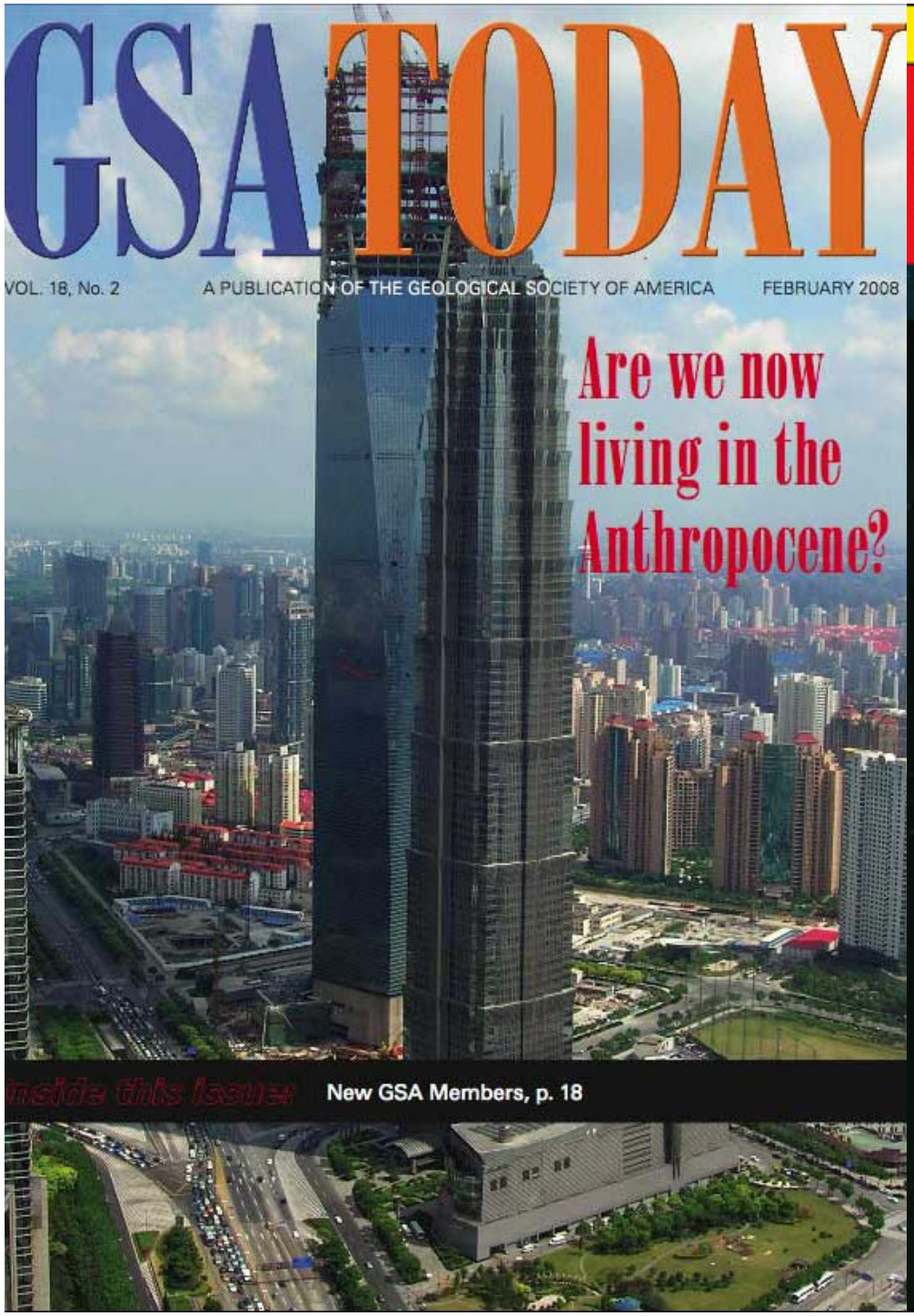
DEL PROFESSORE

ANTONIO STOPPANI.

VOLUME II.

GEOLOGIA STRATIGRAFICA.

MILANO,
G. BERNARDONI E G. BRIGOLA, EDITORI.
1873.


GSA TODAY
VOL. 18, No. 2
A PUBLICATION OF THE GEOLOGICAL SOCIETY OF AMERICA
FEBRUARY 2008
Are we now living in the Anthropocene?
Inside this Issue
New GSA Members, p. 18


THE NEXT GOLDEN STATE: A 16-PAGE SPECIAL REPORT ON AUSTRALIA
The Economist
Obama, Bibi and peace
Huntsman blows his horn
A soft landing for China
The costly war on cancer
How the brain drain reduces poverty
MAY 28TH-JUNE 3RD 2011
Economist.com
Welcome to the Anthropocene
Geology's new age

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Newsletter of the Anthropocene Working Group

Volume 6:Report of activities 2014-15

December 2015

since 2009

International Union of Geological Sciences
International Commission on Stratigraphy

Subcommission on Quaternary Stratigraphy
http://quaternary.stratigraphy.org/workinggroups/anthropocene/

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GROUNDWORK
Furthering the Influence of Earth Science

Is the Anthropocene an issue of stratigraphy or pop culture?

Whitney J. Autin, *Dept. of Earth Sciences, SUNY College at Brockport, Brockport, New York 14420, USA, dirtguy@esc.brockport.edu; and* ***John M. Holbrook,*** *School of Geology, Energy & the Environment, Texas Christian University, Fort Worth, Texas 76129, USA*

THE ANTHROPOCENE DEBATE

The term *Anthropocene* recently entered into the rhetoric of both the scientific community and the popular environmental movement. Scientific proponents argue that global industrialization drives accelerated Earth-system changes unrivaled in Earth's history. The discussion now filters into geological stratigraphy with proposals to amend formal time stratigraphic nomenclature (Zalasiewicz et al., 2008, 2010). Environmentalists suggest that terms like Anthropocene foster broad social and cultural awareness of human-induced environmental changes. Advocates argue that greater awareness of humanity's role in environmental change encourages sustainable resource utilization.

Formal recognition of a new geologic epoch helps the broader scientific community solidify the idea of humanity as an Earth-system driver. Before the scientific community ventures too far, we wish to offer comment that considers the practicality of the Anthropocene to geological stratigraphy, the science to which it ultimately applies.

SUMMARY OF THE TERM ANTHROPOCENE

Crutzen and Stoermer (2000) suggest that modern technology initiated the transformation of Earth-system behavior and altered environmental processes. They offer the term Anthropocene for the time interval dominated by human activities and indicate that the onset of the human ability to significantly shape Earth's environment became notable with the Industrial Revolution. Steffen et al. (2011) argue that The Great Acceleration after World War II records a dramatic departure in monitored Earth processes from Holocene proxy trends. In contrast, Ruddiman (2005) infers that Holocene-scale anthropogenic greenhouse effects began when humans abandoned hunter-gatherer lifestyles for subsistence settlement, animal domestication, and cultivation agriculture.

The idea that humans interact with nature is not new, and philosophical ideologies about human responsibility permeate historical thinking (Hamilton, 2010; Steffen et al., 2011). *Anthropocene* offers a concept fundamentally different from many precursors. Present human society does no
symbiotic relationship with nature. Humanity no
natural processes, such as biogeochemical cycles,
atmosphere transfers, and flux of surficial sedim
al., 2011). Accelerated mass transfer of sediments
Wilkinson, 2005) has particular interest because e
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GSA Today, v. 22, no. 7, doi: 10.1130/G153GW.1.

Rend. Fis. Acc. Lincei (2014) 25:381–392
DOI 10.1007/s12210-014-0317-x

THE TWO CULTURES

Anthropocene: another academic invention?

Guido Visconti

st 2014
ink.com

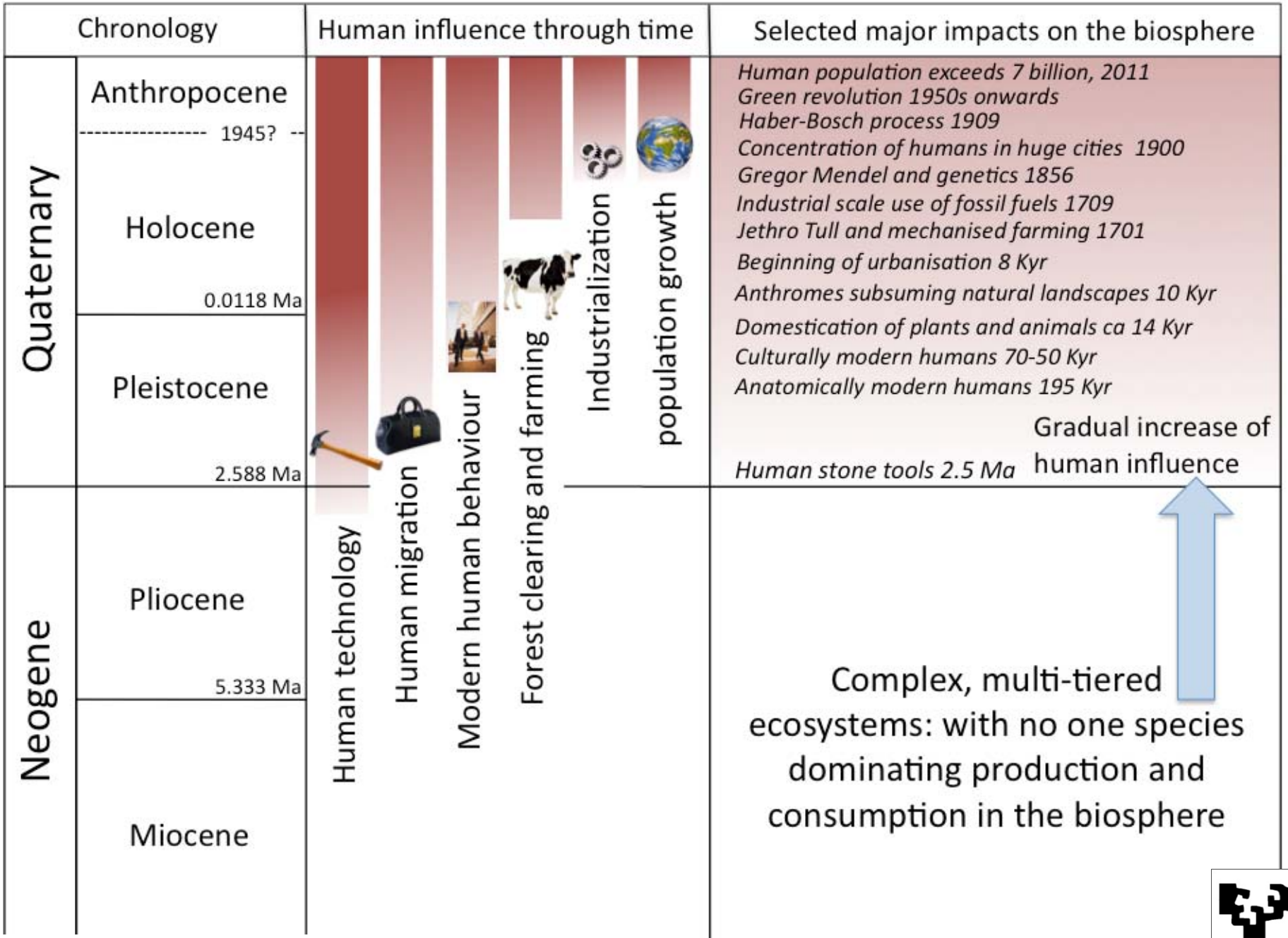
ntroduction

idea of Anthropocene was introduced by Crutzen and
ermer (2000) (apparently Stoermer has used the term
e early 1980s) in a paper in the *Global Change*
sletter of the IGBP in May 2000. The idea was
ewhat refined as a concept in a one-page article in
ure in 2002 (Crutzen 2002). Since then, the Anthro-
ene has been the subject of papers, meetings,[1] and
arch and discussion at the scientific, political, and
osophical levels. The Anthropocene should define a
geologic epoch of the Quaternary Period and appar-
y should not change at all the substance of things, even
the political and economic perspectives of the present
ch.

The initial response to the idea came mainly from
logy. Recently Autin and Holbrook (2012) observed
the main problem was that the proposed Anthropocene
not consistent with the practice of stratigraphy. After
even if the manifestations of the human influence on
landscape are widespread, they are confined only to the
few meters of depth primarily to soils.

The stratigraphy issue seems to be the most important as
ssed recently by Finney (2013) and Cohen et al. (2013).
ey raises a number of issues that must be addressed
de the stratigraphic one. They refer to the Anthropo-
e being a unit of Earth history or human history that is
e like a projection into the future. This point stresses
fact that since the last millennium human observations
re and more complete and refined) will be used to study

e the March 2014 issue of Rendiconti Lincei with the papers
ented at the conference: *Anthropocene: natural and man-made*
ations of the Earth's fragile equilibrium held at the Accademia
Lincei, Rome, November 26-27, 2012.



(Williams, M. et al., 2016. Earth's Future, 4, 1-20)

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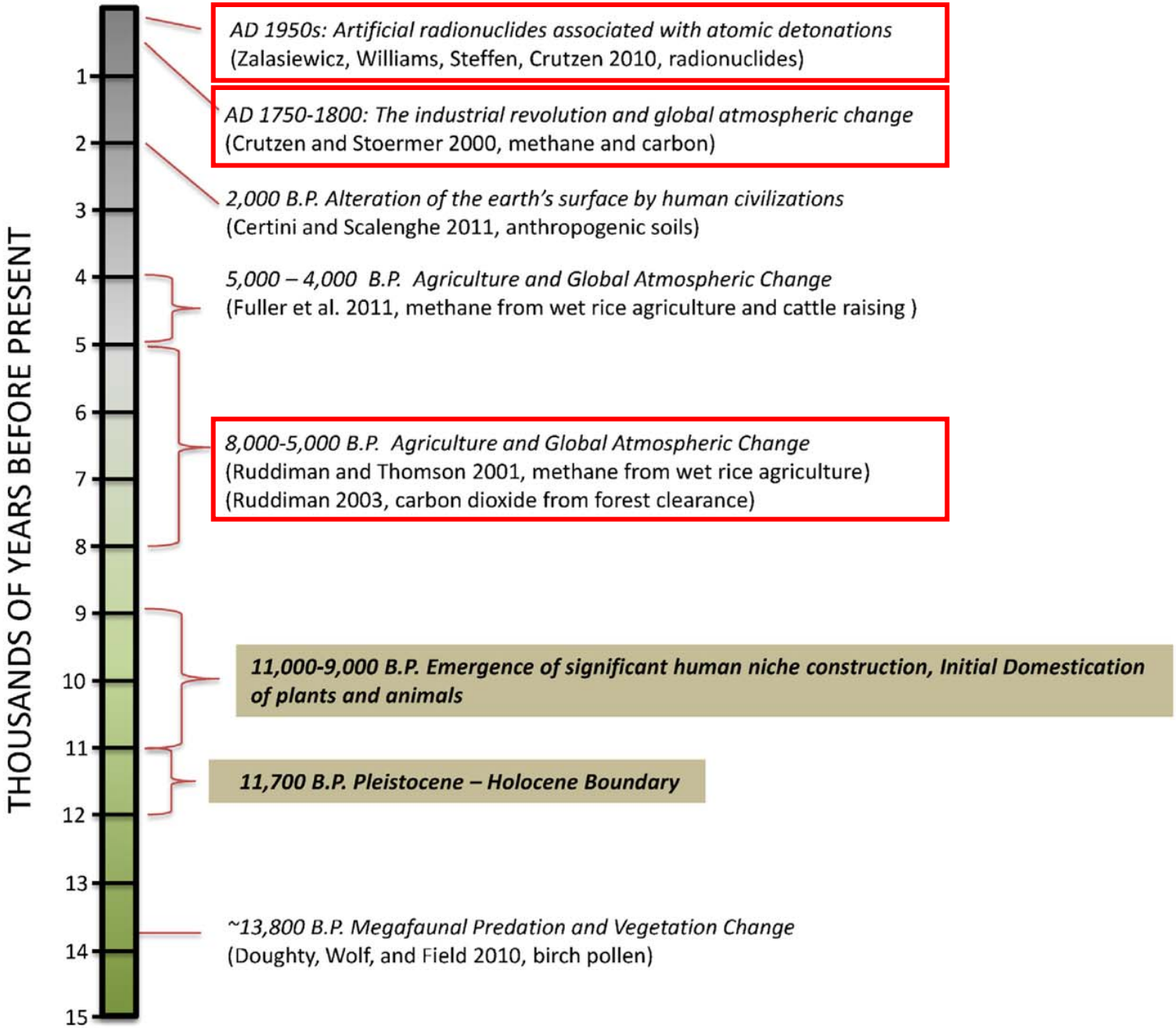

(Smith, B.D. & Zeder, M.A., 2013. Anthropocene, 4, 8-13)

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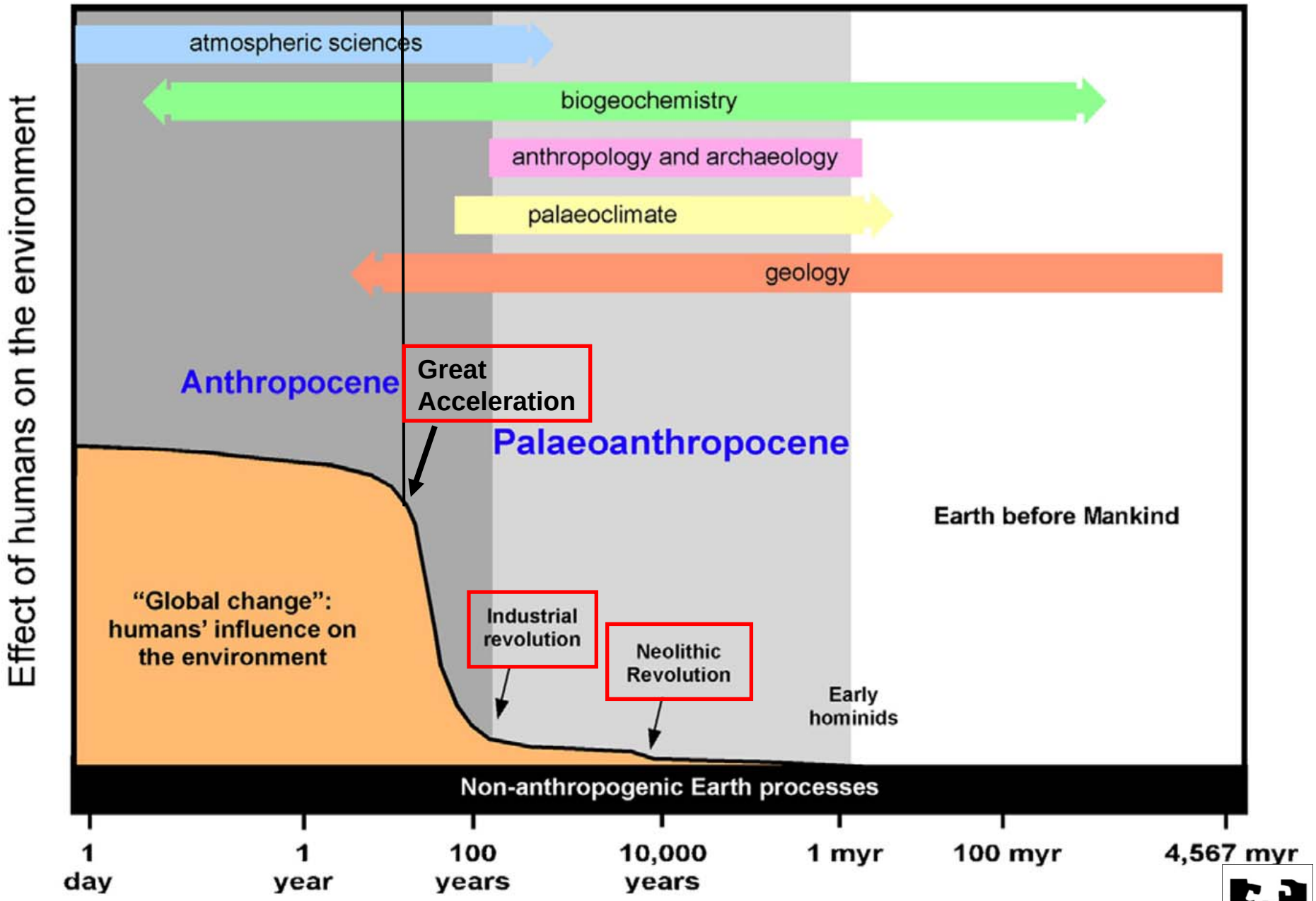

(Foley, S.F. et al., 2013. Anthropocene, 3, 83-88)

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ARCHAEOLOGY

Archaeologists Say the 'Anthropocene' Is Here—But It Began Long Ago

HONOLULU—A vocal group of geologists and other scientists are pushing to define a new geological epoch, marked by climatic and environmental change caused by humans. They've got a catchy name—the Anthropocene or "Age of Man"—plus an eponymous journal starting up this month and an international working group considering whether to make the designation official (*Science*, 7 October 2011, p. 32). At a session at the Society for American Archaeology* meetings here, archaeologists argued that it's high time for their field, which studies humans and their activities over geological time, to have a greater voice in the debate.

Most all the speakers at the standing-room-only session agreed that human impacts on the Earth are dramatic enough to merit a new epoch name—and that drawing attention to our changed relationship with the planet is a good idea. But all felt that such an epoch should start thousands of years ago. Rather than focusing on a relatively sudden planet-wide change—a line in a sedimentary deposit where one could plant a "golden spike" as is traditionally done to mark an epoch—the archaeologists outlined an unbroken chain of human influence stretching far back into prehistory. "Humans have been modifying ecosystems over a long period of time," said archaeologist Bruce Smith of the Smithsonian Institution's National Museum of Natural History (NMNH) in Washington, D.C.

Such a view of the Anthropocene contrasts with that of most geologists and ecologists behind the movement, many of whom have sought a clear time marker for the "golden spike." The most popular suggestion for a time point to end the recognized Holocene epoch, which began 11,700 years ago after the end of the last ice age, is the beginning of the Industrial Revolution about 1750 C.E., when manufacturing began to take hold and human-caused global warming is thought to have begun. Only then, proponents argue, did humans begin to change the chemistry of the atmosphere and oceans worldwide, alter the course of rivers, and transform the landscape, among other impacts. Others have suggested fallout from nuclear bombs as a distinctive Anthropocene signature.

But although the 23-member Working Group on the Anthropocene has no archaeologists or anthropologists, those fields also have bountiful data on major human impacts on the planet, said session chair Todd Braje, an archaeologist at Humboldt State University in Arcata, California. Those data show that humans began making global and large-scale transformations of the Earth long before the 18th century, panel members said.

Jon Erlandson, an archaeologist at the University of Oregon in Eugene, noted that people began transforming continents about 60,000 years ago, when our ancestors began to spread out from their ancestral home in Africa. That's when large-scale hunting, burning vegetation, and cutting down forests, etc., began, and "set the stage for human domination of the earth," Erlandson said.

Shortly after humans arrived in many regions, including most islands and several continents, many large mammals went extinct. Because the climate changed natu-

*Society for American Archaeology 78th Annual Meeting, 3–7 April, Honolulu.

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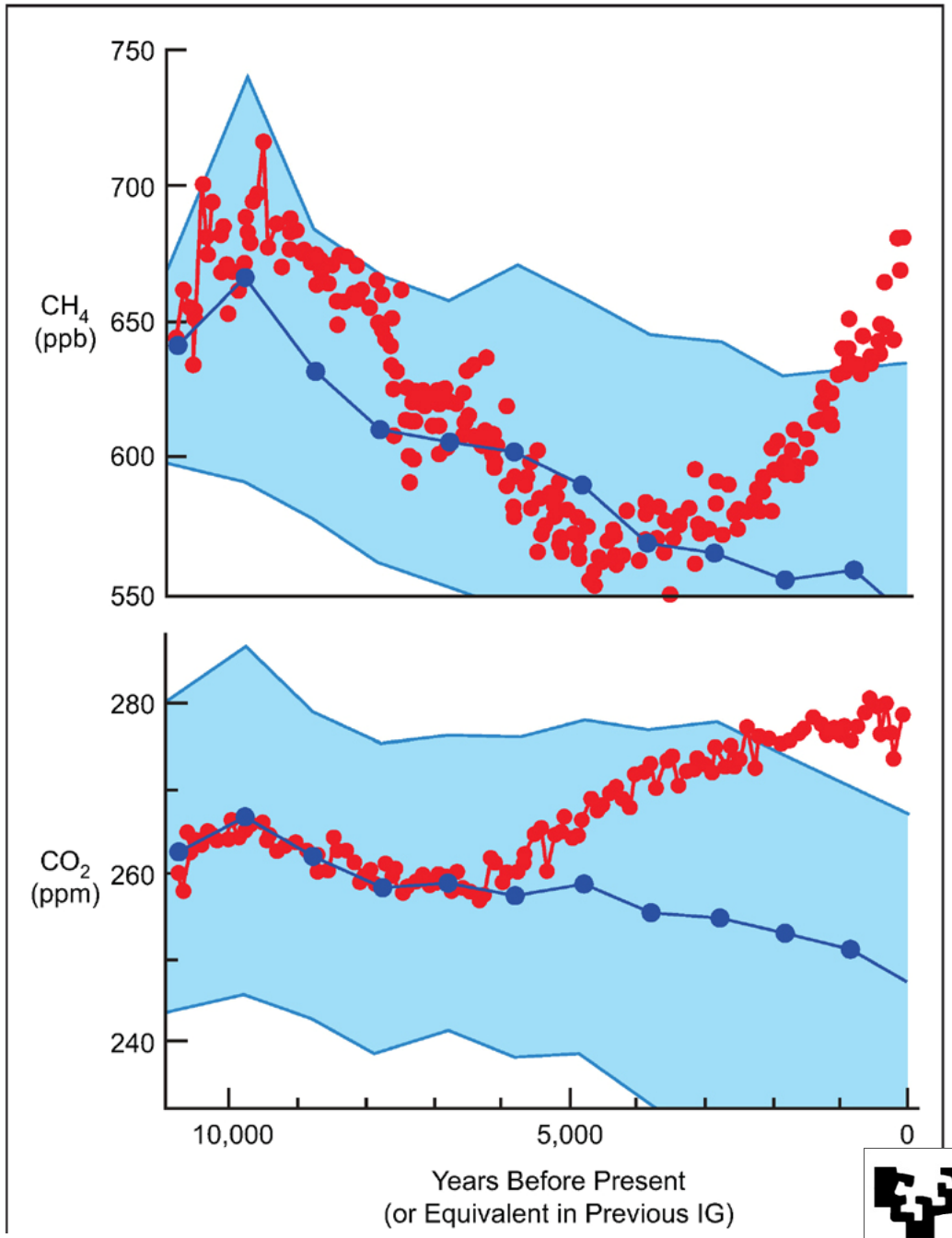

(Ruddiman, W. et al., 2014. The Anthropocene Review, 1, 1-7)

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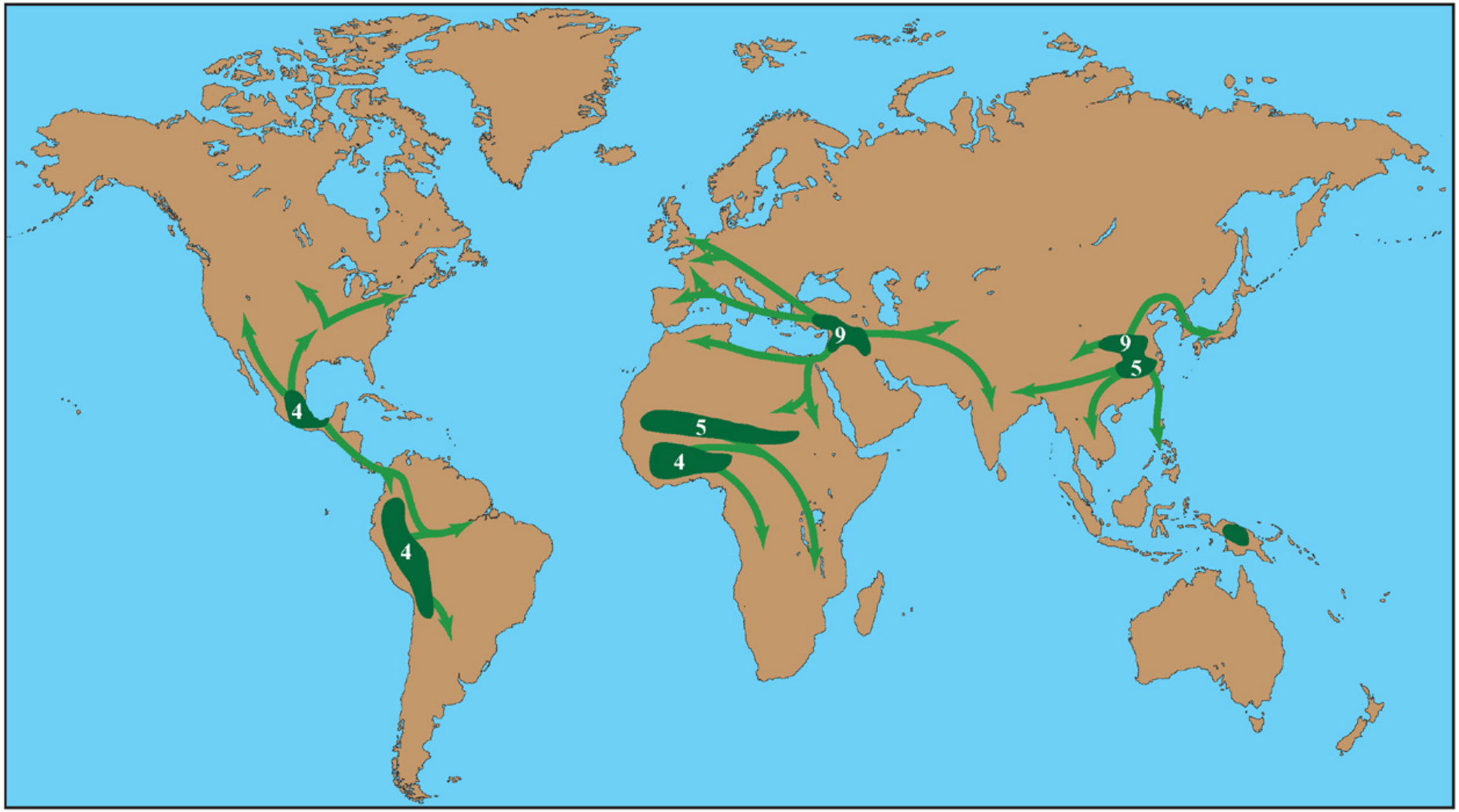

(Ruddiman, W. et al., 2014. The Anthropocene Review, 1, 1-7)

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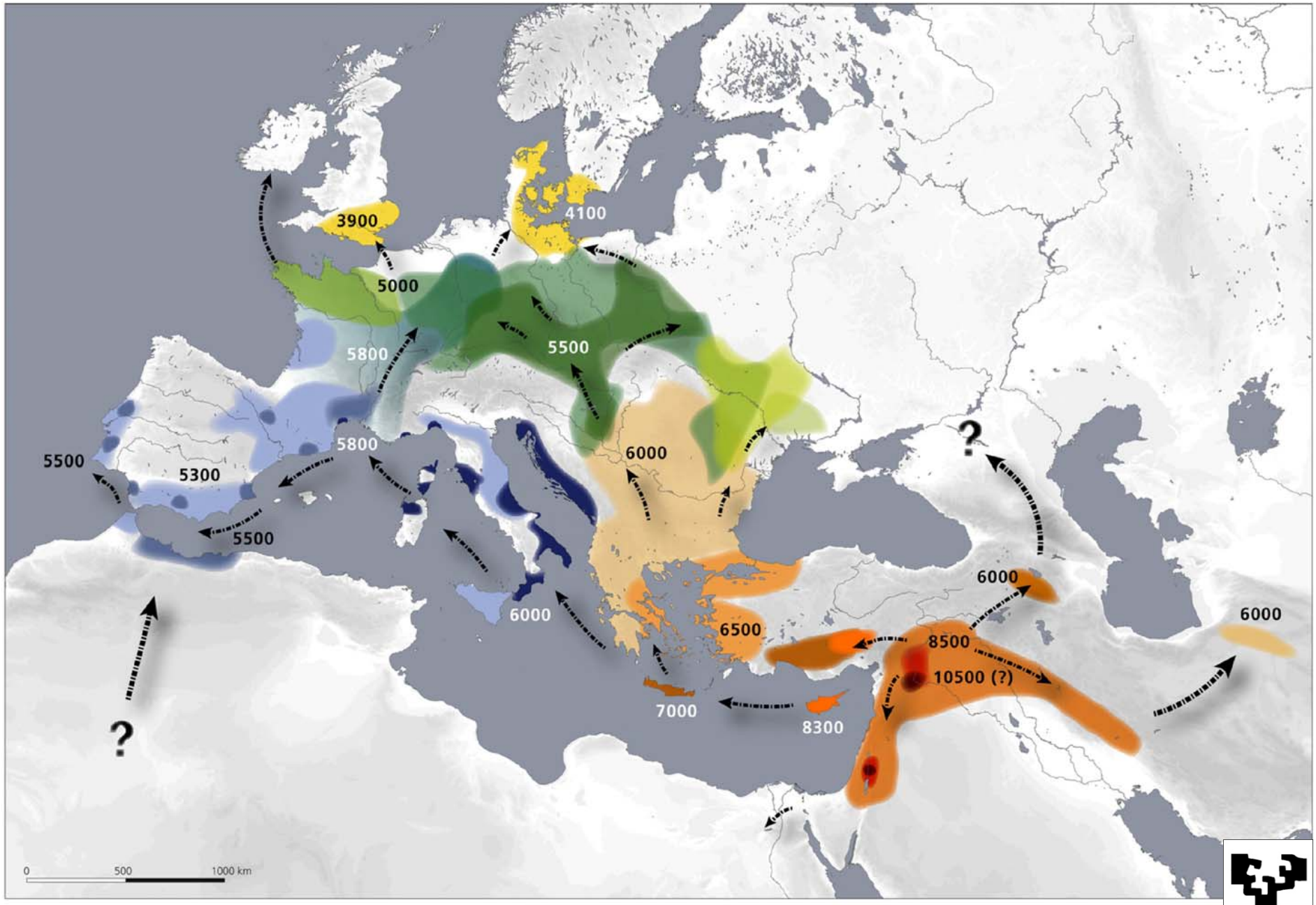

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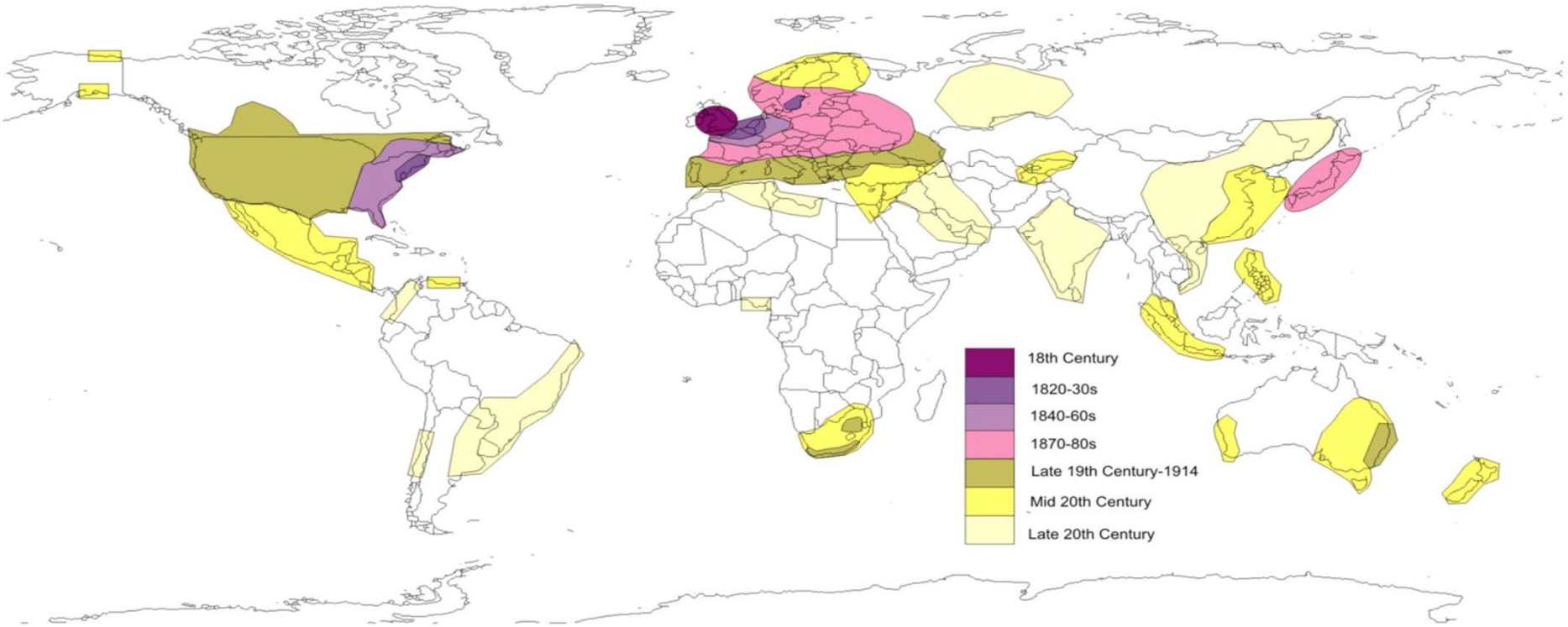

(Waters, C.N. et al., 2014. Geological Society of London Special Publications, 395, 1-21)

UPV-EHU

Article Will Steffen, Paul J. Crutzen and John R. McNeill

The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?

We explore the development of the Anthropocene, the current epoch in which humans and our societies have become a global geophysical force. The Anthropocene began around 1800 with the onset of industrialization, the central feature of which was the enormous expansion in the use of fossil fuels. We use atmospheric carbon dioxide concentration as a single, simple indicator to track the progression of the Anthropocene. From a preindustrial value of 270–275 ppm, atmospheric carbon dioxide had risen to about 310 ppm by 1950. Since then the human enterprise has experienced a remarkable explosion, the Great Acceleration, with significant consequences for Earth System functioning. Atmospheric CO_2 concentration has risen from 310 to 380 ppm since 1950, with about half of the total rise since the preindustrial era occurring in just the last 30 years. The Great Acceleration is reaching criticality. Whatever unfolds, the next few decades will surely be a tipping point in the evolution of the Anthropocene.

INTRODUCTION

Global warming and many other human-driven changes to the environment are raising concerns about the future of Earth's environment and its ability to provide the services required to maintain viable human civilizations. The consequences of this unintended experiment of humankind on its own life support system are hotly debated, but worst-case scenarios paint a gloomy picture for the future of contemporary societies.

Underlying global change (Box 1) are human-driven alterations of *i)* the biological fabric of the Earth; *ii)* the stocks and flows of major elements in the planetary machinery such as nitrogen, carbon, phosphorus, and silicon; and *iii)* the energy balance at the Earth's surface (2). The term *Anthropocene* (Box 2) suggests that the Earth has now left its natural geological epoch, the present interglacial state called the Holocene. Human activities have become so pervasive and profound that they rival the great forces of Nature and are pushing the Earth into planetary *terra incognita*. The Earth is rapidly moving into a less biologically diverse, less forested, much warmer, and probably wetter and stormier state.

The phenomenon of global change represents a profound shift in the relationship between humans and the rest of nature. Interest in this fundamental issue has escalated rapidly in the international research community, leading to innovative new research projects like Integrated History and future of People on Earth (IHOPE) (8). The objective of this paper is to explore one aspect of the IHOPE research agenda—the evolution of humans and our societies from hunter-gatherers to a global geophysical force.

To address this objective, we examine the trajectory of the human enterprise through time, from the arrival of humans on Earth through the present and into the next centuries. Our analysis is based on a few critical questions:

- Is the imprint of human activity on the environment discernible at the global scale? How has this imprint evolved through time?
- How does the magnitude and rate of human impact compare with the natural variability of the Earth's environment? Are human effects similar to or greater than the great forces of nature in terms of their influence on Earth System functioning?
- What are the socioeconomic, cultural, political, and technological developments that change the relationship between human societies and the rest of nature and lead to accelerating impacts on the Earth System?

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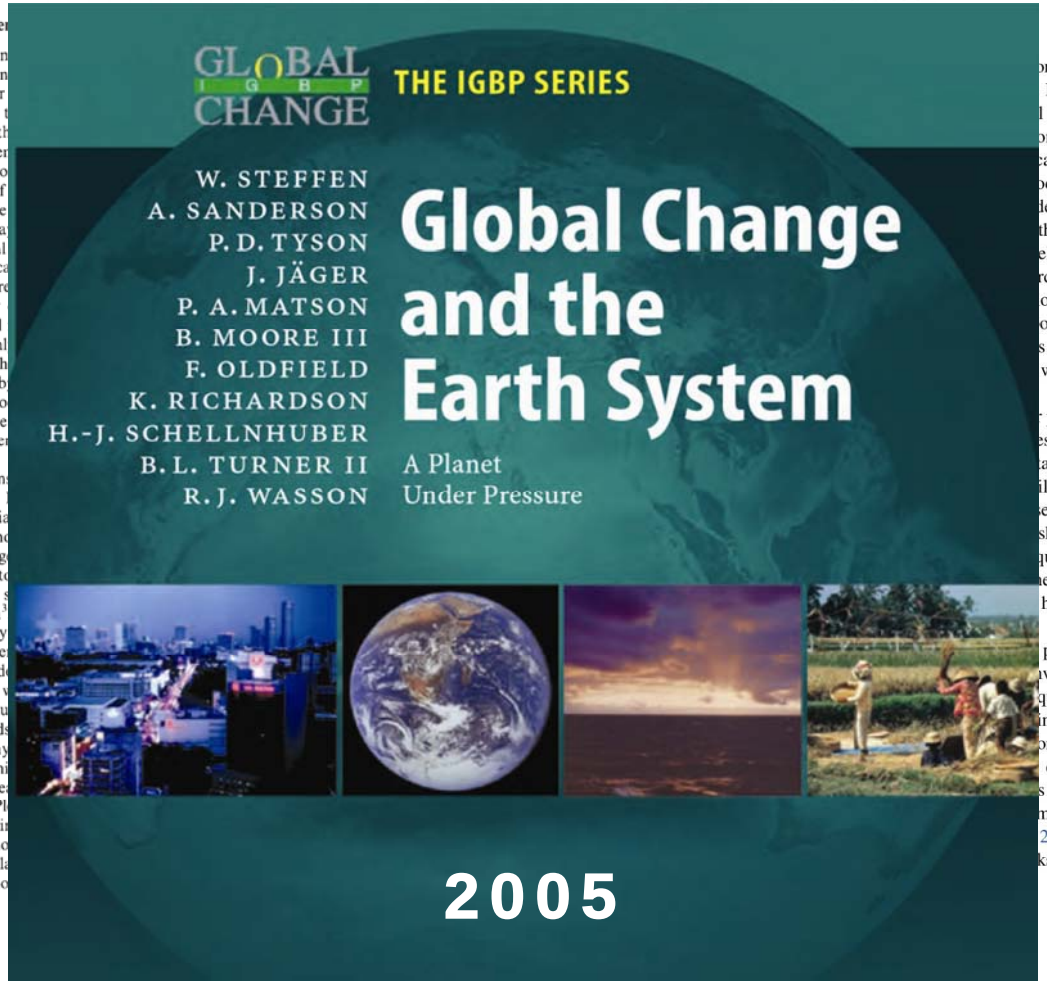
INVITED PAPER

The Anthropocene: From Global Change to Planetary Stewardship

Will Steffen, Åsa Persson, Lisa Deutsch, Jan Zalasiewicz, Mark Williams, Katherine Richardson, Carole Crumley, Paul Crutzen, Carl Folke, Line Gordon, Mario Molina, Veerabhadran Ramanathan, Johan Rockström, Marten Scheffer, Hans Joachim Schellnhuber, Uno Svedin



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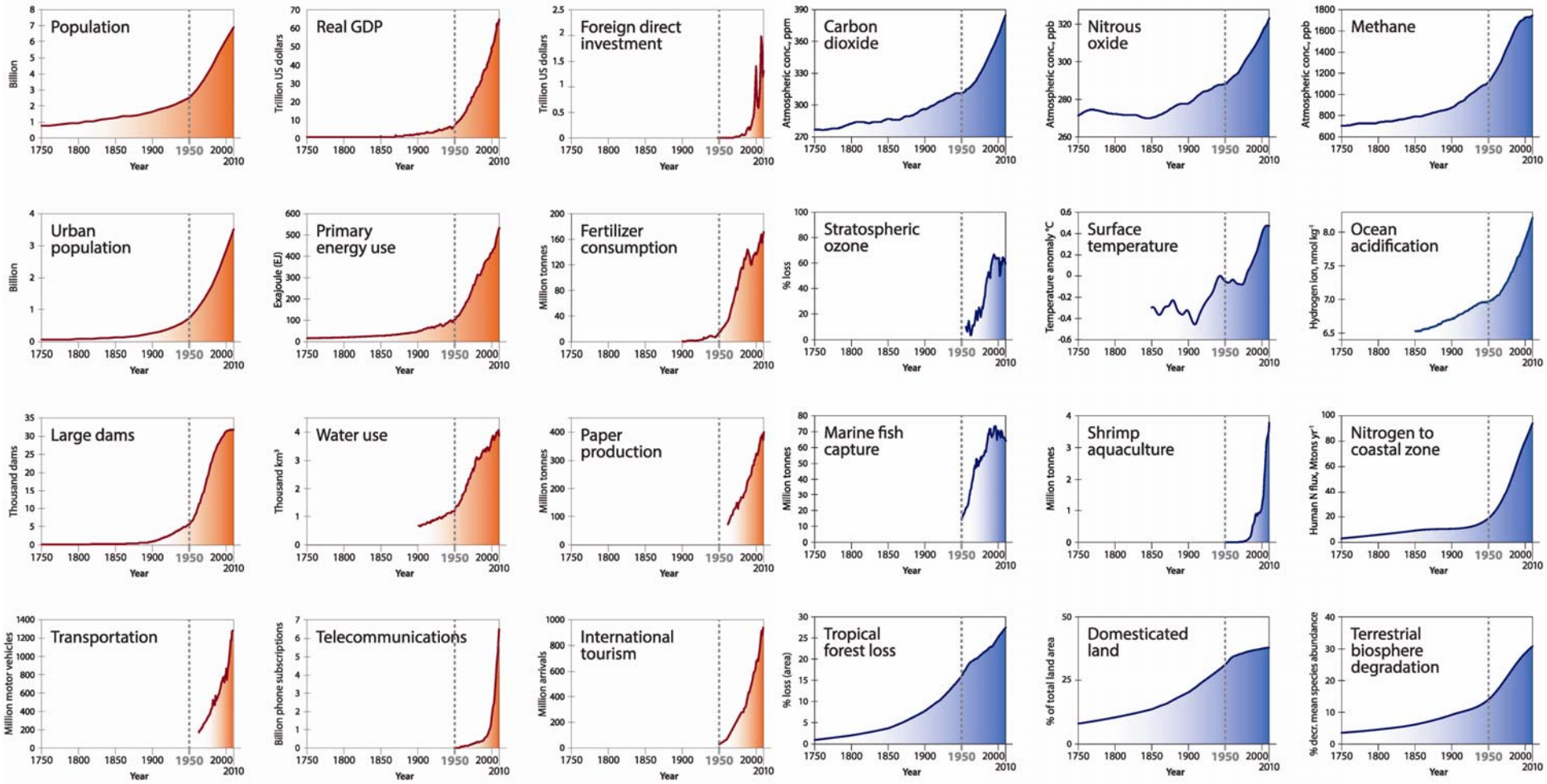

(Steffen, W. et al., 2015. The Anthropocene Review, 2, 81-98)

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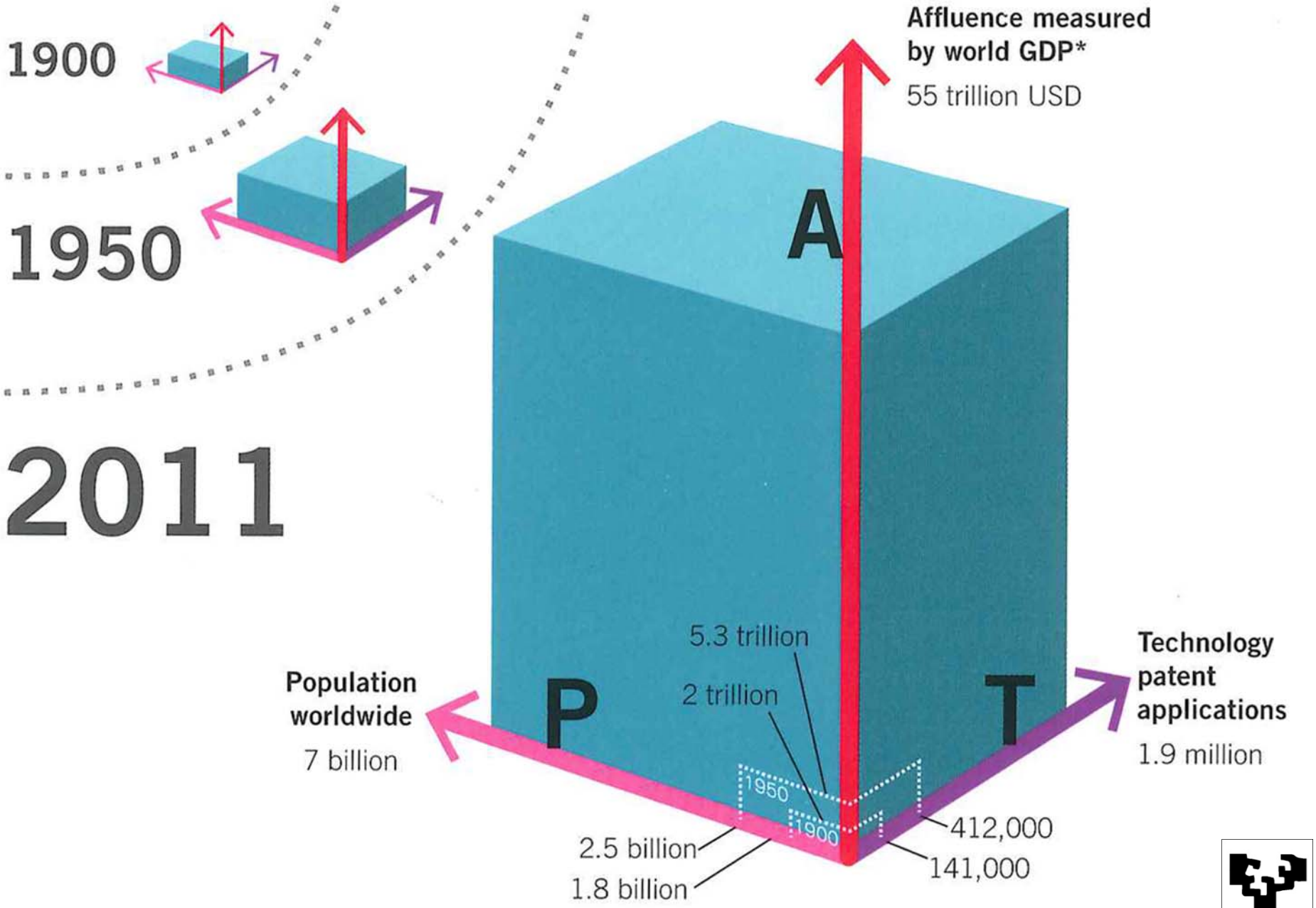

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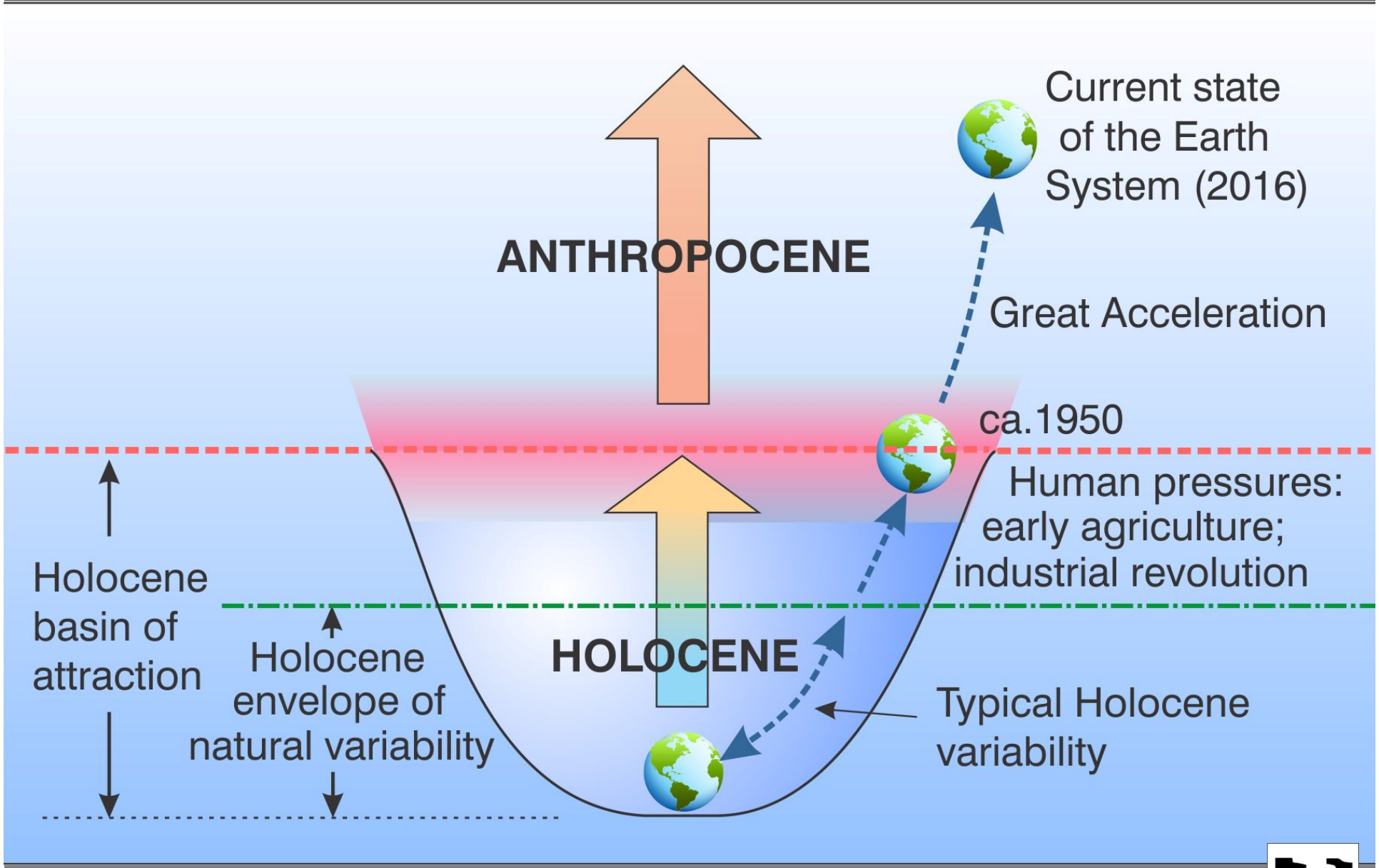

(Steffen, W. et al., 2016. Earth's Future)

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When did the Anthropocene begin? A mid-twentieth century boundary level is stratigraphically optimal

Jan Zalasiewicz [a], Colin N. Waters [b, *], Mark Williams [a], Anthony D. Barnosky [c], Alejandro Cearreta [d], Paul Crutzen [e], Erle Ellis [f], Michael A. Ellis [b], Ian J. Fairchild [g], Jacques Grinevald [h], Peter K. Haff [i], Irka Hajdas [j], Reinhold Leinfelder [k], John McNeill [l], Eric O. Odada [m], Clément Poirier [n], Daniel Richter [o], Will Steffen [p], Colin Summerhayes [q], James P.M. Syvitski [r], Davor Vidas [s], Michael Wagreich [t], Scott L. Wing [u], Alexander P. Wolfe [v], An Zhisheng [w], Naomi Oreskes [x]

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ABSTRACT

We evaluate the boundary of the Anthropocene geological time interval as an epoch, since it is useful to have a consistent temporal definition for this increasingly used unit, whether the presently informal term is eventually formalized or not. Of the three main levels suggested – an 'early Anthropocene' level some thousands of years ago; the beginning of the Industrial Revolution at ~1800 CE (Common Era); and the 'Great Acceleration' of the mid-twentieth century – current evidence suggests that the last of these has the most pronounced and globally synchronous signal. A boundary at this time need not have a Global Boundary Stratotype Section and Point (GSSP or 'golden spike') but can be defined by a Global Standard Stratigraphic Age (GSSA), i.e. a point in time of the human calendar. We propose an appropriate boundary level here to be the time of the world's first nuclear bomb explosion, on July 16th 1945 at Alamogordo, New Mexico; additional bombs were detonated at the average rate of one every 9.6 days until 1988 with attendant worldwide fallout easily identifiable in the chemostratigraphic record. Hence, Anthropocene deposits would be those that may include the globally distributed primary artificial

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IT IS 3 MINUTES TO MIDNIGHT

Bulletin of the Atomic Scientists | 70 Years Speaking Knowledge to Power

Feature

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Can nuclear weapons fallout mark the beginning of the Anthropocene Epoch?

Colin N. Waters, James P. M. Syvitski, Agnieszka Gałuszka, Gary J. Hancock, Jan Zalasiewicz, Alejandro Cearreta, Jacques Grinevald, Catherine Jeandel, J. R. McNeill, Colin Summerhayes, and Anthony Barnosky

Abstract

Many scientists are making the case that humanity is living in a new geological epoch, the Anthropocene, but there is no agreement yet as to when this epoch began. The start might be defined by a historical event, such as the beginning of the fossil-fueled Industrial Revolution or the first nuclear explosion in 1945. Standard stratigraphic practice, however, requires a more significant, globally widespread, and abrupt signature, and the fallout from nuclear weapons testing appears most suitable. The appearance of plutonium 239 (used in post-1945 above-ground nuclear weapons tests) makes a good marker: This isotope is rare in nature but a significant component of fallout. It has other features to recommend it as a stable marker in layers of sedimentary rock and soil, including: long half-life, low solubility, and high particle reactivity. It may be used in conjunction with other radioactive isotopes, such as americium 241 and carbon 14, to categorize distinct fallout signatures in sediments and ice caps. On a global scale, the first appearance of plutonium 239 in sedimentary sequences corresponds to the early 1950s. While plutonium is easily detectable over the entire Earth using modern measurement techniques, a site to define the Anthropocene (known as a "golden spike") would ideally be located between 30 and 60 degrees north of the equator, where fallout is maximal, within undisturbed marine or lake environments.

Keywords

Anthropocene, golden spike, nuclear weapons fallout, radioactive isotope, radiogenic signature, Trinity test

Seventy years ago—at 5:30 a.m. on July 16, 1945—the world's first nuclear device exploded at the Trinity Test Site in what was then the Alamogordo Bombing and Gunnery Range in New Mexico. After an intense flash of light and heat, and a roaring shock wave that took 40 seconds to reach the closest observers, a fireball rose into the sky, forming a mushroom cloud 7.5 miles high. J. Robert Oppenheimer lat
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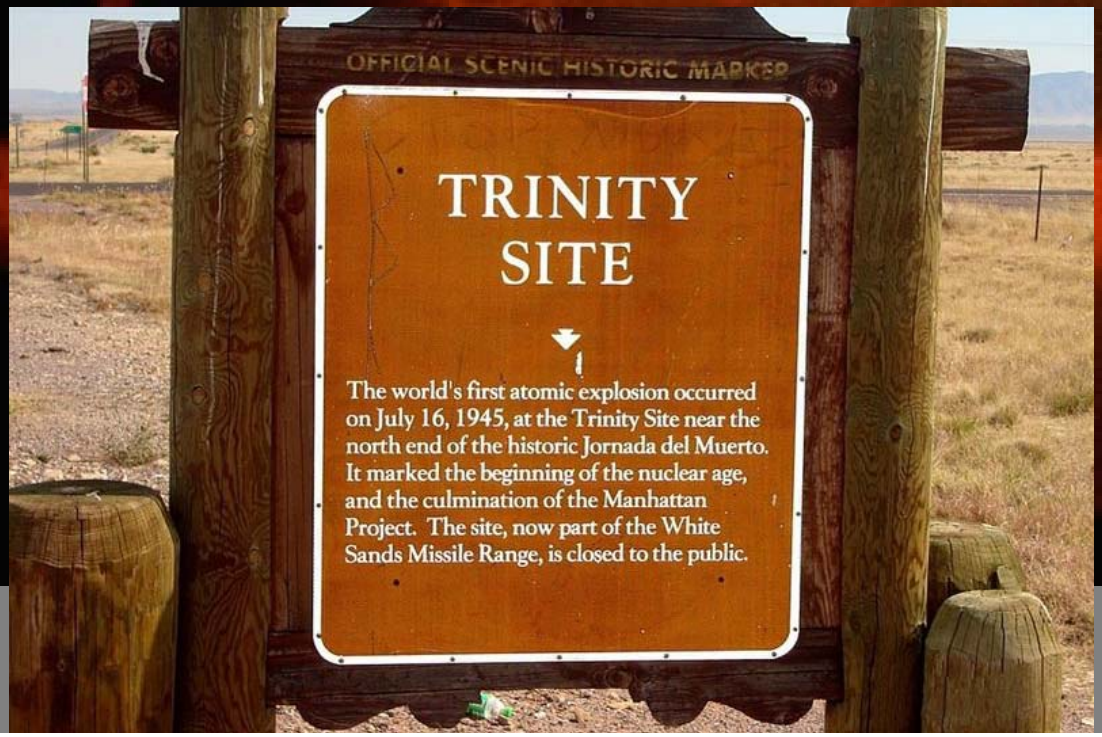
OFFICIAL SCENIC HISTORIC MARKER
TRINITY SITE
The world's first atomic explosion occurred on July 16, 1945, at the Trinity Site near the north end of the historic Jornada del Muerto. It marked the beginning of the nuclear age, and the culmination of the Manhattan Project. The site, now part of the White Sands Missile Range, is closed to the public.

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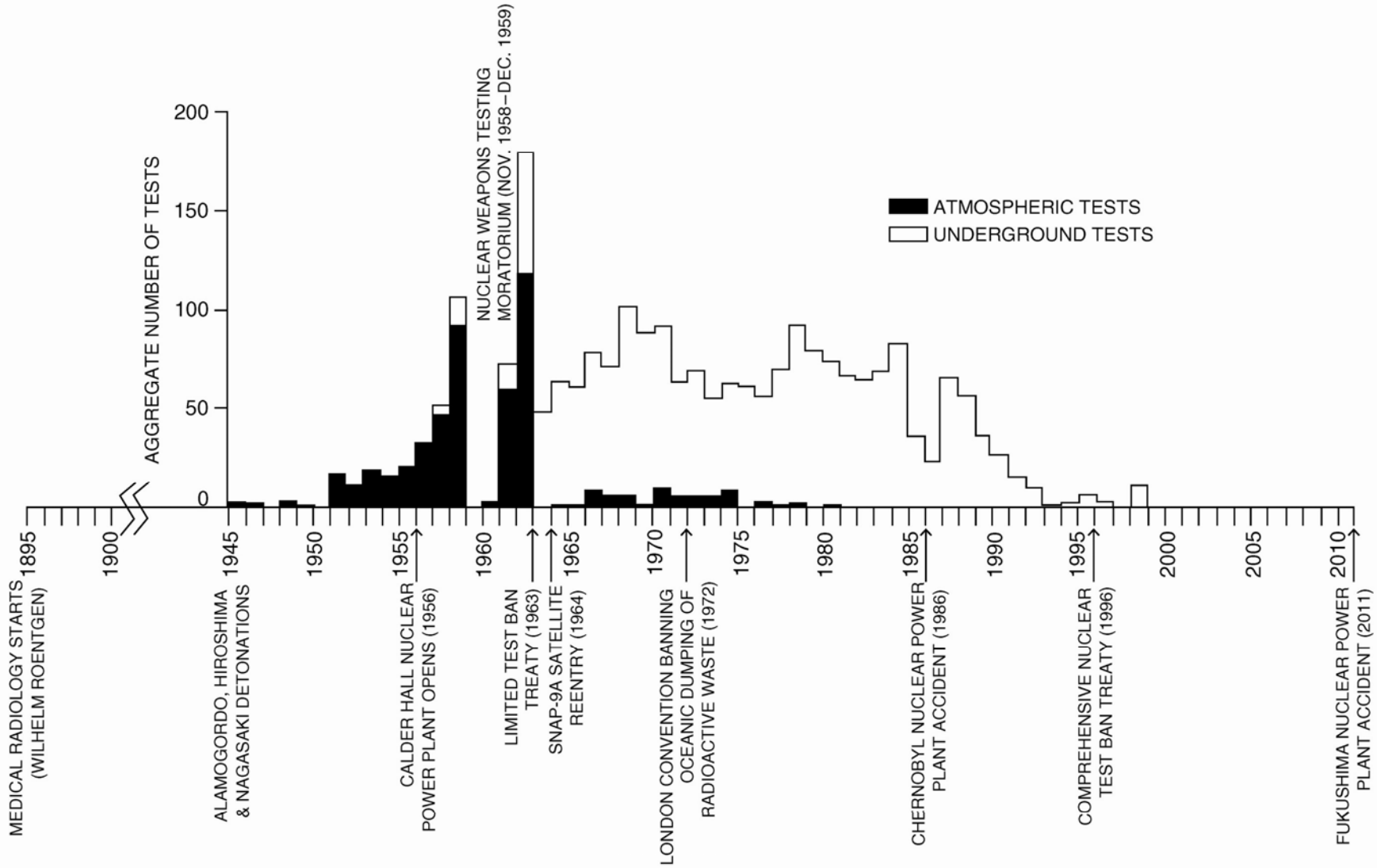

Source: UNSCEAR (2000)

(Waters, C.N. et al., 2015. Bulletin of the Atomic Scientists, 71, 46-57)

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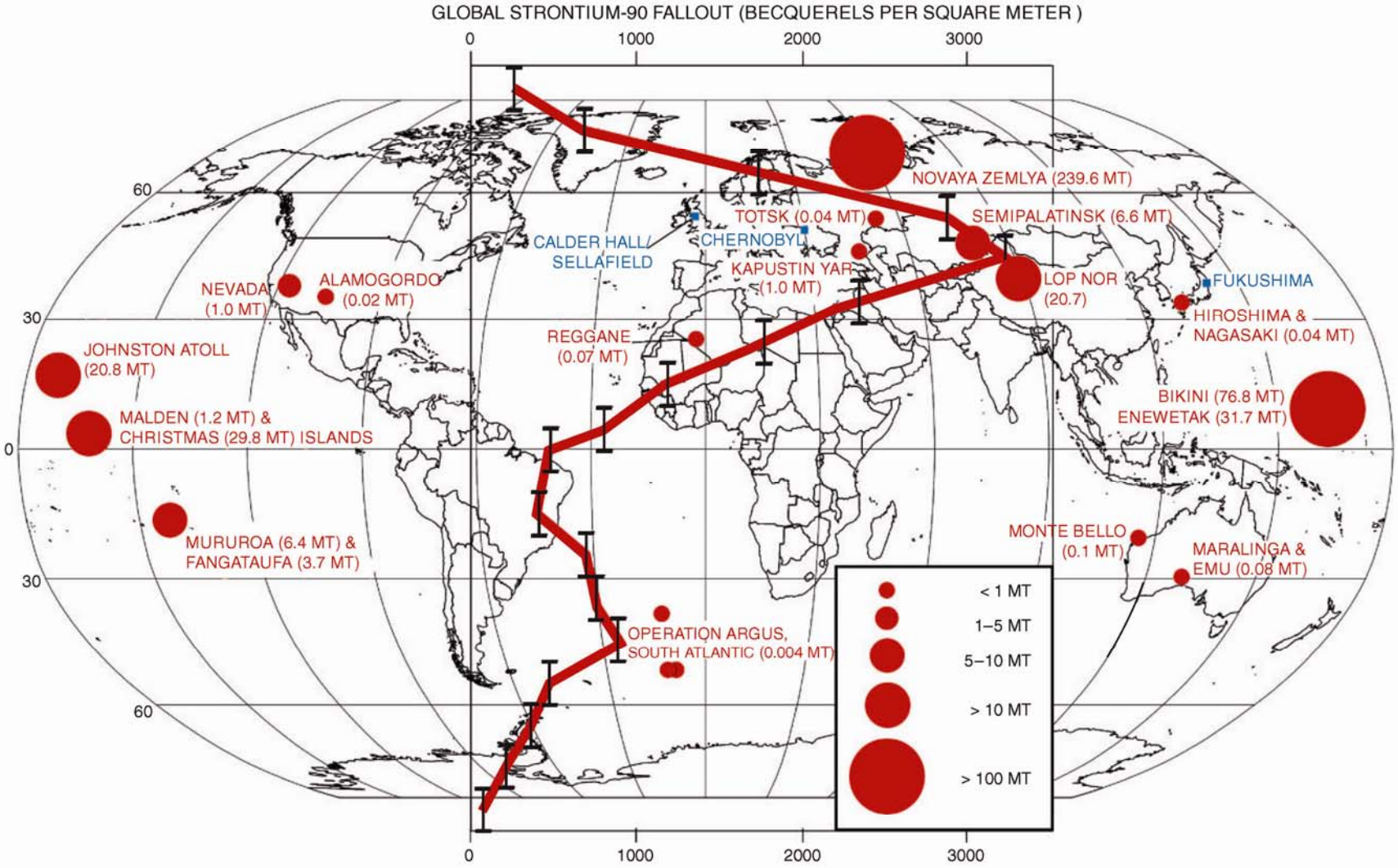

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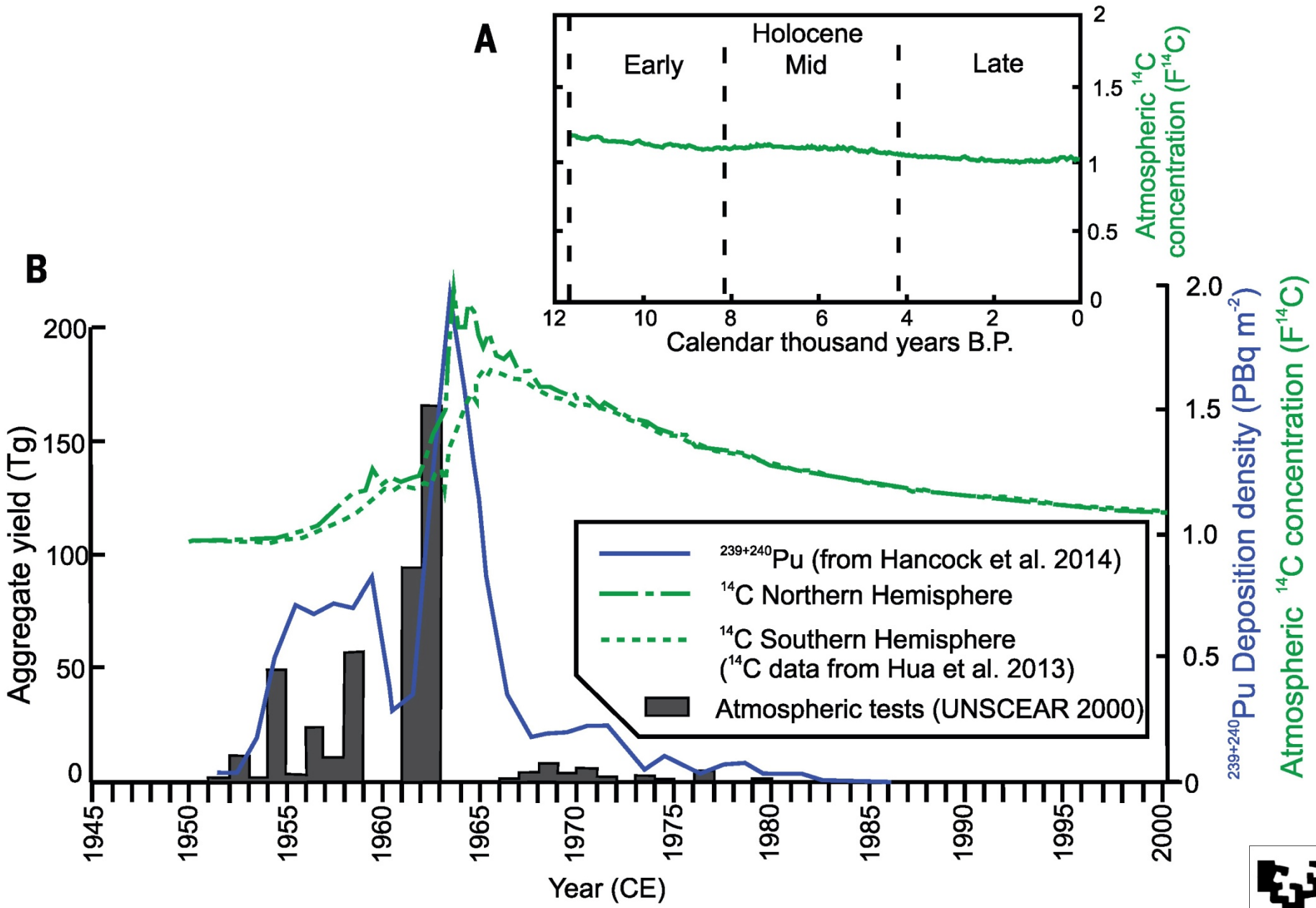

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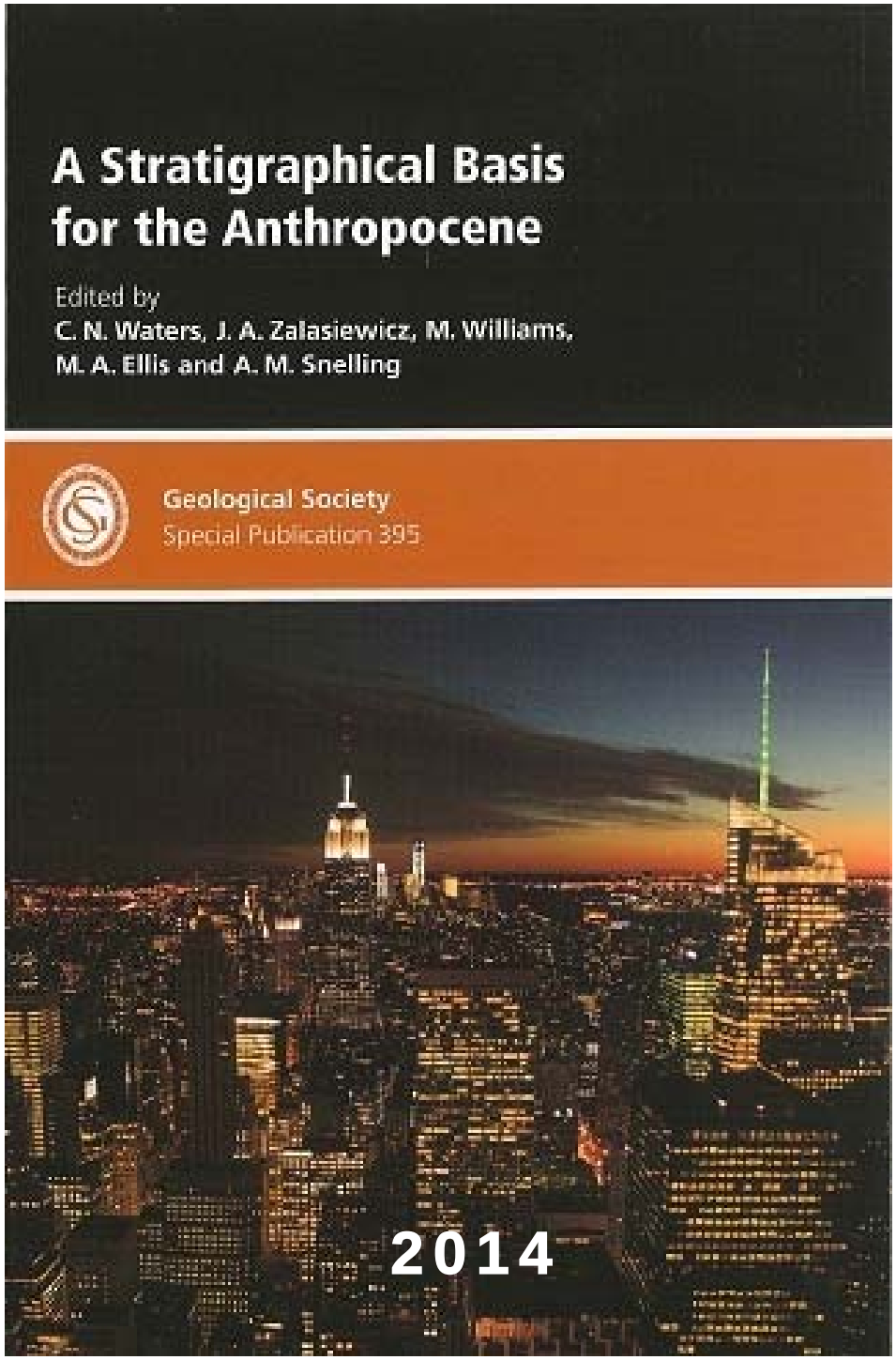

A stratigraphical basis for the Anthropocene?

COLIN N. WATERS[1]*, JAN A. ZALASIEWICZ[2], MARK WILLIAMS[2], MICHAEL A. ELLIS[1] & ANDREA M. SNELLING[3]

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Abstract: Recognition of intimate feedback mechanisms linking changes across the atmosphere, biosphere, geosphere and hydrosphere demonstrates the pervasive nature of humankind's influence, perhaps to the point that we have fashioned a new geological epoch, the Anthropocene. To what extent will these changes be evident as long-lasting signatures in the geological record?

To establish the Anthropocene as a formal chronostratigraphical unit it is necessary to consider a spectrum of indicators of anthropogenically induced environmental change, and to determine how these show as stratigraphic signals that can be used to characterize an Anthropocene unit and to recognize its base. It is important to consider these signals against a context of Holocene and earlier stratigraphic patterns. Here we review the parameters used by stratigraphers to identify chronostratigraphical units and how these could apply to the definition of the Anthropocene. The onset of the range of signatures is diachronous, although many show maximum signatures which post-date1945, leading to the suggestion that this date may be a suitable age for the start of the Anthropocene.

The 'Anthropocene' is in many respects a novel potential geological unit. Stratigraphy, which deals with the classification of geological time (geochronology) and material time-rock units (chronostratigraphy), has historically defined geological units based upon significant, but temporally distant, events. These events are typically, although not exclusively, associated with major changes in the fossil contents of rocks below and above a particular horizon, and therefore with the temporal distribution of life forms. It was only following such observations that new stratigraphical units were proposed and ultimately defined. For example, J. Phillips used the major mass extinction at the end of the Permian in 1840 to recognize the beginning of both the Triassic Period and of the Mesozoic Era. The ultimate definition of the base of the Triassic, however, was accomplished only in 2001, when the Global Stratotype Section and Point (GSSP) was taken at the base of a specific bed in a section in Meishan, China, coinciding with the lowest occurrence of the primary marker, the conodont *Hindeodus parvus* (Yin *et al.* 2001). In contrast, the Anthropocene was proposed as a term (Crutzen & Stoermer 2000) before any consideration of the nature of the signature of this new stratigraphical unit was given. For the first time in geological history, humanity has been able to observe and be part of the processes that potentially may signal such a change from the preceding to succeeding epoch.

What are the key 'events' over the last decades to millennia that have the potential to leave a recognizable record in sediments/ice that could be used to define the base of the Anthropocene? The options cover a diverse range of geoscientific fields and need not be restricted to the biostratigraphical tools typically used throughout much of the geological column to define chronostratigraphical units. Potential stratigraphical tools and techniques that may be used to define the base of the Anthropocene include the following (Fig. 1):

(1) Appearance and increased abundance of anthropogenic deposits:
- artificial anthropogenic deposits;
- anthropogenic soils (anthrosols);
- novel minerals and mineraloids;
- anthropogenic subsurface structures ('trace fossils');
- anthropogenic modification of terrestrial and marine sedimentary systems.

(2) Biotic turnover:
- megafauna;
- reef ecosystems;
- microflora;
- microfauna.

From: Waters, C. N., Zalasiewicz, J. A., Williams, M., Ellis, M. A. & Snelling, A. M. (eds) *A Strat Basis for the Anthropocene*. Geological Society, London, Special Publications, **395**, http://dx.doi.org/10.1144/SP395.18

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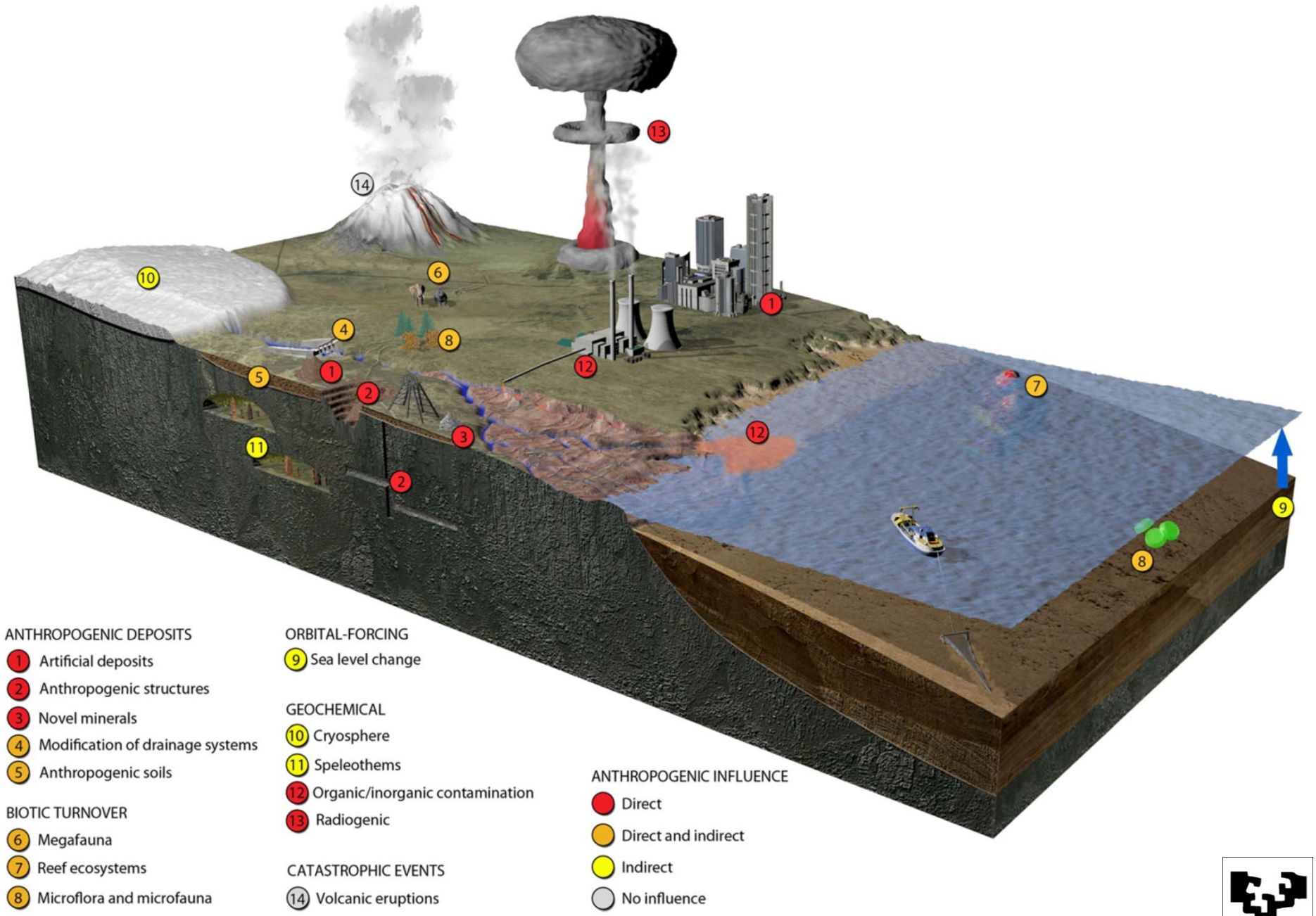

(Waters, C.N. et al., 2014. Geological Society of London Special Publications, 395, 1-21)

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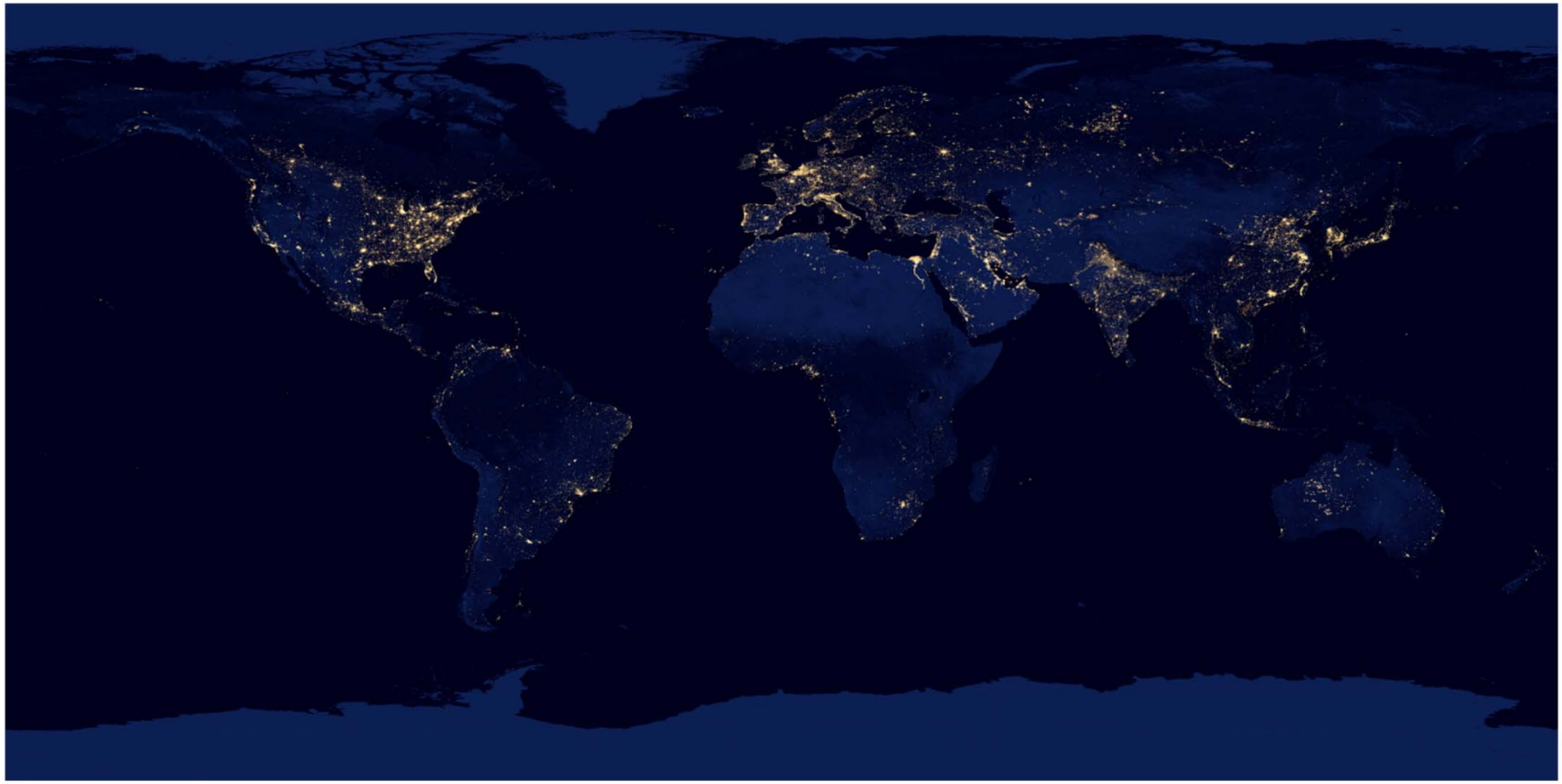

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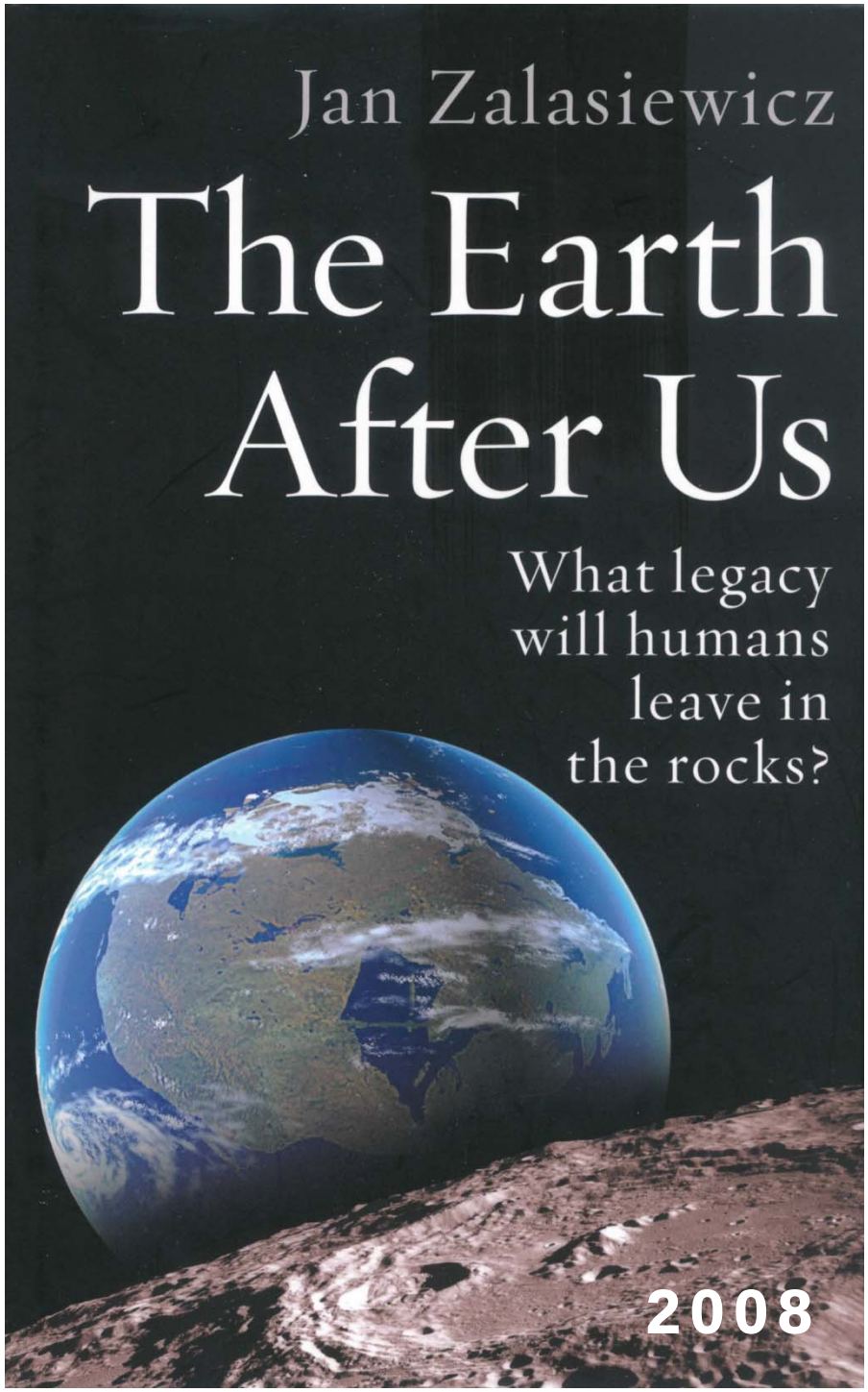

Research article

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The technofossil record of humans

Jan Zalasiewicz,[1] Mark Williams,[1] Colin N Waters,[2] Anthony D Barnosky[3,4,5] and Peter Haff[6]

Abstract

As humans have colonised and modified the Earth's surface, they have developed progressively more sophisticated tools and technologies. These underpin a new kind of stratigraphy, that we term technostratigraphy, marked by the geologically accelerated evolution and diversification of technofossils – the preservable material remains of the technosphere (Haff, 2013), driven by human purpose and transmitted cultural memory, and with the dynamics of an emergent system. The technosphere, present in some form for most of the Quaternary, shows several thresholds. Its expansion and transcontinental synchronisation in the mid 20th century has produced a global technostratigraphy that combines very high time-resolution, great geometrical complexity and wide (including transplanetary) extent. Technostratigraphy can help characterise the deposits of a potential Anthropocene Epoch and its emergence marks a step change in planetary mode.

Keywords

Anthropocene, human artefacts, stratigraphy, technology

Introduction

From the beginnings of geology, fossils have been recognised as central to the science, not only because they are a record of life (the most important feature of our planet) but because biological evolution has provided a means of dating and correlating strata, and hence underpinning the Geological Time Scale. Thus, the Phanerozoic Eon (roughly, the last half-billion years of Earth history) was characterised by complex metazoans with hard skeletal parts. It has a finely resolved timescale largely founded on fossil zones, reflecting the evolution of these organisms. In this way, Phanerozoic time can be split into intervals that may be less than 1 million years in duration, for

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Corrected 8 February 2016; see full text.

REVIEW

EARTH HISTORY

The Anthropocene is functionally and stratigraphically distinct from the Holocene

Colin N. Waters,[1*] Jan Zalasiewicz,[2] Colin Summerhayes,[3] Anthony D. Barnosky,[4] Clément Poirier,[5] Agnieszka Gałuszka,[6] Alejandro Cearreta,[7] Matt Edgeworth,[8] Erle C. Ellis,[9] Michael Ellis,[1] Catherine Jeandel,[10] Reinhold Leinfelder,[11] J. R. McNeill,[12] Daniel deB. Richter,[13] Will Steffen,[14] James Syvitski,[15] Davor Vidas,[16] Michael Wagreich,[17] Mark Williams,[2] An Zhisheng,[18] Jacques Grinevald,[19] Eric Odada,[20] Naomi Oreskes,[21] Alexander P. Wolfe[22]

Human activity is leaving a pervasive and persistent signature on Earth. Vigorous debate continues about whether this warrants recognition as a new geologic time unit known as the Anthropocene. We review anthropogenic markers of functional changes in the Earth system through the stratigraphic record. The appearance of manufactured materials in sediments, including aluminum, plastics, and concrete, coincides with global spikes in fallout radionuclides and particulates from fossil fuel combustion. Carbon, nitrogen, and phosphorus cycles have been substantially modified over the past century. Rates of sea-level rise and the extent of human perturbation of the climate system exceed Late Holocene changes. Biotic changes include species invasions worldwide and accelerating rates of extinction. These combined signals render the Anthropocene stratigraphically distinct from the Holocene and earlier epochs.

The term "Anthropocene" is currently used informally to encompass different geological, ecological, sociological, and anthropological changes in recent Earth history. The origins of the concept of the Anthropocene, its terminology, and its sociopolitical implications are widely discussed (*1*, *2*). When considering the stratigraphic definition of the Anthropocene, there are two basic questions: Have humans changed the Earth system to such an extent that recent and currently forming geological deposits include a signature that is distinct from those of the Holocene and earlier epochs, which will remain in the geological record? If so, when did this stratigraphic signal (not necessarily the first detectable anthropogenic change) become recognizable worldwide? These questions are considered here in the context of how stratigraphic units have been formally recognized earlier in the Quaternary period.

Proposals for marking the start of the Anthropocene have included (i) an "early Anthropocene" associated with the advent of agriculture, animal domestication, extensive deforestation, and gradual increases in atmospheric carbon dioxide (CO_2) and methane (CH_4) levels thousands of years ago (*3*, *4*); (ii) the Columbian Exchange of Old World and New World species associated with colonization of the Americas (*5*); (iii) the beginning of the Industrial Revolution at ~1800 CE (*6*, *7*); and (iv) the mid-20th century "Great Acceleration" of population growth, industrialization, and mineral and energy use (*8*–*10*).

Here we review several lines of evidence suggesting that the Anthropocene's stratigraphic signatures distinguish it from the Holocene (Fig. 1). We find that criteria available to recognize the Anthropocene are consistent with those used to define other Quaternary stratigraphic units. Earlier Quaternary time-unit subdivisions are defined by signals from cyclical forcings of climate change, such as variation in Earth's orbit or solar irradiance, and irregular events such as volcanic eruptions. Although these forcings continue, the Anthropocene markers reflect an additional key driver, that of human modification of global environments at unprecedented rates. This driver has produced a wide range of anthropogenic stratigraphic signals (Fig. 1), including examples that are novel in Earth history, that are global in extent, and that offer fine temporal resolution. The signals vary in their development: Some are already advanced, and others are at early stages. We describe these signals and suggest how they may be used in the stratigraphic characterization and correlation of a formalized Anthropocene epoch with a lower boundary (still to be identified) potentially placed in the mid-20th century.

How are Quaternary stratigraphic units defined?

The Quaternary period, which began 2.6 million years ago (Ma), is subdivided into geochronological time units (epochs and ages) with boundaries that are linked at least in part to climate change events (expressed as marine isotope stages), in association with paleomagnetic reversals (*11*). This contrasts with the subdivision of most of the Phanerozoic eon (the past ~541 ± 1 Ma), for which the first or last appearance of key fossil taxa is typically used to define time units. Fossil-based boundaries represent change at rates too slow and time-transgressive for the geologically recent past, in which the time units are of comparatively short duration (about 12,000 years for the Holocene versus 2 million years or more for earlier epochs). These time intervals are recognizable in the geologic record as chronostratigraphic units (series and stages), which, in contrast to the time units, are physical entities, including rocks, sediments, and glacier ice. Ideally, a chronostratigraphic unit is exemplified, and its lower boundary defined, at a single locality termed the Global Boundary Stratotype Section and Point (GSSP), which is typically in marine strata for pre-Holocene series (*12*).

The start of the Holocene epoch (or series) is based on the termination of the transition from the last glacial phase into an interval of warming accompanied by ~120 m of sea-level rise. The warming took place over about 1600 years and is recorded by a variety of stratigraphic signals that are not all globally synchronous. In the Northern Hemisphere, the signal for the Holocene's beginning

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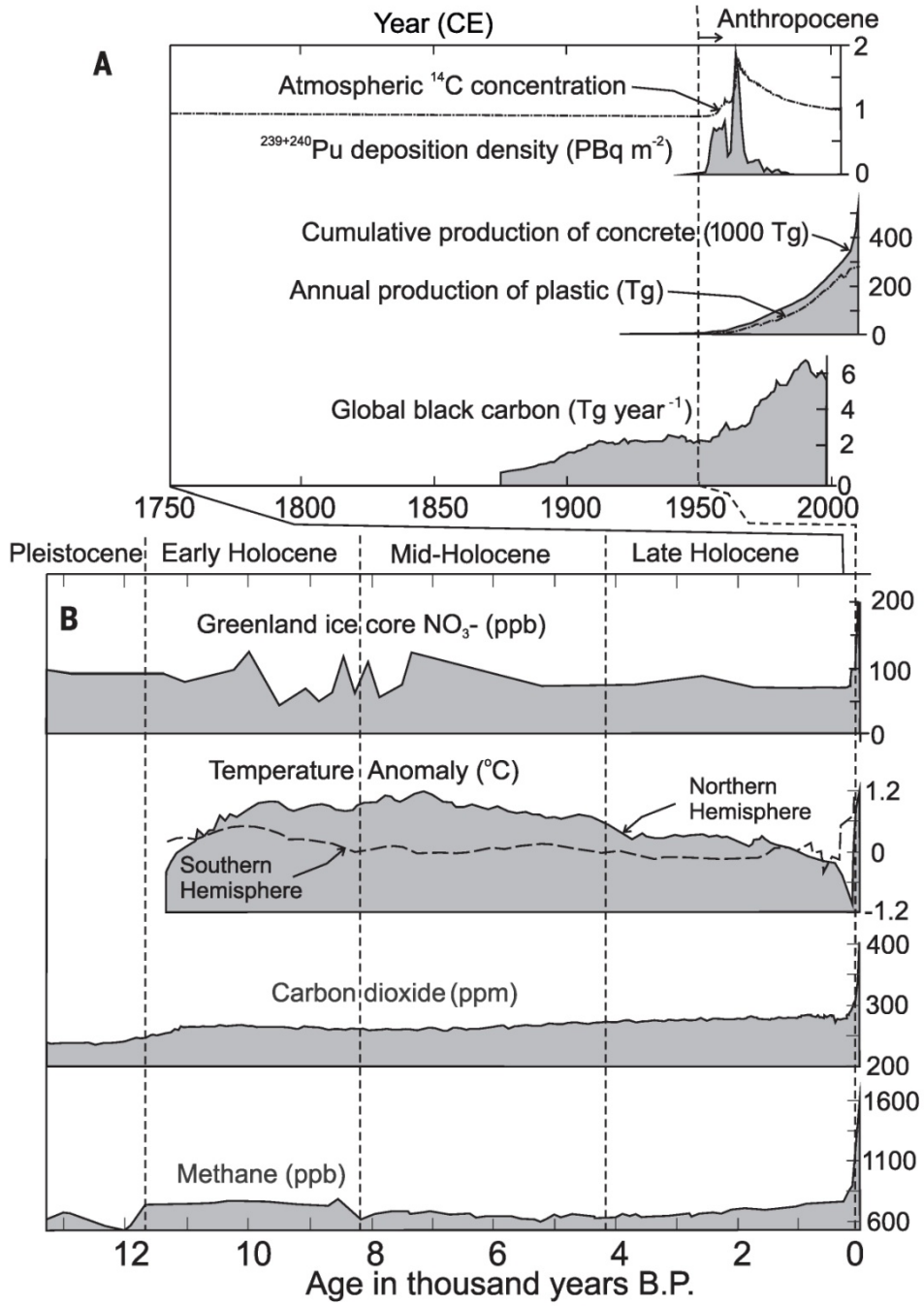
***Corresponding author. E-mail: cnw@bgs.ac.uk**



(Waters, C.N. et al., 2016. Science, 351 (6269), aad2622-1/10)

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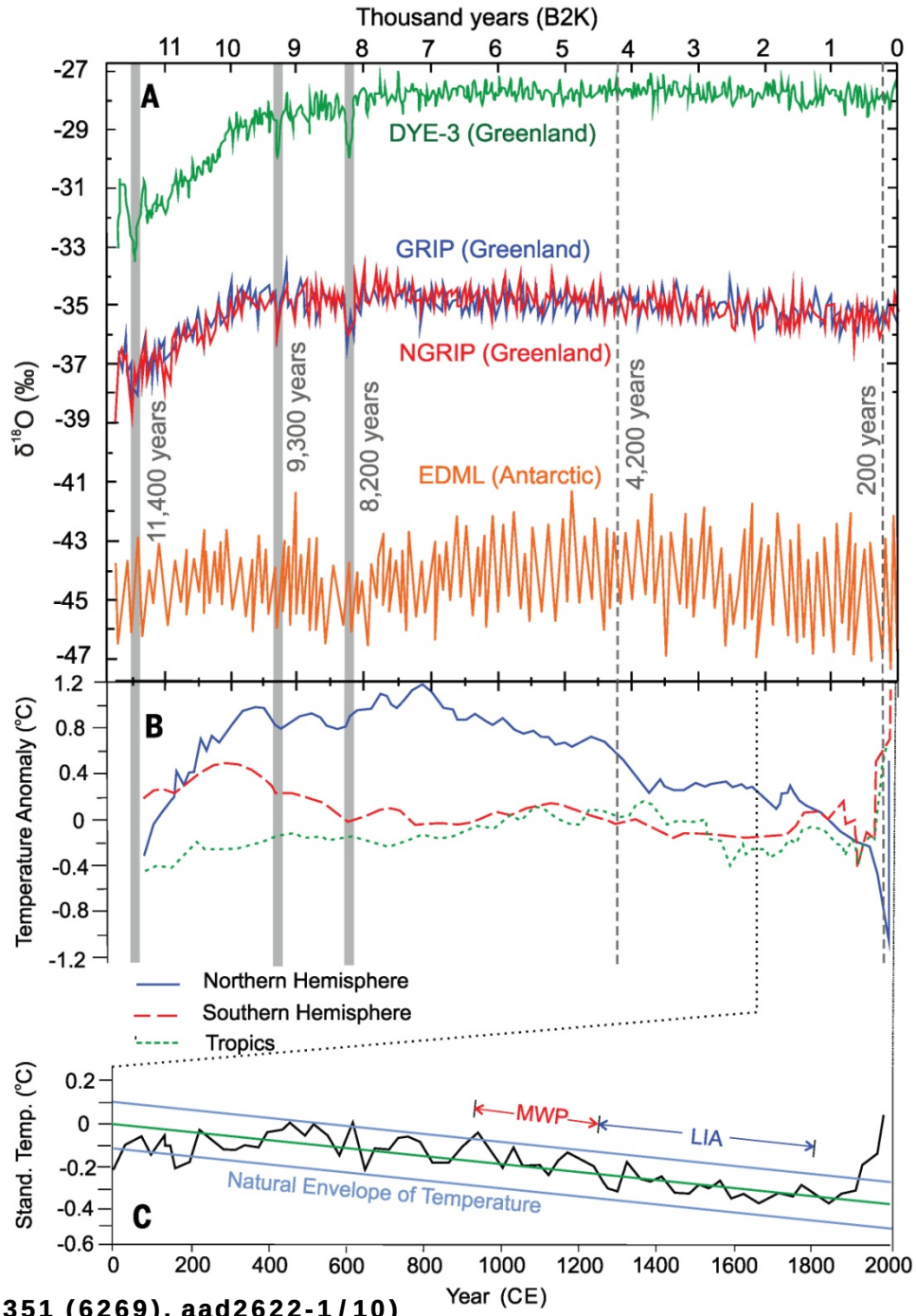

(Waters, C.N. et al., 2016. Science, 351 (6269), aad2622-1/10)

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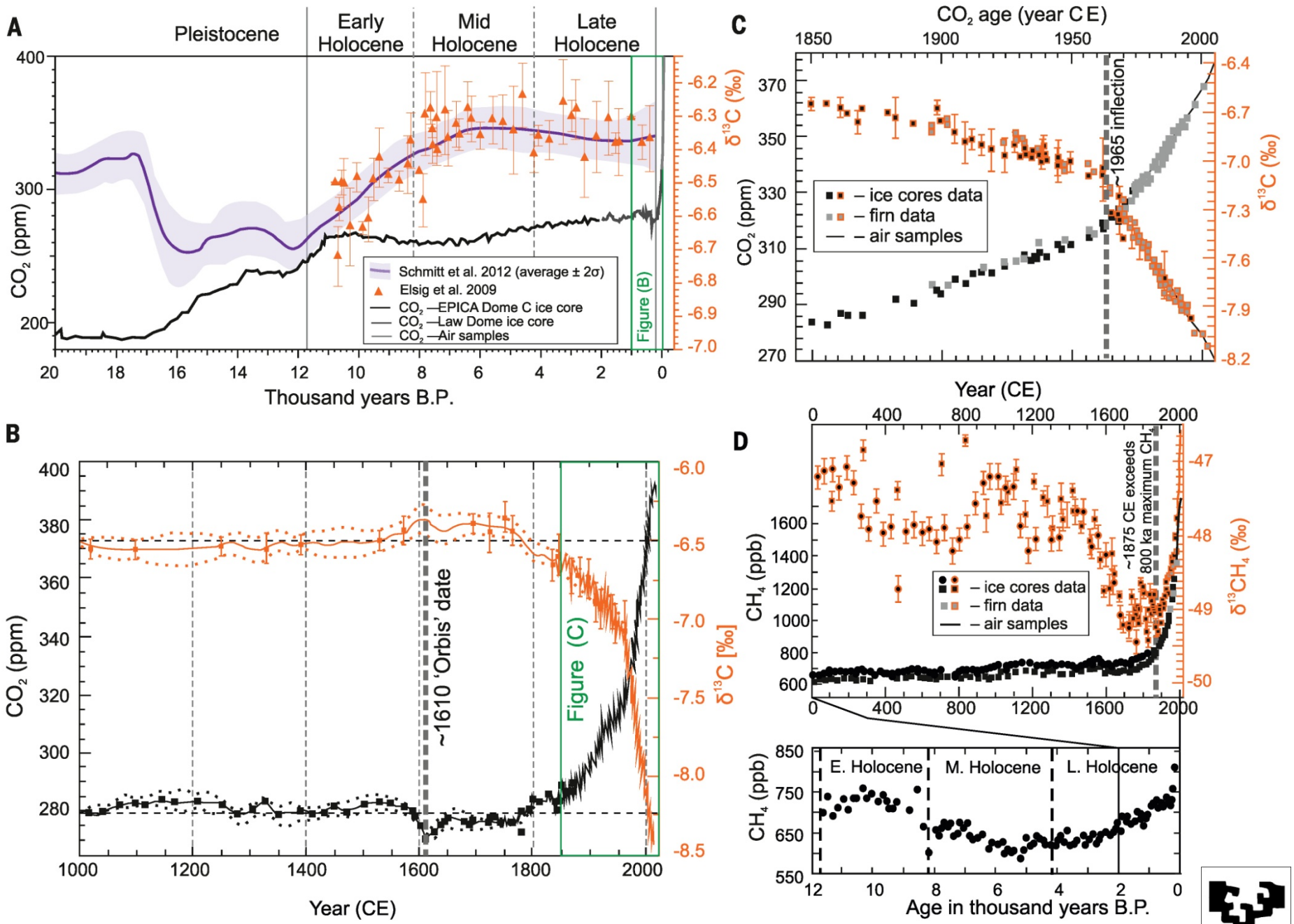

(Waters, C.N. et al., 2016. Science, 351 (6269), aad2622-1/10)

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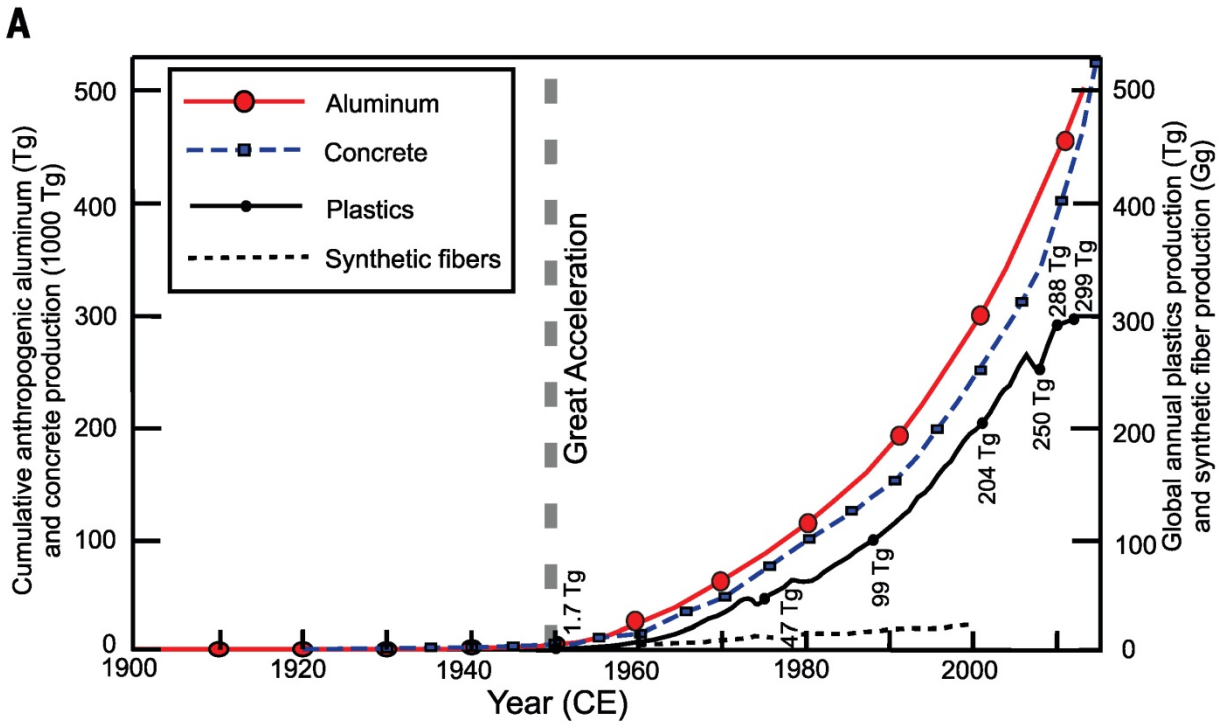

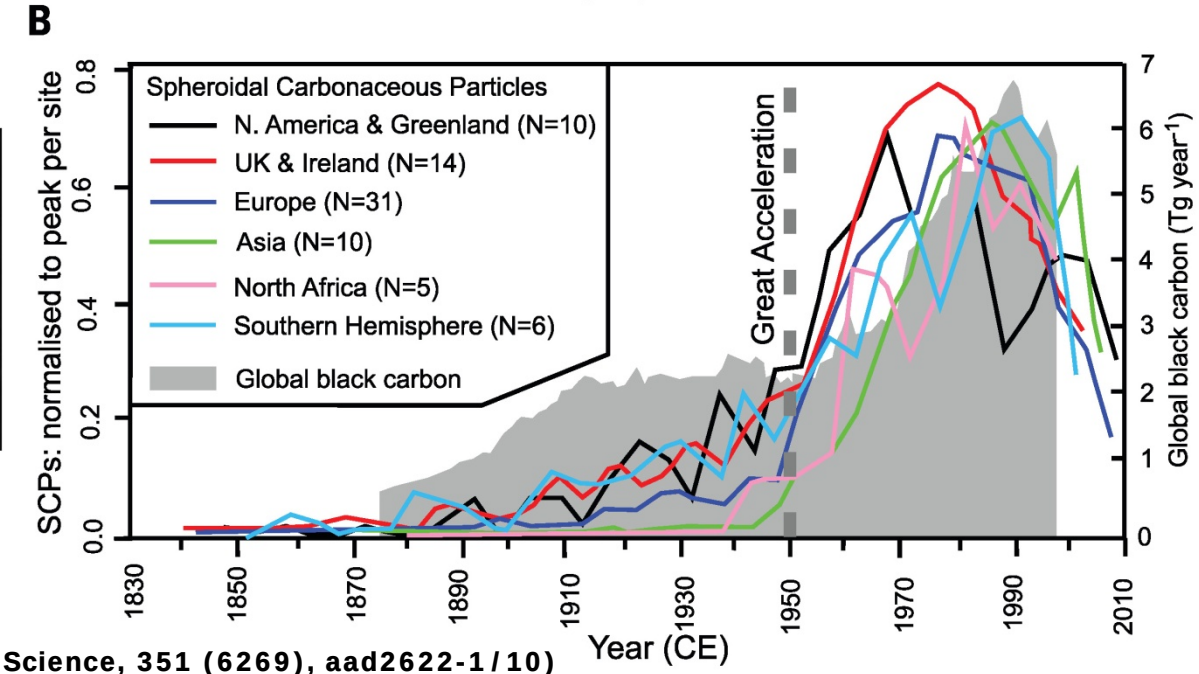

(Waters, C.N. et al., 2016. Science, 351 (6269), aad2622-1/10)

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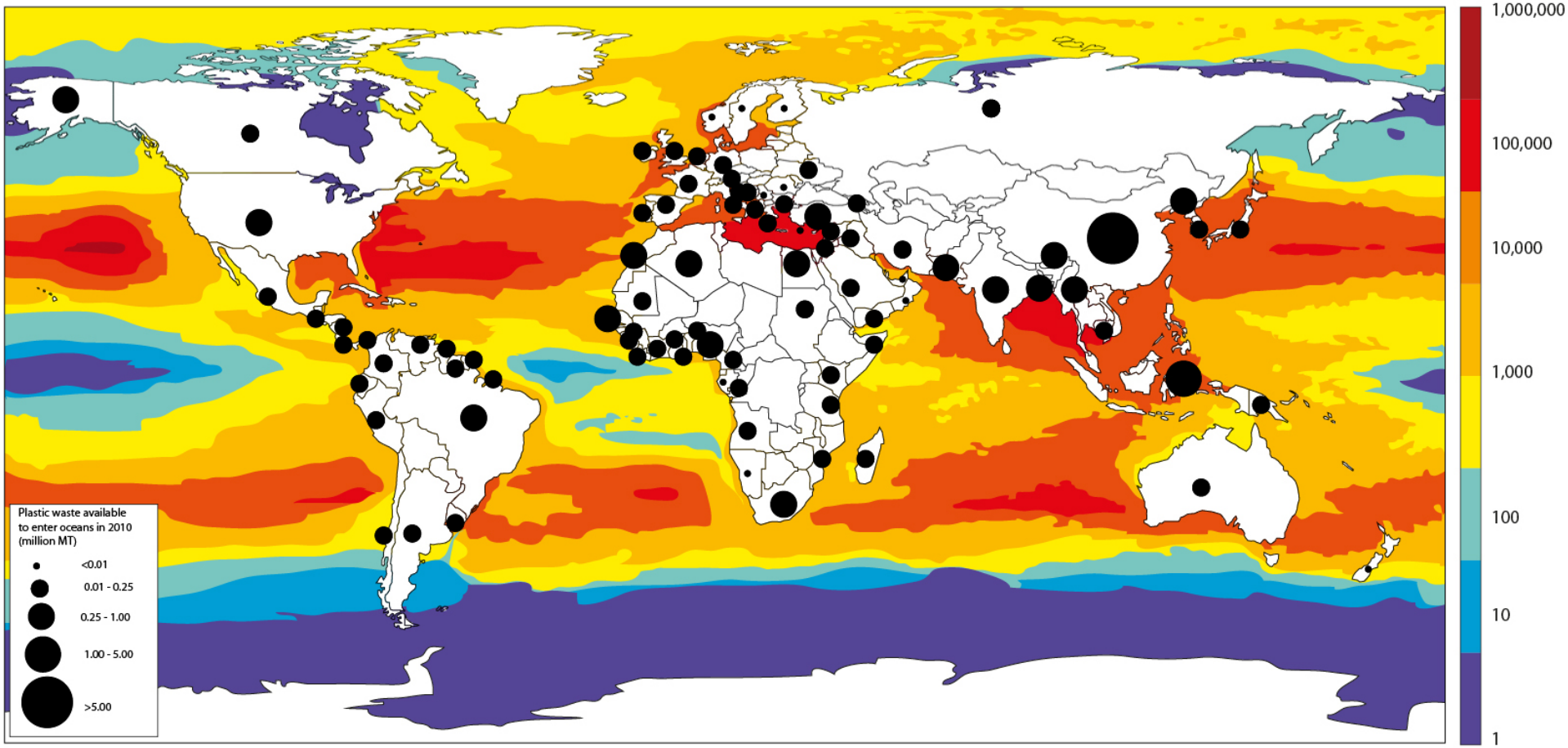

(Zalasiewicz, J. et al., 2016. Anthropocene)

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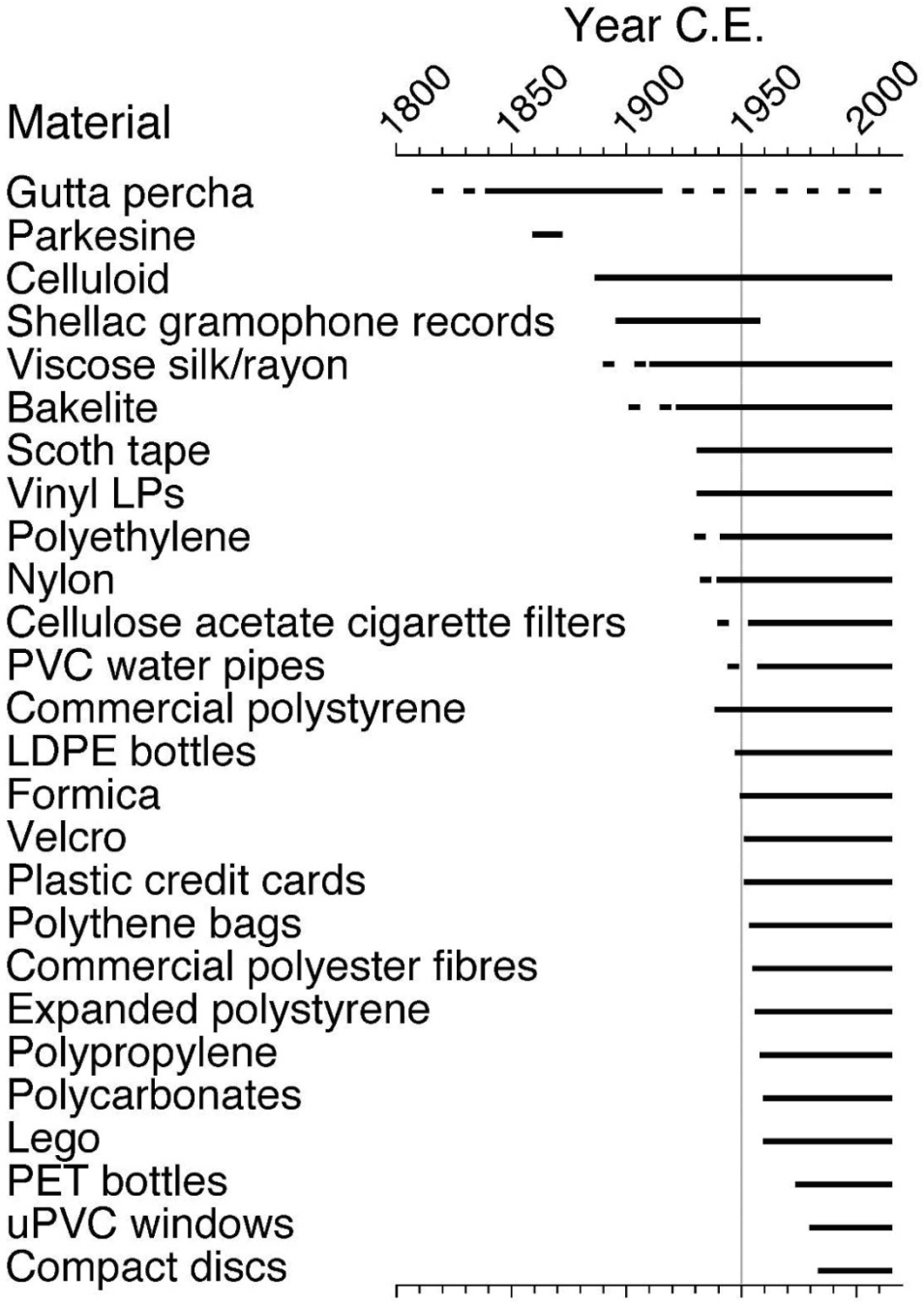

(Zalasiewicz, J. et al., 2016. Anthropocene)

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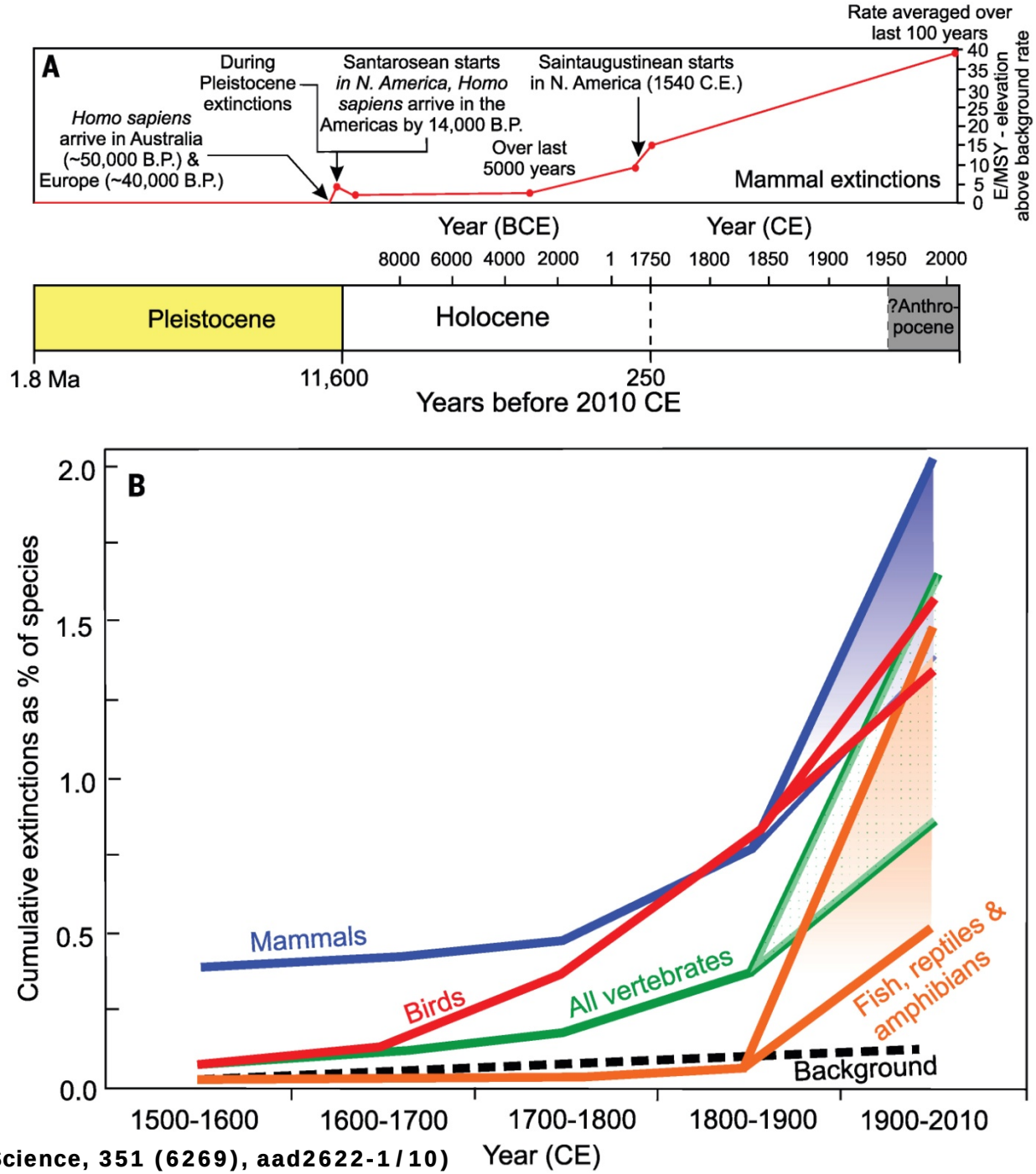

(Waters, C.N. et al., 2016. Science, 351 (6269), aad2622-1/10)

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INTERNATIONAL CHRONOSTRATIGRAPHIC CHART

IUGS

www.stratigraphy.org — **International Commission on Stratigraphy** — **v 2016/04**

Eonothem / Eon	Erathem / Era	System / Period	Series / Epoch	Stage / Age	GSSP	numerical age (Ma)
						present
Phanerozoic	Cenozoic	Quaternary	Holocene		✓	0.0117
			Pleistocene	*Upper*		0.126
				Middle		0.781
				Calabrian	✓	1.80
				Gelasian	✓	2.58
		Neogene	Pliocene	Piacenzian	✓	3.600
				Zanclean	✓	5.333
			Miocene	Messinian	✓	7.246
				Tortonian	✓	11.63
				Serravallian	✓	13.82
				Langhian		15.97
				Burdigalian		20.44
				Aquitanian	✓	23.03
		Paleogene	Oligocene	Chattian		28.1
				Rupelian	✓	33.9
			Eocene	Priabonian		37.8
				Bartonian		41.2
				Lutetian	✓	47.8
				Ypresian	✓	56.0
			Paleocene	Thanetian	✓	59.2
				Selandian	✓	61.6
				Danian	✓	66.0
Mesozoic	Cretaceous		Upper	Maastrichtian	✓	72.1 ±0.2
				Campanian		83.6 ±0.2
				Santonian	✓	86.3 ±0.5
				Coniacian		89.8 ±0.3
				Turonian	✓	93.9
				Cenomanian	✓	100.5
			Lower	Albian	✓	~ 113.0
				Aptian		~ 125.0
				Barremian		~ 129.4
				Hauterivian		~ 132.9
				Valanginian		~ 139.8
				Berriasian		~ 145.0

Eonothem / Eon	Erathem / Era	System / Period	Series / Epoch	Stage / Age	GSSP	numerical age (Ma)
						~ 145.0
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian		152.1 ±0.9
				Kimmeridgian		157.3 ±1.0
				Oxfordian		163.5 ±1.0
			Middle	Callovian		166.1 ±1.2
				Bathonian	✓	168.3 ±1.3
				Bajocian	✓	170.3 ±1.4
				Aalenian	✓	174.1 ±1.0
			Lower	Toarcian	✓	182.7 ±0.7
				Pliensbachian	✓	190.8 ±1.0
				Sinemurian	✓	199.3 ±0.3
				Hettangian	✓	201.3 ±0.2
		Triassic	Upper	Rhaetian		~ 208.5
				Norian		~ 227
				Carnian	✓	~ 237
			Middle	Ladinian	✓	~ 242
				Anisian		247.2
			Lower	Olenekian		251.2
				Induan	✓	252.17 ±0.06
	Paleozoic	Permian	Lopingian	Changhsingian	✓	254.14 ±0.07
				Wuchiapingian	✓	259.8 ±0.4
			Guadalupian	Capitanian	✓	265.1 ±0.4
				Wordian	✓	268.8 ±0.5
				Roadian	✓	272.3 ±0.5
			Cisuralian	Kungurian		283.5 ±0.6
				Artinskian		290.1 ±0.26
				Sakmarian		295.0 ±0.18
				Asselian	✓	298.9 ±0.15
		Carboniferous	Pennsylvanian	Upper	Gzhelian	303.7 ±0.1
					Kasimovian	307.0 ±0.1
				Middle	Moscovian	315.2 ±0.2
				Lower	Bashkirian	✓ 323.2 ±0.4
			Mississippian	Upper	Serpukhovian	330.9 ±0.2
				Middle	Visean	✓ 346.7 ±0.4
				Lower	Tournaisian	✓ 358.9 ±0.4

Eonothem / Eon	Erathem / Era	System / Period	Series / Epoch	Stage / Age	GSSP	numerical age (Ma)
						358.9 ± 0.4
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	✓	372.2 ±1.6
				Frasnian	✓	382.7 ±1.6
			Middle	Givetian	✓	387.7 ±0.8
				Eifelian	✓	393.3 ±1.2
			Lower	Emsian	✓	407.6 ±2.6
				Pragian	✓	410.8 ±2.8
				Lochkovian	✓	419.2 ±3.2
		Silurian	Pridoli		✓	423.0 ±2.3
			Ludlow	Ludfordian	✓	425.6 ±0.9
				Gorstian	✓	427.4 ±0.5
			Wenlock	Homerian	✓	430.5 ±0.7
				Sheinwoodian	✓	433.4 ±0.8
			Llandovery	Telychian	✓	438.5 ±1.1
				Aeronian	✓	440.8 ±1.2
				Rhuddanian	✓	443.8 ±1.5
		Ordovician	Upper	Hirnantian	✓	445.2 ±1.4
				Katian	✓	453.0 ±0.7
				Sandbian	✓	458.4 ±0.9
			Middle	Darriwilian	✓	467.3 ±1.1
				Dapingian	✓	470.0 ±1.4
			Lower	Floian	✓	477.7 ±1.4
				Tremadocian	✓	485.4 ±1.9
		Cambrian	Furongian	*Stage 10*		~ 489.5
				Jiangshanian	✓	~ 494
				Paibian	✓	~ 497
			Series 3	Guzhangian	✓	~ 500.5
				Drumian	✓	~ 504.5
				Stage 5		~ 509
			Series 2	*Stage 4*		~ 514
				Stage 3		~ 521
			Terreneuvian	*Stage 2*		~ 529
				Fortunian	✓	541.0 ±1.0

Eonothem / Eon	Erathem / Era	System / Period	GSSP GSSA	numerical age (Ma)
				541.0 ±1.0
Precambrian	Proterozoic	Neo-proterozoic	Ediacaran ✓	~ 635
			Cryogenian ✓	~ 720
			Tonian ✓	1000
		Meso-proterozoic	Stenian ✓	1200
			Ectasian ✓	1400
			Calymmian ✓	1600
		Paleo-proterozoic	Statherian ✓	1800
			Orosirian ✓	2050
			Rhyacian ✓	2300
			Siderian ✓	2500
	Archean	Neo-archean		2800
		Meso-archean		3200
		Paleo-archean		3600
		Eo-archean		4000
		Hadean		~ 4600

Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Charts and detailed information on ratified GSSPs are available at the website http://www.stratigraphy.org. The URL to this chart is found below.

Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.

Numerical ages for all systems except Lower Pleistocene, Permian, Triassic, Cretaceous and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012); those for the Lower Pleistocene, Permian, Triassic and Cretaceous were provided by the relevant ICS subcommissions.

Coloring follows the Commission for the Geological Map of the World (http://www.ccgm.org)

Chart drafted by K.M. Cohen, S.C. Finney, P.L. Gibba

To cite: Cohen, K.M., Finney, S.C., Gibbard, P.L. & Fa ed)
The ICS International Chronostratigraphic Chart. Epi

URL: http://www.stratigraphy.org/ICSchart/Chronostra

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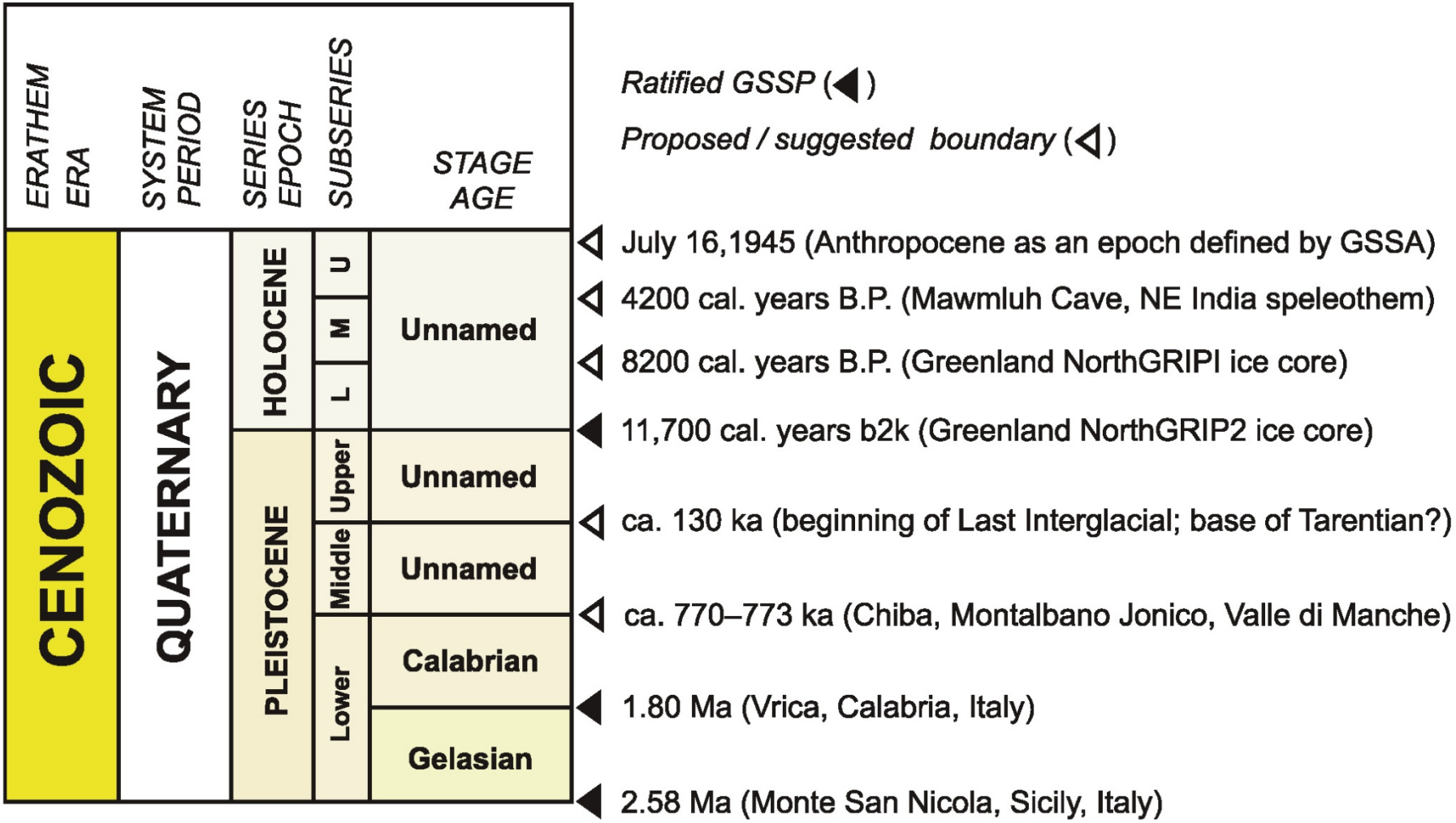

(Head, M.J. et al., 2015. Quaternary International, 383, 1-3)

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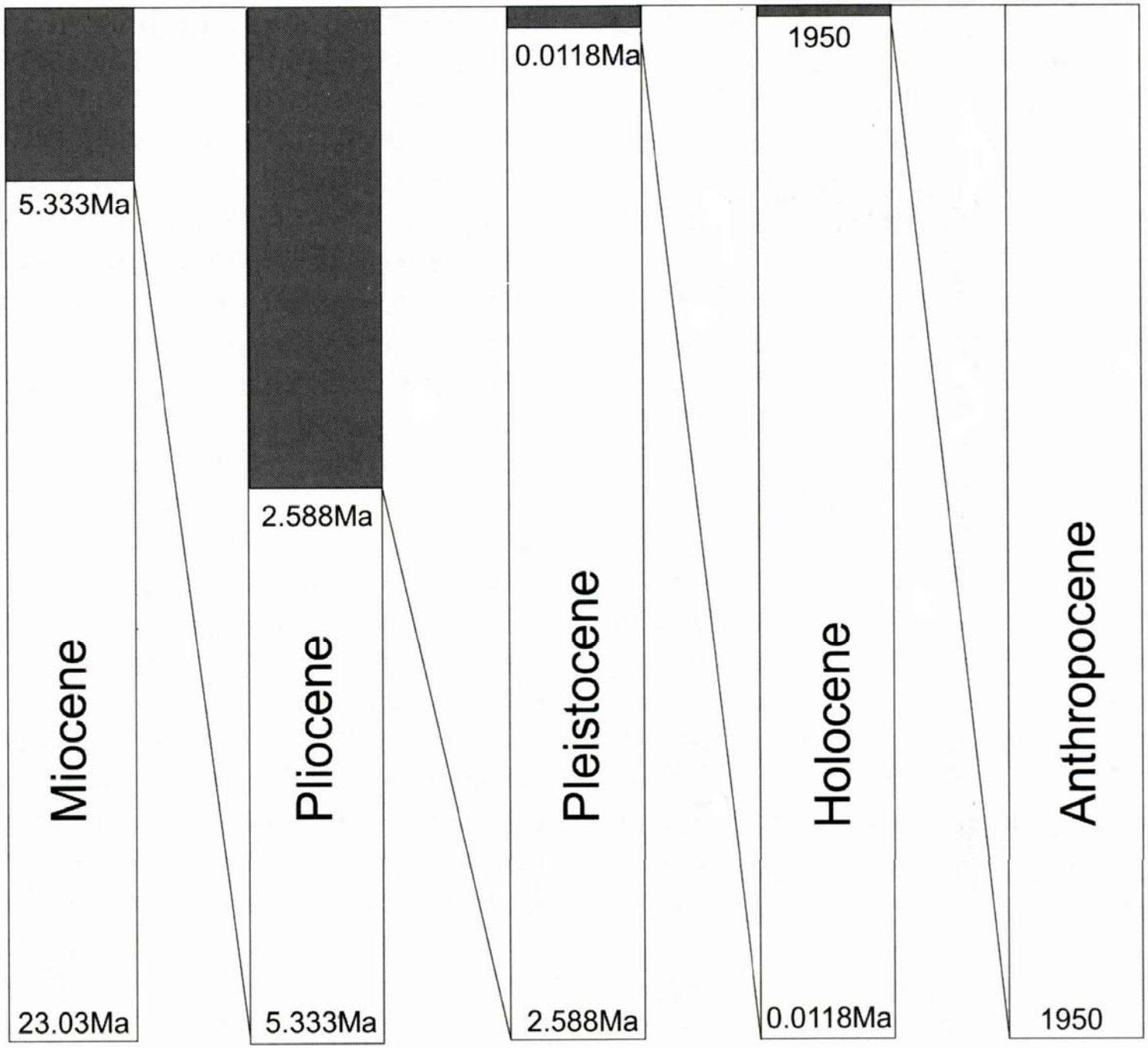

(Zalasiewicz, J. et al., 2014. Geological Society of London Special Publications, 395, 39-53)

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Mesolithic shell midden, El Mazo (Asturias)
8000-6700 yr BP
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ORIGEN DE LA AGRICULTURA EN EL PAÍS VASCO Y TRANSFORMACIONES EN EL PAISAJE: ANÁLISIS DE RESTOS VEGETALES ARQUEOLÓGICOS

2002 Lydia ZAPATA PEÑA

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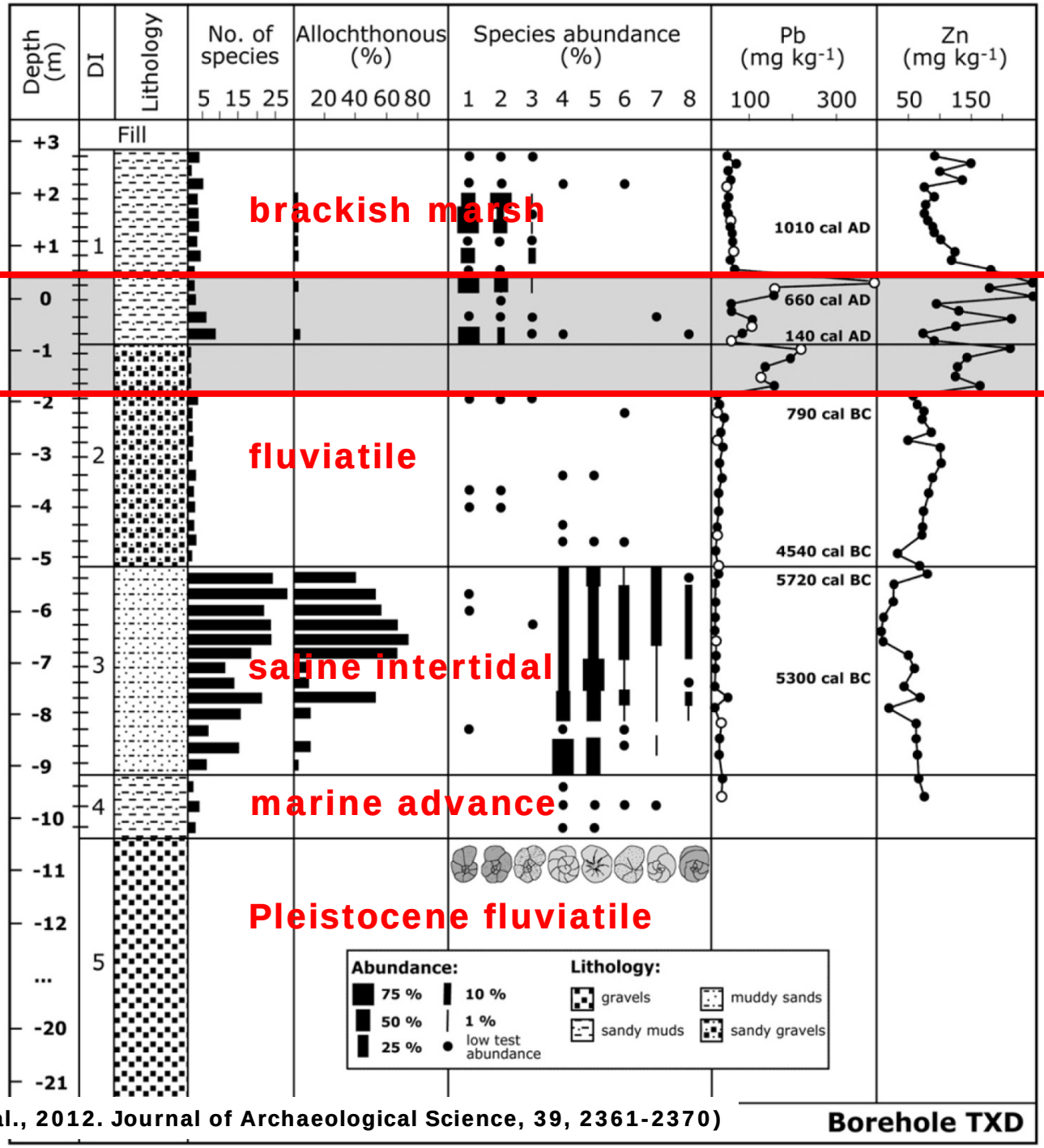
Roman harbour of Oiasso
UPV-EHU



(Irabien, M.J. et al., 2012. Journal of Archaeological Science, 39, 2361-2370)

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Bilbao estuary

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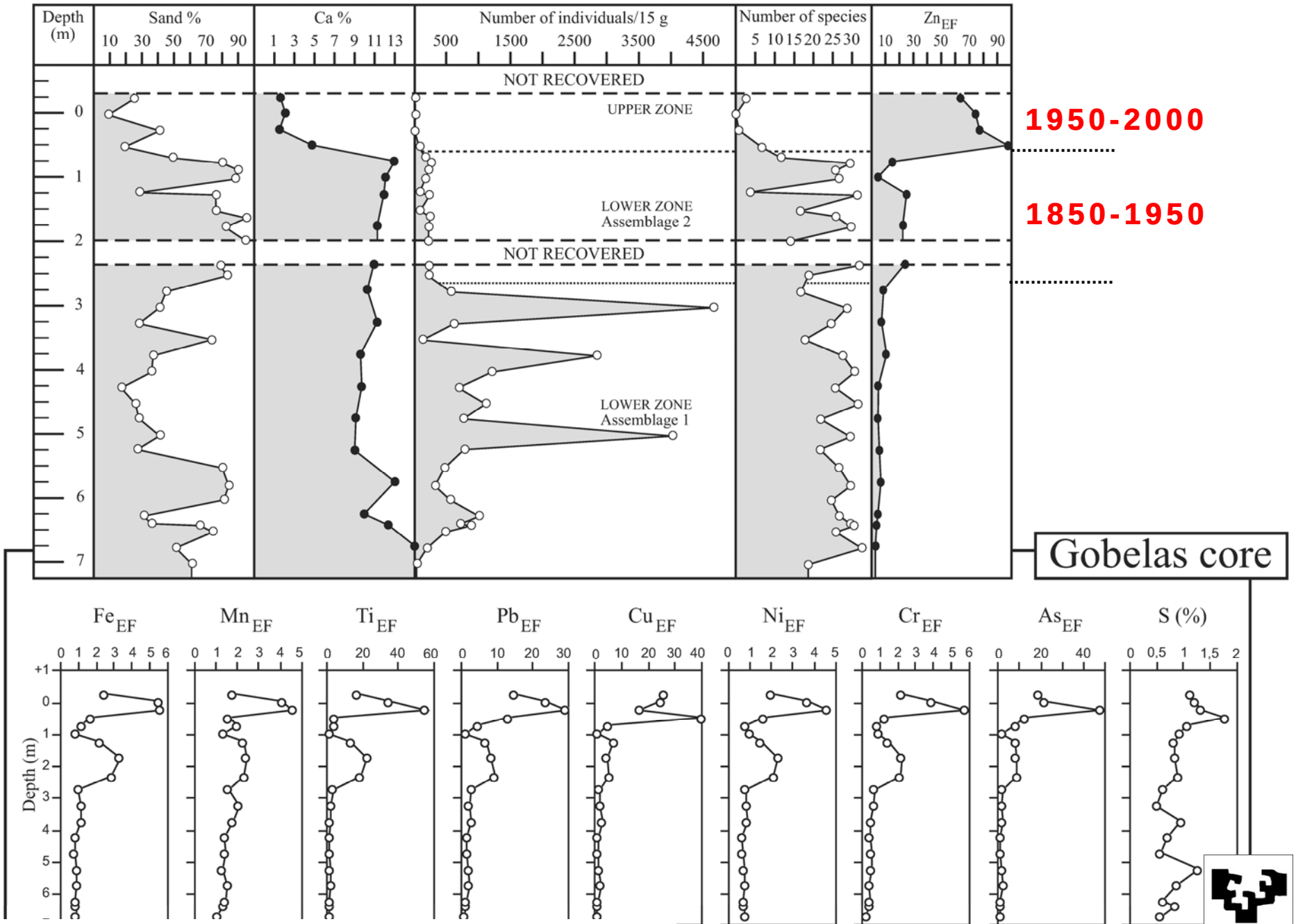

(Cearreta, A. et al., 2002. Marine Pollution Bulletin, 44, 487-503)

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Tunelboca beach
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(Irabien, M.J. et al., 2015. Quaternary International, 364, 196-205)

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(Astibia, H., 2012. Euskonews, 640, 1-11)

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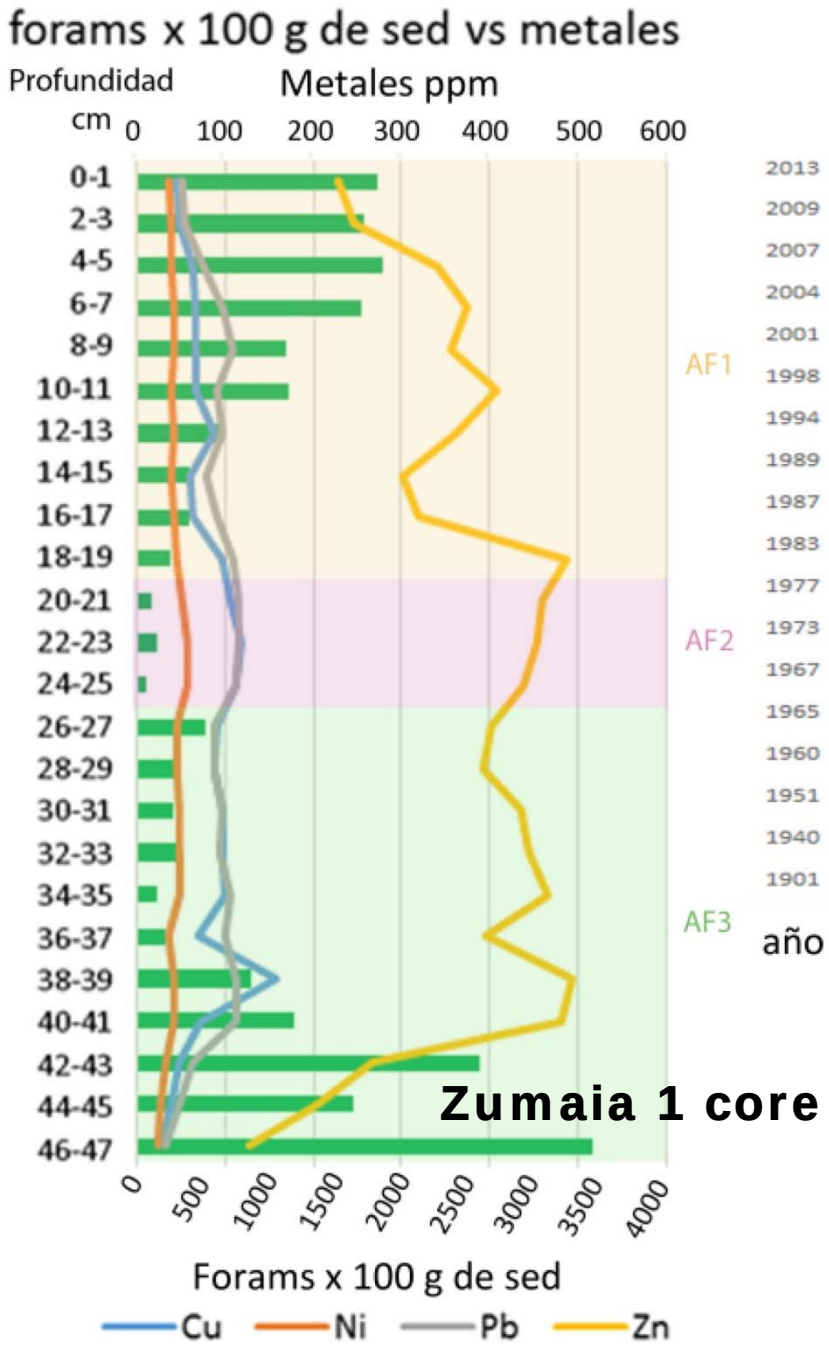

(Goffard, A., 2015. CKQ, 6, 43-60)

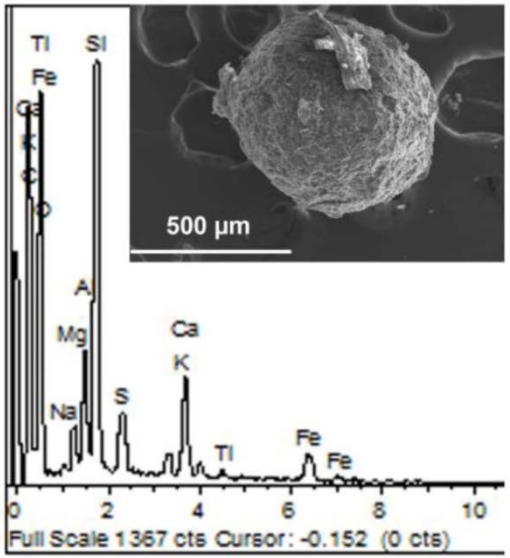

Figura 9: Esferoide carbonáceo

>1900 CE

since 1960s

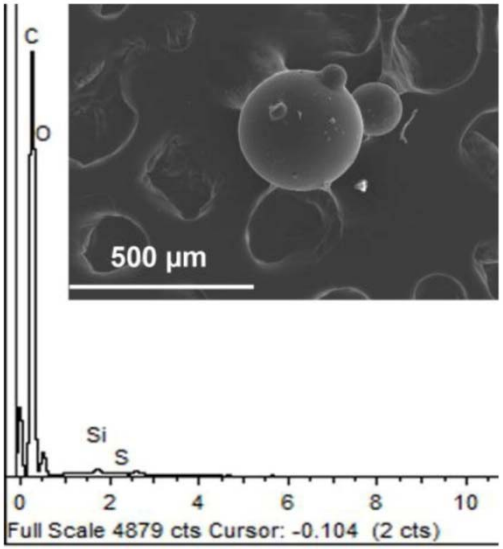

Figura 10: Esferoide polimérico

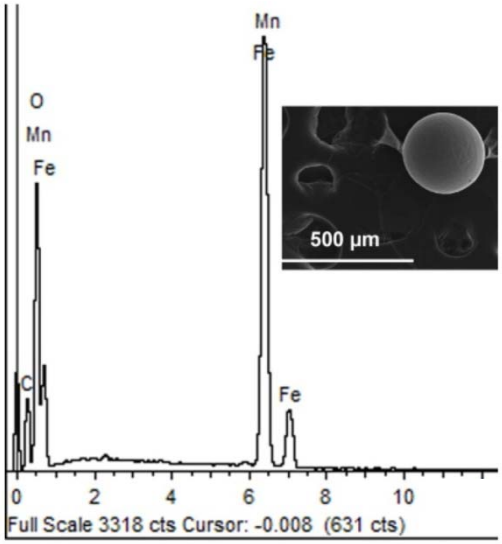

Figura 11: Esferoide metálico

since 1980s

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Urdaibai estuary

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1990
1957
(since beginning of 19th century)
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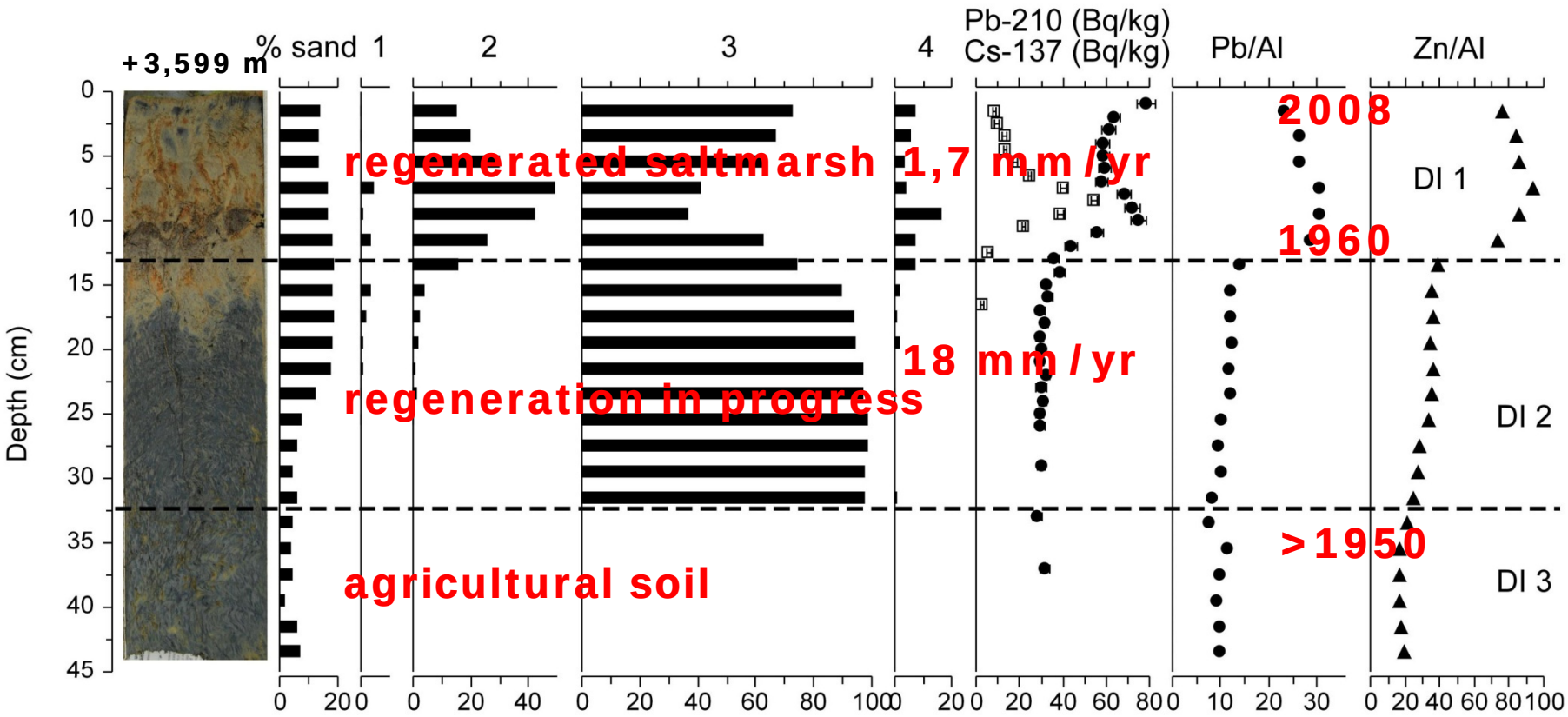

Isla core

(Cearreta, A. et al., 2013. Journal of Marine Systems, 109-110, 203-212)

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Thank you!

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