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From the Guajira Desert to the Apennines, and from Mediterranean Microplates to the Mexican Killer Asteroid

Edited by Christian Koeberl, Philippe Claeys, and Alessandro Montanari

From the Guajira Desert to the Apennines, and from Mediterranean Microplates to the Mexican Killer Asteroid: Honoring the Career of Walter Alvarez

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Cover image: Panoramic view of the lower part of the Furlo Upper Road section (see Alvarez, W., and Lowrie, W., 1984, Magnetic stratigraphy applied to synsedimentary slumps, turbidites, and basin analysis: The Scaglia Limestone at Furlo (Italy): GSA Bulletin, v. 95, p. 324–336, https://doi.org/10.1130/0016 -7606(1984)95<324:MSATSS>2.0.CO;2), exposing the contact between the Scaglia Bianca and the Scaglia Rossa formations marked by the Bonarelli Level (see Alvarez, W., and Sannipoli, E., 2016, Guido Bonarelli and the geological discovery of the Bottaccione Gorge at Gubbio. *in* Menichetti, M., Coccioni, R., and Montanari, A., eds., The Stratigraphic Record of Gubbio: Integrated Stratigraphy of the Late Cretaceous–Paleogene Umbria-Marche Pelagic Basin: Geological Society of America Special Paper 524, p. 1–11, https://doi.org/10.1130/2016.2524(01)), which is the expression of the OAE-2 in the Umbria-Marche basin. The top of the Bonarelli Level corresponds to the Cenomanian–Turonian boundary. Photo by Alessandro Montanari.

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Introduction

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This volume pays tribute to the great career and extensive and varied scientific accomplishments of Walter Alvarez (Fig. 1), who celebrated his 80th birthday in 2020, with a series of papers related to the many topics he worked on during the past 60 years: Tectonics of microplates, structural geology, paleomagnetics, Apennine sedimentary sequences, geoarchaeology and Roman



Figure 1. Walter Alvarez in 2010 in Coldigioco, Italy. The stone wall in the background fittingly is made up of Cretaceous Scaglia Rossa limestone. (Photo: Dona Jalufka.)

volcanics, Big History, and, most famously, the discovery of evidence for a large asteroidal impact event at the Cretaceous-Tertiary (now Cretaceous-Paleogene) boundary site in Gubbio, Italy, 40 years ago, which started a debate about the connection between meteorite impact and mass extinction. The manuscripts in this special volume were written by many of Walter's close collaborators and friends, who have worked with him over the years and participated in many projects he carried out. The papers highlight specific aspects of the research and/or provide a summary of the current advances in the field.

Walter Alvarez has been a professor at the University of California at Berkeley since 1977. He is a recipient of the Penrose Medal of the Geological Society of America and the Vetlesen Prize. He is also a member of the U.S. National Academy of Sciences. Moreover, Walter was made an honorary citizen of Piobbico and Gubbio in Italy and has received honorary doctorates from the University of Siena (also in Italy) and the University of Oviedo in the Principality of Asturias in Spain, where his family originates. A detailed story of Walter's research and life is given in "Life with a field geologist: Improbable adventures on five continents" written by Milly Alvarez in this volume.

Walter was born on 3 October 1940, and raised in Berkeley, California, the son of Luis Walter Alvarez, a Nobel prizewinner in physics (and later collaborator). For his education, he drastically changed scenery and attended Carleton College in Minnesota as an undergraduate in geology (B.A., 1962), followed by a Ph.D. in geology from Princeton University in 1967, just as plate tectonics was being discovered. His Ph.D. thesis research took him, with his wife Milly (they married in 1963),

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to a remote part of northern Colombia. He then joined the oil industry, working first in the Netherlands and then in Libya, and he was in Tripoli when Colonel Muammar Gaddafi took control of the country. After that experience, Walter and Milly returned to less tormented environments, first moving to Italy to work with archaeologists on how volcanism influenced the settling of Rome (Fig. 2). He then returned to plate tectonic-related research, more precisely to Lamont-Doherty Geological Observatory of Columbia University in the United States. While there, Walter returned again to Italy-something he would do many times in the years to come, but this time to the Apennines, to study changes in the magnetic field recorded in deep-sea limestones with paleomagnetist Bill Lowrie from ETH-Zurich (Switzerland). In 1977, Walter returned home to take a faculty position at UC Berkeley, in what was then called the Department of Geology and Geophysics. Still, working in the Gubbio area, he became intrigued by the mechanisms that led to the major extinction that occurred at the end of the Cretaceous. To solve this mystery, he teamed up with his father Luis Alvarez, who developed a keen affinity with geology, and colleagues Frank Asaro and Helen Michel and together published the seminal paper "Extraterrestrial cause for the Cretaceous-Tertiary extinction" in Science in 1980, which described the presence of highly elevated iridium concentrations within the thin clay layer at the boundary. This article first suggested that the mass extinction, and the demise of the dinosaurs, were due to the impact of a giant asteroid or comet on Earth (Alvarez et al., 1980). In 1990, the Chicxulub impact structure was discovered buried under the tip of the Yucatán Peninsula in Mexico. As it turned out, the age of this giant impact crater (180 km in diameter) was precisely the same as the age of the Cretaceous-Tertiary (K-T) boundary. For the next 20 years Walter worked on the K-T boundary (today called the K-Pg boundary), developing arguments to establish the hypothesis that indeed a 10- to 12-km-sized asteroid or comet wiped out the dinosaurs.

The next adventure, almost as perilous as Gaddafi's coup d'état in Tripoli, was to be the chair of the Department of Geology and Geophysics at UC Berkeley between 1994 and 1997. Walter survived and then published his first book T-Rex and the Crater of Doom (Alvarez, 1997), which quickly became a best-seller translated in many languages, and which describes so elegantly his K-T boundary adventures. Walter's next book The Mountains of Saint Francis followed (Alvarez, 2008), using Italy as a way to illustrate the geological events that shaped planet Earth. Walter then became interested in Big History, a new field that covers the history of the universe, starting at the Big Bang, coupled with the history of Earth, all the way to human history, advocating for more importance for geology. He was one of the first to teach that subject at the undergraduate level, at UC Berkeley, and is one of the founders of the International Big History Association, initiated in 2010 at Coldigioco in Italy. Also in 2010, Walter and a student from his Big History course, Roland Saekow, teamed up with Microsoft Research and Moscow State University to develop a zoomable timeline tool called ChronoZoom. The free tool enabled students, teachers, and researchers to browse the entire timescale of Big History on a linear scale from a single day to billions of years. Walter's vision of Big History led to another book, *A Most Improbable Journey: A Big History of Our Planet and Ourselves*, which was published in 2017 (Alvarez, 2017). It also needs to be mentioned that since the early 1990s, Walter was associated with the Osservatorio Geologico di Coldigioco in Central Italy (see Koeberl and Bice, 2019), where many memorable events occurred (often also featuring music, as Walter is a gifted violin [or "fiddle"] player), and where Walter and the three editors of this book spent many interesting days and evenings together, often surrounded by wine and pasta, all of which helped to establish the concept of this volume (Fig. 3).

Of the three editors of this volume, Alessandro Montanari, aka Sandro, is the one who has had the longest interaction with Walter. They first met in the summer of 1978 by total chance, in the field at Furlo while Walter was having a brown bag lunch under a pine tree together with structural geologist Peter Geiser (co-author of Chan et al., this volume). Sandro was hiking around the Furlo anticline doing a geological reconnaissance of the area for his Laurea thesis at the nearby University of Urbino, which focused on the basin analysis of the Scaglia Bianca and Scaglia Rossa formations. Walter was very interested in Sandro's research work and, next year, he invited him to join his Renaissance Geology Group at Berkeley to start a Ph.D. program under his supervision. Eventually, Sandro graduated in the spring of 1986 with a Ph.D. dissertation titled "Event Stratigraphy of Cretaceous and Tertiary Pelagic Limestones from the Northern Apennines, Italy." In those six years at Berkeley, Walter's interaction with Sandro wasn't just a simple mentor-student relationship. Besides being a wonderful teacher, Walter became Sandro's best friend, sharing many common loves, such as playing traditional American and Italian music (Sandro at the harmonica and guitar, Walter at the fiddle and piano), exploring Italian cuisine in Milly's kitchen, chatting about medieval and Renaissance history, and chasing the K-T and other boundaries around the world. As for the Renaissance Geology Group, Sandro found in it a friendly environment with its early members, such as graduate students Mark Rowan, Lung Chan, David Bice, Kevin Stewart, and Mark Anders, all contributors to this volume. Was Walter their father? No, he was more like their big brother.

After getting his Ph.D. in the spring of 1986, Sandro was reluctant to leave his Renaissance Geology family, looking for a job somewhere else in the United States as a faculty applicant, as most Ph.D. neo-laureates would do, nor think to go back to Italy aspiring for a job in the Italian university, which then, as it is now, has a deplorable "not-who-you-are-but-who-you-know" academic-promotion system. And so, with Walter's support, Sandro remained at Berkeley for another six years as postdoc, taking temporary positions such as lecturer, research assistant, and various other odd jobs more-or-less related to geology. But with the years passing, Sandro became overqualified for holding precarious positions at Berkeley, and so returning to Italy was the only viable chance to find an occupation of some sort. In the spring of 1992, Sandro, together with his wife Paula (see Bos and Metallo,



Figure 2. Walter and Milly Alvarez in Coldigioco, Italy, with the medieval tower of Isola in the background. (Photo: Dona Jalufka, 2010.)

this volume) and their daughter Fiorenza, flew back to Italy with a one-way ticket. It was then that Walter, Milly, Paula, and Sandro joined financial and manual forces to create, in the heart of the Umbria-Marche Apennines, an independent, self-financed research center, which they christened Osservatorio Geologico di Coldigioco (OGC) (Fig. 4). The whole story of OGC is recounted by Sandro in "The little big history of the Geological Observatory of Coldigioco" (Montanari, 2019). Since its foundation in 1992, Coldigioco has become Walter and Milly's second home, and for Sandro the chance, at least once a year in the right season, to keep playing music with Walter, experimenting with Italian cuisine in Milly's kitchen, and chasing the K-T and other boundaries around the Umbria-Marche Apennines (see, e.g., Montanari and Koeberl, 2000).

Another editor of this volume, Philippe Claeys, notes that working on the papers that make up this volume for Walter made him happy, excited to honor Walter, and at the same time a bit nostalgic. In the late 1980s, Philippe was a graduate student at the University of California at Davis working with Stan Margolis, when he first met Walter. Walter came to give a seminar, and with



Figure 3. Walter Alvarez (right) with the three editors of this volume (from left: Philippe Claeys, Christian Koeberl, and Alessandro Montanari) on the occasion of the 2010 Geological Society of America Annual Meeting in Denver. (Photo: Sandra Jalufka.)



Figure 4. Left to right: Paula Metallo, Milly and Walter Alvarez, and Alessandro Montanari checking out the K-T boundary at Gubbio in 2010. (Photo: D. Shimabukuro.)

him of course Philippe also met Sandro Montanari. Together, Walter and Stan started organizing the exciting, animated, and cheerful (informally named) "Highway 80" Friday seminars, one week in Davis, one week in Berkeley, to look at K-T boundary sediments and discuss the impact-extinction scenario. Philippe's responsibility was to pilot the UC Davis electron microscope and microprobe in search of new micrometer-sized clues. Not the most glamorous job, as it all occurred in a dark, windowless, little room only lit by the small 1990 green computer screens. Nevertheless, these where incredibly fun times, when amazing and dynamic science was combined with spirited discussions on multivarious topics, punctuated by an espresso, beer, or wine, and most commonly concluded by an excellent dinner. Curiously, this work led to several important papers on the K-T boundary impact glasses in Mexico, such as Smit et al. (1992) and Alvarez et al. (1992), both published in Geology, as well as the first dating of the Chicxulub crater reported in Swisher et al. (1992). When Stan Margolis passed away, much too soon in 1992, Walter adopted Philippe as his Ph.D. student. He guided the last steps of his dissertation, made sure the polish was impeccable and without apparent efforts, and by listening to and learning fervently from Walter, Philippe graduated. All celebrated the Ph.D. completion, with Milly at their home, dressed in Italian renaissance scholar clothing, cooking a dish of pasta and sausages but with a Corona

Figure 5. Italian Renaissance Ph.D. degree signature for Philippe Claeys by Walter Alvarez at his house, February 1993. (Photo: Milly Alvarez.)



in hand, in honor of the Mimbral K-T boundary site that taught us so much. Of course, Walter played some music that night, fiddle and piano combined (Fig. 5).

In early 1994, after a post-doctoral stay at the University of California at Los Angeles, Walter invited Philippe back to Berkeley to join the Renaissance Geology Group to continue working on Chicxulub and the K-T boundary. A lot more was done...and complicity and connivance grew even further, around espressos, Mexican or Chinese dinners, evenings at home with Milly and lots of friends, visitors, or even students, as a Berkeley undergraduate seminar was held in the evening in Walter's house, together with dinner. This friendship and collaboration continued after Philippe returned to Europe (Berlin and Brussels), with frequent summer visits in Berkeley. Walter is an erudite science sherpa, incredibly positive and hard working, full of imagination, unaware of borders or limits, open to all kind of ideas, and always willing to give credit and test even the most impossible hypothesis-until he meticulously and irremediably proves them wrong or even sometimes right. Many years later, the pinnacle of Philippe's renaissance-scientist career was Walter and Milly's visit to Brussels on one of their European train peregrinations to Italy. This was a unique chance for his Brussels Ph.D. students to meet a real gentleman of science. Philippe admits that he saw himself as a sixteenth or seventeenth century "Fiammingo" painter having an Italian master visit his atelier in the Low Country...but this one came from Berkeley and not Florence or Rome.

The third editor of this book, Christian Koeberl, remembers Walter Alvarez from several conferences related to impacts and mass extinctions in the 1980s, and was impressed by his quiet and unexcited way to deal with the often very heated debates that were rather common during these conferences. For a young impact researcher, who had obtained his Ph.D. in Austria in 1983, and then was lucky enough to have a few guest appointments in the United States (Lunar and Planetary Institute/NASA in Houston, Texas, Dartmouth College in New Hampshire, and Carnegie Institution in Washington, D.C.), the resistance that the K-T boundary impact hypothesis met was quite surprising, as the data were rather clear. But of course, as one learns later, not only the lack of knowledge of planetary processes but also personal positions and academic standing were often more important than just looking at the data. Thus, it was a somewhat unexpected development that in the mid-1990s, after meeting Sandro Montanari within the framework of a European Science Foundation Network on impact research, Christian and his wife Dona were convinced by Sandro to buy a-at that time-somewhat dilapidated old Italian country house on the Coldigioco hill, and this made them first neighbors, and soon friends, of Walter and Milly Alvarez, who also have a second home at this place. Over the decades, many interactions with Walter happened, both scientifically and socially. It should be noted that several other authors of papers in this volume, such as Jan Smit (and his wife Jesse Bos) and David Bice, also have second homes in Coldigioco and various connections with Walter Alvarez.

After these more-personal words, it is time to introduce this volume, which contains 28 original papers that are organized into

five parts: (1) The Big (History) Picture; (2) Tectonics and Structural Geology; (3) Stratigraphy; (4) K/Pg Boundary and Impacts; and (5) Geology versus Prehistory and Protohistory.

In Part 1, Milly Alvarez gives her account of Walter's 60 years of field work on five continents as a direct testimony of a constant, omnipresent eye witness. Similarly, Albert Ammerman, in his paper titled "The contribution of Walter Alvarez to the investigation of the Capitoline Hill in Rome," narrates Walter's introduction to Italian geology, archaeology, and culture starting in 1969, when he first came to Italy as a refugee from Gaddafi's coup in Libya. This is followed by the paper by Olga García-Moreno and Maarten Oranje, which is a review of the Big History perspective of the dramatic extinction of the dinosaurs. Finally, Jesse Bos (historian) and Paula Metallo (artist) illustrate the Big History perspective of human exploitation of the Earth's geological resources.

Part 2 counts 10 papers about tectonics and structural geology, which represent Walter's background as an Earth scientist. The first six of these original papers are about various aspects of the Jurassic-to-Quaternary tectonic and structural history of the Italian peninsula, while the remaining four papers are about other extra-Tethyan tectonic domains, including the Gulf of Mexico, the Devonian Hornelen basin of western Norway, and the Appalachian Plateau. The chapter by Massimiliano Barchi and Enrico Tavarnelli discusses the structural style at depth of the Umbria-Marche fold-and-thrust belt in terms of thin-skinned or thick-skinned deformation models. In the next paper, Kevin Stewart and Rachel Boulter present their ground survey and study of the area in the Umbria-Marche Sibillini Mountains, which was struck by devastating earthquakes in the summer and fall of 2016, showing that many of the surface ruptures corresponded to previously mapped normal faults. This is followed by a chapter by Lung Sang Chan et al. on the formation of the "isotropic expansion breccia" in the Lower Cretaceous Maiolica limestone of the Umbria-Marches region of Italy as a result of fluid-assisted brecciation. The paper by David Bice and Enrico Tavarnelli reviews the influence of the Messinian Salinity Crisis on the tectonic evolution of the Northern Apennines. Next, Frank Pazzaglia and James Fisher discuss the uplift history of the Apennine mountain range in Italy. Then, David Shimabukuro and Claire Battistella investigate evidence for a continental margin preserved in an ophiolitic block in Calabria, southern Italy. John Wakabayashi and David Shimabukuro contrast different tectonic settings of subduction initiation preserved in orogenic belts, namely "hot" intraoceanic and "cold" continental margin subduction, and give examples at the Apennine subduction zone and the Alpine orogenic belt. Mark Rowan uses seismic data to analyze and interpret extension and evaporite salt deposition in the ocean-continent transition in the southern Gulf of Mexico rifted margin. Mark Anders and colleagues study the tectonic evolution of the Devonian Hornelen basin of western Norway. Terry Engelder and colleagues use seismic emissions to investigate the mechanical stratigraphy of the middle Paleozoic section under the Appalachian Plateau in Pennsylvania.

Part 3 contains two papers about the integrated stratigraphy of the Umbria-Marche Succession. Angela Baldanza et al.'s paper is a thorough review of the stratigraphy, paleontology, sedimentology, and structural setting of the Umbria-Marche Jurassic succession, corroborated by new data from the type sections of Monte Sasso di Pale, in Umbria. This paper is somewhat supplementary to Walter Alvarez's paper titled "A review of the Earth history record in the Cretaceous, Paleogene, and Neogene pelagic carbonates of the Umbria-Marche Apennines (Italy)," which was published in the Coldigioco volume (Alvarez, 2019). On the other hand, the paper by Rodolfo Coccioni et al. is an original interdisciplinary analysis, including the litho-bio-magneto and chemostratigraphy, and cyclostratigraphic analysis, of the Upper Eocene succession of the classic Bottaccione Gorge section at Gubbio, which leads to the proposal of it as the Global Stratotype Section and Point (GSSP) for the Lutetian-Bartonian boundary.

Part 4 is dedicated to the subject of the K-Pg boundary and impacts, which today represents Walter's most famous legacy. Michael Rampino's review paper examines the evidence related to an underlying ~30-million-year cycle in coordinated geologic, biologic, and astrophysical events, which punctuated the history of the Earth. Birger Schmitz and colleagues outline the importance of ordinary chondrites in the flux of meteorites and asteroids, as is made evident in the stratigraphic record, with particular attention to micrometeorite paleofluxes. Jan Smit reviews the Alvarez K-Pg boundary impact-extinction hypothesis, which, some 42 years ago, had such a paradigmatic impact on the world's natural-science community. Then follow five original papers dealing with various specific subjects about the role that extraterrestrial events had in the evolution of the Earth's ecosystems. José Arz and colleagues find, based on planktic foraminiferal biochronology, no evidence for a multiple impact scenario across the K-Pg boundary. Laia Alegret et al. investigate the oceanic productivity after the Cretaceous/Paleogene impact event. Tushar Mittal and colleagues discuss evidence regarding Deccan volcanism and its relation to the K-Pg boundary. Ellinor Martin and colleagues use chrome spinels derived from micrometeorites in Aptian/Albian age rocks to search for possible ejecta of the (lunar) Tycho impact event on Earth. Lastly, Lea Nagel et al. discuss lessons learned from the current coronavirus pandemic for how to communicate a possible future impact threat and its influence on planetary defense.

Finally, Part 5 presents four original papers that examine cases in which the geology of specific areas has affected the development of human communities in prehistory and protohistory times. Historian Ettore Sannipoli and geologist Corrado Cencetti illustrate how the non-casual locale for the foundation of the city of Gubbio in the Late Bronze Age (second millennium BCE) was chosen to be at the mouth of the Bottaccione Gorge, between the steep southern slope of Monte Ingino and the fertile Gubbio alluvial plain. Mayandi Sivaguru et al. illustrate the depositional and diagenetic history of travertine, which formed within the first century CE *Anio Novus* aqueduct in ancient Rome. Alessandro Montanari et al. document, after their geomorphological, sedimentological, and archaeological study of a large landslide and a fluvial terrace near the lost Roman city of *Tuficum*, in the Marche Apennines, the evidence of the Late Antique Little Ice Age climate event (536–660 CE). Last but not least is the paper by Montanari et al. that illustrates and documents a stratigraphic section of sediments in the Grotta dei Baffoni Cave, in the famous Frasassi Gorge, which records, with remarkable continuity and completeness, the geologic, environmental, and human history of this area from the Middle Pleistocene to Modern times. This paper, in the context of the geological history of the Northeastern Apennines, without saying it explicitly, compares Gubbio, with its Cretaceous-to-Neogene stratigraphic record of the Bottaccione Gorge, to Frasassi with its Pleistocene-to-Holocene stratigraphic record preserved in its caves.

This volume documents not only the variety of research topics that were influenced by the work of Walter Alvarez, but also the influence he had on several generations of scientists. It is difficult to wish for more. With this we want to thank Walter for decades of mentorship and friendship and wish him many more happy and successful years.

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