Earth's Early Atmosphere and Surface Environment

edited by

George H. Shaw
Geology Department
Union College
Schenectady, New York 12308, USA

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Cover: (Front) The first unequivocal evidence of life on Earth, a 3.5 Ga stromatolite, lies nestled in a remote hillside in the Australian Pilbara's North Pole Dome. Photo by Lev Horodyskyj. (Back) Ferruginous stromatolites from the Biwabik Iron Formation, Minnesota (ca. 1.8 Ga). The stromatolite columns are approximately 1 cm across. Photo by E. Calvin Alexander Jr. of a sample from the collections in the Earth Sciences Department, University of Minnesota.

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OHMOTO et al.

REVIEW AND CONCLUSIONS

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Introduction: Earth's early atmosphere and surface environment

Investigations of the chemical state of Earth's early surface and atmosphere have been guided by geological evidence, cosmochemical analysis, and comparisons to other terrestrial bodies. A Pardee Symposium was held at the Geological Society of America Annual Meeting in Minneapolis, Minnesota, on 12 October 2011 with the goal of covering the broadest possible range of ideas that had then been developed addressing this important, if obscure, period in Earth's history.

The symposium provided for the presentation and discussion of several, often contradictory, models for the early Earth. The emphasis was on the later Hadean (post–moon-forming impact) to the late Archean (Great Oxidation Event), that is, from about 4.3 Ga to 2.1 Ga. The symposium used an unusual format with the intention of stimulating the maximum amount of discussion of the various views of the nature of Earth's early environment. There were four invited papers, with one hour devoted to each topic. The presenters were asked to submit in advance a written paper of about 3000 words. Each paper was then sent to a "commentator" who prepared a statement of about 1000–1500 words, which was sent back to the presenter.[1] The commentary was not intended or expected to be (solely) a critique of the original paper, but rather to include additional thoughts based on the content of the paper, in order to further stimulate discussion. At the meeting, each presenter delivered the paper as originally conceived, not in response to the commentary, in about 25 minutes. The commentator then delivered the commentary in about 10 minutes, followed by a brief response from the presenter if desired. The remainder of the time was available for discussion. A recording was made of the entire session in order to prepare a transcript of the discussion. In most cases it was possible to identify those who made comments or asked questions at the meeting, and they are so indicated in the discussion sections. Very minor edits and changes for clarity have been made to the discussion segments.

This volume is the tangible result of the symposium. It incorporates the presentations, commentaries, and discussions in the order presented at the meeting. The review process for the presentations resulted in some modifications to the various texts, but the goal was to preserve, as much as possible, the flavor of the symposium. In addition, the inevitable passage of time for preparation of the volume led to some additional text and references from the past couple years. I believe I have been reasonably true to the essence of the symposium even with these modifications, and they have undoubtedly resulted in improvements to the various texts.

With the hope of further increasing the value of this volume, I also commissioned an audience participant to prepare a paper covering the symposium topic as a whole and summarizing, to the extent possible, the current state of the field (at least from his viewpoint). One of the goals was to demonstrate a somewhat novel session format that might be used in the future, and this volume provides a record that might be useful for someone contemplating this. The success of this effort can perhaps best be suggested by the comment of one audience participant. After the session, he described his skepticism upon being informed at the beginning, of the format to be used. He then stated that he felt it was one of the best sessions at the meeting. It should be clear that this format is probably not amenable to all topics, and may be best suited for those where there is a

[1]Although the paper by K. Zahnle and D. Catling (Chapter 7) was sent to a commentator, the commentator withdrew at a point in time too late to obtain a replacement.

Shaw, G.H., 2014, Introduction: Earth's early atmosphere and surface environment, *in* Shaw, G.H., ed., Earth's Early Atmosphere and Surface Environment: Geological Society of America Special Paper 504, p. v–vi, doi:10.1130/2014.2504(00).

broad range of views in a focused area, with some degree of controversy implicit in the range. It is our hope that this effort could be the stimulus for someone to try this again at a future GSA meeting.

As for the substance of the topic discussed, it is clear that an extremely broad range of viewpoints is held by geologists, geochemists, atmospheric chemists, climate scientists, and various others, as informed by their own perspectives and the data they feel are most critical to discussion. In some cases, there are disparate inferences and conclusions drawn from more or less the same basic data. While this may seem surprising, it is, perhaps, a consequence of the nature of such an ancient and often skimpy geologic record. Although it is unlikely that all (if any) of the views presented can be correct, there appears at least some possibility that some (variable) fraction of each may have some validity in forming a picture of an important period of Earth's history, one in which it is highly probable that life began its long journey. It is our hope that the discussions presented herein will help in the development of a self-consistent model of the early Earth.

The underlying theme of the symposium centers on the question of the oxidation state of the atmosphere, and by extension, the general surface environment. The sequence of presentations was chosen to proceed from consideration of a highly reduced initial surface (G.H. Shaw, Chapter 1), through what is seemingly the generally accepted view of a more or less neutral (in the sense of oxidation state) N_2-CO_2 (w/CO?) atmosphere (J.F. Kasting, Chapter 4), and the processes by which it ultimately became strongly oxidizing and with free O_2 (K. Zahnle and D. Catling, Chapter 7), to the rather controversial view that free oxygen has been present from very early (perhaps since 3.5 Ga) in Earth's history (H. Ohmoto et al., Chapter 9). This scheme to some extent follows the historical development of ideas concerning the atmosphere, but also "bookends" the more conventional view that N_2-CO_2 "defines" the chemical state of the atmosphere and surface, with more radical views on both the more reducing and oxidizing ends of the spectrum. The student of Earth's early atmosphere and/or surface will find here the widest range of thought available on this aspect of a critical and extensive part of Earth's history

I would like to thank GSA and the Pardee Symposia organizers for sponsoring this symposium, allowing us to test a novel (for us) format. I would also like to thank all of the participants for their thoughtful contributions, and the symposium attendees for their energetic discussions. Robert Pepin was gracious enough to be a co-convener and his participation before, during, and after the symposium is much appreciated.

George H. Shaw
Geology Department, Union College, Schenectady, New York 12308, USA
shawg@union.edu