Iain Gilmour  Christian Koeberl

Impacts
and the Early Earth

With 164 Figures and 28 Tables

IMPACT

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Editors:
Dr. Iain Gilmour
Planetary Sciences Institute
The Open University
MK7 6AA Milton Keynes
United Kingdom
E-mail: igilmour@open.ac.uk

Dr. Christian Koeberl
University of Vienna
Institute of Geochemistry
Althansstrasse 14
1090 Vienna
Austria
E-mail: christian.koeberl@univie.ac.at

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Preface

This volume is the first one to result from the activities of the new scientific program on “The Response of the Earth System to Impact Processes” (IMPACT) of the European Science Foundation (ESF). The ESF is the European association of national funding organizations of fundamental research, with more than 60 member organizations from more than 20 countries. One of the main goals of the ESF is to bring European scientists together to work on topics of common concern. The ESF IMPACT program deals with all aspects of impact research, mainly through the organization of workshops, exchange programs, short courses, and related activities. An important aspect of the program is to bring people together to help stimulate interdisciplinary and international research.

Impacts of asteroids or comets on the Earth surface have played an important role in the evolution of the planet. The ESF IMPACT program is an interdisciplinary program aimed at understanding impact processes and their effects on the Earth System, including environmental, biological, and geological changes, and consequences for the biodiversity of ecosystems. The program is geared towards understanding of the linkage between impact processes and the Earth System, i.e., defining and studying the effects of impact events on the environment, including atmospheric, climatic, biologic, and geologic effects and interactions between these subsystems. Important aspects of future research regard also the consequences of the high-energy impact events for the biodiversity of ecosystems. Comprehending the processes that are responsible for these interactions is the key goal of the program. Currently 12 countries sponsor the program, which was launched in 1998, but an expansion to 14 countries is anticipated.

The first workshop to be organized as part of the ESF-IMPACT program was held at Robinson College, Cambridge, United Kingdom, from December 13th to 15th, 1998, in. A total of 56 scientists from 10 European countries, the United States, Russia and South Africa attended.

Contributions at the meeting covered the following themes:

- Impacts and the Origin of Life on Earth and Mars
- Late heavy bombardment and impact processing of the Earth
- The Earth's Early Cratering Record
- Micrometeorites and Spherule layers
- Impacts through geological time
A selection of 17 papers resulting from this meeting is included in the present volume. Manuscripts were reviewed by two referees and were considered for publication on the basis of originality and the themes discussed at the workshop.

There is currently some discussion on the present state of scientific understanding of the role impacts may have played in the biological and geological evolution of the Early Earth. There is good evidence that simple single celled life forms were already present at the start of the Archean, which means that chemical evolution must have occurred during the Hadean and life had probably originated at around 4 Ga. Since there are no Hadean rocks, our knowledge of the Earth's history during this period is necessarily based on indirect evidence. The Earth acquired an oceanic-type crust formed shortly after the process of core-mantle separation occurred some 4.5 Ga, although we have no record of it in the rocks. By 3.8 Ga light granitic continental crust had formed from the mantle. Proof of this comes from the 3.8 Ga granites and associated metamorphosed volcanic and sedimentary rocks at Isua in western Greenland, which represent the oldest piece of primitive crust known to geologists. Conditions at the Earth's surface and in the atmosphere during the Hadean must have had a powerful influence on chemical evolution. Estimates for the growth of continents on the early Earth cover a wide range of parameters save that there were no continents at the beginning. This results in most scientists assuming that a global ocean existed in which the pre-biotic chemistry that led to the origin of life to place.

The possibility of continued intense bombardment by meteorites long after the Earth had formed has led some scientists to conclude that the emergence of life could have been deterred for hundreds of millions of years. Many of the projectiles would have been much large enough that they would have generated enough heat to boil the surface of the oceans as well as throwing large clouds of dust and molten rock into the atmosphere. The implication of this hypothesis is that the impacts would have deterred the emergence of life anywhere near the surface of the oceans until perhaps as late as 3.8 billion years ago. On the other hand, comets and meteorites may have delivered important organic molecules to the Earth. The question of how this delivery could have influenced the development of life on the early Earth, and if bacterial life forms could survive the forces of an impact, are discussed in the paper by Burchell et al. The macromolecular organic materials present in meteorites and their role in the origin of life on Earth are subsequently discussed by Sephton and Gilmour, and in a related paper, Wright et al. discuss the effects of atmospheric heating on carbon compounds in meteorites and micrometeorites.

Only 10% of the 150 or so known impact craters on Earth date from the Precambrian, an Era spanning some 88% of the Earth's history. The Precambrian
encompasses fundamental events in the origin and evolution of our planet from the origin of life itself, the development of continents, to the development of eukaryotic organisms and the vast diversification of life that occurred at the end of this Era. We know from the lunar cratering record that the Earth was subject to intense bombardment by asteroids and comets early in its history on a scale far greater than anything it has experienced since. Koeberl et al. discuss their search for evidence of such a heavy bombardment on Earth in about 3.8 to 3.9 million-year-old rocks from Greenland.

Another hot topic is the geological evidence for Early Archean impact events, in particular the occurrence of spherule layers in the Precambrian Barberton formation (South Africa), which may represent the remnants of large-scale impact events. This is a controversial area, because many of the normally accepted criteria for the identification of impact structures, such as shock metamorphism in rock-forming minerals, are not preserved. Shukolyukov et al. present new data based on chromium isotopic ratios that they argue proves that the large platinum group element enrichments associated with these spherule layers are extraterrestrial in origin. In contrast, Reimold et al. argue that the enrichments are too great to be of primary origin and suggest that the mineralogical and geochemical features of the spherule layers are the result of (secondary) mineralization.

The importance of the recognition of an impact record in the Precambrian sedimentary succession is also emphasized by Simonson et al. Impact structures per se, as well as their proximal ejecta blankets, are limited to areas on the order of a few hundred kilometers in diameter, whereas distal ejecta from the largest impacts can be distributed globally. These authors examined various late Archean to Paleoproterozoic formations from Australia and South Africa that contain preserved spherule layers. They interpreted these layers as altered microtektites and microkrystites and therefore inferred that they have an impact origin.

A different type of extraterrestrial deposit is described by Kettrup et al., who discuss occurrences of fossil micrometeorites from about 18 to 1.9 billion year old sediments in Finland. It is astonishing that these materials have survived with only little alteration.

A major theme of the workshop was the need for the better recognition of ancient impact events in the geological record. Vishnevsky and Raitala describe the use of impact-produced diamonds as indicators of shock metamorphism in Precambrian rocks. Gibson and Reimold provide a useful review of the Vredefort impact structures in South Africa (with an age of 2.02 billion years the oldest, and by chance also the largest known, impact structure on Earth) as a case study for old, deeply eroded impact structures. Kenkman and co-workers cover techniques of structural geology in their contribution that might be applied in future from a
better understanding of the geology of large ancient impact structures. In a related paper, Abels et al. describe the use of remote sensing techniques in the study of old and deeply eroded impact structures.

More general topics follow. Hughes provides a review of cratering rate investigations, and Jones et al. discuss rarely studied features of carbonate rocks that result of from impact-induced melting processes. At the end is a trio of papers by Lilljequist, Suuroja and Suuroja, and Puura et al., describing various Scandinavian structures as case studies of more recent impact events.

From these contributions, and from the discussions at the workshop, it is clear that impact cratering events have played a major role in the very early history of our planet. We are only beginning to try and decipher the evidence of such early events, as we currently do not even have good criteria for the recognition of Early Archean impact events, and a lot remains to be done. We hope that the current volume is a first step in the right direction.

Iain Gilmour
Open University
Milton Keynes, UK

Christian Koeberl
University of Vienna
Vienna, Austria

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List of Contributors

A. Abels
Institute for Planetologie
D-48149 Münster
Germany

L. Bischoff
Institute for Planetologie
D-48149 Münster
Germany

A. Bunch
BioSciences Laboratory
University of Kent
Canterbury
Kent CT2 7NR
United Kingdom

M.J. Burchell
Unit for Space Sciences and Astrophysics
Physics Laboratory
University of Kent
Canterbury, Kent CT2 7NR
United Kingdom

G.R. Byerly
Department of Geology and Geophysics
Louisiana State University
Baton Rouge, LA 70803
USA

P. Claeyss
Museum für Naturkunde
Institut für Mineralogie
Humboldt-Universität Berlin
Invalidenstraße 43
D-10115 Berlin
Germany
A. Deutsch  
Institute for Planetologie  
D-48149 Münster  
Germany  

R.L. Gibson  
Department of Geology  
University of the Witwatersrand  
Johannesburg 2050  
South Africa  

I. Gilmour  
Planetary Sciences Research Institute  
The Open University  
Milton Keynes, MK7 6AA  
United Kingdom  

S. Hassler  
Department of Geological Sciences  
California State University  
Hayward, CA 94542  
U.S.A  

S. Heuschkel  
Museum für Naturkunde  
Institut für Mineralogie  
Humboldt-Universität Berlin  
Invalidenstraße 43  
D-10115 Berlin  
Germany  

M. Hornstein  
Department of Geology  
Oberlin College  
Oberlin, OH 44074-1044  
U.S.A  

D. Hughes  
Department of Physics and Astronomy  
The University  
Sheffield S3 7RH  
United Kingdom
B.A. Ivanov
Institute for Dynamics of Geospheres
Russian Academy of Science
Moscow 117939
Russia

S. Johnson
Impact Cratering Research Group
Department of Geology
University of the Witwatersrand
Johannesburg 2050
South Africa

A.P. Jones
Department of Geological Sciences
University College London
Gower Street
London, WC1E 6BT
United Kingdom

A. Kärki
Department of Geosciences
University of Oulu
P.O. Box 333
FIN-90571 Oulu,
Finland

T. Kenkmann
Museum für Naturkunde
Institut für Mineralogie
Humboldt-Universität Berlin
Invalidenstraße 43
D-10115 Berlin
Germany

D. Kettrup
Institute for Planetologie
D-48149 Münster
Germany
K. Kirsimäa
Institute of Geology
University of Tartu
Vanemuise 46, 51014
Tartu
Estonia

J. Kirs
Institute of Geology
University of Tartu
Vanemuise 46, 51014
Tartu
Estonia

C. Koeberl
Institute of Geochemistry
University of Vienna
Althanstrasse 14
A-1090 Vienna
Austria

M. Konsa
Institute of Geology
Tallinn Technical University
Estonia Ave 7
10143 Tallinn
Estonia

F.T. Kyte
Center for Astrobiology
Institute of Geophysics and Planetary Physics
University of California
Los Angeles, CA 90095-1567
USA

R. Lilljequist
North Atlantic Natural Resources
Kungsgatan 62, S-752 18
Uppsala
Sweden
D.R. Lowe
Department of Geological and Environmental Sciences
Stanford University
Stanford, CA 94305
USA

G.W. Lugmair
Max-Planck- Institute for Chemistry, Cosmochemistry
PO 3060
55020 Mainz
Germany

I. McDonald
School of Earth & Environmental Sciences
University of Greenwich
Chatham Maritime
Kent, ME4 4AW
United Kingdom

M. Niin
Geological Survey of Estonia
Kadaka tee 80/82
12618 Tallinn
Estonia

L.J. Pesonen
Geological Survey of Finland
FIN-02150 Espoo
Finland

P. Pihlaja
Geological Survey of Finland
FIN-02150 Espoo
Finland

C.T. Pilinger
Planetary Sciences Research Institute
The Open University
Milton Keynes, MK7 6AA
United Kingdom
Contributors

J. Plado  
Institute of Geology  
University of Tartu  
Vanemuise 46, 51014  
Tartu  
Estonia

V. Puura  
Institute of Geology  
University of Tartu  
Vanemuise 46, 51014  
Tartu  
Estonia

J. Raitala  
University of Oulu  
P.O Box 3000 Fin-90401  
Oulu  
Finland

W.U. Reimold  
Impact Cratering Research Group  
Department of Geology  
University of the Witwatersrand  
Johannesburg 2050  
South Africa

M. Rosing  
Geologisk Museum  
Oster Voldgade 5-7  
DK-1350 Copenhagen K  
Denmark

M.A. Sephton  
Planetary Sciences Research Institute  
The Open University  
Milton Keynes, MK7 6AA  
United Kingdom
N.R.G. Shrine
Unit for Space Sciences and Astrophysics
Physics Laboratory
University of Kent
Canterbury, Kent CT2 7NR
United Kingdom

A. Shukolyukov
Scripps Institute of Oceanography
University of California San Diego
La Jolla, CA 92093-0212
USA

B.M. Simonson
Department of Geology
Oberlin College
Oberlin, OH 44074-1044
U.S.A

D. Stöffler
Museum für Naturkunde
Institut für Mineralogie
Humboldt-Universität Berlin
Invalidenstraße 43
D-10115 Berlin
Germany

K. Suuroja
Geological Survey of Estonia
Kadaka tee 80/82
EE12618
Tallinn
Estonia

S. Suuroja
Geological Survey of Estonia
Kadaka tee 80/82
EE12618
Tallinn
Estonia
S. Vishnevsky
Institute of Mineralogy and Petrology
Russian Academy of Sciences
Novosibirsk
Russia

I.P. Wright
Planetary Sciences Research Institute
The Open University
Milton Keynes, MK7 6AA
United Kingdom

P.D. Yates
Planetary Sciences Research Institute
The Open University
Milton Keynes, MK7 6AA
United Kingdom

J.C. Zarnecki
Unit for Space Sciences and Astrophysics
Physics Laboratory
University of Kent
Canterbury, Kent CT2 7NR
United Kingdom

H. Zumsprekel
Institute for Planetologie
D-48149 Münster
Germany