

Oman Drilling Project

Scientific Drilling in the Samail Ophiolite, Sultanate of Oman Proceedings of the Oman Drilling Project



Phase 1

Drilling

December 2016–March 2017

Core description

15 July–15 September 2017

Phase 2

Drilling

November 2017–February 2018

Core description

5 July–5 September 2018

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Cover photograph shows science party members receiving a core on deck at Oman Drilling Project Site BA3 (from left: Suzanne Picazo, Laura Crispini, Site Geologist Abdul Rasak Tharayil, Juan Carlos de Obeso, and Luca Notini). Photo credit: Jude Coggon.

Supplemental data were provided by the authors and may not conform to IODP publication formats.

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[D1_Whole thin section images](#) (143 GB)

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[E_Tabulated VCD data](#) (51 MB)

[F1_XRF recalibration](#)

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[K1_On-site curation and descriptions](#) (5 MB)

[K2_On-site igneous unit summaries](#) (0.5 MB)

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Phase 2

Wireline diamond coring (Geosolutions Engineering)

Drillers

Shikh Oliullah (Wali)
Mr. Mansoor

Assistant Driller

Abdul Khaliq

Site Geologist

Abdul Rasak Tharayil

Roughnecks

Mohammed Nabi
Sadik Khan
Mohd Maqsood

Rotary drilling (Lalbuksh Voltas Engineering Services & Trading)

Driller

Mr. Nadeem

Drilling Supervisor

Sunil Pillai

Drilling Supervisor/Hydrogeologist

Sunil Kumar

Drilling Engineer

Ramraj Gopikrishnan

Drilling Superintendents

Mr. Sarbjit
Vidyadharan Thampi

Drilling Mechanic

Mohd Siddique

Rock crushing (University of Southampton)

Catriona Menzies
Nicolas Bompard
James Fielding

OmanChikyu 2018 description

Laboratory Manager

Yusuke Kubo

Laboratory Officers

Soichi Moriya
Tomoy Tanaka
Toru Fujiki

Curators

Shigako Nigi
Masaru Yasunaga

Laboratory Technicians

Akihiko Fujihara
Atsushi Kurasawa
Azusa Suzuki
Chiaki Sasaki
Daiki Kawata
Hideki Yamamoto
Hikaru Kawase
Hiromi Takeda
Htet Naing Lin
Kanao Yoshida
Kazuma Takahashi
Kei Fujiya
Masayuki Abe
Masumi Sakaguchi
Nobuhiro Anraku
Paing Zu
Reina Miyahara
Rui Nitahara
Ryo Ogawa
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Yoshiki Kido
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*At time of publication

Foreword

Funding

The Oman Drilling Project (OmanDP) has been undertaken by an international community of scientists from numerous countries and institutions. It has been possible through co-mingled funds from numerous agencies and institutions:

International Continental Scientific Drilling Program (ICDP; Kelemen, Matter, Teagle Lead PIs),
 Alfred P. Sloan Foundation Deep Carbon Observatory (Grant 2014-3-01, Kelemen PI),
 National Science Foundation (Award NSF-EAR-1516300, Kelemen Lead PI),
 NASA Astrobiology Institute (Award NNA15BB02A, Templeton PI),
 German Research Foundation (DFG Grant KO 1723/21-1, Koepke PI),
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 International Ocean Discovery Program *JOIDES Resolution Science Operator* (IODP JRSO),

with important contributions from the Sultanate of Oman Ministry of Regional Municipalities and Water Resources (MRMWR), the Oman Public Authority of Mining, Sultan Qaboos University, Columbia University of New York (USA), and the University of Southampton (UK).

Disclaimer

Opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of any of the above listed supporting agencies.

Oman Drilling Project Management and Governance

The Oman Drilling Project is guided by a Project Steering Committee (PSC) comprising the lead principal investigators, specialist experts, and important liaisons with national and international bodies such as MRMWR, JAMSTEC, IODP, and ICDP.

Oman Drilling Project Steering Committee

Prof. Peter Kelemen (Columbia University, New York): Chief Scientist of the Oman Drilling Project; Chair PSC; Lead Principal Investigator on Oman Drilling Project
 Prof. Juerg M. Matter (University of Southampton): Principal Investigator on Oman Drilling Project; Principal contact with ICDP; Principal liaison with Omani Government and other bodies; geophysical logging, physical properties measurements, and hydrology
 Prof. Damon A.H. Teagle (University of Southampton): Principal Investigator on Oman Drilling Project, Vice Chair of PSC; Chair of the Sampling Oversight and Allocation Committee (SOAC)
 Dr. Jude Coggon (University of Southampton): OmanDP Project Manager (2015–2019); logistics, personnel, website, organization, publications
 Eng. Zaher Bin Khalid Al Sulaimani: In-Country Project Manager; Logistics and liaison in Oman
 Eng. Said Al-Habsi (MRMWR, Sultanate of Oman): Chair of the Oman Drilling Committee (ODC)
 Dr. Ali Al Rajhi (Public Authority for Mining, Sultanate of Oman): Permitting and government liaison in Oman

Prof. Alexis Templeton (Department of Geological Sciences, University of Colorado Boulder, USA): Biogeochemical and microbiological sampling and borehole incubation experiments

Dr. Marguerite Godard (Directrice de Recherche, CNRS, Universit de Montpellier, France): Geochemical and isotopic analyses of rock samples

Prof. David Goldberg (Lamont-Doherty Earth Observatory, USA): Geophysical logging and borehole packer testing

Dr. Benoit Ildefonse (Directeur de Recherche, CNRS, Universit de Montpellier, France): Outreach; liaison with IODP

Prof. Jürgen Koepke (Leibniz Universitaet, Germany): Petrology of igneous and high-T metamorphic rocks from the lower crust and mantle

Prof. Chris MacLeod (School of Earth and Ocean Sciences, Cardiff University, UK): Structural and petrological work on igneous and high-T metamorphic rocks in the middle crust and sheeted dikes

Prof. Craig Manning (Department of Earth & Space Sciences, University of California Los Angeles, USA): Analyses of low-T metamorphic rocks

Prof. Katsuyoshi Michibayashi (Nagoya University, Japan): Structural analyses of igneous and high-T metamorphic rocks from the lower crust and upper mantle

Dr. Jay Miller (IODP Manager of Technical & Analytical Services, Texas A&M University, USA): Core logging; publication of Initial Report; other liaison with IODP personnel

Prof. Sobhi Nasir (Head, Department of Geology, Sultan Qaboos University, Oman): Participation of undergraduates and graduate students from Oman

Prof. Matthew Shrenk (Michigan State University, USA): Biogeological sampling and borehole incubation experiments

Prof. Everett Shock (Arizona State University, USA): Water and gas sampling and analysis

Prof. Eiichi Takazawa (Niigata University, Japan): Detailed site selection and associated surface mapping and sampling

Day-to-day decisions were made by a Core Team comprising the Chief Scientist and Chair of the PSC (Kelemen), the Oman DP Project Director and Manager (Matter and Coggon, respectively), Mr. Zaher al Sulaimani of the Oman Water Society, and the Vice-Chair of the PSC and Chair of the Sample Oversight and Allocation Committee (Teagle).

Oman Drilling Committee

The Oman Drilling Committee (ODC) was established by representatives of the major stakeholders in the Sultanate of Oman with interests in the Oman Drilling Project. The role of the ODC is to provide independent advice and assist with the drilling permitting processes and other matters. The membership comes from a range of Omani government organizations and Sultan Qaboos University:

Eng. Said Al-Habsi (Chair): MRMWR

Dr. Rashid Al-Abri (Co-Chair): MRMWR

Eng. Salim Al-Khanbashi: MRMWR

Haider Al-Ajmi: MRMWR

Dr. Ali Al-Rajahi: Public Authority for Mining

Prof. Sobhi Nasir: Sultan Qaboos University

Ibrahim Al Ajmi (Director General for Climate Affairs): Ministry of Environment and Climate Affairs

ChikyuOman 2017 Decision-Making Team

The Oman Drilling Project Phase 1 drill cores were described and analyzed onboard the JAMSTEC Drilling Vessel *Chikyu* from 15 July to 15 September 2017 (ChikyuOman2017). For these shipboard activities aboard *Chikyu* a Decision-Making Team (DMT) was established for effective decision making and sharing of information between the OmanDP PSC, the shipboard Co-Chiefs, Staff Scientists, the wider Science party, and

the Center for Deep Earth Exploration (CDEX) Laboratory Managers. When wider discussion was required, for example budget-related issues, the DMT shared information with a broader constituency including the OmanDP PSC, ODS group leaders, and JAMSTEC administrators. Oversight of data and sampling will remain the responsibility of the OmanDP Sample Oversight and Allocation Committee (SOAC) but with refined procedures to approve and facilitate shipboard and personal sample requests (see below).

Membership of the ChikyuOman2017 Phase 1 Decision Making Team (DMT):

Prof. Damon Teagle, Co-Chief Scientist (Part A)
Prof. Eiichi Takazawa, Co-Chief Scientist (Part A)
Prof. Peter Kelemen, Co-Chief Scientist (Parts A and B)
Prof. Katsu Michibayashi, Co-Chief Scientist (Part B)
Dr. Michelle Harris, Staff Scientist (Site BT1)/Co-Chief Scientist (Site GT3)
Dr. Jude Coggon, Staff Scientist (Part A)
Dr. Natsue Abe, Staff Scientist (Parts A and B)
Mr. Juan Carlos de Obeso, Staff Scientist (Part B, Site GT3)
Ms. Chiaki Igarashi, Administration and CDEX Laboratory Manager
Dr. Akihiro Tamura, ChikyuOman2017 Project Manager

ChikyuOman 2018 Decision-Making Team

The Oman Drilling Project Phase 2 drill cores were described and analyzed onboard the JAMSTEC Drilling Vessel *Chikyu* from 5 July to 5 September 2018, ChikyuOman2018. For these shipboard activities aboard *Chikyu* a second DMT was established for effective decision making and sharing of information between the OmanDP PSC, the shipboard Co-Chiefs, Staff Scientists, the wider Science party, and the CDEX Laboratory Managers. When wider discussions were required, for example budget related issues, the DMT shared information with a broader constituency including the OmanDP PSC, ODS group leaders, and JAMSTEC administrators. Oversight of data and sampling will remain the responsibility of the OmanDP SOAC but with refined procedures to approve and facilitate shipboard and personal sample requests (see below).

Membership of the OmanChikyu 2018 Decision Making Team (DMT):

Prof. Damon Teagle, Co-Chief Scientist (Part A)
Prof. Eiichi Takazawa, Co-Chief Scientist (Part A)
Prof. Peter Kelemen, Co-Chief Scientist (Parts A and B)
Prof. Katsu Michibayashi, Co-Chief Scientist (Part B)
Dr. Margot Godard, Co-Chief Scientist (Part B)
Dr. Jude Coggon, Staff Scientist (Part A)
Ms. Saebyul Choe, Staff Scientist (Parts A and B)
Dr. Moe Kyaw, JAMSTEC liaison
Dr. Natsue Abe, JAMSTEC liaison
Ms. Chiaki Igarashi, Administration and CDEX Laboratory Manager

Oman Drilling Project Sample, Data, and Obligations Policies

These policies were developed to ensure transparent access by scientists to Oman Drilling Project samples and data. They are closely related to and similar to established policies used by IODP and other ICDP projects. Scientists who received samples and access data incurred obligations on their use and reporting of the science outcomes from research based on these samples or data. The distribution and use of all cores, samples, and data fall under oversight of the OmanDP Sample Oversight and Allocation Committee (SOAC), a subgroup of the Project Steering Committee.

Oman Drilling Project Sample Oversight and Allocation Committee (SOAC)

Prof. Damon Teagle: Chair of OmanDP SOAC; Principal Investigator OmanDP

Prof. Peter Kelemen: Chief Scientist of the Oman DP; Chair of PSC

Dr. Marguerite Godard: Geochemistry; Co-Chief ChikyuOman2018

Prof. Sobhi Nasir: Representative of the Oman Drilling Committee, co-ordinating sample allocations for Omani institutions

Prof. Alexis Templeton: Waters, gases, microbiology

Dr. Jürg M. Matter: Logging and hydrogeological data

Prof. Eiichi Takazawa: Co-Chief ChikyuOman 2017 and 2018

Prof. Katsu Michibayashi: Co-Chief ChikyuOman 2017 and 2018

The goals of the Oman Drilling Project sample policies were to ensure the:

Availability of samples and data to Science Party members so they can fulfill the objectives of the drilling project and their responsibilities to the OmanDP;

Dissemination of the scientific findings of the Oman Drilling Project coring, logging, sampling, experimentation, and related activities to gain maximum scientific exposure and public engagement;

Scientific community has access to findings and, following the moratorium periods, data and samples to encourage scientific analyses over a wide range of research disciplines; and

Preservation of core and cuttings material as an archive for future description and observations, nondestructive analyses, and sampling.

Sample and Data Requests

There are two classes of sample requesters: Members of the Science Party and Post-Moratorium Researchers. Both groups incur their own particular obligation once a data or sample request has been approved and delivered.

The Moratorium Period is defined as two and a half years following the end of the description of the cores. The Oman Drilling Project will be divided into two Science Parties relating to the 2016–2017 and 2017–2018 Phases of operation. For Phase 1 of the OmanDP the moratorium period will be from September 2017 until the end of February 2020. For Phase 2 of the OmanDP the moratorium period will be from September 2018 until the end of February 2021. To submit a sample/data request you must be registered with OmanDP (via the application form). Membership of one phase does not necessarily ensure membership in the other Science Party unless certain criteria are fulfilled. For example, membership of the OmanDP Phase 1 Science Party requires at least one of the following:

- 1) Participation on site during the Phase 1 drilling, sampling, logging, experiment operations, of OmanDP;
- 2) Contribution to the visual and/or instrumental logging of the Phase 1 Oman DP cores during ChikyuOman2017 (July–September, 2017); or
- 3) A financial contribution to Oman Drilling Project via one or more scientific research grants that provides funds for drilling operations and/or core logging onboard Chikyu.

In addition, the SOAC will also consider sample requests, on a case by case basis, from science groups who provide specific skills or approaches NOT provided by colleagues covered by 1, 2, and/or 3, above.

Personal sample requests are prioritized by the OmanDP SOAC. The SOAC encouraged a pooled sampling approach, as commonly used during IODP expeditions, to ensure that a comprehensive suite of geochemical, mineralogical, and physical properties measurements are made on a representative suite of shared samples/powders. The SOAC also encouraged boutique isotopic and other geochemical measurements to be initially undertaken on the well-characterized pool samples.

Post-moratorium researchers are those who submit sample and data requests after the specific OmanDP Phase moratorium period ends. Sample applications by educators and outreach institutions are also considered on a case-by-case basis.

All data and observations produced from the on-site drilling and logging phases and shipboard activities of the Oman Drilling Project will be published in this open access volume akin to the IODP Expedition Reports following the moratorium period. During the moratorium period, data and samples will be restricted to the Science Party of that phase of the OmanDP.

Requests for data or samples must be made through official OmanDP processes and use the OmanDP sample request form. These requests will be assessed by the SOAC and accepted, refined, combined, or rejected to

ensure the best scientific outcomes. Core samples were generally only taken during the core logging activities (in 2017 onboard *Chikyu*) in a series of sampling meetings immediately following the description of each hole. To oversee these sampling events the SOAC delegated specific sample allocation to a shipboard team comprising the Co-Chief Scientists and Staff Scientists with assistance from the Curator. These teams resolved conflicts and ensured a fair and efficient distribution of samples. All sample request conflicts were resolved aboard.

Obligations for Members of the OmanDP Science Parties receiving Samples and/or Data

All members of the OmanDP Science Parties who receive samples or data incur obligations to conduct research during the moratorium period and publish their data and results in an English language peer-reviewed scientific journal or a peer-reviewed data report that will supplement the open access OmanDP Initial Reports, within 48 months of the core description campaign. Failure to meet these obligations may result in the rejection of future sample requests and may influence participation in other aspects of the Oman Drilling Project.

All publications arising from the OmanDP operations must acknowledge the Oman Drilling Project using a modified version of the following wording:

This research used samples and/or data provided by the Oman Drilling Project. The Oman Drilling Project (OmanDP) was made possible through co-mingled funds from the International Continental Scientific Drilling Project (ICDP; Kelemen, Matter, Teagle Lead PIs), the Sloan Foundation Deep Carbon Observatory (Grant 2014-3-01, Kelemen PI), the National Science Foundation (Award NSF-EAR-1516300, Kelemen lead PI), NASA Astrobiology Institute (Award NNA15BB02A, Templeton PI), the German Research Foundation (DFG Grant KO 1723/21-1, Koepke PI), the Japanese Society for the Promotion of Science (JSPS grants 16H06347, Michibayashi PI; and KAKENHI 16H02742, Takazawa PI), the European Research Council (Adv grant 669972; Jamveit PI), the Swiss National Science Foundation (SNF grant 20FI21_163073, Früh-Green PI), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the International Ocean Discovery Program *JOIDES Resolution Science Operator* (IODP JRSO), and contributions from the Sultanate of Oman Ministry of Regional Municipalities and Water Resources, the Oman Public Authority of Mining, Sultan Qaboos University, CNRS-Université Montpellier (France), Columbia University of New York (USA), and the University of Southampton (UK).

Publications should include the words Oman Drilling Project as keywords provided to the journal or book published of the manuscript.

Authors should send a PDF copy of the manuscript to the Chair and Vice-Chair of the OmanDP Project Steering Committee and the Project Director (Kelemen, Teagle, and Matter, respectively).

All data generated should be made openly available and either lodged in the *OmanDP Proceedings* Volume supplements as data reports or archived in an open access data repository (e.g., PetDP).

Authors wishing to publish scientific papers within the Moratorium Period must receive prior approval in writing by a majority of the scientific party and the support of the OmanDP Project Steering Committee. This approval will be coordinated by the OmanDP Project Manager, who will circulate the manuscript among the scientific party, tabulate responses, and notify the author of the scientific party's decision. Unless specifically agreed, all publications within the Moratorium period must include the Oman Drilling Project Science Team in the authorship.

Acknowledgments

The Oman Drilling Project has received essential assistance from hundreds of volunteers, many of whom covered their own travel expenses as well as providing weeks to months of their time and effort without compensation. We are very grateful for this exceptional community effort.

The In-Country Manager of the Oman Drilling Project is Eng. Zaher Al Sulaimani, Director of the Oman Water Centre. It is likely that the Oman Drilling Project would not have succeeded without his wise guidance. We also thank his son, Mazin Al Sulaimani, for able and efficient assistance with logistics. Eng. Nehal Warsi served as Site Geologist, our dedicated and reliable representative, every day of drilling for two seasons (7 months in total) and also volunteered a month of his time to help with core description on board the Drilling Vessel *Chikyu*.

Funding for the Oman Drilling Project was generously provided by the International Continental Scientific Drilling Program (ICDP), the US National Science Foundation (NSF), the Sloan Foundation Deep Carbon

Observatory (DCO), the US National Aeronautics and Space Administration (NASA), the European Research Council (ERC), the German Research Foundation (DFG), the Swiss National Science Foundation, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the Japanese Society for the Promotion of Science (JSPS), and the International Ocean Discovery Program (IODP). We are particularly grateful for advice from Dr. Uli Harms of ICDP, for support from JAMSTEC President Dr. Asahiko Taira, and for extensive assistance with proposal preparation from Dr. Nobu Eguchi at JAMSTEC. Special thanks also go to Jesse Ausubel of the Sloan Foundation Deep Carbon Observatory and Dr. Leonard Johnson and Dr. Dennis Geist of the US NSF.

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We worked with several drilling contractors in Oman. We particularly thank GeoSolutions Engineering, owned and operated by Managing Director Sultan Al Saadi, who is assisted by the exceptionally able Driller Shaikh Oliullah (Wali) and by Geologist Abdul Rasak Tharayil. Their attention to quality and efficiency were above and beyond the call of duty and resulted in timely acquisition of 3200 meters of core with 100% recovery.

During core description onboard Drilling Vessel (D/V) *Chikyu*, we were ably assisted by the ship's crew and technical staff. We particularly thank President Dr. Asahiko Taira, Dr. Kyoshi Suyehiro, Dr. Nobu Eguchi, Director of the Science Services Department, Center for Deep Earth Exploration (CDEX), Chikyu Laboratory Managers Dr. Lena Maeda and Dr. Yusuke Kubo, shore-based Expedition Manager Dr. Chiaki Igarashi, and Ms. Maya Takebayashi Noguchi at JAMSTEC.

We thank Dr. Jay Miller and Dr. Brad Clement at IODP JRSO at Texas A&M University (TAMU) for their advice and assistance in planning and organizing logistics and protocols for shipboard core description. In addition, Shana Lewis, Rhonda Kappler, Jean Wulfson, and Phil Rumford kindly joined us onboard D/V *Chikyu* to provide publications and curation support, and Lorri Peters and her team at JRSO TAMU worked extremely hard to edit and produce this volume.

Among the scientists involved with the Oman Drilling Project, a few deserve special thanks here. Project Manager Dr. Jude Coggon and Project Director Prof. Jürg Matter did an amazing, exceptional job of managing logistics, arranging contracts, and supervising operations in the field and during core description. Niigata University Prof. Eiichi Takazawa and his students found and mapped the drill sites at the crust–mantle transition zone. Nagoya University Prof. Katsu Michibayashi provided his own research funds to enable core description onboard D/V *Chikyu* in summer 2017. Katsu and Eiichi, together with Dr. Natsue Abe of JAMSTEC, Dr. Jude Coggon, and Prof. Damon Teagle of Southampton University, Dr. Marguerite Godard of the University of Montpellier, Dr. Michelle Harris of Plymouth University, and Prof. Peter Kelemen and graduate student Juan Carlos de Obeso of Columbia University, served as Co-Chief Scientists and Staff Scientists onboard D/V *Chikyu*. Prof. Alexis Templeton, Dr. Eric Ellison, and graduate student Katy Rempfert from the University of Colorado built and operated the biogeoscience laboratory on the drill site in January 2018.

Dedication

His Majesty Sultan Qaboos bin Said al Said

18 November 1940–10 January 2020

Sultan of Oman, 23 July 1970–10 January 2020

The Oman Drilling Project, the results within this volume and our future scientific outcomes are dedicated to His Majesty Sultan Qaboos bin Said al Said.

ع الحفر في سلطنة عمان ، والنتائج المنشورة
في هذا المنشور ، وكذلك النتائج العلمية
التي سنستخلصها في المستقبل ، إلى روح
المغفور له حضرة صاحب الجلالة السلطان قابوس
بن سعيد بن تيمور آل سعيد - رحمه الله - من
بين السيد سيد تيمور

Sultan Qaboos recognized the importance of the unique geology of Oman to his country and the great role that science can play in the development of peace and prosperity. He was instrumental in opening up Oman to national and international scientific collaborations that, together with the warm welcome of the people of Oman, have allowed the mountains of the Samail Ophiolite to become one of the world's most iconic geological terrains.

