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JGR Solid Earth

INTRODUCTION

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Special Section:

Ophiolites and Oceanic Lithosphere, with a focus on the Samail ophiolite in Oman

Key Points:

- In understanding processes that form and modify oceanic lithosphere, the Samail ophiolite is an essential complement for seagoing studies
- Study of the base of the Samail ophiolite provides key insights on mass transfer at the leading edge of the mantle wedge
- Ongoing alteration of mantle peridotite generates highly reduced, alkaline fluids, and hosts an important subsurface microbial ecosystem

Supporting Information:

Supporting Information may be found in the online version of this article.

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Preface: Special Issue on Ophiolites and Oceanic Lithosphere

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Abstract With this Preface, we provide background information, a scientific overview of topics, and an annotated bibliography of the 63 papers published in the Journal of Geophysical Research (JGR) Special Issue on “Ophiolites and Oceanic Lithosphere, with a Focus on the Samail Ophiolite,” collected online at [https://agupubs.onlinelibrary.wiley.com/doi/toc/10.1002/\(ISSN\)2169-9356.SAMAIL1](https://agupubs.onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)2169-9356.SAMAIL1). Topics covered in the Special Issue include formation and alteration of igneous ocean crust at submarine spreading centers, subduction zone mass transfer at the leading edge of the mantle wedge, the tectonic emplacement and evolution of ophiolites, processes of alteration and weathering of tectonically exhumed mantle peridotite, and the subsurface biosphere in the peridotite weathering environment. The bibliography, in the form of a supplementary Excel spreadsheet with links to each paper, is organized by topic, but can be sorted by first author, order of publication, specific Oman Drilling Project boreholes, and other factors.

Plain Language Summary This is a Preface for a Special Issue of papers on “ophiolites”—fragments of oceanic crust and upper mantle, thrust onto continental margins—and related studies of oceanic “lithosphere”—data on submarine, oceanic crust and mantle in situ. The Issue includes papers on the formation and alteration of igneous crust at tectonic spreading centers, the thrusting of ophiolites over and onto continental margins, accompanied by an influx of fluids derived from underthrust materials, weathering of tectonically exhumed rocks from the Earth's mantle (both in ophiolites and on the seafloor), and the subsurface microbial biosphere associated with this weathering.

1. Dedication

On the 41st anniversary of the publication of the Journal of Geophysical Research Special Issue on the Oman Ophiolite, we dedicate this Special Issue to Françoise Boudier, Bob Coleman, Cliff Hopson, and Adolphe Nicolas, who led the way in process-oriented studies of the Samail ophiolite, looking past debates on the tectonic provenance of ophiolites to foster ground-breaking research on mantle melting and melt transport, crustal formation and hydrothermal alteration at oceanic spreading centers. We are indebted to them for their extensive observations, their creative ideas, and their example of a lifetime devoted to scientific research.

2. Introduction

Creating this Special Issue was motivated by several factors. First, we wished to celebrate and extend the remarkable legacy established by the 1981 JGR Special Issue on the Oman Ophiolite, edited by Coleman and Hopson (1981). Since then there have been many books and volumes of collected papers with a substantial focus on the Samail ophiolite (e.g., Boudier & Juteau, 2000; Boudier & Nicolas, 1988; Lippard et al., 1986; Nicolas, 1989; Peters et al., 1991; Robertson et al., 1990; Rollinson et al., 2014), but only a few have contained the backbone of data-rich, observational studies of the Samail ophiolite that characterized the 1981 Issue. We aspired to achieve a similar, quantitative, and comprehensive approach with this Special Issue, 41 years later. Many thanks to the authors of these many papers.

Investigation: Peter B. Kelemen, Jürg M. Matter, Damon A. H. Teagle, Jude A. Coggon, Marguerite Godard, Katsuyoshi Michibayashi, Eiichi Takazawa, Alexis S. Templeton

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Writing – review & editing: Peter B. Kelemen, Jürg M. Matter, Damon A. H. Teagle, Marguerite Godard, Alexis S. Templeton, Ken Williams, Zaher Al Sulaimani

Second, we were aware of the comprehensive data set on the Wadi Gideah crustal section in the ophiolite, collected by a group led by Jürgen Koepke, and we wished to provide a venue where this exceptional set of papers could be published, together and in context. Indeed, three scientific boreholes were cored in the Wadi Gideah to complement the Koepke group's observations. In addition, there have been other detailed studies of oceanic crustal outcrops in this general region. Moreover, for comparison, it is important to include papers on oceanic crust formed in other tectonic settings. Collectively, this focus on the origin and evolution of oceanic crust and the underlying, uppermost mantle accounts for 23 of the papers in this Special Issue (Allard et al., 2021; Belgrano et al., 2021; Boulanger et al., 2021; Carbotte et al., 2021; Carter et al., 2022; Casini et al., 2021; Crotteau et al., 2021; Ferrando et al., 2021; France et al., 2021; Garbe-Schönberg et al., 2022; Grambling et al., 2022; Greenberger et al., 2021; Hatakeyama et al., 2021; Klaessens et al., 2021; Koepke et al., 2022; Kourim et al., 2022; Mock, Ildefonse, Müller, & Koepke, 2021; Mock, Neave, et al., 2021; Müller et al., 2022; VanTongeren et al., 2021; Weber et al., 2021; Xu et al., 2021; Zhang et al., 2021).

Third, the preparation of the papers for this Issue occurred during the culmination of the Oman Drilling Project (OmanDP, <http://publications.iodp.org/other/Oman/OmanDP.html>). We hoped to collect a comprehensive set of papers reporting on the results of that project. OmanDP was a collective effort on the part of more than 200 scientists from 20 countries who provided more than 10 person-years of effort at drill sites and onboard the International Ocean Drilling Program (IODP) Drilling Vessel Chikyu for core logging. OmanDP was funded by the Sloan Foundation, the International Continental Scientific Drilling Program (ICDP), the US National Science Foundation (NSF), the Japanese Marine Science and Technology Center (JAMSTEC), the Japanese Society for the Promotion of Science (JSPS), the IODP, the US National Aeronautics and Space Administration (NASA), and the scientific research foundations of the EU, Germany and Switzerland, plus support from scientists' home institutions. We are also grateful for in-kind assistance from the Omani Ministry of Regional Municipalities and Water Resources, the Public Authority for Mining, Sultan Qaboos University, the German University of Technology in Oman, and Petroleum Development Oman (PDO). OmanDP sampled nine cored boreholes, and drilled another six rotary holes, extending 300–400 m below the surface. Core recovery was consistently ~100%, producing about 3.2 km of core. Geophysical observations in and around some of the boreholes are ongoing. Twenty-four of the papers in this Special Issue focus on observations from OmanDP (Beinlich et al., 2020; Carter et al., 2022; Crotteau et al., 2021; de Obeso et al., 2022; Ellison et al., 2021; France et al., 2021; Godard et al., 2021; Grambling et al., 2022; Greenberger et al., 2021; Hatakeyama et al., 2021; Hong et al., 2022; Katayama et al., 2020; Kelemen et al., 2021, 2022; Klaessens et al., 2021; Kotowski et al., 2021; Kourim et al., 2022; Malvoisin et al., 2020; Menzel et al., 2020; Nothaft, Templeton, Boyd, et al., 2021; Nothaft, Templeton, Rhim, et al., 2021; Okazaki et al., 2021; Templeton et al., 2021; Ternieten et al., 2021a). In addition, of course, many papers have been published in other journals, and research on OmanDP data and samples is ongoing (with another special issue underway in *Lithos*).

Fourth, we've been inspired by recent studies of mass transfer through the basal thrusts of ophiolites, with the realization that these faults originated as subduction zones, so that study of these sites can provide unique observations that constrain subsurface processes that are generally inaccessible to geologists and geochemists. Nine papers in this Special Issue present studies on this and related topics (Al-Khribash and Ahmed, 2021; Ali et al., 2021; Beinlich et al., 2020; de Obeso et al., 2022; Godard et al., 2021; Kelemen et al., 2022; Kotowski et al., 2021; Menzel et al., 2020; Okazaki et al., 2021).

Fifth, there has been a recent surge of interest in weathering and low temperature hydrothermal alteration of mantle peridotite, stimulated in part by the recognition that these environments provide habitable conditions that can sustain several types of chemosynthetic microbial ecosystems. The geochemical gradients that are established within the serpentinite-hosted groundwaters may also be analogous to the conditions suitable for the origin of life on this and other planets. There also is an intrinsic fascination with these active, far from equilibrium chemical systems. And, it has become evident that there is significant uptake of CO₂ from migrating fluids, during weathering of mantle peridotite, and during subduction zone mass transfer (previous paragraph), which can create a globally significant reservoir for carbon in the mantle lithosphere. A supportive community of researchers has grown around these topics, embodied in part by the annual Serpentine Days conferences in Europe. This overall topic is the subject of 24 of the papers in this Special Issue (Bernasconi et al., 2021; Cook, Blank, Rietze, et al., 2021; Cook, Blank, Suzuki, et al., 2021; Cooperdock et al., 2020; de Obeso et al., 2021; Ellison et al., 2021; O. Evans et al., 2020; Hong et al., 2022; Howells et al., 2022; Katayama et al., 2020; Kelemen et al., 2021; Leong et al., 2021; Malvoisin et al., 2020; Monnin et al., 2021; Nothaft, Templeton, Boyd, et al., 2021; Nothaft, Templeton, Rhim,

et al., 2021; Renard, 2021; Sabuda et al., 2021; Schwarzenbach, Vogel, et al., 2021; Schwarzenbach, Vrijmoed, et al., 2021; Templeton et al., 2021; Ternieten et al., 2021a, 2021b; Yoshida et al., 2020).

And finally, studies of the Samail ophiolite have been greatly enriched by ongoing research on the processes of ophiolite emplacement, and related deformation within and surrounding ophiolites. We are delighted that seven papers in this Special Issue address these new data (Cox et al., 2021; A. D. Evans et al., 2021; Garber et al., 2021; Ninkabou et al., 2021; Pilia et al., 2021; Rioux, Benoit, et al., 2021; Rioux, Garber, et al., 2021), though of course much recent work on this topic has also been published elsewhere.

3. Ophiolites and Oceanic Lithosphere

The formation and evolution of oceanic lithosphere at spreading centers, together with its ultimate destruction at subduction zones, are the most important igneous and metamorphic processes on Earth, creating and recycling more than 60% of the Earth's crust on short geological timescales (<200 million years) and forming the locus of thermal and chemical exchange between the solid Earth, the oceans, and the atmosphere. Study of these processes is hampered by a lack of access to outcrops of oceanic lower crust and upper mantle, on the seafloor and in subduction zones. Recognition that “ophiolites”—fragments of mafic crust and depleted upper mantle—were fragments of oceanic lithosphere, formed at spreading centers and then thrust onto the continental margins along subduction zones (e.g., Coleman, 1971, 1977; Dewey & Bird, 1971; Dickinson, 1971; Gass, 1968) offered a unique opportunity to study these otherwise hidden regions in three dimensions. The igneous “stratigraphy” of the Samail ophiolite in Oman—the world's largest ophiolite—has a layered structure that closely resembles the regular, layered seismic velocity structure of the Pacific crust (e.g., Christensen, 1978; Christensen & Salisbury, 1975; Christensen & Smewing, 1981). Both the ophiolite and Pacific crust formed at a fast spreading rate (e.g., Rioux et al., 2012; Tilton et al., 1981). These inferences underlie most of the papers in the 1981 JGR Special Issue. Indeed, to this day, the widely accepted interpretation of the layered structure of the Pacific crust, in terms of a layer of lavas, overlying a layer of sheeted dikes, overlying a lower crust composed of gabbroic rocks, in turn overlying residual mantle peridotites, rests largely on a foundation of observations from the Samail ophiolite.

Early on, it became evident that most or all ophiolites had characteristics that are different from “normal” oceanic crust created at the mid-ocean ridges (e.g., Miyashiro, 1973). The crustal sections in most ophiolites are systematically thinner than Pacific crust, and the lavas in ophiolites have major and trace element characteristics that are consistently different from virtually all lavas sampled from “normal” mid-ocean ridges. In particular, all ophiolite lavas—including those in the Samail ophiolite—systematically have lower Nb/Th ratios than mid-ocean ridge lavas (e.g., Pearce & Peate, 1995), and most ophiolite lava series also show major and minor element chemical differentiation trends that are different from those of mid-ocean ridge lavas (e.g., for Oman, MacLeod et al., 2013; Pearce et al., 1981). These differences have led to a vigorous, ongoing dialog regarding the tectonic provenance of ophiolites, and how ophiolites might differ from “normal” oceanic crust. Discussion of this topic continues to this day (Shervais, 2022).

However, since the Samail ophiolite formed at submarine spreading center with a fast-spreading rate, and has large scale crustal layering (lavas, dikes, gabbros, peridotite) identical in both nature and thickness to most of the crust formed at the East Pacific Rise as exposed in tectonic windows, many scientists studying the ophiolite have adopted the perspective that Samail observations provide essential insights into processes common to both the ophiolite and Pacific crust. Moreover, while at least two highly distinct magma series formed substantial fractions of the northern massifs of the ophiolite, the southern massifs formed predominantly from primitive, tholeiitic, mantle-derived, basaltic magmas that closely resembled primitive mid-ocean ridge basalts (MORBs) in almost every respect (e.g., Pearce & Peate, 1995). It is true that, even in the southern massifs, mantle spinel Cr/Al ratios extend to values slightly higher than the highest observed in peridotites dredged from mid-ocean ridges (e.g., Hanghøj et al., 2010; Le Mée et al., 2004; Monnier et al., 2006), and plagioclase Ca/Na ratios extend to higher values than plagioclase in most mid-ocean ridge gabbros (though see Kelemen et al., 2007, Figure F4). Also, Samail and Wadi Tayin massif lavas fractionated to form Ti poor, Si-rich andesites and dacites that are not observed at mid-ocean ridges (MacLeod et al., 2013). All of these data point to a parental magma with 1–2 wt% H₂O, perhaps five times higher than in primitive MORB. However, these differences define a spectrum of variation, not a bimodal distribution, and they are unlikely to have caused distinctively different processes in the origin and evolution of Pacific versus Samail lithosphere. Most of the 23 papers on crustal genesis and alteration in this

Special Issue (cited in Section 2) adopt this approach. They should be viewed in the context of an ongoing dialectic, in which sea-going investigations are motivated by ophiolite observations, and vice versa.

In this context, Samail studies have discovered and constrained processes that are inferred to occur at most intermediate- to fast-spreading mid-ocean ridges. Samail data have been used to support both sides of a long-standing debate on formation of oceanic lower crustal gabbros, either via (a) most crystallization in a shallow melt lens, followed by transportation of a crystal-rich mush downward and outward to form the lower crust (gabbro glacier, e.g., Nicolas et al., 1988; Phipps Morgan & Chen, 1993; Quick & Denlinger, 1993; Sleep, 1975), or (b) most crystallization in small melt lenses emplaced at the depth where they are now formed (*sheeted sills*). These end-members have combined in various hybrid models in which the “upper gabbros” might have been transported via a “glacier” whereas the “lower gabbros” crystallized in situ. Indeed, even the original papers proposing the “sheeted sills” hypothesis included a hybrid origin for Samail ophiolite lower crust, with a thin “glacier” just beneath the sheeted dikes (Kelemen et al., 1997; Korenaga & Kelemen, 1997). Closely related to the gabbro glacier versus sheeted sill issue is the rate and location of hydrothermal cooling in the lower crust, with concepts spanning the range from an end-member in which (a) only the lavas and sheeted dikes are rapidly cooled by vigorous hydrothermal convection near the axis of the spreading center, while the lower crust is slowly cooled off axis, mainly by conduction, over hundreds of thousands of years (e.g., Coogan et al., 2002; Phipps Morgan & Chen, 1993) to an end-member in which (b) both the upper and lower crust are rapidly cooled by vigorous hydrothermal convection at a nearly constant rate, within a few kilometers of the axis (e.g., Garrido et al., 2001; VanTongeren et al., 2008). Intermediate hypotheses include ideas about rapid hydrothermal convection in near-axis faults extending to the base of the crust, surrounded by less permeable, less altered, more slowly cooled gabbros (e.g., Coogan et al., 2006; Zihlmann et al., 2018). Most of the papers on crustal genesis and alteration in this Special Issue address one or both of these general topics.

4. Subduction Zone Mass Transfer at the Leading Edge of the Mantle Wedge

It has long been recognized that “metamorphic soles” beneath many ophiolites record temperature and pressure conditions in the thrust fault(s) that consumed oceanic lithosphere and then emplaced ophiolites on continental margins (e.g., Boudier et al., 1982; Church & Stevens, 1971; Dewey & Bird, 1971; Malpas et al., 1973). With that said, metamorphic temperatures in the soles generally correspond to granulite facies conditions ~800°C, with pressures ranging from 0.89 to 1.4 GPa (e.g., Ghent & Stout, 1981; Kotowski et al., 2021; Soret et al., 2017), rather than the blueschist facies conditions thought to be typical of steady-state geotherms in established subduction zones consuming old oceanic crust (e.g., Coleman, 1971; Dickinson, 1971; Ernst, 1971; Peacock, 1996). This, and the observation that metamorphic sole ages and ophiolite crustal ages are often very similar, has given rise to the hypothesis that metamorphic soles form during initiation of subduction in young, hot oceanic lithosphere (e.g., Hacker, 1990, 1991, 1994; Jones et al., 1991; Smith & Spray, 1984; Spray, 1983). Recently, Agard and colleagues have added the idea that metamorphic soles record the earliest, hottest stages of subduction initiation, which were followed by cooling and evolution toward a steady state subduction geotherm (e.g., Agard et al., 2016, 2020; Soret et al., 2022).

In any case, metamorphic soles lie along faults that initiated as plate-scale, low angle thrust faults subducting oceanic crust, sediments, and ultimately continental crust beneath the mantle section of ophiolites. Thus, the mantle section of ophiolites can be regarded as having formed the “leading edge of the mantle wedge” (Falk & Kelemen, 2015; Kelemen & Manning, 2015; Kelemen et al., 2013) for millions to tens of millions of years in many cases. Thus, these rocks may preserve a record of mass transfer from subducting material into the forearc mantle (e.g., Boskabadi et al., 2020; Deschamps et al., 2010; Förster et al., 2017; Li & Lee, 2006; Menzel et al., 2018; Nozaka, 2014; Peacock, 1987; Peng et al., 2020; Sachan et al., 2007; Scambelluri et al., 2016, 2022; Schwarzenbach et al., 2018; Sideridis et al., 2022; Spandler et al., 2008; Ulrich et al., 2020; Wu et al., 2021; Zhao et al., 2021).

Based on this reasoning, Oman Drilling Project Hole BT1B was sited to drill carbonated peridotites (listvenites) and their host rocks, serpentinized mantle peridotites, just above the basal thrust of the Samail ophiolite. Six papers in this Special Issue (cited in Section 2) report on studies of core from Hole BT1B and samples from the surrounding area, interpreting their results in terms of carbon mass transfer from subducting sediments into the overlying mantle wedge at the base of the Samail ophiolite mantle section. Structural and geochronological data

supporting this approach are summarized in several papers (e.g., Falk & Kelemen, 2015; Kelemen et al., 2022; Menzel et al., 2022).

However, the hypothesis that listvenites and other features at the base of the ophiolite record subduction zone mass transfer is controversial, with some workers advocating for a younger origin for Samail listvenites (Peer Review File for Menzel et al., 2022; Scharf et al., 2022), in a debate that is likely to continue for some time. Indeed, in Oman and elsewhere, the basal thrust of ophiolites has often been reactivated and cut by post-emplacement deformation, potentially with associated hydrothermal alteration, and so it may be challenging to fully disentangle their histories. Meanwhile, thermodynamic, numerical modeling, and experimental studies (e.g., Falk & Kelemen, 2015; Kelemen et al., 2022; Sieber et al., 2018; Stewart & Ague, 2020) continue to demonstrate the likelihood of substantial mass transfer from subducting material into the leading edge of the mantle wedge, particularly in cases in which deeper fluids migrate up a subduction channel (e.g., de Obeso et al., 2022), and this is likely to be recorded in the mantle section of ophiolites, together with other, similar processes that occur after ophiolite emplacement.

5. Weathering of Mantle Peridotite

Twenty-four of the papers in this Special Issue (cited in Section 2) address various aspects of low temperature weathering/alteration of mantle peridotite and associated biogeochemical activity. Three relatively recent developments led to increased interest in this topic, in the Samail ophiolite and at many other sites encompassed in this issue, such as the Atlantis Massif along the mid-Atlantic ridge as well as several continental sites in California, Italy, and Turkey. First, there has been widespread recognition that highly reducing environments and large redox gradients produced during serpentinization (e.g., Frost, 1985; Neal & Stanger, 1983, 1984, 1985) can stabilize hydrocarbons and provide energy for microbial chemosynthesis, leading to an explosion of hypotheses concerning the scale and function of the subsurface biosphere, abiotic hydrocarbon genesis, and the origin of life on this and other planets (e.g., Berndt et al., 1996; Fisk & Giovannoni, 1999; Foustoukos & Seyfried, 2004; Horita & Berndt, 1999; McCollom, 1999, 2007; Schulte et al., 2006; Shock, 1997; Shock et al., 1995; Sleep et al., 2004; Varnes et al., 2003). There also is intense interest in determining whether or not mineral, isotopic or organic biosignatures can be produced and preserved within serpentinite rocks and fluids, in order to aid in the search for life in analogous systems on Mars, Europa and Enceladus.

Second, reaction between surface waters and altering peridotite forms abundant carbonate veins, stripping carbon from aqueous fluids and producing Ca-OH rich waters that emerge in springs and combine with CO₂ to form travertine deposits on the surface (e.g., Barnes & O'Neil, 1969; Bruni et al., 2002; Clark & Fontes, 1990). Indeed, these processes sometimes even cause 100% replacement of peridotite by listvenites (carbonate + quartz assemblages e.g., Falk & Kelemen, 2015; Halls & Zhao, 1995; Hansen et al., 2005; Naldrett, 1966; Schandl & Naldrett, 1992; Schandl & Wicks, 1991). It has been proposed that these processes may produce a significant mineralized carbon reservoir on this and other planets (e.g., Kelemen & Manning, 2015), and that these spontaneous, natural processes could potentially be emulated in accelerated systems for engineered, in situ carbon capture and storage (e.g., Kelemen & Matter, 2008).

Third, there is renewed interest on volume changes associated with alteration of peridotite, as originally addressed by MacDonald and Fyfe (1985), O'Hanley (1992) and Evans (2004), and on the ways in which these volume changes may be accommodated (Iyer et al., 2008; Jamtveit et al., 2009; Kelemen & Hirth, 2012; Rudge et al., 2010).

One or more of these three topics are addressed by the 24 papers on low temperature weathering/alteration of peridotite, including cracking due to volume change during serpentinization of olivine, and the seven papers on listvenite formation in this Special Issue, as cited in Section 2.

6. Perspectives on Future Work

Proposals and workshops leading up to the Oman Drilling Project outlined several topics of fundamental research which have not been fully addressed in this Special Issue, which we hope will be among the investigations of OmanDP core and boreholes that lie ahead. Some of these topics are uniquely well suited to studies of drill core and/or boreholes, as has been amply demonstrated by scientific ocean drilling.

These include

- Detailed studies of the amplitude and length scale of “cryptic” chemical variation in lower crustal gabbros, which would provide key constraints on the mode of melt transport during formation of igneous cumulates as previously done for a limited set of samples from the Samail ophiolite by Browning (1984) and by Korenaga & Kelemen (1997, 1998).
- Revisiting the classic studies of Gregory and Taylor (1981) and Bosch et al. (2004), building on the whole core mineralogy studies of the crust (Crotteau et al., 2021; Greenberger et al., 2021) and mantle (Okazaki et al., 2021) in this issue, to constrain the extent of water/rock reaction during hydrothermal alteration of the lower crust using oxygen and strontium isotopes, extending past work in terms of the number of samples, and by including “matrix” samples (as in Gregory & Taylor, 1981), veins (Bosch et al., 2004), and fault zones (e.g., Zihlmann et al., 2018), to provide abundance-weighted estimates of the water/rock ratio and cooling power of hydrothermal convection in oceanic lower crust.
- Time series studies of borehole water composition, temperature, and gas flux. As outlined by Kelemen et al. (2021) drilling introduced cold, neutral pH, oxidized water into subsurface aquifers, which have gradually evolved back to more alkaline, reduced compositions. There is much to be learned by studying the rate at which borehole water returns to a steady-state composition, via advection, diffusion, and reaction with surrounding rocks as a function of depth in both peridotite- and gabbro-hosted boreholes.
- Completion and interpretation of downhole logging data, including video, to determine fracture spacing and orientation, combined with comprehensive reorientation of core in a geographical reference frame, to enable detailed studies of structural features in core as related to regional features such as the paleo-seafloor, the crust-mantle transition zone, and the basal thrust of the ophiolite.
- Detailed assessment of the controls on the distribution and activity of the subsurface serpentinite-hosted biosphere. As outlined by Templeton et al. (2021), there are notably high cell densities detected in Oman BA cores and fluids. This observation stands in strong contrast to lower cellular abundances in other low-temperature serpentinizing systems, such as the hydrated lower crustal gabbros at the Atlantis Bank (Wee et al., 2021) and in altered gabbro and peridotite cores recovered from the Atlantis Massif (Früh-Green et al., 2018, 2022). It is timely to assess how the geochemical dynamics in the Samail ophiolite sustain substantial biological activity, by detailed assessment of the locations where microorganisms inhabit reaction zones within the cores, as well as by conducting continued groundwater monitoring and assessment of the microbial community structure, function, and activity at the “active serpentinization” sites.
- More drilling! A variety of things may have been “missed” in OmanDP boreholes so far. For example, we encountered a high temperature fault within the mantle-crust transition zone (MTZ). It seems that the fault does not have a lot of displacement, but drilling the MTZ at another site could be fruitful. As another example, we hypothesize that there must be fault zones carrying a substantial flux of oxidized, carbon-rich water into highly reducing, alkaline, peridotite-hosted aquifers at depth. However, these focused mixing zones were not sampled in OmanDP.

7. Table of Contents Arranged by Topic: Supplementary Table

A sortable Table of Contents for the JGR Special Issue on Ophiolites and Oceanic Lithosphere, is provided in Table S1 for this Preface. As configured, the spreadsheet is sorted according to overall topic and then by locale or rock type. The Table is sortable, so that one can arrange the list of papers in the order that they appear at [https://agupubs.onlinelibrary.wiley.com/doi/toc/10.1002/\(ISSN\)2169-9356.SAMAIL1](https://agupubs.onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)2169-9356.SAMAIL1), or alphabetically by author, or by the date when they were first published online. One can also sort collections of papers reporting observations from a specific OmanDP drill site and its environs. Finally, color coding provides a cross-cutting classification of papers by the geological processes that they address.

8. Conclusion

In concluding, we would like to once more draw attention to our dedication of this special issue to Françoise Boudier, Bob Coleman, Cliff Hopson and Adolphe Nicolas, who laid the groundwork for process-oriented studies of the Samail ophiolite with global significance for understanding oceanic spreading ridges and subduction zones.

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Though we can never aspire to the kind of discoveries they achieved, not long after the discovery of plate tectonics, the Guest Associate Editors hope that this Special Issue can serve as a similar launching pad for future research. Actually, the 1981 JGR Special Issue on the Oman Ophiolite appeared at a time of diminishing interest in ophiolites as a window into mid-ocean ridge processes, as the complexities of their relationship to “normal” oceanic crust became clearer. But the Issue was rediscovered during an exciting time in the 1990s when a broad swath of the geoscience community focused on general processes at spreading centers, stimulated by theoretical advances in understanding polybaric decompression melting in the mantle, reactive melt transport, the three-dimensional seismic structure of the crust at mid-ocean ridges, and chemical exchange between the crust and the oceans. The surge in interest was complemented by major research funding from the US RIDGE Initiative, InterRidge in Europe, and corresponding efforts around the world.

The tide of interest seemed to withdraw again at the start of the new century, when many of us were happy to move on to studying subduction processes, supported by the NSF MARGINS Initiative and similar funding worldwide. And now, we live in a very different world, with earth scientists pulled in many directions by competing motivations to understand and address the problem of global climate change, on the one hand, and the enduring fascination of basic scientific research on the other. There are some potential synergies between these different efforts.

We hope this Special Issue will help to maintain interest in research on the formation and evolution of oceanic lithosphere, in the near future and perhaps even more so when the tide comes in again.

References

Agard, P., Prigent, C., Soret, M., Dubacq, B., Guillot, S., & Deldicque, D. (2020). Slab tectonics: Mechanisms controlling subduction development and viscous coupling. *Earth-Science Reviews*, 208, 10325. <https://doi.org/10.1016/j.earscirev.2020.103259>

Agard, P., Yamato, P., Soret, M., Prigent, C., Guillot, S., Plunder, A., et al. (2016). Plate interface rheological switches during subduction infancy: Control on slab penetration and metamorphic sole formation. *Earth and Planetary Science Letters*, 451, 208–220. <https://doi.org/10.1016/j.epsl.2016.06.054>

Ali, A., Abbasi, I. A., Nogueira, L. B., Hersi, O. S., Al Kindi, S. A., El-Ghali, M. A., & Nasir, S. J. (2021). Geochemical and C-O isotopic study of ophiolite-derived carbonates of the Barzaman formation, Oman: Evidence of natural CO₂ sequestration via carbonation of ultramafic clasts. *Journal of Geophysical Research: Solid Earth*, 126(10), e2020JB021290. <https://doi.org/10.1029/2020jb021290>

Al-Khibbash, S. A., & Ahmed, A. H. (2021). Distribution and mobility of platinum-group elements in the late cretaceous Ni-Laterite in the northern Oman mountains. *Journal of Geophysical Research: Solid Earth*, 126(10), e2021JB022363. <https://doi.org/10.1029/2021JB022363>

Allard, M., Ildefonse, B., Oliot, É., & Barou, F. (2021). Plastic deformation of plagioclase in oceanic gabbro accreted at a slow-spreading ridge (Hole U1473A, Atlantis Bank, Southwest Indian ridge). *Journal of Geophysical Research: Solid Earth*, 126(10), e2021JB021964. <https://doi.org/10.1029/2021jb021964>

Barnes, I., & O’Neil, J. R. (1969). Relationship between fluids in some fresh alpine-type ultramafics and possible modern serpentinization, western United States. *GSA Bull.*, 80(10), 1947–1960.

Beinlich, A., Plümpner, O., Boter, E., Müller, I. A., Kourim, F., Ziegler, M., et al. (2020). Ultramafic rock carbonation: Constraints from listvenite core BT1B, Oman Drilling Project. *Journal of Geophysical Research*, 125(6), e2019JB019060. <https://doi.org/10.1029/2019jb019060>

Belgrano, T. M., Tollan, P. M., Marxer, F., & Diamond, L. W. (2021). Paleobathymetry of submarine lavas in the Samail and Troodos ophiolites: Insights from volatiles in glasses and implications for hydrothermal systems. *Journal of Geophysical Research: Solid Earth*, 126(7), e2021JB021966. <https://doi.org/10.1029/2021jb021966>

Bernasconi, S., Niermeten, L., Früh-Green, G. L., & Bernasconi, S. M. (2021). Carbonate mineralogy in mantle peridotites of the Atlantis massif (IODP Expedition 357). *Journal of Geophysical Research: Solid Earth*, 126(12), e2021JB021885. <https://doi.org/10.1029/2021jb021885>

Berndt, M. E., Allen, D. E., & Seyfried, W. E., Jr. (1996). Reduction of CO₂ during serpentinization of olivine at 300°C and 500 bar. *Geology*, 24(4), 351–354. [https://doi.org/10.1130/0091-7613\(1996\)024<0351:rocdso>2.3.co;2](https://doi.org/10.1130/0091-7613(1996)024<0351:rocdso>2.3.co;2)

Browning, P. (1984). Cryptic variation within the cumulate sequence of the Oman ophiolite: Magma chamber depth and petrological implications. *Geological Society, London, Special Publications*, 13(1), 71–82. <https://doi.org/10.1144/GSL.SP.1984.013.01.07>

Bosch, D., Jamais, M., Boudier, F., Nicolas, A., Dautria, J.-M., & Agrinier, P. (2004). Deep and high-temperature hydrothermal circulation in the Oman ophiolite: Petrological and Isotopic evidence. *Journal of Petrology*, 45(6), 1181–1208. <https://doi.org/10.1093/ptrology/egh010>

Boskabadi, A., Pitcairn, I. K., Leybourne, M. I., Teagle, D. A., Cooper, M. J., Hadzadeh, H., et al. (2020). Carbonation of ophiolitic ultramafic rocks: Listvenite formation in the Late Cretaceous ophiolites of eastern Iran. *Lithos*, 352, 105307. <https://doi.org/10.1016/j.lithos.2019.105307>

Boudier, F., & Juteau, T. (Eds.). (2000). *The ophiolite of Oman and United Arab Emirates. Marine geophysical researches* (Vol. 21, pp. 145–408).

Boudier, F., & Nicolas, A. (Eds.). (1988). *The ophiolites of Oman. Tectonophysics* (Vol. 151, p. 401).

Boudier, F., Nicolas, A., & Bouchez, J. L. (1982). Kinematics of oceanic thrusting and subduction from basal sections of ophiolites. *Nature*, 296(5860), 825–828. <https://doi.org/10.1038/296825a0>

Boulanger, M., France, L., Ferrando, C., Ildefonse, B., Ghosh, B., Sanfilippo, A., et al. (2021). Magma-mush interactions in the lower oceanic crust: Insights from Atlantis Bank layered series (Southwest Indian ridge). *Journal of Geophysical Research: Solid Earth*, 126(9), e2021JB022331. <https://doi.org/10.1029/2021jb022331>

Bruni, J., Canepa, M., Chiodini, G., Cioni, R., Cipolli, F., Longinelli, A., et al. (2002). Irreversible water-rock mass transfer accompanying the generation of the neutral, Mg-HCO₃ and high-pH, Ca-OH spring waters of the Genova province, Italy. *Applied Geochem*, 17(4), 455–474. [https://doi.org/10.1016/s0883-2927\(01\)00113-5](https://doi.org/10.1016/s0883-2927(01)00113-5)

Carbotte, S. M., Marjanović, M., Arnulf, A. F., Nedimović, M. R., Canales, J. P., & Arnoux, G. M. (2021). Stacked magma lenses beneath mid-ocean ridges: Insights from new seismic observations and synthesis with prior geophysical and geologic findings. *Journal of Geophysical Research: Solid Earth*, 126(4), e2020JB021434. <https://doi.org/10.1029/2020jb021434>

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- Carter, E. J., O'Driscoll, B., Burgess, R., Clay, P. L., Hepworth, J., & O. D. P. S. Team. (2022). Bimodal alteration of the oceanic crust revealed by halogen and noble gas systematics in the Oman Ophiolite. *Journal of Geophysical Research: Solid Earth*, 127(1), e2021JB022669. <https://doi.org/10.1029/2021jb022669>
- Casini, L., Maino, M., Sanfilippo, A., Ildefonso, B., & Dick, H. J. (2021). High-temperature strain localization and the nucleation of Oceanic Core Complexes (16.5°N, Mid-Atlantic Ridge). *Journal of Geophysical Research: Solid Earth*, 126(9), e2021JB022215. <https://doi.org/10.1029/2021jb022215>
- Christensen, N. I. (1978). Ophiolites, seismic velocities and oceanic crustal structure. *Tectonophysics*, 47(1–2), 131–157. [https://doi.org/10.1016/0040-1951\(78\)90155-5](https://doi.org/10.1016/0040-1951(78)90155-5)
- Christensen, N. I., & Salisbury, M. H. (1975). Structure and constitution of the lower oceanic crust. *Reviews of Geophysics*, 13(1), 57–86. <https://doi.org/10.1029/rf013i001p00057>
- Christensen, N. I., & Smewing, J. D. (1981). Geology and seismic structure of the southern section of the Oman Ophiolite. *Journal of Geophysical Research*, 86(B4), 2545–2555. <https://doi.org/10.1029/jb086ib04p02545>
- Church, W. T., & Stevens, R. K. (1971). Early Paleozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences. *Journal of Geophysical Research*, 76(5), 1460–1466. <https://doi.org/10.1029/jb076i005p01460>
- Clark, I. D., & Fontes, J.-C. (1990). Paleoclimatic reconstruction in northern Oman based on carbonates from hyperalkaline groundwaters. *Quaternary Research*, 33(3), 320–336. [https://doi.org/10.1016/0033-5894\(90\)90059-t](https://doi.org/10.1016/0033-5894(90)90059-t)
- Coleman, R. G. (1971). Plate tectonic emplacement of upper mantle peridotites along continental edges. *Journal of Geophysical Research*, 76(5), 1212–1222. <https://doi.org/10.1029/jb076i005p01212>
- Coleman, R. G. (1977). *Ophiolites: Ancient oceanic lithosphere?* (p. 229). Springer-Verlag.
- Coleman, R. G., & Hopson, C. A. (Eds.). (1981). *Journal of geophysical research special issue on the Oman ophiolite*.
- Coogan, L. A., Howard, K. A., Gillis, K. M., Bickle, M. J., Chapman, H., Boyce, A. J., et al. (2006). Chemical and thermal constraints on focussed fluid flow in the lower oceanic crust. *American Journal of Science*, 306(6), 389–427. <https://doi.org/10.2475/06.2006.01>
- Coogan, L. A., Jenkin, G. R. T., & Wilson, R. N. (2002). Constraining the cooling rate of lower oceanic crust: A new approach applied to the Oman ophiolite. *Earth and Planetary Science Letters*, 199(1–2), 127–146. [https://doi.org/10.1016/s0012-821x\(02\)00554-x](https://doi.org/10.1016/s0012-821x(02)00554-x)
- Cook, M. C., Blank, J. G., Rietze, A., Suzuki, S., Neelson, K. H., & Morrill, P. L. (2021). A geochemical comparison of three terrestrial sites of serpentinization: The tablelands, the cedars, and Aqua de Ney. *Journal of Geophysical Research: Biogeosciences*, 126(11), e2021JG006316. <https://doi.org/10.1029/2021jg006316>
- Cook, M. C., Blank, J. G., Suzuki, S., Neelson, K. H., & Morrill, P. L. (2021). Assessing geochemical bioenergetics and microbial metabolisms at three terrestrial sites of serpentinization: The Tablelands (NL, CAN), the Cedars (CA, USA), and Aqua de Ney (CA, USA). *Journal of Geophysical Research: Biogeosciences*, 126(6), e2019JG005542. <https://doi.org/10.1029/2019jg005542>
- Cooperdock, E. H. G., Stockli, D. F., Kelemen, P. B., & de Obeso, J. C. (2020). Timing of magnetite growth associated with peridotite-hosted carbonate veins in the SE Samail ophiolite, Wadi Fins. *Journal of Geophysical Research*, 125, e2019JB018632.
- Cox, S., Fagereng, Å., & MacLeod, C. J. (2021). Shear zone development in serpentinized mantle: Implications for the strength of oceanic transform faults. *Journal of Geophysical Research: Solid Earth*, 126(5), e2020JB020763. <https://doi.org/10.1029/2020jb020763>
- Crotteau, M. A., Greenberger, R. N., Ehlmann, B. L., Rossman, G. R., Harris, M., Kelemen, P. B., et al. (2021). Characterizing hydration of the ocean crust using shortwave infrared microimaging spectroscopy of ICDP Oman Drilling Project cores. *Journal of Geophysical Research: Solid Earth*, 126(11), e2021JB022676. <https://doi.org/10.1029/2021jb022676>
- de Obeso, J. C., Kelemen, P. B., Leong, J. A., Menzel, M. D., Manning, C. E., Godard, M., et al. (2022). Deep sourced fluids for peridotite carbonation in the shallow mantle wedge of a fossil subduction zone: Sr and C isotope profiles of OmanDP Hole BT1B. *Journal of Geophysical Research*, 127, e2021JB022704. <https://doi.org/10.1029/2021JB022704>
- de Obeso, J. C., Santiago Ramos, D., Higgins, J., & Kelemen, P. B. (2021). A Mg isotopic perspective on the mobility of magnesium during serpentinization and carbonation of the Oman ophiolite. *Journal of Geophysical Research*, 126, e2020JB020237. <https://doi.org/10.1029/2020JB020237>
- Deschamps, F., Guillot, S., Godard, M., Chauvel, C., Andreani, M., & Hattori, K. (2010). In situ characterization of serpentinites from forearc mantle wedges: Timing of serpentinization and behavior of fluid-mobile elements in subduction zones. *Chemical Geology*, 269(3–4), 262–277. <https://doi.org/10.1016/j.chemgeo.2009.10.002>
- Dewey, J. F., & Bird, J. M. (1971). Origin and emplacement of the ophiolite suite: Appalachian ophiolites in Newfoundland. *Journal of Geophysical Research*, 76(14), 3179–3206. <https://doi.org/10.1029/jb076i014p03179>
- Dickinson, W. R. (1971). Plate tectonics in geologic history. *Science*, 174(4005), 107–113. <https://doi.org/10.1126/science.174.4005.107>
- Ellison, E. T., Templeton, A. S., Zeigler, S. D., Mayhew, L. E., Kelemen, P. B., Matter, J. M., & Oman Drilling Project Science Party. (2021). Low-temperature hydrogen formation during aqueous alteration of serpentinized peridotite in the samail ophiolite. *Journal of Geophysical Research*, 126(6), e2021JB021981. <https://doi.org/10.1029/2021jb021981>
- Ernst, W. G. (1971). Metamorphic zonations on presumably subducted lithospheric plates from Japan. *Contributions to Mineralogy and Petrology*, 34(1), 43–59. <https://doi.org/10.1007/bf00376030>
- Evans, A. D., Teagle, D. A., Craw, D., Henstock, T. J., & Falcon-Suarez, I. H. (2021). Uplift and exposure of serpentinized massifs: Modeling differential serpentinite diapirism and exhumation of the Troodos Mantle Sequence, Cyprus. *Journal of Geophysical Research: Solid Earth*, 126(6), e2020JB021079. <https://doi.org/10.1029/2020jb021079>
- Evans, B. W. (2004). The serpentinite multsystem revisited: Chrysotile is metastable. *International Geology Review*, 46(6), 479–506. <https://doi.org/10.2747/0020-6814.46.6.479>
- Evans, O., Spiegelman, M. W., & Kelemen, P. B. (2020). Phase-field modeling of reaction-driven cracking: Determining conditions for extensive olivine serpentinization. *Journal of Geophysical Research*, 125(1), e2019JB018614. <https://doi.org/10.1029/2019jb018614>
- Falk, E. S., & Kelemen, P. B. (2015). Geochemistry and petrology of listvenite in the Oman ophiolite: Complete carbonation of peridotite during ophiolite emplacement. *Geochimica et Cosmochimica Acta*, 160, 70–90. <https://doi.org/10.1016/j.gca.2015.03.014>
- Ferrando, C., France, L., Basch, V., Sanfilippo, A., Tribuzio, R., & Boulanger, M. (2021). Grain size variations record segregation of residual melts in slow-spreading oceanic crust (Atlantis Bank, 57°E Southwest Indian ridge). *Journal of Geophysical Research: Solid Earth*, 126(4), e2020JB020997. <https://doi.org/10.1029/2020jb020997>
- Fisk, M. R., & Giovannoni, S. J. (1999). Sources of nutrients and energy for a deep biosphere on Mars. *Journal of Geophysical Research*, 104(E5), 11805–11815. <https://doi.org/10.1029/1999je900010>
- Förster, B., Braga, R., Aulbach, S., Pö, D. L., Bargossi, G. M., & Mair, V. (2017). A petrographic study of carbonate phases in the Ulten Zone ultramafic rocks: Insights into carbonation in the mantle wedge and exhumation-related decarbonation. *Ophioliti*, 42, 105–127. <https://doi.org/10.4454/ofioliti.v42i2.487>

- Foustoukos, D. I., & Seyfried, W. E. (2004). Hydrocarbons in hydrothermal vent fluids: The role of chromium-bearing catalysts. *Science*, 304(5673), 1002–1005. <https://doi.org/10.1126/science.1096033>
- France, L., Lombard, M., Nicollet, C., Berthod, C., Debret, B., Koepke, J., et al. (2021). Quantifying the axial magma lens dynamics at the roof of oceanic magma reservoirs (dike/gabbro transition): Oman drilling project GT3 site survey. *Journal of Geophysical Research: Solid Earth*, 126(5), e2020JB021496. <https://doi.org/10.1029/2020jb021496>
- Frost, B. R. (1985). On the stability of sulfides, oxides, and native metals in serpentinite. *Journal of Petrology*, 26(1), 31–63. <https://doi.org/10.1093/petrology/26.1.31>
- Früh-Green, G. L., Kelley, D. S., Lilley, M. D., Cannat, M., Chavagnac, V., & Baross, J. A. (2022). Diversity of magmatism, hydrothermal processes and microbial interactions at mid-ocean ridges. *Nature Reviews Earth & Environment*, 3(12), 1–20. <https://doi.org/10.1038/s43017-022-00364-y>
- Früh-Green, G. L., Orcutt, B. N., Rouméjon, S., Lilley, M. D., Morono, Y., Cotterill, C., et al. (2018). Magmatism, serpentinization and life: Insights through drilling the Atlantis massif (IODP Expedition 357). *Lithos*, 323, 137–155. <https://doi.org/10.1016/j.lithos.2018.09.012>
- Garber, J. M., Rioux, M., Searle, M. P., Kyländer-Clark, A. R., Hacker, B. R., Vervoort, J. D., et al. (2021). Dating continental subduction beneath the Samail Ophiolite: Garnet, zircon, and rutile petrochronology of the as Sifah eclogites, NE Oman. *Journal of Geophysical Research: Solid Earth*, 126(12), e2021JB022715. <https://doi.org/10.1029/2021jb022715>
- Garbe-Schönberg, D., Koepke, J., Müller, S., Mock, D., & Müller, T. (2022). A reference section through fast-spread lower oceanic crust, Wadi Gideah, Samail ophiolite (Sultanate of Oman): Whole rock geochemistry. *Journal of Geophysical Research: Solid Earth*, 127(6), e2021JB022734. <https://doi.org/10.1029/2021JB022734>
- Garrido, C.-J., Kelemen, P. B., & Hirth, G. (2001). Variation of cooling rate with depth in lower crust formed at an oceanic spreading ridge: Plagioclase crystal size distributions in gabbros from the Oman ophiolite. *Geochemistry, Geophysics, Geosystems*, 2(10), 2000GC000136. <https://doi.org/10.1029/2000gc000136>
- Gass, I. (1968). Is the Troodos massif of Cyprus a fragment of Mesozoic ocean floor? *Nature*, 220(5162), 39–42. <https://doi.org/10.1038/220039a0>
- Ghent, E. D., & Stout, M. Z. (1981). Metamorphism at the base of the Samail ophiolite, southeastern Oman mountains. *Journal of Geophysical Research*, 86(B4), 2557–2571. <https://doi.org/10.1029/jb086ib04p02557>
- Godard, M., Carter, E. J., Decrausaz, T., Lafay, R., Bennett, E., Kourim, F., et al. (2021). Geochemical profiles across the listvenite-metamorphic transition in the basal megathrust of the Semail ophiolite: Results from drilling at OmanDP Hole BT1B. *Journal of Geophysical Research: Solid Earth*, 126(12), e2021JB022733. <https://doi.org/10.1029/2021jb022733>
- Grambling, N. L., Dygert, N., Boring, B., Jean, M. M., & Kelemen, P. B. (2022). Thermal history of lithosphere formed beneath fast spreading ridges: Constraints from the mantle transition zone of the East Pacific rise at Hess deep and Oman drilling project, wadi zeeb, samail ophiolite. *Journal of Geophysical Research: Solid Earth*, 127(1), e2021JB022696. <https://doi.org/10.1029/2021jb022696>
- Greenberger, R. N., Harris, M., Ehlmann, B. L., Crotteau, M. A., Kelemen, P. B., Manning, C. E., et al. (2021). Hydrothermal alteration of the ocean crust and patterns in mineralization with depth as measured by micro-imaging infrared spectroscopy. *Journal of Geophysical Research: Solid Earth*, 126(8), e2021JB021976. <https://doi.org/10.1029/2021jb021976>
- Gregory, R. T., & Taylor, H. P., Jr. (1981). An oxygen isotope profile in a section of Cretaceous oceanic crust, Samail ophiolite, Oman: Evidence for $\delta^{18}\text{O}$ buffering of the oceans by deep (>5 km) seawater-hydrothermal circulation at mid-ocean ridges. *Journal of Geophysical Research*, 86(B4), 2737–2755. <https://doi.org/10.1029/jb086ib04p02737>
- Hacker, B. R. (1990). Simulation of the metamorphic and deformational history of the metamorphic sole of the Oman ophiolite. *Journal of Geophysical Research*, 95(B4), 4895–4907. <https://doi.org/10.1029/jb095ib04p04895>
- Hacker, B. R. (1991). The role of deformation in the formation of metamorphic gradients: Ridge subduction beneath the Oman ophiolite. *Tectonics*, 10(2), 455–473. <https://doi.org/10.1029/90tc02779>
- Hacker, B. R. (1994). Rapid emplacement of young oceanic lithosphere: Argon geochronology of the Oman ophiolite. *Science*, 265(5178), 1563–1565. <https://doi.org/10.1126/science.265.5178.1563>
- Halls, C., & Zhao, R. (1995). Listvenite and related rocks: Perspectives on terminology and mineralogy with reference to an occurrence at Cregganbaun, Co. Mayo, Republic of Ireland. *Mineralium Deposita*, 30(3–4), 303–313. <https://doi.org/10.1007/bf00196366>
- Hanghøj, K., Kelemen, P. B., Hassler, D., & Godard, M. (2010). Composition and genesis of depleted mantle peridotites from the Wadi Tayin massif, Oman ophiolite: Major and trace element geochemistry, and Os isotope and PGE systematics. *Journal of Petrology*, 51(1–2), 201–227. <https://doi.org/10.1093/petrology/egp077>
- Hansen, L. D., Dipple, G. M., Gordon, T. M., & Kellett, D. A. (2005). Carbonated serpentinite (listwanite) at Atlin, British Columbia: A geological analogue to carbon dioxide sequestration. *The Canadian Mineralogist*, 43(1), 225–239. <https://doi.org/10.2113/gscanmin.43.1.225>
- Hatakeyama, K., Katayama, I., Abe, N., Okazaki, K., Michibayashi, K., & Party, O. D. P. S. (2021). Effects of alteration and cracks on the seismic velocity structure of oceanic lithosphere inferred from ultrasonic measurements of mafic and ultramafic samples collected by the Oman drilling project. *Journal of Geophysical Research: Solid Earth*, 126(11), e2021JB021923. <https://doi.org/10.1029/2021jb021923>
- Hong, G., Till, J. L., Greve, A., Lee, S. M., & Party, O. D. P. S. (2022). New rock magnetic analysis of ultramafic cores from the Oman drilling project and its implications for alteration of lower crust and upper mantle. *Journal of Geophysical Research: Solid Earth*, 127(7), e2022JB024379. <https://doi.org/10.1029/2022jb024379>
- Horita, J., & Berndt, M. E. (1999). Abiogenic methane formation and isotopic fractionation under hydrothermal conditions. *Science*, 285(5430), 1055–1057. <https://doi.org/10.1126/science.285.5430.1055>
- Howells, A. E., Leong, J. A., Ely, T., Santana, M., Robinson, K., Esquivel-Elizondo, S., et al. (2022). Energetically informed niche models of hydrogenotrophs detected in sediments of serpentinized fluids of the Samail Ophiolite of Oman. *Journal of Geophysical Research: Biogeosciences*, 127(3), e2021JG006317. <https://doi.org/10.1029/2021jg006317>
- Iyer, K., Jamtveit, B., Mathiesen, J., Malthe-Sørenssen, A., & Feder, J. (2008). Reaction-assisted hierarchical fracturing during serpentinization. *Earth and Planetary Science Letters*, 267(3–4), 503–516. <https://doi.org/10.1016/j.epsl.2007.11.060>
- Jamtveit, B., Putnis, C., & Malthe-Sørenssen, A. (2009). Reaction induced fracturing during replacement processes. *Contributions to Mineralogy and Petrology*, 157(1), 127–133. <https://doi.org/10.1007/s00410-008-0324-y>
- Jones, G., Robertson, A. H. F., & Cann, J. R. (1991). Genesis and emplacement of the supra-subduction zone Pindos ophiolite, northwestern Greece. In T. Peters, A. Nicolas, & R. G. Coleman (eds.) *Ophiolite genesis and evolution of the oceanic lithosphere* (pp. 771–799). Kluwer.
- Katayama, I., Abe, N., Hatakeyama, K., Akamatsu, Y., Okazaki, K., Ulven, O. I., et al. (2020). Permeability profiles across the crust–mantle sections in the Oman Drilling Project inferred from dry and wet resistivity data. *Journal of Geophysical Research*, 125(8), e2019JB018698. <https://doi.org/10.1029/2019jb018698>
- Kelemen, P. B., Al Rajhi, A., Godard, M., Ildefonse, B., Kopke, J., MacLeod, C., et al. (2013). Scientific drilling and related research in the samail ophiolite, Sultanate of Oman. *Scientific Drilling Journal*, 15, 64–71. <https://doi.org/10.5194/sd-15-64-2013>

- Kelemen, P. B., de Obeso, J. C., Leong, J. A., Godard, M., Okazaki, K., Kotowski, A. J., et al. (2022). Listvenite formation during mass transfer into the leading edge of the mantle wedge: Initial results from Oman Drilling Project Hole BT1B. *Journal of Geophysical Research*, *127*(2), e2021JB022352. <https://doi.org/10.1029/2021jb022352>
- Kelemen, P. B., & Hirth, G. (2012). Reaction-driven cracking during retrograde metamorphism: Olivine hydration and carbonation. *Earth and Planetary Science Letters*, *345–348*, 81–89. <https://doi.org/10.1016/j.epsl.2012.06.018>
- Kelemen, P. B., Kikawa, E., & Miller, D. J., & Shipboard Scientific Party. (2007). Leg 209 summary: Processes in a 20-km-thick conductive boundary layer beneath the Mid-Atlantic Ridge, 14°–16°N. In *Proceeding of the ODP, Science Results 209* (pp. 1–33). Retrieved from http://www-odp.tamu.edu/publications/209_SR/synth/synth.htm
- Kelemen, P. B., Koga, K., & Shimizu, N. (1997). Geochemistry of gabbro sills in the crust-mantle transition zone of the Oman ophiolite: Implications for the origin of the oceanic lower crust. *Earth and Planetary Science Letters*, *146*(3–4), 475–488. [https://doi.org/10.1016/S0012-821X\(96\)00235-X](https://doi.org/10.1016/S0012-821X(96)00235-X)
- Kelemen, P. B., Leong, J. A., de Obeso, J. C., Matter, J. M., Ellison, E. T., Templeton, A., et al. (2021). Initial results from the Oman drilling project multi-borehole observatory: Petrogenesis and ongoing alteration of mantle peridotite in the weathering horizon. *Journal of Geophysical Research*, *126*(12), e2021JB022729. <https://doi.org/10.1029/2021jb022729>
- Kelemen, P. B., & Manning, C. E. (2015). Reevaluating carbon fluxes in subduction zones: What goes down, mostly comes up. *Proceedings of the National Academy of Sciences*, *112*(30), E3997–E4006. <https://doi.org/10.1073/pnas.1507889112>
- Kelemen, P. B., & Matter, J. (2008). In situ mineral carbonation in peridotite for CO₂ storage. *Proceedings of the National Academy of Sciences*, *105*(45), 17295–17300. <https://doi.org/10.1073/pnas.0805794105>
- Klaessens, D., Reisberg, L., & Jousselin, D., & O. D. P. S. Team. (2021). Highly siderophile element and Os isotope results from the structurally atypical Batin dunite in the Wadi Tayin massif of the Oman ophiolite. *Journal of Geophysical Research: Solid Earth*, *126*(10), e2021JB021977. <https://doi.org/10.1029/2021jb021977>
- Koepke, J., Garbe-Schönberg, D., Müller, T., Mock, D., Müller, S., & Nasir, S. (2022). A reference section through fast-spread lower oceanic crust, Wadi Gideah, samail ophiolite (Sultanate of Oman): Petrography and petrology. *Journal of Geophysical Research: Solid Earth*, *127*(1), e2021JB022735. <https://doi.org/10.1029/2021jb022735>
- Korenaga, J., & Kelemen, P. B. (1997). Origin of gabbro sills in the Moho transition zone of the Oman ophiolite: Implications for magma transport in the oceanic lower crust. *Journal of Geophysical Research*, *102*(B12), 27729–27749. <https://doi.org/10.1029/97jb02604>
- Korenaga, J., & Kelemen, P. B. (1998). Melt migration through the oceanic lower crust: A constraint from melt percolation modeling with finite solid diffusion. *Earth and Planetary Science Letters*, *156*(1–2), 1–11. [https://doi.org/10.1016/S0012-821X\(98\)00004-1](https://doi.org/10.1016/S0012-821X(98)00004-1)
- Kotowski, A. J., Cloos, M., Stockli, D. F., & Bos Orent, E. (2021). Structural and thermal evolution of an infant subduction shear zone: Insights from sub-ophiolite metamorphic rocks recovered from Oman Drilling Project Site BT-1B. *Journal of Geophysical Research: Solid Earth*, *126*(12), e2021JB021702. <https://doi.org/10.1029/2021jb021702>
- Kourim, F., Rospabé, M., Dygert, N., Chatterjee, S., Takazawa, E., Wang, K. L., et al. (2022). Geochemical characterization of the Oman crust-mantle transition zone, OmanDP Holes CM1A and CM2B. *Journal of Geophysical Research: Solid Earth*, *127*(4), e2021JB022694. <https://doi.org/10.1029/2021jb022694>
- Le Mée, L., Girardeau, J., & Monnier, C. (2004). Mantle segmentation along the Oman ophiolite fossil mid-ocean ridge. *Nature*, *432*(7014), 167–172. <https://doi.org/10.1038/nature03075>
- Leong, J. A., Howells, A. E., Robinson, K. J., Cox, A., Debes, R. V., II, Fecteau, K., et al. (2021). Theoretical predictions vs environmental observations on serpentinization fluids: Lessons from the Samail ophiolite in Oman. *Journal of Geophysical Research*, *126*, e2020JB020756. <https://doi.org/10.1029/2020JB020756>
- Li, Z.-X. A., & Lee, C.-T. (2006). Geochemical investigation of serpentinized oceanic lithospheric mantle in the Feather River ophiolite, California: Implications for the recycling rate of water by subduction. *Chemical Geology*, *235*(1–2), 161–185. <https://doi.org/10.1016/j.chemgeo.2006.06.011>
- Lippard, S. J., Shelton, A. W., & Gass, I. G. (1986). *The ophiolite of Northern Oman* (Vol. 11, p. 178). Geological Society London Memoir.
- MacDonald, A. H., & Fyfe, W. S. (1985). Rate of serpentinization in seafloor environments. *Tectonophysics*, *116*(1–2), 123–135. [https://doi.org/10.1016/0040-1951\(85\)90225-2](https://doi.org/10.1016/0040-1951(85)90225-2)
- MacLeod, C. J., Lissenberg, C. J., & Bibby, L. E. (2013). “Moist MORB” axial magmatism in the Oman ophiolite: The evidence against a mid-ocean ridge origin. *Geology*, *41*(4), 459–462. <https://doi.org/10.1130/g33904.1>
- Malpas, J., Stevens, R. K., & Strong, D. F. (1973). Amphibolite associated with the New foundland ophiolite: Its classification and tectonic significance. *Geology*, *1*(1), 45–47. [https://doi.org/10.1130/0091-7613\(1973\)1<45:aawnoi>2.0.co;2](https://doi.org/10.1130/0091-7613(1973)1<45:aawnoi>2.0.co;2)
- Malvoisin, B., Zhang, C., Müntener, O., Baumgartner, L. P., Kelemen, P. B., & Oman Drilling Project Science Team. (2020). Measurement of volume change and mass transfer during serpentinisation: Insights from the Oman Drilling Project. *Journal of Geophysics*, *125*(5), e2019JB018877. <https://doi.org/10.1029/2019JB018877>
- McCollom, T. M. (1999). Methanogenesis as a potential source of chemical energy for primary biomass production by autotrophic organisms in hydrothermal systems on Europa. *Journal of Geophysical Research*, *104*(E12), 30729–30742. <https://doi.org/10.1029/1999je001126>
- McCollom, T. M. (2007). Geochemical constraints on sources of metabolic energy for chemolithoautotrophy in ultramafic-hosted deep-sea hydrothermal systems. *Astrobiology*, *7*(6), 933–950. <https://doi.org/10.1089/ast.2006.0119>
- Menzel, M. D., Garrido, C. J., Sánchez-Vizcaíno, V. L., Marchesi, C., Hidas, K., Escayola, M. P., & Huertas, A. D. (2018). Carbonation of mantle peridotite by CO₂-rich fluids: The formation of listvenites in the Advocate ophiolite complex (Newfoundland, Canada). *Lithos*, *323*, 238–261. <https://doi.org/10.1016/j.lithos.2018.06.001>
- Menzel, M. D., Urai, J. L., Obeso, J. C. D., Kotowski, A., Manning, C. E., Kelemen, P. B., et al. (2020). Brittle deformation of carbonated peridotite: Insights from listvenites of the Samail ophiolite (Oman drilling project Hole BT1B). *Journal of Geophysical Research*, *125*(10), e2020JB020199. <https://doi.org/10.1029/2020jb020199>
- Menzel, M. D., Urai, J. L., Ukar, E., Hirth, G., Schwedt, A., Kovács, A., et al. (2022). Ductile deformation during carbonation of serpentinized peridotite. *Nature Communications*, *13*, 1–13. <https://doi.org/10.1038/s41467-022-31049-1>
- Miyashiro, A. (1973). The Troodos ophiolite complex was probably formed in an island arc. *Earth and Planetary Science Letters*, *19*(2), 218–224. [https://doi.org/10.1016/0012-821X\(73\)90118-0](https://doi.org/10.1016/0012-821X(73)90118-0)
- Mock, D., Ildefonse, B., Müller, T., & Koepke, J. (2021). A reference section through fast-spread lower oceanic crust, Wadi Gideah, Samail ophiolite (Sultanate of Oman): Insights from crystallographic preferred orientations. *Journal of Geophysical Research: Solid Earth*, *126*(6), e2021JB021864. <https://doi.org/10.1029/2021jb021864>
- Mock, D., Neave, D. A., Müller, S., Garbe-Schönberg, D., Namur, O., Ildefonse, B., & Koepke, J. (2021). Formation of igneous layering in the lower oceanic crust from the Samail ophiolite, Sultanate of Oman. *Journal of Geophysical Research: Solid Earth*, *126*(1), e2020JB019573. <https://doi.org/10.1029/2020jb019573>

- Monnier, C., Girardeau, J., Le Mée, L., & Polve, M. (2006). Along-ridge petrological segmentation of the mantle in the Oman ophiolite. *Geochemistry, Geophysics, Geosystems*, 7(11), 11008. <https://doi.org/10.1029/2006GC001320>
- Monnin, C., Quéméneur, M., Price, R., Jeanpert, J., Maurizot, P., Boulart, C., et al. (2021). The chemistry of hyperalkaline springs in serpentinizing environments: 1. The composition of free gases in New Caledonia compared to other springs worldwide. *Journal of Geophysical Research: Biogeosciences*, 126(9), e2021JG006243. <https://doi.org/10.1029/2021jg006243>
- Müller, S., Garbe-Schönberg, D., Koepke, J., & Hoernle, K. (2022). A reference section through fast-spread lower oceanic crust, Wadi Gideah, samail ophiolite (Sultanate of Oman): Trace element systematics and REE crystallization temperatures—Implications for hybrid crustal accretion. *Journal of Geophysical Research: Solid Earth*, 127(3), e2021JB022699. <https://doi.org/10.1029/2021jb022699>
- Naldrett, A. J. (1966). Talc-carbonate alteration of some serpentinized ultramafic rocks south of Timmins, Ontario. *Journal of Petrology*, 7(3), 489–499. <https://doi.org/10.1093/ptrology/7.3.489>
- Neal, C., & Stanger, G. (1983). Hydrogen generation from mantle source rocks in Oman. *Earth and Planetary Science Letters*, 66, 315–320. [https://doi.org/10.1016/0012-821x\(83\)90144-9](https://doi.org/10.1016/0012-821x(83)90144-9)
- Neal, C., & Stanger, G. (1984). Calcium and magnesium hydroxide precipitation from alkaline groundwaters in Oman, and their significance to the process of serpentinization. *Mining Magazine*, 48(347), 237–241. <https://doi.org/10.1180/minmag.1984.048.347.07>
- Neal, C., & Stanger, G. (1985). Past and present serpentinization of ultramafic rocks: An example from the Semail ophiolite nappe of northern Oman. In J. I. Drewer (ed.) *The chemistry of weathering* (pp. 249–275). D. Reidel Publishing Company.
- Nicolas, A. (1989). *Structures in ophiolites and dynamics of oceanic lithosphere* (p. 367). Kluwer.
- Nicolas, A., Reuber, I., & Benn, K. (1988). A new magma chamber model based on structural studies in the Oman ophiolite. *Tectonophysics*, 151(1–4), 87–105. [https://doi.org/10.1016/0040-1951\(88\)90242-9](https://doi.org/10.1016/0040-1951(88)90242-9)
- Ninkabou, D., Agard, P., Nielsen, C., Smit, J., Gorini, C., Rodriguez, M., et al. (2021). Structure of the offshore obducted Oman margin: Emplacement of Semail ophiolite and role of tectonic inheritance. *Journal of Geophysical Research: Solid Earth*, 126(2), JB020187. <https://doi.org/10.1029/2020jb020187>
- Nothaft, D. B., Templeton, A. S., Boyd, E. S., Matter, J. M., Stute, M., Paukert Vankeuren, A. N., & Oman Drilling Project Science Team. (2021). Aqueous geochemical and microbial variation across discrete depth intervals in a peridotite aquifer assessed using a packer system in the Semail ophiolite, Oman. *Journal of Geophysical Research: Biogeosciences*, 126(9), e2021JG006319. <https://doi.org/10.1029/2021jg006319>
- Nothaft, D. B., Templeton, A. S., Rhim, J. H., Wang, D. T., Labidi, J., Miller, H. M., et al. (2021). Geochemical, biological and clumped isotopologue evidence for substantial microbial methane production under carbon limitation in serpentinites of the Semail Ophiolite, Oman. *Journal of Geophysical Research*, 126(10), e2020JG006025. <https://doi.org/10.1029/2020jg006025>
- Nozaka, T. (2014). Metasomatic hydration of the Oeyama forearc peridotites: Tectonic implications. *Lithos*, 184, 346–360. <https://doi.org/10.1016/j.lithos.2013.11.012>
- O'Hanley, D. S. (1992). Solution to the volume problem in serpentinization. *Geology*, 20(8), 705–708. [https://doi.org/10.1130/0091-7613\(1992\)020<0705:sttvpj>2.3.co;2](https://doi.org/10.1130/0091-7613(1992)020<0705:sttvpj>2.3.co;2)
- Okazaki, K., Michibayashi, K., Hatakeyama, K., Abe, N., Johnson, K., & Kelemen, P. B. (2021). Major mineral fraction and physical properties of carbonated peridotite (listvenite) from ICDP Oman Drilling Project Hole BT1B inferred from X-ray CT core images. *Journal of Geophysical Research*, 126(12), e2021JB022719. <https://doi.org/10.1029/2021jb022719>
- Peacock, S. M. (1987). Serpentinization and infiltration metasomatism in the Trinity peridotite, Klamath province, northern California: Implications for subduction zones. *Contributions to Mineralogy and Petrology*, 95(1), 55–70. <https://doi.org/10.1007/bf00518030>
- Peacock, S. M. (1996). Thermal and petrologic structure of subduction zones. *AGU Monograph*, 96, 119–133.
- Pearce, J. A., Alabaster, T., Shelton, A. W., & Searle, M. P. (1981). The Oman ophiolite as a Cretaceous arc-basin complex: Evidence and implications. *Philosophical Transactions of the Royal Society of London*, A300, 299–317.
- Pearce, J. A., & Peate, D. W. (1995). Tectonic implications of the composition of volcanic arc magmas. *Annual Review of Earth and Planetary Sciences*, 23(1), 251–286. <https://doi.org/10.1146/annurev.ea.23.050195.001343>
- Peng, W., Zhang, L., Menzel, M. D., Brovarone, A. V., Tumiati, S., Shen, T., & Hu, H. (2020). Multistage CO₂ sequestration in the subduction zone: Insights from exhumed carbonated serpentinites, SW Tianshan UHP belt, China. *Geochimica et Cosmochimica Acta*, 270, 218–243. <https://doi.org/10.1016/j.gca.2019.11.025>
- Peters, T., Nicolas, A., & Coleman, R. G. (Eds.). (1991). *Ophiolite genesis and evolution of the oceanic lithosphere: Proceedings of the ophiolite conference, held in Muscat, Oman, 7–18 January 1990* (p. 903). Kluwer.
- Phipps Morgan, J., & Chen, Y. J. (1993). The genesis of oceanic crust: Magma injection, hydrothermal circulation, and crustal flow. *Journal of Geophysical Research*, 98(B4), 6283–6297. <https://doi.org/10.1029/92jb02650>
- Pilia, S., Ali, M. Y., Searle, M. P., Watts, A. B., Lü, C., & Thompson, D. A. (2021). Crustal structure of the UAE-Oman mountain range and Arabian rifted passive margin: New constraints from active and passive seismic methods. *Journal of Geophysical Research: Solid Earth*, 126(4), e2020JB021374. <https://doi.org/10.1029/2020jb021374>
- Quick, J. E., & Denlinger, R. P. (1993). Ductile deformation and the origin of layered gabbro in ophiolites. *Journal of Geophysical Research*, 98(B8), 14015–14027. <https://doi.org/10.1029/93jb00698>
- Renard, F. (2021). Reaction-Induced fracturing: When chemistry breaks rocks. *Journal of Geophysical Research: Solid Earth*, 126(2), e2020JB021451. <https://doi.org/10.1029/2020jb021451>
- Rioux, M., Benoit, M., Amri, I., Ceuleneer, G., Garber, J. M., Searle, M., & Leal, K. (2021). The origin of felsic intrusions within the mantle section of the Semail ophiolite: Geochemical evidence for three distinct mixing and fractionation trends. *Journal of Geophysical Research: Solid Earth*, 126(5), e2020JB020760. <https://doi.org/10.1029/2020jb020760>
- Rioux, M., Bowring, S., Kelemen, P. B., Gordon, S., Dudás, F., & Miller, R. (2012). Rapid crustal accretion and magma assimilation in the Oman-U.A.E. ophiolite: High precision U-Pb zircon geochronology of the gabbroic crust. *Journal of Geophysical Research*, 117(B7), B07201. <https://doi.org/10.1029/2012JB009273>
- Rioux, M., Garber, J. M., Searle, M., Kelemen, P. B., Miyashita, S., Adachi, Y., & Bowring, S. (2021). High-precision U-Pb zircon dating of late magmatism in the Semail ophiolite: A record of subduction initiation. *Journal of Geophysical Research: Solid Earth*, 126(5), e2020JB020758. <https://doi.org/10.1029/2020jb020758>
- Robertson, A. H. F., Searle, M. P., & Ries, A. C. (Eds.). (1990). *The geology and tectonics of the Oman region. Geological Society special publication* (p. 831). Geological Society of London.
- Rollinson, H., Searle, M. P., Abbasi, I. A., Al Lazki, A. I., & Al Kindy, M. H. (Eds.). (2014). *Tectonic evolution of the Oman Mountains, Geological Society Special Publication* (p. 460). Geological Society of London.
- Rudge, J. F., Kelemen, P. B., & Spiegelman, M. (2010). A simple model of reaction-induced cracking applied to serpentinization and carbonation of peridotite. *Earth and Planetary Science Letters*, 291(1–4), 215–227. <https://doi.org/10.1016/j.epsl.2010.01.016>

- Sabuda, M. C., Putman, L. I., Hoehler, T. M., Kubo, M. D., Brazelton, W. J., Cardace, D., & Schrenk, M. O. (2021). Biogeochemical gradients in a serpentinization-influenced aquifer: Implications for gas exchange between the subsurface and atmosphere. *Journal of Geophysical Research: Biogeosciences*, *126*(8), e2020JG006209. <https://doi.org/10.1029/2020jg006209>
- Sachan, H. K., Mukherjee, B. K., & Bodnar, R. J. (2007). Preservation of methane generated during serpentinization of upper mantle rocks: Evidence from fluid inclusions in the Nidar ophiolite, Indus Suture Zone, Ladakh (India). *Earth and Planetary Science Letters*, *257*(1–2), 47–59. <https://doi.org/10.1016/j.epsl.2007.02.023>
- Scambelluri, M., Bebout, G. E., Belmonte, D., Gilio, M., Campomenosi, N., Collins, N., & Crispini, L. (2016). Carbonation of subduction-zone serpentinite (high-pressure ophicarbonates; Ligurian Western Alps) and implications for the deep carbon cycling. *Earth and Planetary Science Letters*, *441*, 155–166. <https://doi.org/10.1016/j.epsl.2016.02.034>
- Scambelluri, M., Cannà, E., Guerini, S., Bebout, G. E., Epstein, G., Rotondo, F., & Tartarotti, P. (2022). Carbon mobility and exchange in a plate-interface subduction mélange: A case study of meta-ophiolitic rocks in Champorcher valley, Italian Alps. *Lithos*, *428*, 106813. <https://doi.org/10.1016/j.lithos.2022.106813>
- Schandl, E. S., & Naldrett, A. J. (1992). CO₂ metasomatism of serpentinites south of Timmins, Ontario. *The Canadian Mineralogist*, *30*, 93–108.
- Schandl, E. S., & Wicks, F. J. (1991). Carbonate and associated alteration of ultramafic and rhyolitic rocks at the Hemingway property, Kidd Creek volcanic complex, Timmins, Ontario. *Economic Geology*, *88*(6), 1615–1635. <https://doi.org/10.2113/gsecongeo.88.6.1615>
- Scharf, A., Bailey, C. M., Bolhar, R., Mattern, F., & Ring, U. (2022). Post-obduction listwaenite genesis in the Oman Mountains inferred from structural analysis and U-Pb carbonate dating. *Earth and Planetary Science Letters*, *595*, 117756. <https://doi.org/10.1016/j.epsl.2022.117756>
- Schulte, M., Blake, D., Hoehler, T., & McCollom, T. (2006). Serpentinization and its implications for life on the early Earth and Mars. *Astrobiology*, *6*(2), 364–376. <https://doi.org/10.1089/ast.2006.6.364>
- Schwarzenbach, E. M., Caddick, M. J., Petroff, M., Gill, B. C., Cooperdock, E. H., & Barnes, J. D. (2018). Sulphur and carbon cycling in the subduction zone mélange. *Nature Scientific Reports*, *8*, 1–11. <https://doi.org/10.1038/s41598-018-33610-9>
- Schwarzenbach, E. M., Vogel, M., Früh-Green, G. L., & Boschi, C. (2021). Serpentinization, carbonation, and metasomatism of ultramafic sequences in the Northern Apennine Ophiolite (NW Italy). *Journal of Geophysical Research: Solid Earth*, *126*(5), e2020JB020619. <https://doi.org/10.1029/2020jb020619>
- Schwarzenbach, E. M., Vrijmoed, J. C., Engelmann, J. M., Liesegang, M., Wiechert, U., Rohne, R., & Plümper, O. (2021). Sulfide dissolution and awaruite formation in continental serpentinization environments and its implications to supporting life. *Journal of Geophysical Research: Solid Earth*, *126*(5), e2021JB021758. <https://doi.org/10.1029/2021jb021758>
- Shervais, J. W. (2022). The petrogenesis of modern and ophiolitic lavas reconsidered: Ti-V and Nb-Th. *Geoscience Frontiers*, *13*(2), 101319. <https://doi.org/10.1016/j.gsf.2021.101319>
- Shock, E. L. (1997). High-temperature life without photosynthesis as a model for Mars. *Journal of Geophysical Research*, *102*(E10), 23687–23694. <https://doi.org/10.1029/97je01087>
- Shock, E. L., McCollom, T., & Schulte, M. D. (1995). Geochemical constraints on chemolithoautotrophic reactions in hydrothermal systems. *Origins of Life and Evolution of the Biosphere*, *25*(1–3), 141–159. <https://doi.org/10.1007/bf01581579>
- Sideridis, A., Koutsovitis, P., Tsikouras, B., Karkalis, C., Hauzenberger, C., Zaccarini, F., et al. (2022). Pervasive listwaenitization: The role of subducted sediments within mantle wedge, W. Chalkidiki ophiolites, N. Greece. *Minerals*, *12*(8), 1000. <https://doi.org/10.3390/min12081000>
- Sieber, M. J., Hermann, J., & Yaxley, G. M. (2018). An experimental investigation of C–O–H fluid-driven carbonation of serpentinites under forearc conditions. *Earth and Planetary Science Letters*, *496*, 178–188. <https://doi.org/10.1016/j.epsl.2018.05.027>
- Sleep, N. H. (1975). Formation of oceanic crust: Some thermal constraints. *Journal of Geophysical Research*, *80*(29), 4037–4042. <https://doi.org/10.1029/jb080i029p04037>
- Sleep, N. H., Meibom, A., Fridriksson, T., Coleman, R. G., & Bird, D. K. (2004). H₂-rich fluids from serpentinization: Geochemical and biotic implications. *Proceedings of the National Academy of Sciences*, *101*(35), 12818–12823. <https://doi.org/10.1073/pnas.0405289101>
- Smith, A. G., & Spray, J. G. (1984). *A half-ridge transform model for the Hellenic-Dinaric ophiolites* (Vol. 17, pp. 829–844). Geological Society of London, Special Publications.
- Soret, M., Agard, P., Dubacq, B., Plunder, A., & Yamato, P. (2017). Petrological evidence for stepwise accretion of metamorphic soles during subduction infancy (Semail ophiolite, Oman and UAE). *Journal of Metamorphic Geology*, *35*(9), 1051–1080. <https://doi.org/10.1111/jmg.12267>
- Soret, M., Bonnet, G., Agard, P., Larson, K. P., Cottle, J. M., Dubacq, B., et al. (2022). Timescales of subduction initiation and evolution of subduction thermal regimes. *Earth and Planetary Science Letters*, *584*, 117521. <https://doi.org/10.1016/j.epsl.2022.117521>
- Spandler, C., Hermann, J., Faure, K., Mavrogenes, J. A., & Arculus, R. J. (2008). The importance of talc and chlorite “hybrid” rocks for volatile recycling through subduction zones: Evidence from the high-pressure subduction mélange of New Caledonia. *Contributions to Mineralogy and Petrology*, *155*(2), 181–198. <https://doi.org/10.1007/s00410-007-0236-2>
- Spray, J. G. (1983). Lithosphere–asthenosphere decoupling at spreading centers and initiation of obduction. *Nature*, *304*(5923), 253–255. <https://doi.org/10.1038/304253a0>
- Stewart, E. M., & Ague, J. J. (2020). Pervasive subduction zone devolatilization recycles CO₂ into the forearc. *Nature Communications*, *11*, 1–8. <https://doi.org/10.1038/s41467-020-19993-2>
- Templeton, A., Ellison, E. T., Glombitza, C., Morono, Y., Rempfert, K. R., Hoehler, T. M., et al. (2021). Accessing the subsurface biosphere within rocks undergoing active low-temperature serpentinization in the Semail ophiolite (Oman Drilling Project). *Journal of Geophysical Research*, *126*(10), e2021JG006315. <https://doi.org/10.1029/2021jg006315>
- Ternieten, L., Früh-Green, G. L., & Bernasconi, S. M. (2021a). Carbon geochemistry of the active serpentinization site at the Wadi Tayin massif: Insights from the ICDP Oman Drilling Project, Phase II. *Journal of Geophysical Research: Solid Earth*, *126*(12), e2021JB022712. <https://doi.org/10.1029/2021jb022712>
- Ternieten, L., Früh-Green, G. L., & Bernasconi, S. M. (2021b). Distribution and sources of carbon in serpentinized mantle peridotites at the Atlantis Massif (IODP Expedition 357). *Journal of Geophysical Research: Solid Earth*, *126*(10), e2021JB021973. <https://doi.org/10.1029/2021jb021973>
- Tilton, G. R., Hopson, C. A., & Wright, J. E. (1981). Uranium-lead isotopic ages of the Semail ophiolite, Oman, with applications to Tethyan ocean ridge tectonics. *Journal of Geophysical Research*, *86*(B4), 2736–2775. <https://doi.org/10.1029/jb086ib04p02763>
- Ulrich, M., Muñoz, M., Boulvais, P., Cathelineau, M., Cluzel, D., Guillot, S., & Picard, C. (2020). Serpentinization of New Caledonia peridotites: From depth to (sub-) surface. *Contributions to Mineralogy and Petrology*, *175*(9), 1–25. <https://doi.org/10.1007/s00410-020-01713-0>
- VanTongeren, J. A., Kelemen, P. B., Garrido, C. J., Godard, M., Hanghoj, K., Braun, M., & Pearce, J. A. (2021). The composition of the lower oceanic crust in the Wadi Khafifah section of the southern Semail (Oman) ophiolite. *Journal of Geophysical Research: Solid Earth*, *126*(11), e2021JB021986. <https://doi.org/10.1029/2021jb021986>

- VanTongeren, J. A., Kelemen, P. B., & Hanghøj, K. (2008). Cooling rates in the lower crust of the Oman ophiolite: Ca in olivine, revisited. *Earth and Planetary Science Letters*, 267(1–2), 69–82. <https://doi.org/10.1016/j.epsl.2007.11.034>
- Varnes, E. S., Jakosky, B. M., & McCollom, T. M. (2003). Biological potential of Martian hydrothermal systems. *Astrobiology*, 3(2), 407–414. <https://doi.org/10.1089/153110703769016479>
- Weber, S., Diamond, L. W., Alt-Epping, P., & Brett-Adams, A. C. (2021). Reaction mechanism and water/rock ratios involved in epidote alteration of the oceanic crust. *Journal of Geophysical Research: Solid Earth*, 126(6), e2020JB021540. <https://doi.org/10.1029/2020jb021540>
- Wee, S. Y., Edgcomb, V. P., Beaudoin, D., Yvon-Lewis, S., & Sylvan, J. B. (2021). Microbial abundance and diversity in subsurface lower oceanic crust at Atlantis Bank, Southwest Indian ridge. *Applied and Environmental Microbiology*, 87(22), e01519–e01521. <https://doi.org/10.1128/aem.01519-21>
- Wu, K., Zhang, L., Yuan, H., Sun, W., Deng, J., Zartman, R. E., et al. (2021). Boron, arsenic and antimony recycling in subduction zones: New insights from interactions between forearc serpentinites and CO₂-rich fluids at the slab-mantle interface. *Geochimica et Cosmochimica Acta*, 298, 21–42. <https://doi.org/10.1016/j.gca.2021.01.039>
- Xu, Y., Li, D., Li, D., Dong, G. C., Pearson, D. G., & Liu, J. (2021). Modification of lithospheric mantle by melts/fluids with different sulfur fugacities during the Wilson Cycle: Insights from Lesvos and global ophiolitic peridotites. *Journal of Geophysical Research: Solid Earth*, 126(8), e2021JB022445. <https://doi.org/10.1029/2021jb022445>
- Yoshida, K., Okamoto, A., Shimizu, H., Oyanagi, R., Tsuchiya, N., & O. D. P. S. Party. (2020). Fluid infiltration through oceanic lower crust in response to reaction-induced fracturing: Insights from serpentinized troctolite and numerical models. *Journal of Geophysical Research: Solid Earth*, 125(11), e2020JB020268. <https://doi.org/10.1029/2020jb020268>
- Zhang, C., Koepke, J., Wolff, P. E., Horn, I., Garbe-Schönberg, D., & Berndt, J. (2021). Multi-stage hydrothermal veins in layered gabbro of the Oman ophiolite: Implications for focused fluid circulation in the lower oceanic crust. *Journal of Geophysical Research: Solid Earth*, 126(8), e2021JB022349. <https://doi.org/10.1029/2021jb022349>
- Zhao, M. S., Chen, Y. X., & Zheng, Y. F. (2021). Geochemical evidence for forearc metasomatism of peridotite in the Xigaze ophiolite during subduction initiation in Neo-Tethyan Ocean, south to Tibet. *Lithos*, 380, 105896. <https://doi.org/10.1016/j.lithos.2020.105896>
- Zihlmann, B., Müller, S., Coggon, R. M., Koepke, J., Garbe-Schönberg, D., & Teagle, D. A. H. (2018). Hydrothermal fault zones in the lower oceanic crust: An example from Wadi Gideah, Samail ophiolite, Oman. *Lithos*, 323, 103–124. <https://doi.org/10.1016/j.lithos.2018.09.008>