The Geology and Tectonics of the Jabal Akhdar and Saih Hatat Domes, Oman Mountains

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Preface

The Oman Mountains represent some of the most spectacular exposures of sedimentary, igneous and metamorphic rocks on the Arabian Peninsula with a geological history that spans over 800 million years, including spectacular outcrops that led to a better understanding of the composition of the continental and oceanic lithosphere, as well as sedimentary rocks that form reservoirs and seals in the subsurface to the south. Therefore, the Oman Mountains serve as a prime textbook example for the geological development of the southern margin of the Tethys and geological features related to obduction processes.

This volume reviews the previous geological work carried out in the Jabal Akhdar and Saih Hatat domes of the eastern Oman Mountains (or Hajar Mountains) to synthesize the scientific knowledge of this part of the country which covers an area of approximately 250 km × 125 km. A geological map has been compiled as a comprehensive tectonometamorphic synthesis. The geological map is largely based on the maps of Béchennec *et al.* (1992), Le Métour *et al.* (1992) and Wyns *et al.* (1992). Small inconsistencies found in the previously published maps have been corrected (for details see Appendix D (Scharf *et al.* 2021, Chapter 2, this Memoir)).

The first substantial study of the geology of the Oman Mountains was carried out by George Martin Lees in 1924–25 (Lees 1928) , but it was Ken Glennie and his co-workers from Shell in the 1960s and early 1970s who made the first detailed geological map of the mountains and accounted for the geology in the light of plate tectonics. At that time, the fundamental understanding of the overall architecture of the Oman Mountains and its southern foreland had been established. Marine sediments of the Hawasina Basin and the largest and best-preserved ophiolite sequence of the world form a major part of the Oman Mountains. These rocks have since been a research focus for the international geoscientific community.

The two large tectonic windows and domes (Jabal Akhdar and Saih Hatat) provide insights into the pre-Cretaceous geological development of the southeastern corner of the Arabian Platform. These rocks have received much less attention, despite the fact that their geological record from the Cryogenian to the Cretaceous covers one of the most interesting phases of Earth's history. Here, one can study the diamictites of the 'Snowball Earth' glaciation, the most long-lasting negative carbon isotope excursion of *c.* 17‰ during the Ediacaran ('Shuram Excursion'), the collision between East- and West-Gondwana, and post-tectonic, fossiliferous sedimentary rocks. The Permian breakup of Pangaea also affected the area, and later, during the Late Cretaceous, this eastern margin of the Arabian Platform was dragged down into a subduction zone and then became overridden by the Hawasina nappes and the famous Semail Ophiolite.

Comprehensive geological mapping of the surface outcrops of Oman by teams of the French Geological Survey, BRGM, published many works during the second half of the 1980s and first half of the 1990s, leading to a better understanding of the geology in two tectonic windows (domes) in the mountains and adjoining areas. The remarkable socio-economic transformation of the Sultanate with a rapidly improving infrastructure made once extremely isolated and remote wadis accessible, resulting in an ever-increasing number of publications covering the geology of this region.

The authors of this book are university teachers and researchers in structural geology/tectonics, regional geology, geodynamics, mineralogy/petrology, geochemistry, basin analysis, sedimentology and stratigraphy at two institutions with geoscience programs: the Sultan Qaboos University (SQU) and the German University of Technology in Oman (GUtech). Two authors recently moved to the University of Ferrara (Italy) and University of Sharjah (UAE). A multitude of geoscientific information is spread over an enormously wide range of journals and books, not all of them are readily available. In a first attempt to summarize the knowledge of the Jabal Akhdar and Saih Hatat tectonic windows, a review paper was prepared, but the scope soon exceeded the limitations of many journals, especially regarding the amount of text, illustrations and the inclusion of oversized maps/charts which were required for a better understanding.

This book provides a comprehensive overview and review of the geology and tectonic development of the eastern Oman Mountains and is written for ongoing geologists and professionals who want to work in this area. However, not all aspects can be discussed at length. Thus, we provide the original sources for further details. The compiled geological map depicts an overview of the different formations/units and is coordinated with the text. The original BRGM maps at a scale of 1: 250 000 and 1: 100 000 contain more details and information. Thus, they are indispensable for proper research and field investigations. Our compiled map is not meant to substitute the original maps; rather, it provides a comprehensive overview, ready to hand. We hope that this work will stimulate the continuation of research in the Jabal Akhdar and Saih Hatat domes as well as the surrounding areas and provide a new generation of Omani and international geologists with an overview of existing studies, and with a thorough and up-to-date background information of the relevant literature.

Finally, we would like to thank many colleagues from many different institutes for helpful discussions about several topics. They have been thanked in the acknowledgements.

The authors
Muscat, Oman, March 2020

Content summary

We present a compiled geological/tectonic map of the Jabal Akhdar and Saih Hatat domes and their surroundings, accompanied with crustal-scale cross-sections, kinematic plate reconstructions, and a comprehensive tectono-stratigraphic chart. Our work is largely based on reviewing the literature and complemented by our own investigations, observations and ideas.

The Neoproterozoic is the oldest geological era recorded in the rocks of the study area, and probably witnessed four orogenies, two during the early Cambrian (Cadomian and Angudan), one Late Paleozoic (the enigmatic 'Hercynian Orogeny') and one during the Late Cretaceous (Semail Ophiolite obduction and related processes, referred to as the 'Semail Orogeny'). Furthermore, the study area was affected by at least three Neoproterozoic to earliest Cambrian rifting events (Abu Mahara, Nafun and Fara), a Mid-Ordovician rift event, a latest Paleozoic rifting event (breakup of Pangaea), a late Jurassic rifting event associated with opening of an ocean basin east of Oman and latest Cretaceous to Cenozoic extensional events (orogenic collapse of the Oman Mountains).

The Neoproterozoic to earliest Cambrian extensional events are locally recorded by associated volcanic rocks and extensional structures. The Cadomian Orogeny with an NE–SW-directed stress field has been recently recognized and is associated with tight folds in the Neoproterozoic formations of the western Jabal Akhdar Dome. The Angudan event is recorded by map-scale folds and thrusts of the Jabal Akhdar Dome, indicating a SE–NW direction of compression. The origin/age of these folds has been reinterpreted from 'Hercynian' in the past to Angudan at present. The 'Hercynian' event is characterized mainly by large-scale arch and basin formation as well as block faulting. The latest Paleozoic breakup of Gondwana is well documented by the occurrence of large mafic bodies and volcaniclastics in pre-Permian formations and the Permian Saiq Formation of the Saih Hatat Dome. Oman was situated at an overall passive margin during the Permo-Mesozoic until the late Cretaceous. As an exception, an ocean basin formed between Oman and India during the late Jurassic, leading to some uplift and deformation in northern Oman.

The passive margin changed into an active margin during late Cretaceous. During the Cretaceous, the latest orogeny started probably with Albian intra-oceanic subduction within the Neo-Tethys Ocean, proximal to the Arabian margin. This subduction zone matured, and a self-sustained subduction zone formed during the Cenomanian. This event created new oceanic lithosphere along and above a subduction zone. The supra-subduction spreading center with the

entire ophiolite rotated clockwise during the obduction. SW-directed thrusting led to obduction of the Semail Ophiolite which advanced over a distance of some *c.* 550–600 km over Arabia's passive margin (Hawasina Basin) and the Arabian Platform until the Maastrichtian. A possibly migrating foreland basin (Aruma Basin) in front of the advancing ophiolite formed within the Arabian Platform since the Turonian. During obduction, the extended Arabian continental crust and its attached Neo-Tethyan oceanic lithosphere were subducted northeastward to greater depths (minimum of 80 km), and parts of the continental rocks were metamorphosed to eclogite-facies conditions. Once the allochthonous rocks reached the Arabian Platform during the Late Cretaceous, the oceanic lithosphere separated from the continental lithosphere (possible slab breakoff), resulting in rapid exhumation of the continental Arabian Crust of the Saih Hatat area. Important postobduction tectonics occurred during the Late Eocene to Early Miocene with the final exhumation of the Jabal Akhdar and Saih Hatat domes. The onset of this process precedes the continent-continent collision in the Zagros Mountain Belt. The two domes exhibit Permo-Mesozoic sedimentary rocks of the Arabian Platform on their flanks and Neoproterozoic metasedimentary rocks in their cores. Minor sub-recent to recent tectonics in the study area are reflected by earthquakes, uplift of a series of marine terraces, hot springs, and significant present-day wadi incisions.

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