

Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development

Federico Rossetti · Ana Crespo Blanc · Federica Riguzzi · Estelle Leroux
Kosmas Pavlopoulos · Olivier Bellier · Vasilios Kapsimalis *Editors*

The Structural Geology Contribution to the Africa-Eurasia Geology

Basement and Reservoir Structure,
Ore Mineralisation and Tectonic Modelling

Proceedings of the 1st Springer Conference
of the Arabian Journal of Geosciences (CAJG-1),
Tunisia 2018

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ISSN 2522-8714 ISSN 2522-8722 (electronic)
Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development
ISBN 978-3-030-01454-4 ISBN 978-3-030-01455-1 (eBook)
<https://doi.org/10.1007/978-3-030-01455-1>

Library of Congress Control Number: 2018960212

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This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Deep seismic imagery and mantle tomography have considerably increased our understanding of the lithosphere and crustal architecture, as well as sedimentary basin formation and deformation processes. In the meantime, high-resolution seismic reflection profiles, as calibrated against exploration wells and outcrop studies, also provide a better control of the sedimentary infill and 3D reservoir architecture. Seemingly, source-to-sink studies, coupled with subsidence and kinematic modelling calibrated against paleothermometers, provide accurate reconstructions of the long-term tectono-stratigraphic evolution of sedimentary basins. Thermal and fluid flow modelling are now routinely used to better understand and predict the formation and distribution of ore deposits and petroleum potential, along with the permeability distribution of their hosting reservoirs.

These proceedings volume comprises 74 papers accepted for presentation during the 1st Springer Conference of the Arabian Journal of Geosciences (CAJG-1), Tunisia, 2018. The major topics and issues treated include: (i) Basement geology; (ii) Fluid–rocks interactions, hydrothermalism and ore deposits; (iii) Reservoir geology, structure and stratigraphy; (iv) Mediterranean tectonics; (v) The Alpine-Himalayan convergence zone; (vi) Tectonic modelling.

Individual papers presented in this respect range from local case studies, predominantly relating to the North African, Mediterranean and Mid-Eastern regions, to more global geodynamic syntheses dealing with continental break-ups, oceanic accretion and passive margins' development. The present document will provide an updated portfolio, evidencing the input of structural geology to the understanding of lithosphere and crustal-scale processes activating in the broader Afro-Eurasian realm. It is intended to stand as a highly interesting reference for both students and senior scientists and professionals.

August 2018

François Roure



François Roure is a graduate of the Ecole Normale Supérieure of St-Cloud, France, holder of a Doctorate in Sciences from the University of Paris VI. He joined the IFP's Geology-Geochemistry-Geophysics Division in 1984, following a 4-year career at the CNRS. His research is predominantly focused on the study of sedimentary basins (architecture and geodynamics, thermicity, oil-bearing systems, fluid/rock interactions and reservoir characterization). He was selected as an extraordinary Professor at the Free University of Amsterdam (VU). He also chaired the working group on sedimentary basins in the International Lithosphere Program (ILP). He has contributed more than a hundred articles, published in prestigious international journals.

In 2010, François Roure was honoured by the EAGE (European Association of Geoscientists and Engineers), which selected him as the winner of the 2010 Wegener Award, as a recognition of his contribution to the geoscientific research in the area of petroleum exploration of frontier areas and the search for new reserves, particularly in mountain belts.

Acknowledgements

Our appreciation is extended to the authors of the papers for their hard and diligent work and producing high-quality contributions. We would like to thank the reviewers of the papers for their in-depth reviews and great efforts in improving the quality of the papers. Also, thanks are extended to Amjad Kallel who supervised and handled the evaluation process, to Sahbi Moalla who handled the submission and evaluation system for the ten conference proceedings volumes, and the publishing staff of Springer headed by Nabil Khélifi, Senior Editor for their efforts and contributions in completing this conference proceedings volume. All the above-mentioned efforts were very important in making this book a success.

About the 1st Springer Conference of the Arabian Journal of Geosciences (CAJG-1), Tunisia 2018



The *Arabian Journal of Geosciences* (AJG) is a Springer journal publishing original articles on the entire range of Earth sciences in partnership with the Saudi Society for Geosciences. The journal focuses on, but not limited to, research themes which have regional significance to the Middle East, the Euro-Mediterranean, Africa, and Asia. The journal receives on average 2000 submissions a year and accepts around 500 papers for publication in its 24 annual issues (acceptance rate 25%). It enjoys the participation of an editorial team of 100 international associate editors who generously help in evaluating and selecting the best papers.

In 2008, Prof. Abdullah Al-Amri, in close partnership with Springer, founded the Arabian Journal of Geosciences (AJGS). In this year, the journal celebrates its tenth anniversary. On this occasion and to mark this event, the Founder and Editor-in-Chief of the AJGS Prof. Al-Amri organized in close collaboration with Springer the 1st Conference of the Arabian Journal of Geosciences (1st CAJG) in Hammamet, Tunisia from November 12 to 15, 2018 (www.cajg.org).

The conference was an occasion to endorse the journal's long-held reputation for bringing together leading authors from the Middle East, the Euro-Mediterranean, Africa, and Asia who work at the wide-ranging fields of Earth sciences. The conference covered all crosscutting themes of Geosciences and focused principally on the following ten tracks:

- Track 1. Climate, paleoclimate, and paleoenvironmental changes
- Track 2. Geoinformatics, remote sensing, geodesy
- Track 3. Geo-environmental engineering, geomechanics and geotechnics, geohazards
- Track 4. Geography, geoecology, geoarcheology, geotourism
- Track 5. Geophysics, seismology
- Track 6. Hydrology, hydrogeology, hydrochemistry
- Track 7. Mineralogy, geochemistry, petrology, and volcanology
- Track 8. Petroleum engineering and petroleum geochemistry
- Track 9. Sedimentology, stratigraphy, paleontology, geomorphology, pedology
- Track 10. Structural/petroleum/mining geology, geodynamics, marine geology

The dynamic four-day conference provided more than 450 attendees with opportunities to share their latest unpublished findings and learn the newest geoscience studies. The event also allowed attendees to meet and discuss with the journal's editors and reviewers.

More than 950 short contributing papers to the conference were submitted by authors from more than 70 countries. After a pre-conference peer review process by more than 500 reviewers, 700 papers were accepted. These papers were published as chapters in the conference proceedings by Springer.

The conference proceedings consist of ten edited volumes, each edited by the following group of Arabian Journal of Geosciences (AJGS) editors and other guest editors:

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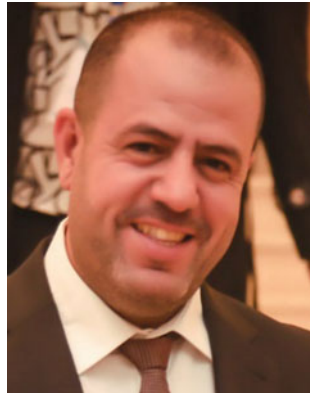
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About the Editors



Dr. Federico Rossetti is a holder of a degree in Geological Sciences (1995), and a Ph.D. in Earth Sciences (1999) from the Sapienza University of Roma, Roma (Italy). He is currently Professor of Structural Geology at the University of 'Roma Tre', Roma (Italy). His research is focused on understanding ductile and brittle continental tectonics in different geodynamic settings, as observed on different spatio-temporal scales. He has executed extensive fieldwork across the Alpine-Himalayan convergence zone (Betic-Rif chain, Apennine and Alpine chain, Iran), the Pan-African orogen in Tanzania and the Ross-Delamerian orogen in Antarctica. He was awarded the 2005 'Felice Ippolito Prize' for the category Earth Sciences, for the research he conducted in Antarctica. His approach is multidisciplinary, integrating geological field survey, structural geology, metamorphic petrology and geodynamic synthesis. He has been occupying the position of a Topical Editor for the EGU journal *Solid Earth* ever since 2010, Chief Editor since 2018. He is currently Associate Editor of the AGU journal *Tectonics*. He is the author of more than 100 research papers published in internationally indexed and refereed journals. In 2015, Dr. Rossetti joined the AJGS as an Associate Editor responsible for evaluating submissions pertaining to the areas of Structural Geology, Continental Tectonics and Metamorphic Petrology.



Ana Crespo Blanc born in Switzerland, is a Full Professor of Geodynamics at the University of Granada (Spain) ever since 1993. She occupied the position of President of the Geological Society of Spain, between 2008 and 2012. Her research has been focused mainly on structural and kinematic analysis, relationships between deformation and metamorphism, isotopic geochemistry, marine geology and analogue modelling. She applied these different methodologies to the knowledge of the tectonic evolution of key areas of the Hercynian chain of Iberia, the Alps, the Himalaya or the Nankay Trough. Since the 90s, her research has mainly been centred on the Mediterranean region, specifically, the Betic-Rif orogen around the Gibraltar Arc. She is particularly interested in the architecture and the strain partitioning of such an arcuate orogen. Presently, she is interested in the kinematic reconstructions of the Western Mediterranean, regarding which she characterized, collaboratively with her research group, the different deformation events affecting the whole area. She is simultaneously involved in significant outreach research activities closely associated with earth sciences.



Federica Riguzzi is a holder of a degree in Physics and a Ph.D. in Earth Sciences at the University of Roma La Sapienza. Senior Researcher at Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy. Her research activity is focused mainly on geodetic methods applied to geophysics. It concerns both methodological and applied studies dedicated to the realization and measurement of crustal deformation control and to fundamental Physics experiment networks; time series analyses of GPS observations, as related to the study of the deformation fields and seismotectonic processes, and the use of historical information and recent seismic data applied to seismic risk areas. The geodetic methodologies have been applied to geophysical studies relating to different regions and with various aims. Her contributions are predominantly centred on the definition of global-scale plate motion models in different reference frames; the study of kinematics and deformation fields of the central Mediterranean and Suez-Sinai areas, along the Betic Cordillera (Spain and Morocco) and the Eastern Himalaya Syntaxis (NE India) through GNSS observations; the analysis of co- and post-seismic deformations after the occurrence of significant seismic events; the estimation of deformation source of the Colli Albani volcano (Roma); the definition of a new methodology based on the joint analysis of deformation rates and seismicity data to assess the earthquake short-term occurrence probability. She has also conducted a number of macroseismic surveys, following the occurrence of significant seismic events, and historical seismicity-related studies. She collaborates with national and international research groups, the Universidad de Jaen (Spain), the National Research Institute of Astronomy and Geophysics (Egypt), as well as the Geological Survey and the Raman Center for

Applied and Interdisciplinary Sciences of Kolkata (India). She has been responsible for the Research Units, financed by the Gruppo Nazionale di Difesa dei Terremoti, and the Department of Civil Defense. Additionally, she took part in several projects supported by the Italian Space Agency. She is an Associate Editor of the *Annals of Geophysics*, and the author of various scientific papers published in reputedly rated national and international journals.



Estelle Leroux obtained her marine technician degree at the National Institute of Science and Marine Technology (INTECHMER), France. She began her career in 2000 working for a few years in a Petroleum Seismic exploration for CGG International (General Company of Geophysics), especially in the Gulf of Mexico offshore. Subsequently, she spent several years reviewing data acquisition and processing on scientific oceanographic vessels, and in different French academic research institutes (IFREMER—French Institute for Marine Research, CNRS—French National Center for Scientific Research, UBO—University of Western Brittany, and IUEM—European University Institute for Marine Research).

She, then, decided to pursue a scientific career. After completing her Ph.D. at UBO/IFREMER on seismic stratigraphy in the Gulf of Lion, in 2012, she joined the UPMC-Sorbonne University, Paris, actively resuming work on seismic and sequence stratigraphy. Her key study areas were centred on the Cenozoic Western Mediterranean area.

In 2016, Estelle Leroux integrated the IFREMER Center in Brest as a marine geologist. Her research was predominantly focused on the combined application of stratigraphy and modelling, in the analysis of ancient and modern sedimentary basin fills. Her expertise is mainly centred on seismic and sequence stratigraphy, as well as numerical geological modelling, both in ‘Source-to-sink’ and ‘Mud-to-Mantle’ approaches.

Her aim is targeting to decode the sediment sequences, sediment architectures and deposit features in past sedimentary basins. It is also dedicated to provide key guides on both qualitative and quantitative paleo-variations of sediment fluxes, sea level, and subsidence in a bid to understand climate and geodynamic changes. She is the (co-)author of scientific publications on internationally recognized peer-reviewed journals, and is also involved in several multidisciplinary projects.



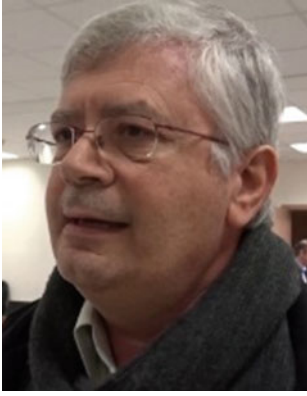
Kosmas Pavlopoulos (KP) was born in Athens, Greece. He received his B.Sc. in Geology, and Ph.D. in Environmental Geomorphology at the University of Athens, Greece in 1986 and 1992, respectively. Since 2013, KP has been a Professor of environmental geomorphology, in the Geography and Planning Department at the University of Paris-Sorbonne, Abu Dhabi. He had been previously appointed in the Geography Department at the Harokopio University, Athens, Greece ever since 1999. He was Chair of the working group on geoarcheology of IAG from 2009 to 2017, and member of the Scientific Committee of the French Archaeological School in Athens, from 2010 to 2017. Since 2017, he has been member of the Executive Committee of IAG (International Association of Geomorphologists), as a Publishing Editor.

He is a recognized specialist in the field of coastal geomorphology, sedimentology, Quaternary geology, sea level changes. His research is predominantly focused on the sediments depositional environments on arid and semi-arid areas, geomorphological evolution of marginal landscapes, sea level changes, hydrogeology and the Wadi dynamics, water resources' management as well as the natural hazards, as predominant in the Mediterranean and Mid-Eastern areas.

He has participated in 62 research projects, and has been the coordinator in 20 among them. He has more than 140 publications in peer-reviewed scientific journals (68 currently shown in Scopus), and his work received more than 677 citations (h-index = 16, co-authors 141, source Scopus) and (156 currently shown in Research Gate), 1181 citations (h-index = 30.88, source Research Gate). KP has been the supervisor of 9 Ph.D., and a member of the supervising committee of 12 Ph.D. students. As an expert in Geosciences and environment, he is member for the evaluation of research projects, launched by the Greek Ministry of Research since 2000, by the French institute of CNRS 2004–2007 (ECLIPSE program), by the French Ministry of Education and Research from 2012–2013 (ANR project), by the MIUR (the Italian Ministry for Education, University and Research) 2015–2016 (Reprise project), and by the Ford Motor Company in 2016 (Conservation and Environmental Grants).



Olivier Bellier is Full Professor of Tectonics Aix Marseille University, CNRS, IRD, INRA, Coll France, CEREGE, Aix-en-Provence, France since 2000. He had been a Joint Director of the Science Faculty of Aix-Marseille (up to 2013), then a Joint director (in charge of the Research) of OSU Pythéas Institute—Observatory of the Universe and Environment of Aix-Marseille University (2013–2018). He is presently a Director of the CEREGE Laboratory (AMU, CNRS, IRD, Collège de Fr., INRA). His research is focused mainly on Tectonics and Seismic hazard: Brittle and active tectonics, Tectonic geomorphology, Structural geology, which he applied to the study of Geodynamics and Geological risks. His research is partly centred on investigating the Mediterranean area: Tunisia, Morocco, SE France, Italy, etc. However, he developed other research collaborations: USA-USGS, China, Peru, Argentina, Venezuela, Indonesia, Turkey, Iran, Armenia, etc. He was a member of the scientific committee of the Sigma program (Seismic Ground Motion Assessment), Consortium EDF, CEA, Areva, ENEL, Italy, (2011–2015), and a member of the scientific committee of the RGF (Référentiel Géologique de la France), the BRGM program, 2014–2017. He was also a member of the Steering Committee of Geological Society of France (Société Géologique de France), 2012–2015, and a member of the expert committee of ECOS Nord (Committee of the scientific cooperation evaluation between France and South America from the Foreign Affairs Ministry (Hubert Curien Program) for Columbia, Venezuela, Mexico. He was leader of the Steering Committee of the International Scientific Congress «Provence 2009 : Seismic risk in moderate seismicity area»—Aix-en-Provence, July 2009, and a leader of the Steering and Scientific Committees of the First International workshop GeoriskMor «Geosciences and Risk assessment in Morocco: an integrated approach» Tétouan (Morocco) 28–30 April 2016, Faculty of Sciences, Abdelmalek-Essaâdi, the University of (Tanger-Tétouan), GeoriskMor project, <http://georisk-morocco.cerege.fr/>, the OT-med workshop. He has been the supervisor of 21 Ph.D. theses since 1991 (19 being presently defended, other in process) and took part in 75 Ph.D. thesis juries, 7 being defended in foreign universities (Iran, Tunisia, Italy, Swiss, etc.). He is the author of 120 international scientific publications (108 indexed in Isi-web of Sciences, in 2018). Besides, he is a co-writer of five scientific books' attached chapters and a co-writer of a chapter of a scientific culture specialized book. He also participated as a co-writer of a jointly scientific culture published book dealing with the Provence earthquake.



Dr. Vasilios Kapsimalis is a Research Director of the Institute of Oceanography of the Hellenic Centre for Marine Research. His scientific interests pertain to the field of marine geology, sediment dynamics and quality, submarine geomorphology, Late Quaternary and Holocene stratigraphy, relative sea level changes, underwater geoarchaeology and management of dredged material coastal erosion. He has published more than 35 papers in peer-reviewed journals, and presented more than 70 original contributions in international and Greek-based conferences. In addition, he has coordinated 25 research projects dealing with sediment quality assessment, monitoring and impact of sediment disposal operations on marine environment, geomorphological mapping of the coastal and offshore areas, paleo-geographical reconstructions of the Greek continental shelf. As a chief scientist, he has organized and participated, in several coastal (in estuarine, lagoonal, beach areas, etc.) and offshore (continental shelves, slopes and deep basins) multi-disciplinary surveys, deploying the HCMR's fleet (R/V AIGAIO and S/V ALKYON). His educational work is related to the teaching of graduate and postgraduate courses at the Harokopio University of Athens (Oceanography), and the National Technical University (Marine Geology and Geophysics), along with the supervision of B.Sc., M.Sc. and Ph.D. theses. Additionally, he has organized a number of international and Greek congresses and workshops of various oceanographic and environmental subjects, and disseminated the results of his work in well-recognized magazines and newspapers. He was the representative of the HCMR (2010–2016) to the Licensing Committee on Marine Research of the Greek Foreign Ministry, which issues licenses for each marine research conducted within the Greek-owned waters.

Part I
Keynote